

**ASSESSMENT OF STATUS AND REQUIREMENTS OF NITROGEN AT
DIFFERENT GROWTH PHASES OF WHEAT AND MAIZE THROUGH
DIGITAL IMAGE ANALYSIS**



A Dissertation

By

SHAMIM ARA BAGUM

Registration No. 1605307

**DEPARTMENT OF CROP PHYSIOLOGY AND ECOLOGY
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY
DINAJPUR-5200**

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Approved as the style and Content by

**Professor Dr. Sripati Sikder
(Supervisor)**

**Professor Dr. Md. Maniruzzaman Bahadur
(Co-supervisor)**

**Professor Dr. Abu Hasan
Chairman
Examination Committee**

**DEPARTMENT OF CROP PHYSIOLOGY AND ECOLOGY
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DECLARATION

I, Shamim Ara Bagum, hereby declared that the dissertation titled “**ASSESSMENT OF STATUS AND REQUIREMENTS OF NITROGEN AT DIFFERENT GROWTH PHASES OF WHEAT AND MAIZE THROUGH DIGITAL IMAGE ANALYSIS**” submitted to Hajee Mohammad Danesh Science and Technology University, Dinajpur in the fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in Crop Physiology and Ecology is a record of bona-fide research designed and carried out by me. No part of this dissertation was produced elsewhere for any degree. It does not contain results of any collaborative study.

(Shamim Ara Bagum)



PROFESSOR DR. SRIPATI SIKDER

B.Sc.Ag. (BAU), MS (BSMRAU), PhD (RU)

Postdoc (Nottingham, UK & Sydney, Australia)

Department of Crop Physiology and Ecology

Hajee Mohammad Danesh Science and Technology University

Dinajpur-5200, Bangladesh

CERTIFICATE

This is to certify that the work embodied in this dissertation is an original research work done by **Shamim Ara Bagum** under my supervision for the degree of Doctor of Philosophy. The references cited in it have duly been acknowledged. The style and contents of the dissertation have been approved and recommended for submission.

(Professor Dr. Sripati Sikder)

Supervisor

BIOGRAPHICAL SKETCH

The author was born on March 1970 at Dhaka district of Bangladesh. She is the fourth of eight children of Md. Belayat Hossain and Monoara Bagum. The author completed her secondary school education from Share-e-Bangla Nagar Govt. Girls High School, Share-e-Bangla Nagar, in 1985 and higher secondary education from Lalmatia Girls College, Dhaka in 1988 from Dhaka Board, Dhaka.

She completed B. Sc. Ag. degree in 1992 (held in 1996) from Hajee Mohammad Danesh Agricultural College, Dinajpur which was an affiliated College of Bangladesh Agriculture University, Mymensingh.

Shamim Ara accomplished Master of Science (MS) degree in Agronomy in 2007 from Share-e-Bangla Agricultural University (SAU), Share-e-Bangla Nagar, Dhaka with CGPA 3.60 out of 4.0. Her thesis title was “Hybrid maize seed production under different levels of lime and boron application.”

The author started professional career in 1997 as a Scientific Officer (SO) at Bangladesh Agricultural Research Institute, Gazipur. Now she has been serving as a Principal Scientific Officer, Seed Technology Division, BARI, Gazipur. Shamim Ara received Chinese Government fellowship as a senior researcher to conduct research program on “Digital Image analysis for precision Agriculture” at Institute of Crop Science, Chinese Academy of Agricultural Sciences (CAAS), Beijing, China.

Shamim Ara Bagum published more than thirty-five scientific articles (including scientific paper, Book chapter, Monograph, Bulletins, proceedings, and popular articles) as a Seed Technologist. She participates in many Nation and International workshops, Seminar, Conference. She is the member of Krishibid Institution and Bangladesh Society of Agronomy. She is happily married to Dr. M. Shalim Uddin and blessed with one son Saif Shalim.

The author

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Shamim Ara Bagum

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Assessment of status and requirements of nitrogen at different growth phases of wheat and maize through digital image analysis

ABSTRACT

The study was conducted to assess the status and requirements of nitrogen at different growth phases of wheat and maize through digital image analysis. The major objectives were to study the effect of nitrogen on morpho-physiological traits; use digital image and software for assessment morpho-physiological traits at different growth stages and establish a relationship between morpho-physiological traits with image parameters. To fulfill the objectives four experiments were conducted in two successive years (2016-17 and 2017-18) at BARI, Gazipur, Bangladesh with wheat and maize crops. Wheat experiment comprised of four wheat varieties (BARI Gom 26, BARI Gom 28, BARI Gom 29 and BARI Gom 30) and four nitrogen levels (0.0 kg N ha^{-1} , 50 kg N ha^{-1} , 100 kg N ha^{-1} , and 150 kg N ha^{-1}) during 2016-17 and three wheat varieties (BARI Gom 26, BARI Gom 28 and BARI Gom 30) and five nitrogen levels (0.0 kg N ha^{-1} , 60 kg N ha^{-1} , 100 kg N ha^{-1} , 120 kg N ha^{-1} and 140 kg N ha^{-1}) during 2017-18. While, the maize experiment comprised of three maize varieties (hybrid 981, BARI Hybrid Maize 9 and hybrid P3396) and three nitrogen levels (100 kg N ha^{-1} , 200 kg N ha^{-1} and 300 kg N ha^{-1}) in both the years. All the experiments were laid out in split plot design with three replications. Data on plant height (cm), Leaf Area Index (LAI), Canopy cover (CC), Soil-Plant Analyses Development (SPAD) reading of leaf, Leaf nitrate content (LNC), Leaf chlorophyll content (LCC), Normalized Difference Vegetation Index (NDVI), Total dry matter (TDM), different yield contributing and yield traits of wheat and maize. CC is an important phenotypic trait which indicates overall plant growth and helpful to predict advanced traits like biomass and yield. Digital image analysis was used as an alternative method to quantify the greenness of foliage as indirect measurements of crop N status and phenotyping. The image was taken from 50 cm above the plant canopy by using modified selfie stick. Two software's (WCC for wheat and MCC for maize) were developed for digital phenotyping in JAVA and Interface design in JFrame. A five-step algorithm was developed to measure the CC of individual plots by RGB (red, green and blue). The output gave 27 digital traits value after analyzing an image including CC and NDVI. The values of canopy cover were closely correlated with the NDVI and the ratio vegetation index. Among the interaction treatments of wheat, maximum grain yield (3.97 t ha^{-1}) was recorded by the interaction of 150 kg N ha^{-1} and BARI Gom 30 which was statistically similar to 100 kg N ha^{-1} and BARI Gom 29, 100 kg N ha^{-1} and BARI Gom 28 during 2016-17 where the maximum grain yield (3.94 t ha^{-1}) was found with treatment combination 120 kg N ha^{-1} and BARI Gom 26 which was statistically similar to 120 kg N ha^{-1} and BARI Gom 30, 120 kg N ha^{-1} and BARI Gom 28 during 2017-18. Among the interaction effect of maize variety and nitrogen level, highest grain yield (14.45 t ha^{-1}) was recorded by the interaction of hybrid P3396 and 300 kg N ha^{-1} which was statistically identical with BHM 9 and 300 kg N ha^{-1} . The results also indicated that, application of nitrogen fertilizer has positive effects on physiological parameters of wheat and hybrid maize. A strong relationship among the traits NDVI, SPAD, CC and LNC was observed across the wheat and maize varieties. The results also suggest that in case of NDVI, SPAD and CC saturation, NDVI and CC could accurately predict nitrogen requirements for wheat and maize. The results of this study partially supported the hypothesis that digital image traits measured by image processing software's (WCC and MCC) can identify and differentiate variations in nitrogen use in wheat and maize crops. The outcomes of study have created a new era of using digital image analysis in the determination of N-requirement in wheat and maize in near future.

ACRONYMS

Abbreviation	Full Name
AEZ	Agro- Ecological Zone
B	Blue
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
BRAVI	Blue-Red Adjusted Vegetation Index
Car	Carotenoid
CAR	Conventional application rate
CC	Canopy cover
Chl	Chlorophyll
Chl a	Chlorophyll a
Chl b	Chlorophyll b
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo
CL	Cob Length (cm)
CV %	Percentage of Coefficient of Variance
cv.	Cultivar
DAP	Diammonium phosphate
DAS	Days After Sowing
DF	Degree of freedom
DFT	Days to Fifty Percent Tasseling
DFS	Days to Fifty Percent Silking
DGCI	dark green color index
DMA	Dry matter accumulation
DMRT	Duncan' Multiple Range Test
DNA	Deoxyribonucleic acid
EC	Emulsifiable Concentrate
EGI	Excessive Greenness Index (EGI)
EH	Ear height (cm)
<i>et al.</i>	and others

Abbreviation	Full Name
etc.	Etcetera
EVIgreen	Enhanced Vegetation Index-Green
FAO	Food and Agricultural Organization
FW	Field Weight (Kg)
FYD	Farmyard manure
G	Green
GDP	Gross domestic product
GMR	Green Minus Red
HI	Harvest Index
Hr	Hour
HSB	Hue, Saturation and Brightness
HYV	High yielding variety
HTP	High Throughput Phenotyping
IRRI	International Rice Research Institute
K	Potassium
Kg ha ⁻¹	Kilogram per hectare
LAI	Leaf area index
LNC	Leaf Nitrogen Content
LSD	Least Significant Difference
M	Meter
m ²	meter squares
MEGI	Modified Excessive Greenness Index
Mm	Millimeter
MoP	Murate of potash
MP	Moisture Percentage
N	Nitrogen
NCPM	Number of Cob Per Meter Square
NDI	Normalized Different Index
NDVI	Normalized Difference Vegetation Index
NDVIrgb	Normalized Difference Vegetation Index R-GB
NFAA	Nitrogen fertilizer application amount

Abbreviation	Full Name
NPPM	Number of Plant Per Meter Square
NRPC	Number of Row Per Cob
Ns/NS	Non significant
NSPC	Number of Seed Per Cob
NSPR	Number of Seed Per Row
P	Phosphorus
PC	Principal component
PCA	Principal component analysis
PGRC	Plant Genetic Resources Centre
pH	Potential of hydrogen
Ppm	Parts per million
R	Red
R/R^2	Coefficient of determination
S	Sulphur
SAT	Hue and saturation
SDW	Shoot Dry Weight
SPAD	Soil-Plant Analyses Development
SRDI	Soil Resource and Development Institute
STAR	Statistical Tool for Agricultural Research
TDM	Total dry matter
TSP	Triple super phosphate
TSW	Thousand Seed Weight (g)
VARI	Visible Atmospherically Resistant Index
viz.	Namely
YTPH	Yield (t ha^{-1})
Zn	Zinc

UNITES

English Abbr.	English Full Name
°C	Degree Celsius
Cm	Centimeter
g	Gram (s)
ha	Hectare
M	Meter
M	Molar
mM	Millimolar
mol/L	Molar concentration/Liter
Mg	Milligram
ml	Milliliter
Min	Minute (s)
MT	Million ton (s)
Ng	Nano gram(s)
T	Ton (s)
μ	Micron
μg	Microgram (s)
μL	Microliter (s)
v/v	Volume per volume
w/v	Weight per volume
t ha ⁻¹	Tons per hectare

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CHAPTER I

GENERAL INTRODUCTION

By 2050 the global population will increase from its current 7.6 billion to 9.7 billion, requiring between a 70% and a 100% increase in the yield of the major food crops due to increases in living standards, an increase in the requirements for plant-based proteins for animal feed, and an increase in the requirements for plant-based fuels (Simkin *et al.*, 2019). Clearing new land to bring it into use for crop production is not a feasible option as there is little quality land available and therefore this approach would require an increase in the use of nutrient and water inputs in order to deliver the yields needed. This would also have negative impacts on marine, freshwater, and terrestrial ecosystems, leading to damage to unique habitats and a decrease in biodiversity (Godfray, 2014).

Cereal grains have been the principal component of human diet for thousands of years and have played a major role in shaping human civilization. Around the world, rice, wheat, and maize, and to a lesser extent, sorghum and millets, are important staples critical to daily survival of billions of people. More than 50% of world daily caloric intake is derived directly from cereal grain consumption. Most of the grain used for human food is milled to remove the bran and germ, primarily to meet sensory expectations of consumers. The milling process strips the grains of important nutrients beneficial to health, including dietary fiber, phenolics, vitamins and minerals. Thus, even though ample evidence exists on the health benefits of whole grain consumption, challenges remain to developing food products that contain significant quantities of whole grain components and meet consumer expectations (Schmutzer *et al.*, 2017).

Nitrogen (N) is one of the most important agricultural inputs affecting crop growth, yield and quality in cereal production. It is a primary constituent of the nucleotides and proteins that are essential for life. Crop productivity relies heavily on nitrogen fertilization. Production and application of N fertilizers consume huge amounts of energy, and excess is detrimental to the environment; therefore, judicious N use is essential for the improvement of sustainable agriculture. Application of chemical N fertilizers during the past five decades has resulted in greatly increased global food production and decreased world hunger. The Declaration of the

World Summit on Food Security (FAO, 2009) calls for an average annual increase in food production of 44 million metric tons to feed approximately 9 billion of people by 2050 (Tester and Langridge, 2010). Accordingly, N fertilizer application is expected to increase by approximately threefold in the next 40 years unless N use efficiency is significantly increased.

In recent years, digital cameras and image analysis programs have been used to quantify the “greenness” of foliage as indirect measurements of crop N status. Digital images record information as amounts of red, green, and blue (RGB) light emitted; however, the intensity of red and blue will often alter how green an image appears (Ali, 2017). To simplify the interpretation of digital color data (Ali, 2017; Friedman, 2016; Vesali, 2015) suggested converting RGB values to the more intuitive hue, saturation, and brightness (HSB) color spectrum, which is based on human perception of color.

Karcher and Richardson (2003), working with quality of turf grass in response to N fertilizer, processed HSB values into a single measure of dark green color, the dark green color index (DGCI). Dark green color index values were a more consistent measure of green color than were individual RGB values across all turf varieties and N treatments.

Plant color has potential to indicate N status of maize and other non-leguminous row crops accurately when the correct methods are applied. Differences in lighting conditions, camera quality, and available camera settings could affect DGCI values and limit their utility in diagnosing N deficiencies; furthermore, factors such as disease, water status, nutritional deficiencies other than N, or differences in hybrid may affect greenness regardless of N status.

Canopy cover (CC) is defined as the fractional or percent area of plant canopies projected vertically onto the horizontal ground surface beneath (Guevara-Escobar *et al.*, 2005). Canopy cover of crops has often been used as a predictor of crop yield and growth parameters such as leaf area index (LAI), above-ground biomass, etc. (Behrens and Diepenbrock 2006; Li *et al.*, 2010; Pan *et al.*, 2007; Richardson *et al.*, 2001). As an alternative method for destructive monitoring of crop growth and nutrition status that is time and resource consuming, digital cameras have increasingly been employed in recent agronomic studies on the characterization of crop growth and nutrition status due to its simplicity and cost-effectiveness. Color digital

image analysis using digital camera have been proposed to evaluate the plant color and nutrition status (Sims *et al.*, 2002; Jia *et al.*, 2004, Yoshioka *et al.*, 2004; Li *et al.*, 2010), canopy cover (Guevara-Escobar *et al.*, 2005; Laliberte *et al.*, 2007; Pan *et al.*, 2007; Li *et al.*, 2010), growth characteristics (Reiko and Hiroyuki 2010), and weed research (Vrindts *et al.*, 2002). Though digital image analysis may provide researchers with improved methods, it is required to develop reliable image analysis techniques to segment plants from a variety of soil backgrounds (Mao *et al.*, 2003). Many studies have been conducted on the plant segmentation performance of several color indices that use color components defined in RGB space in single or in combination. Normalized color indices such as excessive greenness index (EGI) and modified EGI (MEGI) have been successful in several case-studies of plant segmentation from bare upland soil background (Golzarian *et al.*, 2007; Li *et al.*, 2010; Tang *et al.*, 2003). However, few studies have been done on the segmentation of maize and wheat plant from soil backgrounds. Therefore, the research objectives were-

- i. To study nitrogen effect on morpho-physiological traits of wheat and maize.
- ii. To use digital image and software for assessment of morpho-physiological traits of wheat and maize at different growth stages; and
- iii. To establish a relationship between morpho-physiological parameters with image parameters of wheat and maize.

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with brief review of work done by several researchers in the country and abroad related to estimate the status and requirements of nitrogen at different growth phases of wheat and maize through digital image analysis. It also includes the review of literature based on heat yield, biomass yield, nitrogen fertilizer, remote sensing, Image analysis, NDVI and canopy cover.

2.1 EFFECT OF NITROGEN ON WHEAT MORPHO-PHYSIOLOGICAL TRAITS

Wheat (*Triticum aestivum* L.) is the most important cereal crop in the world. It a staple food for more than 35% of the world's population, and a source of food and livelihood for over one billion people in developing countries (Metwali *et al.*, 2011). Wheat grain used to make flour, breads, biscuits, cakes, cookies, pasta, noodles and beer, other alcoholic beverages or biofuel (Knott *et al.*, 2009). The production of wheat is 755 million metric tons from more than 200 million hectares of the world's cultivated land and is the most important agricultural commodity in international trade (FAO, 2018).

Nutrient components e.g. chlorophyll, nitrogen and water at the seedling condition are significant main creator which could impact enhancement, improvement and exactly the last production of wheat (Qiong *et al.*, 2016). Competitiveness, global issues and market demands for manufacture attribute are compels that farmers ought to receive into estimate when using N fertilizer. These botherations have force in modern periods, enforce more proper administration and the adjustment of nitrogen fertilization by the rising period. Plant nitrogen condition is an operation of both plant biomass and nitrogen intentness and can be capable during estimate the NNI (N nutrition index), a largely dependable indicator (Ravier *et al.*, 2017).

Presence of nutrients is the main status of achieving biggest strong outcome of every plant and variety. The issue of keeping balance within plant outcomes, benefits and natural defense can be composed with the support of a recent agricultural deftness that forms in using fertilizers with consideration for local and mundane hybridism of crop arrangement with

nutrients by the vegetation time. It is elliptic that the quantity of nutrients given will be completely utilized by crops (Yakushev and Kanash, 2011).

The lack of N is the main constraint on cereal yields. Therefore, an optimization of N use is critical for increased grain production, especially in the low productive regions (Rigon *et al.*, 2016). So, it is essential to optimize nitrogen arrangement to alleviate the volume of nitrogen input and enhance nitrogen apply efficiency (Townsend *et al.*, 2018).

After rice, wheat is the most significant cereal crop giving sustenance and nourishment safety to the populace in Bangladesh. Wheat outcome in Bangladesh has gradually scaled recent altitude with Illusion enhancement in area, outcome and productivity. At the time of growing periods, desired variations in climatic causes e.g. snowfall or winter rains, least and most heat, wind speed and its way, summer seasons etc. requires to be calculated while manifesting strategies to increase of outcome and biomass in wheat. It is manifest that any important variation in the climate will have influence on agriculture and nourishment production since these two are correlated (Tiwari *et al.*, 2017).

High raise in international wheat genesis, that later occur to be acquainted since the Green Revolution, start in Mexico in the late 1950s, tract to Asia by the 1960s and 1970s, and now extensive in China in the 1980s and 1990s. Worldwide population enhancement measures reveal that during 2050 we will face the difficult expectation of compliance 9 billion population and nevertheless above the posterior 20 years, need for grain crop is likely to enhance by fifty percentages (Furbank *et al.*, 2015).

Hence, it is need to enlarge a fast proper and non-deleterious processing of diagnosis and control for nutrients components e.g. N, chl. (chlorophyll) and water at the seedling condition of wheat (Qiong *et al.*, 2016).

2.1.1 Canopy Cover (CC), Photosynthesis and Nitrogen fertilizer

The canopy of a crop refers to its above ground parts that intercept radiation leaves, sheaths, stems and heads (Pools and Hunt, 2014). Canopy cover is also closely related to leaf area index (LAI) (Nielsen *et al.*, 2012). Canopy cover has traditionally been measured using subjective methods (Richardson *et al.*, 2001; Robson *et al.*, 2013). Th e projection of images

on a grid or transparency for point classification helped to reduce subjectivity, but these methods are not efficient when analyzing large sets of images (Corak *et al.*, 1993; Ribeiro *et al.*, 2011). In recent decades, improvements in the quality of images produced by affordable digital cameras and mobile devices propelled the use of digital images for CC measurements. At the same time, numerous image processing methods (Behrens and Diepenbrock, 2006; Thorp and Dierig, 2011) and software packages (Ewing and Horton, 1999; Rasmussen *et al.*, 2007) have been developed to analyze digital images of plants for a variety of applications.

The CC is characteristics result from several factors, including genetically determined patterns of development, environmental influence on key developmental events and population density. This means that plant canopies, whether considered as single plants or at the community scale, are spatially complex, resulting in a heterogeneous light environment (Russell *et al.*, 1989). Because photosynthetic rate is light intensity dependent, it is convenient to consider canopies as populations of leaves each consisting of surface areas with different characteristics and varying states of photosynthesis at any single time point

Among agronomic and management practices, application of N fertilizer plays a major role in determining productivity. As a primary constituent of essential proteins and enzymes that are involved in important plant metabolic processes, N is essential in the formation of the plant canopy and increasing the leaf photosynthetic area. Photosynthetic components are a significant sink for leaf N: chloroplasts account for up to 80 % of total leaf N with Rubisco being the dominant enzyme (Makino and Osmond, 1991). Leaf photosynthetic capacity and Rubisco content per unit leaf area is highly correlated with leaf N both within and between species (Evans, 1989; Theobald *et al.*, 1998). Nitrogen affects a number of developmental traits including plant height, panicle number, leaf size and the spikelet number: all of which contribute to the yield potential of the crop. During the vegetative growth stage, absorbed N primarily promotes early growth and increases the number of tillers (Mae, 1997). For the formation of dense canopies, large concentrations of N are required (Connor *et al.*, 2011). In N deficient conditions, the plant counterbalances the lack of N by producing a lower number of tillers, this compensations step allows for fewer but fully functional leaves, instead of a higher number of leaves that are only semi-functional. In addition to this, N deficiency

generally reduces leaf area index, plant height and overall crop photosynthesis, which is itself limited by leaf area and leaf capacity for photosynthesis (Connor *et al.*, 2011). This in turn leads to a lower amount of radiation intercepted, leading to lower radiation use efficiency. Spikelet number and the amount of filled spikelets are largely determined during the reproductive phase. Thus, even mild N deficiency can make moderate changes to architecture that will have a large impact on the light distributions and thus productivity of canopies (Burgess, 2017).

2.1.2 Leaf Nitrogen Content (LNC)

The LNC at early growth stages is a good indicator for N fertilizer application and LNC at late growth stages is highly related to the final grain quality of wheat. Quantification of LNC is therefore a prerequisite for the production of high-yield and good-quality crops while causing minimal environmental impact (Zheng *et al.*, 2018). Chlorophyll and N are subject on one another. Measuring one will inflict amount of other. Numerous accesses are detected to calculate the two (Zhai *et al.*, 2013).

For chl. and N in crop leaves of wheat found destructive systems founded on lab methods are proper but time expending and extravagant. In contradict, non-destructive system is small appropriate, but are not time expending nor costly. Therefore, non-destructive processes have been normally applied in measuring foliar chl or nitrogen for huge genesis (Ali *et al.*, 2013). Due to generate biomass, Photosynthesis is a method in which crops apply meridian energy. Green plants apply exotic savings, pre-eminently light, H₂O, carbon dioxide and nutrients, for moving the genesis of dry matter. The viscose going includes the alternative of H₂O and environmental carbon-dioxide into CO₃⁻ and H₂O in the appearance of sunshine. The proficiency of photosynthesis under a secure set of situations will confide upon the suction of photons by the crop, the disposal of this vigor to response centers and its ultimate apply in carbon imitation (Burgess, 2017).

Due to forecast N condition in leaves, Chlorophyll quantity meters can be further applied for reading. These tools that measure a CCI (chlorophyll content index) are founded on estimating the reflectance or engrossment at special wavelengths, though the approaches based on Chl. fluorescence registers are also applied to count the plant nutrient condition (Kalaji *et al.*, 2017).

Various non-destructive processes are obtainable to clench nitrogen arrangement at land level. Several of them are founded on spectra radiometric skills and are envisage as extremely hopeful processes, though they are completely valuable and are only applied principally between experiment actions. Within the devices that can be envisaged as compatible to operational actions at granary level, the maximum comprehensive by the feature of chl. quantity, under the impersonation of an intimate relevance within chl and nitrogen amounts in crop green tissues.

2.1.3 Effect of nitrogen on chlorophyll content

Chl. a and b are the most important pigments active in the photosynthetic process. In photosynthesis, antenna pigments in leaf chloroplasts absorb solar radiation, and through resonance transfer the resulting excitation is channeled to the pigments of reaction center, which release electrons and as a result the photochemical process set in motion. Leaf chlorophyll content (for example, how it varies both, between and within species) is therefore a parameter of significant interest in its own right (Bojovic and Stojanovic 2005).

Leaf chl. is a key indicator of leaf greenness, and it is often used to investigate leaf nutrient deficiencies and changes in chlorophyll (Ali *et al.*, 2017). Canopy chlorophyll content is also an indicator of seasonal carbon uptake in forest ecosystems (Croft *et al.*, 2015). Significant correlations between chlorophyll content and leaf nitrogen have been reported in many agricultural crops (Wang *et al.*, 2014; Kalacska *et al.*, 2015). Chlorophyll content, LAI and leaf dry weight are positively influenced by fertilizer application, especially nitrogen (Hokmalipour and Darbandi, 2011). Dordas and Sioulas (2008) reported that after fertilization, the low N supply would be remobilized for safflower growth, resulting in acceleration of leaf senesce and decreased chlorophyll content. Quantifying leaf pigmentation using this noninvasive optical method is fast, easy and produces reliable estimates of relative leaf chlorophyll when compared to traditional and chemical methods (Richardson *et al.*, 2002). Miri (2009) reported that CCI was significantly and positively correlated with grain yield and a harvest index of wheat. Chl. is not only used as a substitute for leaf nitrogen content, but also as an essential indicator of N-deficiency in agriculture (Cerovic *et al.*, 2012). The relationship between CCI and chlorophyll has been found to be linear in wheat and Asian pear

tree. (Ghasemi *et al.*, 2011; Lunagaria, Patel & Pandey, 2015; Kaur *et al.*, 2015). CCI for relative chlorophyll content can be used for decision support tool for N-fertilization of crops, and even more it may be used for improving the estimation of crop yield and biomass (Liu *et al.*, 2019).

Chlorophyll maintenance is essential for photosynthesis under drought stress in drought-tolerant wheat genotypes (Sairam *et al.* 1998). This trait has been used successfully for screening and selecting drought-tolerant wheat cultivars (Almeselmani *et al.* 2011a, 2012b).

Chl. and carotenoid pigments are responsible for harvesting light energy that is used in producing chemical energy such as Adenosine-5'-triphosphate, ATP and Nicotinamide adenine dinucleotide phosphate-oxidase, NADPH (Taiz and Zeiger 2006). There was a marked decrease in chl. and carotenoid content of hexaploid and diploid wheat subjected to drought for 10 days at 50, 60 and 70 days after sowing (Chandrasekar *et al.* 2000). Drought increases senescence by enhancing chl. degradation, nitrogen loss, and lipid peroxidation (Yang *et al.* 2001). Liu *et al.* (2006) observed marked increase in electrolyte leakage and reduction in chl. a and b in wheat cultivars subjected to water stress.

2.1.4 Soil Plant Analysis Development (SPAD value)

Minolta SPAD® 502 (Soil Plant Analysis Development) emits light at two wavelengths (λ), 650 nm (red) and 940 nm (infrared) and indicates the SPAD chlorophyll index. The devices provide rapid readings proportional to the leaf contents of chlorophylls and carotenoids (Minolta, 1989).

The chlorophyll index from the device Minolta SPAD® 502 showed positive correlation with leaf N concentrations in wheat (Schlichting *et al.*, 2015). Significant and positive correlations existed SPAD reading and petiole sap NO_3^- N concentration (Tavakoli and Gebbers, 2019). Canopy NDVI during mid-bloom to late bloom and SPAD reading during early bloom to late bloom were effective alternative methods for assessing cotton N nutrition status. Leaf chlorophyll content is another useful index to assess the plant vigor and leaf N level (Seemann *et al.*, 1987) and soil plant analysis development (SPAD) chlorophyll meter (Minolta SPAD-502) is a non-destructive analytical tool based on radiation absorbance by leaves in the red

and near-infrared regions (650 and 940 nm). As SPAD readings have an indirect and close relationship with leaf N concentration and leaf chlorophyll concentration (Debaeke *et al.*, 2006; Rorie *et al.*, 2011), the meter has been used on various crops as a quick and reliable method for N management (Saleh, 2012; Vollmann *et al.*, 2011). Bronson *et al.* (2003) already reported a good relationship between SPAD reading and leaf N concentration in cotton leaves. Rapid determination of comparative chlorophyll contents has widely employed in researches on nutrition diagnosis of diverse crops by the Chlorophyll meter. Thirty percentages or more without affecting the yield promotes NUE for real-time nitrogen management (RTNM) of rice that is depending on the SPAD threshold value. But only 6 mm² area is measured by the SPAD-502 and it has to work a large-scale of periodical repeated estimation before a believable result can be acquired. However, SPAD reading depends on the plant growth stages, crops and varieties (Wang *et al.*, 2013).

SPAD value was used to ascertain the onset of senescence and chlorophyll content of leaf over time. According to Manivannan *et al.* (2007) chlorophyll is one of the major components of chloroplasts for photosynthesis which increases biomass production and grain yield (Pandey and Singh 2010).

Saeedipour (2012) reported that the SPAD value progressively increased up to 8-12 days after anthesis (DAA) under control and water deficit conditions then it was decreased in all varieties but well-watered plant higher SPAD value than water stressed plant. Water deficits enhanced the senescence by accelerating loss of leaf chlorophyll and soluble proteins and the loss was more in sensitive one than tolerant one. Declined chlorophyll content from 13 to 15% in water-stressed wheat compared with well-watered plants was also reported by Nikolaeva *et al.* (2010).

Chlorophyll content in leaves reflects photosynthetic activity and the yield potential of wheat plants. SPAD chlorophyll meter readings and their relationships with the grain yield of spring wheat were studied by Barutcular *et al.* (2016). Sixteen spring wheat genotypes were grown under two temperature (cool and warm) and two moisture (rain-fed and irrigated) regimes. There were significant genotypic variations considering the SPAD values under all conditions.

The SPAD values were more strongly affected by heat stress than by drought stress. These results showed that SPAD values can be used as an indicator of grain yield in spring wheat, providing that the measurements are taken at appropriate stages at each location.

A SPAD (Soil Plant Analysis Development) chl. (chlorophyll) meter can be applied to lid to leaf N (nitrogen) intentness in breeding plans (Zakeri *et al.*, 2015).

Chl. (chlorophyll) and N (nitrogen) are significant elements that are actual in crop leaf. Lack of its two may create less or morbid outcomes. To remove this, different fertilizers are obtainable in market that balanced the amount of these elements. These fertilizers are used to crops (Patane and Vibhute, 2014). The maximum broadly applied tool is SPAD meter, a handheld absorbency meter. It estimates the nearly correlated to the leaf nitrogen intentness, SPAD has even been applied to measure nitrogen levels in crops (Ali *et al.*, 2013) .

It's a bearable handheld tool prepared to estimate the chlorophyll amount of crop leaves. The tool applies the content of clear moveable the leaf and the company of Minolta named as SPAD grades to count correlative chl. Amount in plant leaf (Moran *et al.*, 1997).

The reading of SPAD are measured emerged on two inspiration grades: the shipment of red light 650 nanometer, that is concentrated by chl. and 940 nanometer indicates the infrared transmission light, that have no occurrence of chlorophyll exploitation. Applying these device to count leaf chl. intentness has become normal, but calibrating its readings into straight units of chl. intentness is yet cumbersome, and a responsive of the interrelationship within two parameters is essential (Xiong *et al.*, 2015).

Though the SPAD meter has the convenience of a less achievement charge, it demands largely deserving rank to accept specimens a dour methodology. Again, these device has troubles, it sustains out the appraisalment of the nitrogen conditions applying a little specimen area such as 6 mm², besides the assessing are dominated to operator favor and then numerous repeats are need to gain probable results (Reyes *et al.*, 2017).

The crops canopies which has green in color is attached with plant chlorophyll amount that is surely related with leaf nitrogen intentness. Marrowy vegetative development and the leaves that has green in color are innate of crops with an enough nitrogen supply like up to 75% of

N in mesophyll cells can be situated in the chloroplasts (Treder *et al.*, 2016). Plant photosynthesis does not reply fugaciously to an abrupt alternative in light condition: the suspension prior constant stage is attained is tightly attached to the photosynthetic fetching condition that is a physiological state subject on the leaf's new light history (Townsend *et al.*, 2018). The advantage of plant nitrogen is deposited in the chloroplast, where photosynthesis occurs, turn in a potent alignment within leaf photosynthesis and plant nitrogen condition. This coalition simplify modeling crop development and outcome via plant nitrogen measurement, from the new can be quickly calculated applying this device (Zakeri *et al.*, 2015).

Chlorophyll count meter have been applied effectively to measure foliar chl. Amount in different crop genesis in non-destructive system, particularly to research stress physiology and abiotic condition e.g. lack of nutrient (Kalaji *et al.*, 2017).

Again, the device data have been established to be related importantly with chl. Amount, following transmittance quantities. However, these device readings have been confirmed to surely correlated cereal yield in wheat (Liu *et al.*, 2017).

2.1.5 Leaf Area index (LAI)

The LAI is the ratio of leaf area and its ground area (Radford, 1967) and it is the functional size of the standing crop on unit land (Hunt, 1978). Crop growth depends on adequate formation of leaf area for effective interception of light. LAI is an important biophysical variable in many ecological and environmental applications such as in the regional ecosystem models (Waring and Running, 1998). LAI controls many biological and physical processes in the water, nutrient and carbon cycle (Waring and Running, 1998) and hence determines the biomass gain by the crop. LAI is the main physiological determinant of crop yield.

Under little nitrogen supplementation of leaf but not under large nitrogen supplementation observed an important influence of light-dependent stroll of chloroplast on SPAD reading. The environmental cause and leaf characteristic of plant species affects deeply the interrelationship within SPAD readings and leaf nitrogen amount per leaf area that should be

calculated for when applying a Chl. meter to lead nitrogen arrangement in agricultural processes (Xiong *et al.*, 2015).

The estimation of LAI by satellite remote sensing has been investigated in several studies at various spatial scales and environments (Stenberg *et al.*, 2004). In general, the estimation of LAI is based on empirical relationships established between the variable (LAI) measured in the field and satellite data of band reflectance, often expressed in the form of spectral vegetation indices (SVIs). In general, SVIs attempt to enhance the spectral contribution of vegetation while minimizing that of the background. SVIs using some combination of red and near-infrared (NIR) reflectances, like the simple ratio (SR) or the normalized ratio (Normalized difference vegetation Index, NDVI) have been particularly popular. However, the empirical relationships are affected by various factors including lodging, weed population and soil background reflectance's. A set of soil-adjusted vegetation indices like SAVI and GESAVI have been developed to reduce the effects of the soil background reflectance (Major *et al.*, 1990, Qi *et al.*, 1994 and Rondeaux *et al.*, 1996).

2.1.6 Normalized Difference Vegetation Index (NDVI)

Precision agricultural practices have significantly contributed to the improvement of crop productivity and profitability (Koch and Khosla, 2003). Although primarily electro-optical visible sensors have been used, more recently, the application of thermal imagers, synthetic aperture radar (SAR), light detection and ranging (LIDAR), and hyperspectral imagers has gained increasing attention (Teke *et al.*, 2013).

Remote sensing-based indices, such as Normalized Difference Vegetative Index (NDVI) have been used to obtain crop information. It is used to monitor crop development and to provide rapid and nondestructive estimates of plant biomass, nitrogen (N) content and grain yield. Remote sensing tools are helping improve nitrogen use efficiency (Naser, 2012).

The red edge is a region in the red-NIR transition zone of vegetation reflectance spectrum and marks the boundary between absorption by chlorophyll in the red visible region and scattering due to leaf internal structure in the NIR region. This transition zone is in the basis of several vegetation indices like NDVI which is the normalized difference between the reflectance in

the red visible (700 nm) and the NIR (800 nm) reflectance. Also, the red-edge position is used to estimate the chlorophyll content of leaves or over a canopy.

The optical sensing technology is a quick, nondestructive, high-resolution and large scale measurement of plant canopy radiation reflection, can be used to monitor N nutrition status, plant growth and crop yield (Zhou and Yin, 2017). Normalized difference vegetative index (NDVI) is based on the visible red light (660 nm) and near-infrared (780 nm) reflected from crop canopy (Drissi *et al.*, 2009; Gutierrez *et al.*, 2012).

There is usually a good relationship between NDVI and plant biomass, leaf N nutrition and crop yield. As an example, NDVI could be used to predict cotton yield at peak bloom (Gutierrez *et al.*, 2012). Yin and McClure (2013) noticed that corn growth and N nutrition could be assessed, and corn yield could be predicted with combined NDVI and plant height measurements. Ma *et al.* (2001) reported that canopy reflectance provided a reliable, fast, repeatable indicator for screening and ranking soybean genotypes because of the relationship between NDVI and grain yield. Zhou and Yin (2014) found that NDVI was more appropriate for predicting cotton yield than cotton N nutrition status during the growing season.

NDVI is the greatest extensively applied and excellent-cognizant vegetation exponent, was promoted in 1975 to leverage the eerie data from Landsat to count worldwide agriculture and forestry (Bareth *et al.*, 2016). The normalized difference vegetation index (NDVI) was calculated using the equation: $NDVI = (NIR - R) / (NIR + R)$ where R is the reflectance in the red band and NIR is the reflectance in the near infrared band. NDVI was obtained around the flowering stage by using two different approaches: using ground measurements and from aerial multispectral images (Vergara-Díaz *et al.*, 2016).

Potent relations were established within figure NDVI almost blossom time and eventual outcome. Conferred that the figure NDVI involves gestures from background, atmosphere coerture from an exalted accomplishment hand-held camera was applied to synthesize the NDVI from UAV. This shortly raised the relation within synthesize NDVI and outcome (Duan *et al.*, 2017).

The productivity measured from NDVI had a potent co-relationship with cereal outcome in wheat (Duan *et al.*, 2017). Green normalized difference vegetation index (GNDVI) has an excellent preferential proficiency and can be a best predictor of outcome whereas filed at promote reproductive states (Kyratzis *et al.*, 2017). The data which is excerpted by NDVI applying the Green seeker sensors were further remain and submitted low inconstancy whereas comparison to the decagon SRS sensor. The firmness could for Green Seeker method meaning data of further rows. The experiments further reported that though voiced ranging sensor processes may be appointed to gain mean crop height measures, the process is yet a limiting measure to exalted exactness assessing at the crop level (Enciso *et al.*, 2017).

Canopies of plant populations are featured by functional designs with a complex arrangement of leaves and stems, which are subject to temporal and spatial fluctuation on various scales. The potential of leaf display is defined by the genetic framework, which sets up the range for development and environmental responses (Müller-Linow *et al.*, 2015).

The field measured crop height, with an R-squared value of 0.98 with the eradicated crop height had a very high linear correlation. The crops could be identified from the four-band airborne fairy and crop height, with an overall accuracy of 97.50% and a kappa coefficient of 0.95, which were 2.52% and 0.04 higher than those without crop height, respectively because of object-based method (Cooper *et al.*, 2017).

Again, a canopy with more vertical leaves seizes larger light entrance to inferior canopy layers, and in this way superior photosynthetic productivity. By mitigating disclosure to strong light, especially close upon the midday can limit radiation-initiated loss this structural characteristics (Burgess, 2017).

Software package provides whole-leaf statistics but also a local estimation of leaf angles, which may have great potential to better understand and quantify structural canopy traits for guided breeding and optimized crop management (Müller-Linow *et al.*, 2015).

Canopy coverage is an early season trait that is inexpensive to measure and has great potential for application in breeding programs focused on yield improvement. We recommend using the average canopy coverage in multiple trait schemes, especially for the early stages of the

breeding pipeline (including progeny rows and preliminary yield trials), in which the large number of field plots makes collection of grain yield data challenging (Xavier *et al.*, 2017).

A strong linear relationship exists between leaf N concentration and leaf chlorophyll concentration (Evans, 1989; Lamb *et al.*, 2002). Greater leaf area and green plant biomass translate into higher NDVI values (Shaver *et al.*, 2010, 2011). Since N content of the plant is directly related to leaf area and green plant biomass, higher N content in plants also results into higher NDVI values (Shaver *et al.*, 2011). Raun *et al.* (2001) demonstrated that a significant relationship ($R^2 = 0.5$, $p\text{-value} < 0.0001$) exists between NDVI and estimated grain yield in winter wheat. Likewise, Inman *et al.* (2007) found a linear relationship ($R^2 = 0.65$) between NDVI and grain yield in maize. Several other studies revealed significant correlation between NDVI and grain yield from heading to grain filling in wheat (Ball and Konzak, 1993; Marti *et al.*, 2007; Prasad *et al.*, 2007; Reynolds *et al.*, 2001; Royo *et al.*, 2003). The most appropriate stage for estimating yield was reported to be at mid-grain filling stage (Marti *et al.*, 2007; Royo *et al.*, 2003). Aparicio *et al.* (2000) found correlation between NDVI and grain yield increasing as growth stage progressed from booting to maturity, but it was significant only at the maturity stage for durum wheat under irrigated conditions. They also observed a positive correlation between NDVI and grain yield at all wheat growth stages under dryland conditions.

Active remote sensing based on NDVI can be used to estimate biomass and N variability in crop canopies without destructive sampling and thus has the potential to provide a fast, inexpensive, and accurate estimate of plant biomass production and grain yield of the genotypes prior to harvest, which would be beneficial for crop breeders (Elliott and Regan, 1993; Inman *et al.*, 2005; Royo *et al.*, 2003). Also, NDVI can detect subtle differences in sparse canopies which makes it suitable for estimating crop growth at early stages and it is not linear with respect to LAI of > 3.0 (Aparicio *et al.*, 2002; Serrano *et al.*, 2000). The NDVI values range between 0.0 and 1.0. The NDVI values from bare soil reflectance normally ranges between 0.1 and 0.2. The NDVI saturation normally happens around 0.9 when the NDVI reading fail to discern differences in variable crop canopies. Reynolds *et al.* (2001) suggested the use of NDVI as a fast screening tool for grain yield. Similarly, Araus *et al.*

(2001) showed that a spectral vegetation index such as NDVI is a promising tool to screen genotypes.

In recent studies, it was shown that NDVI and other spectral reflectance indices have the potential to differentiate spring wheat genotypes from heading to grain filling stages for crop biomass and grain yield under irrigated conditions (Babar *et al.*, 2006a, 2006b). Ma *et al.* (2001) reported that NDVI could differentiate between high and low grain yield among soybean genotypes. They concluded that NDVI can be a reliable and fast index for screening soybean genotypes and estimating yield under irrigated conditions. However, review of the literature indicates that very few studies have been conducted to identify and differentiate winter wheat genotypes for grain yield using active sensor based NDVI.

2.1.7 RGB (Red, Green, Blue)

The ranges from 400 to 1000nm wavelengths are sensitive for the ethereal Red Green Blue (RGB) color reactions. An infrared (IR) cut-off colander is given by the most color cameras for imaging particularly in the direct spectrum. Again, without filtering, they authorize short-IR imaging e.g. achievement of plants in the dark image (Coppens *et al.*, 2017).

Most unpopulated ethereal stages bear an RGB/CIR camera fervent figuring sensor. Variations of the RGB/CIR cameras which are multispectral and supra spectral sensor of images, though they enhancement the payload but fetch a large range of modern probabilities (Li *et al.*, 2014).

The color components of RGB nearly related the chlorophyll expand of leaves. If color grits of HIS circumstance has enough exponent to determine chlorophyll spread of rice leaves stays to stare it. Important interrelation was found within SPAD readings, LNC (Leaf N concentration) and 13 image color exponents enumerated from digital applying 3 color models (Yuan *et al.*, 2016). Leaf color is usually used as a guide for estimation of nutrient status and plant health and so to determine nitrogen and chlorophyll contents also (Zhai *et al.*, 2013).

The average value of the RGB colors is highly correlated with the amount of the chlorophyll from the rice leaf (Thaiparnit and Ketcham, 2017).

Color is applied like a significant parameter to estimate crop health, attribute of biological outcomes, and agricultural methods in usual. Several important physiological alternatives in the organic specimen may be delimited by alternative in hue. A facile method of red, green and blue (RGB) imaging can road down the alternatives in hue and can presently help in governance the condition growth state and health (Dutta Gupta *et al.*, 2014). The color of leaf is normally applied like an indicator to measure of nutrient condition and crop health so to ordain N and Chl amounts also (Zhai *et al.*, 2013).

The analysis of color is purposed at numbering ordinal images/portions is a proportion of the 3 prime hues such as RGB (red, green and blue). It has been accomplished with various goal e.g. measurement of dissimilation within various crop genesis, disorder, stress, impediments of dry matter and lack of nutrients other than nitrogen (Baresel *et al.*, 2017).

It is concluded that the adoption of RGB-based phenotyping techniques may significantly contribute to the progress of plant breeding and the appropriate management of fertilization (Vergara-Díaz *et al.*, 2016). The image of RGB under natural wavelengths of 3 main colors of red, green and blue (680 nm, 550 nm and 450 nm) were banished from the actual spectral figures to reproduce and gain RGB image applying outlying sensing image processing software (Qiong *et al.*, 2016). Analysis of digital color image found on RGB color image patterns has been applied to calculate crop chlorophyll and nitrogen. Numerous researches applied RBB color patterns to discover a relation with chlorophyll and nitrogen conditions of crop (Ali *et al.*, 2013).

2.1.8 Digital Camera

Digital cameras is a non-destructive and inexpensive tools have been considered in many research efforts as an alternative to expensive commercial sensors (like Yara N-Sensor) for crop nutrients management in agriculture (Tavakoli and Gebbers, 2019).

During this time, the researches on nutrition diagnosis of plants applies largely the asteroid imaginary, natural photographing and hugely- spectral distant sensing technologies to development of remote-sensing technology. The cameras which are digital, the greatest researches instruments which are largely used to remote sensing of discernible spectrum. At

first, 1990s, this instrument was applied in agricultural governance that is supported to find potential virtue of agricultural productions and discovering the weeds, pests and diseases. For enumerating the nutrient grade of crops based on the fixation of chlorophyll extent, a light camera was applied. Most of the scientists apply digital camera to extract the different types of parameters, e.g. green/ red and canopy cover that depends on the fixation of chlorophyll extent on crop nitrogen diagnosis (Wang *et al.*, 2013). Image analysis finds itself a great use to monitor and assess health of plants is mainly focused on leaf area as a feature parameter. Android device and image processing can be accurately identified Leaf color levels. Image processing can be measured from the color photographs successfully (Aydin *et al.*, 2017).

Image exploration is envisaged a hearty technique in large-throughput phenotyping with sampling (not involving damage). Therefore, exploration of digital field –executed images remnants challenging due to the difference of light prominences, development environments, and growth stages. The significant exponent of plant growth and development is PCC (plant canopy coverage) (González-Esquivia *et al.*, 2017). For enumerating the condition of nitrogen and extend of chlorophyll within various remote sensing stages, a less elevation remote sensing method applying digital cameras that plant data in discernible bands can be applied. So, the best result to be accurately approved by the vegetation indices is required (Saberioon *et al.*, 2014).

Estimates obtained from a digital camera or specialized sensors provide equivalent information about crop-N supply to a crop. However, information is needed about crop-N demand as well as N supply in order to estimate fertilizer-N requirement (Li *et al.*, 2010). Access to the 3D shape enables the derivation of parameters that are hidden when using 2D images. Monitoring of growth of individual leaves and their movements is only possible if full access to the geometry is granted (Jansen *et al.*, 2018).

However, developing an easy and proficient automatic method for finding nitrogen and chlorophyll content in a plant based on leaf color and image processing (Zhai *et al.*, 2013).

In elemental experiments, crop development and physiological measurements are yet assessed manually during manually espial, that are time expanding and deleterious. Owing to that there is

a rising assertion for realism and ability. In this way, spontaneous figure analysis process has turned a wonderful device in biological studies. It can be applied to essence and quantify various sort of facts such as color, size, shape and wetness and development rate of a targeted object (Aydin *et al.*, 2017).

Different experiments have indicated the exercise of digital figure analysis to calculate the nutritional conditions, chl. quantity or various measure found on hue of leaf such as variation within forms or lack of nutrient other than nitrogen (Baresel *et al.*, 2017). Spectral figure could visually gleam the morphological fact of wheat development bias at seedling condition, and further the spectral variety of various leaf stratum at several locations in canopy and individual wheat crops could be investigated from the outcome of hyperspectral imaging (Qiong *et al.*, 2016).

Software accommodates group analysis of figures to fluorescence extinguish parameters involves user indicated places of portion and mean of pixel grades on environmental leveled figures. Analyzed data are kept in the database with co-abdication of original image data and analyzed data (Nelson *et al.*, 2007).

The technique of figure can decrease the whole report of crop image for a controllable content, during growing sides and trading geometrical emendations, formerly the analysis of assessing and identification of several appointed trifles e.g. area, shape and size. The largest convenience of image analysis is that it can spectacle appointed places and contradict colors (Aydin *et al.*, 2017).

2.1.9 Smart Phone

New spectral exploitation photometry processes are commenced to determine Chl (chlorophyll) extend of rice leaves by smart phones. So, with light-aided SAP (LASAP), R² of 0.97 was acquired. Within traits, the vegetation exponent sent the most proper indication. It can enumerate that the best performance of LASAP system for determining Chl amount, leads to great advantages bestowed by smart phones at much little cost. This is a largely exact choice to SPAD meters to enumerate Chl amount non-destructively (Yu *et al.*, 2017).

The Lab color models such as RGB, HSB and CIE were essence from the smartphone images and interrelated to chlorophyll values gained applying a chlorophyll meter and by a SLP (Smart Laboratory Protocol). The camera of smartphone was sensorial sufficient to effectively receiving a wide range of chlorophyll and nitrogen amount ocular in rice leaves. The experiment showed that smartphones can be applied to fast and proper determination of chlorophyll and nitrogen content in rice leaves (Rigon *et al.*, 2016).

Intellectual farming is significant to hold the boast of agricultural outcome in sounds of productivity, natural influence, food safety and sustainability. The agriculture which is sustainable is highly relevant and straightly linked for smart farming since it increases the natural efficiency and structure found in which agriculture rely on giving primary human nutrient exigent (Kamilaris *et al.*, 2017).

The developed app on the smartphone, the performance of the models was evaluated again using a new independent set of data collected by Smart SPAD directly from maize plants inside a greenhouse. The Smart SPAD estimation compared well with the corresponding SPAD meter values ($R^2 = 0.88$ and 0.72 , and $RMSE = 4.03$ and 5.96 for neural network and linear model, respectively). The developed app can be considered as a low cost alternative for estimating the chlorophyll content especially when there is a demand for high availability (Rigon *et al.*, 2016).

To measure chl. conditions, a neural-network patterns was revealed found on the RGB elements of the color figure taken with a current digital camera. The red, green and blue color figure technique found system was moved to N measurement in version (Patane and Vibhute, 2015).

2.1.10 Dry Matter

Nitrogen is the most specious inorganic matter that plays a significant character in outcome of plants. N is a chief component to crop development and is a basal portion of Ch. (chlorophyll) that is elementary exploiter of light steam desiderate to photosynthesis (Clevers *et al.*, 2007).

Chlorophyll and nitrogen strafe the crops during green color and finally ordains their dry matter yield and exorcism. Crops adequately supported with nitrogen are salubrious and green, while crops inadequately supplied with nitrogen and flabby green/yellow in color and keep little and stunted. Therefore, the color of leaf variation have infused researchers to absorb this wealth during applying the technique of picture analysis to find out chlorophyll and nitrogen conditions in crops (Ali *et al.*, 2013).

Appropriate timing and wreath of N fertilizer appliance rending a key character to plant outcome and efficiency. Prophecy of nitrogen needs is essential to skilled improvement of N fertilizers. A user-amicable process to calculate foliar N intentness, found on an exploration of color leaf blade, was raised in the experiment (Townsend *et al.*, 2018).

The Chl. take on N component like a significant element. When the crop vanquishes the N, the quantity of the Ch. Will be reduced, that pretense the emaciated-yellow leaf named Chlorosis and invade the productivity of the crop. The N arrangement that strafes the content and exorcism of the maximum outcome, in wheat plantation happens whereas the farmers realize that the content of the N in whole the conditions by the wheat development by measurement the N to the leaf (Thaiparnit and Ketcham, 2017).

Table 2.1. Effects of Nitrogen on morphological and physiological adaptations in wheat

Sl. No	Treatment	Genotype (No.)	Growth Conditions	Growth Stage	Major effect or finding	References
Study of Nitrogen status in rice and maize						
1.	N application rates (0, 60, 120, 180, 240, 300, 360 and 420 kg N ha ⁻¹)	7 German bread wheat varieties were used	Field condition	Mature stage	analysis of canopies with small degree of ground Cover is possible.	(Baresel <i>et al.</i> , 2017)
2.	Five nitrogen fertilization levels (0,10,20,80, and 160kg·ha ⁻¹ NH ₄ NO ₃)	<i>Triticum aestivum</i> L.	Field condition	Mature stage	the SPAD-502 readings and plant photosynthetic pigment content per-leaf area are profoundly affected by salinity and nutrient stress	(Vergara-Díaz <i>et al.</i> , 2016)
3.	757 treatments were used	winter wheat (<i>Triticum aestivum</i>) for six years	Field condition	Mature stage	Normalized measurements limited the biomass and cultivar effects, but not the growth stage effect.	(Ravier <i>et al.</i> , 2017)
4.	four treatments refer to four irrigation and nitrogen treatments	Eight cultivars were selected	Field experiment	Mature stage	Strong correlations were found between image NDVI around flowering time and final yield	(Duan <i>et al.</i> , 2017).
5.	20, 40,60 Kg ha ⁻¹ N	Three variants of the experiment procedure were tried (<i>Triticum aestivum</i> L. cultivar Ester)	Field condition	Mature stage	Increasing yield	(Yakushev and Kanash, 2011)
6.	Different nitrogen status (20 to 60 Kg ha ⁻¹)	<i>Triticum aestivum</i> L.	Field condition	Mature stage	Canopy nitrogen could be lowered with no detriment to carbon gain or grain protein content.	(Townsend <i>et al.</i> , 2018)

Sl. No	Treatment	Genotype (No.)	Growth Conditions	Growth Stage	Major effect or finding	References
7.	using ASD non-imaging field hyper-spectrometer	<i>Triticum aestivum</i> L	greenhouse	seedling stage	superiority of location monitoring of growth at seedling stage of wheat based on hyperspectral imaging is significant	(Bhuiyan <i>et al.</i> , 2017)
8.	Using GNDVI (green normalized difference vegetation index)	Durum Wheat	Field condition	Mature stage	NDVIs recorded at the experimental site were significantly correlated with grain yield of the same set of genotypes grown in other environments.	(Kyratzis <i>et al.</i> , 2017)

2.2 INFLUENCE OF NITROGEN ON MAIZE MORPHO-PHYSIOLOGICAL TRAITS

Maize (*Zea mays* L.) is an important and widely cultivated crop (Calderón-Vázquez *et al.*, 2011) for food, feed, forage and fuel across tropical and temperate soil of the world. It is grown over a wider range of altitudes and latitudes than any other food crop, under temperatures ranging from cool to very hot, on wet to semi-arid lands, and in many different types of soils (Shiferaw *et al.*, 2011). The global area for maize is about 174 million ha. The corresponding average annual production was over 979 million metric tons (USDA, 2013). Maize is the basis for food security in some of the world's poorest regions in Africa, Asia, and Latin America, yet yields are often extremely low, averaging approximately 1.5 tons per hectare about 20% of the average yield in developed countries (Shiferaw *et al.*, 2011). Yields in low productivity rainfed environments are severely limited by an array of factors, including abiotic and biotic stresses.

Maize is the 3rd principal food crop in Bangladesh and accounts for 21% of the total caloric consumption per capita. Increased and sustainable production of maize is required to address the continuous population growth and rural poverty of the country (Tsujimoto *et al.*, 2017). Now a days, hybrids are the best-yielding maize varieties which are gained from a single cross of two best inbred parental lines (Edlich-Muth *et al.*, 2016). Again, about half of the peoples of the world uses maize as a principal food because it is the main global cereal crops. For growth and development of flowers and fruits of maize are especially vulnerable to both drought and saline conditions that attacks crop yield (Dietrich, 2018).

The archetype of maize in the united states of southwest remnant problematical, with contradictory antiquarian data corroborative either littoral or mountainous ways of embrace of maize into the US. Again, the genetics of adjustment to the recent environmental and original behalf of the Southwest is hugely uncharacterized (Da Fonseca *et al.*, 2015). It is phenotypically various and this phenotypic variety is revealed by embodied changes in phenotypic and replication levels within maize lines (Springer *et al.*, 2009).

Nitrogen is a vital element in crops, and its management is a key measure to improve their yield and quality. Real-time monitoring of crop nitrogen content is needed to optimize products and crop production (Yang *et al.*, 2016).

The level of plant N is a very supreme index to evaluate plant development, grain and quality. For acquiring a greater crop yield, farmers use more nitrogen to the field. Extreme nitrogen absorption not only decreases the farmer's income but also occurs the soil water pollution and discharge the greenhouse gas. For proper nitrogen management at the time of plant growth, its need to get an actual and proper understanding of plant nitrogen status. Seed development are affected by the molecular mechanisms that preserved in maize (Liu *et al.*, 2017). The lack of nitrogen (N) is the main constraint on cereal yields in areas with more than 400mm average annual rainfall. Therefore, an optimization of N use is critical for increased grain production, especially in the low productive regions (Rigon *et al.*, 2016).

2.2.1 Yield and yield components traits

Nitrogen (N) is one of the most yield regulating nutrients for crop production in the world. It is also the nutrient element applied in the largest quantity for most annual crops (Huber and Thompson, 2007). Nitrogen also increases shoot dry matter, which is positively associated with grain yield in cereals and legumes (Fageria, 2007a; Fageria, 2008). Grain harvest index (HI) and N harvest index (NHI) are also reported to be improved by the addition of N to crop plants (Fageria and Baligar, 2005; Fageria *et al.*, 2006).

Cereals and legumes plant traits are reported to be positively associated with yield in field crops (Fageria, 2007a; Fageria, 2008). Differences in biomass yield and N uptake varied partly due to decreased soil N mineralization and partly due to the dry weather conditions of different years, and the N uptake rate has been found to assist the improvement of dry matter yield in maize (Greef *et al.*, 1999). Maize biomass yield increases with increase in plant density and N rate (Gaurkar and Bharad, 1998). Increase in biological yield for maize under various N rates has been reported by other researchers (Cox *et al.*, 1993). In a study by Hammad *et al.* (2011), biological yield increased by application of N up to 300 kg/ ha. These results are also supported by the findings of Khaliq *et al.* (2009) who achieved 17.61 t ha⁻¹ mean biological yields with the application of different N rates.

The harvest index is used to assess crop efficiency and forecast grain yields. The study by Sabir *et al.* (2000) indicated the average harvest index, ranging between 30 and 50%. Hamid and Nasab (2001) reported that both grain and biomass yields in maize are correlated with vegetative and reproductive phase duration. Leaf area influences interception and utilization of solar radiation of maize crop canopies and, consequently, maize dry matter accumulation and grain yield. Leaf area and number are important factors in the estimation of canopy photosynthesis in crop growth simulation models that compute dry matter accumulation from temporal integration of canopy photosynthesis (Boote *et al.*, 1996).

The breadth of the leaf profile decreases under high soil nitrogen level and high plant density (Oscar and Tollenaar, 2006). According to Pandey *et al.* (2000), maize genotypes differ in their ability to maintain leaf area, LAI (leaf area index), crop growth rate (CGR) and aboveground dry matter production at different levels of water deficit and N supply. Maize N availability varied greatly from year to year due to weather fluctuation (Harold *et al.*, 2006).

Wang *et al.* (2007) reported that understanding concepts of ideal soil fertility level and response to nutrient management provides practical guidelines for improving nutrient management under the variable rainfall conditions. Application of N at later vegetative stages of maize extended growth phase (Amanullah *et al.*, 2009) and produced relatively more assimilates by maize crop in response to the long growth period, as a result, plant height, mean single leaf area and leaf area per plant were significantly increased and that might be the possible cause of greater biomass yield of maize. Rajcan and Tollenaar (1999) reported that the difference in the dry matter accumulation in maize is attributed to post-silking N uptake and it significantly increased with increase in N rate. Mariga *et al.* (2000) reported that biomass yield in maize considerably increased when N was applied up to the tassel initiation stage. Scharf *et al.* (2002) observed significant increase in maize yield when N was applied in split. Hammad *et al.* (2011) concluded that yield components, Nitrogen use efficiency, Agronomic efficiency and economic yield of maize crop increased with the application of N up to 250 kg ha⁻¹ and there was no further significant increase in economic yield beyond this level. In contrast the biological yield increased up to 300 kg N ha⁻¹. Application of various N

levels also significantly influenced seed protein content and it was increased up to 300 kg N ha⁻¹ application without application of N, grain yield and quality was extremely decreased.

2.2.2 Grain Yield

Grain yield is a function of genotype × environment interaction (Annicchiarico, 2002). A more acceptable crop genotype is the one which exhibits wide adaptability to varying environments. In each environment, the grain yield of a particular maize genotype depends on its potential grain yield components (Grafius, 1960). Grain yield of maize is a product of three yields components, i.e. the number of ears per unit area, the number of grains per ear and the unit grain weight (Gardner *et al.*, 1985). Increase or decrease in any one of these components, keeping the size of other components constant, contributes to increase or decrease in grain yield, respectively, and thus any exercise whether agronomic (management) or breeding type (genotype), which increase any of these components, keeping the other components constant, will increase the final grain yield. Devi *et al.* (2001) reported that ears plant⁻¹, ear length, number of seeds ear⁻¹ and 100-seed weight directly influence the grain yield and indirectly affect several other parameters. Any kind of stress, for example a drought stress, during or around the stage(s) at which these components are formed may severely affect grain yield.

Nitrogen is a key factor in achieving optimum grain yield. On the other hand, grain yield is the main target of crop production. Yield is significantly affected by both N application timing and nitrogen rates. Nitrogen levels significantly increase the grain yield. Yield varying between 4744.8 kg ha⁻¹ in no nitrogen application and 7355.5 kg N ha⁻¹ with application of 225 kg N/ha have been reported by Ali and Raouf (2012). A similar trend in yield differences across nitrogen rates have been reported by Zeidan *et al.* (2006) and Lawrence *et al.* (2008). Bundy and Carter (1988) and Sanjeev and Bangarwa (1997) reported that grain yield increased with increasing nitrogen rate. The fact that grain yield varied significantly with timing and regimentation of nitrogen strongly underscores the necessity of fine-tuning N application to match nutrient supply to crop demand. N applied at 35 DAS or in equal splits at 0 and 35 day after sowing or at 35 and 70 days after sowing gave consistently more grain yield than other modes, particularly when N rate was 120 kg ha⁻¹. The findings confirm the agronomic benefits of split nitrogen application in crops reported (Mungai *et al.*, 1999; Roberts, 2008).

Application of N fertilizer had a much greater effect on maize grain yield; this could be due to the fact that application of N fertilizer in plants increases uptake of other nutrients. This can be explained by the fact that the supply of N enhanced the development of small roots and root hairs which, in turn, facilitate the absorbing ability per unit of dry weight (Hammad *et al.*, 2011). Thereafter grain yield did not respond to further increase of N rates implying that increasing the rate of N fertilizer beyond 250 kg N /ha is not a sound strategy for obtaining maximum grain yield (Gheysari *et al.*, 2009). The grain yield is the magnitude of thousand grain weight number of grains per cob and biological yield and same trend was observed in these parameters with application of N at a rate of 250 kg ha⁻¹. Also, the potential of a crop yield depends upon its yield contributing factors, such as thousand grain weight of the crop (Khaliq, 2008). Moreover, results revealed that N dose above 250 kg N ha⁻¹ in maize did not increase thousand grain weights. Ragheb and Rassy (1989) reported that hybrids generally differ from each other in grain yield due to genetic factors and the different physiological performance. The physiological factors include extended root system with more root hairs to absorb more nutrients and the canopy architecture to intercept more photosynthetic light.

The general conclusion of grain yield increase over control per kg N applied and time of N application in maize has been due to good synchrony if N is applied nearest to the time it is needed by the crop (Bundy, 1986; Vetsch and Randall, 2004). In the highland ecosystem, anthesis and 50% pollen shed of modern maize varieties occur between 85 and 95 days after seedling emergence, which coincides with V6 and R1 stages of growth (KARI, 2005).

2.2.3 Kernel number per ear

Ear and grain development are severely inhibited by N deficiency. It was found that yield reduction at low N stress is largely due to increased kernel abortion and formation of fewer kernels per ear (Below, 2002). It appears that N metabolism in kernels has a direct effect on kernel development and productivity since the provision of N to developing maize kernels can increase their capacity to synthesize protein and to utilize sugars for the biosynthesis of starch (Singletary and Below 1990). Modern cultivars usually achieve higher yields than the old cultivars not only at high N but also under low N supply. In general, a genotype × N rate interaction cannot be observed when a large number of hybrids are compared (Below, 2002).

Modern cultivars are, therefore, more N efficient because the physiological traits related to yield formation and resistance are comprehensively improved in modern cultivars. However, this does not mean that the physiological and morphological traits in a modern high yielding cultivar have been optimized for adaptation to low N conditions. These cultivars still show large variations in yield formation in low N stress conditions, indicating the possibility that NUE can be further improved by plant breeding endeavors.

In comparison with N inefficient hybrids, N efficient maize hybrids have a higher net photosynthetic rate at the kernel filling stage, although their N concentrations in the vegetative organs are similar (Chen *et al.*, 2006). One possible explanation is that the photosynthetic NUE is higher in N efficient cultivars. Indeed, as a C₄ plant, maize has much higher photosynthetic NUE than other cereals (Sinclair and Vadez, 2002). An alternative explanation might be that there is weak negative feedback on photosynthetic rate from sink requirement in N efficient cultivars because they have more fertile kernels than the N inefficient cultivars. One of the important roles of N in ensuring high productivity of crop plants is establishment of reproductive sink capacity (Below, 2002).

In N efficient maize hybrids, the number of kernels per ear is much higher than in N inefficient hybrids (Chun *et al.*, 2005), even when their above ground vegetative biomass is similar (Chen *et al.*, 2006). Gallais and Hirel (2004) reported that, among the yield components, kernel number was the most affected (32%) while kernel weight was reduced by only 9% and the decline in yield due to the reduction of N caused ovule abortion after fertilization. Ovule abortion can also cause the limited product of photosynthesis that affect, in turn growth of vegetative and after flowering (McCullough *et al.*, 1994). Such abortion could be the result of a limitation in the source of photosynthetic products, which also affects post anthesis growth (29% reduction) much more than vegetative development (14% reduction). This proposes that, just after fertilization, the sink demand must be too high compared with the availability of resources, thus leading to embryo abortion in a genotype-dependent manner.

2.2.4 Response of maize to nitrogen application

Nitrogen is the most important and limited nutrient in maize production. Several studies have reported positive effects of N fertilization on corn plant biomass, photosynthesis and grain

yield (Fabrizzi *et al.*, 2005; Ma *et al.*, 2005; Uribeharrea *et al.*, 2009). Precision agriculture technologies are becoming an integral part of farming operations for crop production and fertilizer management. These technologies, especially optical sensing, can help estimate plant nutrient status. Normalized difference vegetative index (NDVI) and chlorophyll soil plant analysis development (SPAD) measurements are commonly used spectral indices in field practices due to their effectiveness and ease of use. Plant NDVI relates the reflectance in the red (Red NDVI) and near Infrared (NIR) spectral light bands. Many researchers have reported a good relationship between plant NDVI and photosynthetic efficiency (Freeman *et al.*, 2007; Inman *et al.*, 2007), plant N status (Rui *et al.*, 2009; Rambo *et al.*, 2010) and maize yield (Martin *et al.*, 2007; Inman *et al.*, 2008). SPAD measures relative chlorophyll content in plant leaves. Because chlorophyll content is closely related to N supply (Pandey *et al.*, 2000), Soil Plant Analysis Development (SPAD) is also used to diagnose maize N and predict maize grain yield potential (Bullock and Anderson, 1998; Vetsch and Randall, 2004).

Nitrogen availability has been shown to play an important role in maize plant growth and elongation (Rui *et al.*, 2009). Bukan *et al.*, (2009) reported that with 150 kg N/ha applied to maize, significantly increased grain yield by 9.09%, ear height by 4.13% and leaf length and width by 2.36 and 4.30%, respectively, compared to treatments without N application. Increasing N application increased N content and chlorophyll content in maize (Pandey *et al.*, 2000; Rambo *et al.*, 2010).

Clay *et al.* (2006) observed that increasing N rate from 0-12 kg ha⁻¹ decreased reflectance in the red (661 nm) bands at V8-V9 corn growth stage. Nitrogen stress reduced the production of chlorophyll that is involved in the photosynthesis. Reduced chlorophyll content increased reflectance of photosynthetically active light (Rui *et al.*, 2009) and contributed to low SPAD and NDVI readings from treatments without N application. Insufficient water availability during the maize reproductive silking stage, which is the most critical stage, most likely contributed to reduced yields. Haghighi *et al.* (2010) and Viswakumar *et al.* (2008) reported very poor maize yields under dry conditions due to insufficient rainfall and little response to N application.

Kiziloglu *et al.* (2009) observed a linear relationship between water use efficiency and maize grain yield. They found that higher water deficiency resulted in a significant reduction in water use efficiency and maize yields. Increasing N fertilization increased maize grain yield. It was consistent with other studies (Halvorson *et al.*, 2006; Gagnon and Ziadi, 2010).

Halvorson *et al.* (2006) reported a significant increase in grain yields with rates up to 224 kg N/ha under irrigated conditions. But Ma *et al.* (2005) observed that corn grain yields increased significantly with rates up to 120 kg ha⁻¹. Al-Kaisi and Kwaw-Mensah (2007) reported in their study that N rate of 85 kg ha⁻¹ increased corn grain yield and found that further increase in N application did not result in significant yield increase. Water availability and insufficient rainfall was most likely the limiting factor to N use efficiency. Fertilization timing did not influence corn grain yield. Other studies also revealed the effect of N application timing on corn grain yields (Tarkalson *et al.*, 2009).

However, Gehl *et al.* (2005) observed that corn N uptake improved and grain yield increased with split N fertilization compared to one single application at planting under irrigation system. Ma *et al.* (2005) observed that drought conditions may severely affect N utilization and corn yields. Some studies reported no association between corn grain yield and SPAD (Bullock and Anderson, 1998) and NDVI (Teal *et al.*, 2006) at growth stages between V6 and V9 stages, but other research has shown a strong relationship between these parameters and corn grain yield at around V8 to R1 growth stage (Vetsch and Randall, 2004; Inman *et al.*, 2007). A study by Machado *et al.* (2002) showed that 61% of the variation in grain yield could be explained by plant height in a dry year.

2.2.5 Non-destructive digital image methods for N determination

Leaf area index (LAI), shoot dry weight (SDW), and N accumulation are good indicators of crop growth and N status and provide useful and important information for the precision N fertilizer management and the crop yield prediction during growing season (Inoue *et al.*, 1998; Xue *et al.*, 2004; Cui & Lee, 2002). However, these measurements done by field survey require manual sampling and laboratory procedures as well. Thus, the use of methods can be less efficient, often difficult, and time- and resource-consuming (Mao *et al.*, 2003; Pan *et al.*, 2007). Remote sensing has been proved useful for providing information of the actual status

of crop growth and nutrition status. Due to its fast, non-destructive, and relatively cheap characterization of crop status, ground-based remote sensing has attracted a great deal of attention in terms of application for crop growth and N nutrition status monitoring for precision management in many crops (Nguyen & Lee, 2006; Li *et al.*, 2010). Ground-based remote sensing devices such as hyper-spectral reflectance meters, SPAD 502 (Minolta, Japan), and LAI-2000 canopy analyzer (Li-Cor Inc., USA) measure reflectance or absorption of light by leaves or the entire crop canopy to facilitate adjustments of crop management during the growth period. These devices have been developed and applied successfully for monitoring crop growth and/or N nutrition status (Li *et al.*, 2010; Chung, 2009). The hyper-spectral images containing the hundreds of narrow bands have the potential to detect N concentration of the foliage as well as CC (Haboudane *et al.*, 2004). However, hyper-spectral information may be useful after full CC and the information about N concentration data need to be combined with the information about crop biomass in order to indicate the mass of N per unit area (Li *et al.*, 2010). The SPAD 502 measures the absorbance of a leaf in the red and near-infrared region. SPAD readings have been successfully related to canopy N status in (Jongschaap and Booij, 2004), corn (Blackmer and Schepers, 1995), and rice (Chung, 2009). However, the SPAD readings are affected by leaf thickness and measure the small leaf area of 6 mm² (Pagola *et al.*, 2009). Also, their measurements are subject to operator bias in the selection of leaves and data collection of SPAD readings is too time-consuming for the monitoring of large areas (Jia *et al.*, 2004). The LAI-2000 canopy analyzer estimates leaf area index (LAI) and the fraction of sky visible from beneath the canopy. The LAI-2000 method is fast, but it is sensitive to illumination conditions and boundary effects. LAI derived from LAI-2000 can be estimated up to 40% lower than those provided by direct measurements in canopies with large gaps (Welles and Cohen, 1996). Alternatively, the use of the digital camera as a low-cost and highly efficient tool has been examined in recent researches. Image analysis of color digital image has been used with some success in diagnosis of crop growth and N nutrition status (Kawashima and Nakatani, 1998; Ku *et al.*, 2004; Jia *et al.*, 2004; Behrens and Diepenbrock, 2006; Pagola *et al.*, 2009; Li *et al.*, 2010). Images of digital camera provide spectral information in the red, green, and blue (RGB) wavelength. Spectral information of digital camera image reflects the properties of crop or background surfaces.

Original RGB bands were transformed into other color indices such as Hue-Saturation-Intensity space, normalized color components to increase accuracy in vegetation analysis (Lailiberte *et al.*, 2007). Ku *et al.* (2004) and Pagola *et al.* (2009) developed color indices to estimate chlorophyll content and/or greenness at the leaf level using color digital camera image analysis, while Jia *et al.* (2004) at the canopy level. They also reported high negative correlation of greenness intensity with wheat canopy biomass at booting and flowering stage and suggested the possibility of crop growth status monitoring with color digital camera image analysis. Canopy cover (CC) would most closely correspond to plant volume that is correlated with above-ground biomass (Poissonet *et al.*, 1973), and is related to leaf area index (LAI). Behrens and Diepenbrock (2006) and Li *et al.* (2010) estimated canopy cover (CC) from color image analysis of wheat and oilseed rape, respectively and reported that CC values were closely correlated with LAI of oilseed rape and with LAI, above-ground biomass, and N content of wheat during the vegetative stage. Leaf color of crops is related to their N nutrition status (Jia *et al.*, 2004). Generally, leaves of N-sufficient crop have more deep color than those of N-deficient crop at the visible spectrum. McMurtrey *et al.*, 1994 showed that color digital camera image analysis had potential for detecting the N status of winter wheat. However, sufficient information has not been accumulated to apply these methods to characterizing crop growth and N nutrition status at the canopy level under various crop management conditions and of the other crops like rice. In the present study, we aimed to develop a non-destructive method for monitoring crop growth and N nutrition status such as LAI, SDW, and shoot N accumulation with digital camera image analysis at the canopy level of rice plant.

2.2.6 SPAD value

Current maize generation needs comparatively huge amounts of nitrogen that are normally issued by fertilizers. Besides, nitrogen (N) is fateful to the plant's development, so, proper assessment of their intentness in crops is essential to measurement the volume of nitrogen to impregnate by their vegetative growth (Reyes *et al.*, 2017). The entire chl (chlorophyll) of leaf in the land was measured by using this device. The device ejects two various light strength from two diodes. One is top wavelength 650 nanometer (red) engrossed by the leaf tissue

that calculates the chl amount (greenness). A second top 940 nm is ejected at one time with red LED to recoup to leaf perforation (Ali *et al.*, 2013).

The SPAD (Soil Plant Analysis Development) chl meter is the best usually applied indication tools to dimension plant N condition. The results exposed that a status 2/3 of the total leaf basis to the top could describe the chl (chlorophyll) amount of the total leaf blade, since reported by the comparatively less dissonance of assessments at that status. The Soil Plant Analysis Development (SPAD) grade emerged on di-positional leaves and the removed chl a and b volumes were compared. The reports represented the 2/3 location on that leaf was best compatible to predict the N condition of maize (Turner and Jund, 1994). N (nitrogen) is the key verdant material for plant chlorophyll implication, and the chlorophyll is a significant part of plant photosynthesis (Yang *et al.*, 2016).

With a view to establishing an interrelation within the nitrogen intentness and the Soil Plant Analysis Development (SPAD) assessment, a mean grade in SPAD units and a delegate color units were appointment to every leaf (Reyes *et al.*, 2017).

The Soil Plant Analysis Development (SPAD) tools transmit a light gleam of 2 wavelengths (940 and 650 nanometer) from top place of the leaf, imprison emitted light. The variation between the emitted and imprison light is an intimation of comparative Chl amount per unit of the leaf area (Vesali *et al.*, 2017).

It measures the red light drowned by the leaf. The over drowned red light, the larger the chl intentness in the leaf. The relations within the Plant Analysis Development meter grade and leaf chl intentness is curvilinear according to either explicative or polynomial operations (Rhezali, 2016).

2.2.7 Canopy Cover

At the high-elevation site, the N application improved its stagnant initial canopy development and increased both RUE and LI. The simple and inexpensive imagery technique should be useful to identify physiological basis of maize responses to fertilizer application and its interaction with regional environment even under poorly equipped regions in the tropics (Tsujimoto *et al.*, 2017).

The crop canopies that color is green connected with leaf chl amount that is surely interrelated with the nitrogen concentration of leaf (Treder *et al.*, 2016).

Chlorophyll measurement in loose canopy tree grains is done applying hyperspectral tools and feint model. To test various modelling impersonation, applying hyperspectral optical tools correlated with leaf chlorophyll. Images are captured and tools are measured by them. These indices gives more accurate and development results (Patane and Vibhute, 2014).

Applying canopy cover (CC), measured by digital images applying an image resolution program, and was largely related with development and nitrogen nutrition parameters for example LAI (leaf area index) dry weight of shoot and shoot nitrogen collection also established that digital camera could be appointed to characterize the plant development and nitrogen accumulation condition of maize (Pagola *et al.*, 2009).

Further, CC (Canopy cover) impetus immediately the reflectance to nitrogen intentness. NDVI measurement to maize leaf nitrogen intentness is prejudiced when canopy cover is less than 100 percentage (Rhezali, 2016).

2.2.8 Leaf Nitrogen Content (LNC)

The photosynthetic proficiency of maize crops plants decreased and water need reduced when they were under less light predominance on 6 am and 18 pm (Zhuang *et al.*, 2017).

Vigorous vegetative development and leaves of dark green are features of crops with an enough nitrogen serve, like up to 75% of N in mesophyll cells can be placed in the chloroplasts (Treder *et al.*, 2016).

Chl (Chlorophyll) and N (nitrogen) are existent in plant leaf that are significant elements. Lack of these two may occurs minor or poorly productions. Maximum farmers uses on the base of preset date of low yield (Patane and Vibhute, 2014).

The N amount in leaf is a significant exponent to find the nutritional status of crop, which can gleam the healthy condition for crops development (Yang *et al.*, 2016).

2.2.9 RGB (Red, Green, Blue)

Color is applied as a significant parameter to detect crop health, characteristic of biological outcome, and agricultural method in general. Some important physiological changes in the biological specimen may be delineate by changing in color (Gupta *et al.*, 2014).

To crop phenotypic research, image processing skill have been largely applied in crop science. For processing large image data, these quick algorithms are required. Current imaging processes accommodate to supposition of multi-dimensional and multi-changeable data that are applied to quantify the development, outcome and use to stress. The crop images are given with a big range of wave of electromagnetic wavelength to the verity that crop leaves interact with light at various wavelength reflecting various information (Cao, 2017).

It is concluded that the adoption of RGB-based phenotyping techniques may significantly contribute to the progress of plant breeding and the appropriate management of fertilization (Vergara-Díaz *et al.*, 2016).

For measuring crop Chlorophyll and nitrogen on the basis of RGB (Red, Green and Blue) color models have been applied by the digital color image analysis. To detect an interrelation with chlorophyll and nitrogen condition of crop, RGB color models were applied the many researches (Cao, 2017) .

The obtain images were analyzed to gain mean charges of main color: RGB (red, green and blue) analyzes of the interrelationship within nitrogen intentness in the leaves, greenness of leaf tools and red, green and blue color elements were completed. The RGB based basic color values contain a multiple recoil model and a model which involved the values of the red and blue color as well as parameter recount the time of leaf were the most fitted model (Treder *et al.*, 2016). The content of chl from the maize leaf is largely interrelated with the mean value of the (red, green and blue) RGB colors. The chl prognosis has been turned with 60 various maize leaves and the exactness of the mentioned process is 96.12% for evaluating the accuracy (Thaiparnit and Ketcham, 2017).

The LCC (leaf color chart) is a free-to-apply and accessible diagnostic devices to monitor the correlative greenness of a maize leaf like an indicative of crop nitrogen condition. Crop

without nitrogen uses become yellowish. Lack of N (nitrogen) is ensured when the leaf color chart reading within 2 and 3. At less fertilizer of nitrogen rates in photos the crops appearance better, but the less leaf color chart (LCC) reading only evidences nitrogen deficiency. When the crops gets large amount of fertilizer, its look well growth and the canopy are stopped (Singh *et al.*, 2002).

The digital images of maize lid were gained by digital camera at the flowering and fruiting period. To identify the means of red, green and blue colors, the image was processed. RGB (red, green and blue) characters were evicted from the images and related with the SPAD values (Gupta *et al.*, 2014).

2.2.10 Camera

To identify N concession a commitment cheap alternative at canopy balance apply digital image analyzes. Current research assessed maize canopy SPAD recitation by analyzing digital image taken with a homely digital camera (Adamsen *et al.*, 1999).

Color images were taken with a digital camera, refined and different (red, green and blue) RGB parameters were destined. R and B colors presented to be more proper prophecy of N conditions. The color parameters related better with the condition of crop N than the SPAD grade (Dutta Gupta *et al.*, 2014).

For dispelling the image rears, the images were divided and a (dark green color index) DGCI. The exponent, which is formed from values of color, impregnation and glossiness, was applied to count the greenness of the maize canopy. The dark green color index was importantly related with mean SPAD recitation maize canopy at every growth state, but the recoil lines were various from one another (Pérez-Patricio *et al.*, 2018).

Imaging rehashes feasible the assessment of progressive changes in crop structure, on the basis of parameters for example LAI (leaf area index), tillering and agglomeration on huge numbers of isolates extra time, development the potential of indicating, 'hidden traits' (Neilson *et al.*, 2015).

An adequate process to evaluate crop nitrogen condition is the predominance of green color to digital presentment of leaves. The camera registers the images, or particular software

resolution the images by standardized the vert of the leaf depend on RGB (red, green and blue) colors of the image. The red, green and blue (RGB) grade are changed into color, impregnation and glossiness values applying a process (Rhezali and Lahlali, 2017).

2.7. Smart Phone

The developed app on the smartphone, the performance of the models was evaluated again using a new independent set of data collected by Smart SPAD directly from maize plants inside a greenhouse. The Smart SPAD estimation compared well with the corresponding SPAD meter values ($R^2 = 0.88$ and 0.72 , and $RMSE = 4.03$ and 5.96 for neural network and linear model, respectively). The developed app can be considered as a low cost alternative for estimating the chlorophyll content especially when there is a demand for high availability (Rigon *et al.*, 2016).

Recent eerie intentness photometry processes are inaugurated for measuring chl (chlorophyll) amount of maize leaves by smart phones. The exalted representation of LASAP system to measure chlorophyll amount, direction to fresh advantage given by smart phones at plenty less cost (Vesali *et al.*, 2017).

2.2.11. Dry Matter

Plant yield is fast interactively estimated by genetic GEM (characteristics, environment and management). Large population consistency results in a hazard of tenement and minimizes crop yield by 5-25% in maize. Internationally, the recent new hybrids of grain crops enhance yield dynamic by approving farmers to enhancement planting density (Zhang *et al.*, 2017). The outcome of biomass evaluate and NDVI 680 (normalized difference vegetative index) increased the best measurement of chl (chlorophyll) amount per crop's plant while measures of chl intentness per unit of leaf weight were poor (Jinwen, 2014).

N fertilizer impressions the entire nitrogen boosts as well as entire plant dry matter outcome. By the time of crop production, crop N boost was larger compared to dry matter N uptake. An inter-relationship within entire N boost in straw, entire biomass and nitrogen uptake in crops and grain outcome were largely importance and linear in both the events (Bhuiyan *et al.*, 2017).

2.2.12 Leaf area index (LAI)

Leaf area index (LAI) is the most agronomical changeable which better shorten the perplexity produced by the summation of intimate and emerged factors impresses the condition of crop canopies, being sharply impacted by whole the interactions within genotype and environmental causes (Gilardelli *et al.*, 2013). Comparison of leaf area index estimates by comptometer and Pocket LA smart app in canopies with different structures

The DGCI (Dark Green Color Index) is a quantitative estimate of vert which is tightly inter-related for leaf nitrogen intenttness. The intenttness of nitrogen in the crop has a firm relationship with its development, and lack of nitrogen may change or suppress crop development. The crop is impotent to acquire its greatest if the intenttness of any nutrient in tissue is under the ticklish intenttness (Rhezali, 2016).

The normalized difference vegetation index (NDVI) was calculated using the equation: $NDVI = (NIR - R) / (NIR + R)$ where R is the reflectance in the red band and NIR is the reflectance in the near infrared band. NDVI was obtained around the flowering stage by using two different approaches: using ground measurements and from aerial multispectral images (Vergara-Díaz *et al.*, 2016).

Table 2.2. Effects of Nitrogen on morphological and physiological adaptations in maize

SL NO	Treatment	Genotype (No.)	Growth Conditions	Growth Stage	Major effect or finding	References
Genetic variability study in rice and maize for Nitrogen status						
1	N application rates (0, 30, and 80 kg N ha ⁻¹)	Matuba, a maize variety were used	Field condition	Mature stage	The N application improved its stagnant initial canopy development and increased both RUE and LI.	(Tsujimoto <i>et al.</i> , 2017)
2.	Five nitrogen fertilization levels (0,10,20,80, and 160 kg·ha ⁻¹ NH ₄ NO ₃)	Ten maize hybrids were sown,	Field condition	Mature stage	The leaf traits evaluated also seemed in efficient as phenotyping parameters.	(Vergara-Díaz <i>et al.</i> , 2016)
3.	(20, 100, 250) kg N ha ⁻¹ for three nitrogen fertilizer levels respectively	30 maize plants	Greenhouse	Seedling stage	It was shown that better correlations between SPAD and nitrogen fertilizer were obtained when a combination of two-color channels, from the same or different color spaces, were applied in the correlation.	(Reyes <i>et al.</i> , 2017)
4.	three water treatments were used	ZhengDan958, a maize variety were used	Field condition	Mature stage	two-stage model had an effective detection performance between water suitability and water stress conditions in the maize fields	(Zhuang <i>et al.</i> , 2017)
5.	195 inbred genotypes and	maize cultivars	Greenhouse	Seedling stage	The utility of early-stage parental lines is	(Edlich-Muth <i>et al.</i> , 2016)

SL NO	Treatment	Genotype (No.)	Growth Conditions	Growth Stage	Major effect or finding	References
6.	382 hybrid genotypes Applying DHEAP and plant density	three maize cultivars	Field condition	Mature stage	very encouraging. maize yield could be enhanced by optimizing plant density	(Zhang <i>et al.</i> , 2017)
7.	Five varied N rate (0–320kg _{ha} ⁻¹) were used	Different maize varieties	Field condition	Mature stage	To screen nitrogen efficient maize cultivars in future to address environmental problems, energy issues and cost of production of nitrogen fertilizers, needed in huge quantities for maize cultivation.	(Singh and Verma, 2013)
8.	Different indices	Different maize varieties	Greenhouse	Mature stage	The Smarts PAD estimation compared well with the corresponding SPAD meter values (R ² = 0.88 and 0.72, and RMSE = 4.03 and 5.96 for neural network and linear model, respectively)	(Rigon <i>et al.</i> , 2016)
9.	Different doses of nitrogen fertilization (56, 112, 168, and 224 kg ha ⁻¹)	Different maize varieties	Greenhouse	Seedling stage	A highly accurate alternative to SPAD meters for estimating Chl content nondestructively.	(Vesali <i>et al.</i> , 2017)

SL NO	Treatment	Genotype (No.)	Growth Conditions	Growth Stage	Major effect or finding	References
10.	120 kg nitrogen (N), 60 kg phosphorus (P ₂ O ₅), and 60 kg potash (K ₂ O) through Urea (46%),	14 inbred lines of maize	Field	Mature stage	the gene action and identify the best combiners for grain yield and its associated traits	(Singh <i>et al.</i> , 2017)
11.	N-0, N-70, N- ¹⁴⁰ , N-280 kg ha ⁻¹	Dekalbkc57-67 maize leaves	Field and lad	Mature stage	LCC panel values of selected were highly correlated to chlorophyll content and chlorophyll meter value	(Friedman <i>et al.</i> , 2016)
12.	Urea-5kg ha ⁻¹	Maize plant	Networking laboratory	Mature stage	This access was upper to detection chlorophyll extent in leaf image technology and mamdane fuzzy	(Huang <i>et al.</i> , 2010)

CHAPTER III

3.1 EXPERIMENT I: EFFECT OF NITROGEN ON MORPHO-PHYSIOLOGICAL TRAITS OF WHEAT

Abstract

Wheat yield enormously influenced by on nitrogen (N), judicious use of N is essential for the improvement of sustainable wheat production. The objectives of the study are to study nitrogen effect on morpho-physiological traits of wheat; to develop algorithms for relationship between manual phenotyping and digital phenotyping of wheat and to develop algorithms for relationship between leaf nitrogen and digital field image traits of wheat. The experiment comprised of four wheat varieties viz. (i) V₁ = BARI Gom 26, (ii) V₂ = BARI Gom 28, (iii) V₃ = BARI Gom 29 and (iv) V₄ = BARI Gom 30 and four nitrogen levels viz. (i) N₀ = Control (N=0.0 kg N ha⁻¹), (ii) N₁ = 50 kg N ha⁻¹, (iii) N₂ = 100 kg kg N ha⁻¹, (iv) N₃ = 150 kg N ha⁻¹ during 2016-17 and next year (2017-18) the experiment comprised of three wheat varieties viz. (i) V₁ = BARI Gom 26, (ii) V₂ = BARI Gom 28 and (iii) V₃ = BARI Gom 30 and five nitrogen levels viz. (i) N₀ = Control (N=0.0 kg N ha⁻¹), (ii) N₁ = 60 kg N ha⁻¹, (iii) N₂ = 100 kg kg N ha⁻¹, (iv) N₃ = 120 kg N ha⁻¹ and (v) N₄ = 140 kg N ha⁻¹. The experiment was laid out in a split-plot design with three replications. The results revealed that different wheat varieties (V), different level of nitrogen (N) and interaction effect of V×N showed the significant variation on maximum traits studied. Among the different nitrogen levels, the highest grain yield was obtained from the 150 kg N ha⁻¹ during 2016-17 and 140 kg N ha⁻¹ during 2016-17 treatment, respectively. Among the interaction treatments, maximum grain yield (3.97 t ha⁻¹) was recorded by the interaction of N₃V₄ (150 kg N ha⁻¹ and BARI Gom 30) which was statistically similar with N₂V₃ (100 kg N ha⁻¹ and BARI Gom 29), N₃V₂ (100 kg N ha⁻¹ and BARI Gom 28) during 2016-17 where the maximum grain yield (3.94 t ha⁻¹) was found with treatment combination N₃V₁ (120 kg N ha⁻¹ and BARI Gom 26) which was statistically similar with N₃V₃ (120 kg N ha⁻¹ and BARI Gom 30), N₃V₂ (120 kg N ha⁻¹ and BARI Gom 28) during 2017-18. The genotypic and phenotypic correlation coefficient of NDVI, CC, SPAD and LNC were directly correlated with TDM at 75 DAS. The response of morpho-physiological traits against different nitrogen levels in both the years were linear and positively significant for all the varieties. The Treatment × Trait biplot condensed the information from this matrix into PCs, the first two of which comprised 89.71% and 87.59% of the total variation within the dataset, respectively both the years. Heatmap displaying the relationship matrix among treatments interaction revealed four clusters. Among 43 morpho-physiological, digitally extract, yield and yield contributing traits showed significant correlation between grain yield and positively associated with one another. The results of this study partially supported the hypothesis that digital image traits measured by image processing software (WCC) can identify and differentiate variations in nitrogen of wheat. It could be concluded that application of nitrogen fertilizer has positive effects on morpho-physiological trait of wheat variety and if the farmers use this variety with high dose of nitrogen, they will be benefited by receiving higher grain yield but if they use lower doses of nitrogen will be less benefited.

3.1.1 INTRODUCTION

The synchrony of cereal crop production and fertilizer supply, especially in regard to nitrogen (N) fertilizers, plays an important role in optimizing trade-offs between grain yield and profits. Nitrogen is an important and costly input for non-leguminous grain crops, and producers are applying N fertilizer in large amounts to ensure high yields over a range of environmental conditions. Excessive N fertilization may cause increased plant vigour, extending foliar growth and delaying harvest, as well as increased nitrate accumulation, susceptibility to disease and contributing to environmental contamination.

There are many methods for nitrogen assessment for predicting nitrogen fertilizer need for crops like, soil nitrogen estimation; chlorophyll meter measurement; petiole sap nitrogen measurement and estimation of N status by color image. Among them, estimation of N status by color image in these methods, the determination of plant nutritional status by using color image analysis is a quick and non-destructive methods.

Nitrogen is one of the most yield regulating nutrients for crop production in the world. It is also the nutrient element applied in the largest quantity for most annual crops (Huber and Thompson, 2007). Nitrogen also increases shoot dry matter, which is positively associated with grain yield in cereals and legumes (Fageria, 2007a; Fageria, 2008).

In recent years, digital cameras and image analysis programs have been used to quantify the “greenness” of foliage as indirect measurements of crop N status. Digital images record information as amounts of red, green, and blue (RGB) light emitted; however, the intensity of red and blue will often alter how green an image appears (Karcher and Richardson, 2003). To simplify the interpretation of digital color data, Karcher and Richardson (2003) suggested converting RGB values to the more intuitive hue, saturation, and brightness (HSB) color spectrum, which is based on human perception of color.

Karcher and Richardson (2003), working with quality of turfgrass in response to N fertilizer, processed HSB values into a single measure of dark green color, the dark green color index (DGCI). Dark green color index values were a more consistent measure of green color than were individual RGB values across all turf varieties and N treatments.

Plant color has potential to indicate N status of corn and other non-leguminous row crops accurately when the correct methods are applied. Differences in lighting conditions, camera quality, and available camera settings could affect DGCI values and limit their utility in diagnosing N deficiencies; furthermore, factors such as disease, water status, nutritional deficiencies other than N, or differences in hybrid may affect greenness regardless of N status.

Canopy cover (CC) is defined as the fractional or percent area of plant canopies projected vertically onto the horizontal ground surface beneath (Guevara-Escobar *et al.* 2005). Canopy cover of crops has often been used as a predictor of crop yield and growth parameters such as leaf area index (LAI), above-ground biomass, etc. (Behrens and Diepenbrock 2006; Li *et al.* 2010; Pan *et al.* 2007; Richardson *et al.* 2001). As an alternative method for destructive monitoring of crop growth and nutrition status that is time and resource consuming, digital cameras have increasingly been employed in recent agronomic studies on the characterization of crop growth and nutrition status due to its simplicity and cost-effectiveness. Many studies have been conducted on the plant segmentation performance of several color indices that use color components defined in RGB space in single or in combination. Normalized color indices such as excessive greenness index (EGI) and modified EGI (MEGI) have been successful in several case-studies of plant segmentation from bare upland soil background (Golzarian *et al.* 2007; Li *et al.* 2010; Tang *et al.* 2003). However, few studies have been done on the segmentation of wheat.

The main objectives of the study are follows

- i) To study nitrogen effect on morpho-physiological traits of wheat.
- ii) To develop algorithms for relationship between manual phenotyping and digital phenotyping of wheat and
- iii) To develop algorithms for relationship between leaf nitrogen and digital field image traits of wheat.

3.1.2 MATERIALS AND METHODS

The materials used in the present experiment and the details methodology followed during the research period are presented in this chapter.

3.1.2.1 Location and duration

The experiment was conducted at Seed Technology Division field, Bangladesh Agricultural Research Institute during November 2016 to March, 2017 and November, 2017 to March, 2018. The experimental site is situated under the Gazipur Sadar Upazila and located at 23.9886367 N latitude and 90.413055 longitude with an elevation of 71 meter above the sea level (Appendix 3.1.1).

3.1.2.2 Soil characteristics of the experimental field

The soil of the experimental area is Dark Grey Terrace Soil which belongs to the Modhupur Tract under AEZ 28. Soils of the experimental sites were analyzed before sowing of wheat.

Initial soil status

The soils are acidic in nature containing low organic matter. Ca, Mg, K, P, S, Cu, Fe, Mn and Zn content of the soil are high. N content of soils are low. B content of Gazipur soil is low. However, N content was very low in both the locations as shown in Table 3.1.1.

3.1.2.3 Climate conditions during the experimental period

The climate of study site is subtropical, characterized by three distinct seasons, the winter season (November–February; night time: 8–12°C; day time: 20–25°C), the pre-monsoon period or hot season (March–April; night time: 15–18°C; day time: 35–40°C) and the monsoon period (May–October; night time: 18–24°C; day time: 30–35°C). Climatic parameters are presented in the Appendix Figure 3.1.2

3.1.2.4 Land preparation

The land was well prepared by repeated ploughing and cross-ploughing with a tractor followed by laddering for breaking the clods, leveling the lands and collecting the stubbles. The individual plots were prepared by making ridges (8-10 cm) around each plot to restrict the lateral run off of fertilizer with irrigation water. To control soil-borne insects, Furadan 5G containing

Carbofuran (systemic pesticide; FMC Corp., Philadelphia, PA, USA) was broadcast at 10 kg ha^{-1} during final land preparation.

3.1.2.5 Experimental treatments and design

The experiment was laid out in split plot design with three replications. Basic information of the experiment was shown in Table 3.1.2. Wheat varieties in main plot and levels of nitrogen in sub-plot treatment. Each plot was consisted of 6 rows of each genotype with 2.5-meter-long; row to row distance was 20 cm with continuous seeding.

3.1.2.6 Fertilizer application

The blanket dose of fertilizers were applied at the rate of Fertilizers were applied @ 30-60-20-4.45-1-5000 kg ha^{-1} of P, K, S, Zn, B, and cow-dung (well decomposed) in the form of triple super phosphate, muriate of potash, gypsum, zinc sulphate and baric acid, respectively. Two-third of urea and total amount of other fertilizers were applied during final land preparation in the well-watered plot. The rest amount of urea was top dressed at crown root initiation stage (CRI) i.e., 18 days after sowing (DAS) followed by first irrigation. Full doses of N, P, K, S, Zn, and B were incorporated thoroughly into the soil as a basal dose.

3.1.2.7 Sowing of seeds

Wheat seeds at the rate of 120 kg ha^{-1} in case of bolder grain size, and 140 kg ha^{-1} in case of smaller grain size of wheat were sown in line by hand on November 23, 2016 and November 27, 2017. Seeds were placed continuously in lines by making narrow and shallow furrows and covered with soil by hand. To accomplish excellent germination and protecting against fungal attack during the seedling stage, seeds were pre-treated with a fungicide Provax-200 WP (containing Carboxin and Thiram) an effective fungicide for seeds. Light irrigation at 10 days before sowing of seeds was given to ensure uniform germination of seeds.

Table 3.1.1. Analytical data of soil sample of wheat filed

Sample no.	pH	O.M.%	Ca	Mg	K	Total N%	P	S	B	Cu	Fe	Mn	Zn
			Meq/100 gm				µg/gm						
							Bray						
STD, BARI, Gazipur	6.40	1.47	6.9	2.4	.16	.078	27.3	25.3	.12	2.1	34	6.1	3.65
Critical Level			2.0	0.5	0.12		7.0	10	0.2	0.2	4.0	1.0	0.6

Table 3.1.2. Basic information regarding experiments

Experiment No.	Location	Date of sowing	Date of harvest	Name of Variety	Nitrogen treatment (Kg N ha ⁻¹)	Remarks
Expt.1 2016- 2017	Seed Technology Division, BARI, Gazipur	23th November , 2016	4th April, 2017	BARI Gom 26, BARI Gom 28, BARI Gom 29 and BARI Gom 30	N ₀ =0.0 N ₁ =50 N ₂ =100 N ₃ =150	Based on recommendations of first seminar rearrange the second-year treatment combinations
Expt.2 2017-2018	Seed Technology Division, BARI, Gazipur	27th November , 2017	12th April, 2018	BARI Gom 26, BARI Gom 28 and BARI Gom 30	N ₀ =0.0 N ₁ = 60 N ₂ =100 N ₃ =120 N ₄ =140	

3.1.2.8 Intercultural operation

After sowing, care was taken against birds up to 15 days from sowing. Intercultural operations were done uniformly in each plot to ensure normal growth of the crop. Weeding and mulching were done simultaneously in the experimental plot for two times, firstly at 14 DAS and secondly at 26 DAS. Thinning was also done as required. Three irrigations were given at 19, 53 and 81 DAS in well-watered plot. Plant protection measures were taken when some plots were slightly infested by field rat a few days before harvesting. The attack of rats was controlled instantly by using Lanirat or other process.

3.1.2.9 Harvesting

The crop was harvested on 4th April 2017 and 12th April 2018 when the plants attained full maturity. The crop was cut at the soil surface level. After harvesting the sample were sun dried. Ten plants from each plot were sampled randomly for data collection. Threshing, cleaning and drying of grains were done separately plot by plot. The weight of grain and straw were recorded plot wise and adjusted at 12% moisture content.

3.1.2.10 Data collection

The data were recorded different growth stages and also at harvest.

Plant height: Plant height was recorded from the average of 10 selected plants at maturity. Plant height (cm) was measured by a meter scale from soil surface to the tip of the spike excluding awns and averaged.

Number of spikes m⁻²

The numbers of developed and underdeveloped spikes were counted from whole plot and then converted into spikes per m². Counting should be done diagonally at physiological maturity to avoid damage of plants due to walking inside plot.

Spike length: Length of spike from 10 selected plants per plot were recorded in cm and averaged.

Spikelets per spike: From the spikes of 10 plants number of spikelets per spike was recorded.

Grains per spike: From the spikes of the 10 plants, the number of filled and unfilled grains per spike was counted and averaged.

Grain and straw yields: The plants from whole plot comprising 0.8 m² from each plot were harvested randomly through the soil surface for computation of grain and straw yields. After threshing, cleaning and drying, the grain and straw yields were recorded plot-wise and adjusted at 12% moisture content (MC) as follows. Finally, the grain and straw yields were converted into gram per m².

Data on grain yield (GY) was determined and adjusted to 12% moisture level by the following equation (Hellevang 1995).

$$Y(M2) = \frac{100-M1}{100-M2} \times Y(M1); \text{ Where,}$$

Y (M2) = Weight of grain at expected moisture percentage (generally 12% for wheat),

Y (M1) = Weight of grain at actual moisture percentage, M1= Actual moisture percentage,

M2= Expected moisture percentage.

3.1.2.11 NDVI value

The normalized difference vegetation index (NDVI) was measured by hand green seeker (Trimble) and green seeker RT100 (Agri Optics). NDVI quantify vegetation by measuring the difference between near-infrared (NIR) (which vegetation strongly reflects) and red light (which vegetation absorbs).

The formula NDVI is:
$$NDVI = \frac{NIR-Red}{NIR+Red}$$

3.1.2.12 Canopy Coverage (CC)

The canopy cover provided by the crops was assessed at four successive dates between the November 2016 and March 2017 and November 2017 and March 2018: at 25, 50, 75, and 100 days after seeding. Canopy cover was measured by “Canopeo” an android mobile phone application (Patrignani and Ochsner, 2015).

3.1.2.13 SPAD (Soil Plant Analyses Development) value

The chlorophyll content in plant leaves was determined with a SPAD meter (Model: SPAD-502, Minolta Co. Ltd., Japan). The SPAD value was taken from middle portion of the flag leaf of the tagged main shoot at 25, 50, 75 and 100 days after sowing (DAS). A through using self-calibrating Minolta chlorophyll meter. Measurements at each experimental plot consisted of average of five readings (Reynolds *et al.* 1998).

3.1.2.14 Leaf Area Index (LAI)

Leaf area was calculated with an Automatic Leaf Area Meter (Leaf area meter-LICOR-3300, USA) at 25, 50, 75 and 100 DAS from an area of one square meter. The leaf area index (LAI) of the crop at different growth stages was calculated using the following equation as described by Radford (1967).

$$LAI = \frac{\text{Surface area of leaf sample}}{\text{Ground area of the sample}}$$

3.1.2.15 Chlorophyll and carotenoid determination

Extraction and determination of chlorophyll (Chl) and carotenoid (Car) was performed according to the method of Arnon (1949). Chlorophyll content was calculated using the formula of Arnon (1949) and expressed in mg g⁻¹ fresh weight (FW).

$$\text{Total Chl (mg g}^{-1}\text{FW}^{-1}) = (0.0202) \times (A_{645}) + (0.00802) \times (A_{663})$$

$$\text{Chl } a \text{ (mg g}^{-1}\text{FW}^{-1}) = (0.0127) \times (A_{663}) - (0.00269) \times (A_{645})$$

$$\text{Chl } b \text{ (mg g}^{-1}\text{FW}^{-1}) = (0.0229) \times (A_{645}) - (0.00468) \times (A_{663})$$

Car content was estimated using the formula of Kirk and Allen (1965)

$$\text{Car (mg g}^{-1}\text{FW}^{-1}) = A_{470} + (0.114 \times A_{663} - 0.638 \times A_{645}).$$

3.1.2.16 Leaf nitrate content (LNC) measure

Leaf nitrate content (LNC) was measured with an LAQUAtwin (B 741) at 25, 50, 75 and 100 DAS from leaf sample. The meter analyses the sap in just few seconds and displays reading expressed as either nitrate (NO_3) or nitrate-nitrogen ($\text{NO}_3\text{-N}$) ppm units.

3.1.2.17 Total dry matter (TDM) measure

Wheat biomass samples were collected four times during the growing season at 30, 60, 90 DAS and harvest stages. Crop biomass samples consisted of 0.5 m row length acquired from each plot. Harvest biomass samples were determined with a 1 m row length and were taken from the middle of the experimental plot. Biomass samples were pulled up, bagged, and transferred to a cooler and stored until processed. Plants were freed from their roots and were placed into an oven to dry at about 68-70°C until they reached a constant weight.

3.1.2.18. Image acquisition

Canon camera and Android mobile phone were utilized for image acquisition. Images were stored in the JPG format. The photos were taken 50 cm above the crops surface and 180° inverted the camera and mobile. Substantial effort was made develop a standard imaging protocol to ensure imaging consistency and quality.

3.1.2.19 Statistical analysis

The data were analyzed by partitioning the total variance with the help of computer by using STAR Version 2.0.1 (IRRI 2014) Microsoft Excel 2016 and statistical software R with the functions “agrocolea”, and package “tree” with the functions “tree”, “cv.tree” and “prune.tree” R program (R Development Core Team, 2018).

3.1.3 RESULTS AND DISCUSSION

The field experiment was conducted to investigate the influence of nitrogen on morpho-physiological traits of wheat. This chapter comprised with presentation and discussion of the results obtained from the study. Treatments effect of varieties and nitrogen on all the studied parameters have been presented in Figure 3.1.1 to Figure 3.1.40 and interaction effect of varieties and nitrogen Table 3.1.3 to Table 3.1.23. Summary of mean square values of different parameters are also given in Appendices 3.1.1 to 3.1.20.

3.1.3.1 Morphological traits of wheat

3.1.3.1.1 Plant height

Effect of wheat varieties on plant height (cm)

The plant height of different wheat varieties at different growth stages significantly differs except 30 days after sowing (DAS) is shown in Appendix 3.1.1, Figure 3.1.1 for 2016-17 and Appendix 3.1.2, Figure 3.1.2 for 2017-18, respectively. plant height increased slowly up to 60 DAS and then increased rapidly with the advancement of growing period of all the varieties for both the years. Regardless of treatment differences, plant height increased progressively up to 90 DAS. At 30 DAS, maximum plant height (60.62 cm) was observed in BARI Gom 29 and minimum (58.77 cm) was obtained in BARI Gom 30 during 2016-17 and maximum (58.9 cm) in BARI Gom 30 and minimum (56.10 cm) in BARI Gom 28 during 2017-18. At 60 DAS, highest plant height (69.85 cm) was found in BARI Gom 29 which was identical with BARI Gom 30 and lowest (61.50 cm) in BARI Gom 26 during 2016-17 and highest plant height was found in BARI Gom28 and lowest (69.20 cm) in BARI Gom 26 which was identical with BARI Gom 30 during 2017-18. At 90 DAS, taller plant (95.00 cm) was found in BARI Gom 29 which was followed by BARI Gom 30 and shorter plant (91.50 cm) was observed in BARI Gom 28 during 2016-17 and highest plant height (82.45 cm) was found in BARI Gom28 which was identical with BARI Gom 26 and lowest (72.40 cm) in BARI Gom 30 during 2017-18. At harvesting stage, highest plant height (98.40 cm) was obtained in BARI Gom 29 which was identical with BARI Gom 30 and lowest plant height (94.75 cm) was in BARI Gom 26 during 2016-17 and taller plant (84.20 cm) was found in BARI Gom28 which was identical with BARI Gom 26 and shorter plant (75.40 cm) in BARI Gom 30 during 2017-18.

Plant height is an inherent character and varies with genotype and environmental conditions. In this research, plant height varied due to variety, nitrogen level and the combined effect of growing condition. Nahar *et al.*, (2015) reported that effect of wheat variety on plant height was significant at all sampling dates such as 15, 30, 45, 60, 75, 90 DAS and at harvest. The variety BARI Gom 21 produced the tallest plants (94.9, 97.9 and 99.4 cm at 75, 90 DAS and

at harvest, respectively) which was superior to all other varieties. But at 15, 30, 45 and 60 DAS the variety BARI Gom 25 produced the maximum plant height (33.1, 36.5, 56.9 and 88.2 cm, respectively) which was statistically similar to the variety BARI Gom 26 at 30 DAS. On the other hand, the variety BARI Gom 21 was shorter than other varieties from 15 DAS to at 60 but it was observed that at 75, 90 DAS and at harvest the variety BARI Gom 24 produced the shorter plants (90.3, 91.9 and 91.9 cm, respectively). The results obtained from the present study were also conformity with the findings of Tariq (2010) and Rahman *et al.* (2009). Wheat varieties showed a significant effect of varieties on plant height (Mattas *et al.* 2011, Mohammad *et al.* 2011) and varied greatly among various wheat genotypes (Ford and Throne, 2001). The differences in plant height due to various varieties might be due to varied genetic makeup of the variety and interaction between variety and environment.

Effect of nitrogen on plant height

Effect of N levels showed a significant variation on plant height for all growth stages (Figure 3.1.5 and Appendix 3.1.2 for 2016-17 and Figure 3.1.6 and Appendix 3.1.2 for 2017-18). Regardless of treatment differences, plant height increased progressively up to maturity. At 30 DAS maximum plant height (60.88 cm) was observed with N₃ (150 kg N ha⁻¹) which was significantly identical with N₁ and N₂. and minimum (42.11 cm) was found with N₀ (0 kg N ha⁻¹) during 2016-17 and highest plant height (60.54 cm) was obtained with N₄ and minimum (40.23 cm) with control which was significantly differ with N₁ and N₂ during 2017-18. At 60 DAS, tallest plant (71.94 cm) was found with N₃ (100 kg N ha⁻¹) which was statically differ with N₁ (50 kg N ha⁻¹) and N₂ (150 kg N ha⁻¹) and shortest plant with N₀ (0 kg N ha⁻¹) during 2016-17 and similar trend also observed during 2017-18. At 90 DAS, highest plant height (100.58 cm) was obtained with N₂ (100 kg N ha⁻¹) which was statistically at par with N₃ (150 kg N ha⁻¹) and N₂ (50 kg N ha⁻¹) and shortest plant with N₀ (0 kg N ha⁻¹) during 2016-17 and maximum plant height (94.87 cm) was obtained with N₂ (140 kg N ha⁻¹) which was significantly differ with N₁ (60 kg N ha⁻¹) and N₂ (120 kg N ha⁻¹) and shortest plant with N₀ (0 kg N ha⁻¹) during 2017-18. The similar trend was obtained at harvesting stage. It was observed that N₄ (140 kg N ha⁻¹) influenced plant after 30 DAS and proved superior up to harvest. It might be due to continuous availability of N and its enhanced growth to crop.

The plant height differed significantly among the different nitrogenous fertilizer at all sampling dates (Nahar *et al.*, 2015). The tallest plant was found in 100 kg N ha⁻¹ from prilled urea (at all sampling dates (32.9, 36.3, 54.3, 88.0, 92.5, 95.6 and 94.9 cm at 15, 30, 45, 60, 75, 90 DAS and at harvest, respectively). On the other hand, the shorter plant was found in control (N₀)

treatment throughout the growing season. The result obtained from the present study was also conformity with the findings of Rahman (2005) and Akter (2005).

Different levels of nitrogen affected the plant height significantly (Ali *et al.*, 2018). They found that taller plant (107.60 cm) was recorded from treatment T₈ where nitrogen was applied @ 203 Kg ha⁻¹ while minimum plant height was recorded from T₁ where nitrogen was not applied. As the level of nitrogen increased plant was also gradually increased. Cells protein content increase as the application of nitrogen increase and size of plant cell increases, as a result of that leaf area and photosynthesis rate rises which ultimately make the plant taller (Wysocki *et al.*, 2007). Wheat growth can be increased by nitrogen by increasing the process of cell division and also help to uptake other nutrients from the soil through synergistic effect which increases the shoot length of plant. The increase in plant height was because nitrogen increases leaf area which results in high rate of photosynthesis, more production of assimilates and plant dry matter. These results are similar to Rahman *et al.*, (2014) and Ali *et al.*, (2003) who also reported that plant height was significantly increased by different doses of nitrogen.

Interaction effect of wheat varieties and nitrogen on plant height

The interaction effect of varieties and nitrogen levels on plant height was statistically significant except 30 DAS (Table 3.1.3 and appendix 3.1.1 for 2016-17 and Table 3.1.4 and appendix 3.1.2 for 2017-18). At 30 DAS, the tallest plant (49.81 cm) was recorded by the interaction of N₃V₂ (150 kg N ha⁻¹ and BARI Gom 28) and at par with N₂V₃ (100 kg N ha⁻¹ and BARI Gom 29), N₃V₃ (150 kg N ha⁻¹ and BARI Gom 29) and N₂V₂ (150 kg N ha⁻¹ and BARI Gom 28) during 2016-17 and maximum plant height (62.67 cm) was found with treatment combination N₄V₂ (140 kg N ha⁻¹ and BARI Gom 28) which was followed by treatment combination N₄V₁ (62.00 cm) and N₄V₃ (62 cm) during 2017-18. The lowest plant height (43.06 cm) was observed from the treatment combination of N₀V₄ (0 kg N ha⁻¹ and BARI Gom 30) during 2016-17 and treatment combination of N₀V₁ (42.00 cm) during 2017-18. At 60 DAS, the tallest plant (74.21 cm) was resulted by the interaction of N₂V₂ (100 kg N ha⁻¹ and BARI Gom 28) and similar with N₂V₄ and N₃V₂ where the lowest plant height (57.70 cm) was observed from the treatment combination of N₀V₁ during 2016-17 and maximum plant height (86.76 cm) was found from the interaction of N₄V₁ (140 kg N ha⁻¹ and BARI Gom 26) where the minimum plant height (55.57 cm) was found from the treatment combination of N₀V₃ (0.0 kg N ha⁻¹ and BARI Gom 30) during 2017-18.

At 90 DAS, the maximum plant height (89.29 cm) was observed from interaction of N_2V_3 (100 kg N ha⁻¹ and BARI Gom 29) and minimum plant height was found from interaction treatment of N_0V_1 (0.0 kg N ha⁻¹ and BARI Gom 26) during 2016-17 and maximum plant height (96.67 cm) was found with treatment combination N_4V_2 (140 kg N ha⁻¹ and BARI Gom 28) which was similar with N_4V_1 where minimum plant height was found by treatment combination of N_0V_3 (71.33 cm) during 2017-18. At harvesting, the tallest plant (97.15 cm) was recorded by the interaction of N_3V_1 (150 kg N ha⁻¹ and BARI Gom 26) which was statistically identical with treatment combination N_2V_3 (100 kg N ha⁻¹ and BARI Gom 29), N_3V_4 (150 kg N ha⁻¹ and BARI Gom 30) and N_3V_2 (150 kg N ha⁻¹ and BARI Gom 28) during 2016-17 and maximum plant height (102.33 cm) was found with treatment combination N_4V_2 (140 kg N ha⁻¹ and BARI Gom 28) which was followed by treatment combination N_4V_3 (140 kg N ha⁻¹ and BARI Gom 29) and N_4V_1 (140 kg N ha⁻¹ and BARI Gom 26) during 2017-18. The lowest plant height (91.44 cm) was observed from the treatment combination of N_0V_1 (0 kg N ha⁻¹ and BARI Gom 26) during 2016-17 and minimum plant height was recorded from treatment combination of N_0V_3 (75.00 cm) during 2017-18.

Nahar *et al.*, (2015) reported that plant height differed significantly due to the interaction effect of variety and different nitrogenous fertilizer at all sampling dates. The maximum plant height was obtained from V_3N_3 at 15, 30, 45 and 60 DAS (34.5, 40.7, 59.3 and 90.1, respectively) which was statistically similar to V_2N_3 and V_3N_0 at 15 and 60 DAS and V_3N_4 at 60 DAS. But at 75, 90 DAS and at harvest the tallest plant was obtained from V_1N_3 (98.2, 100.4 and 100.7 cm, respectively). On the other hand, the shortest plant (30.0 cm) was obtained from V_2N_4 combination at 15 DAS, but at 30, 45 and 60 DAS, the shortest plant

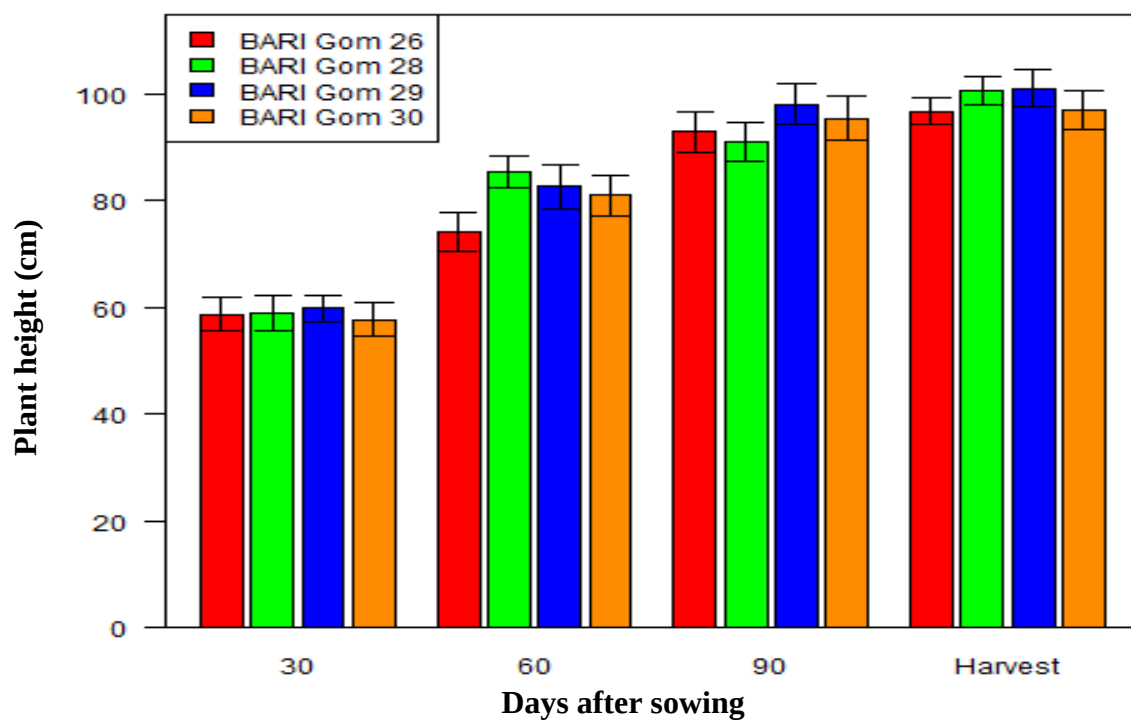


Figure 3.1.1: Effect of wheat varieties on plant height at different days after sowing from original values during 2016-17.

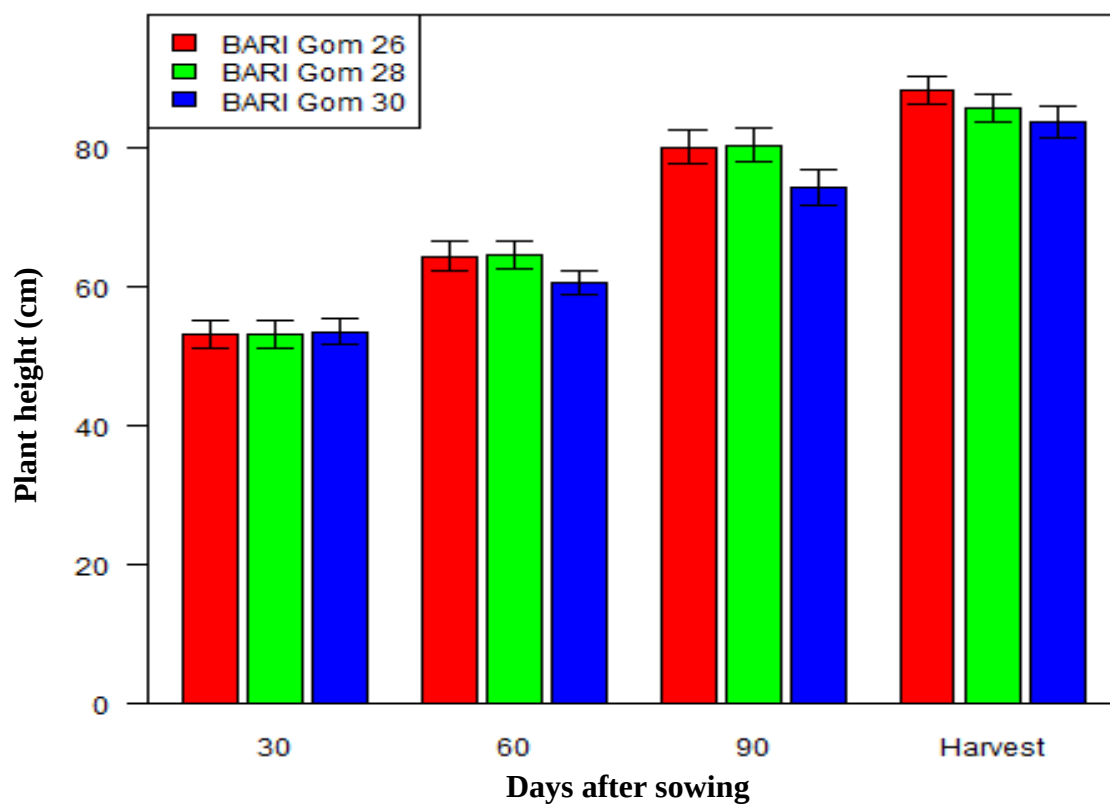


Figure 3.1.2: Effect of wheat varieties on plant height at different days after sowing from original values during 2017-18.

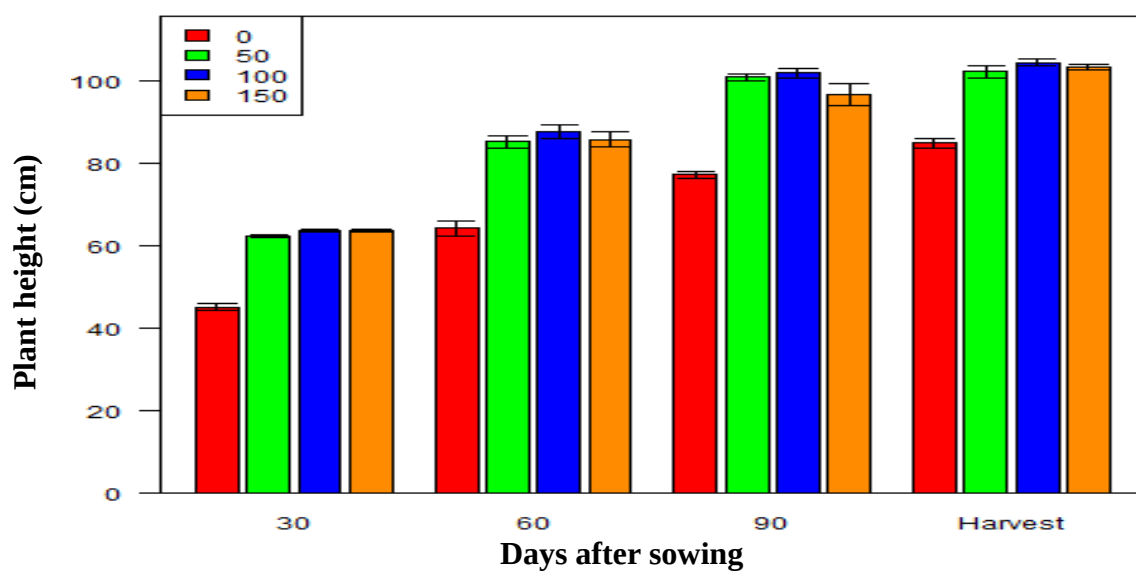


Figure 3.1.3: Effect of nitrogen on plant height (PH) at different days after sowing from original values during 2016-17.

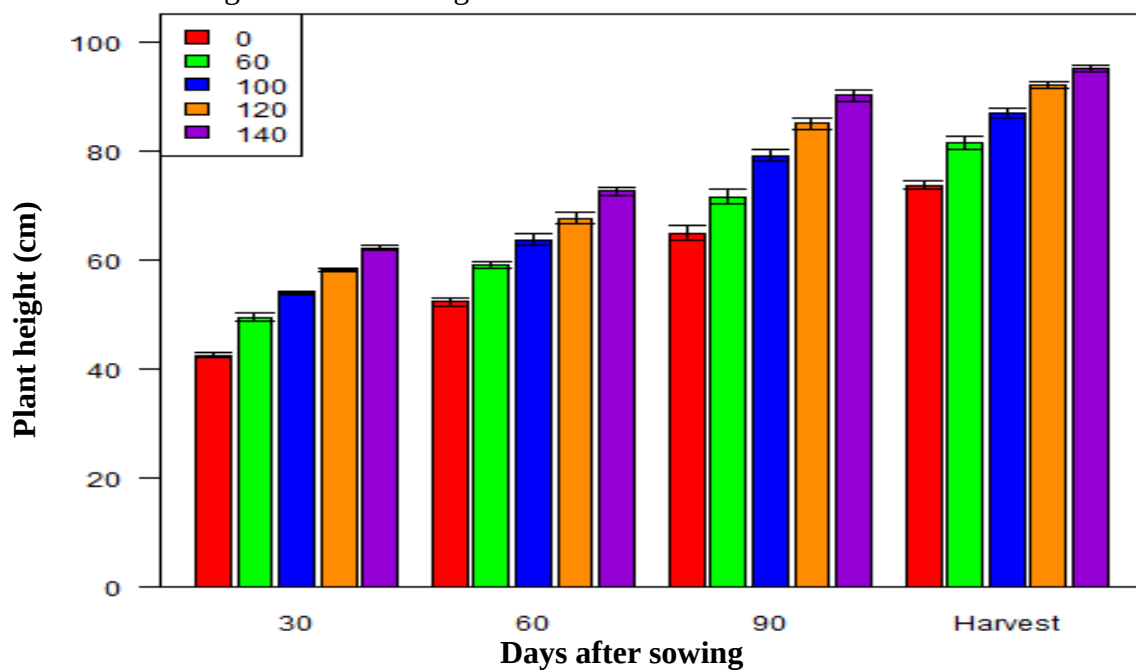


Figure 3.1.4: Effect of nitrogen on plant height (PH) at different days after sowing from original values during 2017-18.

Table 3.1.3. Interaction effect of varieties and nitrogen on plant height (cm) at different days after sowing of wheat during 2016-17

Interaction Treatment	Days After Sowing (DAS)			
	30 DAS	60 DAS	90 DAS	At harvest
N ₀ ×V ₁	44.83	57.70	74.88	91.44
N ₁ ×V ₁	46.02	63.11	80.93	94.59
N ₂ ×V ₁	46.28	63.77	82.66	96.68
N ₃ ×V ₁	46.71	61.42	81.77	97.15
N ₀ ×V ₂	44.03	71.69	77.93	90.22
N ₁ ×V ₂	45.42	71.76	85.14	95.13
N ₂ ×V ₂	47.35	74.21	81.88	95.45
N ₃ ×V ₂	49.81	73.00	77.98	96.22
N ₀ ×V ₃	45.51	63.83	80.51	91.96
N ₁ ×V ₃	45.98	72.23	87.21	93.13
N ₂ ×V ₃	46.74	71.90	89.29	96.04
N ₃ ×V ₃	47.08	71.46	84.01	95.26
N ₀ ×V ₄	43.06	63.94	76.16	90.54
N ₁ ×V ₄	44.66	66.08	82.50	93.26
N ₂ ×V ₄	45.98	73.04	86.27	95.81
N ₃ ×V ₄	45.93	69.74	85.62	96.17
LSD (0.05)	1.77	1.78	1.18	1.71

N₀ = 0 kg N ha⁻¹, N₁ = 50 kg N ha⁻¹, N₂ = 100 kg N ha⁻¹, N₃ = 150 kg N ha⁻¹ and V₁= BARI Gom 26, V₂= BARI Gom 28, V₃= BARI Gom 29, V₄= BARI Gom 30

Table 3.1.4. Interaction effect of varieties and nitrogen on plant height (cm) at different days after sowing of wheat during 2017-18

Interaction Treatment	Days After Sowing (DAS)			
	30DAS	60DAS	90DAS	At harvest
N ₀ ×V ₁	42.00	60.33	74.00	80.33
N ₁ ×V ₁	49.67	69.67	81.00	88.33
N ₂ ×V ₁	54.00	75.67	86.00	93.67
N ₃ ×V ₁	58.00	80.67	92.00	99.00
N ₄ ×V ₁	62.00	86.67	95.33	101.00
N ₀ ×V ₂	42.67	58.67	76.00	81.33
N ₁ ×V ₂	48.00	67.00	85.33	89.67
N ₂ ×V ₂	53.67	70.00	89.67	95.00
N ₃ ×V ₂	58.67	73.67	93.67	99.00
N ₄ ×V ₂	62.67	79.00	96.67	102.33
N ₀ ×V ₃	43.00	55.67	71.33	75.00
N ₁ ×V ₃	51.00	65.33	78.00	88.33
N ₂ ×V ₃	54.00	70.33	85.00	91.00
N ₃ ×V ₃	57.67	74.33	90.67	96.00
N ₄ ×V ₃	62.00	80.33	93.67	100.67
LSD (0.05)	2.27	2.16	2.70	2.71

N₀ = 0 kg N ha⁻¹, N₁ = 60 kg N ha⁻¹, N₂ = 100 kg N ha⁻¹, N₃ = 120 kg N ha⁻¹ and N₄ = 140 kg N ha⁻¹ and V₁= BARI Gom 26, V₂= BARI Gom 28, V₃= BARI Gom 30

3.1.3.1.2 Leaf area index (LAI)

Leaves area is made up of the total lamina area of emerged leaves. Dry matter production of crop plant depends almost wholly on the amount and matter of intercepted photoactive radiation by the crop with the conversion of efficiency the absorbed radiation. However, greater leaf area development is assumed to absorb of more light and consequently greater photosynthesis as long as the lower leaves are not shaded (Gadner *et al.*, 1985).

The LAI is an important biophysical trait in many ecological and environmental applications such as in the regional ecosystem models (Waring and Running, 1998). LAI controls many biological and physical processes in the water, nutrient and carbon cycle (Waring and Running, 1998) and hence determines the biomass gain by the crop.

Effect of wheat varieties on LAI

The Leaf area index (LAI) of different wheat varieties at different growth stages highly significantly differs at different days after sowing (DAS) is shown in Appendix 3.1.3, Figure 3.1.5 for 2016-17 and Appendix 3.1.4, Figure 3.1.6 for 2017-18, respectively. Leaf area index increased up to 75 DAS during 2016-17, 50 DAS during 2018-19, respectively and decreased with the advancement of growing period of all the varieties for both the years. Regardless of treatment differences, LAI increased progressively up to 75 DAS during 2016-17 and 50 DAS during 2017-19. A similar result was reported by Nahar *et al.*, (2015); Ashraf and Bhatti (1998). They observed that LAI of all wheat genotypes for both the growing conditions started from a lower value and reached the highest level at a certain stage of growth and declined thereafter. The decline in LAI following the flag leaf stage might be ascribed by aging of leaves, leaf senescence and thermal stress at later growth stages (Dalirie *et al.* 2010).

At 25 DAS, maximum LAI (0.51) was observed in BARI Gom 30 which was statistically identical with BARI Gom 26 and minimum LAI (0.48) was obtained in BARI Gom 29 which was also statistically similar with BARI Gom 28 during 2016-17 and maximum LAI (0.68) was found in BARI Gom 26 and minimum LAI (0.65) was found in BARI gom 30 during 2017-18. At 50 DAS, highest Leaf area index (1.80) was found in BARI Gom 26 which was significantly varies from other varieties and lowest LAI (1.55) was observed in BARI Gom 28 during 2016-17 and highest LAI (2.41) was found in BARI Gom28 and lowest LAI (2.05)was found in BARI Gom 30 during 2017-18. At 75 DAS, maximum LAI (2.52) was found in BARI Gom 26 which was significantly differ with other varieties and minimum LAI (2.24) was observed in BARI Gom 28 during 2016-17 and highest LAI (2.03) was found in BARI Gom 26 and lowest LAI (1.85) was found from BARI Gom 30 during 2017-18 which was little bit lower than the wheat growing season 2016-17 it may be due to variation of weather condition of growing

season. At 100 DAS stage, highest LAI (1.86) was obtained in BARI Gom 26 which was identical with BARI Gom 30 and lowest LAI (1.59) was in BARI Gom 28 which was statically identical with BARI Gom 29.

LAI of different wheat varieties was significant at different days after sowing (Nahar *et al.*, 2015). They reported that the highest LAI was obtained from BARI Gom 26 where the lowest LAI was obtained from BARI Gom 25.

LAI range was found in this study from 0.36 to 2.52 among the cultivars which was similar with the results found by Awal *et al.*, (2017). They reported that the variability of LAIs found from 0.56 to 2.53 for tested wheat varieties (BARI wheat-23, BARI wheat-24, BARI wheat-25, BARI wheat-26, and BARI wheat-27) were similar to that of the findings reported else (BARI Gom-23, BARI Gom -24, BARI Gom -25, BARI Gom - 26, and BARI Gom - 27).

Effect of nitrogen on LAI

Effect of N levels revealed that a highly significant variation on leaf area index for all growth stages (Figure 3.1.7 & Appendix 3.1.3 for 2016-17 and Figure 3.1.8 & Appendix 3.1.4 for 2017-18). Irrespective of treatment differences, Leaf area index increased progressively up to 75 DAS after that it was gradually decreased. At 25 DAS maximum LAI (0.83) was observed with N₂ (100 kg N ha⁻¹) which was significantly differ with other level on N doses and minimum LAI (0.34) was found with N₀ (0.0 kg N ha⁻¹) during 2016-17 and highest LAI (3.18) was obtained with N₄ which was significantly differ from other N level and lowest LAI (1.29) was found with control (0 kg N ha⁻¹) during 2017-18. At 50 DAS, highest Leaf area index (2.71) was found with N₂ (100 kg N ha⁻¹) which was statically differ with N₁ (50 kg N ha⁻¹) and N₂ (150 kg N ha⁻¹) and lowest LAI was attained with N₀ (0 kg N ha⁻¹) during 2016-17 and highest Leaf area index (2.71) was found with N₂ (100 kg N ha⁻¹) which was statistically differ with N₁ (50 kg N ha⁻¹) and N₂ (150 kg N ha⁻¹) and lowest LAI (1.26) was attained with N₀ (0 kg N ha⁻¹) observed during 2017-18. At 75 DAS, maximum LAI (3.10) was obtained with N₃ (150 kg N ha⁻¹) which was statistically at par with N₂ (100 kg N ha⁻¹) and minimum LAI (0.59) was found with N₀ (0 kg N ha⁻¹) during 2016-17 and maximum LAI (2.29) was obtained with N₄ (140 kg N ha⁻¹) which was significantly differ with N₃ (120 kg N ha⁻¹) and minimum LAI (1.81) was found with N₀ (0 kg N ha⁻¹) during 2017-18.

At 100 DAS, maximum LAI (2.25) was obtained with N₂ (100 kg N ha⁻¹) which was significantly higher than the other N level and minimum with N₀ (0 kg N ha⁻¹) during 2016-17 and maximum LAI (1.56) was obtained with N₄ (140 kg N ha⁻¹) which was significantly identical with N₃ (120 kg N ha⁻¹) and minimum LAI (1.69) was found with N₀ (0 kg N ha⁻¹) during 2017-18.

A similar result was reported by Nahar *et al.*, (2015). They reported that the significant variation was observed on leaf area index in case of different forms of nitrogenous fertilizer application in the field. It was found that the highest LAI was found with N1 (urea super granules; 1.8 g) at all growth stages (18.2, 29.5, 38.3, 27.8, 22.7, 22.1 and 16.8 at 15, 30, 45, 60, 75, 90 DAS and at harvest respectively) which was significantly different from all other treatments. On the other hand, the minimum leaf area index (12.5, 18.6, 23.1, 13.5, 12.4, 13.1 and 9.2 at 30, 60, 90 DAS and at harvest respectively) was found in N0 (control) which was also significantly different from all other treatments. Mandal *et al.* (2015) also reported that LAI of wheat varied significantly due to various source of nitrogen at different DAS.

The LAI differed significantly with different doses of nitrogen application (Rahman *et al.*, 2014). They revealed that the treatment CN150 produced the higher LAI which was statistically identical with the treatment CN120 at all the growth stages of measurements while minimum LAI was produced by the treatment receiving no nitrogen (N0). The results are confirmed by Bali *et al.* (1991) who reported maximum LAI with enhancement of N fertilization. The increase in LAI is caused by increased in number of tillers and in size of successive leaves in presence of increased dose of N.

Interaction effect of wheat varieties and nitrogen on LAI

The interaction effect of varieties and nitrogen levels on LAI was statistically significant except 50 DAS and 100 DAS during 2017-18 (Table 3.1.5 and appendix 3.1.3 for 2016-17 and Table 3.1.6 and appendix 3.1.4 for 2017-18). At 25 DAS, the maximum LAI (1.03) was recorded by the interaction of N₂V₄ (150 kg N ha⁻¹ and BARI Gom 30) which was statistically similar with N₂V₁ (100 kg N ha⁻¹ and BARI Gom 29), N₃V₁ (150 kg N ha⁻¹ and BARI Gom 26), N₂V₂ (100 kg N ha⁻¹ and BARI Gom 28), N₃V₂ (150 kg N ha⁻¹ and BARI Gom 28), N₂V₃ (100 kg N ha⁻¹ and BARI Gom 28) and N₃V₃ (150 kg N ha⁻¹ and BARI Gom 29) during 2016-17 and maximum Leaf area index (0.74) was found with treatment combination N₃V₁ (120 kg N ha⁻¹ and BARI Gom 26) which was identical with treatment combination N₄V₁ (0.73), N₃V₂ (0.71, N₃V₂ (0.71) and N₄V₃ (0.68) during 2017-18. The minimum LAI (0.30) was observed from the treatment combination of N₀V₂ (0 kg N ha⁻¹ and BARI Gom 28) during 2016-17 and treatment combination of N₀V₃ (0.49) during 2017-18. At 50 DAS, highest LAI (2.73) was resulted by the interaction of N₂V₁ (100 kg N ha⁻¹ and BARI Gom 26) which was statistically identical with N₂V₂ (2.46), N₂V₃ (2.65) and N₂V₄ (2.59) where the lowest LAI (0.52) was observed from the treatment combination of N₀V₂ (0.0 kg N ha⁻¹ and BARI Gom 28) during 2016-17. During the crop season 2017-18, interaction effects of wheat varieties and nitrogen levels for LAI was found insignificant at 50 DAS. At 75 DAS, maximum leaf area index (3.38) was found from

interaction of N_3V_3 (150 kg N ha⁻¹ and BARI Gom 29) which was identical with treatment combination of N_3V_1 (150.0 kg N ha⁻¹ and BARI Gom 26) and N_3V_4 (150.0 kg N ha⁻¹ and BARI Gom 30) where minimum LAI (0.98) was found from interaction treatment of N_0V_4 (0.0 kg N ha⁻¹ and BARI Gom 30) during 2016-17. Maximum LAI (2.27) was found with treatment combination N_4V_3 (140 kg N ha⁻¹ and BARI Gom 30) which was statically non-significant from other treatment combinations during 2017-18. At 100 DAS, the highest LAI (2.74) was recorded by the interaction of N_3V_4 (150 kg N ha⁻¹ and BARI Gom 30) which was statistically identical with treatment combination N_3V_1 (150 kg N ha⁻¹ and BARI Gom 26) during 2016-17 and maximum LAI (1.95) was found with treatment combination N_3V_2 (120 kg N ha⁻¹ and BARI Gom 28) which was followed by treatment combination N_4V_2 (140 kg N ha⁻¹ and BARI Gom 28), N_3V_1 (120 kg N ha⁻¹ and BARI Gom 28), N_4V_1 (140 kg N ha⁻¹ and BARI Gom 26) and N_4V_3 (140 kg N ha⁻¹ and BARI Gom 30) during 2017-18. The lowest LAI (0.41) was observed from the treatment combination of N_0V_1 (0 kg N ha⁻¹ and BARI Gom 28) during 2016-17 and minimum Leaf area index was recorded from treatment combination of N_0V_3 (1.05) during 2017-18. Nahar, (2013) reported that LAI of wheat was significantly influenced by the interaction of variety and nitrogenous fertilizer at different days after sowing (DAS). Who found that the maximum LAI was obtained from V_4 (BARI Gom 26) N_1 (84 kg N ha⁻¹ from USG) at 15, 30, 45, 60, 75, 90 DAS.

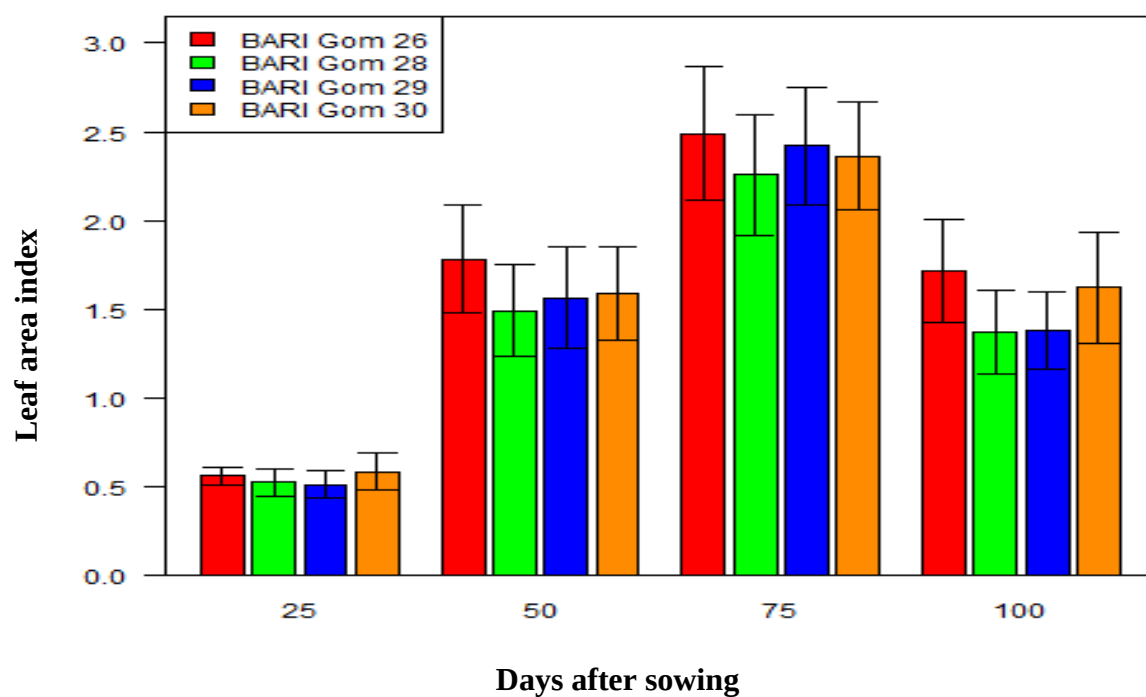


Figure 3.1.5: Effect of wheat varieties on Leaf area index (LAI) at different days after sowing (2016-17).

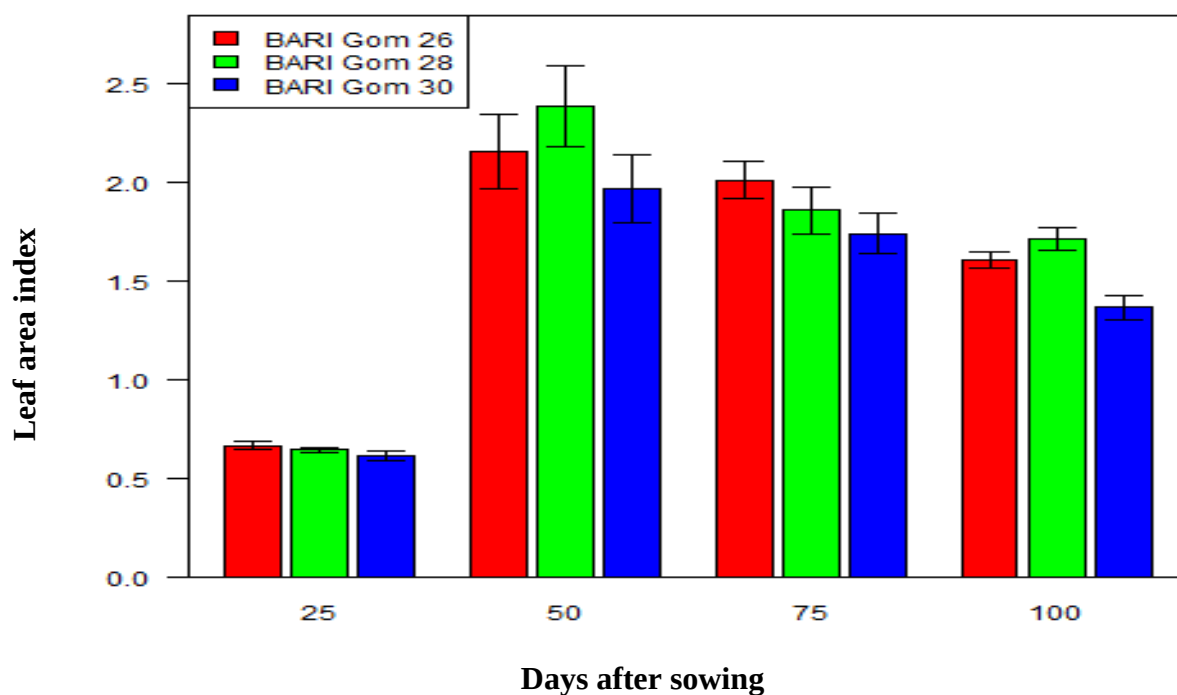


Figure 3.1.6: Effect of wheat varieties on Leaf area index (LAI) at different days after sowing (2017-18).

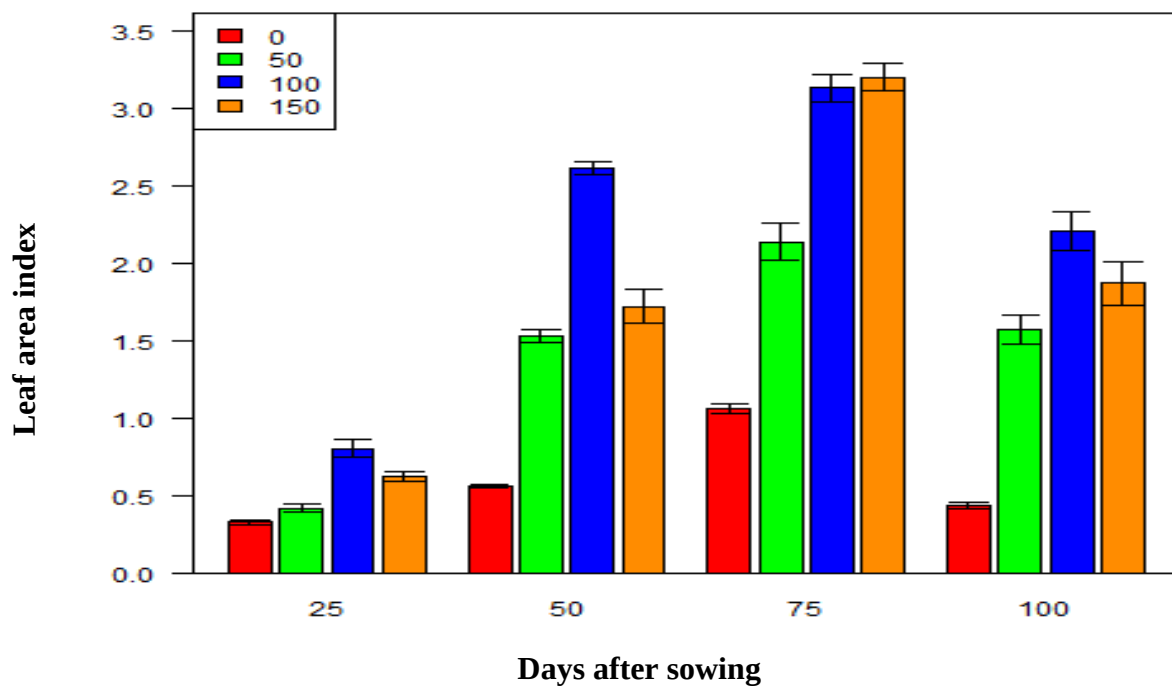


Figure 3.1.7: Effect of nitrogen on Leaf area index (LAI) at different days after sowing (2016-17).

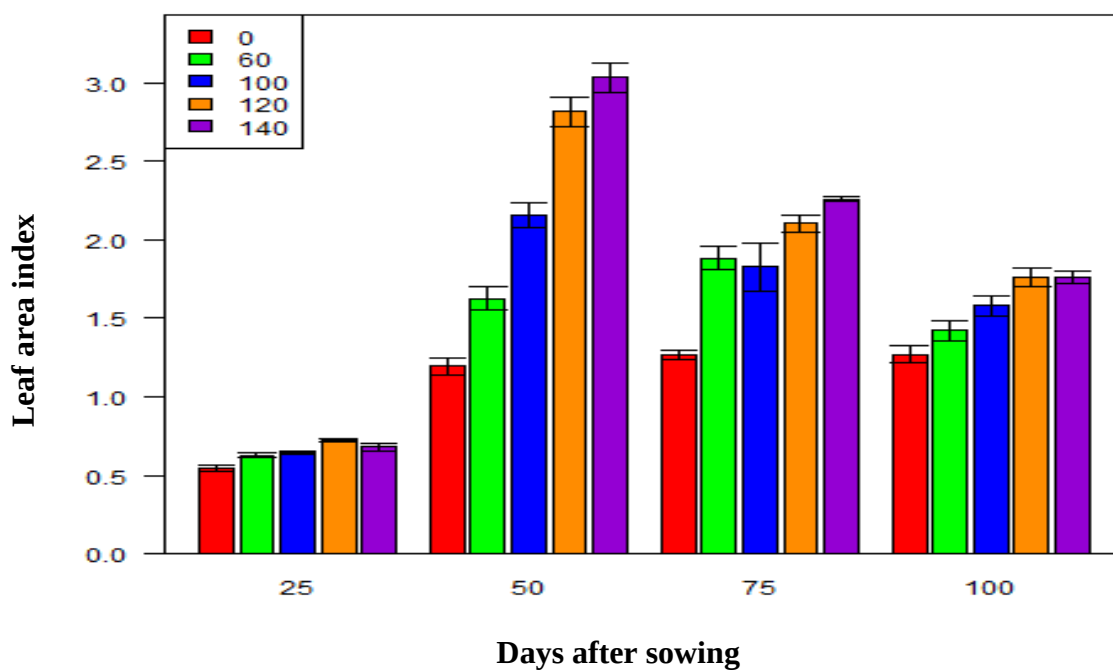


Figure 3.1.8: Effect of nitrogen on Leaf area index LAI at different days after sowing during 2017-18.

Table 3.1.5. Interaction effect of varieties and nitrogen on LAI at different days after sowing of wheat during 2016-17

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	0.37	0.58	1.12	0.48
N ₁ ×V ₁	0.53	1.59	1.96	1.75
N ₂ ×V ₁	0.66	2.73	3.41	2.12
N ₃ ×V ₁	0.87	2.22	3.47	2.51
N ₀ ×V ₂	0.30	0.53	1.00	0.42
N ₁ ×V ₂	0.40	1.42	1.83	1.26
N ₂ ×V ₂	0.84	2.47	3.24	2.09
N ₃ ×V ₂	0.56	1.54	2.95	1.71
N ₀ ×V ₃	0.28	0.54	1.15	0.42
N ₁ ×V ₃	0.35	1.42	2.11	1.56
N ₂ ×V ₃	0.69	2.65	3.04	1.88
N ₃ ×V ₃	0.72	1.64	3.38	1.67
N ₀ ×V ₄	0.36	0.61	0.98	0.42
N ₁ ×V ₄	0.39	1.68	2.65	1.73
N ₂ ×V ₄	1.03	2.59	2.82	2.75
N ₃ ×V ₄	0.56	1.48	3.00	1.59
LSD (0.05)	0.06	0.06	0.13	0.26

Table 3.1.6. Interaction effect of varieties and nitrogen on LAI at different days after sowing of wheat during 2017-18

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	0.55	1.26	1.34	1.37
N ₁ ×V ₁	0.63	1.48	2.01	1.51
N ₂ ×V ₁	0.68	2.19	2.13	1.62
N ₃ ×V ₁	0.74	2.83	2.31	1.77
N ₄ ×V ₁	0.73	3.01	2.24	1.74
N ₀ ×V ₂	0.59	1.27	1.28	1.39
N ₁ ×V ₂	0.69	1.93	2.03	1.57
N ₂ ×V ₂	0.61	2.28	1.70	1.78
N ₃ ×V ₂	0.71	3.13	2.03	1.95
N ₄ ×V ₂	0.62	3.30	2.24	1.85
N ₀ ×V ₃	0.49	1.06	1.18	1.05
N ₁ ×V ₃	0.56	1.47	1.61	1.18
N ₂ ×V ₃	0.63	2.01	1.65	1.34
N ₃ ×V ₃	0.71	2.50	1.97	1.56
N ₄ ×V ₃	0.68	2.79	2.28	1.69
LSD (0.05)	0.08	Ns	ns	0.12

N₀ = 0 kg N ha⁻¹, N₁ = 60 kg N ha⁻¹, N₂ = 100 kg N ha⁻¹, N₃ = 120 kg N ha⁻¹ and N₄ = 140 kg N ha⁻¹ and V₁= BARI Gom 26, V₂= BARI Gom 28, V₃= BARI Gom 30

3.1.3.1.3 NDVI value

Normalized Difference Vegetative Index (NDVI) have been used to obtain crop information. It is used to monitor crop development and to provide rapid and nondestructive estimates of plant biomass, nitrogen content and grain yield (Naser, 2012).

Effect of wheat varieties on NDVI value

The NDVI value of different wheat varieties at different growth stages highly significantly differs at different days after sowing (DAS) is shown in Appendix 3.1.5, Figure 3.1.9 for 2016-17 and Appendix 3.1.6, Figure 3.1.10 for 2017-18, respectively. NDVI increased gradually up to 50 DAS, then increased up to 75 DAS and decreased with the advancement of growing period of all the varieties for both the years. Regardless of variety differences, NDVI increased progressively up to 75 DAS. At 25 DAS maximum NDVI (0.42) was observed in BARI Gom 29 which was statistically identical with BARI Gom 28 and minimum NDVI (0.35) was obtained in BARI Gom 30 which was also statistically similar with BARI Gom 26 during 2016-17. Maximum NDVI (0.57) was found in BARI Gom 28 which was significantly differ from other wheat varieties and minimum NDVI (0.44) was found in BARI gom 26 during 2017-18. At 50 DAS, highest NDVI (0.68) was found in BARI Gom 29 which was non-significantly varies from other varieties and lowest NDVI (0.66) was observed in BARI Gom 26 during 2016-17. Highest NDVI (0.78) was found in BARI Gom 28 which was significantly higher then the other variety and lowest NDVI (.69) was found from BARI Gom 26 which was identical with BARI Gom 30 during 2017-18. At 75 DAS, maximum NDVI (0.76) was found in BARI Gom 26 which was statistically insignificant with other varieties and minimum NDVI (0.74) which was observed in BARI Gom 30 during 2016-17. Highest NDVI (0.72) was found in BARI Gom 28 and lowest NDVI (0.66) was found from BARI Gom 30 followed BARI Gom 28 by during 2017-18. At 100 DAS stage, highest NDVI (0.61) was obtained in BARI Gom 28 which was statistically insignificant with other varieties of wheat and lowest NDVI (0.59) was in BARI Gom 26 during 2016-17. Maximum NDVI value (0.65) was obtained in BARI Gom 29 which was statistically identical with BARI Gom 26 and BARI Gom 30 during 2016-17.

Sultana *et al.*, (2014) reported that the variation among the cultivars on NDVI score was differed significantly at all growth stages. Who was found cultivar Faisalabad-2008 gave maximum NDVI value (0.88) at grain filling stage and minimum NDVI value (0.36) was found from cultivar Chakwal-97 at tillering stage.

The NDVI values varied from 0.36 to 0.76 during 2016-17 and from 0.45 to 0.83 during 2017-2018 among the wheat cultivars, which were in good agreement with the measurements of Sugár *et al.*, (2019) they reported that NDVI values varied from 0.54 to 0.80 for common wheat and from 0.51 to 0.82 for spelt wheat. Piekarczyk and Sulewska (2010) also observed 0.72 and 0.71 average NDVI values for spelt and common wheat, respectively around flowering.

Effect of nitrogen on NDVI value

Effect of N levels revealed that a highly significant variation on NDVI for all growth stages (Figure 3.1.11 & Appendix 3.1.5 for 2016-17 and Figure 3.1.12 & Appendix 3.1.6 for 2017-18). Irrespective of treatment differences, NDVI increased rapidly up to 50 DAS after that it was slowly decreased. At 25 DAS maximum NDVI (0.49) was observed with N₃ treatment (150 kg N ha⁻¹) which was significantly differ with other level on N doses. Minimum NDVI (0.32) was found with N₀ treatment (0.0 kg N ha⁻¹) during 2016-17. Highest NDVI (0.61) was obtained with N₄ treatment (140.0 kg N ha⁻¹) which was significantly differ from other N level and lowest NDVI (0.38) was found with control (0.0 kg N ha⁻¹) during 2017-18. At 50 DAS, highest NDVI (0.8) was found with N₃ (150 kg N ha⁻¹) which was statically identical with N₂ (100 kg N ha⁻¹) and lowest NDVI (.049) was attained with control (0.0 kg N ha⁻¹) during 2016-17. The maximum NDVI (0.85) was found with N₄ (140 kg N ha⁻¹) which was statistically differ with N₂ (100 kg N ha⁻¹) and N₃ (120 kg N ha⁻¹) and lowest NDVI (0.52) was attained with N₀ (0.0 kg N ha⁻¹) observed during 2017-18. At 75 DAS, maximum NDVI (0.82) was obtained with N₃ (150 kg N ha⁻¹) which was statistically at par with N₂ (100 kg N ha⁻¹) and minimum NDVI (0.65) was found with N₀ (0 kg N ha⁻¹) during 2016-17. Maximum NDVI (0.91) was obtained with N₄ (140 kg Na⁻¹) which was significantly differ with N₃ (120 kg N ha⁻¹) and minimum NDVI (0.72) was found with N₀ (0 kg N ha⁻¹) during 2017-18.

At 100 DAS, maximum NDVI (0.71) was obtained with N₄ (150 kg N ha⁻¹) which was identical with N₃ (100 kg N ha⁻¹) and minimum (0.0.48) with N₀ (0.0 kg N ha⁻¹) during 2016-17 and the

maximum NDVI (0.78) was obtained with N₄ (140 kg N ha⁻¹) which was significantly identical with N₃ (120 kg N ha⁻¹) and minimum NDVI (0.48) was found with control (0 kg N ha⁻¹) during 2017-18.

The effect of nitrogen on NDVI score at various growth stages was significant (Sultana *et al.*, 2014). Who observed maximum values of NDVI were observed in N₄ (220 kg N ha⁻¹) and minimum values were showed in N₁ (0 kg N ha⁻¹) at different growth stages in chronological order, respectively, Other treatments of nitrogen N₃ (110 kg N ha⁻¹) and N₂ (55 kg N ha⁻¹) showed values of NDVI score. In chronological order, NDVI score ranged from 0.32 to 0.43, 0.53 to 0.70, 0.55 to 0.74, 0.74 to 0.85, 0.78 to 0.88, and 0.40 to 0.65 at tillering, stem elongation, booting, anthesis, grain filling and physiological maturity stages, respectively.

The NDVI values increased from 0.64 to 0.82 during 2016-17 and from 0.71 to 0.91 during 2017- 2018 by increasing N level at 75 DAS which were in good agreement with the measurements of Sugár *et al.*, (2019) they observed NDVI score significant and moderate reaction to the increasing N fertilizer doses for common and spelt wheat where, NDVI values range from 0.43 and 0.83 by increasing N fertilizer during flowering stage.

Interaction effect of wheat varieties and nitrogen on NDVI

The interaction effect of varieties and nitrogen levels on NDVI was statistically significant except 75 DAS during 2017-18 (Table 3.1.7 and appendix 3.1.5 for 2016-17) and 25 DAS & 75 DAS during 2017-18 (Table 3.1.8 and appendix 3.1.6 for 2017-18). At 25 DAS, the maximum NDVI (0.52) was recorded by the interaction of N₃V₁ (150 kg N ha⁻¹ and BARI Gom 26) which was statistically similar with N₂V₂ (100 kg N ha⁻¹ and BARI Gom 28), N₃V₂ (150 kg N ha⁻¹ and BARI Gom 28), N₃V₃ (150 kg N ha⁻¹ and BARI Gom 29), N₂V₄ (100 kg N ha⁻¹ and BARI Gom 30), N₂V₃ (100 kg N ha⁻¹ and BARI Gom 28) during 2016-17. The maximum NDVI (0.68) was found with treatment combination N₄V₂ (140 kg N ha⁻¹ and BARI Gom 28) and minimum (0.31) N₀V₁ (0.0 kg N ha⁻¹ and BARI Gom 26) during 2017-18. At 50 DAS, highest NDVI (0.81) was resulted by the interaction of N₂V₄ (100 kg N ha⁻¹ and BARI Gom 30) which was statistically identical with N₂V₄ (0.80), N₃V₂ (0.80), N₃V₃ (0.79) N₃V₁ (0.79) and N₂V₁ (0.78) where the lowest NDVI (0.45) was observed from the treatment combination of N₀V₁ (0.0 kg N ha⁻¹ and BARI Gom 26) during 2016-17. The highest NDVI (0.97) was found from the treatment

interaction of N_4V_2 (140 kg N ha⁻¹ and BARI Gom 28) which was statistically significant with other treatment combinations where the lowest NDVI (0.50) was observed from the treatment combination of N_0V_1 (0.0 kg N ha⁻¹ and BARI Gom 26) during 2017-18. At 75 DAS, interaction effects of wheat varieties and nitrogen levels for NDVI was found insignificant during both years. At 100 DAS, the highest NDVI (0.68) was recorded by the interaction of N_3V_4 (150 kg N ha⁻¹ and BARI Gom 30) which was statistically insignificant with other treatment combinations during 2016-17. The maximum NDVI (0.78) was found with treatment combination N_3V_3 (120 kg N ha⁻¹ and BARI Gom 30) which was followed by treatment combination N_4V_3 (140 kg N ha⁻¹ and BARI Gom 30), N_3V_2 (120 kg N ha⁻¹ and BARI Gom 28), N_4V_1 (140 kg N ha⁻¹ and BARI Gom 26) and N_4V_2 (140 kg N ha⁻¹ and BARI Gom 28) during 2017-18. The lowest NDVI (0.58) was observed from the treatment combination of N_0V_3 (0.0 kg N ha⁻¹ and BARI Gom 30) during 2017-18.

The interaction of between nitrogen rates and cultivars for NDVI score increased from 0.62 to 0.84 during 2016-17 and from 0.70 to 0.97 during 2017- 2018 by increasing N level at 75 DAS which were in good agreement with the measurements of Sugár *et al.*, (2019) they observed NDVI score significant and moderate reaction to the interaction between cultivar and N fertilizer doses for common and spelt wheat where, NDVI values range from 0.44 and 0.89 during flowering stage.

The interaction of between nitrogen rates and cultivars for NDVI was highly significant at different growth stages of wheat and nitrogen treatment N_4 (220 kg ha⁻¹) and cultivar Faisalabad-2008 gave maximum NDVI value (0.85) at grain filling stage (Sultana *et al.*, 2014).

Gamon *et al.*, (1992 and 1997) reported that at grain filling stage NDVI decreases up to 0.3 because crop becomes under stressed and its capacity to absorb PAR is reduced. But Fernandez *et al.*, (1994) described that NDVI score reached up to 0.4 in productive environments which have high TDM and LAI thus showing the vigorous crop canopy as dark foliage. The milky-grain stage is the best depictive stage for recording NDVI as it directly correlates to yield than earlier measurements (Royo *et al.*, 2003). More of the literature showed that the relationship between biomass and NDVI but less information for prediction of biomass and yield at early growth stages of the crop consistent (Babar *et al.*, 2006), NDVI score increased until the onset

of grain filling and the highest score of NDVI recorded near milky-grain stage and then decrease up to maturity. Biomass and yield was strongly correlated with each other.

The NDVI values consistently increased with crop growth stages in early season and it reached a plateau when the ground surface was completely covered by the canopy. The plateau in NDVI values seems to correspond to the saturation of the sensor that loses sensitivity to changes in vegetation amount when LAI is higher than three (Aparicio *et al.*, 2000). The NDVI decrease at the end of the season is attributed to physiological maturity, change in crop color and senescence leaf, which increases red band reflectance and decreases NIR band reflectance. This phenomenon was observed by Aparicio *et al.* (2000) and Prasad *et al.* (2007) on vegetation with lower amount of green biomass due to either water stress or to normal senescence through the mid-grain filling stage. As expected, we observed increasing green biomass from early spring to mid-season and decreasing green biomass from mid-season to late season, which was reflected into NDVI values. Other reflectance-based indices such as green NDVI (GNDVI) and SR can also detect seasonal variations in green biomass (Babar *et al.*, 2006; Prasad *et al.*, 2007).

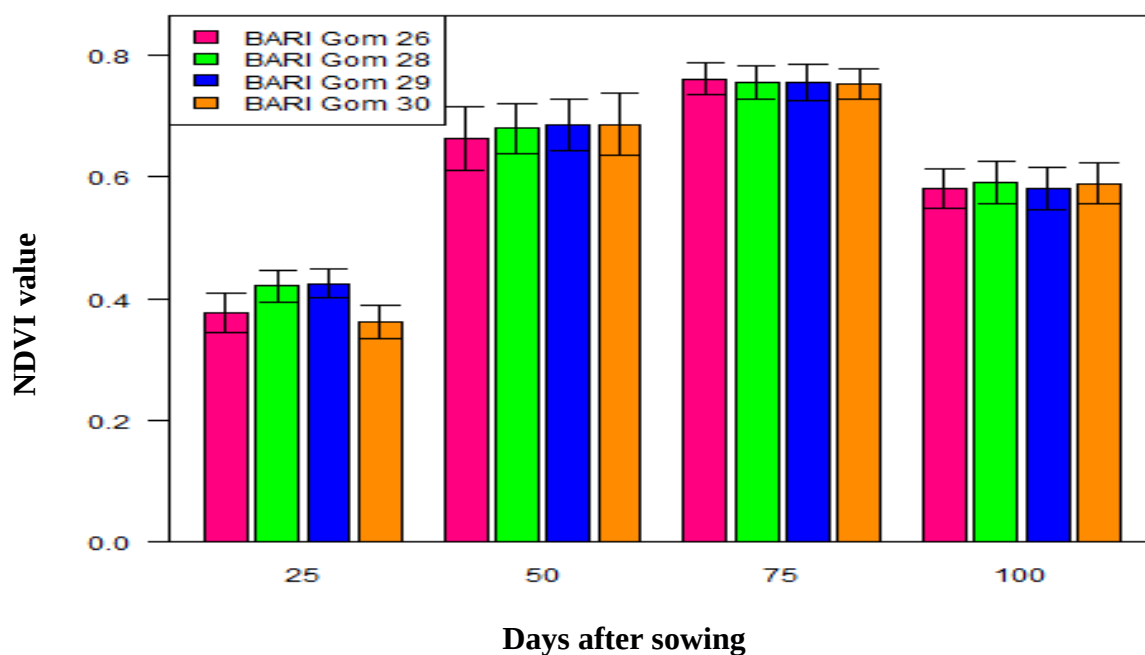


Figure 3.1.9: Effect of wheat varieties on NDVI at different days after sowing during 2016-17.

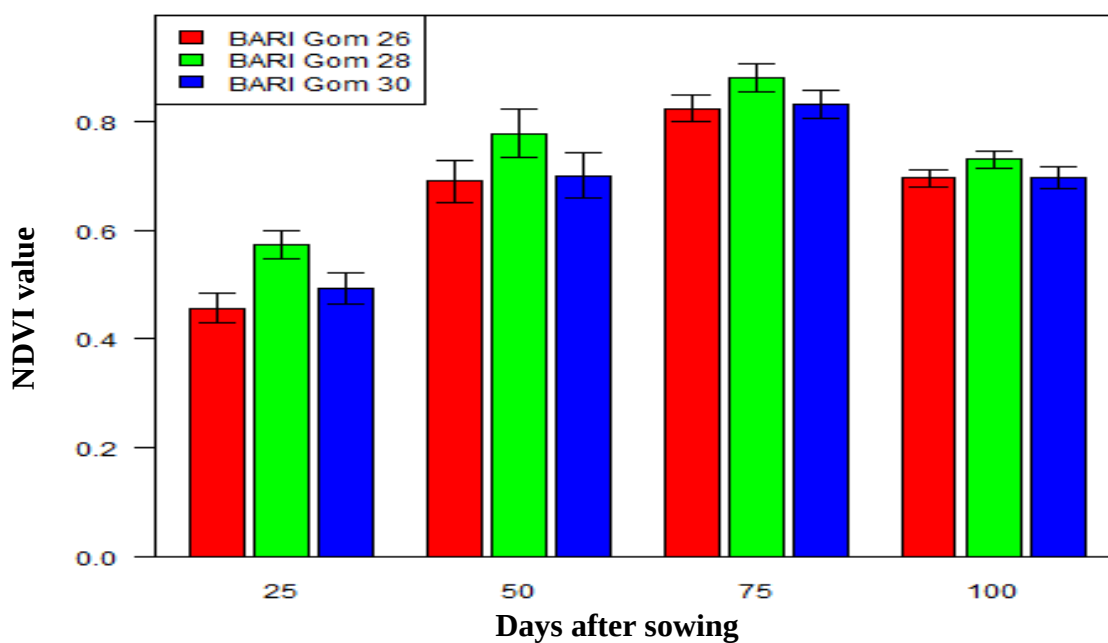


Figure 3.1.10: Effect of wheat variety on NDVI at different days after sowing during 2017-18. Vertical bars indicate $\pm$ SE value.

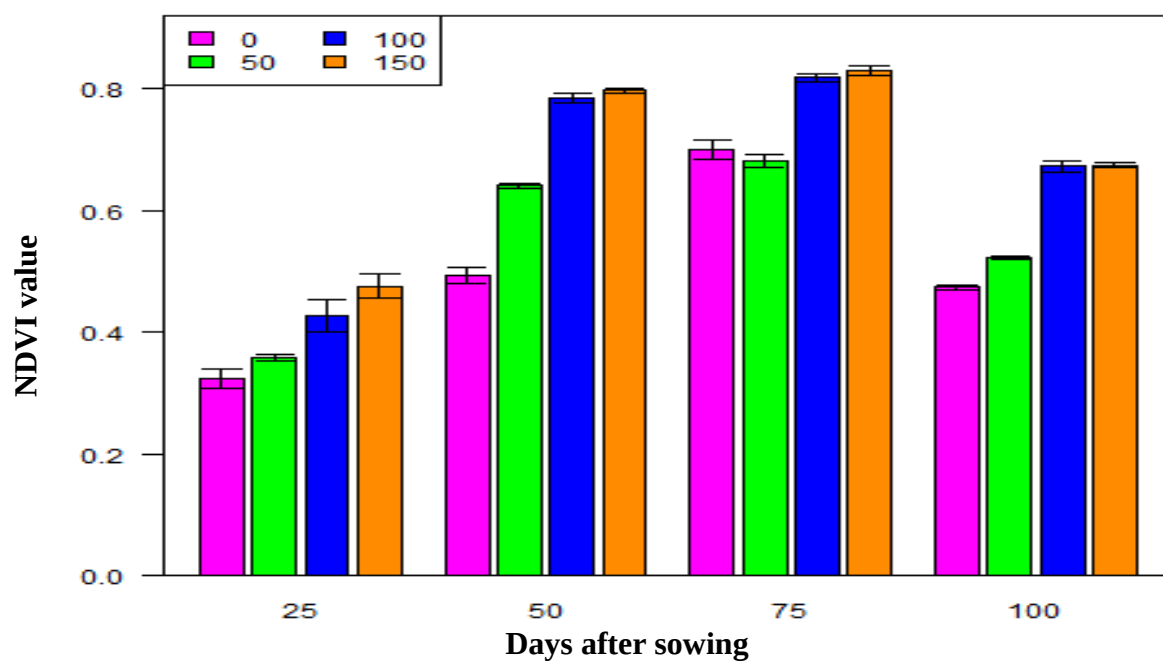


Figure 3.1.11: Effect of nitrogen on NDVI at different days after sowing (2016-17).

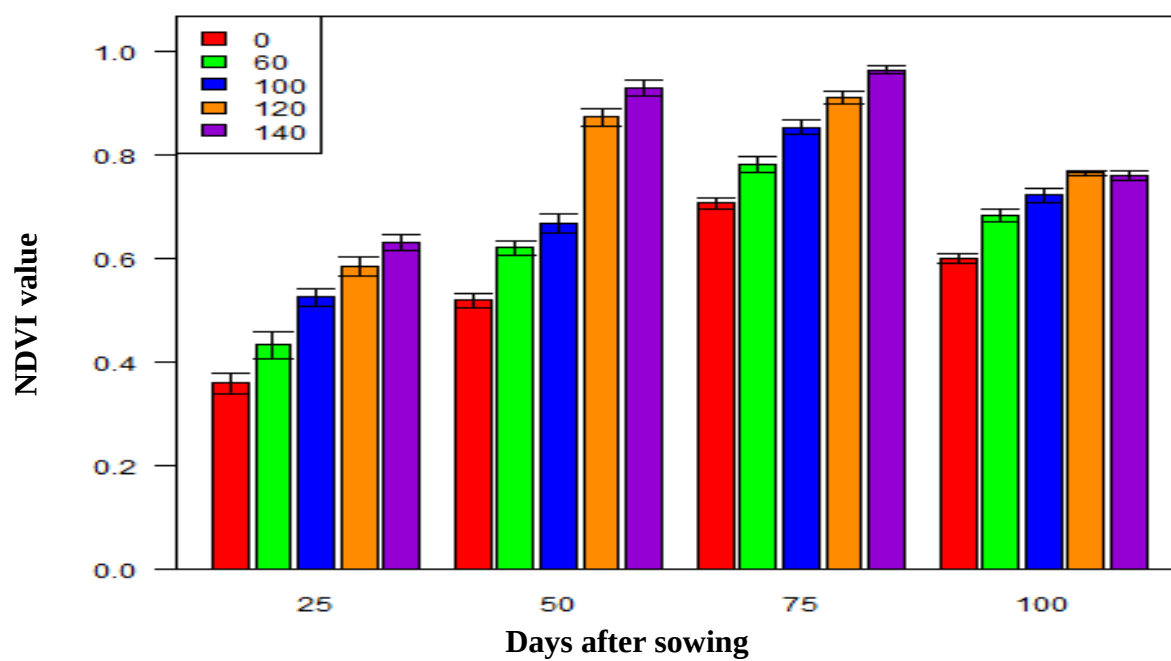


Figure 3.1.12: Effect of nitrogen on NDVI at different days after sowing (2017-18).

Table 3.1.7. Interaction effect of varieties and nitrogen levels on NDVI at different days after sowing of wheat during 2016-17

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	0.32	0.45	0.68	0.47
N ₁ ×V ₁	0.36	0.64	0.71	0.52
N ₂ ×V ₁	0.31	0.78	0.81	0.67
N ₃ ×V ₁	0.52	0.79	0.84	0.67
N ₀ ×V ₂	0.34	0.52	0.67	0.48
N ₁ ×V ₂	0.37	0.64	0.71	0.52
N ₂ ×V ₂	0.47	0.76	0.81	0.68
N ₃ ×V ₂	0.50	0.80	0.82	0.68
N ₀ ×V ₃	0.37	0.53	0.72	0.47
N ₁ ×V ₃	0.35	0.62	0.64	0.52
N ₂ ×V ₃	0.47	0.80	0.82	0.66
N ₃ ×V ₃	0.50	0.79	0.84	0.67
N ₀ ×V ₄	0.26	0.48	0.69	0.47
N ₁ ×V ₄	0.34	0.65	0.69	0.53
N ₂ ×V ₄	0.46	0.81	0.82	0.68
N ₃ ×V ₄	0.38	0.80	0.81	0.68
LSD (0.05)	0.04	0.03	ns	ns
CV (a)%	5.96	1.32	3.30	3.14
CV (b)%	3.74	2.39	3.77	3.67

Table 3.1.8. Interaction effect of varieties and nitrogen levels on NDVI at different days after sowing of wheat during 2017-18

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	0.31	0.51	0.70	0.59
N ₁ ×V ₁	0.37	0.59	0.76	0.67
N ₂ ×V ₁	0.49	0.64	0.83	0.70
N ₃ ×V ₁	0.53	0.83	0.89	0.75
N ₄ ×V ₁	0.58	0.88	0.95	0.76
N ₀ ×V ₂	0.42	0.54	0.73	0.63
N ₁ ×V ₂	0.53	0.68	0.83	0.72
N ₂ ×V ₂	0.58	0.74	0.90	0.77
N ₃ ×V ₂	0.65	0.94	0.95	0.77
N ₄ ×V ₂	0.68	0.97	0.97	0.76
N ₀ ×V ₃	0.35	0.51	0.70	0.58
N ₁ ×V ₃	0.41	0.60	0.76	0.66
N ₂ ×V ₃	0.51	0.63	0.83	0.70
N ₃ ×V ₃	0.57	0.85	0.90	0.78
N ₄ ×V ₃	0.63	0.92	0.96	0.77
LSD (0.05)	Ns	0.03	Ns	0.04
CV (a)%	6.55	2.53	3.28	1.83
CV (b)%	4.01	2.55	2.59	3.00

N₀ = 0 kg N ha⁻¹, N₁ = 60 kg N ha⁻¹, N₂ = 100 kg N ha⁻¹, N₃ = 120 kg N ha⁻¹ and N₄ = 140 kg N ha⁻¹ and V₁= BARI Gom 26, V₂= BARI Gom 28, V₃= BARI Gom 30

3.1.3.1.4 Canopy cover (CC) value

The canopy cover (CC) is characteristics result from several factors, including genetically determined patterns of development, environmental influence on key developmental events and population density. This means that plant canopies, whether considered as single plants or at the community scale, are spatially complex, resulting in a heterogeneous light environment (Russell *et al.*, 1989).

Effect of wheat varieties on Canopy cover (CC) value

The CC value of different wheat varieties at different growth stages highly significantly differs at different days after sowing (DAS) is shown in Appendix 3.1.7, Figure 3.1.13 for 2016-17 and Appendix 3.1.8, Figure 3.1.14 for 2017-18, respectively. CC increased slowly up to 50 DAS and then increased rapidly up to 75 DAS and decreased with the advancement of growing period of all the varieties for both the years. Regardless of treatment differences, CC increased progressively up to 75 DAS. At 25 DAS maximum CC (0.72) was observed in BARI Gom 29 which was significantly differ with other wheat varieties. and minimum CC (0.57) was obtained in BARI Gom 26 which was also statistically similar with BARI Gom 30 during 2016-17 and the maximum CC (0.69) was found in BARI Gom 28 and minimum CC (0.61) was found in BARI Gom 26 during 2017-18. At 50 DAS, highest CC (0.81) was found in BARI Gom 28 which was significantly varies from other varieties and lowest CC (0.68) was observed in BARI Gom 30 which was statistically identical with BARI Gom 26 during 2016-17. The highest CC (0.75) was found in BARI Gom 30 and lowest CC (0.65) was found in BARI Gom 30 and BARI Gom 28 during 2017-18. At 75 DAS, maximum CC (0.92) was found in BARI Gom 29 which was significantly differ with other varieties. Minimum CC (0.78) was observed in BARI Gom 26 which was identical with BARI Gom 30 during 2016-17. The highest CC (0.89) was found in BARI Gom 28 and lowest CC (0.79) was found from BARI Gom 30 which was similar with BARI Gom 26 during 2017-18. At 100 DAS stage, highest CC (0.78) was obtained in BARI Gom 29 and lowest CC (0.65) was in BARI Gom 26 which was statically identical with BARI Gom 30 during 2016-17. The maximum CC (0.70) was found from BARI Gom 29 and lowest CC (0.64) was in BARI Gom 26 which was statically identical with BARI Gom 30 during 2017-18.

As expected, the canopy cover increased progressively with growing stage and peaked at the anthesis among the varieties (Yanli *et al.*, 2007). They reported that differences in leaf spatial distribution resulted in different canopy cover between the two varietal groups. However, differences in canopy spectral reflectance between groups decreased with the growing stage.

Effect of nitrogen on CC

Effect of N levels revealed that a highly significant variation on CC for all growth stages of wheat (Figure 3.1.15 & Appendix 3.1.7 for 2016-17 and Figure 3.1.16 & Appendix 3.1.8 for 2017-18). Nevertheless, of treatment differences, CC increased progressively up to 75 DAS after that it was gradually decreased. At 25 DAS maximum CC (0.82) was observed with N₃ (150 kg N ha⁻¹) which was significantly differ with other level on N and minimum CC (0.40) was found with N₀ (0.0 kg N ha⁻¹) during 2016-17 and highest CC (0.78) was obtained with N₄ which was significantly differ from other N level and lowest CC (0.35) was found with control (0 kg N ha⁻¹) during 2017-18. At 50 DAS, highest CC (0.88) was found with N₃ (150 kg N ha⁻¹) which was statically differ with N₂ (100 kg N ha⁻¹) and N₁ (50 kg N ha⁻¹) and lowest CC (0.60) was attained with N₀ (0 kg N ha⁻¹) during 2016-17 and maximum CC (0.82) was found with N₄ (140 kg N ha⁻¹) which was statistically differ with N₃ (120 kg N ha⁻¹) and N₂ (100 kg N ha⁻¹) and minimum CC (0.58) was attained with N₀ (0 kg N ha⁻¹) observed during 2017-18. At 75 DAS, maximum CC (0.96) was obtained with N₃ (150 kg N ha⁻¹) which was statistically at par with N₂ (100 kg N ha⁻¹) and minimum CC (0.71) was found with N₀ (0 kg N ha⁻¹) during 2016-17 and maximum CC (0.95) was obtained with N₄ (140 kg N ha⁻¹) which was significantly differ with N₃ (120 kg N ha⁻¹) and minimum CC (0.68) was found with N₀ (0 kg N ha⁻¹) during 2017-18. At 100 DAS, maximum CC (0.81) was obtained with N₃ (150 kg N ha⁻¹) which was significantly higher than the other N levels and minimum (0.58) with N₀ (0.0 kg N ha⁻¹) during 2016-17 and maximum CC (0.76) was obtained with N₄ (140 kg N ha⁻¹) which was significantly identical with N₃ (120 kg N ha⁻¹) and minimum CC (0.52) was found with N₀ (0 kg N ha⁻¹) during 2017-18.

Interaction effect of wheat varieties and nitrogen on CC

The interaction effect of varieties and nitrogen levels on CC at different growth stage of wheat was statistically significant except 75 DAS during 2016-17 (Table 3.1.9 and appendix 3.1.7 for 2016-17) and 25 DAS & 75 DAS during 2017-18 (Table 3.1.10 and appendix 3.1.8 for 2017-

18). At 25 DAS, the maximum CC (0.67) was recorded by the interaction of $N_2 \times V_3$ (100 kg N ha⁻¹ and BARI Gom 29) which was statistically identical with treatment combinations $N_3 \times V_3$ (150 kg N ha⁻¹ and BARI Gom 29), $N_3 \times V_1$ (150 kg N ha⁻¹ and BARI Gom 26) and $N_3 \times V_4$ (150 kg N ha⁻¹ and BARI Gom 30) during 2016-17 and maximum CC (0.80) was found with treatment combination of N_4V_2 (140 kg N ha⁻¹ and BARI Gom 28) which was identical with treatment combination of N_3V_2 (120 kg N ha⁻¹ and BARI Gom 28) during 2017-18. The minimum CC (0.24) was observed from the treatment combination of N_0V_2 (0 kg N ha⁻¹ and BARI Gom 28) during 2016-17 and minimum CC (0.31) was found from treatment combination of N_0V_1 (0.0 kg N ha⁻¹ and BARI Gom 26) during 2017-18. At 50 DAS, highest CC (0.89) was resulted by the interaction of N_2V_4 (100 kg N ha⁻¹ and BARI Gom 30) which was statistically identical with treatment combination of N_1V_4 (0.85) where the lowest CC (0.55) was observed from the treatment combination of N_0V_1 (0.0 kg N ha⁻¹ and BARI Gom 26) during 2016-17. During the crop season 2017-18, interaction effects of wheat varieties and nitrogen levels for CC was found insignificant at 50 DAS. At 75 DAS, maximum CC (0.99) was found from interaction of N_3V_3 (150 kg N ha⁻¹ and BARI Gom 29) which was identical with treatment combination of N_3V_2 (150.0 kg N ha⁻¹ and BARI Gom 28) and N_2V_3 (100.0 kg N ha⁻¹ and BARI Gom 29) where minimum CC (0.67) was found from interaction treatment of N_0V_4 (0.0 kg N ha⁻¹ and BARI Gom 30) during 2016-17. Maximum CC (0.97) was found with treatment combination N_4V_2 (140 kg N ha⁻¹ and BARI Gom 28) which was statically non-significant from other treatment combinations during 2017-18. At 100 DAS, the highest CC (0.92) was recorded by the interaction of N_3V_3 (150 kg N ha⁻¹ and BARI Gom 29) and minimum in treatment combination N_0V_4 (0.0 kg N ha⁻¹ and BARI Gom 30) during 2016-17. Maximum CC (0.79) was found with treatment combination of N_3V_2 (120 kg N ha⁻¹ and BARI Gom 28) which was followed by treatment combination of N_4V_2 (140 kg N ha⁻¹ and BARI Gom 28), N_4V_3 (140 kg N ha⁻¹ and BARI Gom 29) during 2017-18. The lowest CC (0.52) was recorded from treatment combination of N_0V_3 (0.0 kg N ha⁻¹ and BARI Gom 29) during 2017-18

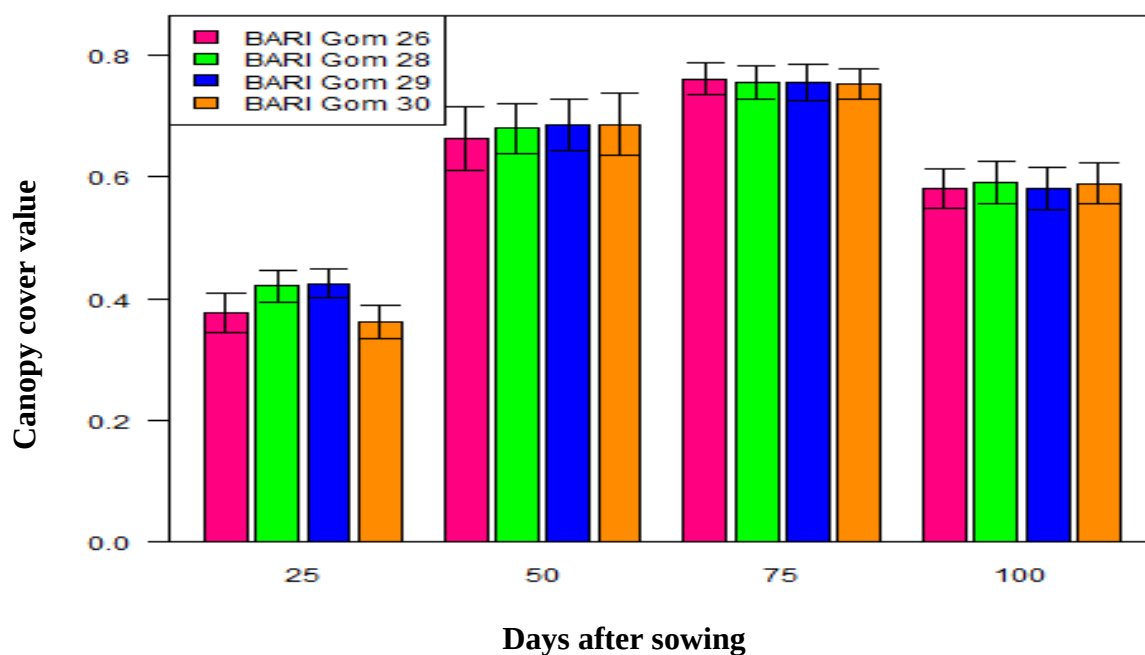


Figure 3.1.13: Effect of wheat varieties on CC at different days after sowing (2016-17).

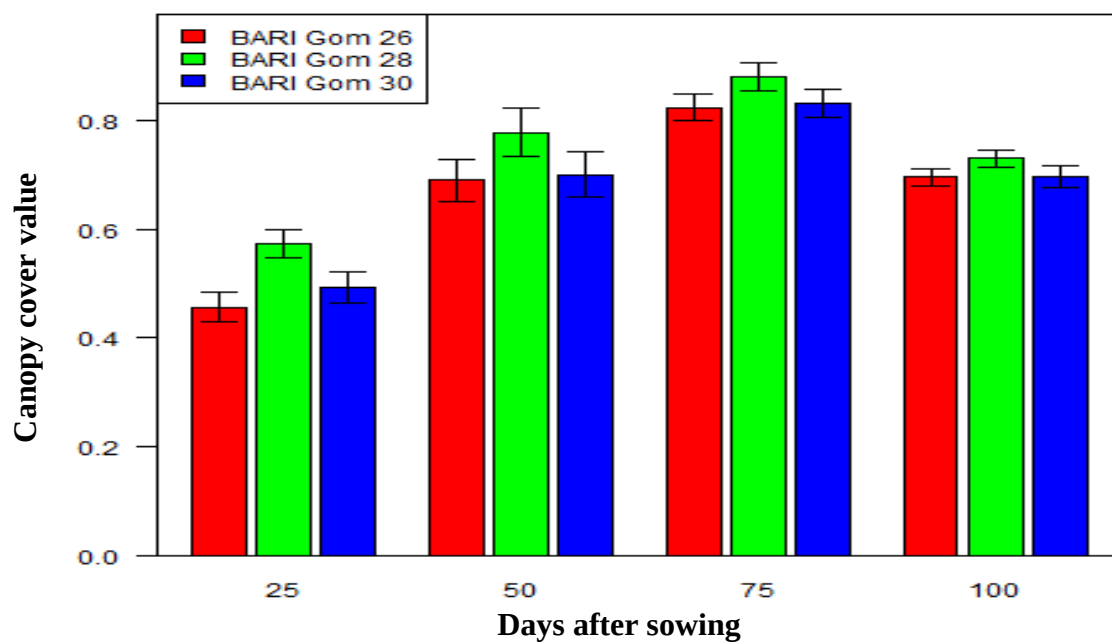


Figure 3.1.14: Effect of wheat variety on CC at different days after sowing (2017-18). Vertical bars indicate $\pm$ SE value.

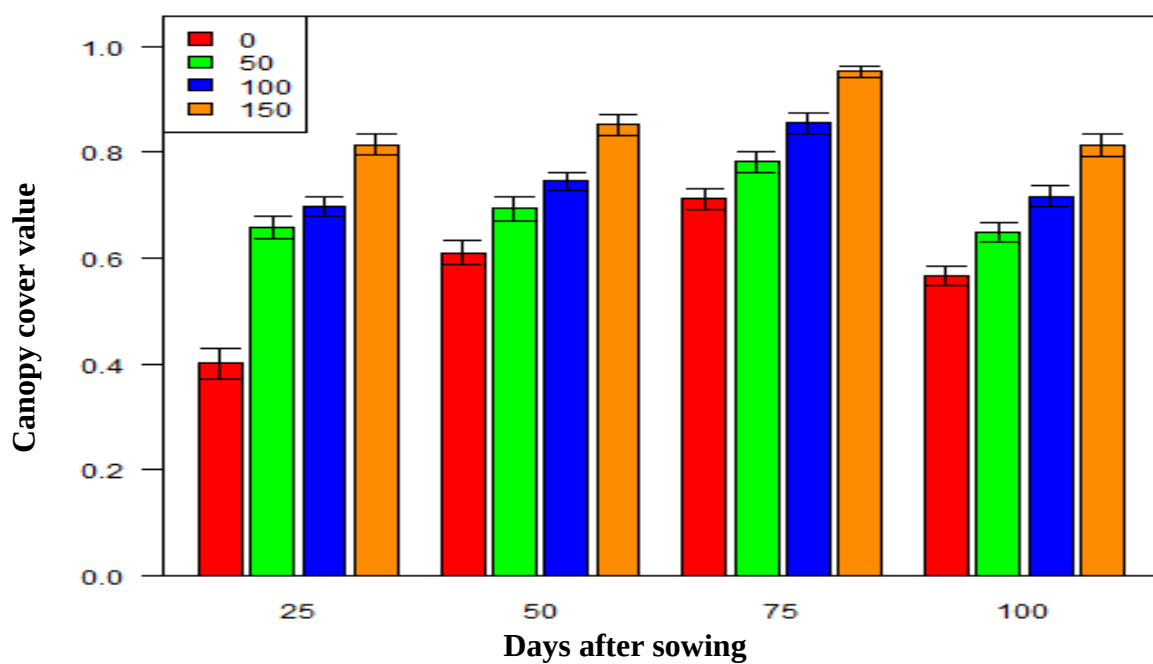


Figure 3.1.15: Effect of nitrogen on canopy cover at different days after sowing (2016-17).

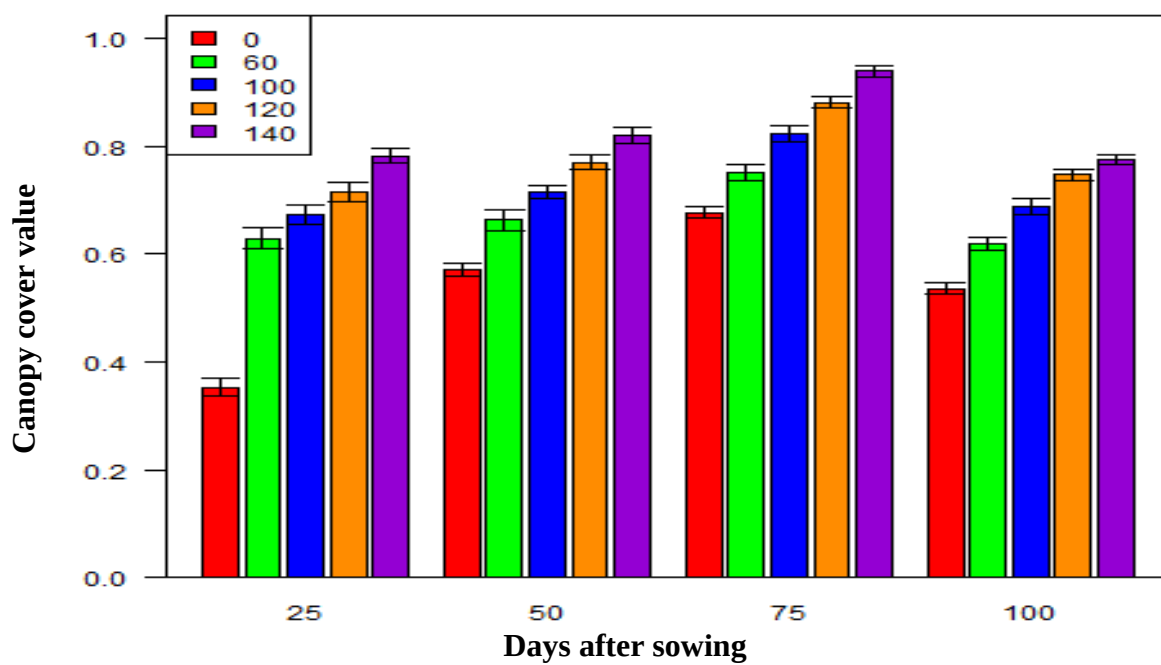


Figure 3.1.16: Effect of nitrogen on canopy cover at different days after sowing (2017-18).

Table 3.1.9. Interaction effect of varieties and nitrogen levels on CC at different days after sowing of wheat during 2016-17

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	0.31	0.55	0.67	0.53
N ₁ ×V ₁	0.50	0.57	0.73	0.61
N ₂ ×V ₁	0.57	0.73	0.80	0.67
N ₃ ×V ₁	0.66	0.59	0.92	0.77
N ₀ ×V ₂	0.24	0.63	0.70	0.56
N ₁ ×V ₂	0.59	0.72	0.80	0.66
N ₂ ×V ₂	0.62	0.78	0.87	0.74
N ₃ ×V ₂	0.63	0.64	0.97	0.78
N ₀ ×V ₃	0.45	0.71	0.81	0.66
N ₁ ×V ₃	0.64	0.75	0.87	0.74
N ₂ ×V ₃	0.67	0.83	0.95	0.80
N ₃ ×V ₃	0.67	0.79	0.99	0.92
N ₀ ×V ₄	0.30	0.70	0.67	0.52
N ₁ ×V ₄	0.50	0.85	0.73	0.60
N ₂ ×V ₄	0.52	0.89	0.80	0.66
N ₃ ×V ₄	0.66	0.80	0.93	0.78
LSD (0.05)	0.03	0.04	0.04	Ns
CV (a)%	4.66	2.34	2.35	1.26
CV (b)%	2.51	3.39	2.60	3.33

Table 3.1.10. Interaction effect of varieties and nitrogen levels on CC at different days after sowing of wheat during 2017-18

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	0.31	0.55	0.67	0.53
N ₁ ×V ₁	0.60	0.63	0.73	0.61
N ₂ ×V ₁	0.67	0.71	0.80	0.67
N ₃ ×V ₁	0.69	0.75	0.86	0.72
N ₄ ×V ₁	0.76	0.80	0.92	0.77
N ₀ ×V ₂	0.34	0.57	0.70	0.56
N ₁ ×V ₂	0.69	0.72	0.80	0.66
N ₂ ×V ₂	0.72	0.75	0.87	0.74
N ₃ ×V ₂	0.78	0.81	0.92	0.79
N ₄ ×V ₂	0.80	0.87	0.97	0.78
N ₀ ×V ₃	0.40	0.59	0.67	0.52
N ₁ ×V ₃	0.60	0.64	0.73	0.60
N ₂ ×V ₃	0.62	0.69	0.80	0.66
N ₃ ×V ₃	0.67	0.75	0.87	0.74
N ₄ ×V ₃	0.76	0.80	0.93	0.78
LSD (0.05)	0.03	ns	ns	0.04
CV (a)%	5.50	3.32	3.23	1.92
CV (b)%	2.94	3.4	2.66	3.15

N₀ = 0 kg N ha⁻¹, N₁ = 60 kg N ha⁻¹, N₂ = 100 kg N ha⁻¹, N₃ = 120 kg N ha⁻¹ and N₄ = 140 kg N ha⁻¹ and V₁= BARI Gom 26, V₂= BARI Gom 28, V₃= BARI Gom 30

3.1.3.1.5 Total Dry Matter (TDM) production(gm⁻²)

Dry matter is the material which was dried to a constant weight. Total dry matter (TDM) production indicates the production potential of a crop. A high TDM production is the first prerequisite for high yield.

Effect of wheat varieties

The total dry matter (TDM) accumulation of different wheat varieties at different growth stages highly significantly differs at different days after sowing (DAS) is shown in Appendix 3.1.9, Figure 3.1.20 for 2016-17 and Appendix 3.1.10, Figure 3.1.21 for 2017-18, respectively. TDM accumulation increased gradually up to harvest of all the varieties for both the years. Regardless of varietal differences, TDM accumulation increased progressively up to harvest. Awal *et al.*, (2017) also confirmed our findings for TDM accumulation was lower at initial growth stage. Thereafter the TDM almost linearly and steadily increased to attain its peak or maximum value at 102 days after sowing (DAS). Then the TDM slowly declined at the approach of maturity of crops.

At 25 DAS, maximum TDM accumulation (400.10 gm⁻²) was observed in BARI Gom 26 which was statistically identical with BARI Gom 28 and BARI Gom 30 and minimum TDM accumulation (385.35 gm⁻²) was obtained in BARI Gom 29 during 2016-17. The maximum TDM accumulation (425.80 gm⁻²) was found in BARI Gom 30 and minimum TDM accumulation (394.12 gm⁻²) was found in BARI gom 26 during 2017-18. At 50 DAS, highest TDM accumulation (705.30 gm⁻²) was found in BARI Gom 29 which was significantly varies from other varieties and lowest TDM accumulation (6150.51 gm⁻²) was observed in BARI Gom 26 during 2016-17 and highest TDM accumulation (1085.22 gm⁻²) was found in BARI Gom 30 and lowest TDM accumulation (924.89 gm⁻²) was found in BARI Gom 26 during 2017-18. At 75 DAS, maximum TDM accumulation (896.50 gm⁻²) was found in BARI Gom 29 which was statistically identical BARI Gom 26 and BARI Gom 28 and minimum TDM accumulation (850.67 gm⁻²) was observed in BARI Gom 30 during 2016-17 and highest TDM accumulation (1340 gm⁻²) was found in BARI Gom 30 which was statistically identical BARI Gom 26 and lowest TDM accumulation (1215.84 gm⁻²) was found from BARI Gom 28 during 2017-18 which was little bit lower than the wheat growing season 2016-17 it may be due to variation of

weather condition of growing season. At harvest stage, highest TDM accumulation (1187.34 gm^{-2}) was obtained in BARI Gom 29 which was identical with BARI Gom 26 and BARI Gom 28 and lowest TDM accumulation (1103.51 gm^{-2}) was in BARI Gom 30 during 2016-17, where maximum TDM accumulation (1386.23 gm^{-2}) was obtained in BARI Gom 30 which was identical with BARI Gom 26 and lowest TDM accumulation (1245.29 gm^{-2}) was in BARI Gom 26 during 2017-18 which indicated that newly released cultivar have the capacity to produce more TDM. Awal *et al.*, (2017) also confirmed our findings for TDM accumulation, They reported that BARI Gom-23 accumulated comparatively greater amount of TDM than BARI Gom-25 and lower TDM was noticed in BARI Gom-27 while the other varieties ranked intermediate.

Effect of nitrogen on TDM (gm^{-2})

Effect of N levels revealed that a highly significant variation on TDM accumulation for all growth stages (Figure 3.1.17 & Appendix 3.1.9 for 2016-17 and Figure 3.1.18 & Appendix 3.1.10 for 2017-18). Nevertheless, of treatment differences, TDM accumulation increased progressively up to 75 DAS after that it was gradually decreased. At 25 DAS, maximum TDM accumulation (435.75 gm^{-2}) was observed with N_3 (150 kg N ha^{-1}) which was significantly differ with other level on N doses and minimum TDM accumulation (270.56 gm^{-2}) was found with N_0 (0.0 kg N ha^{-1}) during 2016-17 and highest TDM accumulation (444.58 gm^{-2}) was obtained with N_4 (140 kg N ha^{-1}) which was similar with N_3 (120 kg N ha^{-1}) and lowest TDM accumulation (355.21 gm^{-2}) was found with N_1 ($50.00 \text{ kg N ha}^{-1}$) which was identical with control during 2017-18. At 50 DAS, highest TDM accumulation (756.97 gm^{-2}) was found with N_3 (150 kg N ha^{-1}) which was statically differ from other N levels and lowest TDM accumulation (586.88 gm^{-2}) was attained with N_0 (0 kg N ha^{-1}) during 2016-17 and highest TDM accumulation (1155.32 gm^{-2}) was found with N_3 (120 kg N ha^{-1}) which was statistically differ with N_4 (140 kg N ha^{-1}) and N_2 (100 kg N ha^{-1}) and lowest TDM accumulation (584.19 gm^{-2}) was attained with N_0 (0 kg N ha^{-1}) observed during 2017-18. At 75 DAS, maximum TDM accumulation (921.65 gm^{-2}) was obtained with N_3 (150 kg N ha^{-1}) which was statistically at par with N_2 (100 kg N ha^{-1}) and minimum TDM accumulation (765.43 gm^{-2}) was found with N_0 (0 kg N ha^{-1}) during 2016-17 and maximum TDM accumulation (1510.75 gm^{-2}) was obtained with N_3 (120 kg N ha^{-1}) which

was significantly differ with N₄ (140 kg N ha⁻¹) and minimum TDM accumulation (947.58 gm⁻²) was found with N₀ (0 kg N ha⁻¹) during 2017-18. At harvest, maximum TDM accumulation (1467.62 gm⁻²) was obtained with N₃ (150 kg N ha⁻¹) which was significantly higher than the other N level and minimum TDM accumulation (838.59 gm⁻²) with N₀ (0 kg N ha⁻¹) during 2016-17 and maximum TDM accumulation (1673.78 gm⁻²) was obtained with N₃ (120 kg N ha⁻¹) which was significantly identical with N₄ (140 kg N ha⁻¹) and minimum TDM accumulation (820.27 gm⁻²) was found with N₀ (0 kg N ha⁻¹) during 2017-18.

Maximum TDM accumulation was observed from 75 DAS to harvesting time in respect of nitrogen levels. Plants grown under the treatment N₀ produced significantly lower total dry matter than those treated with N₅₀, N₁₀₀ and N₁₅₀ during 2016-17 and N₆₀, N₁₀₀, N₁₂₀ and N₁₄₀ during 2017-18 because of due time N application leads to proper tiller formation as well as normal growth and development of wheat. It also might be due to increased dose of N leads to increase in photosynthetic rate and higher leaf area that results increased total dry matter production. This result is also in agreement with the findings of Rahman *et al.*, (2014) they reported that maximum dry matter production was observed from 70 to 90 DAS in respect of nitrogen levels. Kumar and Sharma (1999) who also observed that dry matter production in wheat increased significantly when the rate of N application increased. Higher doses of N fertilization results increased dry matter production over lower doses N fertilization in wheat (Mehrotra and Singh, 1982).

Significant variation was observed in dry weight plant⁻¹ at all sampling dates. Results indicated that at 30 DAS, variety had no significant effect but at 60, 90 DAS and at harvest and the variety BARI Gom 24 produced significantly higher dry weight plant⁻¹ (6.34, 15.48 and 18.19 g, respectively). Results also showed that the variety BARI Gom 25 produced the lowest dry weight plant⁻¹ at 30, 60, 90 DAS and at harvest (5.8, 13.8 and 16.9 g, respectively) which was statistically similar to the variety BARI Gom 21 and BARI Gom 26 at the time of harvest.

Interaction effect of wheat varieties and nitrogen on TDM (gm^{-2})

The combined effect of varieties and nitrogen levels on TDM was statistically significant except 100 DAS during 2016-17 (Table 3.1.11 and appendix 3.1.9) and 25 DAS during 2017-18 (Table 3.1.12 and appendix 3.1.10), respectively. At 25 DAS, the maximum TDM (505.18 gm^{-2}) was recorded by the interaction of treatment combination of N_3V_2 (150 kg N ha^{-1} and BARI Gom 28) which was significantly differ from other treatment combinations during 2016-17 and maximum TDM (516.00 gm^{-2}) was found with treatment combination N_3V_2 (120 kg N ha^{-1} and BARI Gom 28) which was non-significant with other treatment combinations during 2017-18. The minimum TDM (259.20 gm^{-2}) was observed from the treatment combination of N_0V_2 (0 kg N ha^{-1} and BARI Gom 28) during 2016-17 and the lowest TDM (276.00 gm^{-2}) was found from treatment combination of N_0V_1 (0 kg N ha^{-1} and BARI Gom 26) during 2017-18. At 50 DAS, highest TDM (845.82 gm^{-2}) was resulted by the interaction of N_3V_2 (100 kg N ha^{-1} and BARI Gom 28) which was significantly differ from other treatment combinations where the lowest TDM (508.84 gm^{-2}) was observed from the treatment combination of N_0V_1 (0.0 kg N ha^{-1} and BARI Gom 26) during 2016-17. During the crop season 2017-18, interaction effects of wheat varieties and nitrogen levels, highest TDM (1348 gm^{-2}) was found from treatment combination of N_3V_3 (120 kg N ha^{-1} and BARI Gom 29) which significantly differ from other treatment combinations where the lowest TDM (475.2 gm^{-2}) was observed from the treatment combination of N_0V_1 (0.0 kg N ha^{-1} and BARI Gom 26). At 75 DAS, maximum TDM (996.85 gm^{-2}) was found from interaction of N_3V_3 (150 kg N ha^{-1} and BARI Gom 29) which was identical with treatment combination of N_3V_2 ($150.0 \text{ kg N ha}^{-1}$ and BARI Gom 28) where minimum TDM (712.24 gm^{-2}) was found from interaction treatment of N_0V_4 (0.0 kg N ha^{-1} and BARI Gom 30) during 2016-17. The highest TDM (1587.63 gm^{-2}) was found with treatment combination N_3V_1 (120 kg N ha^{-1} and BARI Gom 26) which was statically identical with treatment combination of N_4V_1 ($140.00 \text{ kg N ha}^{-1}$ and BARI Gom 26) during 2017-18. At harvest, the highest TDM (1499.91 gm^{-2}) was recorded by the interaction of N_3V_2 (150 kg N ha^{-1} and BARI Gom 28) which was statistically insignificant with other treatment combinations during 2016-17 and maximum TDM (1676.5 gm^{-2}) was found with treatment combination N_3V_2 (120 kg N ha^{-1} and BARI Gom 28) which was followed by treatment combination N_3V_1 (120 kg N ha^{-1} and BARI Gom 26), N_4V_3 (120 kg N ha^{-1} and BARI Gom 29), N_4V_2 (140 kg N ha^{-1} and BARI Gom 28) and

N₃V₃ (120 kg N ha⁻¹ and BARI Gom 29) during 2017-18. The lowest TDM (845.41 gm⁻²) was observed from the treatment combination of N₀V₄ (0 kg N ha⁻¹ and BARI Gom 30) during 2016-17 and minimum TDM (939.22 gm⁻²) was recorded from treatment combination of N₀V₁ (0 kg N ha⁻¹ and BARI Gom 29) during 2017-18. This result is also in agreement with the findings of Nahar *et al.*, (2015) they reported that dry weight plant⁻¹ was significantly influenced by interaction of variety and N at different DAS. Their results showed that the highest dry weight plant⁻¹ was obtained from V2N1 (BARI Gom 24 and Urea supergranules (1.8g), i.e. 84 kg ha⁻¹) at 30, 60, 90 DAS and at harvest (0.64, 7.73, 18.8 and 21.2 g respectively) which was statistically similar with V₁N₁, V₃N₁ and V₄N₁ at 30 DAS, but at 60, 90 DAS and at harvest. On the other hand, the lowest dry weight plant⁻¹ at 30, 60, 90 DAS and at harvest was observed as 0.20, 3.88, 8.83 and 10.36 g respectively with V₃N₀.

TDM is in increasing trend till flowering stage thereafter it declines at post anthesis stages. This decrease in TDM might be due to leaf senescence (Chalihan *et al.*, 1996 and Sarkar *et al.*, 1999). TDM is positively correlated with leaf area and high TDM is due to the fast development of leaf area. Leaf area decreases at later stage and likewise the TDM. The initial increase in TDM was mainly associated with tillering. During this phase, the number of meristems producing leaf increases. The decline TDM after reaching a maximum was due to senescence and death of leaves in succession from the base of stem upward. However, grain yield, on other hand, increases with increase in maximum TDM only upto a point. (Saharan *et al.*, 1985). The increase in TDM is closely followed by increased in canopy photosynthesis (Puckridge, 1971).

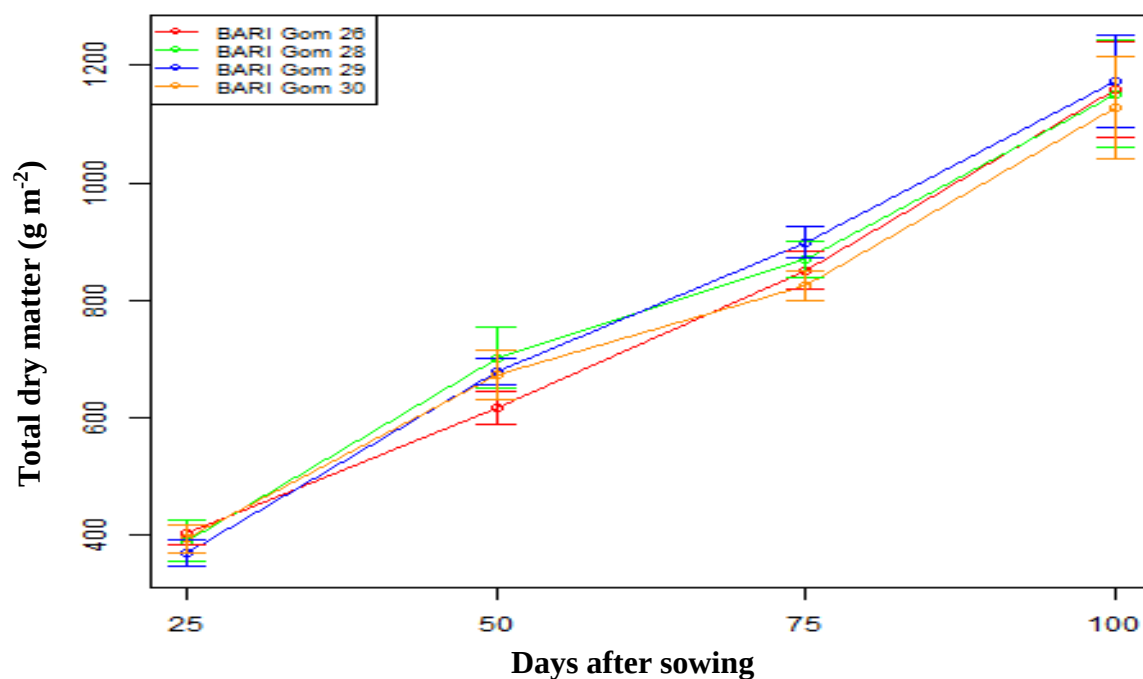


Figure 3.1.17: Effect of wheat varieties on Total dry matter (TDM) at different days after sowing (2016-17).

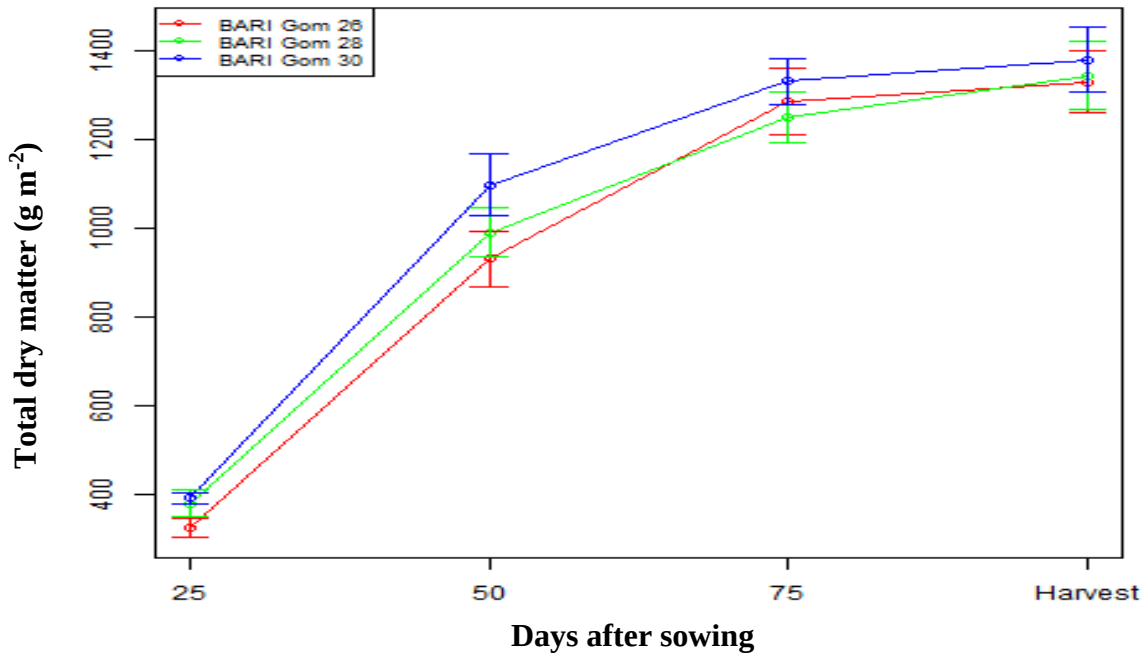


Figure 3.1.18: Effect of wheat variety on Total dry matter (TDM) at different days after sowing (2017-18). Vertical bars indicate $\pm$ SE value.

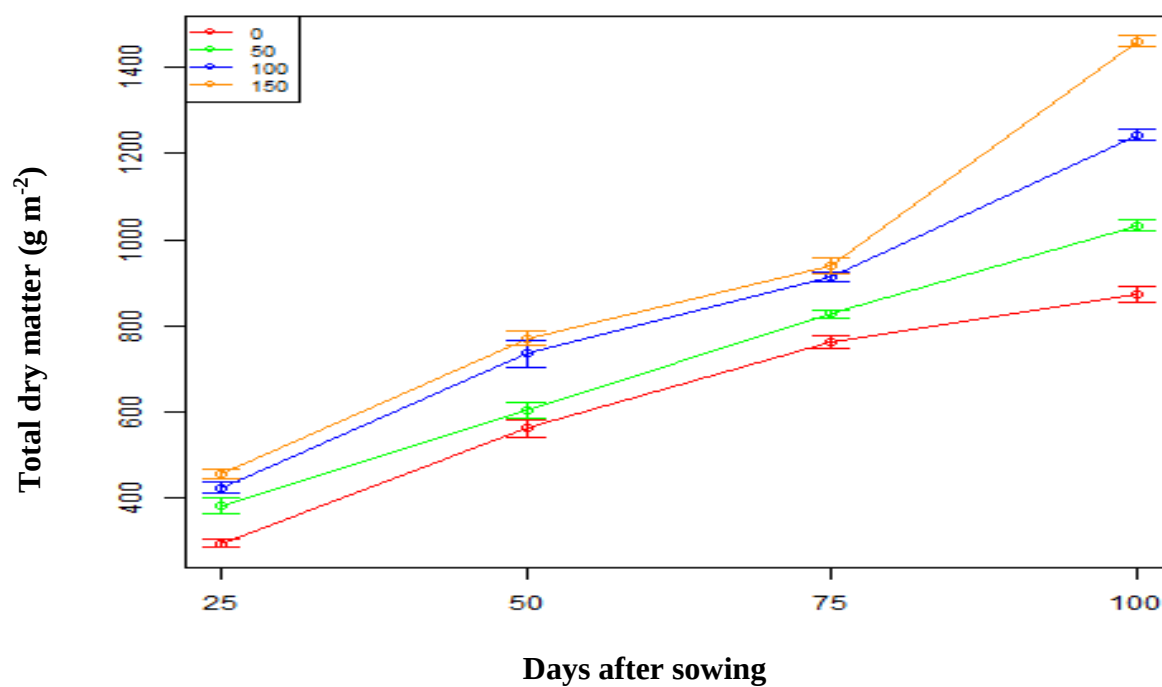


Figure 3.1.19: Effect of nitrogen on Total dry matter (TDM) at different days after sowing (2016-17).

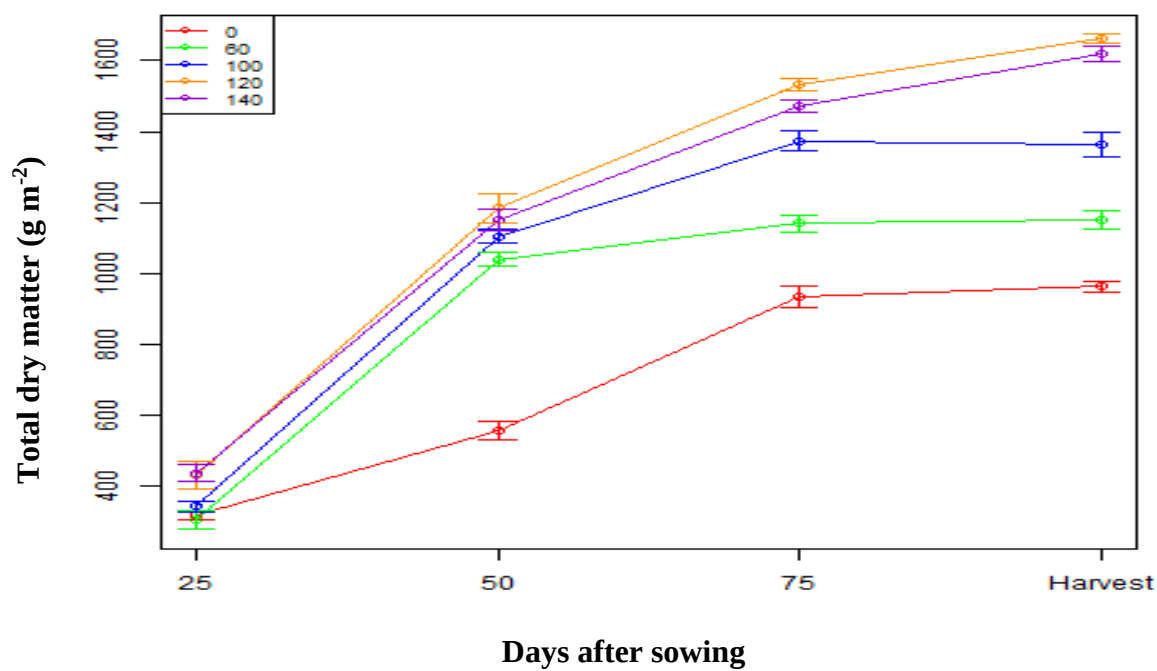


Figure 3.1.20: Effect of nitrogen on Total dry matter (TDM) at different days after sowing (2017-18).

Table 3.1.11. Interaction effect of varieties and nitrogen on TDM at different days after sowing of wheat during 2016-17

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	At harvest
N ₀ ×V ₁	326.20	508.84	743.56	890.59
N ₁ ×V ₁	362.66	636.42	799.22	1036.32
N ₂ ×V ₁	380.48	599.90	940.12	1261.16
N ₃ ×V ₁	449.97	724.08	922.38	1450.32
N ₀ ×V ₂	259.20	510.98	774.19	857.01
N ₁ ×V ₂	362.84	633.86	814.24	1032.51
N ₂ ×V ₂	439.24	816.99	923.13	1216.73
N ₃ ×V ₂	505.18	845.82	968.83	1499.91
N ₀ ×V ₃	289.42	618.05	821.46	903.82
N ₁ ×V ₃	340.75	620.29	843.24	1063.23
N ₂ ×V ₃	408.03	735.27	933.63	1288.02
N ₃ ×V ₃	443.30	741.53	996.85	1437.05
N ₀ ×V ₄	306.01	609.70	712.24	845.41
N ₁ ×V ₄	371.66	624.94	852.70	1000.13
N ₂ ×V ₄	469.05	788.11	862.93	1208.60
N ₃ ×V ₄	432.34	773.96	869.60	1457.11
LSD (0.05)	21.20	15.90	22.35	Ns
CV (a)%	3.18	1.62	2.36	1.60
CV (b)%	2.34	1.09	1.19	3.94

Table 3.1.12. Interaction effect of varieties and nitrogen on TDM at different days after sowing of wheat during 2017-18

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	At harvest
N ₀ ×V ₁	276.00	475.20	839.22	939.22
N ₁ ×V ₁	320.00	972.00	1117.80	1217.80
N ₂ ×V ₁	330.00	1032.00	1367.37	1279.23
N ₃ ×V ₁	347.80	1092.00	1587.63	1675.63
N ₄ ×V ₁	370.00	1092.50	1522.64	1540.31
N ₀ ×V ₂	344.24	580.00	937.50	960.16
N ₁ ×V ₂	352.32	1056.00	1095.10	1095.10
N ₂ ×V ₂	386.00	1120.00	1274.70	1344.70
N ₃ ×V ₂	516.00	1112.00	1509.83	1676.50
N ₄ ×V ₂	492.00	1092.00	1442.47	1649.84
N ₀ ×V ₃	330.12	616.00	1022.89	989.56
N ₁ ×V ₃	352.00	1092.00	1209.60	1142.93
N ₂ ×V ₃	403.32	1164.00	1479.60	1467.20
N ₃ ×V ₃	428.00	1348.00	1498.60	1632.93
N ₄ ×V ₃	452.00	1272.00	1449.45	1666.40
LSD (0.05)	ns	45.25	74.96	96.17
CV (a)%	3.42	2.39	2.54	1.99
CV (b)%	7.67	2.66	3.45	4.22

N₀ = 0 kg N ha⁻¹, N₁ = 60 kg N ha⁻¹, N₂ = 100 kg N ha⁻¹, N₃ = 120 kg N ha⁻¹ and N₄ = 140 kg N ha⁻¹ and V₁= BARI Gom 26, V₂= BARI Gom 28, V₃= BARI Gom 30

3.1.3.2 Physiological traits of wheat

3.1.3.2.1 SPAD value

Rapid determination of non-destructive chlorophyll contents has widely used for nutrition diagnosis of diverse crops by the Chlorophyll meter (SPAD-502). only 6 mm² area is measured by the SPAD-502 and it has to work a large-scale of periodical repeated estimation before a authentic result can be acquired. However, SPAD reading depends on the plant growth stages, crops, nitrogen and varieties (Wang *et al.*, 2013).

Effect of wheat varieties on SPAD value

The SPAD value of different wheat varieties at different growth stage significantly differs at different days after sowing (DAS) except 50 DAS during 2016-17 is shown in Appendix 3.1.11, Figure 3.1.21 for 2016-17 and Appendix 3.1.12, Figure 3.1.22 for 2017-18, respectively. SPAD value increased gradually up to 50 DAS, then increased up to 75 DAS and decreased with the advancement of growing period of all the varieties for both the years. Regardless of variety differences, SPAD value increased progressively up to 75 DAS. At 25 DAS maximum SPAD (37.41) was observed in BARI Gom 29 which was statistically identical with BARI Gom 26 and minimum SPAD value (34.26) was obtained in BARI Gom 30 which was also statistically similar with BARI Gom 28 during 2016-17. The maximum SPAD value (53.62) was found in BARI Gom 26 which was significantly differ from other wheat varieties and minimum SPAD value (48.59) was found in BARI gom 28 during 2017-18. At 50 DAS, highest SPAD value (45.83) was found in BARI Gom 28 which was not significantly varies from other varieties and lowest SPAD value (42.75) was observed in BARI Gom 26 during 2016-17. Highest SPAD (58.39) was found in BARI Gom 28 which was statistically identical with BARI Gom 30 and lowest SPAD value (51.83) was found from BARI Gom 28 during 2017-18. At 75 DAS, maximum SPAD value (46.60) was found in BARI Gom 26 which was identical with BARI Gom 29 and BARI Gom 30 and minimum SPAD value (41.40) which was observed in BARI Gom 28 during 2016-17. Highest SPAD value (62.60) was found in BARI Gom 26 which was statistically similar with BARI Gom 30 and lowest SPAD value (58.20) was found from BARI Gom 28 during 2017-18. At 100 DAS stage, highest SPAD value (41.58) was obtained in BARI Gom 26 which was statistically identical with BARI Gom 29 and BARI Gom 30 and lowest

SPAD value (38.00) was found from BARI Gom 28 during 2016-17. Maximum SPAD value (39.70) was obtained in BARI Gom 26 which was statistically identical with BARI Gom 30 and minimum SPAD value (34.50) was found from BARI Gom 28 during 2017-18.

Effect of nitrogen on SPAD value

Effect of N levels revealed that a highly significant variation on SPAD for all growth stages (Figure 3.1.23 & Appendix 3.1.11 for 2016-17 and Figure 3.1.24 & Appendix 3.1.12 for 2017-18). Irrespective of treatment differences, SPAD value increased rapidly up to 75 DAS after that it was slowly decreased. At 25 DAS, maximum SPAD value (41.50) was observed with N₃ treatment (150 kg N ha⁻¹) which was significantly differ with other level on N doses. Minimum SPAD value (29.00) was found with N₀ treatment (0.0 kg N ha⁻¹) during 2016-17. Highest SPAD value (60.80) was obtained with N₄ treatment (140.0 kg N ha⁻¹) which was significantly differ from other N level and lowest SPAD value (40.00) was found with control (0.0 kg N ha⁻¹) during 2017-18. At 50 DAS, highest SPAD value (50.00) was found with N₃ (150 kg N ha⁻¹) which was statically identical with N₂ (100 kg N ha⁻¹) and lowest SPAD value (32.40) was attained with control (0.0 kg N ha⁻¹) during 2016-17. The maximum SPAD value (68.30) was found with N₄ (140 kg N ha⁻¹) which was statistically differ with N₃ (120 kg N ha⁻¹) and N₂ (100 kg N ha⁻¹) and lowest SPAD value (39.47) was attained with N₀ (0.0 kg N ha⁻¹) observed during 2017-18. At 75 DAS, maximum SPAD value (50.00) was obtained with N₃ (150 kg N ha⁻¹) which was statistically at par with N₂ (100 kg N ha⁻¹) and minimum SPAD value (39.76) was found with N₀ (0 kg N ha⁻¹) during 2016-17. Maximum SPAD value (71.00) was obtained with N₄ (140 kg Na⁻¹) which was significantly differ with N₃ (120 kg N ha⁻¹) and minimum SPAD value (49.58) was found with N₀ (0 kg N ha⁻¹) during 2017-18. At 100 DAS, maximum SPAD value (45.70) was obtained with N₂ (100 kg N ha⁻¹) which was statistically similar with N₃ (150 kg N ha⁻¹) and minimum SPAD value (31.50) with N₀ (0.0 kg N ha⁻¹) during 2016-17 and the maximum SPAD value (48.40) was obtained with N₄ (140 kg N ha⁻¹) which was significantly identical with N₃ (120 kg N ha⁻¹) and minimum SPAD value (29.10) was found with control (0 kg N ha⁻¹) during 2017-18.

The chlorophyll meter reading (SPAD) at different DAS of wheat were showed an increasing trend with the increase of N dose. Irrespective of fertilizer management options, the SPAD

values showed an increasing trend with the advance of plant growth. The SPAD values varied from 28.56-50.00 during 2016-17 and 31.50-71.00 during 2017-18 among different fertilizer treatments. SPAD chlorophyll meter reading gave the best indicator of photosynthetic activity as found by Sarkar *et al.* (1998), which may offer sufficient photosynthesis, growth and development of wheat. Moreover, the increased SPAD chlorophyll meter reading may also be correlated with the increase in wheat yield (Sarkar *et al.*, 1998).

Interaction effect of wheat varieties and nitrogen on SPAD

The combined effect of varieties and nitrogen levels on SPAD value was statistically significant for all the growth stage during both years, respectively (Table 3.1.13 and appendix 3.1.11 for 2016-17; Table 3.1.14 and appendix 3.1.12 for 2017-18). At 25 DAS, the maximum SPAD value (45.58) was recorded by the interaction of N_3V_2 (150 kg N ha⁻¹ and BARI Gom 28) which was statistically similar with N_2V_3 (100 kg N ha⁻¹ and BARI Gom 29), N_3V_3 (150 kg N ha⁻¹ and BARI Gom 29) and minimum SPAD value (25.30) was found from treatment combination of N_0V_4 (0.0 kg N ha⁻¹ and BARI Gom 30) during 2016-17. The maximum SPAD value (65.10) was found with treatment combination N_4V_3 (140 kg N ha⁻¹ and BARI Gom 30) which was statistically similar with N_4V_1 (140 kg N ha⁻¹ and BARI Gom 26) and minimum SPAD value (37.87) was found from treatment combination of N_0V_3 (0.0 kg N ha⁻¹ and BARI Gom 30) during 2017-18. At 50 DAS, highest SPAD value (51.53) was resulted by the interaction of N_3V_3 (150 kg N ha⁻¹ and BARI Gom 29) which was statistically identical with N_3V_1 (49.78), N_3V_1 (49.23), N_2V_1 (49.13), N_2V_4 (48.03) and N_3V_4 (48.03) where the lowest SPAD value (29.65) was observed from the treatment combination of N_0V_1 (0.0 kg N ha⁻¹ and BARI Gom 26) during 2016-17. The highest SPAD value (67.63) was found from the treatment interaction of N_4V_3 (140 kg N ha⁻¹ and BARI Gom 30) which was statistically significant with other treatment combinations where the lowest SPAD value (45.77) was observed from the treatment combination of N_0V_1 (0.0 kg N ha⁻¹ and BARI Gom 26) during 2017-18. At 75 DAS, interaction effects of wheat varieties and nitrogen levels for SPAD value maximum (52.23) was found from treatment interaction of N_3V_3 (150 kg N ha⁻¹ and BARI Gom 29) which was statistically identical with N_2V_4 (51.93), N_3V_1 (51.58), N_3V_2 (51.38) where the lowest SPAD value (38.05) was observed from the treatment combination of N_0V_2 (0.0 kg N ha⁻¹ and BARI Gom 28) during

2016-17 and maximum SPAD value (74.70) was observed from treatment interaction of N_4V_3 (140 kg N ha⁻¹ and BARI Gom 30) which was statistically identical with treatment combination of N_4V_1 (73.50) and N_4V_2 (71.10) where the lowest SPAD value (45.67) was observed from the treatment combination of N_0V_3 (0.0 kg N ha⁻¹ and BARI Gom 30) during 2017-18 . At 100 DAS, the highest SPAD value (46.58) was recorded by the interaction of N_2V_1 (100 kg N ha⁻¹ and BARI Gom 26) which was statistically alike with the treatment combination of N_3V_3 (45.28), $N_3 \times V_3$ (45.28), $N_2 \times V_3$ (44.53), $N_2 \times V_4$ (44.53) and $N_3 \times V_1$, (44.03) and the lowest SPAD value (26.00) was observed from the treatment combination of N_0V_2 (0.0 kg N ha⁻¹ and BARI Gom 28) during 2016-17. The maximum SPAD value (47.77) was found with treatment combination N_4V_3 (140 kg N ha⁻¹ and BARI Gom 30) which was followed by treatment combination N_4V_1 (140 kg N ha⁻¹ and BARI Gom 26) where, the lowest SPAD value (26.30) was observed from the treatment combination of N_0V_3 (0.0 kg N ha⁻¹ and BARI Gom 30) during 2017-18.

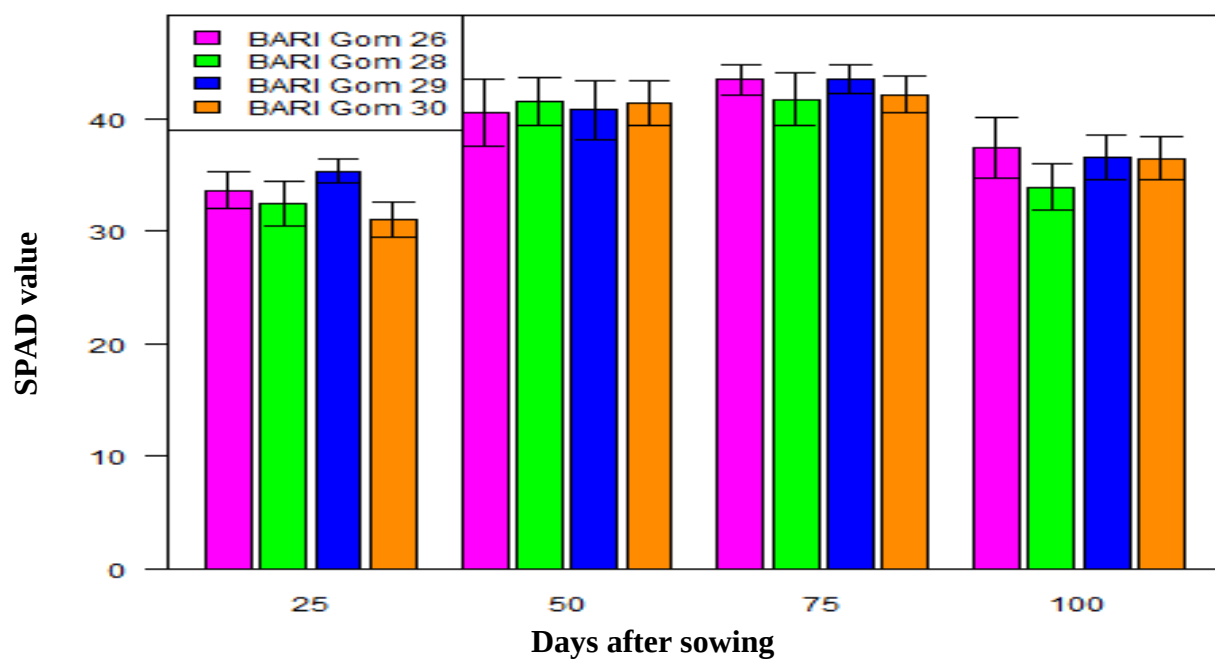


Figure 3.1.21: Effect of wheat varieties on SPAD at different days after sowing (2016-17).

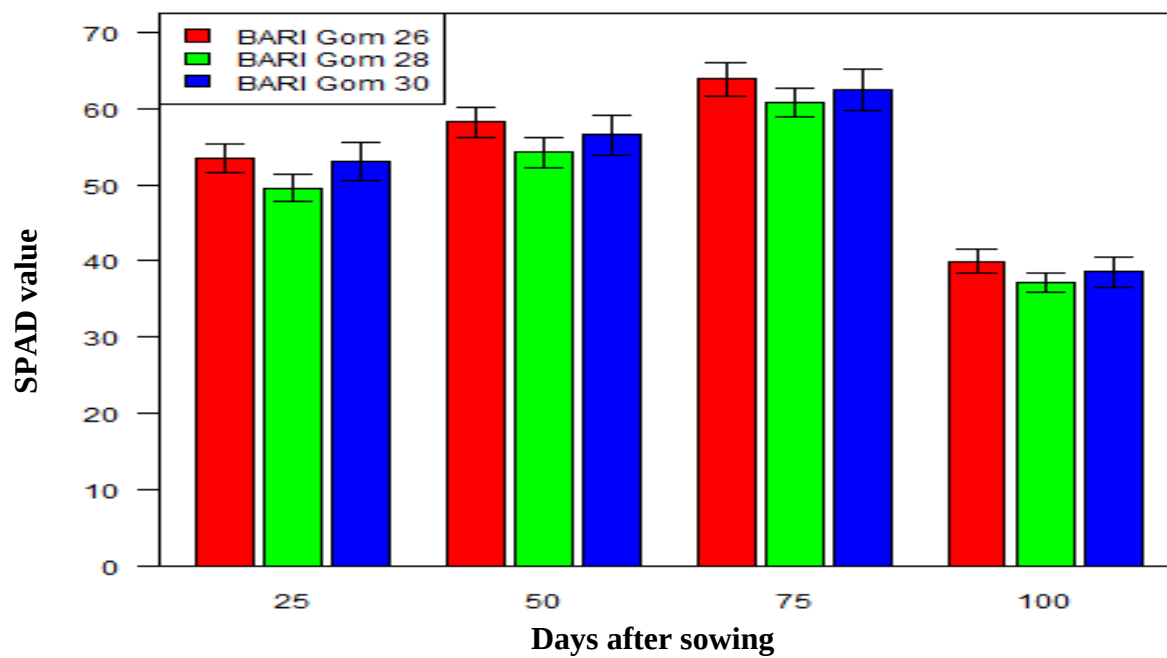


Figure 3.1.22: Effect of wheat variety on SPAD at different days after sowing (2017-18).

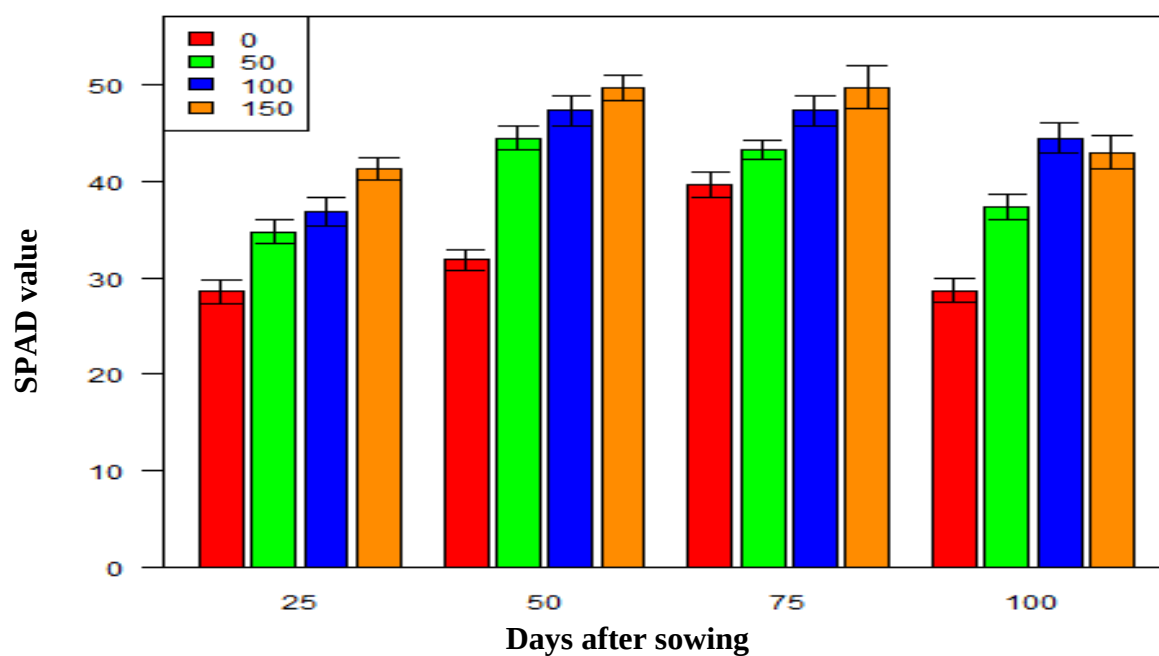


Figure 3.1.23: Effect of nitrogen on SPAD at different days after sowing (2016-17).

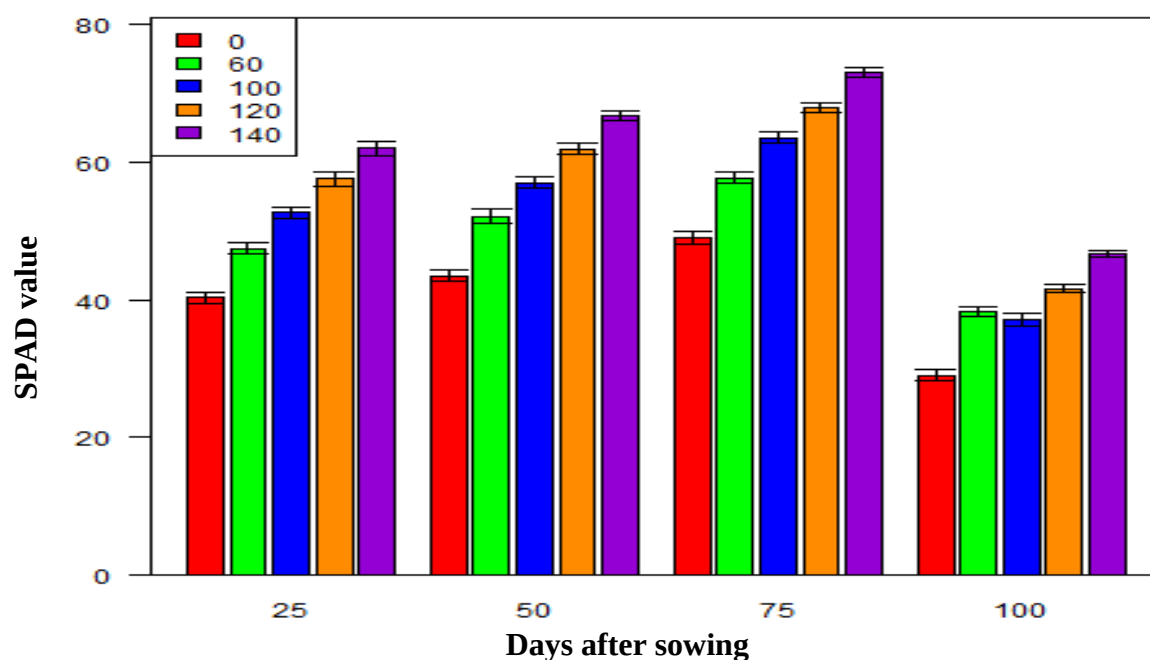


Figure 3.1.24: Effect of nitrogen on SPAD at different days after sowing (2017-18).

Table 3.1.13. Interaction effect of varieties and nitrogen levels on SPAD at different days after sowing of wheat during 2016-17

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	28.05	29.65	40.95	26.10
N ₁ ×V ₁	38.60	42.45	43.25	41.80
N ₂ ×V ₁	38.38	49.13	46.98	46.58
N ₃ ×V ₁	38.53	49.78	51.58	44.03
N ₀ ×V ₂	29.60	32.65	38.05	26.00
N ₁ ×V ₂	30.80	45.75	43.80	35.95
N ₂ ×V ₂	32.93	47.38	42.68	42.13
N ₃ ×V ₂	45.58	49.23	51.38	40.63
N ₀ ×V ₃	31.30	31.35	39.25	29.45
N ₁ ×V ₃	35.10	44.75	43.90	36.00
N ₂ ×V ₃	42.08	44.48	47.48	44.53
N ₃ ×V ₃	41.88	51.53	52.23	45.28
N ₀ ×V ₄	25.30	33.65	40.40	33.05
N ₁ ×V ₄	34.50	44.80	41.75	35.35
N ₂ ×V ₄	33.83	48.03	51.93	44.53
N ₃ ×V ₄	39.28	48.03	43.53	41.98
LSD (0.05)	4.45	4.56	4.52	5.51
CV (a)%	5.15	11.58	15.83	7.88
CV (b)%	5.78	9.66	9.23	13.19

Table 3.1.14. Interaction effect of varieties and nitrogen levels on SPAD at different days after sowing of wheat during 2017-18

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	42.40	45.77	50.37	29.73
N ₁ ×V ₁	49.87	55.13	60.33	40.77
N ₂ ×V ₁	54.20	58.57	65.30	39.17
N ₃ ×V ₁	58.50	63.13	69.43	43.00
N ₄ ×V ₁	62.63	68.17	73.50	47.17
N ₀ ×V ₂	40.67	44.03	51.33	31.10
N ₁ ×V ₂	44.77	49.13	55.10	36.27
N ₂ ×V ₂	49.60	54.07	60.57	33.87
N ₃ ×V ₂	54.20	59.37	65.60	39.40
N ₄ ×V ₂	58.43	64.37	71.10	45.20
N ₀ ×V ₃	37.87	40.77	45.67	26.30
N ₁ ×V ₃	47.77	52.10	57.87	37.77
N ₂ ×V ₃	54.30	58.47	64.97	38.53
N ₃ ×V ₃	59.97	63.43	68.83	42.40
N ₄ ×V ₃	65.10	67.63	74.70	47.77
LSD (0.05)	2.25	2.30	2.12	1.98
CV (a)%	1.90	2.22	1.46	2.45
CV (b)%	2.57	2.42	2.02	3.05

N₀ = 0 kg N ha⁻¹, N₁ = 60 kg N ha⁻¹, N₂ = 100 kg N ha⁻¹, N₃ = 120 kg N ha⁻¹ and N₄ = 140 kg N ha⁻¹ and V₁= BARI Gom 26, V₂= BARI Gom 28, V₃= BARI Gom 30

3.1.3.2.2 Leaf Chlorophyll a (Chl a) content (mg g⁻¹)

Chlorophyll a and b are the most important pigments active in the photosynthetic process. Leaf chl. is a key indicator of leaf greenness, and it is often used to investigate leaf nutrient deficiencies and changes in chlorophyll (Ali *et al.*, 2017). Canopy chlorophyll content is also an indicator of seasonal carbon uptake (Croft *et al.*, 2015). Chlorophyll content is positively influenced by fertilizer application, especially nitrogen (Hokmalipour and Darbandi, 2011). Quantifying leaf pigmentation using this noninvasive optical method is fast and easy, and produces reliable estimates of relative leaf chlorophyll when compared to traditional and chemical methods (Richardson *et al.*, 2002). Chl. is not only used as a substitute for leaf nitrogen content, but also as an essential indicator of N-deficiency in agriculture (Cеровic *et al.*, 2012).

Effect of wheat varieties on Chl a content (mg g⁻¹)

The Chl a content of different wheat varieties at different growth stages significantly differs at different days after sowing (DAS) is shown in Appendix 3.1.13, Figure 3.1.25 for 2016-17 and Appendix 3.1.14, Figure 3.1.26 for 2017-18, respectively. Chl a content increased gradually up to 50 DAS and decreased with the advancement of growing period of all the varieties for both the years. Irrespective of variety differences, Chl a content increased progressively up to 50 DAS. At 25 DAS maximum Chl a content (0.40) was observed in BARI Gom 30 and BARI Gom 28, and the minimum Chl a content (0.37) was obtained in BARI Gom 26 during 2016-17. Maximum Chl a content (0.47) was found in BARI Gom 26 which was statistically identical with BARI Gom 30 and minimum Chl a content (0.44) was found in BARI gom 28 during 2017-18. At 50 DAS, highest Chl a content (0.49) was found in BARI Gom 28 which was non-significantly varies from other wheat varieties and lowest Chl a content (0.47) was observed in BARI Gom 30 during 2016-17. Highest leaf Chl a content (0.53) was found in BARI Gom 28 which was identical with BARI Gom 30 and lowest Chl a content (0.50) was found from BARI Gom 26 during 2017-18. At 75 DAS, maximum Chl a content (0.57) was found in BARI Gom 26 which was statistically insignificant with other varieties and minimum Chl a content (0.56) which was observed in BARI Gom 30 during 2016-17. Highest Chl a content (0.56) was found in BARI Gom 30 and lowest Chl a content (0.54) was found from BARI Gom 28 during 2017-18. At 100 DAS stage, highest Chl a content (0.45) was obtained in BARI Gom 29 which was

statistically insignificant with other varieties of wheat and lowest Chl a content (0.37) was in BARI Gom 28 during 2016-17. Maximum Chl a content (0.51) was obtained in BARI Gom 28 and minimum (0.47) from BARI Gom 30 during 2017-18. The variability of Chl a found from 0.28 to 0.70 mg g⁻¹ for tested wheat varieties were similar to that of the findings reported by Saitanis *et al.*, (2014) Who reported that Chl a varied 0.25 - 0.80 mg g⁻¹ based on different cultivars.

Effect of nitrogen chlorophyll a (Chl a) content (mg g⁻¹)

Effect of N levels revealed that a highly significant variation on Chl a content for all growth stages (Figure 3.1.25 & Appendix 3.1.13 for 2016-17 and Figure 3.1.26 & Appendix 3.1.14 for 2017-18). Irrespective of treatment differences, Chl a content increased rapidly up to 75 DAS after that it was slowly decreased. At 25 DAS, maximum Chl a content (0.48) was observed with N₃ treatment (150 kg N ha⁻¹) which was significantly differed with other level on N doses. Minimum Chl a content (0.31) was found with N₀ treatment (0.0 kg N ha⁻¹) during 2016-17. Highest Chl a content (0.55) was obtained with N₄ treatment (140.0 kg N ha⁻¹) which was significantly differed from other N level and lowest Chl a content (0.36) was found with control (0.0 kg N ha⁻¹) during 2017-18. At 50 DAS, highest Chl a content (0.58) was found with N₄ (150 kg N ha⁻¹) which was significantly varied from others N level and lowest Chl a content (0.44) was attained with control (0.0 kg N ha⁻¹) during 2016-17. The maximum Chl a content (0.63) was found with N₄ (140 kg N ha⁻¹) which was significantly varied from other N level and lowest Chl a content (0.37) was attained with treatment N₀ (0.0 kg N ha⁻¹) observed during 2017-18. At 75 DAS, maximum Chl a content (0.62) was obtained with N₃ (150 kg N ha⁻¹) which was statistically at par with N₂ (100 kg N ha⁻¹) and minimum Chl a content (0.52) was found with N₀ (0 kg N ha⁻¹) during 2016-17. Maximum Chl a content (0.63) was obtained with N₄ (140 kg N ha⁻¹) which was significantly varied from others N level and minimum Chl a content (0.42) was found with N₀ (0.0 kg N ha⁻¹) during 2017-18. At 100 DAS, maximum Chl a content (0.52) was obtained with N₄ (150 kg N ha⁻¹) which was identical with N₃ (100 kg N ha⁻¹) and minimum (0.0.38) with N₀ (0.0 kg N ha⁻¹) during 2016-17 and the maximum Chl a content (0.53) was obtained with N₄ (140 kg N ha⁻¹) which was significantly identical with N₃ (120 kg N ha⁻¹) and minimum Chl a content (0.44) was found with control (0 kg N ha⁻¹) during 2017-18. The

variability of Chl a found from 0.28 to 0.70 mg g⁻¹ for tested wheat varieties were similar to that of the findings reported by Saitanis *et al.*, (2014). Who reported that Chl a varied 0.25 - 0.80 mg g⁻¹ based on cultivars.

Interaction effect of wheat varieties and nitrogen on Chl a content (mg g⁻¹)

The interaction effect of varieties and nitrogen levels on Chl a content was statistically significant except 75 DAS during 2017-18 (Table 3.1.15 and appendix 3.1.13 for 2016-17) and 25 DAS & 75 DAS during 2017-18 (Table 3.1.16 and appendix 3.1.14 for 2017-18). At 25 DAS, the maximum Chl a content (0.49) was recorded by the interaction of N₃V₂ (150 kg N ha⁻¹ and BARI Gom 28) which was statistically similar with N₂V₂ (100 kg N ha⁻¹ and BARI Gom 28), N₃V₂ (150 kg N ha⁻¹ and BARI Gom 28), N₃V₄ (150 kg N ha⁻¹ and BARI Gom 30), N₃V₁ (150 kg N ha⁻¹ and BARI Gom 26) and minimum (0.29) N₀V₁ (0.0 kg N ha⁻¹ and BARI Gom 26) during 2016-17. The maximum Chl a content (0.57) was found with treatment combination N₄V₂ (140 kg N ha⁻¹ and BARI Gom 28) and minimum (0.32) N₀V₁ (0.0 kg N ha⁻¹ and BARI Gom 26) during 2017-18. At 50 DAS, highest Chl a content (0.57) was resulted by the interaction of N₃V₂ (150 kg N ha⁻¹ and BARI Gom 28) which was statistically identical with N₃V₁ (0.56), N₃V₄ (0.56) and N₃V₃ (0.55) where the lowest Chl a content (0.43) was observed from the treatment combination of N₀V₄ (0.0 kg N ha⁻¹ and BARI Gom 30) during 2016-17. The highest Chl a content (0.65) was found from the treatment interaction of N₄V₂ (140 kg N ha⁻¹ and BARI Gom 28) which was statistically significant with other treatment combinations where the lowest Chl a content (0.36) was observed from the treatment combination of N₀V₃ (0.0 kg N ha⁻¹ and BARI Gom 29) during 2017-18. At 75 DAS, the maximum Chl a content (0.57) was recorded by the interaction of N₃V₁ (150 kg N ha⁻¹ and BARI Gom 26) which was statistically similar with N₃V₂ (150 kg N ha⁻¹ and BARI Gom 28) and N₃V₃ (150 kg N ha⁻¹ and BARI Gom 29) and minimum (0.45) from treatment combination N₀V₁ (0.0 kg N ha⁻¹ and BARI Gom 26) and N₀V₁ (0.0 kg N ha⁻¹ and BARI Gom 29) during 2016-17. The maximum Chl a content (0.67) was found with treatment combination N₄V₃ (140 kg N ha⁻¹ and BARI Gom 30) which was statistically similar with N₄V₃ (140 kg N ha⁻¹ and BARI Gom 29) and N₄V₁ (140 kg N ha⁻¹ and BARI Gom 29) and minimum (0.41) N₀V₃ (0.0 kg N ha⁻¹ and BARI Gom 30) during 2017-18. At 100 DAS, the highest Chl a content (0.54) was recorded by the interaction of N₃V₄ (150 kg

N ha⁻¹ and BARI Gom 30) which was statistically insignificant with other treatment combinations and the lowest Chl a content (0.31) was observed from the treatment combination of N₀V₂ (0.0 kg N ha⁻¹ and BARI Gom 28) during 2016-17. The maximum Chl a content (0.65) was found with treatment combination N₃V₃ (120 kg N ha⁻¹ and BARI Gom 30) which was followed by treatment combination N₂V₂ (100 kg N ha⁻¹ and BARI Gom 28), N₃V₂ (120 kg N ha⁻¹ and BARI Gom 28), N₄V₃ (140 kg N ha⁻¹ and BARI Gom 30) and N₄V₁ (140 kg N ha⁻¹ and BARI Gom 26) during 2017-18. The lowest Chl a content (0.43) was observed from the treatment combination of N₀V₃ (0.0 kg N ha⁻¹ and BARI Gom 30) during 2017-18.

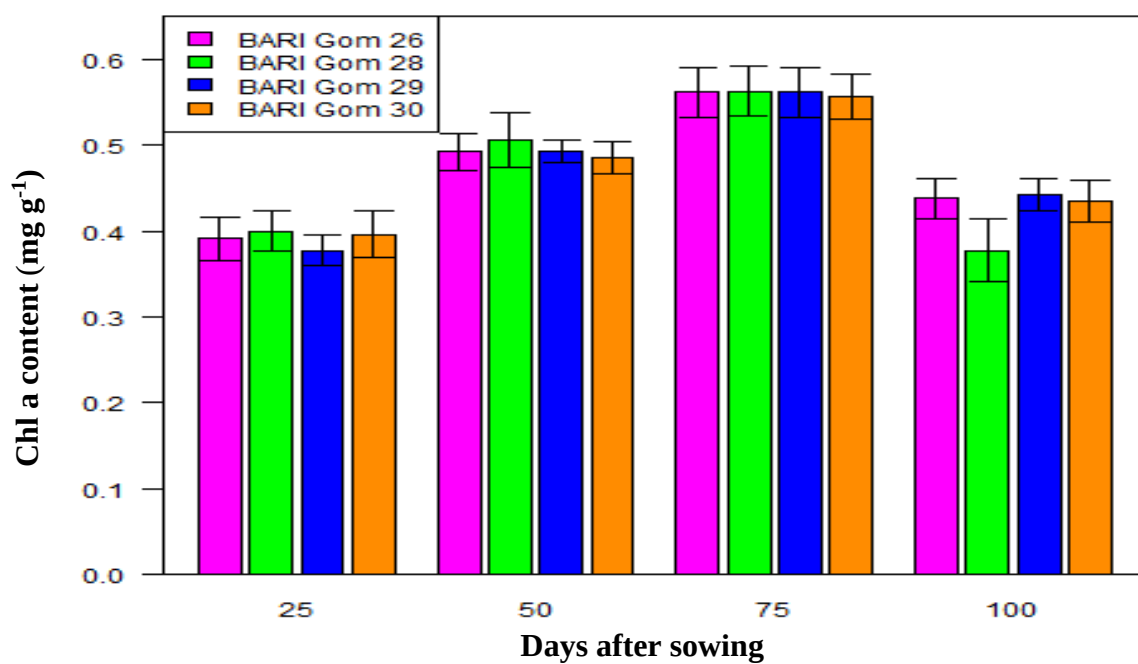


Figure 3.1.25: Effect of wheat varieties on Chl a content at different days after sowing (2016-17).

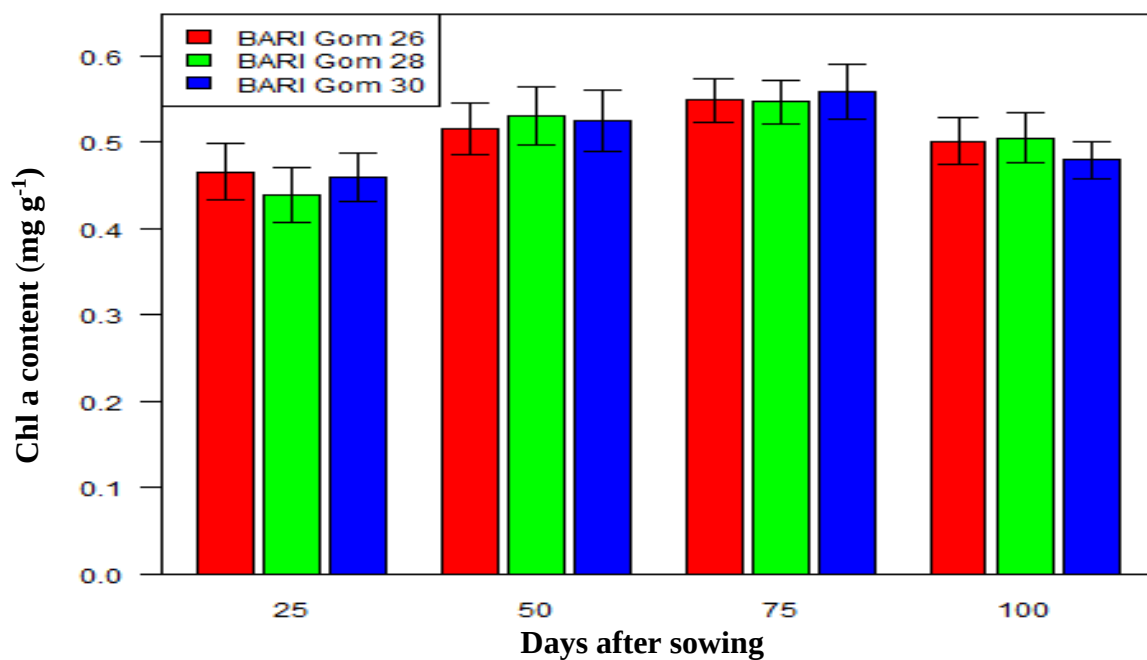


Figure 3.1.26: Effect of wheat variety on Chl a content at different days after sowing (2017-18).

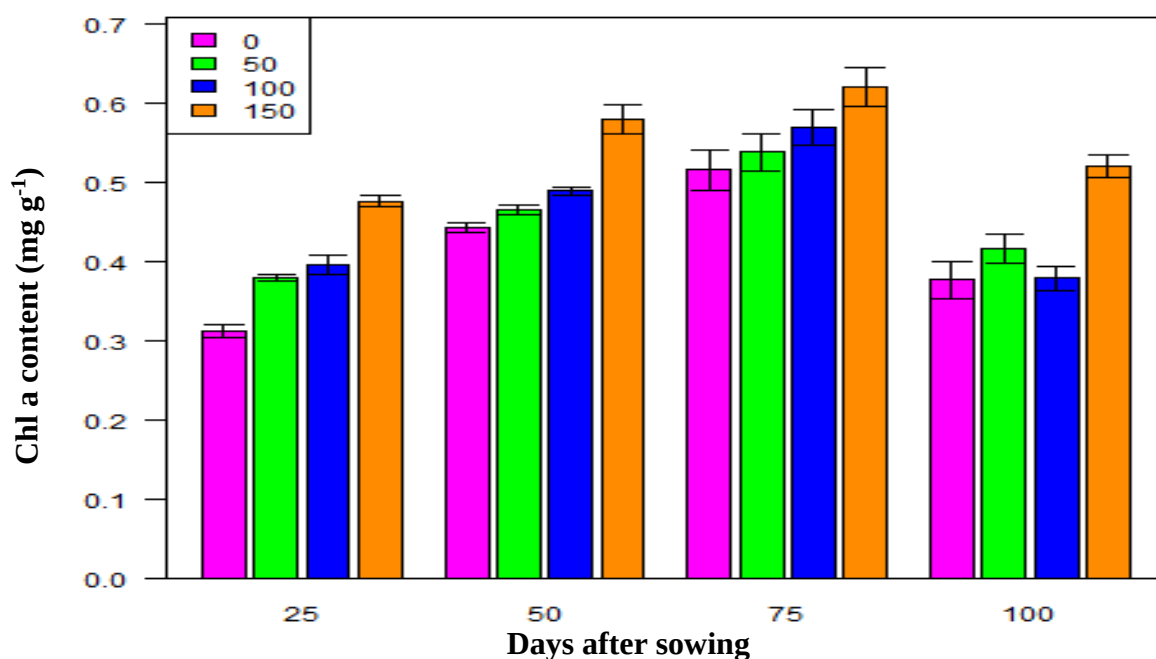


Figure 3.1.27: Effect of nitrogen on Chl a content at different days after sowing (2016-17).

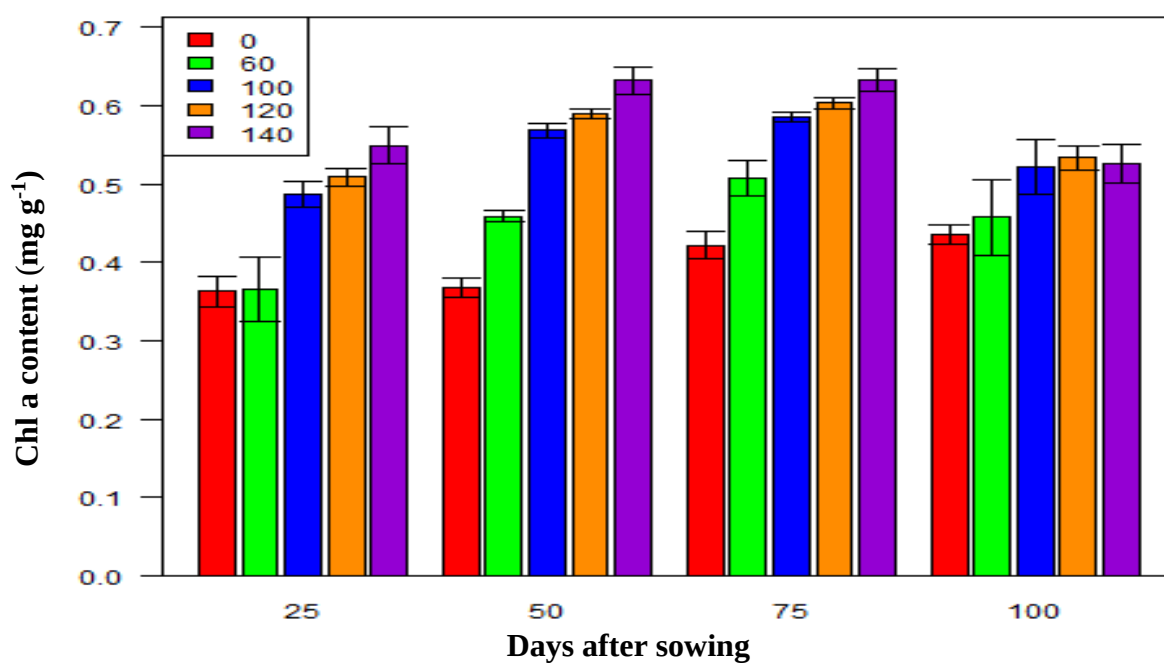


Figure 3.1.28: Effect of nitrogen on Chl a content at different days after sowing (2017-18).

Table 3.1.15. Interaction effect of varieties and nitrogen levels on Chl a content at different days after sowing of wheat during 2016-17

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	0.29	0.45	0.45	0.38
N ₁ ×V ₁	0.39	0.46	0.48	0.44
N ₂ ×V ₁	0.42	0.48	0.51	0.37
N ₃ ×V ₁	0.48	0.56	0.57	0.51
N ₀ ×V ₂	0.32	0.45	0.47	0.31
N ₁ ×V ₂	0.39	0.46	0.47	0.33
N ₂ ×V ₂	0.41	0.49	0.50	0.34
N ₃ ×V ₂	0.49	0.57	0.57	0.47
N ₀ ×V ₃	0.34	0.46	0.45	0.38
N ₁ ×V ₃	0.39	0.46	0.48	0.45
N ₂ ×V ₃	0.34	0.49	0.52	0.44
N ₃ ×V ₃	0.45	0.55	0.56	0.51
N ₀ ×V ₄	0.31	0.43	0.46	0.39
N ₁ ×V ₄	0.37	0.47	0.48	0.45
N ₂ ×V ₄	0.43	0.50	0.51	0.37
N ₃ ×V ₄	0.49	0.56	0.54	0.54
LSD (0.05)	0.02	0.02	0.01	0.04
CV (a)%	3.94	1.61	1.89	2.95
CV (b)%	2.93	2.99	1.70	4.00

Table 3.1.16. Interaction effect of varieties and nitrogen levels on Chl a content at different days after sowing of wheat during 2017-18

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	0.32	0.36	0.42	0.43
N ₁ ×V ₁	0.42	0.46	0.52	0.47
N ₂ ×V ₁	0.48	0.58	0.59	0.60
N ₃ ×V ₁	0.62	0.58	0.59	0.54
N ₄ ×V ₁	0.56	0.60	0.62	0.46
N ₀ ×V ₂	0.35	0.37	0.43	0.44
N ₁ ×V ₂	0.33	0.47	0.50	0.44
N ₂ ×V ₂	0.46	0.57	0.59	0.53
N ₃ ×V ₂	0.49	0.60	0.61	0.53
N ₄ ×V ₂	0.57	0.65	0.61	0.58
N ₀ ×V ₃	0.38	0.36	0.41	0.43
N ₁ ×V ₃	0.35	0.45	0.51	0.46
N ₂ ×V ₃	0.53	0.56	0.59	0.44
N ₃ ×V ₃	0.53	0.60	0.61	0.53
N ₄ ×V ₃	0.51	0.65	0.67	0.54
LSD (0.05)	0.09	0.04	0.06	0.40
CV (a)%	15.63	3.94	4.23	8.17
CV (b)%	14.98	5.40	8.69	17.20

N₀ = 0 kg N ha⁻¹, N₁ = 60 kg N ha⁻¹, N₂ = 100 kg N ha⁻¹, N₃ = 120 kg N ha⁻¹ and N₄ = 140 kg N ha⁻¹ and V₁= BARI Gom 26, V₂= BARI Gom 28, V₃= BARI Gom 3

3.1.3.2.3 Leaf Chlorophyll b (Chl b) content (mg g⁻¹)

Effect of wheat varieties on Chl b content (mg g⁻¹)

The Chl b content of different wheat varieties at different growth stages highly significantly differs at different days after sowing (DAS) is shown in Appendix 3.1.15, Figure 3.1.27 for 2016-17 and Appendix 3.1.16, Figure 3.1.28 for 2017-18, respectively. Chl b content increased gradually up to 50 DAS, then increased up to 75 DAS and decreased with the advancement of growing period of all the varieties for both the years. Regardless of variety differences, Chl b content increased progressively up to 75 DAS. At 25 DAS maximum Chl b content (0.42) was observed in BARI Gom 29 which was statistically identical with BARI Gom 28 and minimum Chl b content (0.35) was obtained in BARI Gom 30 which was also statistically similar with BARI Gom 26 during 2016-17. Maximum Chl b content (0.57) was found in BARI Gom 28 which was significantly differ from other wheat varieties and minimum Chl b content (0.44) was found in BARI gom 26 during 2017-18. At 50 DAS, highest Chl b content (0.68) was found in BARI Gom 29 which was non-significantly varies from other varieties and lowest Chl b content (0.66) was observed in BARI Gom 26 during 2016-17. Highest Chl b content (0.78) was found in BARI Gom 28 which was significantly higher than the other variety and lowest Chl b content (.69) was found from BARI Gom 26 which was identical with BARI Gom 30 during 2017-18. At 75 DAS, maximum Chl b content (0.76) was found in BARI Gom 26 which was statistically insignificant with other varieties and minimum Chl b content (0.74) which was observed in BARI Gom 30 during 2016-17. Highest Chl b content (0.72) was found in BARI Gom 28 and lowest Chl b content (0.66) was found from BARI Gom 30 followed BARI Gom 28 by during 2017-18. At 100 DAS stage, highest Chl b content (0.61) was obtained in BARI Gom 28 which was statistically insignificant with other varieties of wheat and lowest Chl b content (0.59) was in BARI Gom 26 during 2016-17. Maximum Chl b content value (0.65) was obtained in BARI Gom 29 which was statistically identical with BARI Gom 26 and BARI Gom 30 during 2016-17.

Effect of nitrogen on Chl b content (mg g⁻¹)

Effect of N levels revealed that a highly significant variation on CHL B CONTENT for all growth stages (Appendix 3.1.15, Figure 3.1.29 for 2016-17 and Appendix 3.1.16, Figure 3.1.30 for 2017-18). Irrespective of treatment differences, Chl b content increased rapidly up to 50 DAS after that it was slowly decreased. At 25 DAS maximum Chl b content (0.49) was observed with N₃ treatment (150 kg N ha⁻¹) which was significantly differ with other level on N doses. Minimum Chl b content (0.32) was found with N₀ treatment (0.0 kg N ha⁻¹) during 2016-17. Highest Chl b content (0.61) was obtained with N₄ treatment (140.0 kg N ha⁻¹) which was significantly differ from other N level and lowest Chl b content (0.38) was found with control (0.0 kg N ha⁻¹) during 2017-18. At 50 DAS, highest Chl b content (0.8) was found with N₃ (150 kg N ha⁻¹) which was statically identical with N₂ (100 kg N ha⁻¹) and lowest Chl b content (.049) was attained with control (0.0 kg N ha⁻¹) during 2016-17. The maximum Chl b content (0.85) was found with N₄ (140 kg N ha⁻¹) which was statistically differ with N₂ (100 kg N ha⁻¹) and N₃ (120 kg N ha⁻¹) and lowest Chl b content (0.52) was attained with N₀ (0.0 kg N ha⁻¹) observed during 2017-18. At 75 DAS, maximum Chl b content (0.82) was obtained with N₃ (150 kg N ha⁻¹) which was statistically at par with N₂ (100 kg N ha⁻¹) and minimum Chl b content (0.65) was found with N₀ (0 kg N ha⁻¹) during 2016-17. Maximum Chl b content (0.91) was obtained with N₄ (140 kg Na⁻¹) which was significantly differ with N₃ (120 kg N ha⁻¹) and minimum Chl b content (0.72) was found with N₀ (0 kg N ha⁻¹) during 2017-18. At 100 DAS, maximum Chl b content (0.71) was obtained with N₄ (150 kg N ha⁻¹) which was identical with N₃ (100 kg N ha⁻¹) and minimum (0.0.48) with N₀ (0.0 kg N ha⁻¹) during 2016-17 and the maximum Chl b content (0.78) was obtained with N₄ (140 kg N ha⁻¹) which was significantly identical with N₃ (120 kg N ha⁻¹) and minimum Chl b content (0.48) was found with control (0 kg N ha⁻¹) during 2017-18.

Interaction effect of wheat varieties and nitrogen on Chl b content (mg g⁻¹)

The interaction effect of varieties and nitrogen levels on Chl b content was statistically significant except 75 DAS during 2017-18 (Table 3.1.17 and appendix 3.1.15 for 2016-17) and 25 DAS & 75 DAS during 2017-18 (Table 3.1.18 and appendix 3.1.16 for 2017-18). At 25 DAS, the maximum Chl b content (0.52) was recorded by the interaction of N₃V₁ (150 kg N ha⁻¹ and BARI Gom 26) which was statistically similar with N₂V₂ (100 kg N ha⁻¹ and BARI Gom 28), N₃V₂ (150 kg N ha⁻¹ and BARI Gom 28), N₃V₃ (150 kg N ha⁻¹ and BARI Gom 29), N₂V₄ (100 kg N ha⁻¹ and BARI Gom 30), N₂V₃ (100 kg N ha⁻¹ and BARI Gom 28) during 2016-17. The maximum Chl b content (0.68) was found with treatment combination N₄V₂ (140 kg N ha⁻¹ and BARI Gom 28) and minimum (0.31) N₀V₁ (0.0 kg N ha⁻¹ and BARI Gom 26) during 2017-18. At 50 DAS, highest Chl b content (0.81) was resulted by the interaction of N₂V₄ (100 kg N ha⁻¹ and BARI Gom 30) which was statistically identical with N₂V₄ (0.80), N₃V₂ (0.80), N₃V₃ (0.79) N₃V₁ (0.79) and N₂V₁ (0.78) where the lowest Chl b content (0.45) was observed from the treatment combination of N₀V₁ (0.0 kg N ha⁻¹ and BARI Gom 26) during 2016-17. The highest Chl b content (0.99) was found from the treatment interaction of N₄V₂ (140 kg N ha⁻¹ and BARI Gom 28) which was statistically significant with other treatment combinations where the lowest Chl b content (0.50) was observed from the treatment combination of N₀V₁ (0.0 kg N ha⁻¹ and BARI Gom 26) during 2017-18. At 75 DAS, interaction effects of wheat varieties and nitrogen levels for Chl b content was found insignificant during both years. At 100 DAS, the highest Chl b content (0.68) was recorded by the interaction of N₃V₄ (150 kg N ha⁻¹ and BARI Gom 30) which was statistically insignificant with other treatment combinations during 2016-17. The maximum Chl b content (0.78) was found with treatment combination N₃V₃ (120 kg N ha⁻¹ and BARI Gom 30) which was followed by treatment combination N₄V₃ (140 kg N ha⁻¹ and BARI Gom 30), N₃V₂ (120 kg N ha⁻¹ and BARI Gom 28), N₄V₁ (140 kg N ha⁻¹ and BARI Gom 26) and N₄V₂ (140 kg N ha⁻¹ and BARI Gom 28) during 2017-18. The lowest Chl b content (0.58) was observed from the treatment combination of N₀V₃ (0.0 kg N ha⁻¹ and BARI Gom 30) during 2017-18.

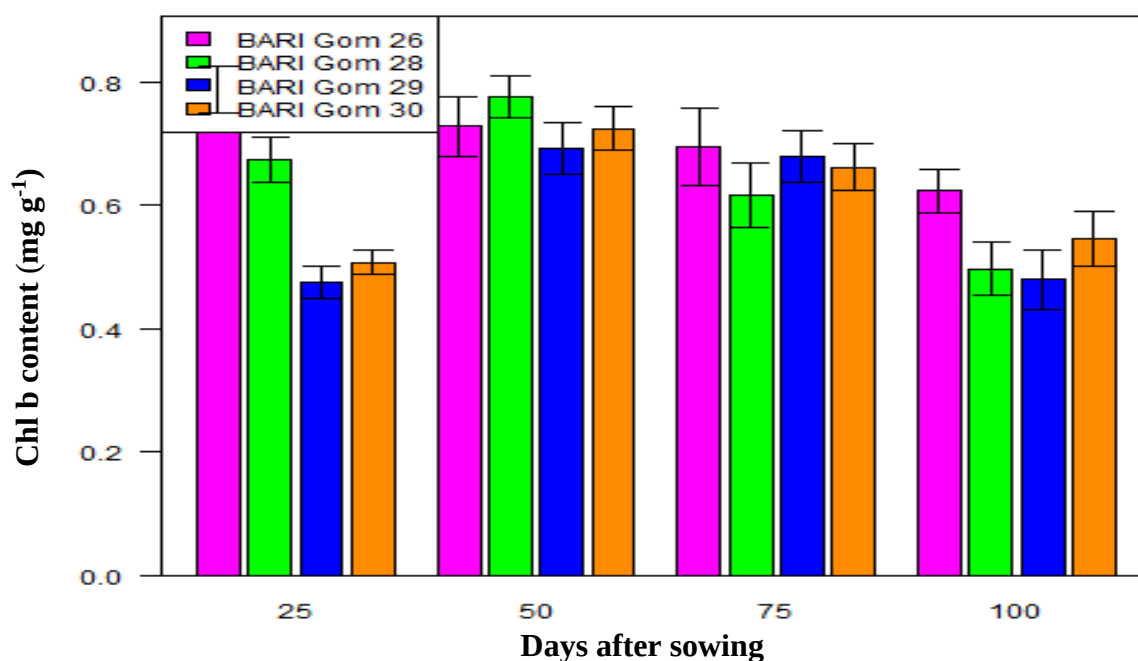


Figure 3.1.29: Effect of wheat varieties on Chl b content at different days after sowing (2016-17).

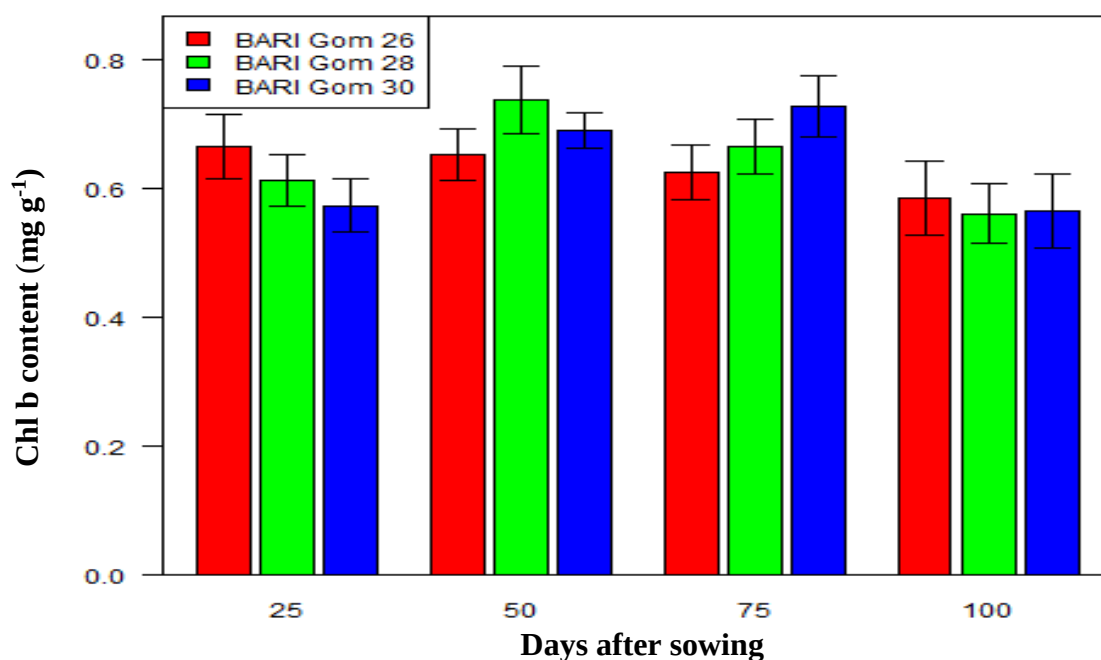


Figure 3.1.30: Effect of wheat variety on Chl b content at different days after sowing (2017-18).
Vertical bars indicate $\pm$ SE value.

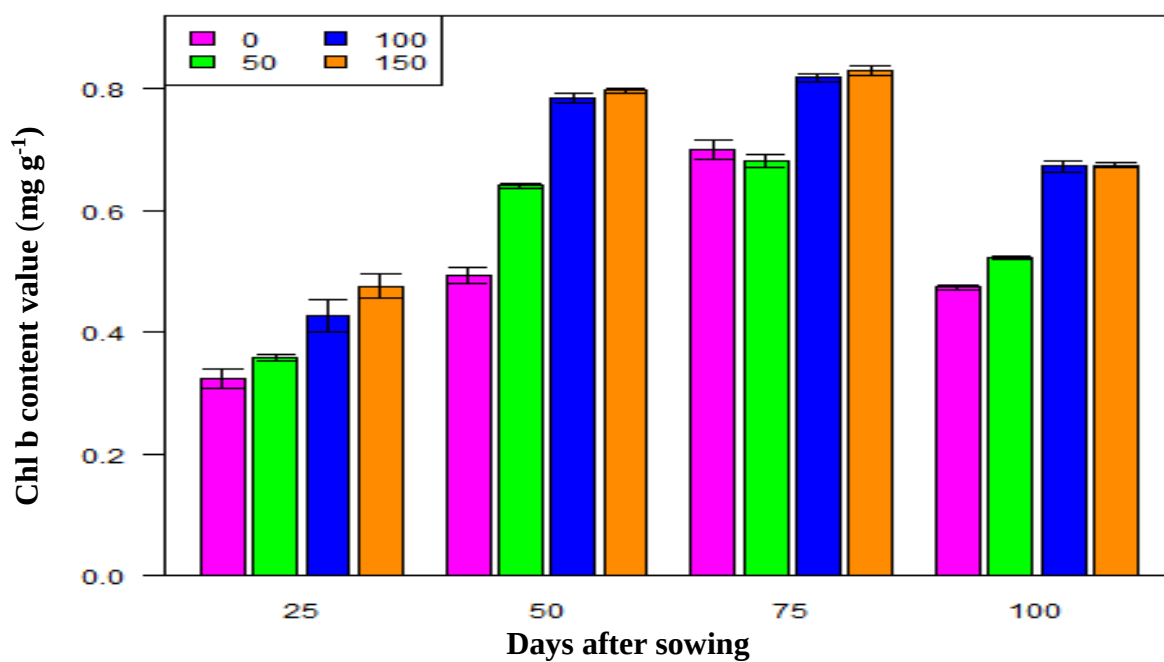


Figure 3.1.31: Effect of nitrogen on Chl b content at different days after sowing (2016-17).

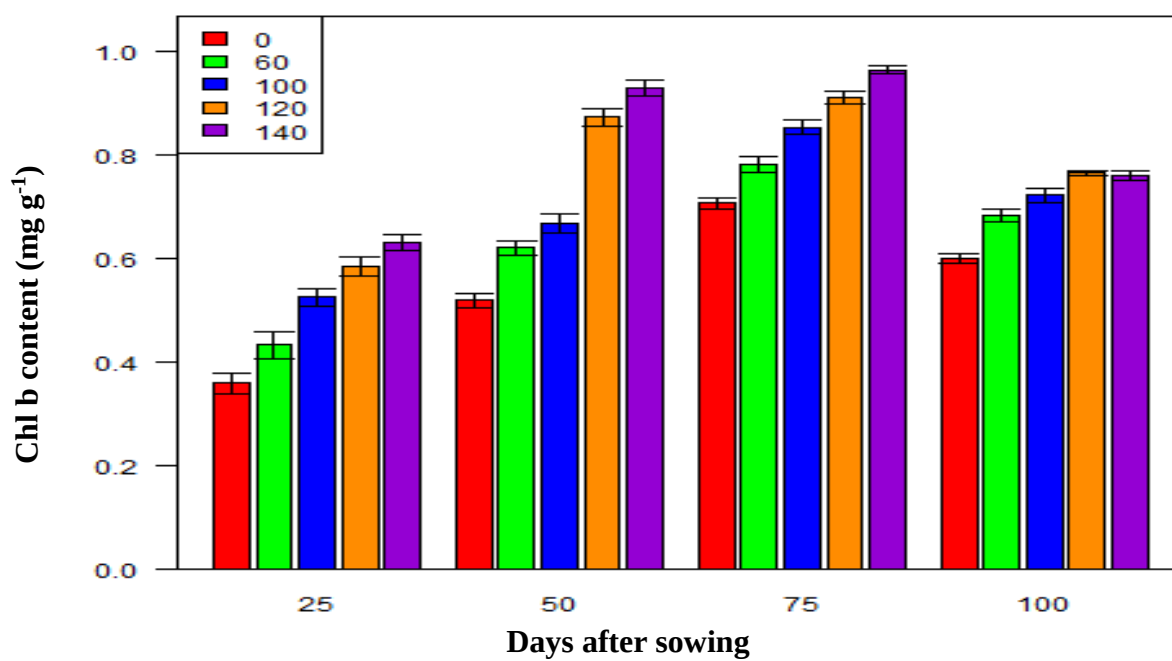


Figure 3.1.32: Effect of nitrogen on Chl b content at different days after sowing (2017-18).

Table 3.1.17. Interaction effect of varieties and nitrogen levels on Chl b content at different days after sowing of wheat during 2016-17

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	0.68	0.57	0.48	0.68
N ₁ ×V ₁	0.75	0.64	0.62	0.47
N ₂ ×V ₁	0.78	0.87	0.84	0.63
N ₃ ×V ₁	0.95	0.84	0.85	0.71
N ₀ ×V ₂	0.53	0.65	0.39	0.43
N ₁ ×V ₂	0.67	0.81	0.72	0.44
N ₂ ×V ₂	0.79	0.89	0.72	0.43
N ₃ ×V ₂	0.72	0.75	0.64	0.69
N ₀ ×V ₃	0.38	0.53	0.60	0.31
N ₁ ×V ₃	0.58	0.71	0.59	0.55
N ₂ ×V ₃	0.48	0.69	0.66	0.42
N ₃ ×V ₃	0.47	0.84	0.86	0.64
N ₀ ×V ₄	0.44	0.61	0.64	0.43
N ₁ ×V ₄	0.49	0.70	0.59	0.44
N ₂ ×V ₄	0.58	0.73	0.60	0.63
N ₃ ×V ₄	0.52	0.86	0.83	0.69
LSD (0.05)	0.04	0.02	0.11	0.02
CV (a)%	1.73	1.21	7.25	1.37
CV (b)%	2.84	1.36	7.36	1.72

Table 3.1.18. Interaction effect of varieties and nitrogen levels on Chl b content at different days after sowing of wheat during 2017-18

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	0.70	0.56	0.77	0.67
N ₁ ×V ₁	0.57	0.50	0.56	0.77
N ₂ ×V ₁	0.48	0.73	0.55	0.62
N ₃ ×V ₁	0.73	0.75	0.61	0.43
N ₄ ×V ₁	0.84	0.72	0.62	0.44
N ₀ ×V ₂	0.60	0.78	0.80	0.76
N ₁ ×V ₂	0.72	0.56	0.72	0.55
N ₂ ×V ₂	0.46	0.63	0.56	0.58
N ₃ ×V ₂	0.53	0.86	0.66	0.43
N ₄ ×V ₂	0.75	0.86	0.59	0.49
N ₀ ×V ₃	0.51	0.69	0.66	0.72
N ₁ ×V ₃	0.60	0.60	0.75	0.59
N ₂ ×V ₃	0.76	0.65	0.60	0.44
N ₃ ×V ₃	0.53	0.70	0.72	0.55
N ₄ ×V ₃	0.47	0.81	0.91	0.54
LSD (0.05)	0.24	0.14	0.12	0.25
CV (a)%	9.09	11.99	23.99	13.84
CV (b)%	17.66	15.87	20.19	31.50

N₀ = 0 kg N ha⁻¹, N₁ = 60 kg N ha⁻¹, N₂ = 100 kg N ha⁻¹, N₃ = 120 kg N ha⁻¹ and N₄ = 140 kg N ha⁻¹ and V₁= BARI Gom 26, V₂= BARI Gom 28, V₃= BARI Gom 30

3.1.3.2.4 Leaf Carotenoid Content (LCC)

Effect of wheat varieties on Leaf Carotenoid Content (mg g⁻¹)

The leaf carotenoid content (LCC) value of different wheat varieties at different growth stages significantly differed at different days after sowing (DAS) is shown in Appendix 3.1.17, Figure 3.1.33 for 2016-17 and Appendix 3.1.18, Figure 3.1.34 for 2017-18, respectively. Carotenoid increased gradually up to 75 DAS and decreased with the advancement of growing period of all the varieties for both the years. Regardless of variety differences, LCC increased progressively up to 75 DAS. At 25 DAS, maximum LCC (0.42) was observed in BARI Gom 29 which was statistically identical with BARI Gom 28 and minimum LCC (0.35) was obtained in BARI Gom 30 which was also statistically similar with BARI Gom 26 during 2016-17. Maximum LCC (0.57) was found in BARI Gom 28 which was significantly differ from other wheat varieties and minimum LCC (0.44) was found in BARI gom 26 during 2017-18. At 50 DAS, highest LCC (0.68) was found in BARI Gom 29 which was non-significantly varies from other varieties and lowest LCC (0.66) was observed in BARI Gom 26 during 2016-17. Highest LCC (0.78) was found in BARI Gom 28 which was significantly higher than the other variety and lowest LCC (0.69) was found from BARI Gom 26 during 2017-18. At 75 DAS, maximum LCC (0.76) was found in BARI Gom 26 which was statistically insignificant with other varieties and minimum LCC (0.74) which was observed in BARI Gom 30 during 2016-17. Highest LCC (0.82) was found in BARI Gom 28 and lowest LCC (0.76) was found from BARI Gom 30 followed BARI Gom 28 by during 2017-18. At 100 DAS stage, highest LCC (0.61) was obtained in BARI Gom 28 which was statistically insignificant with other varieties of wheat and lowest LCC (0.59) was in BARI Gom 26 during 2016-17. Maximum LCC content (0.65) was obtained in BARI Gom 29 which was statistically identical with BARI Gom 26 and BARI Gom 30 during 2016-17.

Effect of nitrogen on carotenoid (mg g⁻¹)

Effect of N levels revealed that a highly significant variation on LCC for all growth stages (Figure 3.1.35 & Appendix 3.1.17 for 2016-17 and Figure 3.1.36 & Appendix 3.1.18 for 2017-18). Irrespective of treatment differences, LCC increased rapidly up to 75 DAS after that it was slowly decreased. At 25 DAS, maximum LCC (0.49) was observed with N₃ treatment (150 kg

N ha⁻¹) which was significantly differ with other level on N doses. Minimum LCC (0.32) was found with N₀ treatment (0.0 kg N ha⁻¹) during 2016-17. Highest LCC (0.61) was obtained with N₄ treatment (140.0 kg N ha⁻¹) which was significantly differ from other N level and lowest LCC (0.38) was found with control (0.0 kg N ha⁻¹) during 2017-18. At 50 DAS, highest LCC (0.8) was found with N₃ (150 kg N ha⁻¹) which was statically identical with N₂ (100 kg N ha⁻¹) and lowest LCC (.049) was attained with control (0.0 kg N ha⁻¹) during 2016-17. The maximum LCC (0.85) was found with N₄ (140 kg N ha⁻¹) which was statistically differ with N₂ (100 kg N ha⁻¹) and N₃ (120 kg N ha⁻¹) and lowest LCC (0.52) was attained with N₀ (0.0 kg N ha⁻¹) observed during 2017-18. At 75 DAS, maximum LCC (0.82) was obtained with N₃ (150 kg N ha⁻¹) which was statistically at par with N₂ (100 kg N ha⁻¹) and minimum LCC (0.65) was found with N₀ (0 kg N ha⁻¹) during 2016-17. Maximum LCC (0.91) was obtained with N₄ (140 kg Na⁻¹) which was significantly differ with N₃ (120 kg N ha⁻¹) and minimum LCC (0.72) was found with N₀ (0 kg N ha⁻¹) during 2017-18. At 100 DAS, maximum LCC (0.71) was obtained with N₄ (150 kg N ha⁻¹) which was identical with N₃ (100 kg N ha⁻¹) and minimum (0.0.48) with N₀ (0.0 kg N ha⁻¹) during 2016-17 and the maximum LCC (0.78) was obtained with N₄ (140 kg N ha⁻¹) which was significantly identical with N₃ (120 kg N ha⁻¹) and minimum LCC (0.48) was found with control (0 kg N ha⁻¹) during 2017-18.

Interaction effect of wheat varieties and nitrogen on LCC

The interaction effect of varieties and nitrogen levels on LCC was statistically significant except 75 DAS during 2016-17 (Table 3.1.19 and appendix 3.1.17 for 2016-17) and 25 DAS & 75 DAS during 2017-18 (Table 3.1.20 and appendix 3.1.18 for 2017-18). At 25 DAS, the maximum LCC (0.52) was recorded by the interaction of N₃V₁ (150 kg N ha⁻¹ and BARI Gom 26) which was statistically similar with N₂V₂ (100 kg N ha⁻¹ and BARI Gom 28), N₃V₂ (150 kg N ha⁻¹ and BARI Gom 28), N₃V₃ (150 kg N ha⁻¹ and BARI Gom 29), N₂V₄ (100 kg N ha⁻¹ and BARI Gom 30), N₂V₃ (100 kg N ha⁻¹ and BARI Gom 28) during 2016-17. The maximum LCC (0.68) was found with treatment combination N₄V₂ (140 kg N ha⁻¹ and BARI Gom 28) and minimum (0.31) N₀V₁ (0.0 kg N ha⁻¹ and BARI Gom 26) during 2017-18. At 50 DAS, highest LCC (0.81) was resulted by the interaction of N₂V₄ (100 kg N ha⁻¹ and BARI Gom 30) which was statistically identical with N₂V₄ (0.80), N₃V₂ (0.80), N₃V₃ (0.79) N₃V₁ (0.79) and N₂V₁ (0.78) where the

lowest LCC (0.45) was observed from the treatment combination of N_0V_1 (0.0 kg N ha⁻¹ and BARI Gom 26) during 2016-17. The highest LCC (0.99) was found from the treatment interaction of N_4V_2 (140 kg N ha⁻¹ and BARI Gom 28) which was statistically significant with other treatment combinations where the lowest LCC (0.50) was observed from the treatment combination of N_0V_1 (0.0 kg N ha⁻¹ and BARI Gom 26) during 2017-18. At 75 DAS, interaction effects of wheat varieties and nitrogen levels for LCC was found insignificant during both years. At 100 DAS, the highest LCC (0.68) was recorded by the interaction of N_3V_4 (150 kg N ha⁻¹ and BARI Gom 30) which was statistically insignificant with other treatment combinations during 2016-17. The maximum LCC (0.78) was found with treatment combination N_3V_3 (120 kg N ha⁻¹ and BARI Gom 30) which was followed by treatment combination N_4V_3 (140 kg N ha⁻¹ and BARI Gom 30), N_3V_2 (120 kg N ha⁻¹ and BARI Gom 28), N_4V_1 (140 kg N ha⁻¹ and BARI Gom 26) and N_4V_2 (140 kg N ha⁻¹ and BARI Gom 28) during 2017-18. The lowest LCC (0.58) was observed from the treatment combination of N_0V_3 (0.0 kg N ha⁻¹ and BARI Gom 30) during 2017-18.

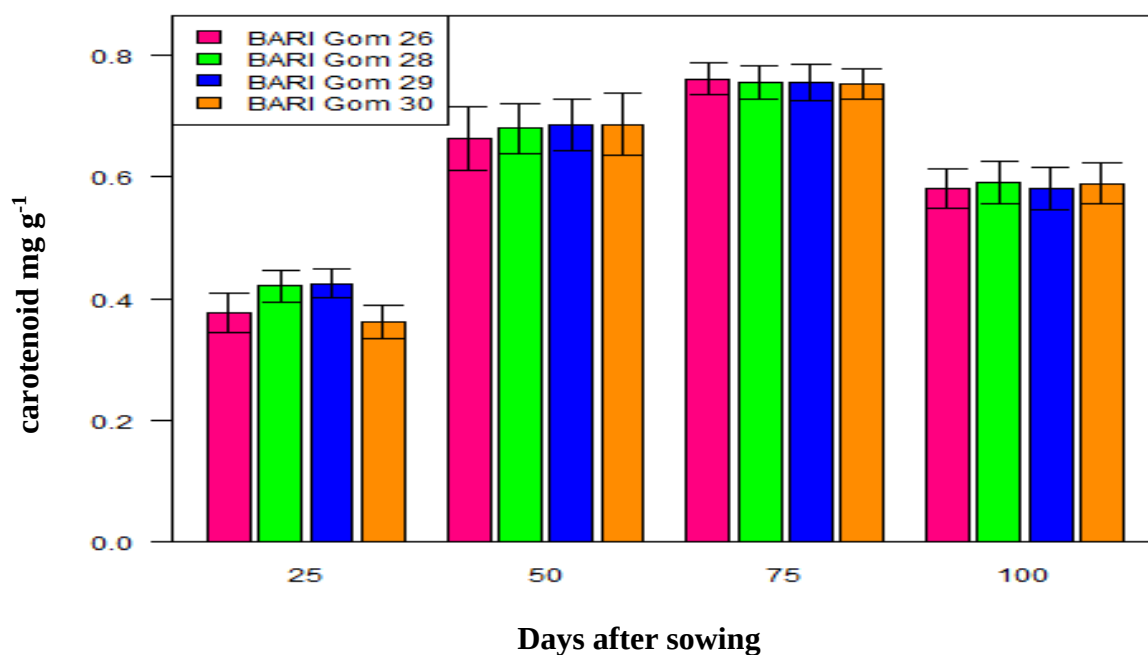


Figure 3.1.33: Effect of wheat varieties on carotenoid at different days after sowing (2016-17).

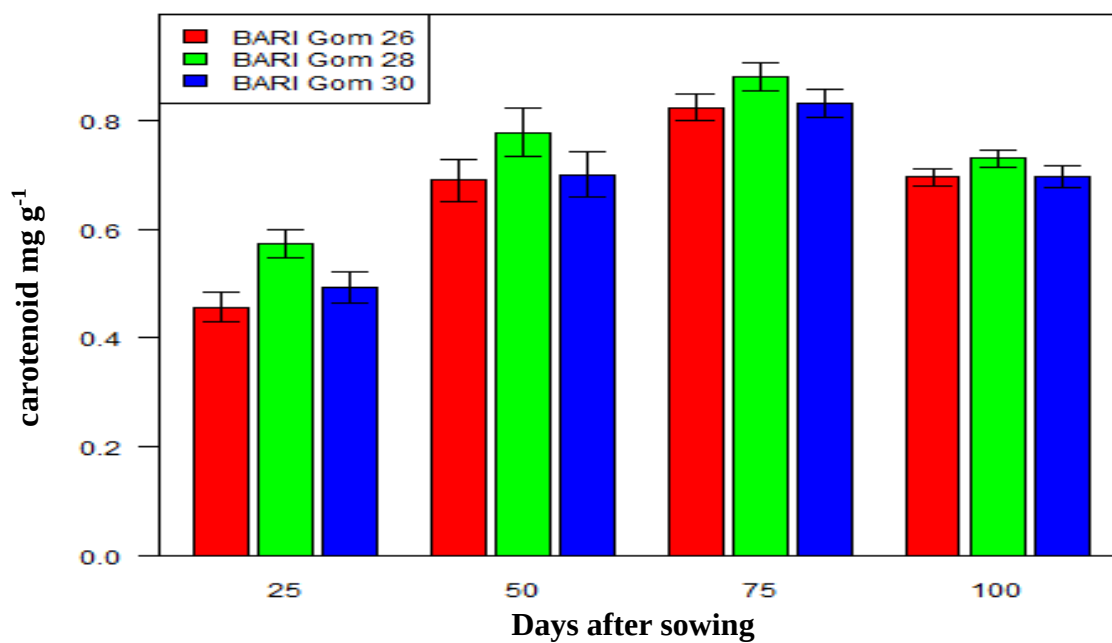


Figure 3.1.34: Effect of wheat variety on carotenoid at different days after sowing (2017-18).

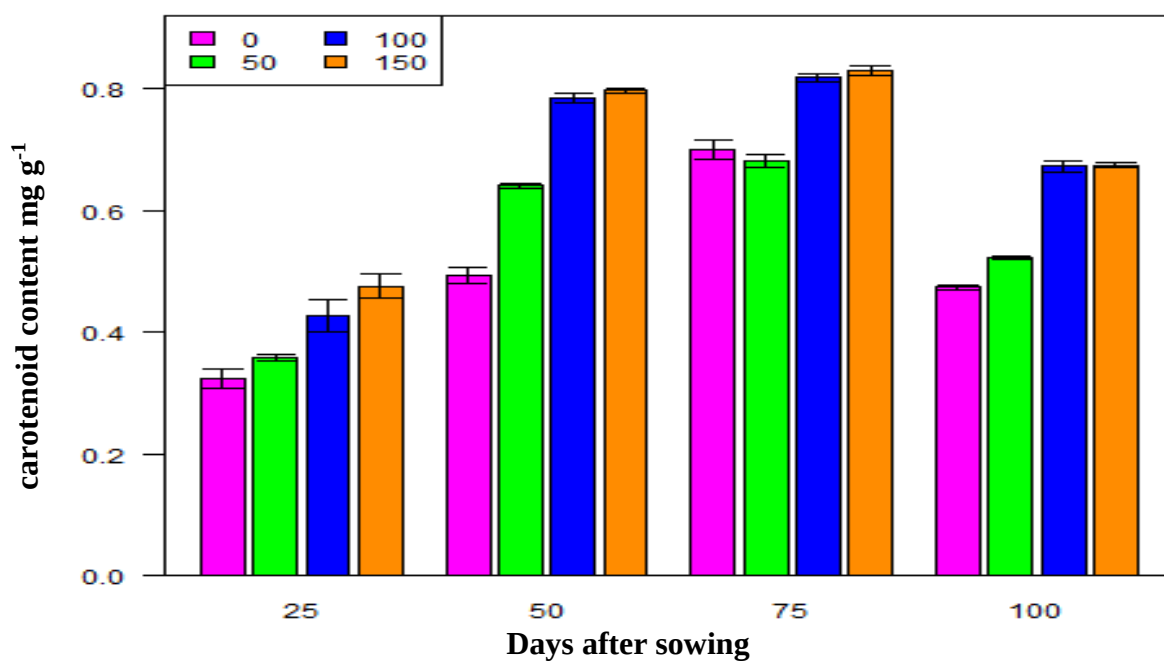


Figure 3.1.35: Effect of nitrogen on carotenoid at different days after sowing (2016-17).

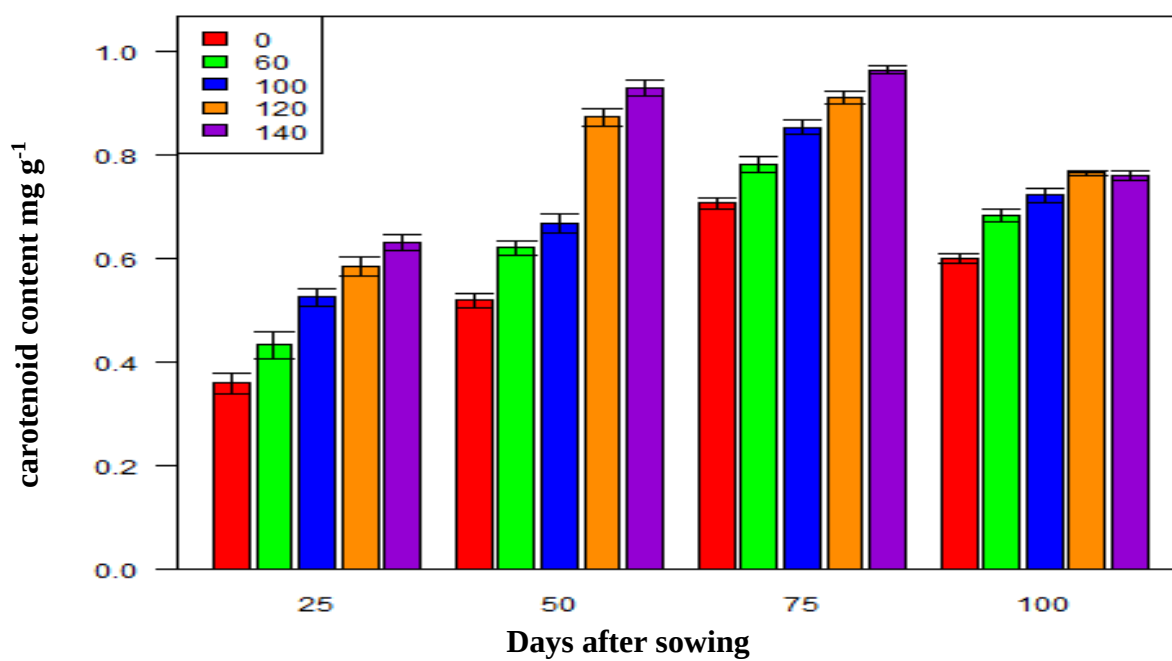


Figure 3.1.36: Effect of nitrogen on carotenoid at different days after sowing (2017-18).

Table 3.1.19. Interaction effect of varieties and nitrogen levels on LCC at different days after sowing of wheat during 2016-17

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	0.05	0.09	0.11	0.10
N ₁ ×V ₁	0.06	0.07	0.12	0.11
N ₂ ×V ₁	0.09	0.08	0.15	0.20
N ₃ ×V ₁	0.11	0.08	0.08	0.04
N ₀ ×V ₂	0.07	0.07	0.15	0.07
N ₁ ×V ₂	0.08	0.05	0.15	0.15
N ₂ ×V ₂	0.08	0.14	0.15	0.14
N ₃ ×V ₂	0.06	0.11	0.13	0.10
N ₀ ×V ₃	0.05	0.10	0.11	0.10
N ₁ ×V ₃	0.06	0.07	0.13	0.15
N ₂ ×V ₃	0.07	0.11	0.13	0.13
N ₃ ×V ₃	0.14	0.11	0.08	0.19
N ₀ ×V ₄	0.08	0.15	0.11	0.06
N ₁ ×V ₄	0.09	0.07	0.13	0.13
N ₂ ×V ₄	0.10	0.15	0.14	0.12
N ₃ ×V ₄	0.11	0.07	0.11	0.11
LSD (0.05)	0.03	0.04	0.03	0.04
CV (a)%	7.52	20.66	19.61	15.12
CV (b)%	5.05	18.76	19.02	16.81

Table 3.1.20. Interaction effect of varieties and nitrogen levels on LCC at different days after sowing of wheat during 2017-18

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	0.06	0.11	0.10	0.16
N ₁ ×V ₁	0.08	0.12	0.13	0.09
N ₂ ×V ₁	0.09	0.06	0.10	0.07
N ₃ ×V ₁	0.09	0.07	0.10	0.13
N ₄ ×V ₁	0.10	0.12	0.12	0.13
N ₀ ×V ₂	0.09	0.10	0.11	0.11
N ₁ ×V ₂	0.05	0.16	0.12	0.09
N ₂ ×V ₂	0.08	0.09	0.14	0.10
N ₃ ×V ₂	0.06	0.08	0.13	0.09
N ₄ ×V ₂	0.08	0.08	0.15	0.15
N ₀ ×V ₃	0.13	0.06	0.11	0.14
N ₁ ×V ₃	0.07	0.08	0.09	0.07
N ₂ ×V ₃	0.07	0.09	0.11	0.10
N ₃ ×V ₃	0.04	0.09	0.14	0.14
N ₄ ×V ₃	0.11	0.14	0.11	0.12
LSD (0.05)				
CV (a)%	5.17	22.85	16.23	21.70
CV (b)%	6.15	34.23	24.18	28.96

N₀ = 0 kg N ha⁻¹, N₁ = 60 kg N ha⁻¹, N₂ = 100 kg N ha⁻¹, N₃ = 120 kg N ha⁻¹ and N₄ = 140 kg N ha⁻¹ and V₁= BARI Gom 26, V₂= BARI Gom 28, V₃= BARI Gom 30

3.1.3.2.5 Leaf Nitrogen Content (LNC)

The Leaf Nitrogen Content (LNC) at early growth stages is a good indicator for N fertilizer application and LNC at late growth stages is highly related to the final grain quality of wheat. Quantification of LNC is therefore a prerequisite for the production of high-yield and good-quality crops while causing minimal environmental impact (Zheng *et al.*, 2018).

Effect of wheat varieties on LNC

The LNC content of different wheat varieties at different growth stages shows insignificant at different days after sowing (DAS) is shown in Appendix 3.1.19, Figure 3.1.37 for 2016-17 and Appendix 3.1.20, Figure 3.1.38 for 2017-18, respectively. LNC increased gradually up to 50 DAS, then decreased with the advancement of growing period of all the varieties for both the years. Regardless of variety differences, LNC increased progressively up to 50 DAS. At 25 DAS, maximum LNC (1633 ppm) was observed in BARI Gom 28 and minimum LNC (1575 ppm) was obtained in BARI Gom 26 during 2016-17. Maximum LNC (1680 ppm) was found in BARI Gom 29 and minimum LNC (1647 ppm) was found in BARI Gom 26 and BARI Gom 30 during 2017-18. At 50 DAS, highest LNC (1792 ppm) was found in BARI Gom 28 which was non-significantly varies from other varieties and lowest LNC (1767 ppm) was observed in BARI Gom 29 and BARI Gom 30 during 2016-17. Highest LNC (1867 ppm) was found in BARI Gom 28 which was insignificant than the other variety and lowest LNC (1833 ppm) was found from BARI Gom 30 during 2017-18. At 75 DAS, maximum LNC (1197 ppm) was found in BARI Gom 28 and minimum LNC (1092 ppm) which was observed in BARI Gom 26 during 2016-17. Highest LNC (1254 ppm) was found in BARI Gom 28 and lowest LNC (1164 ppm) was found from BARI Gom 26 during 2017-18. At 100 DAS stage, highest LNC (880 ppm) was obtained in BARI Gom 29 which was statistically insignificant with other varieties of wheat and lowest LNC (804 ppm) was in BARI Gom 28 during 2016-17. Maximum LNC (860 ppm) was obtained in BARI Gom 28 and minimum LNC (833 ppm) was found from BARI Gom 26 during 2017-18.

Effect of nitrogen on LNC content

Effect of nitrogen treatments revealed that a highly significant variation on LNC for all growth stages (Figure 3.1.39 & Appendix 3.1.19 for 2016-17 and Figure 3.1.40 & Appendix 3.1.20 for 2017-18). Irrespective of treatment differences, LNC increased rapidly up to 50 DAS after that it was gradually decreased. At 25 DAS maximum LNC (2108 ppm) was observed with N_3 treatment (150 kg N ha^{-1}) which was significantly differ with other level on N treatments. Minimum LNC (1158 ppm) was found with N_0 treatment (0.0 kg N ha^{-1}) during 2016-17. Highest LNC (2111 ppm) was obtained with N_4 treatment ($140.0 \text{ kg N ha}^{-1}$) which was significantly differ from other N level and lowest LNC (1167 ppm) was found with control (0.0 kg N ha^{-1}) during 2017-18. At 50 DAS, highest LNC (2346 ppm) was found with N_3 (150 kg N ha^{-1}) which was significantly differ with other level on N treatments and lowest LNC (1244 ppm) was attained with control (0.0 kg N ha^{-1}) during 2016-17. The maximum LNC (2356 ppm) was found with N_4 (140 kg N ha^{-1}) which was significantly differ with other level on N treatments and lowest LNC (1256 ppm) was attained with N_0 (0.0 kg N ha^{-1}) observed during 2017-18. At 75 DAS, maximum LNC (1737 ppm) was obtained with N_3 (150 kg N ha^{-1}) which was significantly differ with other level on N treatments and minimum LNC (664 ppm) was found with N_0 (0 kg N ha^{-1}) during 2016-17. Maximum LNC (1746 ppm) was obtained with N_4 (140 kg N ha^{-1}) which was significantly differ with N_3 (120 kg N ha^{-1}) and minimum LNC (660 ppm) was found with N_0 (0 kg N ha^{-1}) during 2017-18. At 100 DAS, maximum LNC (900 ppm) was obtained with N_4 (150 kg N ha^{-1}) which was identical with N_3 (100 kg N ha^{-1}) and minimum (825 ppm) with N_0 (0.0 kg N ha^{-1}) during 2016-17 and the maximum LNC (851 ppm) was obtained with N_4 (140 kg N ha^{-1}) which was insignificantly differ with other level on N treatments and minimum LNC (820 ppm) was found with control (0 kg N ha^{-1}) during 2017-18.

Interaction effect of wheat varieties and nitrogen on LNC

The interaction effect of varieties and nitrogen levels on LNC was statistically significant except 100 DAS during 2016-17 (Table 3.1.21 and appendix 3.1.19 for 2016-17) and during 2017-18 (Table 3.1.22 and appendix 3.1.20 for 2017-18). At 25 DAS, the maximum LNC (2133 ppm) was recorded by the interaction of N_3V_2 (150 kg N ha^{-1} and BARI Gom 28) which was statistically similar with N_3V_1 (150 kg N ha^{-1} and BARI Gom 26), N_3V_3 (150 kg N ha^{-1} and

BARI Gom 29) and N_3V_4 (100 kg N ha⁻¹ and BARI Gom 30) during 2016-17. The maximum LNC (2135 ppm) was found with treatment combination N_4V_2 (140 kg N ha⁻¹ and BARI Gom 28) which was statistically similar with N_4V_1 (140 kg N ha⁻¹ and BARI Gom 26), N_3V_3 (150 kg N ha⁻¹ and BARI Gom 30) and minimum (1140) N_0V_3 (0.0 kg N ha⁻¹ and BARI Gom 30) during 2017-18. At 50 DAS, highest LNC (2367 ppm) was resulted by the interaction of N_3V_1 (150 kg N ha⁻¹ and BARI Gom 26) which was statistically identical with N_3V_2 (150 kg N ha⁻¹ and BARI Gom 28), N_3V_3 (150 kg N ha⁻¹ and BARI Gom 29) and N_3V_4 (150 kg N ha⁻¹ and BARI Gom 30) where, the lowest LNC (1200 ppm) was observed from the treatment combination of N_0V_3 (0.0 kg N ha⁻¹ and BARI Gom 29), N_0V_2 (0.0 kg N ha⁻¹ and BARI Gom 28) and N_0V_4 (0.0 kg N ha⁻¹ and BARI Gom 29) during 2016-17. The highest LNC (2370 ppm) was found from the treatment interaction of N_4V_1 (140 kg N ha⁻¹ and BARI Gom 26) which was statistically significant with other treatment combinations where the lowest LNC (1250 ppm) was observed from the treatment combination of N_0V_3 (0.0 kg N ha⁻¹ and BARI Gom 30) during 2017-18. At 75 DAS, the highest LNC (1813 ppm) was recorded by the interaction of N_3V_2 (150 kg N ha⁻¹ and BARI Gom 29) which was statistically identical with N_3V_1 (150 kg N ha⁻¹ and BARI Gom 26), N_3V_3 (150 kg N ha⁻¹ and BARI Gom 29) and N_3V_4 (150 kg N ha⁻¹ and BARI Gom 30) during 2016-17. The maximum LNC (1850 ppm) was found with treatment combination N_4V_2 (140 kg N ha⁻¹ and BARI Gom 28) which was followed by treatment combination N_4V_1 (140 kg N ha⁻¹ and BARI Gom 26) and N_4V_3 (140 kg N ha⁻¹ and BARI Gom 30) during 2017-18. The lowest LNC (650 ppm) was observed from the treatment combination of N_0V_1 (0.0 kg N ha⁻¹ and BARI Gom 26) during 2017-18. At 100 DAS, interaction effects of wheat varieties and nitrogen levels for LNC was found insignificant during both years.

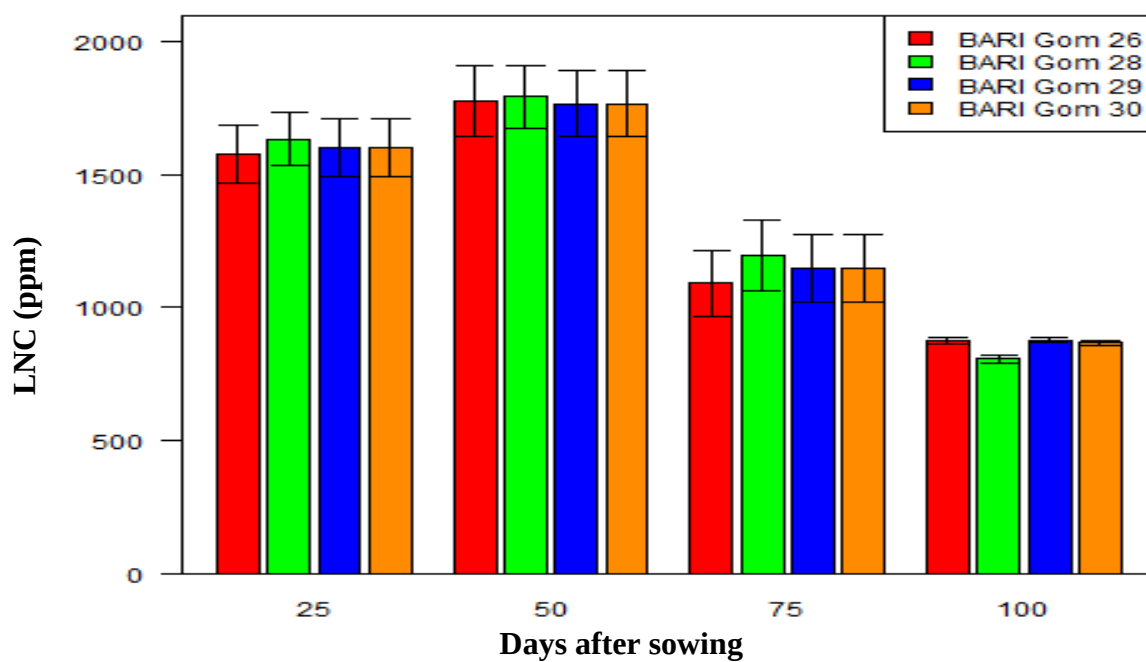


Figure 3.1.37: Effect of wheat varieties on LNC at different days after sowing (2016-17).

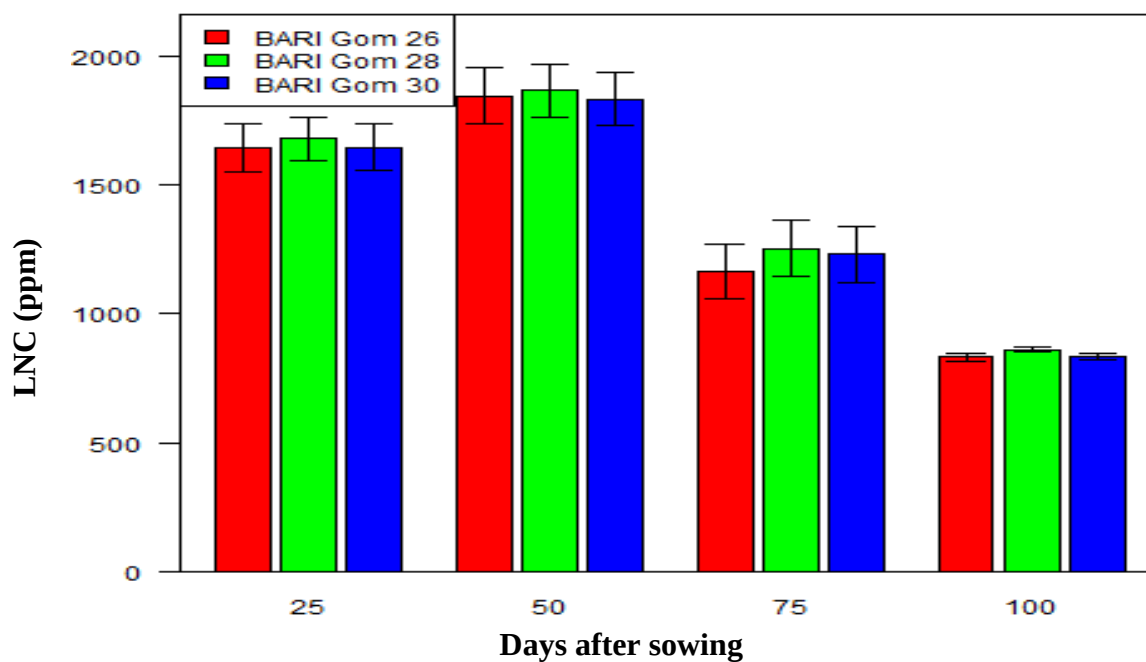


Figure 3.1.38: Effect of wheat variety on LNC at different days after sowing (2017-18).

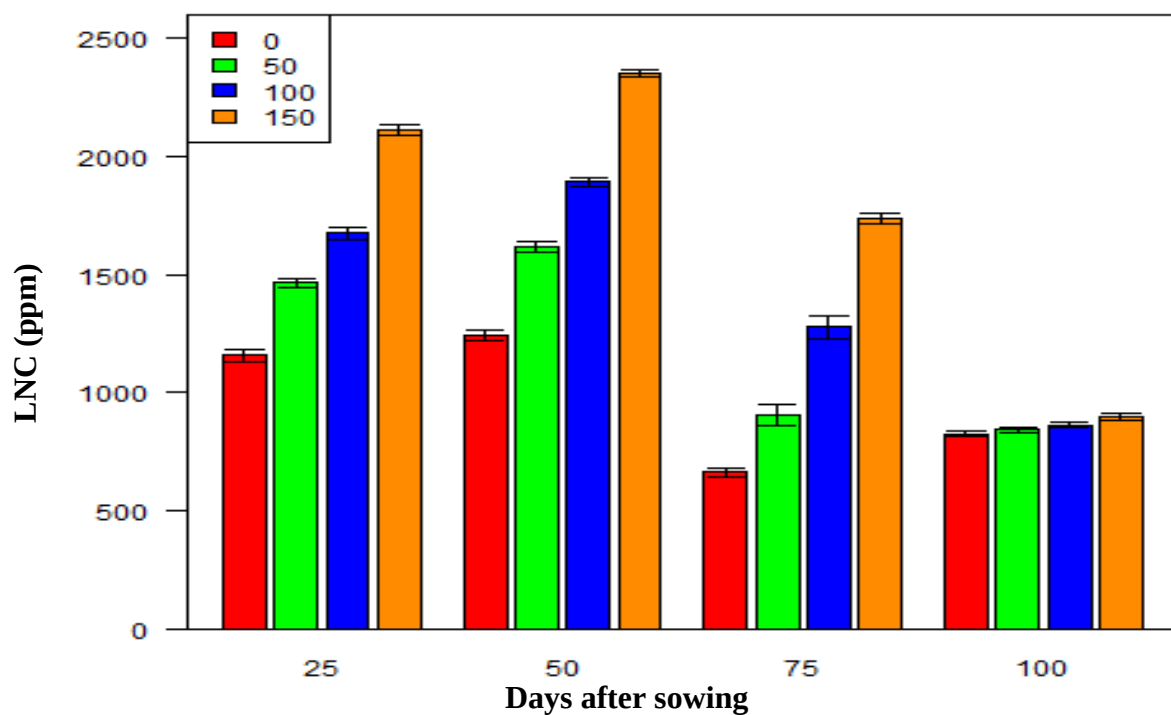


Figure 3.1.39: Effect of nitrogen on LNC at different days after sowing (2016-17).

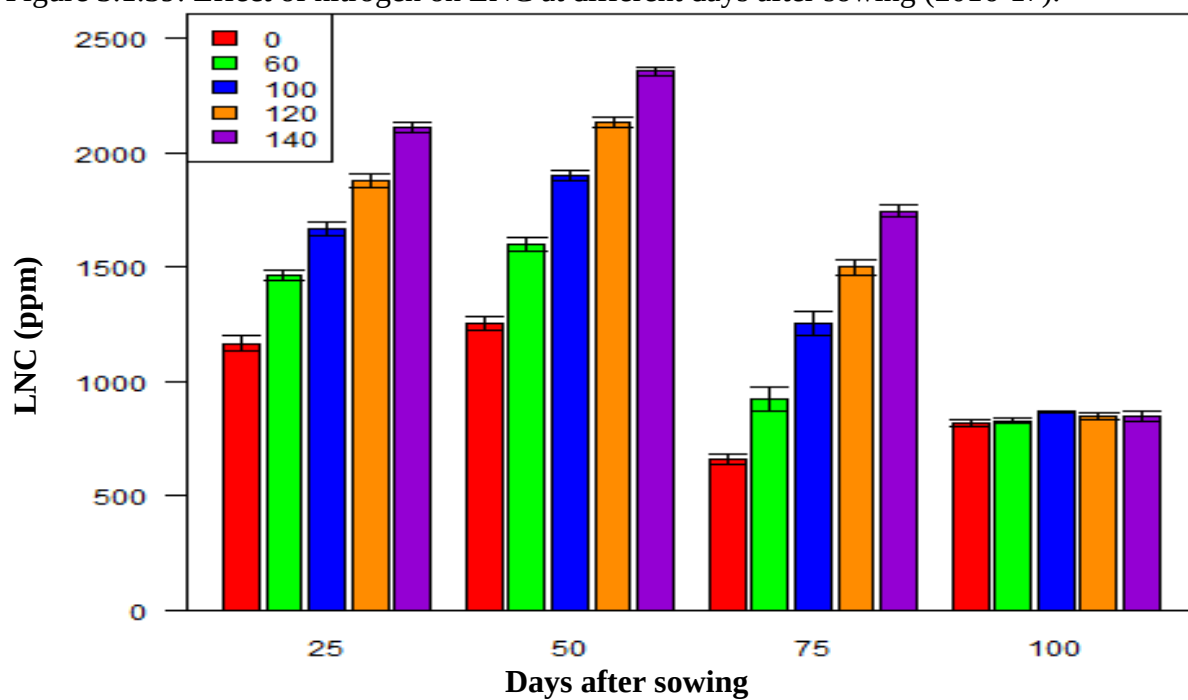


Figure 3.1.40: Effect of nitrogen on LNC at different days after sowing (2017-18).

Table 3.1.21. Interaction effect of varieties and nitrogen levels on LNC at different days after sowing of wheat during 2016-17

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	1133	1333	643	845
N ₁ ×V ₁	1433	1600	890	849
N ₂ ×V ₁	1633	1867	1120	879
N ₃ ×V ₁	2100	2367	1713	932
N ₀ ×V ₂	1233	1200	660	775
N ₁ ×V ₂	1500	1667	1027	795
N ₂ ×V ₂	1667	1867	1287	821
N ₃ ×V ₂	2133	2333	1813	838
N ₀ ×V ₃	1133	1200	677	842
N ₁ ×V ₃	1467	1667	853	868
N ₂ ×V ₃	1700	1867	1353	876
N ₃ ×V ₃	2100	2333	1710	929
N ₀ ×V ₄	1133	1242	677	839
N ₁ ×V ₄	1467	1617	853	859
N ₂ ×V ₄	1700	1892	1353	873
N ₃ ×V ₄	2100	2350	1710	902
LSD (0.05)	67	112	107	14
CV (a)%	5.18	2.41	9.27	7.58
CV (b)%	4.93	3.76	11.05	1.92

Table 3.1.22. Interaction effect of varieties and nitrogen levels on LNC at different days after sowing of wheat during 2017-18

Interaction Treatment	Days After Sowing (DAS)			
	25 DAS	50 DAS	75 DAS	100 DAS
N ₀ ×V ₁	1140	1273	650	819
N ₁ ×V ₁	1433	1533	890	816
N ₂ ×V ₁	1650	1967	1120	859
N ₃ ×V ₁	1933	2133	1453	852
N ₄ ×V ₁	2100	2370	1713	819
N ₀ ×V ₂	1250	1333	660	829
N ₁ ×V ₂	1500	1600	1027	825
N ₂ ×V ₂	1667	1867	1287	879
N ₃ ×V ₂	1867	2167	1483	873
N ₄ ×V ₂	2133	2367	1850	895
N ₀ ×V ₃	1133	1250	677	811
N ₁ ×V ₃	1467	1667	853	845
N ₂ ×V ₃	1700	1867	1353	867
N ₃ ×V ₃	1833	2100	1567	820
N ₄ ×V ₃	2100	2333	1710	838
LSD (0.05)	84	66	118	ns
CV (a)%	4.88	2.91	9.25	4.80
CV (b)%	5.2	3.69	10.00	5.78

N₀ = 0 kg N ha⁻¹, N₁ = 60 kg N ha⁻¹, N₂ = 100 kg N ha⁻¹, N₃ = 120 kg N ha⁻¹ and N₄ = 140 kg N ha⁻¹ and V₁= BARI Gom 26, V₂= BARI Gom 28, V₃= BARI Gom 30

3.1.3.3 Yield and yield contributing traits of wheat

3.1.3.3.1 Number of spikelets spike⁻¹

Effect of variety on Number of spikelets spike⁻¹

The number of spikelets spike⁻¹ of different wheat variety was significantly differed are presented in Tables 3.1.3.23 and 3.1.3 24 during 2016-17 and 2017-18, respectively. Results showed that the highest number of spikelets spike⁻¹ (17.80) was found in V₂ (BARI Gom 28) which was statistically identical with all other varieties and lowest number of spikelets spike⁻¹ (15.60) was found in V₂ (BARI Gom 29) during 2016-17. The maximum number of spikelets spike⁻¹ (18.47) was found in V₂ (BARI Gom 28) which was statistically identical with V₃ (BARI Gom 30) and lowest number of spikelets spike⁻¹ (17.00) was found in V₂ (BARI Gom 29) during 2017-18. This result is in agreement with the findings of Nahar *et al.*, (2015), they reported that the highest number of filled spikelets spike⁻¹, non-filled spikelets spike⁻¹ and total spikelets spike⁻¹ (17.23, 3.05 and 19.95 respectively) was found in V₂ (BARI Gom 24) which was significantly different from all other treatments. On the other hand, the lowest filled spikelets spike⁻¹ was found in V₃ (BARI Gom 25) but the lowest number of non-filled spikelets spike⁻¹ and total spikelets spike⁻¹ were found in V₄ (BARI Gom 26). Similar results were also found by Nadim *et al.* (2012), Hussain *et al.* (2010) and Rahman (2009). They found that the variation for number of spikelets spike⁻¹ in different varieties. It may be due to genetic difference of variety.

Effect of nitrogen on Number of spikelets spike⁻¹

Significant variation was observed on number of spikelets spike⁻¹ in case of different level of nitrogen application in the field (Tables 3.1.3.23 and 3.1.3 24 during 2016-17 and 2017-18, respectively). It was found that the maximum number of spikelets spike⁻¹ (18.52) was observed with N₂ treatment (100 kg N ha⁻¹) which was statistically similar with N₃ treatment (150 kg N ha⁻¹). Minimum number of spikelets spike⁻¹ (12.63) was found with N₀ treatment (0.0 kg N ha⁻¹) during 2016-17. Highest number of spikelets spike⁻¹ (19.11) was obtained with N₃ treatment (120.0 kg N ha⁻¹) which was statistically similar with N₄ treatment (140 kg N ha⁻¹) and lowest number of spikelets spike⁻¹ (12.56) was found with control (0.0 kg N ha⁻¹) during 2017-18. This result is in agreement with the findings of Nahar *et al.*, (2015) they reported that the highest

number of filled spikelets spike⁻¹, the lowest number of non-filled spikelets spike⁻¹ and the highest number of total spikelets spike⁻¹ (20.63, 1.05 and 21.76 respectively) was achieved from N₁ (urea supergranules; 1.8 g) which was significantly different from all other treatments. On the other hand, the lowest number of filled spikelets spike⁻¹, the highest number of non-filled spikelets spike⁻¹ and the lowest number of total spikelets spike⁻¹ (9.43, 4.70 and 13.89 respectively) was found in N₀ (control) which was significantly different from all other treatments. Mandal *et al.*, (2015) reported that maximum number of spikelets (18.3/spike) was found from N₁(urea super granules (1.8 g) @ 60 kg N/ha) while minimum from N₀ (15.2/spike). Mandal *et al.*, (2015) also found maximum number of spikelets was found from N₁ (18.3/spike) while minimum from N₀ (15.2/spike). Similar result was also found by Mozumder (2001); Rahman (2005) Hossain *et al.* (2005) and Islam *et al.*(2011).

Interaction effect of variety and nitrogen on Number of spikelets spike⁻¹

The interaction effect of variety and nitrogen levels on number of spikelets spike⁻¹ was statistically significant during both the year (Table 3.1.23 for 2016-17 and Table 3.1.24 for 2017-18). The maximum number of spikelets spike⁻¹ (21.13) was recorded by the interaction of N₃V₃ (150 kg N ha⁻¹ and BARI Gom 29) which was statistically at par with N₂V₃ (100 kg N ha⁻¹ and BARI Gom 29) and N₂V₂ (100 kg N ha⁻¹ and BARI Gom 28). Minimum spikelets spike⁻¹ (9.27) was obtained from N₀V₂ (0.0 kg N ha⁻¹ and BARI Gom 28) during 2016-17. The maximum number of spikelets spike⁻¹ (19.67) was found with treatment combination N₄V₁ (140 kg N ha⁻¹ and BARI Gom 26) which was statistically similar with N₄V₃ (140 kg N ha⁻¹ and BARI Gom 30) and minimum spikelets spike⁻¹ (11.67) was obtained from N₀V₂ (0.0 kg N ha⁻¹ and BARI Gom 28) during 2017-18. This result is in agreement with the findings of Nahar *et al.*, (2015) they reported that the highest number of filled spikelets spike⁻¹ and total spikelets spike⁻¹ (22.30 and 23.27 respectively) were found with the treatment combination of V₂N₁ and the highest number of non-filled spikelets spike⁻¹ (5.50) was found in V₂N₀. On the other hand the lowest number of filled spikelets spike⁻¹ and total spikelets spike⁻¹ (9.27 and 13.33 respectively) were observed with V₃N₀. But the lowest number of non-filled spikelet spike⁻¹ (0.47) was found in V₄N₁ which was statistically similar with V₄N₂.

3.1.3.3.2 Number of grains spike⁻¹

Effect of variety Number of grains spike⁻¹

The number of grains spike⁻¹ of different wheat varieties significantly differed which is shown in Table 3.1.23 for 2016-17 and Table 3.1.24 for 2017-18, respectively. Maximum number of grains spike⁻¹ (52.93) was observed in BARI Gom 30 which was statistically identical with BARI Gom 29 and minimum number of grains spike⁻¹ (45.29) was obtained in BARI Gom 26 which was also statistically similar with BARI Gom 28 during 2016-17 and maximum number of grains spike⁻¹ (52.76) was found in BARI Gom 30 and minimum number of grains spike⁻¹ (46.60) was found in BARI Gom 26 during 2017-18. This result is agreement with the findings of Nahar *et al.*, (2015) they reported that the highest number of grains spike⁻¹ (37.10) was found in V₂ (BARI Ghom 24) which was significantly different from all other treatments. On the other hand the lowest number of grains spike⁻¹ (33.50) was found in V₃ (BARI Gom 25) which was also significantly different from all other treatments. The results on number of grains spike⁻¹ under the present study were similar with the findings of Rahman *et al.* (2009), Mehmet and Telat (2006) and Sikder *et al.* (2001).

Effect of nitrogen Number of grains spike⁻¹

Effect of N levels revealed that a highly significant variation on number of grains spike⁻¹ (Table 3.1.23 for 2016-17 and Table 3.1.24 for 2017-18). maximum number of grains spike⁻¹ (46.75) was observed with N₃ treatment (150 kg N ha⁻¹) which was significantly differed with other level on N doses. Minimum number of grains spike⁻¹ (34.05) was found with N₀ treatment (0.0 kg N ha⁻¹) during 2016-17. Highest number of grains spike⁻¹ (58.00) was obtained with N₄ treatment (140.0 kg N ha⁻¹) which was significantly differed from other N level and lowest number of grains spike⁻¹ (38.89) was found with control (0.0 kg N ha⁻¹) during 2017-18. This result is also in agreement with the findings of Nahar *et al.*, (2015) they reported that the highest number of grains spike⁻¹ (44.05) was achieved from N₁ (urea super-granules; 1.8 g) which was significantly different from all other treatments. On the other hand, the lowest number of grains spike⁻¹ (24.86) was found in N₀ (control) which was also significantly different from all other treatments. The results on number of grains spike⁻¹ under the present study also was similar with the findings of Sushila and Giri (2000); Das (2003); Mazurkiewicz & Bojarezyk (2004).

Interaction effect of variety and nitrogen Number of grains spike⁻¹

The interaction effect of variety and nitrogen levels on number of number of grains spike⁻¹ was statistically significant during both the year (Table 3.1.23 for 2016-17 and Table 3.1.24 for 2017-18). The maximum number of number of grains spike⁻¹ (46.51) was recorded by the interaction of N₂V₁ (100 kg N ha⁻¹ and BARI Gom 26) which was statistically identical with N₃V₃ (150 kg N ha⁻¹ and BARI Gom 29) ; N₃V₄ (150 kg N ha⁻¹ and BARI Gom 30) and minimum number of grains spike⁻¹ (23.87) was obtained from N₀V₁ (0.0 kg N ha⁻¹ and BARI Gom 26) during 2016-17. The maximum number of number of grains spike⁻¹ (59.00) was found with treatment combination N₄V₃ (140 kg N ha⁻¹ and BARI Gom 30) which was statistically similar with N₄V₁ (140 kg N ha⁻¹ and BARI Gom 26), N₃V₃ (120 kg N ha⁻¹ and BARI Gom 30) and minimum number of grains spike⁻¹ (36.67) was obtained from N₀V₂ (0.0 kg N ha⁻¹ and BARI Gom 28) during 2017-18. This result is agreement with the findings of Nahar *et al.*, (2015) they reported that that the highest number of grains spike⁻¹ (46.34) was found with the treatment combination of V₂N₁ which was significantly different from all other treatment combinations. The treatment combinations of V₁N₁, V₂N₄, V₃N₁ and V₄N₁ also showed comparatively higher number of grains spike⁻¹ but significantly different from V₂N₁. On the other hand, the lowest number of grains spike⁻¹ (22.90) was observed with V₁N₀ which was significantly different from all other treatment combinations. The treatment combinations of V₂N₀, V₃N₀ and V₄N₀ also showed comparatively lower number of grains spike⁻¹ but significantly different from V₁N₀.

Table 3.1.23. Effect of variety, nitrogen and their interaction on yield and yield contributing characters of wheat during 2016-17

Treatments	Number of spikelets spike ⁻¹	Number of grains spike ⁻¹	Spike length (cm)	Straw yield (t ha ⁻²)	Harvest index (%)	Grain Yield (t ha ⁻¹)
Effect of variety						
V ₁	16.30	45.29	13.30	3.67	39.29	3.32
V ₂	17.80	47.60	12.81	3.45	41.08	3.29
V ₃	15.60	50.47	13.52	3.75	39.00	3.35
V ₄	17.28	52.93	13.65	4.23	48.69	3.43
LSD (0.05)	0.53	2.59	0.30	0.03	1.11	0.01
CV (a)%	4.46	3.50	2.67	4.29	1.84	5.67
Effect of nitrogen						
N ₀	12.63	44.05	15.3	2.39	33.96	1.69
N ₁	17.77	36.67	16.8	3.58	40.20	2.41
N ₂	18.52	36.53	15.9	3.83	49.20	3.32
N ₃	18.41	36.75	15.8	3.58	45.03	3.39
LSD (0.05)	0.31	1.27	0.48	0.02	1.059	0.110
Interaction effect of variety and nitrogen						
N ₀ ×V ₁	9.43	23.87	13.1	3.02	37.22	1.85
N ₁ ×V ₁	12.30	36.34	14.6	3.25	40.42	2.53
N ₂ ×V ₁	17.97	46.51	16.6	3.60	36.16	3.67
N ₃ ×V ₁	18.00	37.94	16.1	3.57	45.39	3.32
N ₀ ×V ₂	9.27	40.66	13.5	3.41	38.94	1.94
N ₁ ×V ₂	18.43	24.44	15.5	3.36	39.18	2.52
N ₂ ×V ₂	19.00	41.14	14.6	3.56	44.13	3.73
N ₃ ×V ₂	16.67	33.42	15.7	3.61	34.98	3.26
N ₀ ×V ₃	10.97	34.32	13.7	3.17	43.51	1.87
N ₁ ×V ₃	16.70	34.01	15.9	3.22	38.68	2.7
N ₂ ×V ₃	19.80	28.24	15.1	3.42	38.05	3.77
N ₃ ×V ₃	21.13	45.04	14.6	3.61	39.45	3.33
N ₀ ×V ₄	10.23	37.86	13.7	3.14	35.32	1.93
N ₁ ×V ₄	15.40	36.18	15.5	3.33	42.07	2.58
N ₂ ×V ₄	16.47	34.14	15.4	3.66	44.53	3.97
N ₃ ×V ₄	18.30	43.87	15.3	3.59	43.35	3.43
LSD (0.05)	0.50	4.30	2.10	0.30	2.70	0.32
CV (b)%	6.4	2.7	2.4	2.3	2.6	2.4

V₁= BARI Gom 26, V₂= BARI Gom 28, V₃= BARI Gom 29, V₄= BARI Gom 30 and N₀ = 0 kg N ha⁻¹, N₁ = 50 kg N ha⁻¹, N₂ = 100 kg N ha⁻¹, N₃ = 150 kg N ha⁻¹

Table 3.1.24. Effect of variety, nitrogen and their interaction on yield and yield contributing characters of wheat during 2017-18

Treatments	Number of spikelets spike ⁻¹	Number of grains spike ⁻¹	Spike length (cm)	Straw yield (gm ⁻²)	Harvest index (%)	Grain Yield (t ha ⁻¹)
Effect of variety						
V ₁	17.00	46.60	9.53	3.19	45.97	3.78
V ₂	18.47	47.47	8.37	3.72	44.13	3.72
V ₃	18.33	52.76	8.80	3.21	47.04	3.93
LSD (0.05)	0.69	1.59	0.30	0.03	1.97	0.40
CV (a)%	6.10	3.80	7.40	5.30	4.20	3.70
Effect of nitrogen						
N ₀	12.56	38.89	6.18	1.70	34.36	1.85
N ₁	14.66	46.22	7.66	2.29	41.45	2.18
N ₂	16.55	50.11	8.89	2.68	45.49	3.23
N ₃	19.11	53.44	10.22	3.52	48.79	3.45
N ₄	18.44	58.00	11.56	5.01	49.4	3.49
LSD (0.05)	0.67	1.91	0.57	0.17	2.64	0.48
Interaction effect of variety and nitrogen						
N ₀ ×V ₁	13.33	37.33	6.33	1.94	37.16	1.87
N ₁ ×V ₁	15.67	43.00	8.33	2.56	43.90	2.85
N ₂ ×V ₁	17.67	48.00	9.67	3.00	48.19	3.70
N ₃ ×V ₁	18.67	51.67	11.00	3.77	47.89	3.94
N ₄ ×V ₁	19.67	58.00	12.33	4.65	49.71	3.20
N ₀ ×V ₂	11.67	36.67	5.87	1.59	29.79	1.40
N ₁ ×V ₂	13.67	45.00	6.97	1.81	37.74	2.63
N ₂ ×V ₂	15.33	47.33	8.33	2.11	43.47	2.88
N ₃ ×V ₂	17.67	51.33	10.67	3.08	49.76	3.27
N ₄ ×V ₂	19.00	57.00	11.00	5.00	45.89	2.60
N ₀ ×V ₃	12.67	42.67	6.33	1.56	36.14	1.44
N ₁ ×V ₃	14.67	50.67	7.67	2.49	42.70	2.95
N ₂ ×V ₃	16.67	55.00	9.67	2.93	47.80	3.16
N ₃ ×V ₃	18.00	57.33	10.00	3.69	48.71	3.87
N ₄ ×V ₃	19.67	59.00	11.33	5.38	47.88	3.70
LSD (0.05)	1.17	3.31	0.98	0.03	4.56	0.84
CV (b)%	5.20	4.30	4.00	6.60	6.10	5.90

V₁= BARI Gom 26, V₂= BARI Gom 28, V₃= BARI Gom 30 and N₀ = 0 kg N ha⁻¹, N₁ = 60 kg N ha⁻¹, N₂ = 100 kg N ha⁻¹, N₃ = 120 kg N ha⁻¹ and N₄ = 140 kg N ha⁻¹

3.1.3.3.3 Spike length (cm)

Effect of variety on Spike length (cm)

The spike length of different wheat varieties significantly differed is shown in Table 3.1.23 for 2016-17 and Table 3.1.24 for 2017-18, respectively. Maximum spike length (13.65 cm) was observed in BARI Gom 30 which was statistically identical with BARI Gom 29 and minimum spike length (13.30 cm) was obtained in BARI Gom 28 during 2016-17 and maximum spike length (14.80 cm) was found in BARI Gom 30 and minimum spike length (13.75 cm) was found in BARI gom 30 during 2017-18. This result is in agreement with the findings of Nahar *et al.*, (2015) they reported that the variety BARI Gom 24 (V2) produced the longest spike (16.50, 15.84 and 16.02 cm respectively) which was significantly different from all other treatments. On the other hand, the variety BARI Gom 25 (V3) produced the shortest spike length (15.8, 15.2 and 15.4 cm respectively) which was statistically similar with the variety BARI Gom 21 (Shatabdi) (V1) and the variety BARI Gom 26 (V4).

Effect of nitrogen Spike length (cm)

Effect of N levels revealed that a highly significant variation on spike length for all growth stages (Table 3.1.23 for 2016-17 and Table 3.1.24 for 2017-18). Maximum spike length (16.84 cm) was observed with N₃ treatment (150 kg N ha⁻¹) which was significantly differ with other level on N doses. Minimum spike length (12.30 cm) was found with N₀ treatment (0.0 kg N ha⁻¹) during 2016-17. Highest spike length (15.56 cm) was obtained with N₄ treatment (140.0 kg N ha⁻¹) which was significantly differ from other N level and lowest spike length (9.18 cm) was found with control (0.0 kg N ha⁻¹) during 2017-18. This result is also in agreement with the findings of Nahar *et al.*, (2015) they reported that the highest spike length was found with N₁ (urea supergranules; 1.8 g) at all growth stages (16.74, 15.84 and 15.95 cm at 60, 90 DAS and at harvest respectively) which was statistically similar with N₃ (100 kg urea ha⁻¹) at the time of harvest. On the other hand, the lowest spike length (14.66, 14.66 and 14.93 cm at 60, 90 DAS and at harvest respectively) was found in N₀ (control) which was significantly different from all other treatments. Mandal *et al.*, (2015) was observed that the longest spike was found from N₂ (17.3 cm) which was statistically identical with N₁ (17.2 cm) and N₃ (16.5 cm) while minimum from N₀ (14.3 cm). Hasan (2011) also found that urea super granules when placed at 10 cm

depth at 20 DAS gave the longest spike (24.1 cm). The shortest spike length (17.3 cm) was recorded in the case of prilled urea broadcast. Similar results were also reported by Mozumder (2001); Rahman (2005) and Akter (2005).

Interaction effect of variety and nitrogen Spike length (cm)

The interaction effect of variety and nitrogen levels on spike length was statistically significant during both the year (Table 3.1.23 for 2016-17 and Table 3.1.24 for 2017-18). The maximum spike length (16.60 cm) was recorded by the interaction of N_2V_1 (100 kg N ha⁻¹ and BARI Gom 26) which was statistically similar with N_3V_1 (150 kg N ha⁻¹ and BARI Gom 26) and minimum spike length (14.40 cm) was recorded by the interaction of N_0V_2 (0.0 kg N ha⁻¹ and BARI Gom 28) during 2016-17. The maximum spike length (2135 ppm) was found with treatment combination N_4V_2 (140 kg N ha⁻¹ and BARI Gom 28) which was statistically similar with N_4V_1 (140 kg N ha⁻¹ and BARI Gom 26), N_3V_3 (150 kg N ha⁻¹ and BARI Gom 30) and minimum (1140) N_0V_3 (0.0 kg N ha⁻¹ and BARI Gom 30) during 2017-18. This result is also in agreement with the findings of Nahar *et al.*, (2015) they reported that the highest spike length was obtained from V_2N_1 at 60, 90 DAS and at harvest (17.97, 16.60 and 16.80 cm respectively) which was statistically similar with V_3N_1 at harvest. On the other hand, the lowest spike length at 60, 90 DAS and at harvest was observed as 14.10, 14.57 and 14.23 cm respectively with V_3N_0 which was statistically similar with V_1N_0 , V_2N_0 and V_4N_0 at 90 DAS.

3.1.3.3.4 Straw yield

Effect of variety Spike length (cm)

The spike length of different wheat varieties significantly differed is shown in Table 3.1.23 for 2016-17 and Table 3.1.24 for 2017-18, respectively. Maximum straw yield (4.23 t ha⁻¹) was observed in BARI Gom 30 which was statistically identical with BARI Gom 29 and minimum straw yield (3.67 t ha⁻¹) was obtained in BARI Gom 26 during 2016-17 and maximum straw yield (47.04) was found in BARI Gom 30 and minimum straw yield (44.13 t ha⁻¹) was found in BARI gom 28 during 2017-18. This result is also in agreement with the findings of Nahar *et al.*, (2015) they reported that the highest stover yield (3.57 t ha⁻¹) was found in V_1 (BARI Gom 21; Shatabdi) which was statistically similar with V_2 (BARI Gom 24) and V_3 (BARI Ghom 25). On

the other hand, the lowest stover yield (3.53 t ha^{-1}) was found in V₄ (BARI Ghom 26). Similar result was also found by Hussain *et al.* (2010).

Effect of nitrogen Spike length (cm)

Effect of N levels revealed that a highly significant variation on straw yield for all growth stages (Table 3.1.38 for 2016-17 and Table 3.1.39 for 2017-18). Maximum straw yield (3.82 t ha^{-1}) was observed with N₂ treatment (100 kg N ha^{-1}) which was significantly differed with other level on N doses. Minimum straw yield (2.39 t ha^{-1}) was found with N₀ treatment (0.0 kg N ha^{-1}) during 2016-17. Highest straw yield (5.01 t ha^{-1}) was obtained with N₄ treatment ($140.0 \text{ kg N ha}^{-1}$) which was significantly differed from other N level and lowest straw yield (1.70 t ha^{-1}) was found with control (0.0 kg N ha^{-1}) during 2017-18. This result is also in agreement with the findings of Nahar *et al.*, (2015) they reported that the highest straw yield (3.59 t ha^{-1}) was achieved from N₁ which was statistically similar with N₂ ($80 \text{ kg urea ha}^{-1}$), N₃ ($100 \text{ kg urea ha}^{-1}$) and N₄ ($120 \text{ kg urea ha}^{-1}$). On the other hand, the lowest stover yield (3.43 t ha^{-1}) was found in N₀ (control) which was also significantly different from all other treatments. Similar result was found by Akter (2005), Pandey *et al.* (2004), Das (2002) and Ottman *et al.* (2000).

Interaction effect of variety and nitrogen on Spike length (cm)

The interaction effect of variety and nitrogen levels on straw yield was statistically significant during both the year (Table 3.1.23 for 2016-17 and Table 3.1.24 for 2017-18). The maximum straw yield ($3.90 \text{ tons ha}^{-1}$) was recorded by the interaction of N₃V₂ (150 kg N ha^{-1} and BARI Gom 28) which was statistically similar with N₂V₄ (150 kg N ha^{-1} and BARI Gom 30) and N₃V₃ (150 kg N ha^{-1} and BARI Gom 29), while minimum straw yield ($2.54 \text{ tons ha}^{-1}$) was recorded by the interaction of N₀V₄ (0.0 kg N ha^{-1} and BARI Gom 30) during 2016-17. The maximum straw yield ($5.38 \text{ tons ha}^{-1}$) was found with treatment combination N₄V₃ (140 kg N ha^{-1} and BARI Gom 30) which was statistically similar with N₄V₂ (140 kg N ha^{-1} and BARI Gom 28), N₃V₁ (150 kg N ha^{-1} and BARI Gom 26) and minimum straw yield ($1.56 \text{ tons ha}^{-1}$) was recorded by the interaction of N₀V₃ (0.0 kg N ha^{-1} and BARI Gom 30) during 2017-18. This result is also in agreement with the findings of Nahar *et al.*, (2015) they reported that the highest straw yield (3.67 t ha^{-1}) was found with the treatment combination of V₂N₃ which was statistically similar with V₃N₄ and V₄N₁. The results obtained from V₁N₄, V₂N₂, V₃N₁ and V₄N₄ also showed

comparatively higher straw yield but significantly different from V_2N_3 . On the other hand the lowest straw yield (3.36 t ha^{-1}) was observed with V_2N_0 which was statistically similar with V_2N_0 and V_4N_0 .

3.1.3.3.5 Harvest index (%)

Effect of variety on Harvest index (%)

The harvest index of different wheat varieties significantly differed is shown in Table 3.1.23 for 2016-17 and Table 3.1.24 for 2017-18, respectively. Maximum harvest index (48.69) was observed in BARI Gom 30 which was statistically identical with BARI Gom 28 and minimum harvest index (39.00) was obtained in BARI Gom 29 during 2016-17. The maximum harvest index (47.04) was found in BARI Gom 30 and minimum harvest index (44.13) was found in BARI gom 28 during 2017-18. This result is also in agreement with the findings of Nahar *et al.*, (2015) they reported that the highest harvest index (41.08%) was found in V_2 (BARI Gom 24) which was statistically similar with V_4 (BARI Ghom 26). On the other hand the lowest harvest index (39.00%) was found in V_4 (BARI Ghom 26) which was statistically similar with V_1 (BARI Gom 21; Shatabdi). The results obtained from the present study were conformity with the findings of Khakwani *et al.* (2012), Hussain *et al.* (2010) and Tariq (2010).

Effect of nitrogen on Harvest index (%)

Effect of N levels revealed that a highly significant variation on harvest index for all growth stages (Table 3.1.23 for 2016-17 and Table 3.1.24 for 2017-18). The maximum harvest index (49.20) was observed with N_2 treatment (100 kg N ha^{-1}) which was significantly differed with other level on N doses. Minimum harvest index (33.96) was found with N_0 treatment (0.0 kg N ha^{-1}) during 2016-17. Highest harvest index (49.40) was obtained with N_4 treatment ($140.0 \text{ kg N ha}^{-1}$) which was significantly differed from other N level and lowest harvest index (34.36) was found with control (0.0 kg N ha^{-1}) during 2017-18. This result is also in agreement with the findings of Nahar *et al.*, (2015) they reported that the highest harvest index (43.96%) was achieved from N_1 (urea supergranules; 1.8 g) which was significantly different from all other treatments. On the other hand, the lowest harvest index (35.69%) was found in N_0 (control) which was also significantly different from all other treatments. The results obtained from all other treatments gave intermediate results compared to the highest and the lowest harvest index.

The results obtained from the present study were also conformity with the findings of Rahman (2005), Pandey *et al.* (2004), Das (2002) and Mozumder (2001).

Interaction effect of variety and nitrogen on Harvest index (%)

The interaction effect of variety and nitrogen levels on harvest index was statistically significant during both the year (Table 3.1.23 for 2016-17 and Table 3.1.24 for 2017-18). The maximum harvest index (45.39) was recorded by the interaction of N_3V_1 (150 kg N ha⁻¹ and BARI Gom 26) which was statistically similar with N_2V_2 (100 kg N ha⁻¹ and BARI Gom 28), N_2V_4 (100 kg N ha⁻¹ and BARI Gom 30) and N_3V_4 (150 kg N ha⁻¹ and BARI Gom 30); while minimum harvest index (34.98) was recorded by the interaction of N_0V_4 (0.0 kg N ha⁻¹ and BARI Gom 30) during 2016-17. The maximum harvest index (49.76) was found with treatment combination N_4V_2 (140 kg N ha⁻¹ and BARI Gom 28) which was statistically similar with N_3V_2 (120 kg N ha⁻¹ and BARI Gom 28), N_4V_1 (140 kg N ha⁻¹ and BARI Gom 26), and while minimum harvest index (29.79) was recorded by the interaction of N_0V_2 (0.0 kg N ha⁻¹ and BARI Gom 28) during 2017-18. This result is also in agreement with the findings of Nahar *et al.*, (2015) they reported that the highest harvest index (45.39%) was found with the treatment combination of V_2N_1 which was statistically similar with V_4N_1 . The results obtained from V_1N_1 , V_2N_3 , V_2N_4 , V_4N_2 and V_4N_3 also showed comparatively higher harvest index but significantly different from V_2N_1 . On the other hand, the lowest harvest index (34.98%) was observed with V_3N_0 which was statistically similar with V_4 . The treatment combinations of V_1N_0 , V_1N_3 and V_2N_0 also showed comparatively lower harvest index but significantly different from V_3N_0 .

3.1.3.3.6 Grain yield

Effect of variety on Grain yield

The grain yield of different wheat varieties significantly differed is shown in Table 3.1.23 for 2016-17 and Table 3.1.24 for 2017-18, respectively. Maximum grain yield (3.43 t ha^{-1}) was observed in BARI Gom 30 which was statistically identical with BARI Gom 29 and minimum grain yield (3.29 t ha^{-1}) was obtained in BARI Gom 26 during 2016-17. The maximum grain yield (3.93 t ha^{-1}) was found in BARI Gom 30 and minimum grain yield (3.72 t ha^{-1}) was found in BARI Gom 28 during 2017-18. This result is in agreement with the findings of Nahar *et al.*, (2015) they reported that the highest grain yield (2.49 t ha^{-1}) was found in V₂ (BARI Gom 24) which was statistically similar with V₄ (BARI Gom 26). On the other hand, the lowest grain yield (2.28 t ha^{-1}) was found in V₃ (BARI Gom 25) which was statistically similar with V₁ (BARI Gom 21; Shatabdi). The results obtained from the present study were also conformity with the findings of Khakwani *et al.* (2012), Nadim *et al.* (2012).

Effect of nitrogen on Grain yield

Effect of N levels revealed that a highly significant variation on grain yield for all growth stages (Table 3.1.23 for 2016-17 and Table 3.1.24 for 2017-18). Maximum grain yield (3.89 t ha^{-1}) was observed with N₃ treatment (150 kg N ha^{-1}) which was significantly differed with other level on N doses. Minimum grain yield (1.69 t ha^{-1}) was found with N₀ treatment (0.0 kg N ha^{-1}) during 2016-17. Highest grain yield (3.49 t ha^{-1}) was obtained with N₄ treatment ($140.0 \text{ kg N ha}^{-1}$) which was significantly differed from other N level and lowest grain yield (1.85 t ha^{-1}) was found with control (0.0 kg N ha^{-1}) during 2017-18. This result is also in agreement with the findings of Nahar *et al.*, (2015) they reported that the highest grain yield (2.69 t ha^{-1}) was achieved from N₁ (urea supergranules; 1.8 g) which was significantly different from all other treatments. On the other hand, the lowest grain yield (1.97 t ha^{-1}) was found in N₀ (control) which was also significantly different from all other treatments. The results obtained from all other treatments gave intermediate results. The results obtained from the present study was conformity with the findings of Chandurkar *et al.* (2004), Rahman (2005), Akter (2005) and Yadav *et al.* (2005).

Interaction effect of variety and nitrogen Grain yield

The interaction effect of variety and nitrogen levels on grain yield was statistically significant during both the year (Table 3.1.23 for 2016-17 and Table 3.1.24 for 2017-18). The maximum grain yield (3.97 t ha^{-1}) was recorded by the interaction of N_3V_4 (150 kg N ha^{-1} and BARI Gom 30) which was statistically similar with N_2V_3 (100 kg N ha^{-1} and BARI Gom 29), N_3V_2 (100 kg N ha^{-1} and BARI Gom 28) while minimum grain yield (1.87 t ha^{-1}) was recorded by the interaction of N_0V_3 (0.0 kg N ha^{-1} and BARI Gom 29) during 2016-17. The maximum grain yield (3.94 t ha^{-1}) was found with treatment combination N_3V_1 (120 kg N ha^{-1} and BARI Gom 26) which was statistically similar with N_3V_3 (120 kg N ha^{-1} and BARI Gom 30), N_3V_2 (120 kg N ha^{-1} and BARI Gom 28) and while minimum grain yield (1.40 t ha^{-1}) was recorded by the interaction of N_0V_2 (0.0 kg N ha^{-1} and BARI Gom 28) during 2017-18. Results This result is also in agreement with the findings of Nahar *et al.*, (2015) they reported that the highest grain yield (2.80 t ha^{-1}) was found with the treatment combination of V_2N_1 which was statistically similar with V_4N_1 and significantly similar with V_2N_4 . The results obtained from V_1N_1 , V_3N_1 , V_4N_2 and V_4N_3 also showed comparatively higher grain yield but significantly different from V_2N_1 . On the other hand, the lowest grain yield (1.97 t ha^{-1}) was observed with V_3N_0 and V_4N_0 which was statistically similar with V_1N_0 and V_2N_0 . The treatment combinations of V_1N_3 , V_3N_2 and V_3N_3 also showed comparatively lower grain yield but significantly different from V_3N_0 . Kumar *et al.*, (2011) found that highest grain yield (4.93 t ha^{-1}) was given by Prodip with 135 kg N ha^{-1} which was statistically similar to Prodip with 90 kg N ha^{-1} (3.82 t ha^{-1}) and lowest grain yield (0.62 t ha^{-1}) was given by Bijoy with control. Similar trend of the effect of nitrogen was observed by Upadhyay & Tiwari (1996) and Alam *et al.* (2007). Ali *et al.* (2005) also reported that the interactions between cultivars and nitrogen levels were found to be significant. Bakhar-2000 gave maximum grain yield ($4.85 \text{ tons ha}^{-1}$) with 210 kg N ha^{-1} while minimum grain yield was obtained ($3.50 \text{ tons ha}^{-1}$) in case of Inqlab-91 under control conditions

3.1.3.4 Correlation matrix of different traits of wheat

3.1.3.4.1 Genotypic (r_g) and phenotypic (r_p) correlation matrix among the morpho-physiological trait of wheat

The phenotypic and genotypic correlation matrix among the morpho-physiological traits are presented in Table 25 & Table 26 for during 2016-17 and Table 27 & Table 28 for during 2017-18. Both the year, genotypic correlation coefficients were higher than their corresponding phenotypic correlation in most of the cases which indicated that the association was largely due to genetic factors. Highly significant positive genotypic and phenotypic correlation was observed for plant height with LAI ($r_g=0.85$, $r_p=0.82$), NDVI ($r_g=0.80$, $r_p=0.52$), CC ($r_g=0.68$, $r_p=0.66$), SPAD ($r_g=0.63$, $r_p=0.56$), LNC ($r_g=0.68$, $r_p=0.65$), Chl a ($r_g=0.65$, $r_p=0.64$), Chl b ($r_g=0.52$, $r_p=0.48$) and TDM ($r_g=0.75$, $r_p=0.72$) during 2016-17 (Table 3.1.25 and Table 3.1.26).

Plant height had positive and significant correlation with LAI ($r_g=0.86$, $r_p=0.72$), NDVI ($r_g=0.96$, $r_p=0.88$), CC ($r_g=0.96$, $r_p=0.82$), SPAD ($r_g=0.88$, $r_p=0.60$), LNC ($r_g=0.90$, $r_p=0.64$) and TDM ($r_g=0.75$, $r_p=0.59$) during 2017-18 (Table 3.1.27 and Table 3.1.28). . These results indicated that LAI, NDVI, CC, LNC and TDM would be increased with increasing of plant height

Leaf area index (LAI) had positive and significant correlation with NDVI ($r_g=0.81$, $r_p=0.50$), CC ($r_g=0.78$, $r_p=0.73$), SPAD ($r_g=0.79$, $r_p=0.61$), LNC ($r_g=0.88$, $r_p=0.82$), Chl a ($r_g=0.85$, $r_p=0.56$), Chl b ($r_g=0.80$, $r_p=0.74$), and TDM ($r_g=0.90$, $r_p=0.85$) during 2016-17 (Table 3.1.25 and Table 3.1.26).

LAI had positive and significant correlation with NDVI ($r_g=0.85$, $r_p=0.78$), CC ($r_g=0.81$, $r_p=0.69$), SPAD ($r_g=0.84$, $r_p=0.51$), LNC ($r_g=0.79$, $r_p=0.57$), Chl a ($r_g=0.77$, $r_p=0.28$), Chl b ($r_g=-0.23$, $r_p=0.07$), and TDM ($r_g=0.74$, $r_p=0.72$) during 2017-18 (Table 3.1.27 and Table 3.1.28).

Significant positive genotypic and phenotypic correlation was observed for NDVI with CC ($r_g=0.71$, $r_p=0.55$), SPAD ($r_g=0.85$, $r_p=0.46$), LNC ($r_g=0.78$, $r_p=0.48$), and TDM ($r_g=0.93$, $r_p=0.57$) during 2016-17 (Table 3.1.25 and Table 3.1.26). However, this was insignificant both in genotypic and phenotypic components with Chl b ($r_g= 0.30$, $r_p= 0.12$) and Car ($r_g= -0.11$, $r_p= -0.21$). The assorted results might be indicating the plausible involvement of microclimatic factors.

NDVI had positive and significant correlation with CC ($r_g=0.98$, $r_p=0.92$), SPAD ($r_g=0.86$, $r_p=0.67$), LNC ($r_g=0.91$, $r_p=0.72$), Chl a ($r_g=0.83$, $r_p=0.30$) and TDM ($r_g=0.72$, $r_p=0.50$) during 2017-18 (Table 3.1.27 and Table 3.1.28). However, this was insignificant and negative both in genotypic and phenotypic components with Chl b ($r_g= -0.06$, $r_p=-0.09$) and Car ($r_g= -0.44$, $r_p= -0.32$). Significant positive genotypic and phenotypic correlation was observed for CC with SPAD ($r_g=0.74$, $r_p=0.53$), LNC ($r_g=0.90$, $r_p=0.85$), Chl a ($r_g=0.86$, $r_p=0.83$) and TDM ($r_g=0.71$, $r_p=0.58$) during 2017-18 (Table 3.1.25 and Table 3.1.26). However, this was insignificant and negative both in genotypic and phenotypic components with Chl b ($r_g= -0.31$, $r_p= -0.20$) and Car ($r_g= -0.38$, $r_p= -0.23$).

Highly significant positive genotypic and phenotypic correlation was observed for CC with SPAD ($r_g=0.86$, $r_p=0.54$), LNC ($r_g=0.92$, $r_p=0.74$), Chl a ($r_g=0.82$, $r_p=0.65$) and TDM ($r_g=0.71$, $r_p=0.58$) during 2017-18 (Table 3.1.27 and Table 3.1.28). The results showed that the genotypic correlation value was higher than the phenotypic correlation of CC which is indicated that CC is highly influenced by environment. However, this was insignificant both in genotypic and phenotypic components with Chl b ($r_g= 0.30$, $r_p=0.12$) and Car ($r_g=0.-0.11$, $r_p=-0.21$). SPAD had positive and significant correlation with LNC ($r_g=0.74$, $r_p=0.62$), Chl a ($r_g=0.80$, $r_p=0.66$), Chl b ($r_g=0.87$, $r_p=0.67$), Car ($r_g=0.61$, $r_p=0.54$) and TDM ($r_g=0.73$, $r_p=0.63$) during 2016-17 (Table 3.1.25 and Table 3.1.26).

SPAD had positive and significant correlation with LNC ($r_g=0.79$, $r_p=0.57$), Chl a ($r_g=0.77$, $r_p=0.28$), Chl b ($r_g=-0.23$, $r_p=0.07$), and TDM ($r_g=0.74$, $r_p=0.72$) during 2017-18 (Table 3.1.27 and Table 3.1.28). This result suggested that increase in the SPAD value increases the LNC and TDM of wheat at 75 DAS. Parvizi *et al.* (2004) observed that the SPAD meter reading correlated well ($r=0.92^*$) with dry matter yield in wheat. In general, such relationship become stronger at the reproductive phase of crops. Ramesh *et al.* (2002) observed highly significant correlations of SPAD readings with the grain yield of direct wet seeded rice at 79 DAS. Many studies using the SPAD to assess N status have shown reliable indication of N stress and relationship to relative yield (Earl and Tollenaar, 1997; Fox *et al.*, 2001). SPAD reading was found closely related to grain yield reported by Blackmer and Schepers, (1995); Maiti *et al.*, (2004); Boggs *et al.*, (2003).

Table 3.1.25. Genotypic (r_g) correlation matrix of morpho-physiological trait of wheat during 2016-17

	PH	LAI	NDVI	CC	SPAD	LNC	Chl a	Chl b	Car	TDM
PH	1									
LAI	0.85**	1								
NDVI	0.80**	0.81**	1							
CC	0.68**	0.78**	0.71**	1						
SPAD	0.63**	0.79**	0.85**	0.74**	1					
LNC	0.68**	0.88**	0.78**	0.90**	0.74**	1				
Chl a	0.65**	0.85**	0.68**	0.86**	0.80**	0.71**	1			
Chl b	0.52**	0.80**	-0.31 ^{ns}	-0.24 ^{ns}	0.87**	0.75**	0.67**	1		
Car	0.25 ^{ns}	-0.10 ^{ns}	-0.31 ^{ns}	-0.38 ^{ns}	0.61**	-0.40 ^{ns}	-0.33 ^{ns}	0.49 ^{ns}	1	
TDM	0.75**	0.90**	0.93**	0.88**	0.73**	0.87**	0.75**	0.68**	0.09 ^{ns}	1

NS: Non-Significant at 5%, *: Significant at 5%, **: Highly Significant at 1

PH = Plant height (cm), LAI= Leaf Area Index, NDVI= Normalized Difference Vegetative Index, CC= Canopy Cover, SPAD= Soil Plant Analysis Development, LNC= Leaf Nitrogen Content (ppm), Chl a= Chlorophyll a content (mg g⁻¹), Chl b= Chlorophyll b content (mg g⁻¹), Car= Carotenoid Content (mg g⁻¹), TDM= Total Dry Matter (gm⁻²)

Table 3.1.26. Phenotypic (r_p) correlation matrix of morpho-physiological trait of wheat during 2016-17

	PH	LAI	NDVI	CC	SPAD	LNC	Chl a	Chl b	Car	TDM
PH	1									
LAI	0.82**	1								
NDVI	0.52 ^{ns}	0.50**	1							
CC	0.66**	0.73**	0.55**	1						
SPAD	0.56**	0.61**	0.46*	0.53**	1					
LNC	0.65**	0.82**	0.48*	0.85**	0.62**	1				
Chl a	0.64**	0.56**	-0.20 ^{ns}	0.83**	0.66**	0.65**	1			
Chl b	0.48**	0.74**	0.12 ^{ns}	-0.19 ^{ns}	0.44**	0.67**	0.64**	1		
Car	0.13 ^{ns}	-0.07 ^{ns}	-0.21 ^{ns}	-0.23 ^{ns}	0.54**	-0.36 ^{ns}	-0.28 ^{ns}	-0.31 ^{ns}	1	
TDM	0.72**	0.85**	0.57*	0.85**	0.63**	0.81**	0.69**	0.62**	0.14 ^{ns}	1

NS: Non-Significant at 5%, *: Significant at 5%, **: Highly Significant at 1

PH = Plant height (cm), LAI= Leaf Area Index, NDVI= Normalized Difference Vegetative Index, CC= Canopy Cover, SPAD= Soil Plant Analysis Development, LNC= Leaf Nitrogen Content (ppm), Chl a= Chlorophyll a content (mg g⁻¹), Chl b= Chlorophyll b content (mg g⁻¹), Car= Carotenoid Content (mg g⁻¹), TDM= Total Dry Matter (gm⁻²)

Table 3.1.27. Genotypic (r_g) correlation matrix of morpho-physiological trait of wheat during 2017-18

	PH	LAI	NDVI	CC	SPAD	LNC	Chl a	Chl b	Car	TDM
PH	1									
LAI	0.86**	1								
NDVI	0.96**	0.85**	1							
CC	0.96**	0.81**	0.98**	1						
SPAD	0.88**	0.84**	0.86**	0.86**	1					
LNC	0.90**	0.79**	0.91**	0.92**	0.91**	1				
Chl a	0.84**	0.77**	0.83**	0.82**	0.89**	0.84**	1			
Chl b	-0.12	-0.23	-0.06	-0.06	-0.11	-0.14	0.78**	1		
Car	0.48*	0.35	-0.44	0.45	0.27	0.32	0.38 ^{ns}	-0.36 ^{ns}	1	
TDM	0.75**	0.74**	0.72**	0.71**	0.79**	0.77**	0.81**	0.33 ^{ns}	0.40 ^{ns}	1

NS: Non-Significant at 5%, *: Significant at 5%, **: Highly Significant at 1

PH = Plant height (cm), LAI= Leaf Area Index, NDVI= Normalized Difference Vegetative Index, CC= Canopy Cover, SPAD= Soil Plant Analysis Development, LNC= Leaf Nitrogen Content (ppm), Chl a= Chlorophyll a content (mg g^{-1}), Chl b= Chlorophyll b content (mg g^{-1}), Car= Carotenoid Content (mg g^{-1}), TDM= Total Dry Matter (gm^{-2})

Table 3.1.28. Phenotypic (r_p) correlation matrix of morpho-physiological trait of wheat during 2017-18

	PH	LAI	NDVI	CC	SPAD	LNC	Chl a	Chl b	Car	TDM
PH	1									
LAI	0.72**	1								
NDVI	0.88**	0.78**	1							
CC	0.82**	0.69**	0.92**	1						
SPAD	0.60**	0.51*	0.67**	0.54**	1					
LNC	0.64**	0.57*	0.72**	0.74**	0.80**	1				
Chl a	0.24 ^{ns}	0.28 ^{ns}	0.30 ^{ns}	0.65**	0.58**	0.72**	1			
Chl b	0.07 ^{ns}	0.07 ^{ns}	-0.09 ^{ns}	0.15 ^{ns}	-0.17 ^{ns}	-0.23 ^{ns}	0.69**	1		
Car	-0.17 ^{ns}	-0.06 ^{ns}	-0.32 ^{ns}	-0.25 ^{ns}	-0.27 ^{ns}	-0.12 ^{ns}	0.29 ^{ns}	-0.19 ^{ns}	1	
TDM	0.59*	0.61*	0.50*	0.58**	0.68**	0.71**	0.53*	0.20 ^{ns}	0.18 ^{ns}	1

NS: Non-Significant at 5%, *: Significant at 5%, **: Highly Significant at 1

PH = Plant height (cm), LAI= Leaf Area Index, NDVI= Normalized Difference Vegetative Index, CC= Canopy Cover, SPAD= Soil Plant Analysis Development, LNC= Leaf Nitrogen Content (ppm), Chl a= Chlorophyll a content (mg g^{-1}), Chl b= Chlorophyll b content (mg g^{-1}), Car= Carotenoid Content (mg g^{-1}), TDM= Total Dry Matter (gm^{-2})

Highly significant positive genotypic and phenotypic correlation was observed for LNC with Chl a ($r_g=0.71$, $r_p=0.$), Chl b ($r_g=0.75$, $r_p=0.67$) and TDM ($r_g=0.87$, $r_p=0.81$) during 2016-17 (Table 3.1.25 and Table 3.1.26). However, this was insignificant and negative both in genotypic and phenotypic components with Car ($r_g= -0.40$, $r_p= -0.36$). Spaner *et al.* (2005) and Shukla *et al.* (2004) have successfully used leaf chlorophyll concentrations estimated by SPAD meter for assessing the N status in wheat.

Chl a had positive and significant correlation with Chl b ($r_g=0.67$, $r_p=0.64$) and TDM ($r_g=0.75$, $r_p=0.69$) during 2016-17. However, this was insignificant and negative both in genotypic and phenotypic components with Car ($r_g= -0.33$, $r_p= -0.28$).

Highly significant positive genotypic and phenotypic correlation was observed for Chl a with Chl b ($r_g=0.78$, $r_p=0.69$) and TDM ($r_g=0.81$, $r_p=0.53$) during 2017-18 (Table 3.1.27 and Table 3.1.28). However, this was insignificant both in genotypic and phenotypic components with Car ($r_g=0.38$, $r_p=-0.29$). The assorted results might be indicating the plausible involvement of microclimatic factors.

Both genotypic and phenotypic correlation co-efficient analyses carried in this study suggested that plant height (PH), leaf area index (LAI), normalized difference vegetative index (NDVI), canopy cover (CC), soil plant analysis development (SPAD), leaf nitrogen content (LNC), chlorophyll a content (Chl a) are major components of total dry matter (TDM). The correlation coefficient analysis of wheat varieties and nitrogen levels interaction indicated that the physiological traits NDVI, CC, SPAD and LNC were directly correlated with TDM at 75 DAS, which would be effective trait for improvement of dry matter accumulation as well as yield of wheat.

3.1.3.5 Regression analysis of different morpho-physiological trait of wheat with different nitrogen levels

The regression analysis of some morpho-physiological traits of wheat at different nitrogen levels for the year of 2016-17 and 2017-18 was carried out and the result is presented in Figure 3.1.41-3.1.50 for 75 DAS.

3.1.3.5.1 Response of plant height against different nitrogen levels

The response of plant height against different nitrogen levels in both the years were linear and positively significant for all the varieties. This showed that increasing different nitrogen level significantly increased plant height of different variety of wheat (Figure 3.1.41-3.1.42). The linear models had an R^2 value of 0.91 for BARI Gom 26, 0.71 for BARI Gom 28, 0.75 for BARI Gom 29 and 0.79 for BARI Gom 30 during 2016-17 and R^2 value of 0.96 for BARI Gom 26, 0.98 for BARI Gom 28, and 0.99 for BARI Gom 30 during 2017-18, respectively which indicating that higher doses of nitrogen provided taller plant. The linear equations were y (BARI Gom 26) $=88+0.11x$, y (BARI Gom 28) $=94+0.09x$, y (BARI Gom 29) $=92+0.12x$ and y (BARI Gom 30) $=87+0.14x$ during 2016-17 and the linear relationships as estimated were y (BARI Gom 26) $=58+0.14x$, y (BARI Gom 28) $=59+0.18x$ and y (BARI Gom 30) $=54+0.18x$, during 2017-18, respectively.

3.1.3.5.2 Response of Leaf Area index (LAI) against different nitrogen levels

Response on Leaf Area index (LAI) of wheat varieties at different doses of nitrogen presented in Figure 3.1.43-3.1.44. The relationship between LAI and different nitrogen levels in both the years were linear and positively significant for all the varieties. The linear models had an R^2 value of 0.96 for BARI Gom 26, 0.90 for BARI Gom 28, 0.80 for BARI Gom 29 and 0.92 for BARI Gom 30 during 2016-17 and R^2 value of 0.95 for BARI Gom 26, 0.92 for BARI Gom 28, and 0.76 for BARI Gom 30 during 2017-18, respectively which indicating that higher doses of nitrogen provided higher LAI. The linear equations were y (BARI Gom 26) $=0.73+0.021x$, y (BARI Gom 28) $=0.70+0.019x$, y (BARI Gom 29) $=0.80+0.019x$ and y (BARI Gom 30) $=0.65+0.016x$ during 2016-17 and the linear relationships as estimated were y (BARI Gom 26) $=1.4+0.0065x$, y (BARI Gom 28) $=1.4+0.0063x$ and y (BARI Gom 30) $=1.1+0.0094x$, during 2017-18, respectively.

3.1.3.5.3 Response of NDVI against different nitrogen levels

Response on NDVI of wheat varieties at different doses of nitrogen presented in Figure 3.1.45-3.1.46. The relationship between NDVI and different nitrogen levels in both the years were linear and positively significant for all the varieties. The linear models had an R^2 value of 0.80 for BARI Gom 26, 0.74 for BARI Gom 28, 0.84 for BARI Gom 29 and 0.73 for BARI Gom 30 during 2016-17 and R^2 value of 0.98 for BARI Gom 26, 0.97 for BARI Gom 28, and 0.99 for BARI Gom 30 during 2017-18, respectively which indicating that higher doses of nitrogen provided higher NDVI. The linear equations were y (BARI Gom 26) $=0.55+0.0018x$, y (BARI Gom 28) $=0.52+0.0019x$, y (BARI Gom 29) $=0.55+0.0017x$ and y (BARI Gom 30) $=0.52+0.002x$ during 2016-17 and the linear relationships as estimated were y (BARI Gom 26) $=0.50+0.0032x$, y (BARI Gom 28) $=0.52+0.0037x$ and y (BARI Gom 30) $=0.48+0.0034x$, during 2017-18, respectively.

3.1.3.5.4 Response of Canopy Cover (CC) against different nitrogen levels

The response of Canopy Cover (CC) against different nitrogen levels in both the years were linear and positively significant for all the varieties. This showed that increasing different nitrogen level significantly increased CC of different variety of wheat (Figure 3.1.47-3.1.48). The linear models had an R^2 value of 0.97 for BARI Gom 26, 0.98 for BARI Gom 28, 0.95 for BARI Gom 29 and 0.96 for BARI Gom 30 during 2016-17 and R^2 value of 0.96 for BARI Gom 26, 0.96 for BARI Gom 28, and 0.95 for BARI Gom 30 during 2017-18, respectively which indicating that higher doses of nitrogen provided higher CC. The linear equations were y (BARI Gom 26) $=0.64+0.0016x$, y (BARI Gom 28) $=0.71+0.0017x$, y (BARI Gom 29) $=0.79+0.0015x$ and y (BARI Gom 30) $=0.64+0.0018x$ during 2016-17 and the linear relationships as estimated were y (BARI Gom 26) $=0.63+0.0017x$, y (BARI Gom 28) $=0.70+0.0018x$ and y (BARI Gom 30) $=0.63+0.002x$, during 2017-18, respectively.

3.1.3.5.5 Response of TDM against different nitrogen levels

Response on TDM accumulation of wheat varieties at different doses of nitrogen presented in Figure 3.1.49-3.1.50. The relationship between TDM and different nitrogen levels in both the years were linear and positively significant for all the varieties. The linear models had an R^2 value of 0.95 for BARI Gom 26, 0.98 for BARI Gom 28, 0.96 for BARI Gom 29 and 0.93 for BARI Gom 30 during 2016-17 and R^2 value of 0.92 for BARI Gom 26, 0.87 for BARI Gom 28, and 0.94 for BARI Gom 30 during 2017-18, respectively which indicating that higher doses of nitrogen provided higher TDM. The linear equations were y (BARI Gom 26) = $680 + 2.0x$, y (BARI Gom 28) = $700 + 1.9x$, y (BARI Gom 29) = $670 + 2.4x$ and y (BARI Gom 30) = $670 + 2.1x$ during 2016-17 and the linear relationships as estimated were y (BARI Gom 26) = $570 + 4.4x$, y (BARI Gom 28) = $660 + 3.9x$ and y (BARI Gom 30) = $680 + 5x$, during 2017-18, respectively.

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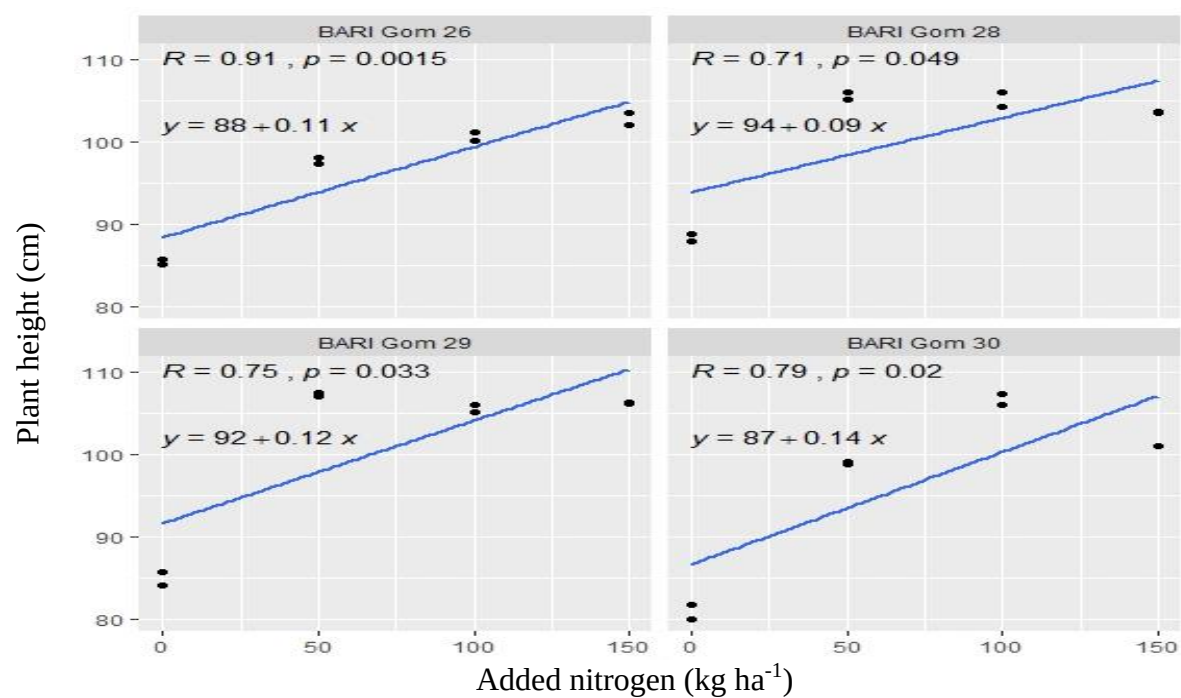


Figure 3.1.41: Response on plant height (PH) of wheat varieties at different doses of nitrogen during 2016-17.

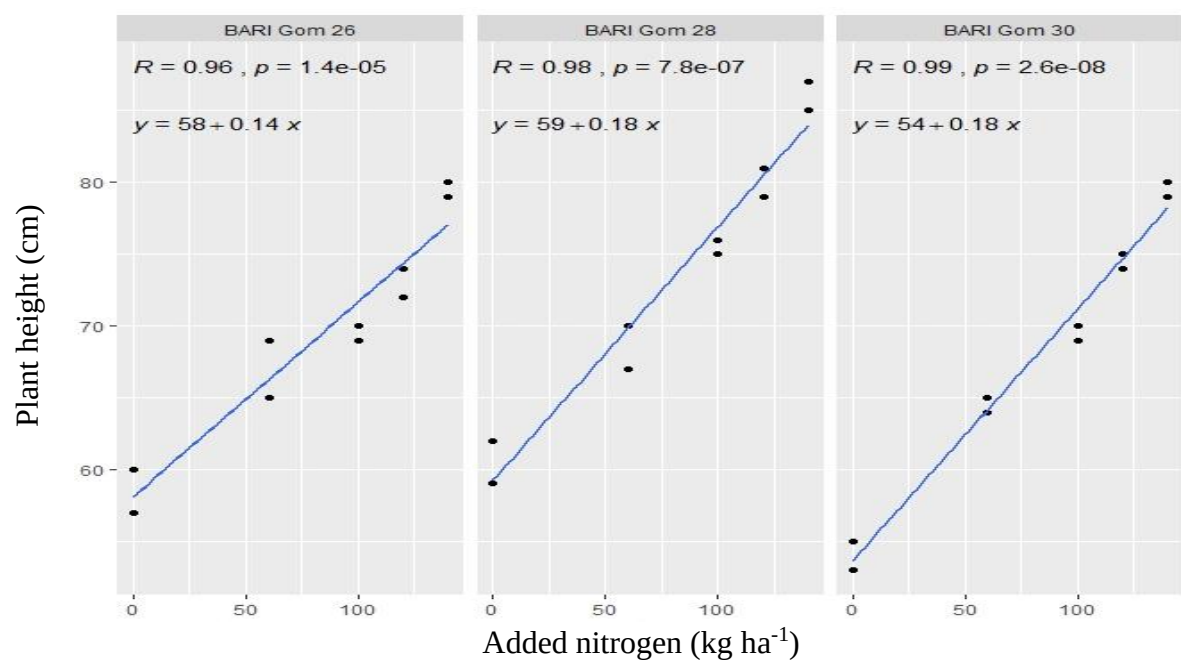


Figure 3.1.42: Response on plant height (PH) of wheat varieties at different doses of nitrogen during 2017-18.

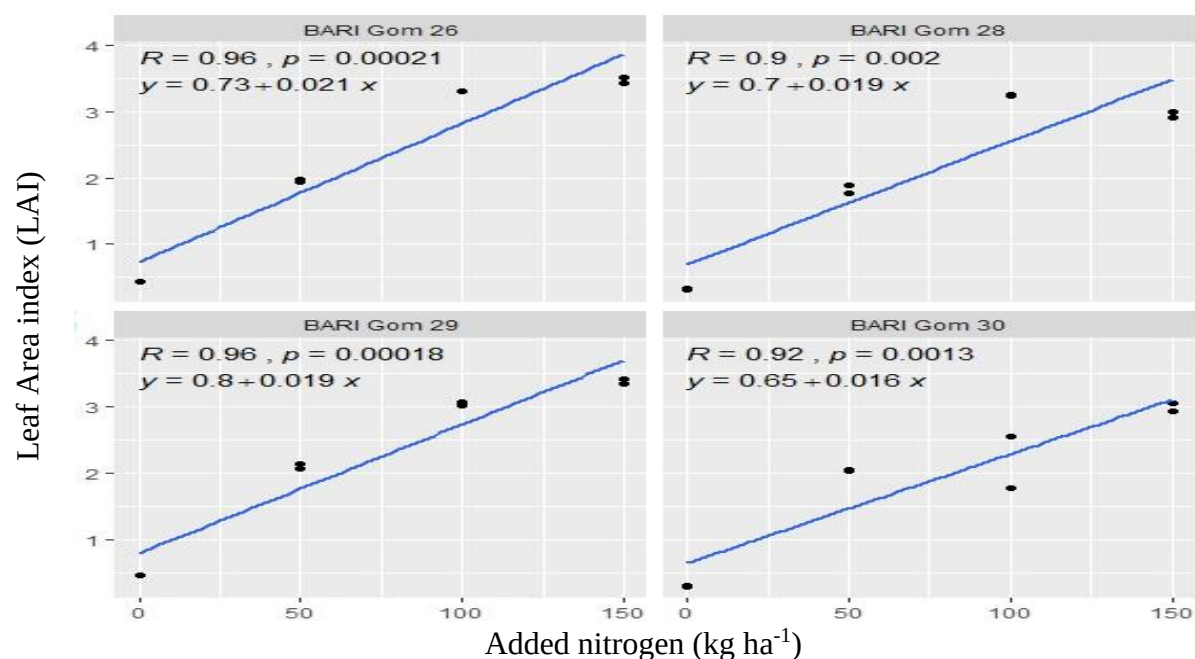


Figure 3.1.43: Response on Leaf Area index (LAI) of wheat varieties at different doses of nitrogen during 2016-17.

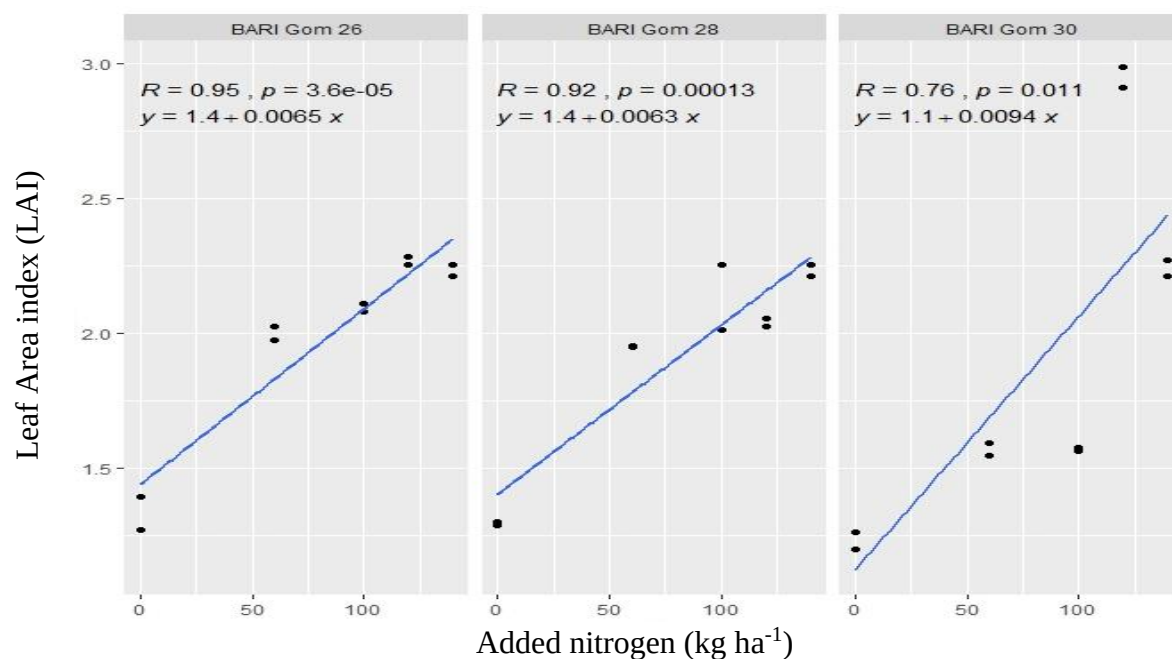


Figure 3.1.44: Response on Leaf Area index (LAI) of wheat varieties at different doses of nitrogen during 2017-18.

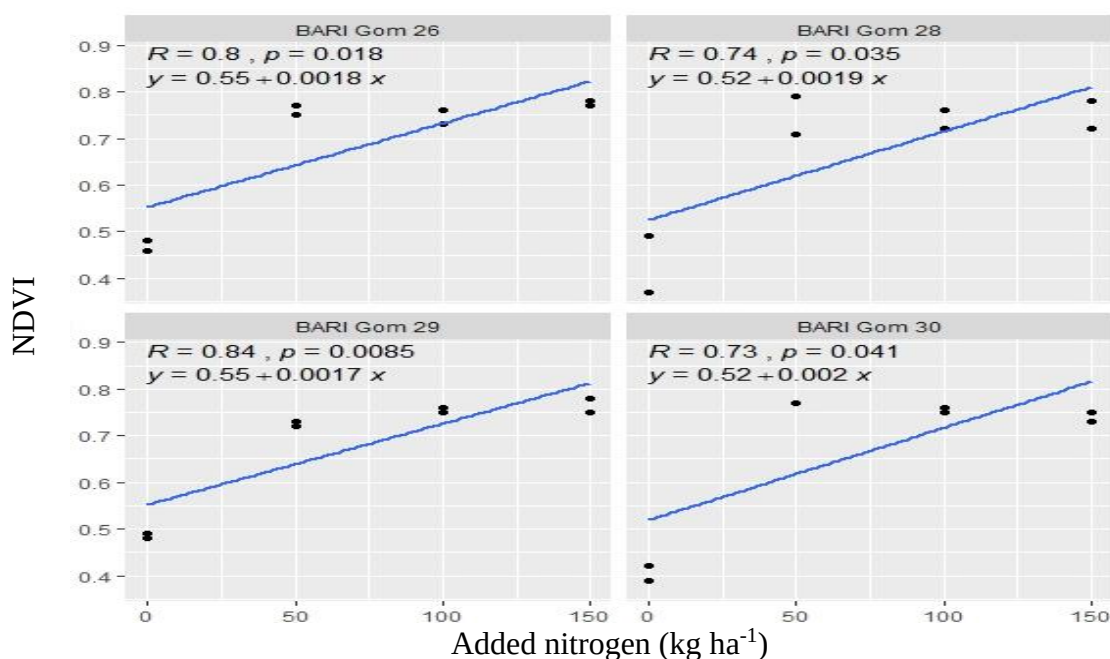


Figure 3.1.45: Response on NDVI of wheat varieties at different doses of nitrogen (2016-17).

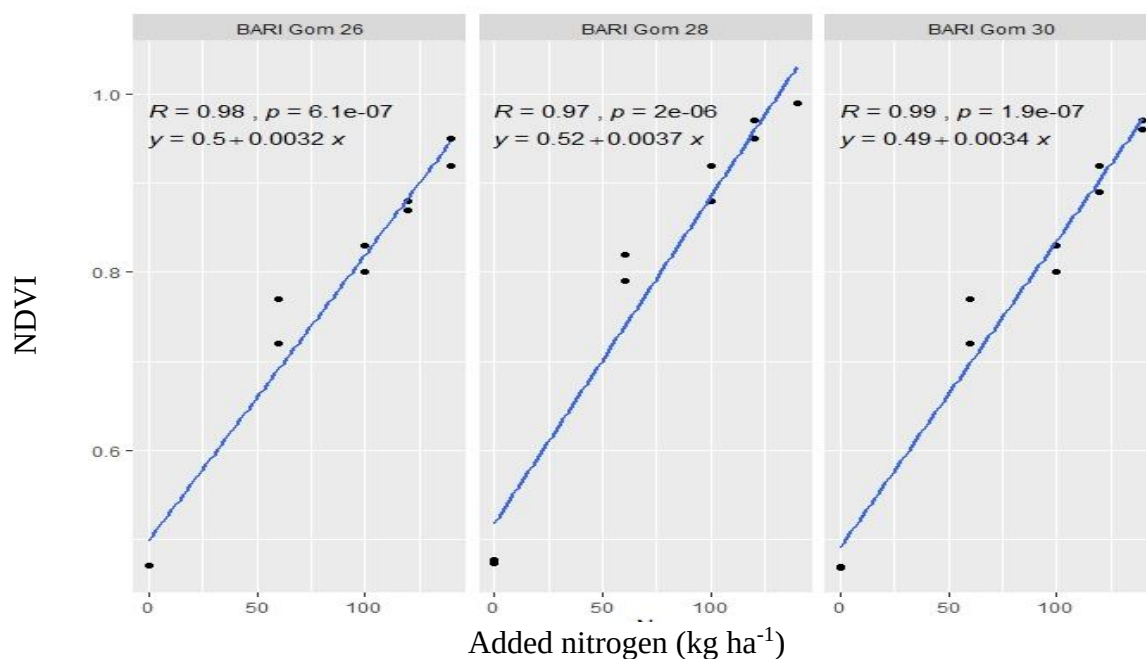


Figure 3.1.46: Response on NDVI of wheat varieties at different doses of nitrogen during 2017-18.

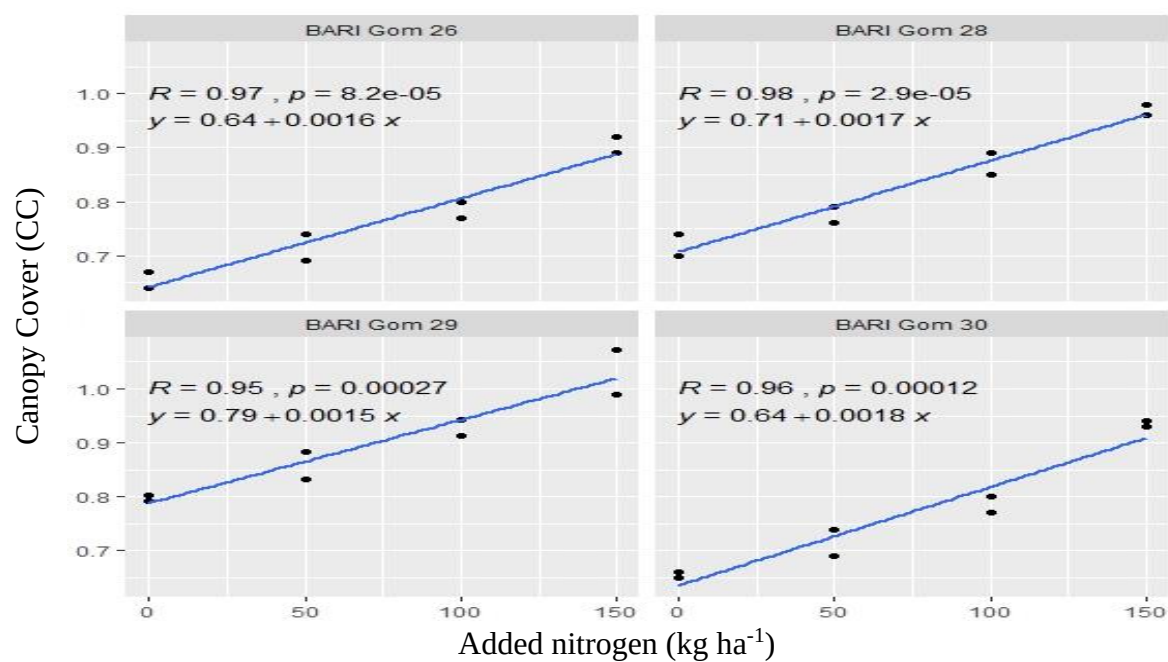


Figure 3.1.47: Response on Canopy Cover (CC) of wheat varieties at different doses of nitrogen during 2016-17.

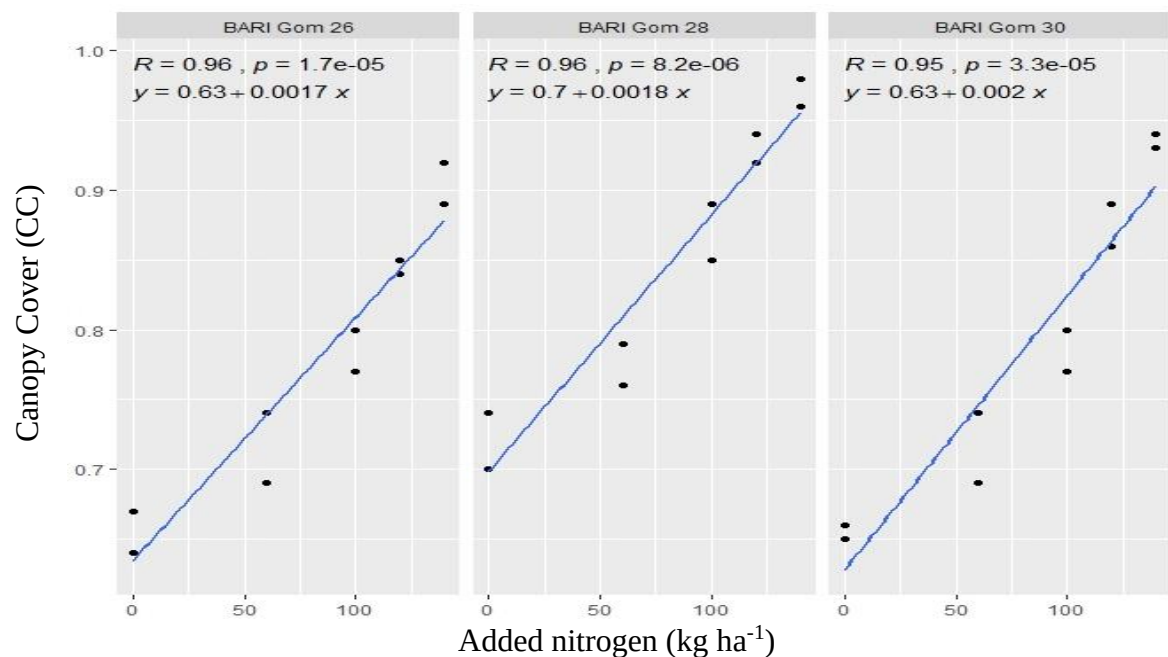


Figure 3.1.48: Response on Canopy Cover (CC) of wheat varieties at different doses of nitrogen during 2017-18.

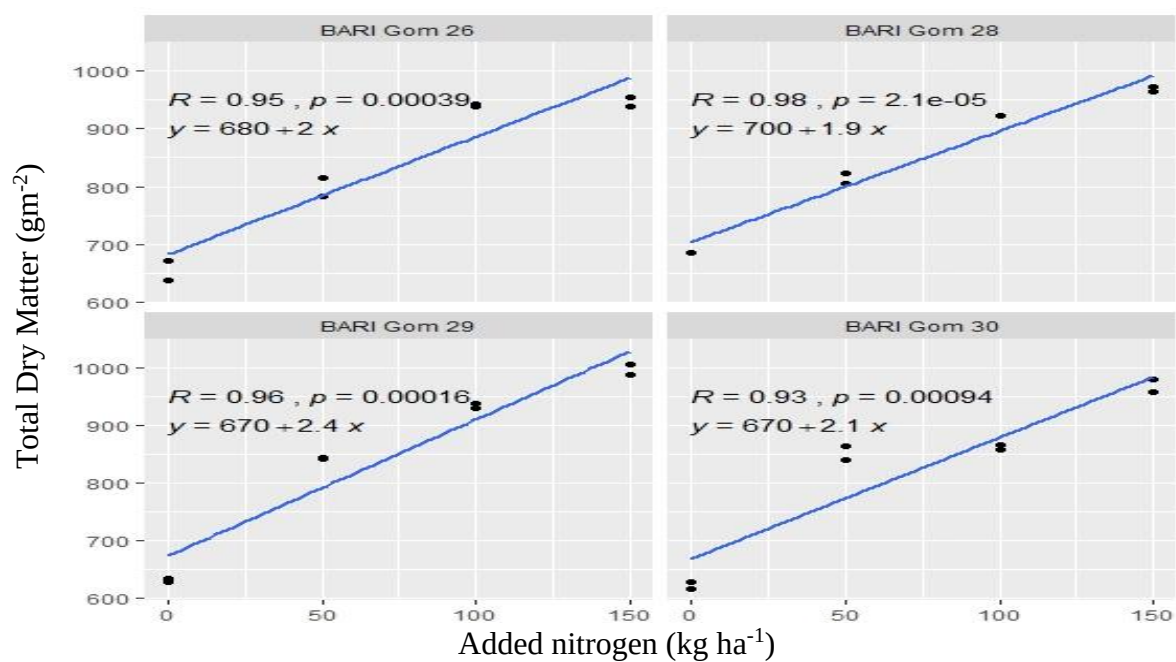


Figure 3.1.49: Response on Total Dry Matter (gm⁻²) of wheat varieties at different doses of nitrogen (2016-17).

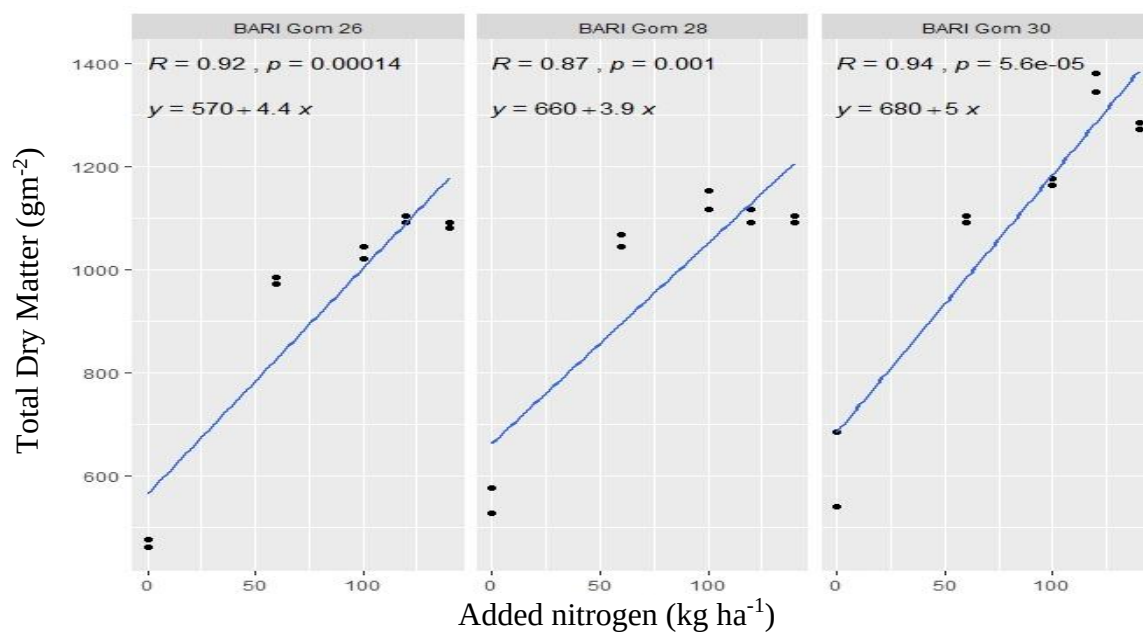


Figure 3.1.50: Response on Total Dry Matter (gm⁻²) of wheat varieties at different doses of nitrogen during 2017-18.

3.1.3.6 Relationship of different morpho-physiological trait of wheat

Regression was used to further investigate the relationship between some morpho-physiological characters to total dry matter (TDM) accumulation of different wheat varieties at 75 DAS present in Figure 3.1.51-3.1.68.

3.1.3.6.1 Relationship between plant height and TDM accumulation

The relationship between plant height and TDM accumulation in both years was linear and positively significant (Figure 3.1.51-3.1.52). The linear models had a highly significant R^2 value of 0.96 for BARI Gom 26, 0.81 for BARI Gom 28, 0.90 for BARI Gom 29 and 0.87 for BARI Gom 30 during 2016-17 and R^2 value of 0.86 for BARI Gom 26, 0.78 for BARI Gom 28, and 0.92 for BARI Gom 30 during 2017-18, respectively. The positive relationship indicated that TDM increased with the increasing of PH depression for each variety. The linear equations were y (BARI Gom 26) = $17x-830$, y (BARI Gom 28) = $12x-400$, y (BARI Gom 29) = $13x-490$ and y (BARI Gom 30) = $11x-280$ during 2016-17 and the linear relationships as estimated were y (BARI Gom 26) = $29x-1100$, y (BARI Gom 28) = $19x-430$ and y (BARI Gom 30) = $28x-780$, during 2017-18, respectively. The multiple R-squared value was found 0.75 and adjusted R-squared value was found 0.74. The R^2 values for over all varieties indicated that the 74% increase in average TDM.

3.1.3.6.2 Relationship between LAI and TDM accumulation

The relationship between LAI and TDM accumulation in both years was linear and positively significant (Figure 3.1.53-3.1.54). The linear models had highly significant R^2 value of 0.99 for BARI Gom 26, 0.97 for BARI Gom 28, 1.0 for BARI Gom 29 and 0.98 for BARI Gom 30 during 2016-17 and R^2 value of 0.99 for BARI Gom 26, 0.95 for BARI Gom 28, and 0.78 for BARI Gom 30 during 2017-18, respectively. The positive relationship indicated that TDM increased with the increasing of LAI depression for each variety. The linear equations were y (BARI Gom 26) = $98x+610$, y (BARI Gom 28) = $92x+650$, y (BARI Gom 29) = $120x+580$ and y (BARI Gom 30) = $120x+590$ during 2016-17 and the linear relationships as estimated were y (BARI Gom 26) = $680x-420$, y (BARI Gom 28) = $620x-210$ and y (BARI Gom 30) = $430x-460$, during 2017-18, respectively. The multiple R-squared value was found 0.94 and adjusted

R-squared value was found 0.94. The R^2 values for over all varieties indicated that the 94% increase in average TDM.

3.1.3.6.3 Relationship between NDVI and TDM accumulation

The relationship between NDVI and TDM accumulation in both years was linear and positively significant (Figure 3.1.55-3.1.56). The linear models had highly significant R^2 value of 0.87 for BARI Gom 26, 0.81 for BARI Gom 28, 0.96 for BARI Gom 29 and 0.91 for BARI Gom 30 during 2016-17 and R^2 value of 0.97 for BARI Gom 26, 0.95 for BARI Gom 28, and 0.96 for BARI Gom 30 during 2017-18, respectively. The positive relationship indicated that TDM increased with the increasing of NDVI depression for each variety. The linear equations were y (BARI Gom 26) $=830x+270$, y (BARI Gom 28) $=620x+430$, y (BARI Gom 29) $=1100x+68$ and y (BARI Gom 30) $=750x+320$ during 2016-17 and the linear relationships as estimated were y (BARI Gom 26) $=1400x-140$, y (BARI Gom 28) $=1100x+65$ and y (BARI Gom 30) $=1500x-36$, during 2017-18, respectively. The multiple R-squared value was found 0.81 and adjusted R-squared value was found 0.75. The R^2 values for over all varieties indicated that the 75% increase in average TDM.

3.1.3.6.4 Relationship between CC and TDM accumulation

The relationship between CC and TDM accumulation in both years was linear and positively significant (Figure 3.1.57-3.1.58). The linear models had highly significant R^2 value of 0.88 for BARI Gom 26, 0.93 for BARI Gom 28, 0.88 for BARI Gom 29 and 0.86 for BARI Gom 30 during 2016-17 and R^2 value of 0.80 for BARI Gom 26, 0.73 for BARI Gom 28, and 0.83 for BARI Gom 30 during 2017-18, respectively. The positive relationship indicated that TDM increased with the increasing of CC depression for each variety. The linear equations were y (BARI Gom 26) $=1100x-18$, y (BARI Gom 28) $=1100x-35$, y (BARI Gom 29) $=1300x-350$ and y (BARI Gom 30) $=1000x+34$ during 2016-17 and the linear relationships as estimated were y (BARI Gom 26) $=2100x-690$, y (BARI Gom 28) $=1700x-450$ and y (BARI Gom 30) $=2100x-580$ during 2017-18, respectively. The multiple R-squared value was found 0.78 and adjusted R-squared value was found 0.71. The R^2 values for over all varieties indicated that the 71% increase in average TDM.

3.1.3.6.5 Relationship between SPAD and TDM accumulation

The relationship between SPAD and TDM accumulation in both years was linear and positively significant (Figure 3.1.59-3.1.60). The linear models had highly significant R^2 value of 0.88 for BARI Gom 26, 0.93 for BARI Gom 28, 0.88 for BARI Gom 29 and 0.86 for BARI Gom 30 during 2016-17 and R^2 value of 0.80 for BARI Gom 26, 0.73 for BARI Gom 28, and 0.83 for BARI Gom 30 during 2017-18, respectively. The positive relationship indicated that TDM increased with the increasing of SPAD depression for each variety. The linear equations were y (BARI Gom 26) = $1100x - 18$, y (BARI Gom 28) = $1100x - 35$, y (BARI Gom 29) = $1300x - 350$ and y (BARI Gom 30) = $1000x + 34$ during 2016-17 and the linear relationships as estimated were y (BARI Gom 26) = $2100x - 690$, y (BARI Gom 28) = $1700x - 450$ and y (BARI Gom 30) = $2100x - 580$ during 2017-18, respectively. The multiple R-squared value was found 0.78 and adjusted R-squared value was found 0.71. The R^2 values for over all varieties indicated that the 71% increase in average TDM.

3.1.3.6.6 Relationship between Leaf Nitrogen Content (ppm) and TDM accumulation

The relationship between Leaf Nitrogen Content (LNC) and TDM accumulation in both years was linear and positively significant (Figure 3.1.61-3.1.62). The linear models had highly significant R^2 value of 0.89 for BARI Gom 26, 0.91 for BARI Gom 28, 0.89 for BARI Gom 29 and 0.85 for BARI Gom 30 during 2016-17 and R^2 value of 0.82 for BARI Gom 26, 0.70 for BARI Gom 28, and 0.85 for BARI Gom 30 during 2017-18, respectively. The positive relationship indicated that TDM increased with the increasing of LNC depression for each variety. The linear equations were y (BARI Gom 26) = $0.27x + 550$, y (BARI Gom 28) = $0.22x + 600$, y (BARI Gom 29) = $0.31x + 490$ and y (BARI Gom 30) = $0.28x + 510$ during 2016-17 and the linear relationships as estimated were y (BARI Gom 26) = $0.5x + 360$, y (BARI Gom 28) = $0.36x + 540$ and y (BARI Gom 30) = $0.57x + 390$ during 2017-18, respectively. The multiple R-squared value was found 0.77 and adjusted R-squared value was found 0.71. The R^2 values for over all varieties indicated that the 71% increase in average TDM.

3.1.3.6.7 Relationship between Chl a and TDM accumulation

The relationship between leaf Chl a and TDM accumulation in both years was linear and positively significant (Figure 3.1.63-3.1.64). The linear models had highly significant R^2 value of 0.94 for BARI Gom 26, 0.92 for BARI Gom 28, 0.93 for BARI Gom 29 and 0.92 for BARI Gom 30 during 2016-17 and R^2 value of 0.89 for BARI Gom 26, 0.80 for BARI Gom 28, and 0.80 for BARI Gom 30 during 2017-18, respectively. The positive relationship indicated that TDM increased with the increasing of Chl a depression for each variety. The linear equations were y (BARI Gom 26) $=1000x+310$, y (BARI Gom 28) $=840x+400$, y (BARI Gom 29) $=970x+340$ and y (BARI Gom 30) $=1000x+290$ during 2016-17 and the linear relationships as estimated were y (BARI Gom 26) $=2800x-600$, y (BARI Gom 28) $=2300x-270$ and y (BARI Gom 30) $=2200x-120$ during 2017-18, respectively. The multiple R-squared value was found 0.86 and adjusted R-squared value was found 0.82. The R^2 values for over all varieties indicated that the 82% increase in average TDM.

3.1.3.6.8 Relationship between leaf Chl b and TDM accumulation

The relationship between leaf Chl b and TDM accumulation in both years was linear and positively significant except BARI Gom 26 and BARI Gom 28 during 2017-18 (Figure 3.1.65-3.1.66). The linear models had highly significant R^2 value of 0.90 for BARI Gom 26, 0.92 for BARI Gom 28, 0.92 for BARI Gom 29 and 0.94 for BARI Gom 30 during 2016-17 and R^2 value of 0.41^{ns} for BARI Gom 26, 0.39^{ns} for BARI Gom 28, and 0.63 for BARI Gom 30 during 2017-18, respectively. The positive relationship indicated that TDM increased with the increasing of Chl b depression for each variety. The linear equations were y (BARI Gom 26) $=820x+290$, y (BARI Gom 28) $=590x+450$, y (BARI Gom 29) $=840x+310$ and y (BARI Gom 30) $=840x+290$ during 2016-17 and the linear relationships as estimated were y (BARI Gom 26) $=870x+440$, y (BARI Gom 28) $=720x+550$ and y (BARI Gom 30) $=880x+520$ during 2017-18, respectively. The multiple R-squared value was found 0.68 and adjusted R-squared value was found 0.65. The R^2 values for over all varieties indicated that the 65% increase in average TDM.

3.1.3.6.9 Relationship between Car and TDM accumulation

The relationship between leaf Car and TDM accumulation in both years was linear and positively significant (Figure 3.1.67-3.1.68). The linear models had highly significant R^2 value of 0.92 for BARI Gom 26, 0.94 for BARI Gom 28, 0.94 for BARI Gom 29 and 0.94 for BARI Gom 30 during 2016-17 and R^2 value of 0.92 for BARI Gom 26, 0.84 for BARI Gom 28, and 0.68 for BARI Gom 30 during 2017-18, respectively. The positive relationship indicated that TDM increased with the increasing of Car depression for each variety. The linear equations were y (BARI Gom 26) $=4000x+300$, y (BARI Gom 28) $=5600x+74$, y (BARI Gom 29) $=5900x+58$ and y (BARI Gom 30) $=6700x-75$ during 2016-17 and the linear relationships as estimated were y (BARI Gom 26) $=9600x-170$, y (BARI Gom 28) $=5900x+210$ and y (BARI Gom 30) $=7800x+190$ during 2017-18, respectively. The multiple R-squared value was found 0.87 and adjusted R-squared value was found 0.84. The R^2 values for over all varieties indicated that the 84% increase in average TDM.

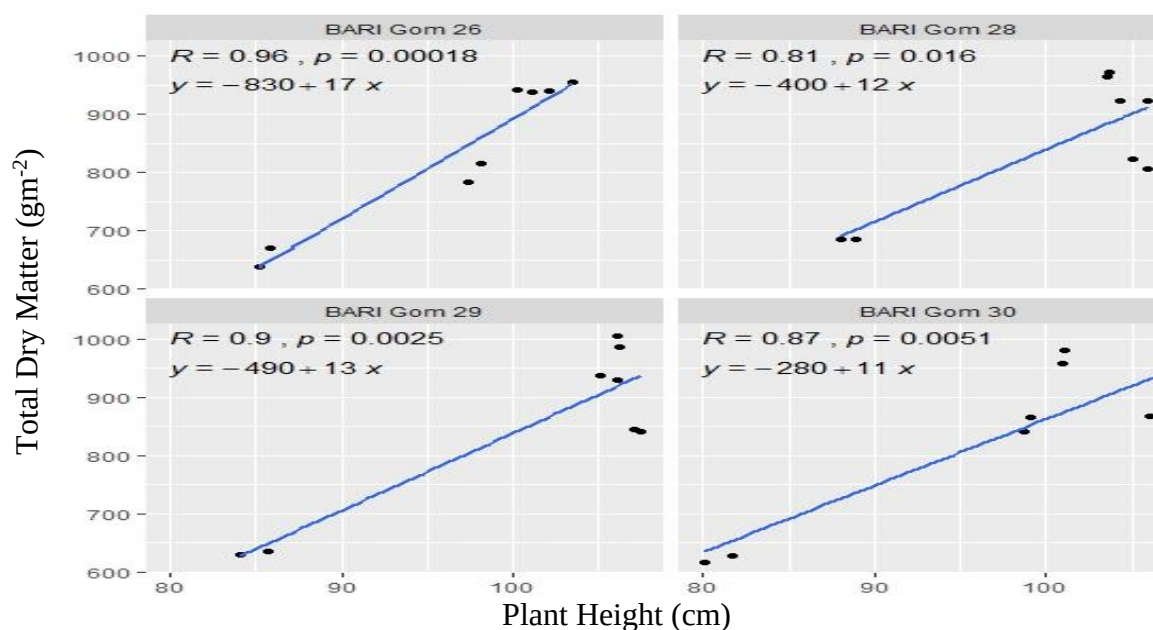


Figure 3.1.51: Relationship between total dry matter (gm^{-2}) and plant height (cm) of wheat varieties (2016-17).

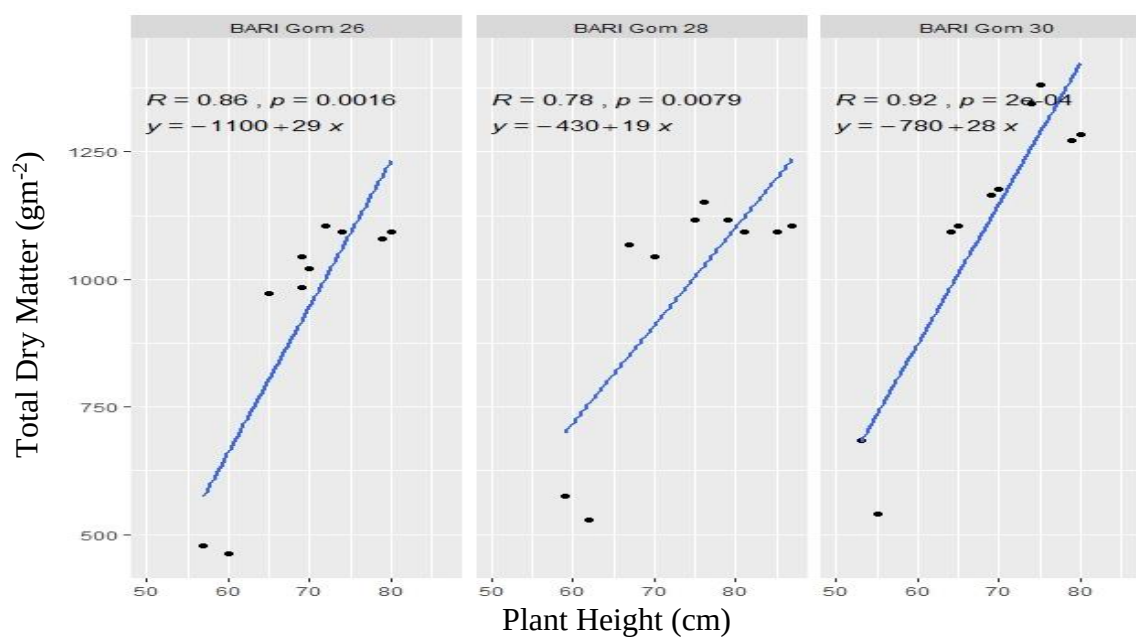


Figure 3.1.52: Relationship between total dry matter (gm^{-2}) and plant height (cm) of wheat varieties during 2017-18.

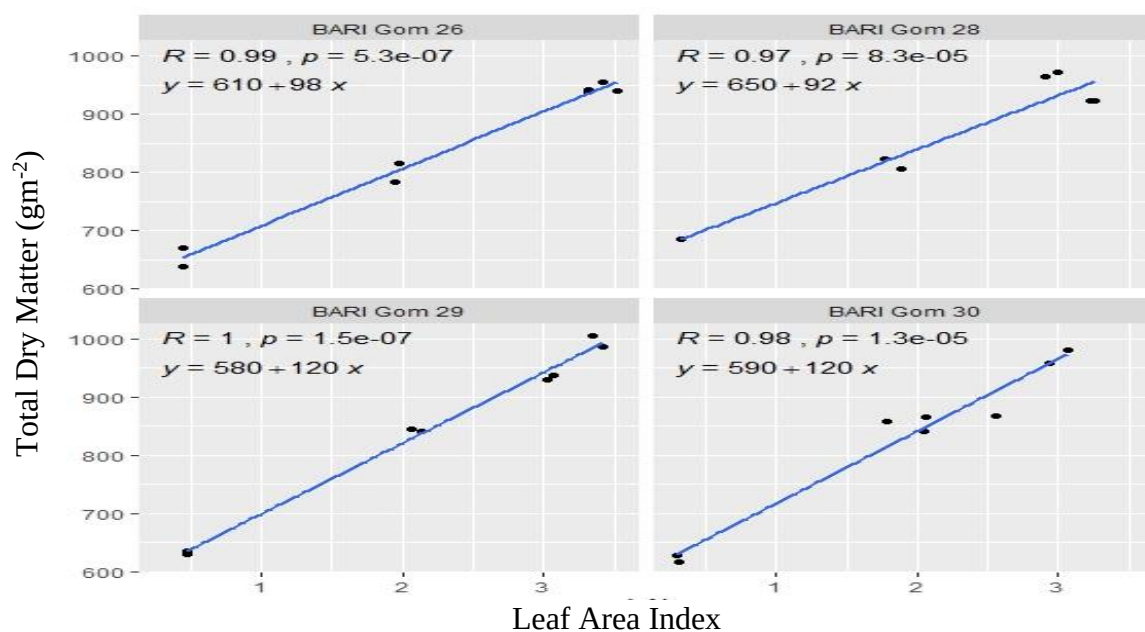


Figure 3.1.53: Relationship between total dry matter (gm⁻²) and leaf area index (LAI) of wheat varieties 2016-17.

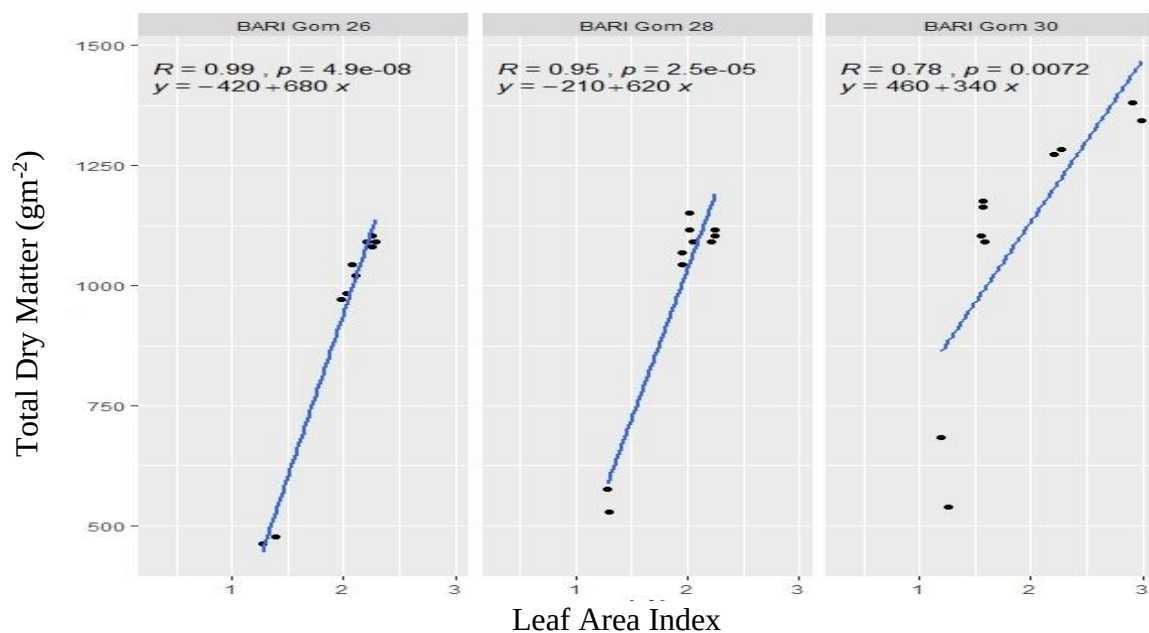


Figure 3.1.54: Relationship between total dry matter (gm⁻²) and leaf area index (LAI) of wheat varieties 2017-18.

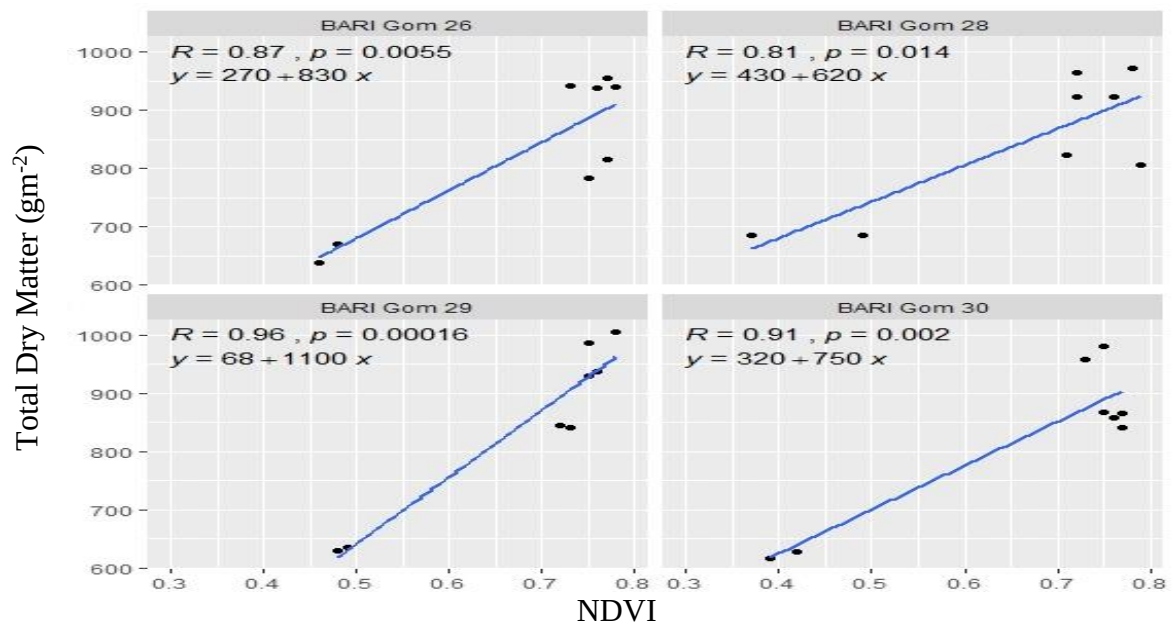


Figure 3.1.55: Relationship between total dry matter (gm⁻²) and NDVI of wheat varieties during 2016-17.

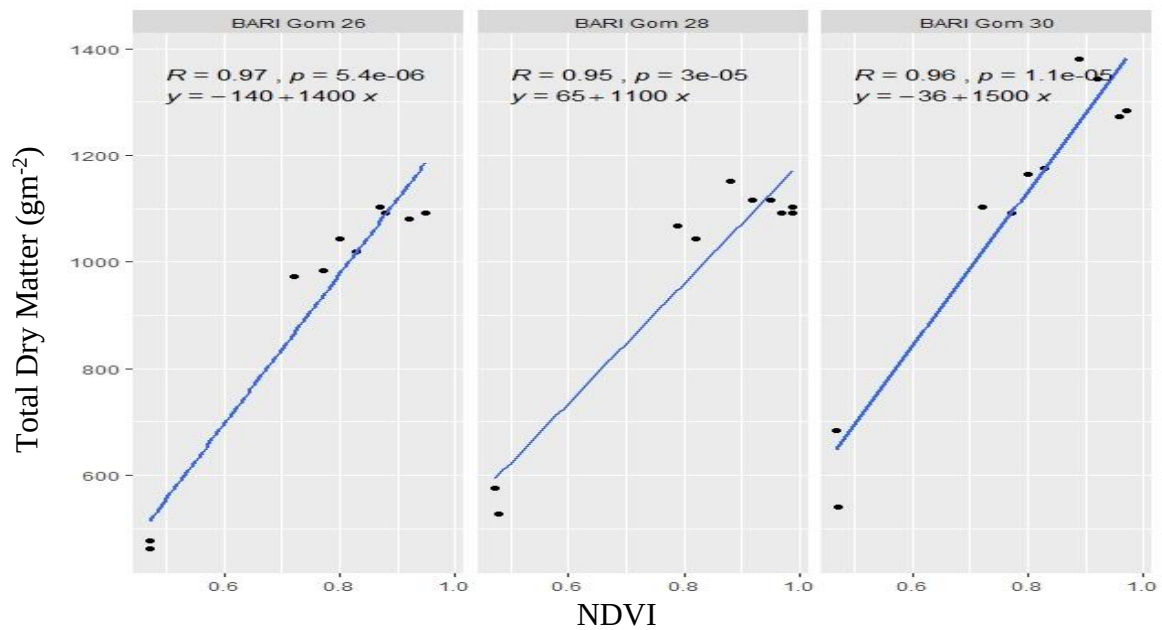


Figure 3.1.56: Relationship between total dry matter (gm⁻²) and NDVI of wheat varieties during 2017-18.

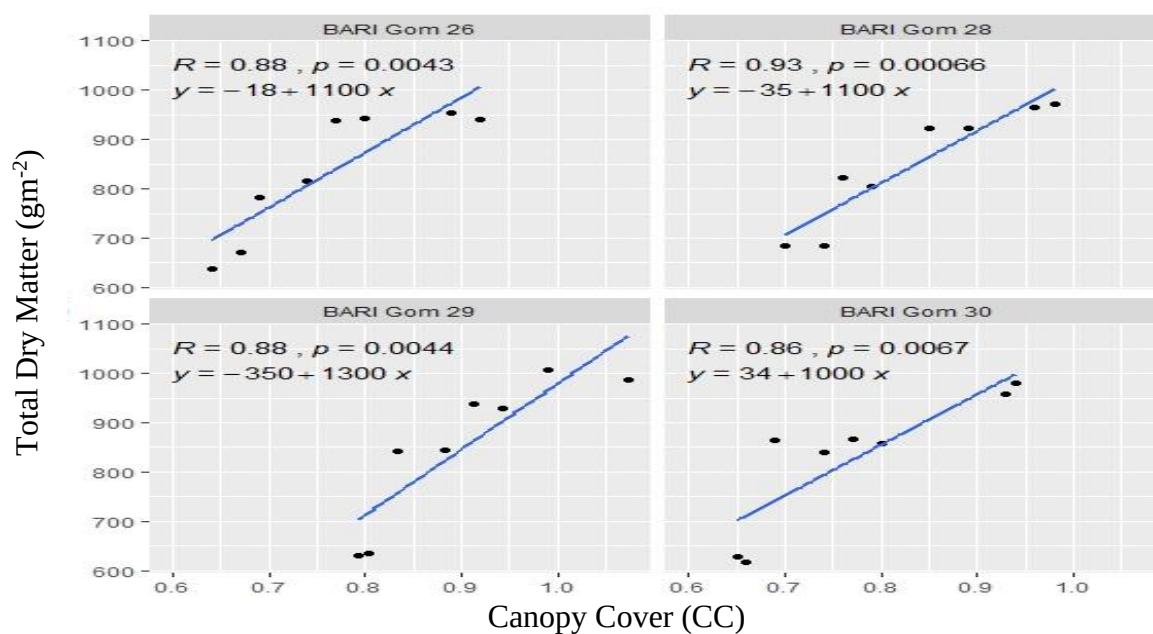


Figure 3.1.57: Relationship between total dry matter (gm⁻²) and CC of wheat varieties during 2016-17.

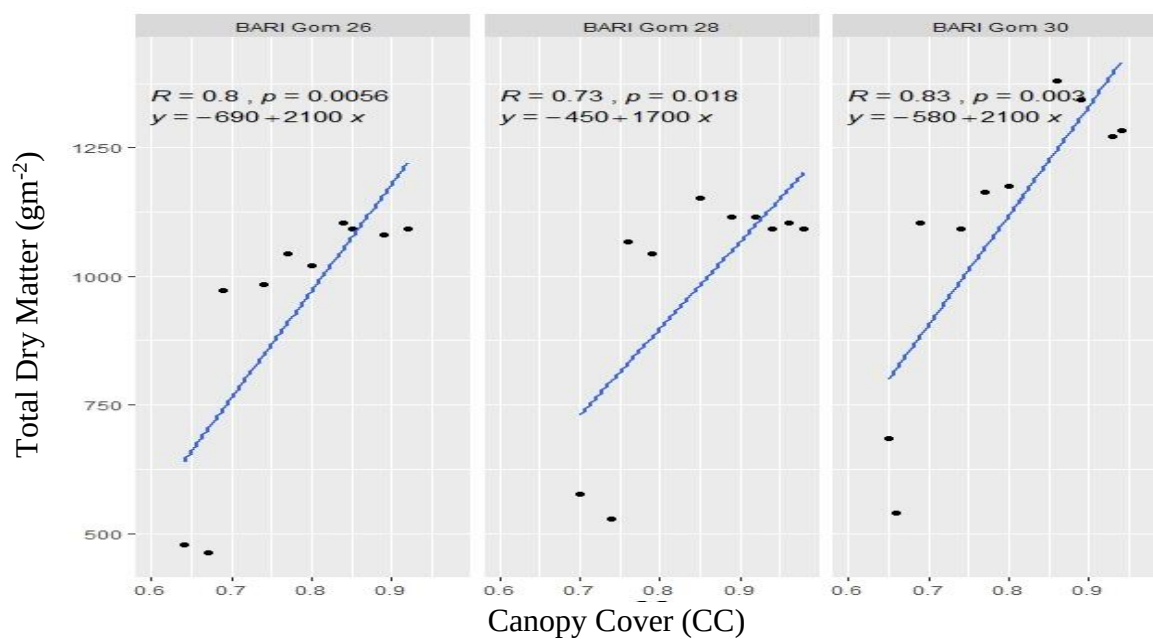


Figure 3.1.58: Relationship between total dry matter (gm⁻²) and CC of wheat varieties during 2017-18.

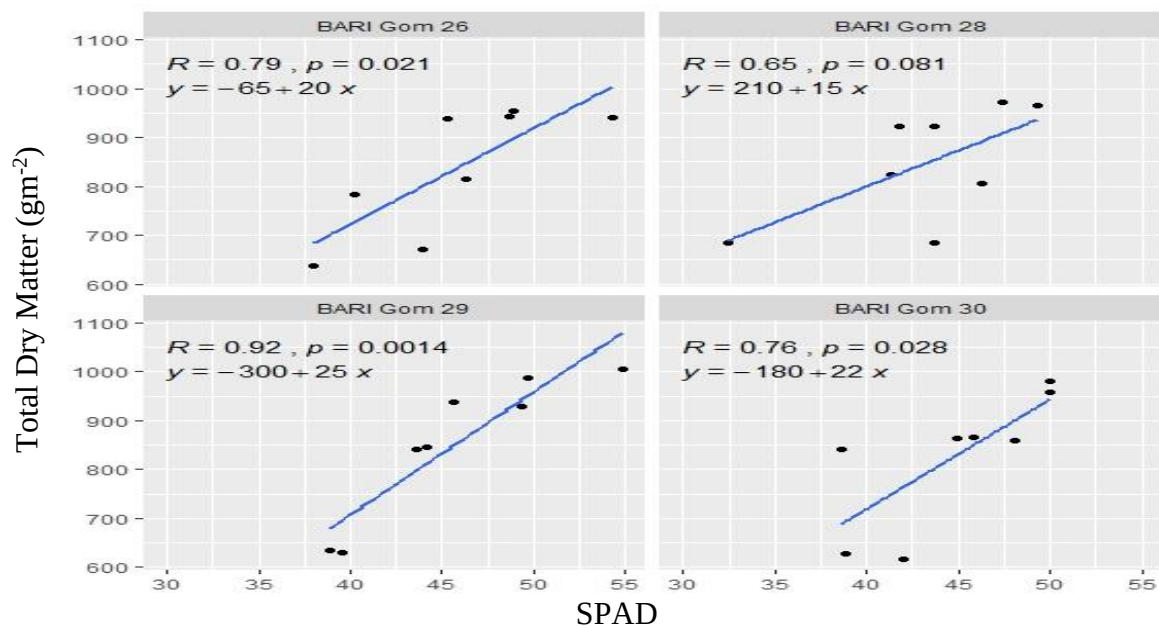


Figure 3.1.59: Relationship between total dry matter (gm^{-2}) and SPAD value of wheat varieties during 2016-17.

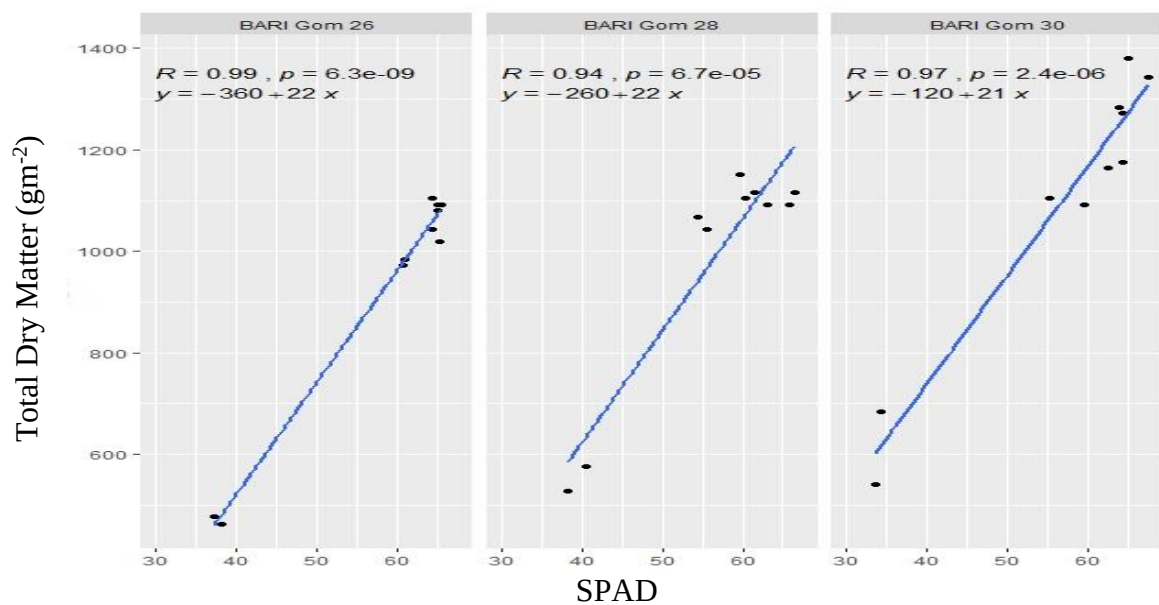


Figure 3.1.60: Relationship between total dry matter (gm^{-2}) and SPAD of wheat varieties during 2017-18.

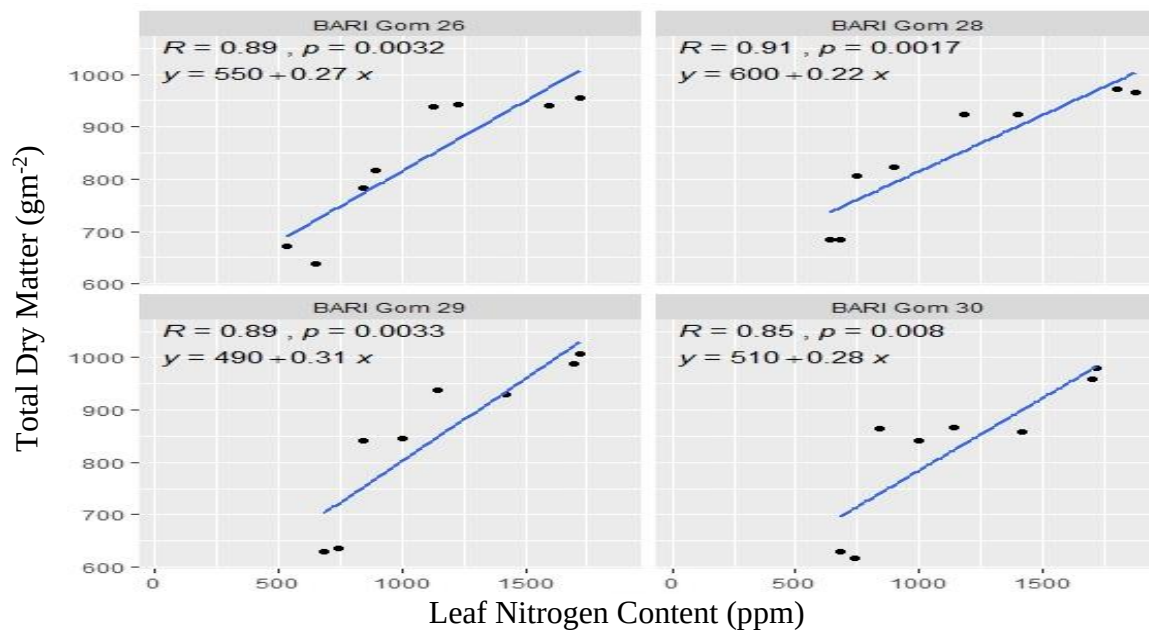


Figure 3.1.61: Relationship between total dry matter (gm⁻²) and NDVI of wheat varieties during 2016-17.

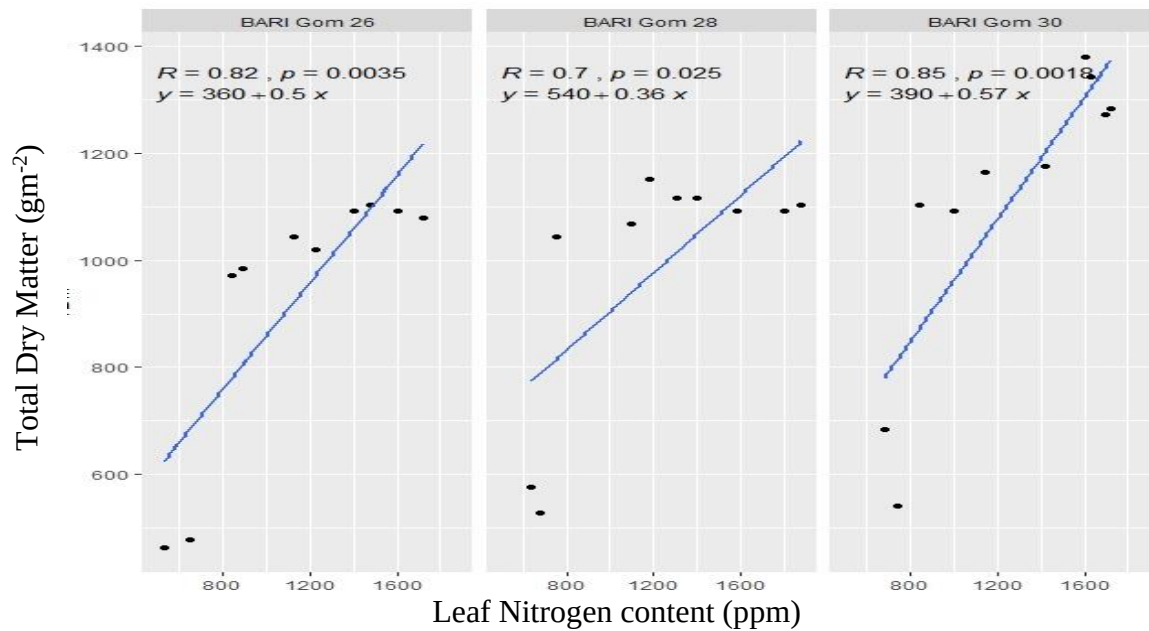


Figure 3.1.62: Relationship between total dry matter (gm⁻²) and NDVI of wheat varieties during 2017-18.

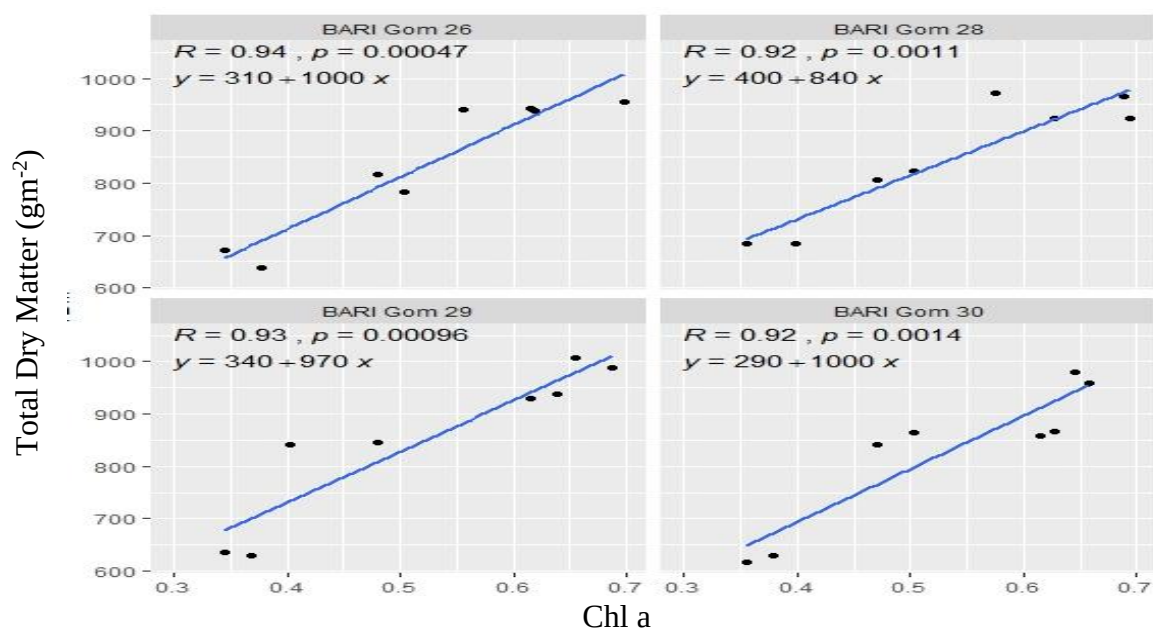


Figure 3.1.63: Relationship between total dry matter (gm⁻²) and Chl a of wheat varieties during 2016-17.

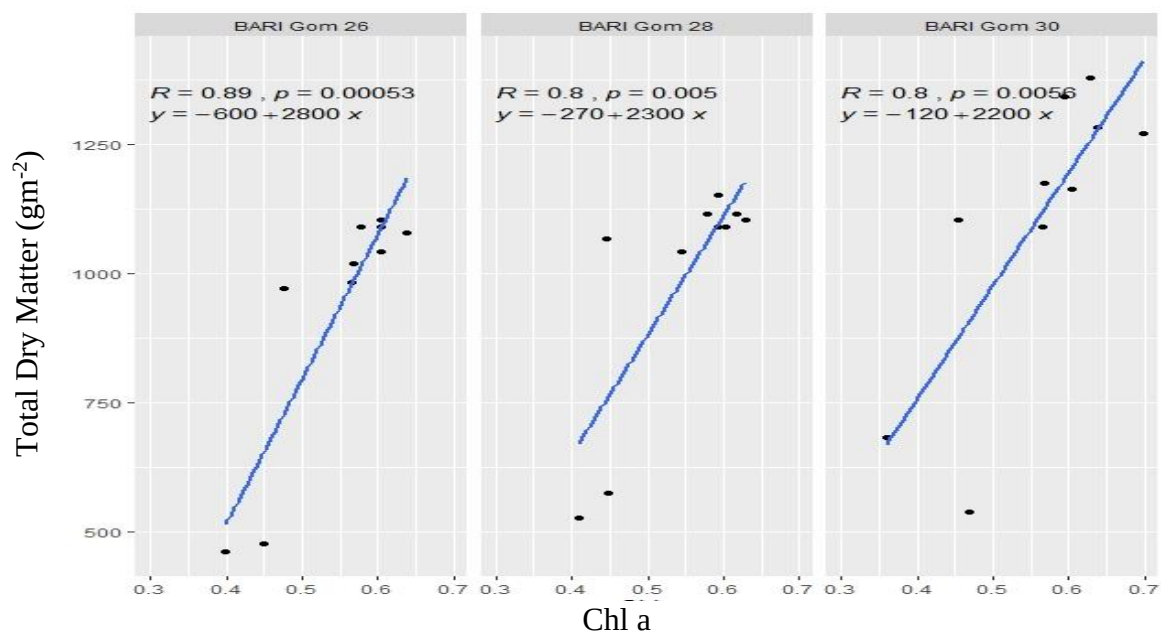


Figure 3.1.64: Relationship between total dry matter (gm⁻²) and Chl a of wheat varieties during 2017-18.

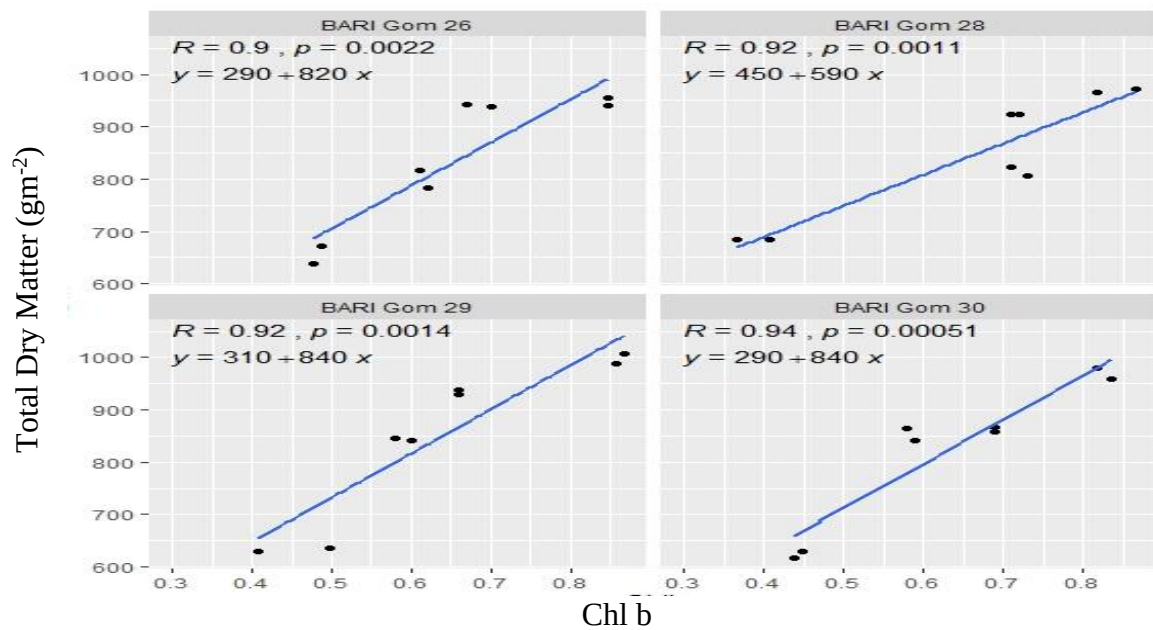


Figure 3.1.65: Relationship between total dry matter (gm⁻²) and NDVI of wheat varieties during 2016-17.

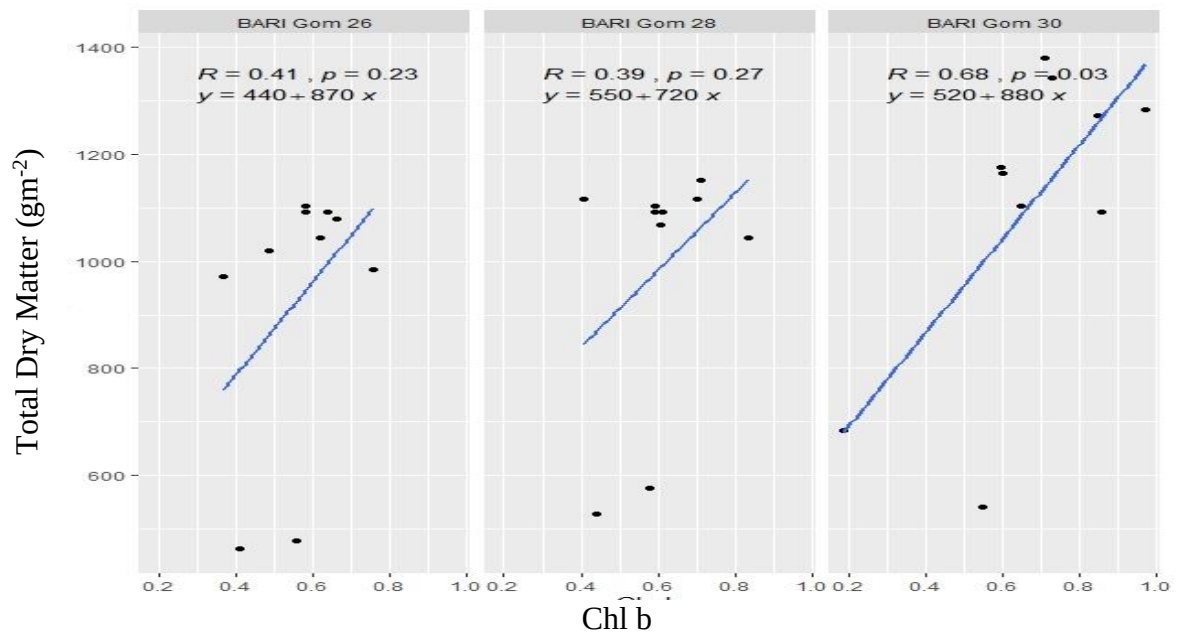


Figure 3.1.66: Relationship between total dry matter (gm⁻²) and Chl b of wheat varieties during 2017-18.

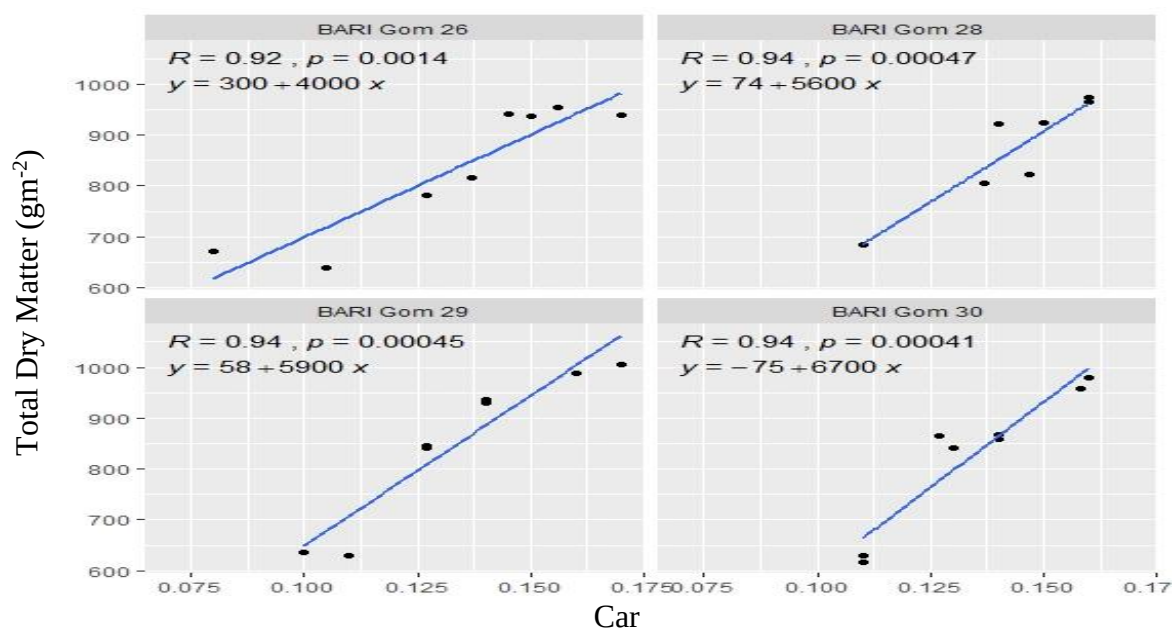


Figure 3.1.67: Relationship between total dry matter (gm^{-2}) and Car of wheat varieties during 2016-17.

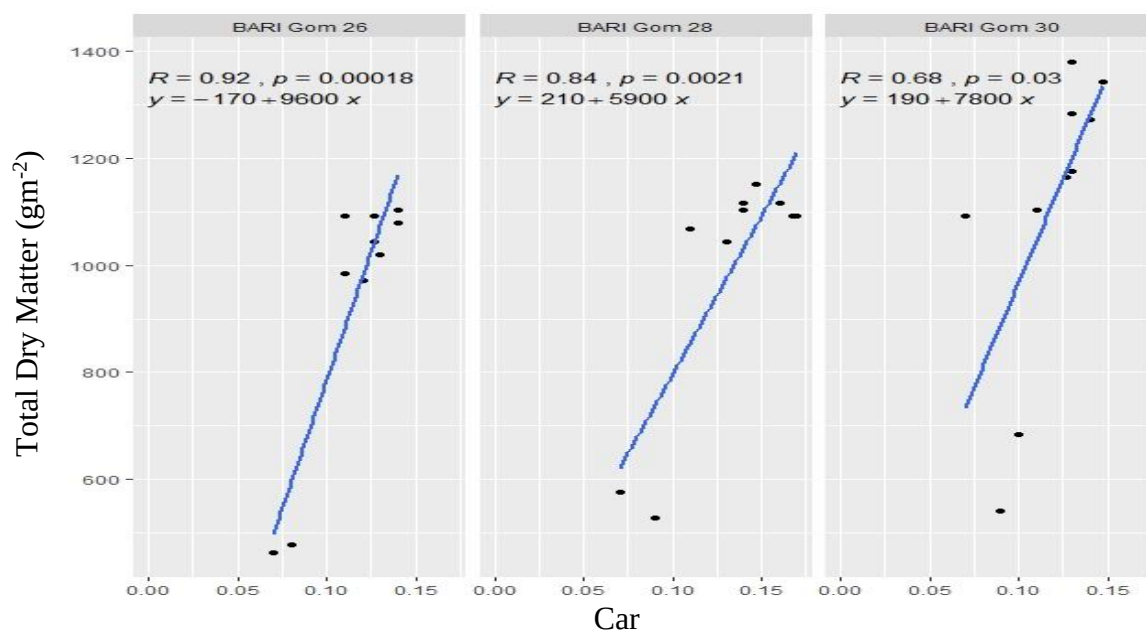


Figure 3.1.68: Relationship between total dry matter (gm^{-2}) and Car of wheat varieties during 2017-18.

3.1.3.7 Multivariate analysis of wheat

Multivariate analysis is a tool to find patterns and relationships between several variables simultaneously. Unlike univariate and bivariate statistical methods, multivariate statistical methods are capable of analyzing more than one relationship at a time. There are a number of multivariate data analysis methods, each with its own purpose like Regression Analysis, Factor analysis, Cluster analysis, Variance analysis, Discriminant analysis etc. In order to study the relationship among interaction treatments (wheat variety and nitrogen levels) with various morpho-physiological traits. Principal component analysis biplot, heatmap analysis were done which revealed different clusters of treatments that performed better in different aspects.

3.1.3.7.1 Biplot analysis (Treatments $\times$ Traits)

Biplot analysis mostly used to determine the components which effect is more to create the treatment variation. The highest values indicate the highest influence of the trait to the total variation. It describes the association among the traits across different treatments or genotypes (Yan and Reid, 2008).

Using all trait values, a $T \times T$ biplot was constructed from a two-way matrix of 16 traits by 16 Treatments in Figure 3.1.69 during 2016-17 and a two-way matrix of 16 traits by 15 Treatments in Figure 3.1.70 during 2017-18. The plot condensed the information from this matrix into PCs, the first two of which comprised 89.71% during 2016-17 and 87.59% during 2017-18 of the total variation within the dataset. This comparatively high percentage reveals the complication of the relations among the treatments and the evaluated morpho-physiological traits. The treatments 16 and 8 that very closed to x-axis and coincided with as a $16=N_3 \times V_4$, and $8=N_3 \times V_2$ treatment scored significantly the highest values compared to other. As a treatment $16=N_3 \times V_4$, and $8=N_3 \times V_2$ for LNC and HI scored the highest values during 2016-17 (Figure 3.1.69). The treatments 14 and 7 that very closed to x-axis and coincided with as a $14=N_3 \times V_3$, and $7=N_2 \times V_2$ treatment scored significantly the highest values compared to other. As a treatment $14=N_3 \times V_3$, and $7=N_2 \times V_2$ for TDM, Yield and SPAD scored the highest values during 2017-18 (Figure 3.1.70).

The plot shows the relationship between traits. The cosine of the angle between vectors connecting traits to the origin is proportional to the correlation coefficient between those traits (Yan and Kang, 2003). Thus, traits on opposite sides of the origin are negatively correlated, traits near each other are positively correlated and traits at 90° to each other with respect to the origin are not correlated. The T×T biplot showed superior treatment with relatively greater expression of combinations of favorable traits.

Again, biplot analysis showed the trait profiles of the treatments, especially, those treatments positioned far away from the origin and the results indicated correlation between traits with treatments. Biplot revealed that treatment 14 and 2 was performed better for SL and PH, Treatment 15 has performed better due to higher NGS, on the contrary treatment 5, 7 and 13 had the maximum SY, Chl a, HI and Yield. SPAD value during 2016-17 (Figure 3.1.69). The treatment 14 and 7 was performed better for SPAD, TDM and Yield, Treatment 12 has performed better due to higher Chl b, on the contrary treatment 5 and 10 had the maximum LNC, SL and CC value during 2017-18 (Figure 3.1.70). The results suggest that SPAD, LNC, TDM, LAI and yield could be used to identify superior treatment from this study.

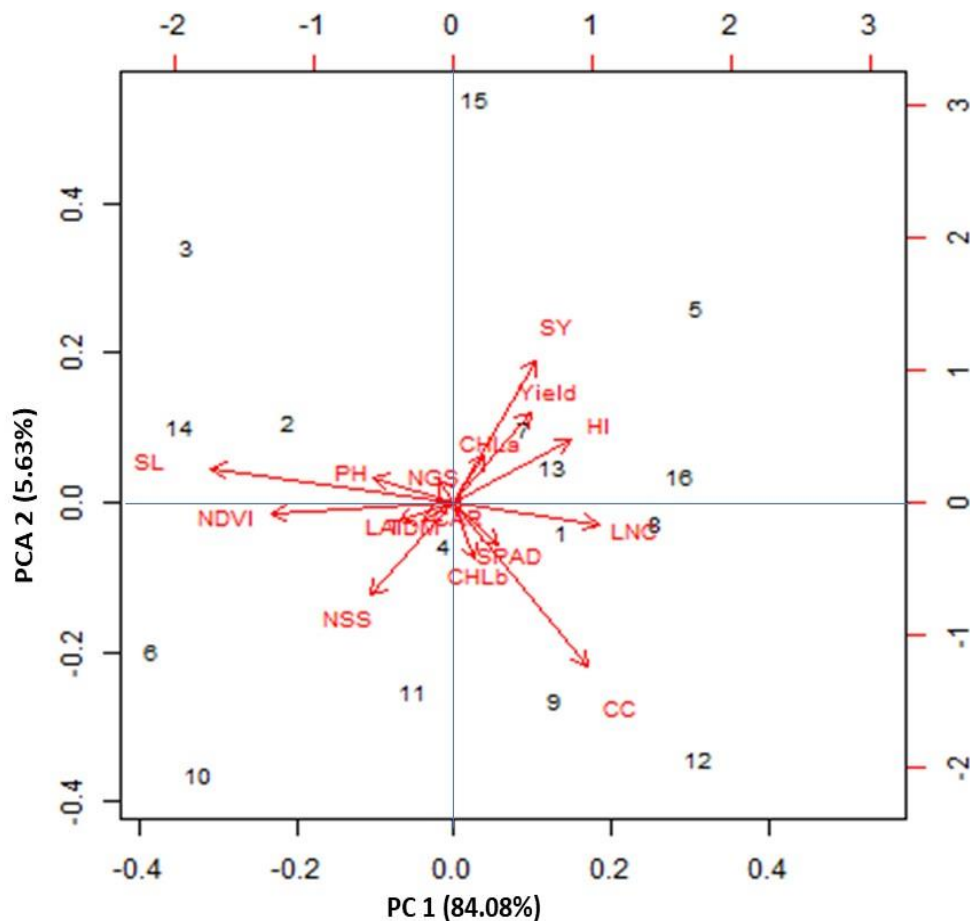


Figure 3.1.69: Ordination of treatment by trait biplots of principal component analysis outputs during 2016-17.

Treatments in black colour and traits in red colour. 1= $N_0 \times V_1$, 2= $N_1 \times V_1$, 3= $N_2 \times V_1$, 4= $N_3 \times V_1$, 5= $N_0 \times V_2$, 6= $N_1 \times V_2$, 7= $N_2 \times V_2$, 8= $N_3 \times V_2$, 9= $N_0 \times V_3$, 10= $N_1 \times V_3$, 11= $N_2 \times V_3$, 12= $N_3 \times V_3$, 13= $N_0 \times V_4$, 14= $N_1 \times V_4$, 15= $N_2 \times V_4$, 16= $N_3 \times V_4$; ($N_0 = 0 \text{ kg N ha}^{-1}$, $N_1 = 50 \text{ kg N ha}^{-1}$, $N_2 = 100 \text{ kg N ha}^{-1}$, $N_3 = 150 \text{ kg N ha}^{-1}$ and $V_1 = \text{BARI Gom 26}$, $V_2 = \text{BARI Gom 28}$, $V_3 = \text{BARI Gom 29}$, $V_4 = \text{BARI Gom 30}$); PH = Plant height (cm), LAI= Leaf Area Index, NDVI= Normalized Difference Vegetative Index, CC= Canopy Cover, SPAD= Soil Plant Analysis Development, LNC= Leaf Nitrogen Content (ppm), Chl a= Chlorophyll a content (mg g^{-1}), Chl b= Chlorophyll b content (mg g^{-1}), Car= Carotenoid Content (mg g^{-1}), TDM= Total Dry Matter (gm^{-2}), NSS=Number of spikelets spike $^{-1}$, NGS= Number of grains spike $^{-1}$, SL=Spike length (cm), SY= Straw yield (t ha^{-2}), HI=Harvest index (%), Yield=Grain Yield (t ha^{-1}).

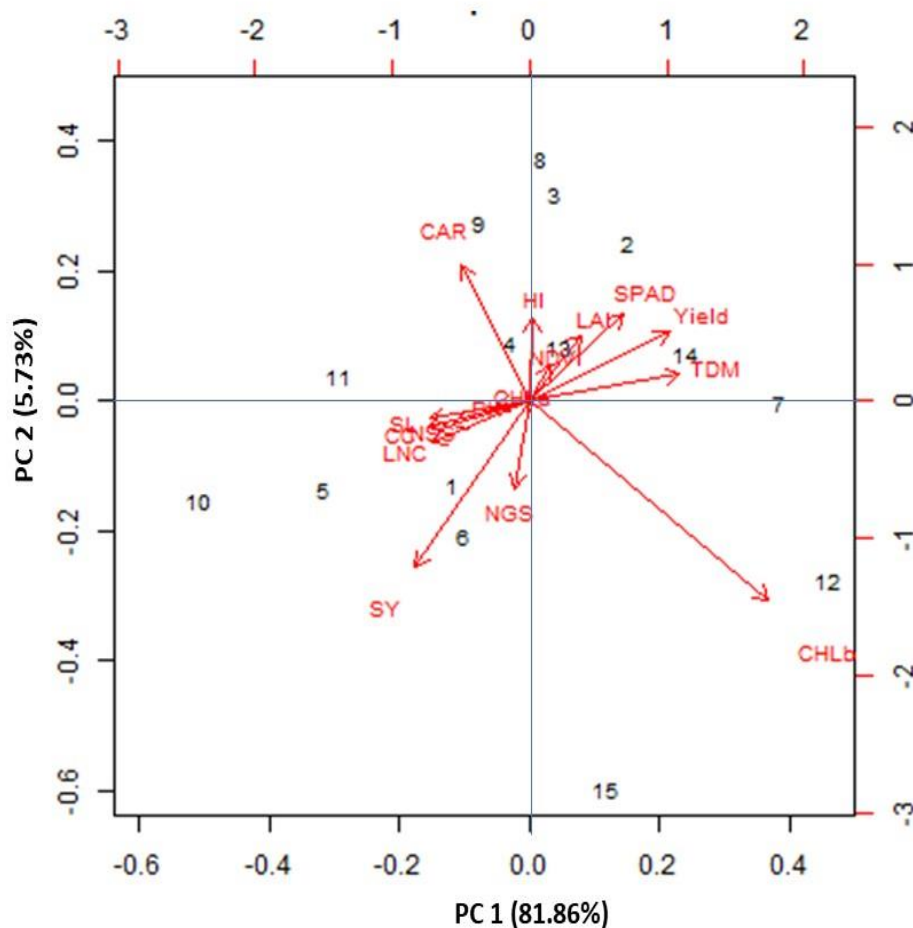


Figure 3.1.70: Ordination of treatment by trait biplots of principal component analysis outputs during 2017-18.

Treatments in black colour and traits in red colour. 1= $N_0 \times V_1$, 2= $N_1 \times V_1$, 3= $N_2 \times V_1$, 4= $N_3 \times V_1$, 5= $N_4 \times V_1$, 6= $N_0 \times V_2$, 7= $N_1 \times V_2$, 8= $N_2 \times V_2$, 9= $N_3 \times V_2$, 10= $N_4 \times V_1$, 11= $N_0 \times V_3$, 12= $N_1 \times V_3$, 13= $N_2 \times V_3$, 14= $N_3 \times V_3$, 15= $N_4 \times V_3$; (V_1 = BARI Gom 26, V_2 = BARI Gom 28, V_3 = BARI Gom 30 and N_0 = 0 kg N ha⁻¹, N_1 = 60 kg N ha⁻¹, N_2 = 100 kg N ha⁻¹, N_3 = 120 kg N ha⁻¹ and N_4 = 140 kg N ha⁻¹); PH = Plant height (cm), LAI= Leaf Area Index, NDVI= Normalized Difference Vegetative Index, CC= Canopy Cover, SPAD= Soil Plant Analysis Development, LNC= Leaf Nitrogen Content (ppm), Chl a= Chlorophyll a content (mg g⁻¹), Chl b= Chlorophyll b content (mg g⁻¹), Car= Carotenoid Content (mg g⁻¹), TDM= Total Dry Matter (gm⁻²), NSS=Number of spikelets spike⁻¹, NGS= Number of grains spike⁻¹, SL=Spike length (cm), SY= Straw yield (t ha⁻²), HI=Harvest index (%), Yield=Grain Yield (t ha⁻¹).

3.1.3.7.2 Heatmap analysis

Heatmap explored the performances of the interaction between wheat variety and nitrogen doses regarding their morpho-physiological, yield and yield contributing traits. It shows the highest and lowest values of each treatment in different colors against all the traits. The intensity of the color indicates the degree of high or low of the traits. Amber color indicates higher value while white color indicates lower value. Heat map displaying the relationship matrix among 16 treatments of wheat varieties and nitrogen interaction. The amber diagonal represents a perfect relationship of each treatment with itself. The symmetric off-diagonal elements represent the relationship measures for pairs of treatments. The white of warmer colors on the diagonal show clusters of closely related treatments.

Hierarchical clustering based on the morpho-physiological, yield and yield contributing traits of the treatments (Interaction of variety and Nitrogen doses) studied revealed four clusters namely Cluster A, Cluster B, Cluster C, and Cluster D in Figure 3.1.3.71 during 2016-17 and in Figure 3.1.3.72 during 2017-18. During 2016-17 all cluster accommodated four treatments but during 2017-18 cluster A accommodated five treatments, while cluster B and D composed of three treatments and cluster C consisted four treatments. It is clear that the treatments having similarity in their morpho-physiological, yield and yield contributing traits composition were grouped together (Figure 3.1.3.71 and Figure 3.1.3.72). However, the heatmap also revealed the overall performance of each treatment regarding the observed traits.

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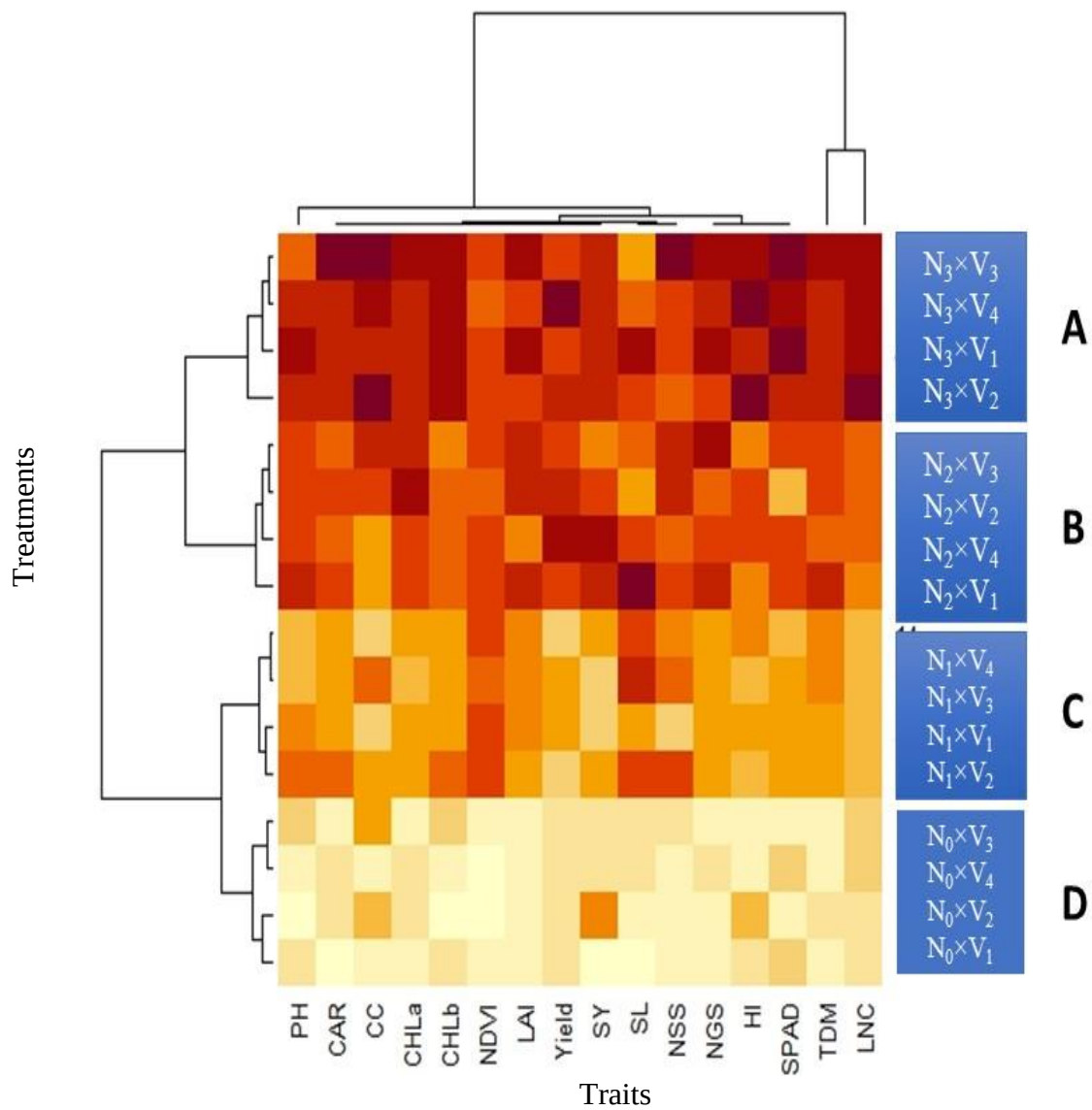


Figure 3.1.71: Heatmap showing the clustering pattern of 16 treatments of wheat varieties and nitrogen interaction with 16 morpho-physiological traits during 2016-17.

Heat map displaying the relationship matrix among 16 treatments of wheat varieties and nitrogen interaction. The amber diagonal represents a perfect relationship of each treatments with itself. The symmetric off-diagonal elements represent the relationship measures for pairs of treatments. The white of warmer colors on the diagonal show clusters of closely related treatments.

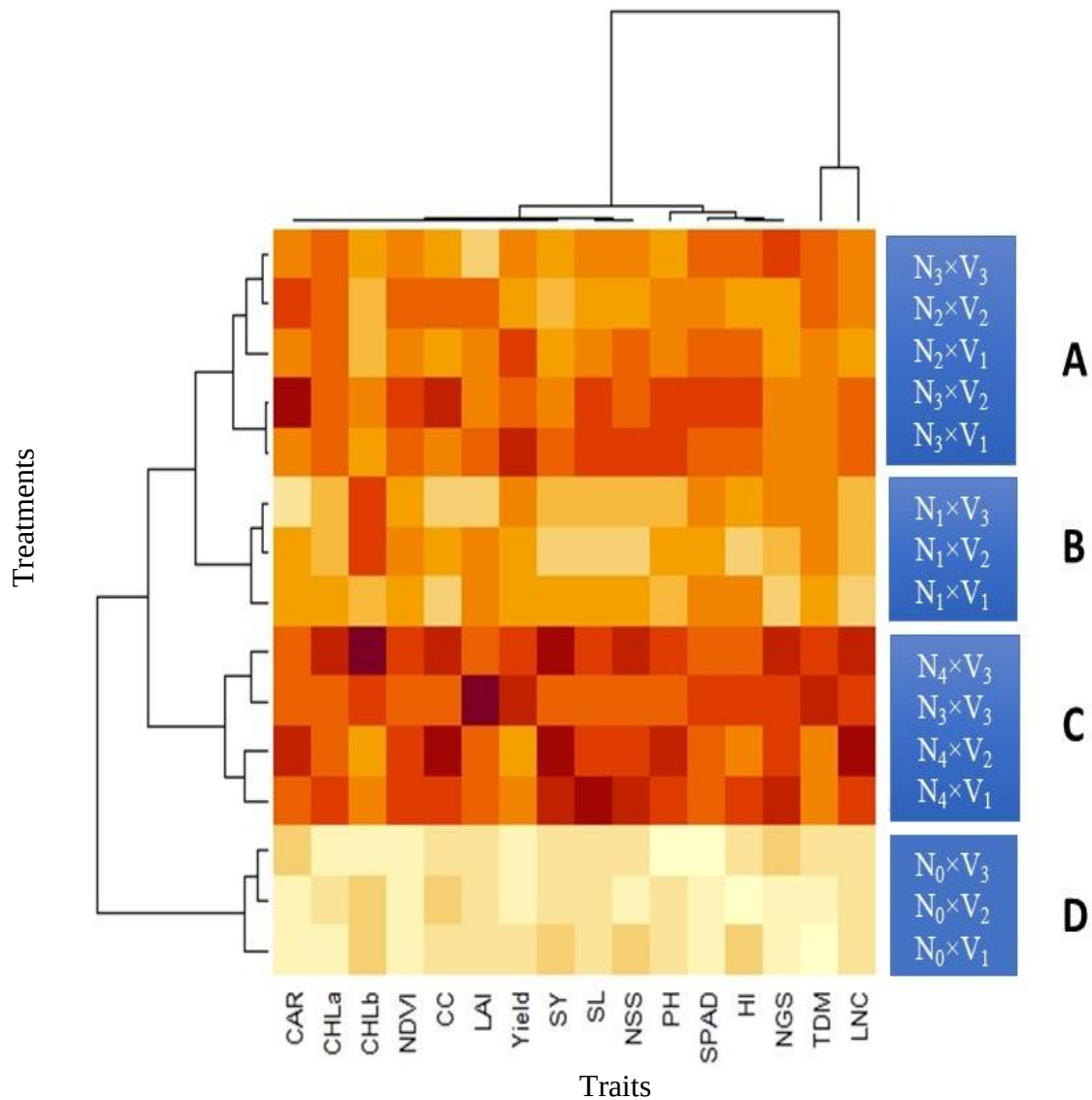


Figure 3.1.72: Heatmap showing the clustering pattern of 15 treatments of wheat varieties and nitrogen interaction with 16 morpho-physiological traits during 2017-18. Heat map displaying the relationship matrix among 15 treatments of wheat varieties and nitrogen interaction. The amber diagonal represents a perfect relationship of each treatments with itself. The symmetric off-diagonal elements represent the relationship measures for pairs of treatments. The white of warmer colors on the diagonal show clusters of closely related treatments.

3.1.3.8 Software development, Image processing and modeling of wheat

3.1.3.8.1 WCC_BARI software description

WCCBARI is automatic color threshold (ACT) image analysis software developed in the JAVA programming language using color values in the red, green, blue (RGB) system. MCC analyzes and classifies all pixels in the image (Figure 3.1.74). The analysis is based on the selection of pixels according to ratios of R/G, B/G and the excess green index. The result of the analysis is a binary image where white pixels correspond to the pixels that satisfied the selection criteria (green canopy) and black pixels correspond to the pixels that did not meet the selection criteria (not green canopy). Fractional green canopy cover ranges from 0 (no green canopy cover) to 1 (100% green canopy cover). The classification of green canopy is based on the following criteria:

$$R/G < X1 \text{ and } B/G < X2 \text{ and } 2G-R-B > X3$$

where X1 and X2 are parameters that typically have a value near 1 to classify pixels that are predominantly in the green band (~500–570 nm), and X3 is a parameter that sets the minimum excess green index, which typically has a value around 20 to select green vegetation (Meyer and Neto, 2008; Richardson *et al.*, 2007). The default parameter values for WCCBARI are X1 = 0.89, X2 = 0.89, and X3 = 25.

The threshold value for the excess green index was set constant at a value of 20. The excess green index effectively classifies dark or gray pixels that cannot be adequately discriminated using the R/G and B/G ratios alone. WCCBARI also has the capability to reduce noise by removing isolated green pixels. Isolated pixels that meet the color ratio specifications can sometimes occur in other objects and are not exclusively part of green canopy. For instance, some isolated pixels in residue shadows may have R/G and B/G ratios similar to those found in green canopies. WCCBARI can remove these pixels or small clusters of pixels (e.g., small weeds in a row crop) by analyzing connected neighboring pixels. WCCBARI saves a text file which can be opened in spreadsheet (Microsoft Excel format). WCC_BARI saves the image file name, picture taken date and time, total plant pixel, plant pixel percentage values, intensity, saturation, NDVI value etc. The supported image formats are .jpeg (Joint Photographic Experts Group), .png (Portable Network Graphic).

Digital photo provides spectral information in the red, green, and blue wave lengths (Reiko and Hiroyuki 2010). RGB color component has 256 levels, numbered 0 to 255, and in total, 256, 3

colors can be represented, with black shown as 0, 0, 0 and white shown as 255, 255, 255 (Gonzalez *et al.* 1987). Digital images were analyzed with a computer program (Image Analysis of Fertilizer) written in Microsoft visual basic 6.0 for the present study. The program extracts red, green, and blue (RGB) features from the digital camera image files and computes color indices.

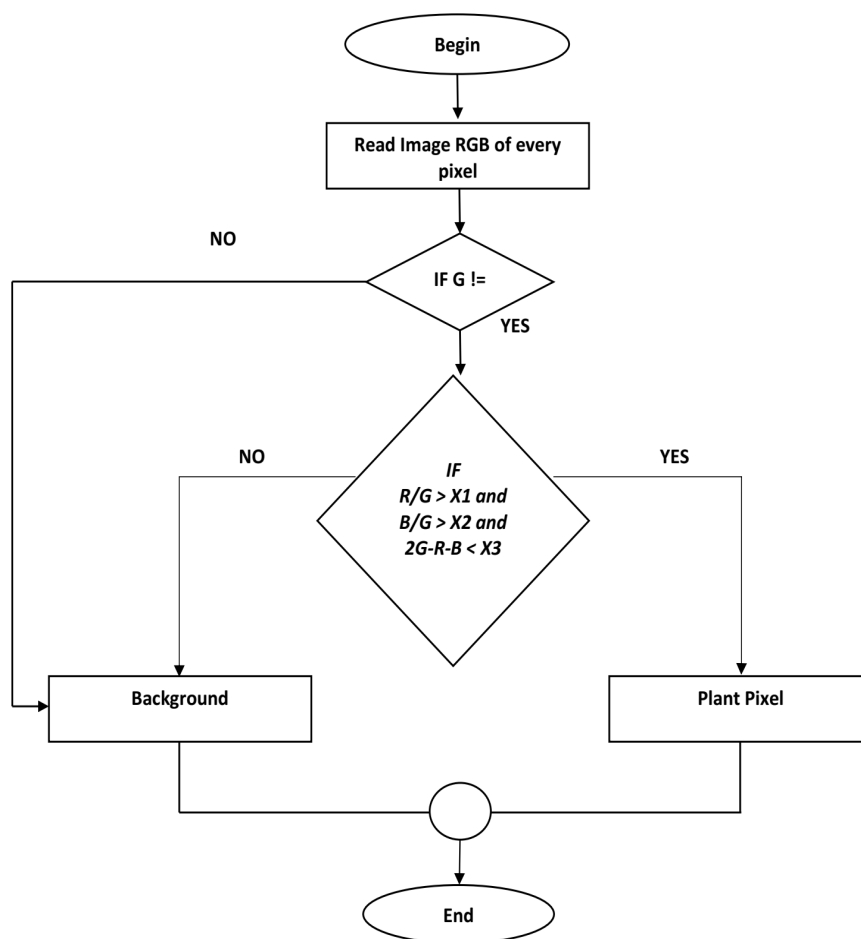


Figure3.2.73: Flowchart algorithm of the overall methodology and modeling

3.1.3.8 2. Calculation of color indices

$$\text{Canopy Cover (CC)} = (1 + \frac{(G-R)}{(G+R+L)})$$

The detail software algorithm of the computer programmer as follows:

If $R < 2.6$ and $R < G - 5$ and $G > G + 5$

Then canopy pixel

if $R + G + B < 200$

then sunlit canopy (SC) pixel

else shaded canopy (ShC) pixel

end if else soil backgrounds

if $R + G + B > 250$

then sunlit soil (SS) pixel

else

shaded soil (ShS) pixel-----Kuk and Uzun (2013)

HUE

$$\text{Hue} = 120 + \{60(B-R) / \max(R; G; B) - \min(R; G; B)\} \text{-----Karcher and Richardson (2003)}$$

EGI

$$\text{EGI} = 3 \times g^{-1}$$

MEGI

If $g < r$ or $g < b$

Then $\text{MEGI} = 0$

else

$\text{MEGI} = \text{EGI}$

Normalized Different Index (NDI)

$$\text{NDI} = (g - r) / (g + r + 0.01) \text{ ----- Mao et al. (2003)}$$

Normalized Difference Vegetation Index R-GB

$$\text{NDVI}_{\text{rgb}} = (g + b) - r / (g - b) + r \text{ ----- Putra and Soni (2017)}$$

Normalized Difference Vegetation Index-Green

$$\text{NDVI}_{\text{green}} = (g + b) / (g + b) \text{ ----- Gitelson et al. (2002)}$$

Soil Adjusted Vegetation Index-Green

$$\text{SAVI}_{\text{green}} = (1 + L) \times (g - r) / (g + r + L) \text{ ----- Li et al. (2010)}$$

L = correction factor

Green Minus Red (GMR)

$$\text{GMR} = g - r \text{ ----- Wang et al. (2013)}$$

Simple Ratio (SR)

$$\text{SR} = g / r \text{ ----- Wang et al. (2013)}$$

Visible Atmospherically Resistant Index (VARI)

$$\text{VARI} = (g - r) / (g + r - b) \text{ ----- Gitelson et al. (2002)}$$

Blue-Red Adjusted Vegetation Index (BRAVI)

$$\text{BRAVI} = N (g - r) / (g + r + N), \text{ where noise intensity 'N'} \text{ ----- Putra and Soni (2017)}$$

BRAVI-Simple Ratio

$$\text{Braves} = N \times g / (r + N), \text{ noise intensity 'N'} \text{ ----- Putra and Soni (2017)}$$

Enhanced Vegetation Index-Green

$$\text{EVI}_{\text{green}} = 2.5 \times (g - r) / (g + 6 \times r - 7.5 \times b + 1) \text{ ----- Huete et al. (2002)}$$

Enhanced Vegetation Index 2-Green

$$\text{EVI}_{\text{green}2} = 2.5 \times (g - r) / (g + 2.4 \times r + 1) \text{ ----- Jiang et al. (2008)}$$

Optimized Soil Adjusted Vegetation Index-Green

$$\text{OSVIgreen} = 1.5 \times (g - r) / (g + r) + 0.16 \text{ -----Rondeaux } et al. (1996)$$

Simple Ratio Intensity R-GB

$$\text{SRrgb} = r / (g + b) \text{ ----- Putra and Soni (2017)}$$

R, G, B

R = RED

G = GREEN

B = BLUE

Normalized 'r' 'g' 'b'

"r", (Normalized r)

$$r = R / R+G+B$$

"g", (Normalized g)

$$g = G / R+G+B$$

"b", (Normalized b)

$$b = B / R+G+B$$

Sum of R, G, B

$$\text{SumRGB} = \text{Total } (R + G + B)$$

Intensity

$$\text{Total } (R + G + B) / 3$$

Saturation

$$\text{SAT} = 1 - 3 \times \min (r, g, b)$$

or

$\{[\max(\text{RGB}) - \min(\text{RGB})] / \max(\text{RGB})\}$ ----- Matthew (2011)

HUE

If $\max(\text{RGB}) = \text{R}$, $60 * \{(G - B) / [\max(\text{RGB}) - \min(\text{RGB})]\}$

If $\max(\text{RGB}) = \text{G}$, $60 * \{2 + \{(B - R) / [\max(\text{RGB}) - \min(\text{RGB})]\}\}$

If $\max(\text{RGB}) = \text{B}$, $60 * \{4 + \{(R - G) / [\max(\text{RGB}) - \min(\text{RGB})]\}\}$ Matthew (2011)

Excessive green index (EGI) is a linear function of normalized green (g) and modified EGI (MEGI) is a variation of EGI (Mao *et al.* 2003). Hue and saturation (SAT) were calculated according to Tang *et al.* (2003). Hue can be visualized as a circular variable measured as an angle between 0 and 2π radians. Hue value is 0 for red, $2/3\pi$ for green, and $4/3\pi$ for blue. Saturation or chroma is purity of color. A saturation value of 1 is indicative of pure color that is absent of white light, and a saturation value of 0 means white or grey that has no hue (Ahmad and Reid 1996).

WCC (Wheat Canopy Cover) Software

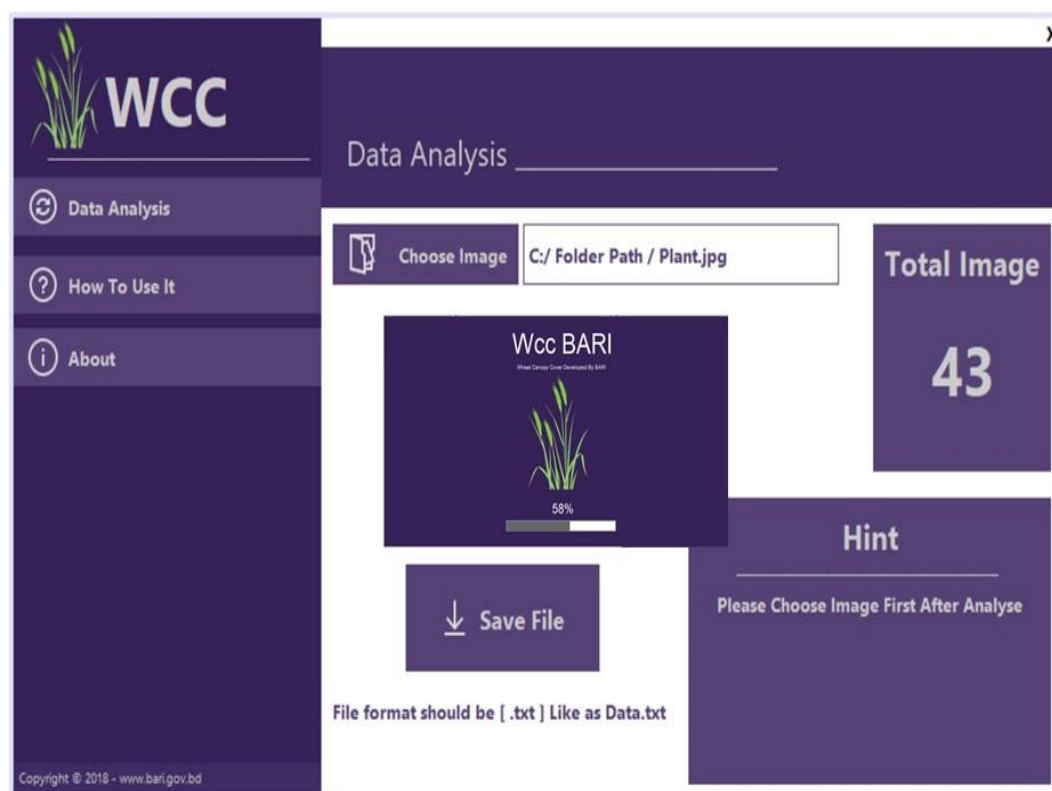


Figure 3.1.74: Outlook of the developed software WCC (Wheat Canopy Cover)

Name	Date	TPixl	PPixl	CCover	R	G	B	SumRGB	r	g	b	MT	SAT	HUE	ECI	MEGI	NDI	NDVIrgb	NDVlgreen	SAVlgreen	GMR	SR	VARI	BRARI	BRARlr	EVlgreen	EVlgreen2	GOVlgreen	SRgb	HUE
can_plot (10).JPG	17/2018 11:46	20153392	11311243	56.12%	101	142	72	315	0.32	0.45	0.23	105.00	0.31	1.67	0.35	0.35	-0.17	0.66	0.71	0.15	0.13	1.41	0.24	0.04	0.23	0.20	0.15	0.21	0.47	95
can_plot (11).JPG	17/2018 11:46	20153392	10277510	50.39%	105	146	65	316	0.33	0.46	0.21	105.33	0.38	1.58	0.39	0.39	-0.16	0.57	0.72	0.15	0.13	1.39	0.22	0.04	0.23	0.17	0.14	0.20	0.50	90
can_plot (12).JPG	17/2018 11:46	20153392	10475145	51.37%	110	152	69	331	0.33	0.46	0.21	110.33	0.37	1.58	0.38	0.38	-0.16	0.58	0.72	0.15	0.13	1.38	0.22	0.04	0.23	0.17	0.14	0.20	0.50	90
can_plot (13).JPG	17/2018 11:46	20153392	11864674	58.87%	105	146	63	314	0.33	0.46	0.20	104.67	0.40	1.56	0.39	0.39	-0.16	0.55	0.72	0.15	0.13	1.39	0.22	0.04	0.23	0.17	0.14	0.20	0.50	88
can_plot (14).JPG	17/2018 11:47	20153392	12354472	64.27%	104	147	69	320	0.33	0.46	0.22	106.67	0.35	1.63	0.38	0.38	-0.17	0.62	0.71	0.16	0.13	1.41	0.24	0.04	0.23	0.19	0.15	0.21	0.48	93
can_plot (15).JPG	17/2018 11:47	20153392	13120133	65.03%	105	148	70	323	0.33	0.46	0.22	107.67	0.35	1.63	0.37	0.37	-0.17	0.62	0.71	0.16	0.13	1.41	0.23	0.04	0.23	0.19	0.15	0.21	0.48	93
can_plot (16).JPG	17/2018 12:25	20153392	12853888	63.77%	102	144	64	310	0.33	0.46	0.21	103.33	0.38	1.60	0.39	0.39	-0.17	0.58	0.71	0.16	0.14	1.41	0.23	0.04	0.23	0.18	0.15	0.21	0.49	91
can_plot (17).JPG	17/2018 12:25	20153392	9380012	46.54%	100	139	68	307	0.33	0.45	0.22	102.33	0.34	1.63	0.36	0.36	-0.16	0.63	0.72	0.15	0.13	1.39	0.23	0.04	0.23	0.18	0.14	0.20	0.48	92
can_plot (18).JPG	17/2018 12:26	20153392	12940885	64.21%	101	142	73	316	0.32	0.45	0.23	105.33	0.31	1.68	0.35	0.35	-0.17	0.67	0.71	0.15	0.13	1.41	0.24	0.04	0.23	0.20	0.15	0.21	0.47	95
can_plot (19).JPG	17/2018 12:26	20153392	12850277	63.80%	97	139	73	309	0.31	0.45	0.24	103.00	0.29	1.73	0.35	0.35	-0.18	0.71	0.70	0.16	0.14	1.43	0.26	0.04	0.23	0.22	0.15	0.22	0.46	98
can_plot (20).JPG	17/2018 11:44	20153392	14250593	70.73%	102	146	71	319	0.32	0.46	0.22	106.33	0.33	1.67	0.37	0.37	-0.18	0.65	0.70	0.16	0.14	1.43	0.25	0.04	0.23	0.20	0.15	0.22	0.47	95
can_plot (21).JPG	17/2018 12:26	20153392	14335750	71.15%	97	140	71	308	0.31	0.45	0.23	102.67	0.31	1.71	0.36	0.36	-0.18	0.69	0.69	0.16	0.14	1.44	0.26	0.04	0.23	0.22	0.16	0.23	0.46	97
can_plot (22).JPG	17/2018 12:27	20153392	10805195	53.61%	99	138	66	303	0.33	0.46	0.22	101.00	0.35	1.62	0.37	0.37	-0.16	0.61	0.72	0.15	0.13	1.39	0.23	0.04	0.23	0.18	0.14	0.20	0.49	92
can_plot (23).JPG	17/2018 12:27	20153392	14706625	72.35%	98	141	66	305	0.32	0.46	0.22	101.67	0.35	1.66	0.39	0.39	-0.18	0.63	0.70	0.16	0.14	1.44	0.25	0.04	0.23	0.20	0.16	0.22	0.47	94
can_plot (24).JPG	17/2018 12:27	20153392	8377737	41.57%	100	138	66	304	0.33	0.45	0.22	101.33	0.35	1.60	0.36	0.36	-0.16	0.60	0.72	0.15	0.13	1.38	0.22	0.04	0.23	0.17	0.14	0.20	0.49	91

Figure 3.2.75: Output of the developed software WCC (Wheat Canopy Cover)

3.1.3.8.3 Correlation matrix of morpho-physiological, digitally extract traits, yield and yield contributing traits of wheat

Pearson's correlation coefficients (lower diagonal) among 43 morpho-physiological, digitally extract, yield and yield contributing attributes of wheat varieties grown under different level of nitrogen fertilizer treatments are shown in Figure 3.1.76 for 2016-17 and Figure 3.1.77 for 2017-18. There was noted a significant correlation between grain yield and most of the studied traits, i.e., NDVI, LAI, NGS, Chl a, PH, Chl b, SPAD, HUEp, SAT, NDVIrgb, EIG, HUE, LNC, HI, CC and DCC which are highly positively associated with one another during 2016-17. There was no significant correlation between seed yield and TP or TF and TT. In addition, there was a negative association between grain yield and r, G, b, SRrgb, g, Vari, NDI etc

The correlation matrix of digitally extracted trait and morpho-physiological traits results agree with a number of previous studies on the use of spectral indices to estimate the N-nutrition status (Mistele and Schmidhalter, 2010; Erdle *et al.*, 2011, Baresel *et al.*, 2017). There are differences in the ranking of correlation coefficients in various studies. Due to the large confidence intervals correlation coefficients usually have, many of the reported differences may be statistically not significant and should not be over-interpreted. Furthermore, the results concerning the SPAD-measurements coincide with those from previous studies (Uddling *et al.*, 2007), confirming the suitability of the method, and indicating, that the method has been applied correctly.

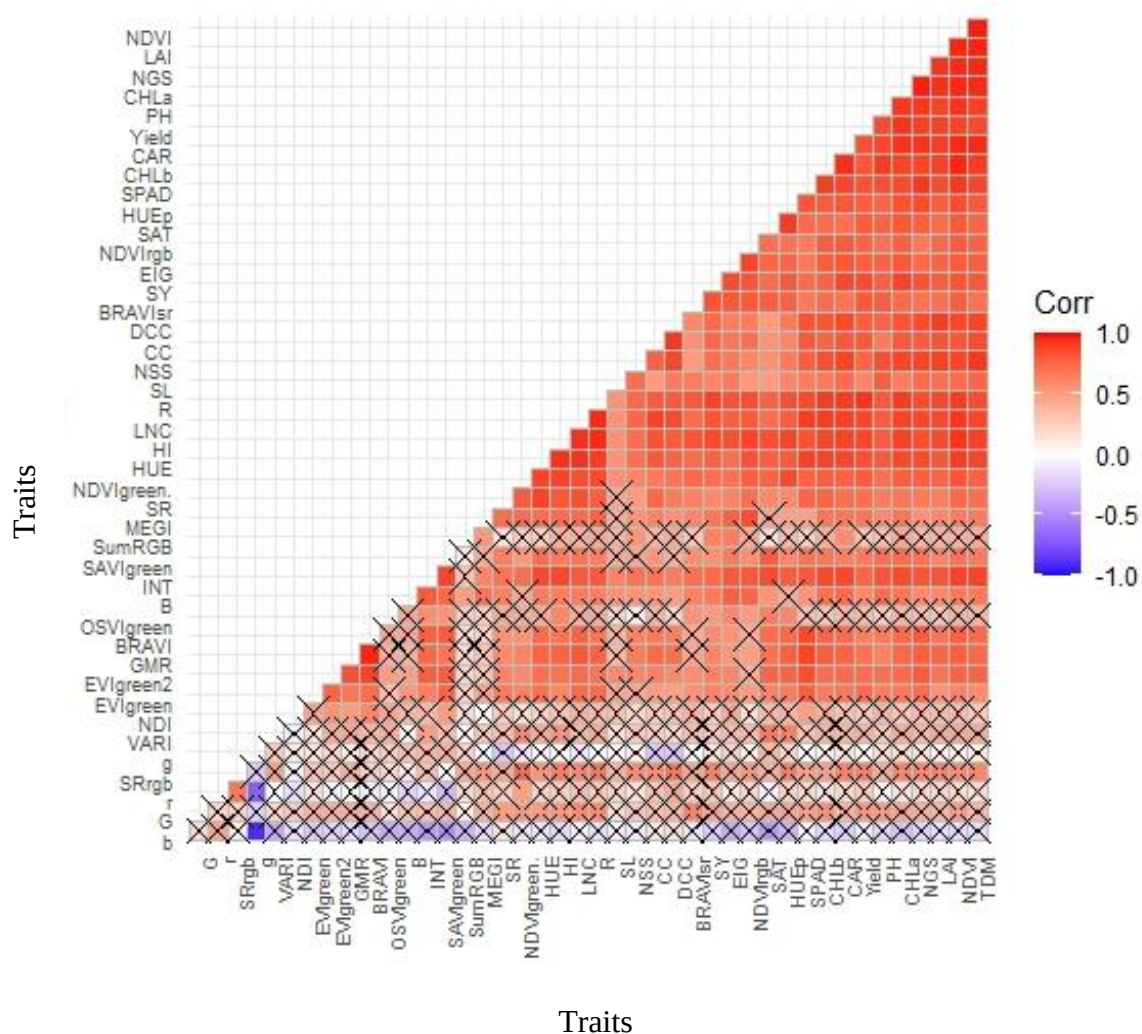


Figure 3.1.76: Heatmap showing the Correlation matrix of 43 morpho-physiological, digitally extract traits, yield and yield contributing traits during 2016-17.

Heat map displaying the relationship matrix among 43 wheat traits. The red colour diagonal represents a perfect positive relationship between two traits with itself and blue colour diagonal represents a perfect negative correlation between two traits. ×= Non-Significant at 5%

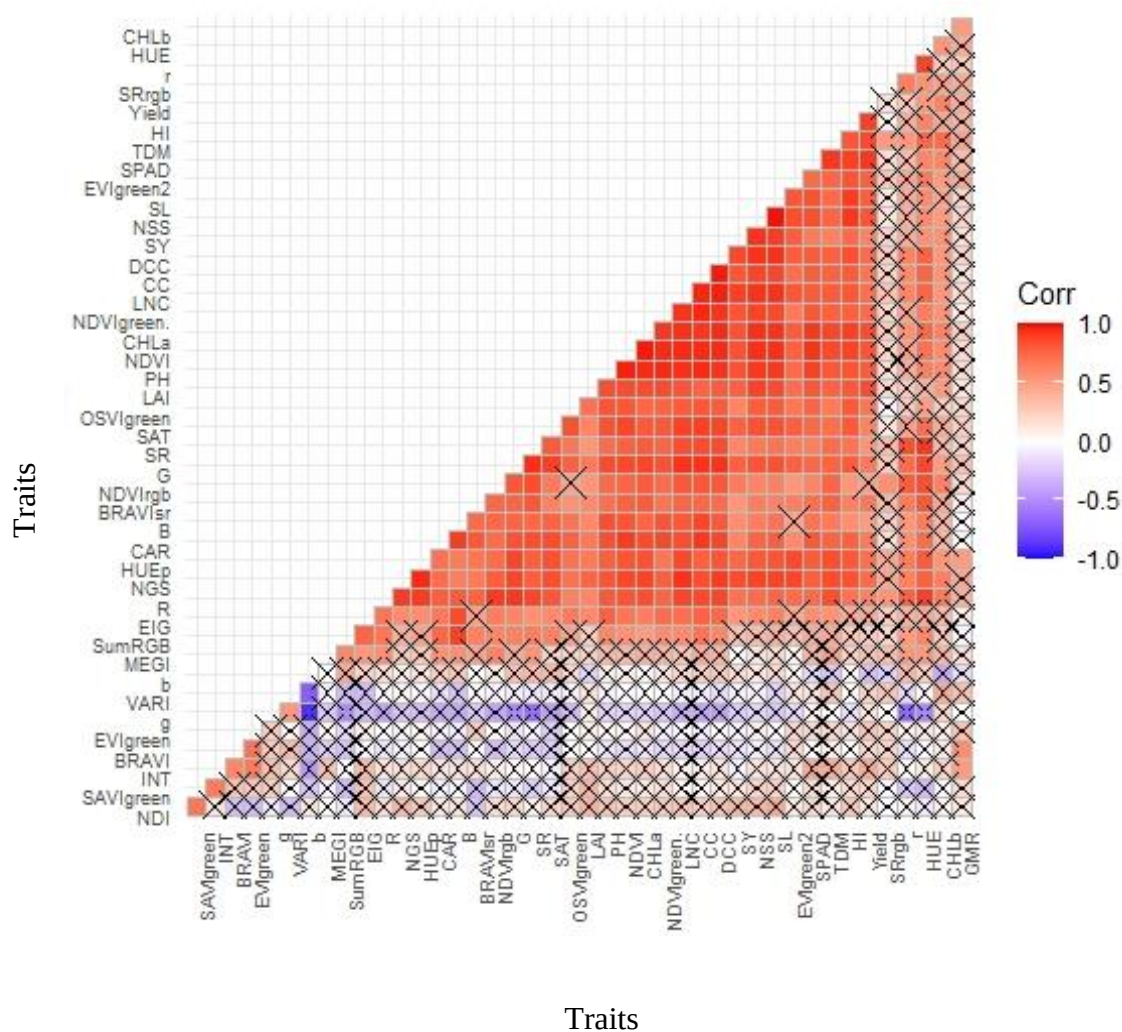


Figure 3.1.77: Heatmap showing the Correlation matrix of 43 morpho-physiological, digitally extract traits, yield and yield contributing traits during 2017-18.

Heat map displaying the relationship matrix among 43 wheat traits. The red colour diagonal represents a perfect positive relationship between two traits with itself and blue colour diagonal represents a perfect negative correlation between two traits. ×= Non Significant at 5%

3.2 EXPERIMENT II: EFFECT OF NITROGEN ON MORPHO-PHYSIOLOGICAL TRAITS OF MAIZE

Abstract

Maize (*Zea mays* L.) yield extremely influenced by on nitrogen fertilization. This study investigates the effect of nitrogen on morpho-physiological traits; develop algorithms for relationship between manual phenotyping and digital phenotyping of maize and develop algorithms for relationship between leaf nitrogen and digital field image traits of maize. The experiment comprised three hybrid maize varieties viz. V_1 =Hybrid 981, V_2 =BARI Hybrid maize-9, and V_3 =Hybrid P3396 with three levels of nitrogen (N_1 =100 kg N ha⁻¹, N_2 =200 kg N ha⁻¹, N_3 =300 kg N ha⁻¹). The experiment was laid out in split plot design with three replications. Experimental results indicated that different varieties (V), nitrogen level (N) and interaction of V×N had the significant effect on morpho-physiological, yield, and yield contributing traits viz. PH, LAI, NDVI, CC, SPAD, Chl a, Chl b, Car, LNC, TDM, EH, DFT, DFS, NRPC, NSPR, NSPC, FW, TSW and YTPH. Among the maize hybrid maize varieties, 981 had the maximum grain yield (13.80 t ha⁻¹) which was statistically identical with hybrid P3396 and minimum grain yield (12.47 t ha⁻¹) was found form BHM9. The trend of grain yield was in order of 981>P3396> BHM 9. Nitrogen levels affects maize dry matter production by influencing leaf area development, leaf area maintenance. The highest value of PH, NDVI, CC, LNC, Chl a, SPAD was found in the flowering period, between nitrogen fertilizer treatment in each period of performance of $N_3 > N_2 > N_1$ in 120 DAS. Among the maize hybrids, 981 had the highest (13.80 t ha⁻¹) grain yield which was statistically identical with hybrid P3396 and minimum grain yield (12.47 t ha⁻¹) was found form BHM9 and among the nitrogen level highest grain yield (13.84 t ha⁻¹) was found from N_3 treatment (300 kg N ha⁻¹). Among the interaction treatments, maximum grain yield (14.45 t ha⁻¹) was recorded by the interaction of V_3N_3 (P3396 and 300 kg N ha⁻¹) which was statistically identical with V_2N_3 (BHM 9 and 300 kg N ha⁻¹). A strong relationship between NDVI, SPAD, CC and LNC across the maize varieties was observed. The results also suggest that because of NDVI, SPAD and CC saturation, NDVI and CC could accurately predict nitrogen requirements for maize. The results of this study partially supported the hypothesis that digital image traits measured by image processing software (MCC) can identify and differentiate variations in nitrogen of hybrid maize. It could be concluded that under the conditions of the current experiment, application of nitrogen fertilizer has positive effects on physiological parameter of hybrid maize variety and if the farmers use this variety with high dose of nitrogen, they will be benefited by receiving higher grain yield but if they use lower doses of nitrogen will be less benefited.

3.2.1 INTRODUCTION

Nitrogen (N) is a primary constituent of the nucleotides and proteins that are essential for life. Crop productivity relies heavily on N fertilization. Production and application of N fertilizers consume huge amounts of energy, and excess is detrimental to the environment; therefore, judicious use of N is essential for the development of sustainable agriculture. Application of chemical N fertilizers during the past five decades has resulted in greatly increased global food production and decreased world hunger (Good *et al.*, 2004 and Ju *et al.*, 2009). The Declaration of the World Summit on Food Security (FAO, 2009) calls for an average annual increase in food production of 44 million metric tons to feed approximately 9 billion people by 2050 (Tester and Langridge, 2010). Accordingly, N fertilizer application is expected to increase by approximately threefold in the next 40 years unless N use efficiency (NUE) is significantly increased.

The benefits of N added to cropping systems come with well-documented energy and environmental costs (Xu *et al.*, 2012). In a collaborative report, the International Fertilizer Industry Association and United Nations Environment Programme estimated that production of 1 metric ton of fertilizer N synthesized through the Haber-Bosch process consumes 873 m³ of natural gas. For many crops, N fertilization has become the highest input cost, and this cost will only increase as resources become scarcer. Excess N compounds released from agricultural systems threaten the quality of air, water, and soil. Increased soil leaching into drainage water and the release of atmospheric nitrous oxide and reactive N gases into the troposphere accelerate the eutrophication of waterways and acidify soils (Guo *et al.* 2010; Robertson *et al.*, 2009). Because the intricate effects of reactive N cascade through its many chemical forms, N pollution poses an even greater challenge than carbon (C); excess N in the environment is also currently costing the European Union between €70 billion and €320 billion per year (Sutton *et al.*, 2011). Improving NUE is therefore crucial and represents a significant challenge for us.

The average global grain yield of maize has increased 25% in the past 20 years compared with the previous 50 years, which relied on improved genetic and cultural practices (Duvick, 2005; Ciampitti and Vyn, 2012). About 50% of total DM in a maize plant of maturity is obtained

during the post-silking period, with the majority of this post-silking DM gain occurring in the grain (Rajcan and Tollenaar, 1999; Tollenaar *et al.*, 2004; Lee and Tollenaar, 2007). New maize varieties accumulate more post-silking DM than old varieties, which has contributed significantly to the greater grain yield of new varieties (Rajcan and Tollenaar, 1999; Tollenaar and Wu, 1999; Wang *et al.*, 1999; Echarte *et al.*, 2008). Leaves are determinate organs that serve as the main photosynthetic structures of land plants (Piazza *et al.*, 2005). New maize varieties have higher leaf area index, longer duration of photosynthesis, delayed leaf senescence and higher rates of DM accumulation during the grain-filling period (Ma and Dwyer, 1998; Tollenaar and Wu, 1999; Borrell *et al.*, 2001; Duvick, 2005; Echarte *et al.*, 2008).

N drives plant DM production through control of both the leaf area index and the amount of N per unit of leaf area (Below, 2002). A positive response of photosynthetic rate to leaf N concentration has been widely reported (Muchow and Sinclair, 1994; Sinclair and Muchow, 1995; Paponov and Engels, 2003). Ding *et al.* (2005) reported that the difference in dry matter accumulation between maize grown under high and low N conditions was associated with sustained higher leaf carbon exchange rate (CER) and chlorophyll content during the grain-filling period and that this response to N availability was consistent for a set of older and newer maize hybrids.

Partitioning of leaf N between photosynthetic and non-photosynthetic components and, within the photosynthetic apparatus, among light harvesting, electron transport, and carbon reduction can influence the photosynthetic N-use efficiency (Pons *et al.*, 1994). Partitioning of leaf N among the various components is regulated by N supply, available light energy, and the ratio of red to farred radiation (Lawlor, 1994) and has been shown to vary among plant species (Pons *et al.*, 1994).

Changes in the partitioning of photosynthates in crop plants, expressed as harvest index, have been an important aspect of improving grain yield under both adequate and N-limited conditions (Sinclair, 1998; Mosisa and Habtamu, 2007). Rajcan and Tollenaar (1999a) found that greater dry matter accumulation and partitioning during grain filling contributed to the better performance of a newly developed hybrid compared to an old hybrid under low N stress.

Although N can be easily remobilized within plants, N deficiency suppresses overall plant metabolism and development, and severely reduces crop yield (Amanullah and Khalil 2009). Increasing N fertilization is an efficient way to improve the grain yield of cereals (Hirel *et al.* 2001). In China, cereal production increased 2.6-fold from the 1970s to 1990s largely owing to a 7-fold increase in N fertilizer use (Zhu and Chen 2002). Meanwhile, a steady increase in N fertilizer application has clearly contributed to worldwide food security over the past several decades (Ladha and Pathak 2005). However, N over-supply reduces N uptake and utilization efficiency and alters amino acid composition in xylem sap (Gallais and Hirel 2004). In some rapidly developing countries, extensive N oversupply causes serious soil and environmental problems, such as soil acidification, N emission, runoff, or leaching (Liu and Diamond 2005; Zhao *et al.* 2006; Ju *et al.* 2009). This study investigates the following objectives

- i) To study nitrogen effect on morpho-physiological traits of maize
- ii) To develop algorithms for relationship between manual phenotyping and digital phenotyping of maize and
- iii) To develop algorithms for relationship between leaf nitrogen and digital field image traits of maize.

3.2.2 MATERIALS AND METHODS

The materials used in the present experiment and the details methodology followed during the research period are presented in this chapter.

3.2.2.1 Location and duration

The experiment was conducted at Seed Technology Division field, Bangladesh Agricultural Research Institute (BARI) during November 2016 to May 2017 and November 2017 to May, 2018. The experimental site is situated under the Gazipr Sadar Upazila and located at 23.9886369 N latitude and 90.413056 longitude with an elevation of 71 meter above the sea level (Appendix 3.1. 1111).

3.2.2.2 Soil characteristics and Analysis of the experimental field

The soil of the experimental area is Dark Grey Terrace Soil which belongs to the Modhupur Tract under AEZ 28. This is characterized by poor fertility and impeded by internal drainage. Soil pH was measured by a combined glass calomel electrode). Organic carbon determination by wet oxidation method (Walkley and Black). Total N was determined by modified Kjeldahl method. Ca and Mg were by KCL extractable method. K, Cu, Fe, Mn and Zn were determined by NaHCO₃ extraction followed by AAS reading. Boron was determined by CaCl₂ extraction method. Phosphorus was determined by Bray and Kurtz method. S was determined by turbidity method with BaCl₂. The pH of the experimental soil ranges from 6.11 to 6.50. Soils of the experimental sites were analyzed before sowing of maize seed (Table 3.2.1). The soils are acidic in nature containing low organic matter. Ca, Mg, K, P, S, Cu, Fe, Mn and Zn content of the soil are high. N content of soil.

3.2.2.3 Climate conditions during the experimental period

The climate of study site is subtropical, characterized by three distinct seasons, the winter season (November–February; night time: 8–12°C; day time: 20–25° C), the pre-monsoon period or hot season (March–April; night time: 15–18° C; day time: 35–40°C) and the monsoon period (May–October; night time: 18–24°C; day time: 30–35°C). Climatic parameters are presented in the Appendix. 3.1.2.

3.2.2.4 Land preparation

The land was well prepared by repeated ploughing and cross-ploughing with a tractor followed by laddering for breaking the clods, leveling the lands and collecting the stubbles. The individual plots were prepared by making ridges (8-10 cm) around each plot to restrict the lateral run off of fertilizer with irrigation water. To control soil-borne insects, Furadan 5G containing Carbofuran (systemic pesticide; FMC Corp., Philadelphia, PA, USA) was broadcast at 10 kg ha^{-1} during final land preparation.

3.2.2.5 Experimental treatments and design

The experiment was laid out in split plot design with three replications. Three hybrid maize varieties (V_1 =Hybrid 981, V_2 =BARI Hybrid maize-9 and V_3 = Hybrid P3396) in main plot and three levels of nitrogen (N_1 = 100 Kg N ha^{-1} , N_2 = 200 Kg N ha^{-1} and N_3 = 300 Kg N ha^{-1}) in sub-plot treatment. Each plot was $5 \times 3 \text{ m}^2$, row to row distance was 75 cm and plant to plant distance 20 cm. The Basic information regarding maize experiments given in Table 3.2.2.

3.2.2.6 Fertilizer application

Recommended dose of P_{55} K_{110} , S_{40} Zn_5 and $B_1 \text{ kg ha}^{-1}$ and cowdung 5 ton ha^{-1} was used in the form of TSP, MoP, Gypsum and Zinc oxide respectively. All P, K, S, Zn, B and cowdung and $1/3$ rd N were applied at the time of final land preparation. The remaining $2/3$ rd N were applied in two equal installments at 40 and 80 days after sowing (DAS).

3.2.2.7 Sowing of seeds

Seeds were sown with a spacing of row to row 75 cm and seed to seed 20 cm @ $25 \text{ kg seeds ha}^{-1}$. Two seed were sown per hill at a depth of 3-5 cm. The seeds were covered with soil for uniform germination. To accomplish excellent germination and protecting against fungal attack during the seedling stage, seeds were pre-treated with a fungicide Provax-200 WP (containing Carboxin and Thiram) an effective fungicide for seeds. Light irrigation at 2 days after sowing of seeds was given to ensure uniform germination of seeds.

Table 3.2.1. Analytical data of soil sample of maize field

Sample no.	pH	O.M.%	Ca	Mg	K	Total N%	P	S	B	Cu	Fe	Mn	Zn
			Meq/100 gm				µg/gm						
							Bray						
STD, BARI, Gazipur	6.11	1.06	7.0	2.4	0.17	0.056	45.5	27.9	0.30	1.9	40	7.1	3.18
Critical Level			2.0	0.5	0.12		7.0	10	0.2	0.2	4.0	1.0	0.6

Table 3.2.2. Basic information regarding maize experiments

Experiment No.	Location	Date of sowing	Date of harvesting	Name of Variety	Nitrogen treatment (Kg ha ⁻¹)
Expt.1. 2016-2017	Seed Technology Division, BARI, Gazipur	20 th November 2016	3 rd May 2017	V ₁ =Hybrid 981 V ₂ =BARI Hybrid maize-9 and V ₃ =Hybrid P3396	N ₁ =100 N N ₂ = 200 N N ₃ = 300 N
Expt.2. 2017-2018	Seed Technology Division, BARI, Gazipur	23 th November 2017	10 th May 2018	V ₁ =Hybrid 981 V ₂ =BARI Hybrid maize-9 and V ₃ =Hybrid P3396	N ₁ =100 N N ₂ = 200 N N ₃ = 300 N

3.2.2.8 Drive away birds

Drive birds away for 10-12 days after sowing to protect the crop from bird damage.

3.2.2.9 Thinning

Thinning was done to maintain the desired number of plant population (66,666 plants ha⁻¹.) maintaining plant to plant distances as 20 cm within two weeks of emergence.

3.2.2.10 Weed control

One weeding was done at the 4-5 leaf stage of seedling growth.

3.2.2.11 Irrigation

The plot was irrigated four times during the growing period of the crop; first irrigation was given at 3 to 5 leaf stage. The second irrigation after 8-10 leaf stage, the third irrigation during tassel emergence stage and the fourth irrigation was given at grain filling stage. Excess water was drained out from the field.

3.2.2.12 Earthing up

Earthing up was done in between the two lines, making a 15-20 cm ridge and furrow at 8-10 leaf stage.

3.2.2.13 Insect control

Cutworms were observed at the 2-4 leaf stage. This insect cuts the stem of young seedlings from the base at night and hides under the soil surface at daytime. This insect was controlled spray Dursban 20EC (5 ml in 1-liter water) in a 15-20 cm radius of the plant base.

3.2.2.14 Disease control

Leaf blight (*Helminthosporium maydis*) was observed in the experimental field during tassel initiating stage. This disease was controlled by spraying Tilt 25 EC (Triazole group) 0.1%.

3.2.2.15 Harvesting

Harvesting was done when plants show distinct signs of drying, the husk cover is completely dry, and the grains are fully mature. Grain maturity was identified from the milk line of kernels or the formation of a black layer at the junction of grain and placenta. The crop was harvested on 3rd May 2017, and 10th May 2018, respectively. The harvested crop of each plot was bundled separately, tagged and taken to the threshing floor and threshed and the grain cleaned properly.

Grains were thoroughly dried in the sun for 5-6 days. The grain of each plot was then weighted individually. The weight of grain and straw were recorded plot wise and adjusted at 12% moisture content.

3.2.2.16 Data collection

The data were recorded different growth stages and also at harvest.

Plant height (cm)

Height of plant was measured with meter scale from the ground level to the top of the main shoot and the average was determinate.

Mature cobs plant⁻¹

The number of mature cobs of each plant from ten plants was recorded and the mean was expressed plant⁻¹ basis.

Length of cob (cm)

Ten randomly selected cobs were taken from the cobs harvested for determining grain yield and length of the cob was measured from the bottom to the top of the cob by a measuring tape.

Number of seeds cob⁻¹

Ten randomly selected cobs were taken from the samples harvested for grain yield and the number of seeds in three to four rows was counted and the mean value was multiplied by number of rows present in each cob. The mean value of ten cobs was recorded.

Grain yield (t ha⁻¹)

The cobs harvested from each plot were separated from plants, cleaned, dried and weighted separately. Grain yield of each plot was recorded and adjusted at 12% moisture content.

3.2.2.17 NDVI value

The normalized difference vegetation index (NDVI) was measured by hand green seeker (Trimble) and green seeker RT100 (Agri Optics). NDVI quantify vegetation by measuring the difference between near-infrared (NIR) (which vegetation strongly reflects) and red light (which vegetation absorbs).

The formula NDVI is:
$$\text{NDVI} = \frac{\text{NIR}-\text{Red}}{\text{NIR}+\text{Red}}$$

where R is the reflectance in the red light band (wavelengths 600 to 720 nm) and NIR is the reflectance in the near-infrared band (wavelengths 720⁻¹300 nm).

Where, Near Infra red (NIR), Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1); however, no green leaves give a value close to zero. A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green.

3.2.2.18 Canopy Coverage (CC)

The canopy cover provided by the crops was assessed at ten successive dates between the November 2016 and March 2017: at 20, 40, 60, 80 and 100 days after seeding. Canopy cover was measured by “Canopeo” an android mobile phone application (Patrignani and Ochsner, 2015).

3.2.2.19 SPAD (Soil Plant Analyses Development) value

The chlorophyll content in plant leaves was determined with a SPAD meter (Model: SPAD-502, Minolta Co. Ltd., Japan). The meter determines the relative amount of chlorophyll present on the leaf in two wavelength regions as chlorophyll absorbance peaks in the blue (400-500nm) and red (600-700nm) with no transmittance in the near-infrared region. This is the reason why SPAD 502 measures the absorbance in red and near infrared regions on a leaf area of 2 mm × 3 mm. The SPAD value was taken from middle portion of the flag leaf of the tagged main shoot at 40, 60, 80, 100, 120 and 140 days after sowing (DAS). A through using self-calibrating Minolta chlorophyll meter. Measurements at each experimental plot consisted of average of five readings (Reynolds *et al.* 1998).

3.2.2.20 Leaf area index

Leaf area was calculated with an Automatic Leaf Area Meter (Leaf area meter-LICOR-3300, USA) at 40, 60, 80, 100, 120 and 140 DAS from an area of one square meter. The leaf area index (LAI) of the crop at different growth stages was calculated using the following equation as described by Radford (1967).

$$LAI = \frac{\text{Surface area of leaf sample}}{\text{Ground area of the sample}}$$

3.2.2.21 Chlorophyll and carotenoid determination

Extraction and determination of chlorophyll (Chl) and carotenoid (Car) was performed according to the method of Arnon (1949). Five hundred milligram of fresh leaf material was homogenized in 10 ml of 80% acetone at 4°C and centrifuged at 2500 rpm for 10 minutes at 4°C. This procedure was repeated until the residue became colorless. The extract was transferred to a graduated tube and made up to 10 ml with 80% acetone and assayed immediately. Three milliliters aliquots of the extract were transferred to a cuvette and the absorbance was read at 645, 663 and 480 nm with a spectrophotometer (UV⁻¹800, Shimadzu, Japan) against 80% acetone as blank. Chlorophyll content was calculated using the formula of Arnon (1949) and expressed in mg g⁻¹ fresh weight (FW).

$$\text{Total Chl (mg g}^{-1}\text{FW}^{-1}) = (0.0202) \times (A_{645}) + (0.00802) \times (A_{663})$$

$$\text{Chla (mg g}^{-1}\text{FW}^{-1}) = (0.0127) \times (A_{663}) - (0.00269) \times (A_{645})$$

$$\text{Chlb (mg g}^{-1}\text{FW}^{-1}) = (0.0229) \times (A_{645}) - (0.00468) \times (A_{663})$$

Car content was estimated using the formula of Kirk and Allen (1965) and also expressed in mg g⁻¹ FW.

$$\text{Car (mg g}^{-1}\text{FW}^{-1}) = A_{470} + (0.114 \times A_{663} - 0.638 \times A_{645}).$$

Maize leaf tissue (0.5g) was homogenized in 1 ml of 50 mM ice-cold K–P buffer (pH 7.0) by mortar and pestle containing 100 mM KCl, 1 mM ascorbate, 5 mM β-mercaptoethanol and 10 %

(w/v) glycerol. The homogenates were centrifuged at $11,500\times g$ for 10 min and the supernatants were used for determination of enzyme activity. All procedures were performed below 4 °C.

3.2.2.22 Leaf nitrate content (LNC) measure

Plant uptake nitrogen nutrient in the form of ammonium and nitrate ions for their green leafy growth. When ammonium fertilizers are applied to plants, the ammonium is converted to nitrate by nitrification process. Plant tissue such as leaf and petiole contain high levels of nitrate, which has been shown over many years to be a good indication of the nitrogen status of the plant. Testing laboratories analyzing for nitrogen content of dry plant tissue usually require ample time for collecting, transporting, drying, grinding and analysis. They deliver results after several days. With modern technology, quick tests for determining the nitrogen content in plant tissue like handheld nitrate meters with ion selective electrode, chlorophyll meter, and nitrate test strips have been developed.

The LAQUAtwin (B 741) nitrate ion meter provides the easiest way to measure nitrate concentration in fresh plant sap. The sensor requires only few drops of sap, which can be quickly extracted using a garlic press. The meter analyses the sap in just few seconds and displays reading expressed as either nitrate (NO_3^-) or nitrate-nitrogen ($\text{NO}_3\text{-N}$) ppm units. Results can be obtained immediately in the field with much less effort and relatively low cost. These advantages over conventional laboratory testing are useful for onion growers in determining fertilization applications.

Select mg/L or ppm $\text{NO}_3^- \text{ N}$ in the LAQUAtwin nitrate ion meter set-up. Calibrate the meter according to manufacturer's instructions using the 150ppm and 2000ppm nitrate standards included in the kit. The readings of 150ppm and 2000ppm nitrate standards will be calibrated as 34 ppm and 450 ppm $\text{NO}_3^- \text{ N}$, respectively.

Measurements were made with LAQUAtwin Compact Nitrate Meter B-741 (Horba, 2012). The procedure was conducted as follows; (1) leaf samples were hand grinded, and 0.1 g of the grinded material was used to prepare a homogeneous solution by adding 1mL of distillate water (H_2O); (2) samples were mixed by vortexing until the plant material was dissolved, and then

centrifuged for 4 min in order to separate the remaining plant material from the sap; (3) with a pipet 0.1 ml solution was taken, and put into the sensor part of the meter to measure the NO₃- concentration of the sap. Initial calibration of the apparatus was done with a standardized solution containing 300ppm and 5000ppm KNO₃-. After each measurement, the sensor was cleaned with water and gently dried with a paper towel (Horiba, 2012).

3.2.2.23 Total dry matter (TDM) measure

Three plants were sampled in each plot at 40, 60, 80, 100, 120 and 140 DAS. At each sampling plants were cut at the ground level, separated into leaf, stover, and reproductive parts. The segmented plant parts were oven dried at 70°C for constant weight.

3.2.2.24. Image acquisition

Canon camera and Android mobile phone were utilized for image acquisition. Images were stored in the JPG format. The photos were taken 50 cm above the crops canopy and 180° inverted the camera and mobile by using customize selfie stick (Plate 8). Substantial effort was made develop a standard imaging protocol to ensure imaging consistency and quality.

3.2.2.25 Statistical analysis

The data were analyzed by partitioning the total variance with the help of computer by using STAR Version 2.0.1 (IRRI 2014) Microsoft Excel 2016 and R-package (2018, version) program. The treatment means were compared using LSD at $P \leq 5\%$ level.

3.2.3 RESULTS AND DISCUSSION

3.2.3.1 Morphological traits of maize

3.2.3.1.1 Plant height (cm)

Effect of hybrid maize varieties on plant height of hybrid maize

The plant height of different hybrid maize varieties at different growth stages (DAS) significantly varied is shown in Figure 3.2.1 during 2016-17 but non-significant at 40 DAS and 60 DAS is showing in Figure 3.2.2 for 2017-18, respectively. Regardless of treatment differences, plant height increased progressively up to 140 DAS. Different hybrid varieties showed different plant height at different growth stages and finally the variety BARI Hybrid Maize 9 produced the significantly the tallest plant (55.0, 71.8, 131.7, 158.3, 179.8 and 233.5 cm at 40, 60, 80, 100, 120 and 140 DAS, respectively) which was superior from all other varieties during 2016-17. BARI Hybrid Maize 9 also produced the tallest plant height (130.33, 156.40, 176.80 and 239.29 cm at 80, 100, 120 and 140 DAS, respectively) which was superior than other varieties during 2017-18. Taller plants of BARI Hybrid Maize 9 might be due to its genetically governed traits. The hybrid P3396 produce dwarf plant (46.44, 66.56, 98.67, 123.78 and 134.86 cm at 40, 60, 80, 100, 120 and 140 DAS, respectively) during the both seasons which is our desired trait in case of hybrid maize. Plant height is an inherent character and varies with varieties and environmental conditions. In this research, plant height varied due to variety, nitrogen level and the combined effect of growing condition. Hasan *et al.* (2018), they reported that effect of hybrid maize variety on plant height was significantly. The variety BARI Hybrid Maize 9 produced the tallest plants (232.6 cm) which was superior to all other varieties. On the other hand, the hybrid variety P3396 was shorter plant (217.6 cm). The differences in plant height due to various varieties might be due to varied genetic makeup of the variety and interaction between variety and environment.

Effect of nitrogen on plant height of hybrid maize

Effect of N levels showed a significant variation on plant height for all growth stages (Figure 3.2.3 for 2016-17 and Figure 3.2.4 for 2017-18). Regardless of treatment differences, plant height increased progressively up to maturity. It was found that the tallest plant height was obtained from the 300 kg N ha⁻¹ treatment at all growth stages (55.89, 76.56, 114.78, 141.33, 157.03 and 219.10 cm at 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the maximum plant height was obtained from the N₃₀₀ (300 kg N ha⁻¹) treatment at all growth stages (62.11, 76.56, 114.78, 141.33, 157.03 and 219.10 cm at 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the dwarf plant structure was found in N₁₀₀ (100 kg N ha⁻¹) treatment (45.67, 63.22, 102.22, 125.89, 144.11, and 19462 cm at 40, 60, 80, 100, 120 and

140 DAS, respectively) during 2016-17 and the shorter was observed in N₁₀₀ (100 kg N ha⁻¹) treatment (51.44, 63.22, 102.22, 125.89, 144.11 and 196.84 cm at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. Increasing nitrogen level from 100 kg N ha⁻¹ to 300 kg N ha⁻¹ also increased the plant height of hybrid maize varieties. These results are in conformity with the results obtained by Akbar *et al.*, (1999) who found that plant height in maize increased with increase in N rate. However, in contrast to the results of this study, Sadeghi and Bahrani (2002) reported that increase in N rate had no significant effect on plant height. The discrepancy in the results obtained in this study and that of Sadeghi & Bahrani (2002) might be due to the difference in the range of population stand, soil fertility status, and the crop varieties used. Higher N applications increase the cell division, cell elongation, nucleus formation as well as green foliage. It also encourages the shoot growth. Therefore, higher doses of nitrogen increased the chlorophyll content which increased the rate of photosynthesis and extension of stem resulting increased plant height (Dawadi and Sah, 2012; Thakur *et al.*, 1997; Diallo *et al.*, 1996).

Interaction effect of hybrid maize varieties and nitrogen on plant height

The interaction effect of varieties and nitrogen levels on plant height was statistically significant at different DAS (Table 3.2.3 and appendix 3.2.1 for 2016-17 and Table 3.2.4 and appendix 3.2.2 for 2017-18). Results showed that the tallest plant was obtained from combination of BHM9×300 (58.33, 78.33, 138.67, 165.00, 185.67 and 243.33 cm at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the tallest plant also was obtained from combination of BHM9×300 (60.33, 78.33, 138.67, 165.00, 185.67 and 253.33 cm at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the shortest plant stature (40.67, 60.67, 88.67, 113.33, 130.33 and 173.50 cm at 40, 60, 80, 100, 120 and 140 DAS, respectively) was obtained from hybrid 981×100 combination during 2016-17 and the shortest plant stature (51.67, 62.67, 88.67, 114.33, 134.33 and 175.50 cm at 40, 60, 80, 100, 120 and 140 DAS, respectively) was obtained from hybrid 981×100 combination during 2017-18.

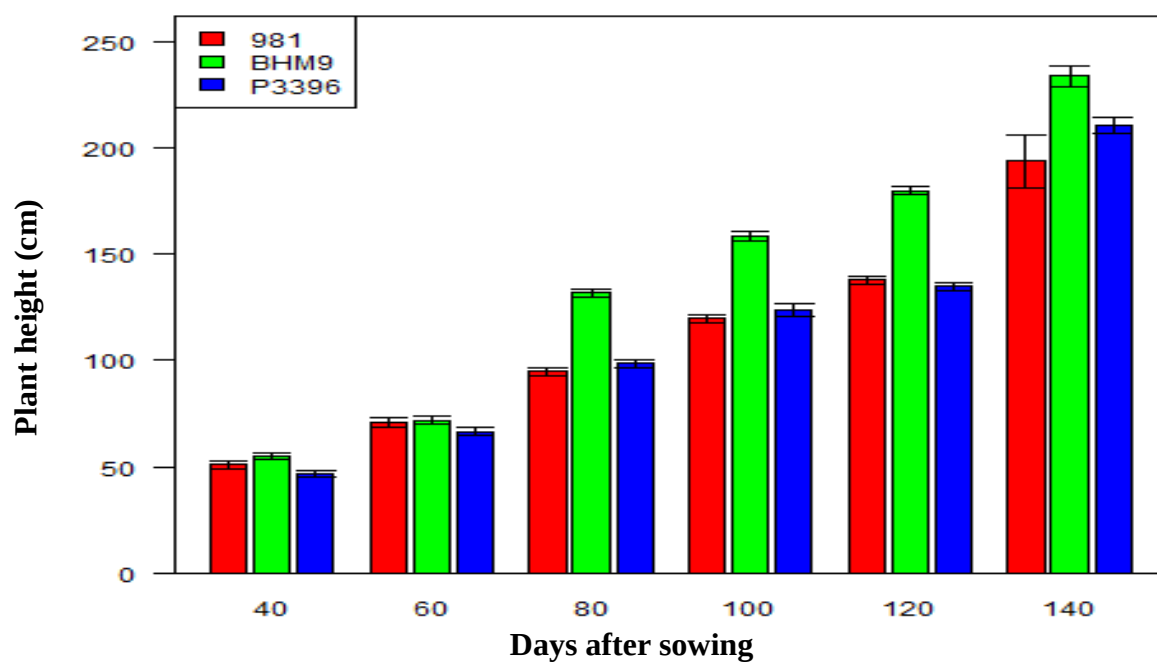


Figure 3.2.1: Effect of hybrid maize varieties on plant height at different days after sowing from original values during 2016-17.

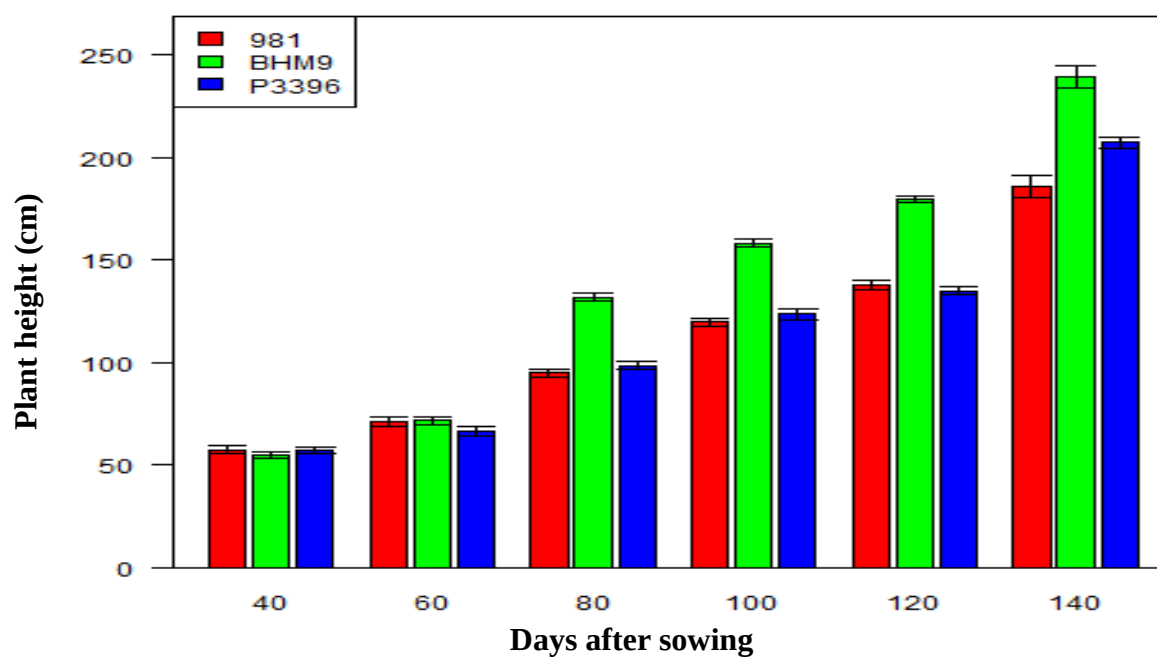


Figure 3.2.2: Effect of hybrid maize varieties on plant height at different days after sowing from original values during 2017-18.

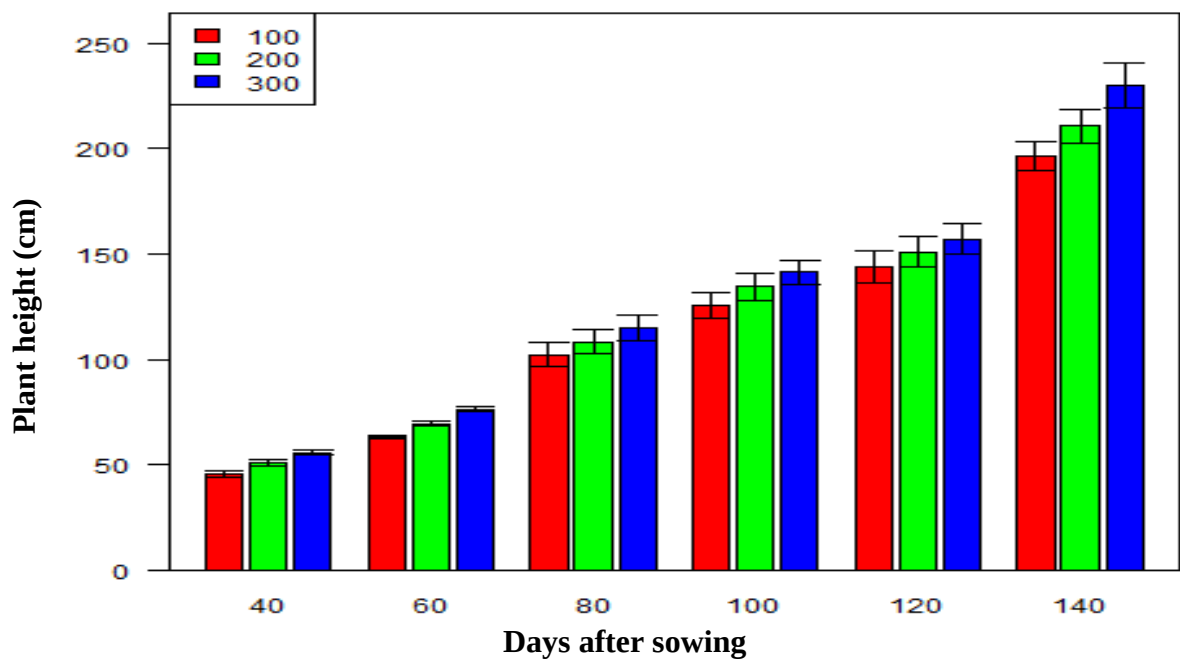


Figure 3.2.3: Effect of nitrogen on plant height of hybrid maize at different days after sowing from original values during 2016-17.

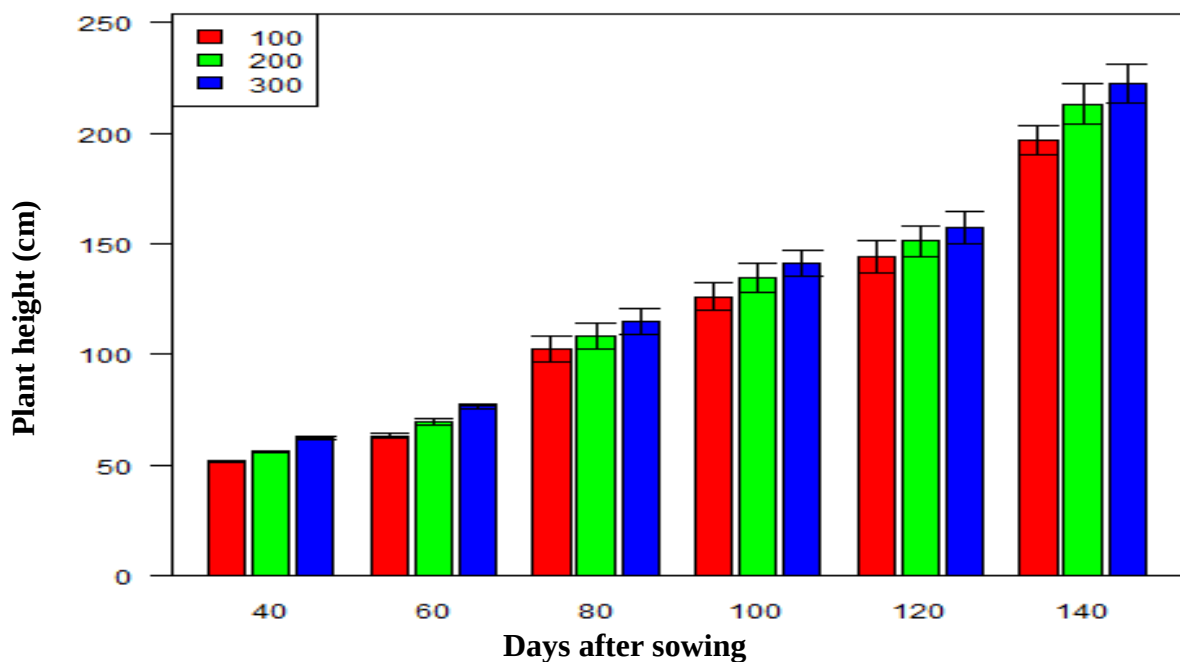


Figure 3.2.4: Effect of nitrogen on plant height of hybrid maize at different days after sowing from original values during 2017-18.

Table 3.2.3. Interaction effect of varieties and nitrogen on plant height (cm) at different days after sowing of hybrid maize during 2016-17

V×N	Days After Sowing (DAS)					
Interaction	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	40.67	60.67	88.67	113.33	130.33	173.50
981×200	51.00	73.00	95.33	118.67	138.43	185.00
981×300	57.33	77.67	100.67	127.00	144.43	188.97
BHM9×100	50.33	65.67	125.33	150.67	174.33	217.87
BHM9×200	56.33	71.33	131.00	159.33	179.33	239.33
BHM9×300	58.33	78.33	138.67	165.00	185.67	243.33
P3396×100	42.00	61.33	92.67	113.67	127.67	198.50
P3396×200	45.33	64.67	98.33	125.67	135.90	208.17
P3396×300	52.00	73.67	105.00	132.00	141.00	225.00
LSD (0.05)	2.17	2.81	0.80	1.37	1.26	11.77

Table 3.2.4. Interaction effect of varieties and nitrogen on plant height (cm) at different days after sowing of hybrid maize during 2017-18

V×N	Days After Sowing (DAS)					
Interaction	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	51.67	62.67	88.67	114.33	134.33	175.50
981×200	57.67	73.00	95.33	118.67	138.43	185.00
981×300	63.67	77.67	100.67	127.00	144.43	188.97
BHM9×100	50.33	65.67	125.33	150.67	174.33	218.53
BHM9×200	54.33	71.33	131.00	159.33	179.33	246.00
BHM9×300	60.33	78.33	138.67	165.00	185.67	253.33
P3396×100	52.33	61.33	92.67	113.67	127.67	198.50
P3396×200	56.33	64.67	98.33	125.67	135.90	208.17
P3396×300	62.33	73.67	105.00	132.00	141.00	215.00
LSD (0.05)	1.72	1.29	1.75	2.29	2.15	8.11

3.2.3.1.2 Leaf Area Index (LAI)

Effect of hybrid maize varieties on LAI

The leaf area index (LAI) of different hybrid maize varieties at different growth stages significantly differs at different days after sowing (DAS) is shown in Appendix 3.2.3, Figure 3.2.5 for 2016-17 and Appendix 3.2.4, Figure 3.2.6 for 2017-18, respectively. Leaf area index increased up to 100 DAS during 2016-17 and 2018-19, respectively and decreased with the advancement of growing period of all the hybrid varieties for both the years. Regardless of varietal differences, LAI increased progressively up to 100 DAS during 2016-17 and 2017-19. Different hybrid varieties showed different LAI at different growth stages and finally the variety BARI Hybrid Maize 9 produced the highest LAI (1.51, 1.84, 3.22, 2.78 and 2.28 at 60, 80, 100, 120 and 140 DAS, respectively) which was insignificant from all other varieties during 2016-17. BARI Hybrid Maize 9 also produced the maximum (1.16, 1.56, 2.02, 3.21, 2.76 and 2.66 at 40, 60, 80, 100, 120 and 140 DAS, respectively) which was superior than other varieties during 2017-18. Production of highest LAI at different DAS of BARI Hybrid Maize 9 might be due to its genetically governed traits. Lowest LAI was found from the hybrid P3396 produce minimum LAI (1.56, 1.84, 3.19, 2.56 and 2.36 at 60, 80, 100, 120 and 140 DAS, respectively) during the both seasons. According to Pandey *et al.* (2000), maize genotypes differ in their ability to maintain leaf area, LAI. Nasab (2001) reported that both grain and biomass yield in maize are correlated with vegetative and reproductive phase duration. Leaf area influences interception and utilization of solar radiation of maize crop canopies and, consequently, maize dry matter accumulation and grain yield. Leaf area and number are important factors in the estimation of canopy photosynthesis in crop growth simulation models that compute dry matter accumulation from temporal integration of canopy photosynthesis (Boote *et al.*, 1996).

Effect of nitrogen on Leaf area index (LAI) of hybrid maize

Effect of N levels revealed that a highly significant variation on leaf area index for all growth stages (Figure 3.2.7 & Appendix 3.2.3 for 2016-17 and Figure 3.2.8 & Appendix 3.2.4 for 2017-18). Irrespective of treatment differences, Leaf area index increased progressively up to 100 DAS after that it was gradually decreased. It was found that the maximum LAI was obtained from the 300 kg N ha⁻¹ treatment at all growth stages (1.29, 1.70, 2.05, 3.79, 3.22 and 2.62 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the maximum LAI also was obtained from the N₃₀₀ (300 kg N ha⁻¹) treatment at all growth stages (1.30, 1.74, 2.19, 3.56, 3.14 and 2.97 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the minimum LAI was found in N₁₀₀ (100 kg N ha⁻¹) treatment (0.95, 1.41, 1.63, 2.51, 2.26 and 1.93 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the minimum LAI also was observed in N₁₀₀ (100 kg N ha⁻¹) treatment (0.96, 1.41, 1.63, 2.59, 2.26

and 2.34 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. Increasing nitrogen level from 100 kg N ha⁻¹ to 300 kg N ha⁻¹ also increased the LAI of hybrid maize varieties. Generally, an increasing trend in LAI was observed with increased N application rates. The increase in LAI was possibly due to the improved leaf expansion in plants by giving optimum nitrogenous fertilizers. Similar to this finding, Haghighi *et al.* (2010) on maize reported an increasing trend in LAI on maize due to an increase in N fertilizer application rates. Various nitrogen levels had a significant influence on leaf area. These results are supported by those of Boonlertnirun *et al.*, (2010) and Kaur *et al.*, (2012). Squire *et al.*, (1987) concluded that the main effect of nitrogen fertilizer was to increase the rate of leaf expansion which ultimately leads to the increased interception of daily solar radiation by the canopy. LAI is a measure of leafiness per unit ground area and denotes the extent of photosynthetic machinery. It is the most important indicator of the size of the assimilatory system in maize to maximize harvest of the incident solar radiation Mahmood *et al.*, (1998). Oscar and Tollenaar (2006) reported that LAI increased with the application of higher rate of nitrogen. The increased LAI with increasing nitrogen supply may be due to the effect of nitrogen on the rate of growth of meristem and the appearance and development of leaves Worku *et al.*, (2012). Maize crop differs in its ability to maintain LAI and above ground dry matter production at different levels of nitrogen supply Pandey *et al.*, (2000).

Argenta *et al.*, (2004) speculated that nitrogen taken up by maize during early growth stages is used primarily to produce other plant structures (formation and expansion of leaves and stems) rather than chlorophyll early in the crop ontogeny. Because a fast establishment of such structures is useful to enhance light interception, leading to an increase in radiation use efficiency and grain yield Marschner (1995). In the present studies, various nitrogen fertilizer rates had an impact on leaf greenness at three phenological stages in case of long duration genotypes and the impact of nitrogen deficiency at photosynthetic maturity (anthesis stage) was greater in hybrids than its parents. Similar results have been reported by Zaidi *et al.*, (2003).

Interaction effect of hybrid maize varieties and nitrogen on leaf area index

The interaction effect of hybrid maize varieties and nitrogen levels on LAI was statistically significant both the years (Table 3.2.5 and appendix 3.2.3 for 2016-17 and Table 3.2.6 and appendix 3.2.4 for 2017-18). Similar to this finding, Abera, *et al.* (2017) reported that interaction of maize varieties by nitrogen rates significantly affected leaf area index. Results showed that the maximum LAI was obtained from combination of P3396×300 (1.32, 1.72, 2.10, 3.77, 3.09 and 2.74 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the maximum LAI also was obtained from combination of BHM9×300 (1.35, 1.75, 2.10, 3.51, 3.09

and 2.73 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the minimum LAI (0.94, 1.39, 1.61, 2.51, 2.44 and 1.90 at 40, 60, 80, 100, 120 and 140 DAS, respectively) was obtained from hybrid 981×100 combination during 2016-17 and the lowest LAI also found (0.92, 1.40, 1.63, 2.51, 2.44 and 2.32 at 40, 60, 80, 100, 120 and 140 DAS, respectively) was obtained from hybrid 981×100 combination during 2017-18. All hybrid maize varieties produced higher leaf area index when higher nitrogen level indicating significant role of nitrogen for leaf development of maize varieties. According to Pandey *et al.* (2000), maize genotypes differ in their ability to maintain leaf area, LAI (leaf area index) at different levels of N supply.

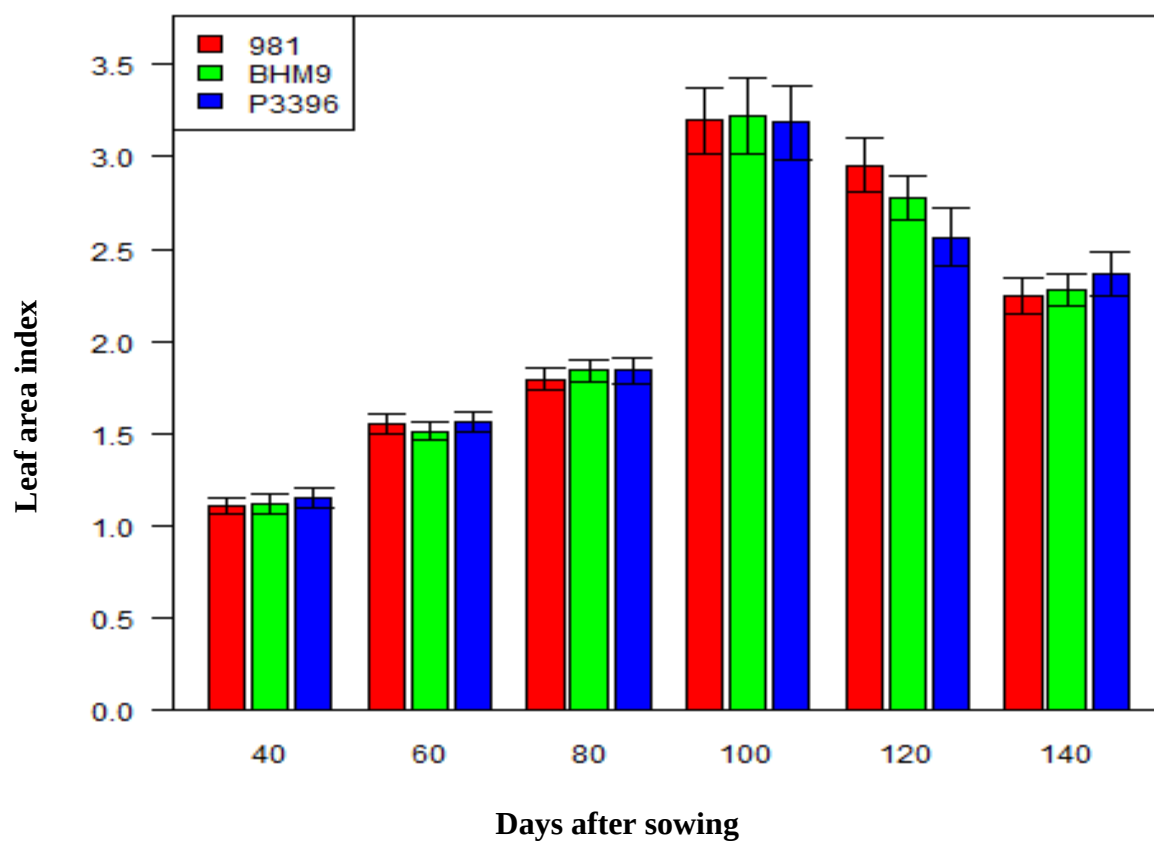


Figure 3.2.5: Effect of hybrid maize varieties on leaf area index of hybrid maize at different days after sowing during 2016-17.

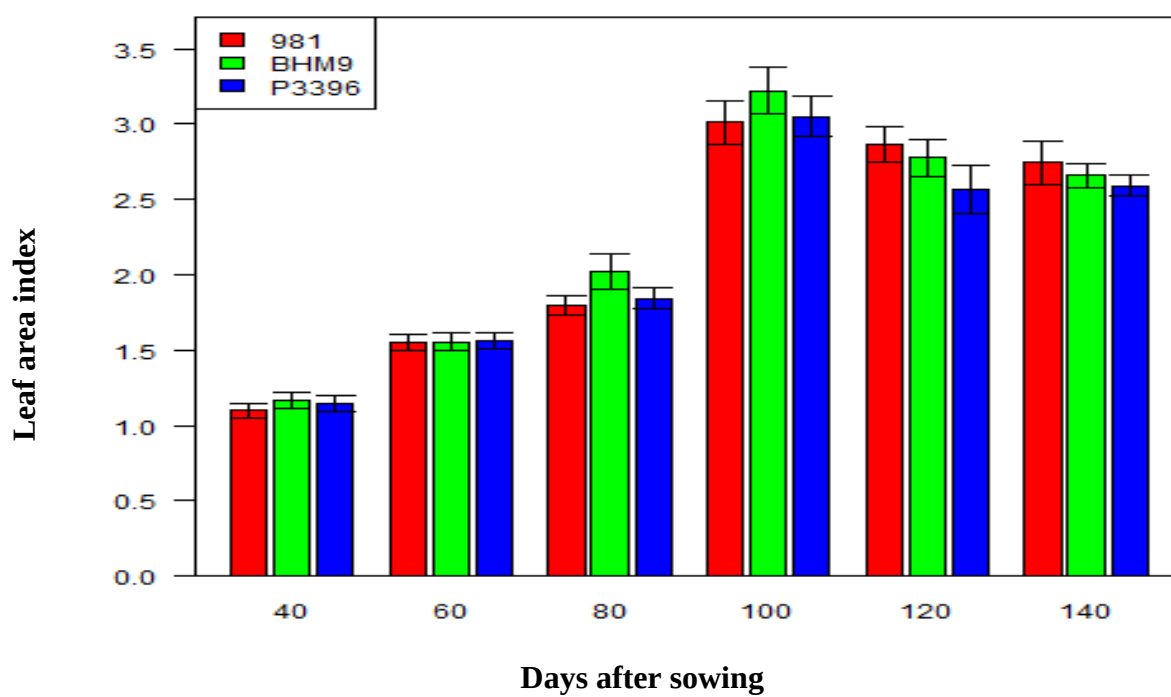


Figure 3.2.6: Effect of hybrid maize varieties on leaf area index at different days after sowing during 2017-18.

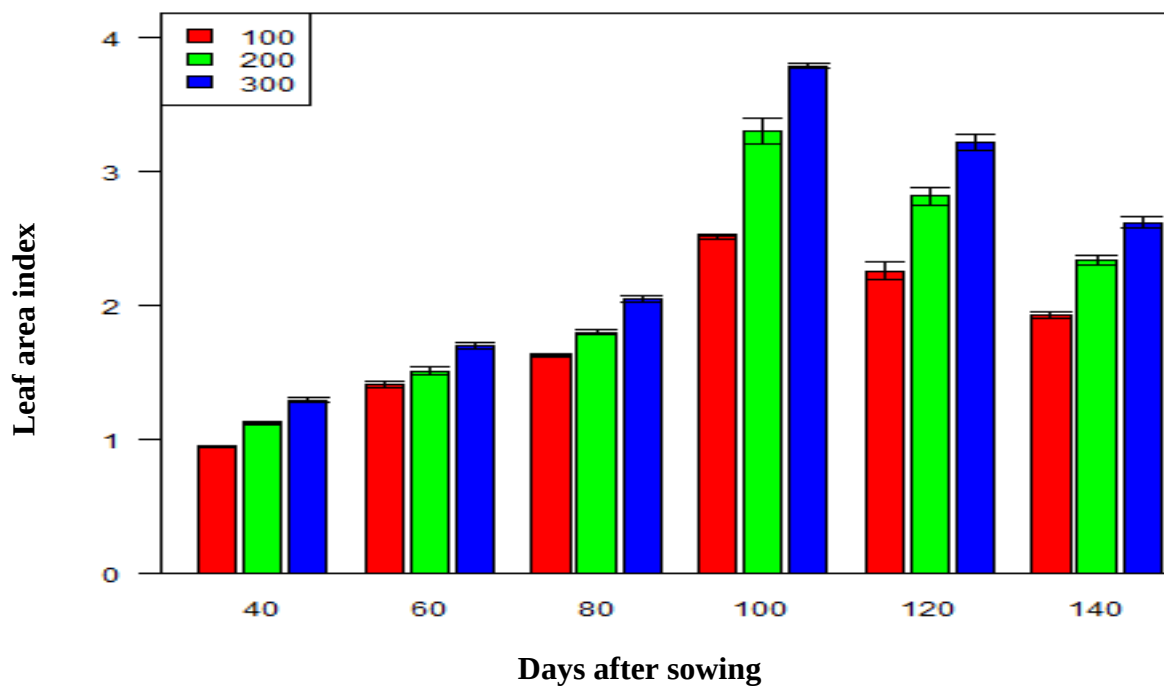


Figure 3.2.7: Effect of nitrogen on leaf area index of hybrid maize at different days after sowing during 2016-17.

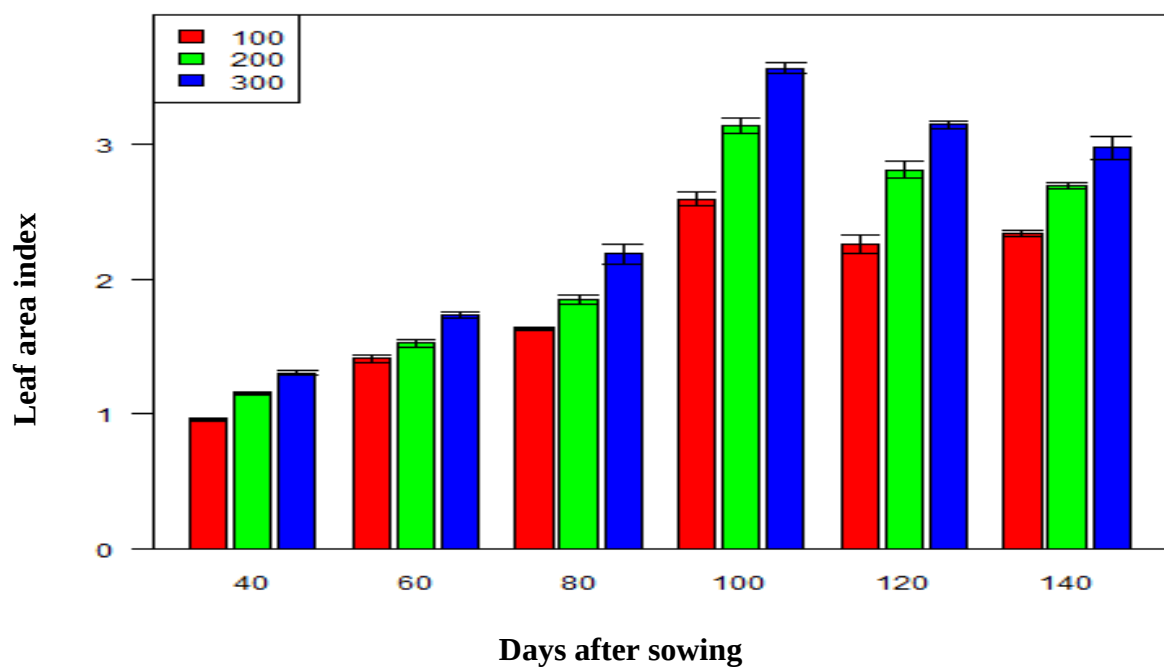


Figure 3.2.8: Effect of nitrogen on leaf area index of hybrid maize at different days after sowing during 2017-18.

Table 3.2.5. Interaction effect of varieties and nitrogen on LAI at different days after sowing of hybrid maize during 2016-17

V×N	Days After Sowing (DAS)					
Interaction	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	0.94	1.39	1.61	2.51	2.44	1.90
981×200	1.13	1.54	1.78	3.30	2.99	2.25
981×300	1.25	1.73	2.00	3.74	3.44	2.58
BHM9×100	0.95	1.35	1.64	2.56	2.33	1.94
BHM9×200	1.10	1.53	1.82	3.35	2.87	2.33
BHM9×300	1.31	1.66	2.06	3.85	3.13	2.55
P3396×100	0.96	1.50	1.63	2.53	2.01	1.92
P3396×200	1.16	1.47	1.80	3.25	2.59	2.44
P3396×300	1.32	1.72	2.10	3.77	3.09	2.74
LSD (0.05)	0.05	0.09	0.09	0.36	0.14	0.15

Table 3.2.6. Interaction effect of varieties and nitrogen on LAI at different days after sowing of hybrid maize during 2017-18

V×N	Days After Sowing (DAS)					
Interaction	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	0.92	1.40	1.63	2.51	2.44	2.32
981×200	1.13	1.54	1.78	3.04	2.96	2.65
981×300	1.25	1.73	2.00	3.48	3.21	3.28
BHM9×100	0.99	1.35	1.64	2.66	2.33	2.38
BHM9×200	1.16	1.56	1.95	3.32	2.87	2.70
BHM9×300	1.34	1.76	2.46	3.69	3.13	2.91
P3396×100	0.96	1.50	1.63	2.60	2.01	2.32
P3396×200	1.18	1.47	1.80	3.05	2.59	2.72
P3396×300	1.35	1.75	2.10	3.51	3.09	2.73
LSD (0.05)	0.05	0.04	0.10	0.22	0.15	0.16

3.2.3.1.3 NDVI value

Effect of hybrid maize varieties on NDVI value

The NDVI value of different hybrid maize varieties at different growth stages highly significantly differs at different days after sowing (DAS) is shown in Figure 3.2.9 for 2016-17 and Figure 3.2.10 for 2017-18, respectively. NDVI increased gradually up to 100 DAS, after that decreased with the advancement of growing period of all the hybrid varieties for both the years. Regardless of variety differences, NDVI increased progressively up to 100 DAS. The NDVI values varied from 0.60 to 0.98 during 2016-17 and from 0.61 to 0.98 during 2017- 2018 which were in good agreement with the measurements of Lawal *et al.*, (2018) they reported that hybrid maize variety significantly influenced the NDVI values throughout the growing period varied from 0.24 to 0.53 among the hybrid maize varieties. Different hybrid varieties showed different NDVI at different growth stages and finally the variety hybrid 981 produced the highest NDVI (0.61, 0.69, 0.86, 0.98, 0.61 and 0.64 at 60, 80, 100, 120 and 140 DAS, respectively) which was insignificant from all other varieties during 2016-17. The hybrid 981 also produced the maximum NDVI (0.60, 0.69, 0.71, 0.84, 0.88 and 0.72 at 40,60, 80, 100, 120 and 140 DAS, respectively) which was superior than other varieties during 2017-18. Production of highest NDVI at different DAS of hybrid 981 might be due to its genetically governed traits. Lowest NDVI was found from the hybrid P3396 produce dwarf plant (0.60, 0.69, 0.86, 0.95, 0.60 and 0.64 at 60, 80, 100, 120 and 140 DAS, respectively) during the both seasons.

Effect of nitrogen on NDVI value of hybrid maize

Effect of N levels revealed that a highly significant variation on NDVI for all growth stages (Figure 3.2.11 & Appendix 3.2.5 for 2016-17 and Figure 3.2.12 & Appendix 3.2.6 for 2017-18). Irrespective of treatment differences, NDVI increased rapidly up to 100 DAS after that it was decreased. The NDVI values varied from 0.57 to 0.98 during 2016-17 and from 0.56 to 0.90 during 2017- 2018 which were in good agreement with the measurements of Lawal *et al.*, (2018) they reported that nitrogen levels significantly influenced the NDVI values throughout the growing period varied from 0.25 to 0.56 among the N levels. It was found that the maximum NDVI was obtained from the 300 kg N ha⁻¹ treatment at all growth stages (0.66, 0.72, 0.90, 0.98, 0.63 and 0.68 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the

maximum NDVI also was obtained from the N₃₀₀ (300 kg N ha⁻¹) treatment at all growth stages (0.63, 0.69, 0.74, 0.86, 0.87 and 0.74 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the minimum NDVI was found in N₁₀₀ (100 kg N ha⁻¹) treatment (0.57, 0.66, 0.81, 0.95, 0.57 and 0.60 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the minimum NDVI also was observed in N₁₀₀ (100 kg N ha⁻¹) treatment (0.56, 0.66, 0.69, 0.83, 0.87 and 0.73 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. Increasing nitrogen level from 100 kg N ha⁻¹ to 300 kg N ha⁻¹ also increased the NDVI of hybrid maize varieties which were in good agreement with the measurements of Lawal *et al.*, (2018) they reported that the highest NDVI value (0.56) was recorded on treated with 100 kg N ha⁻¹ while the least (0.34) was recorded without application of N fertilizer.

Interaction effect of hybrid maize varieties and nitrogen on NDVI

The interaction effect of varieties and nitrogen levels on NDVI was statistically significant during 2017-18 (Table 3.2.7 and appendix 3.2.5 for 2016-17) and during 2017-18 (Table 3.2.8 and appendix 3.2.6 for 2017-18). The interaction of between nitrogen rates and cultivars for NDVI score increased from 0.52 to 0.99 during 2016-17 and from 0.49 to 0.92 during 2017-2018 by increasing N level which were in good agreement with the measurements of Aparicio *et al.*, (2000) they reported that NDVI values consistently increased with crop growth stages in early season and it reached a plateau when the ground surface was completely covered by the canopy. Results showed that the maximum NDVI was obtained from combination of BHM9×300 (0.65, 0.72, 0.89, 0.99, 0.79 and 0.69 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the maximum NDVI also was obtained from combination of BHM9×300 (0.60, 0.67, 0.69, 0.92, 0.88 and 0.77 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the minimum NDVI was obtained from hybrid 981×100 combination during both years which were in good agreement with the measurements of Lawal *et al.*, (2018) they reported that the highest NDVI value recorded at 2 WAP (0.31) was recorded on LY1001-22 at 80 kg N ha⁻¹.

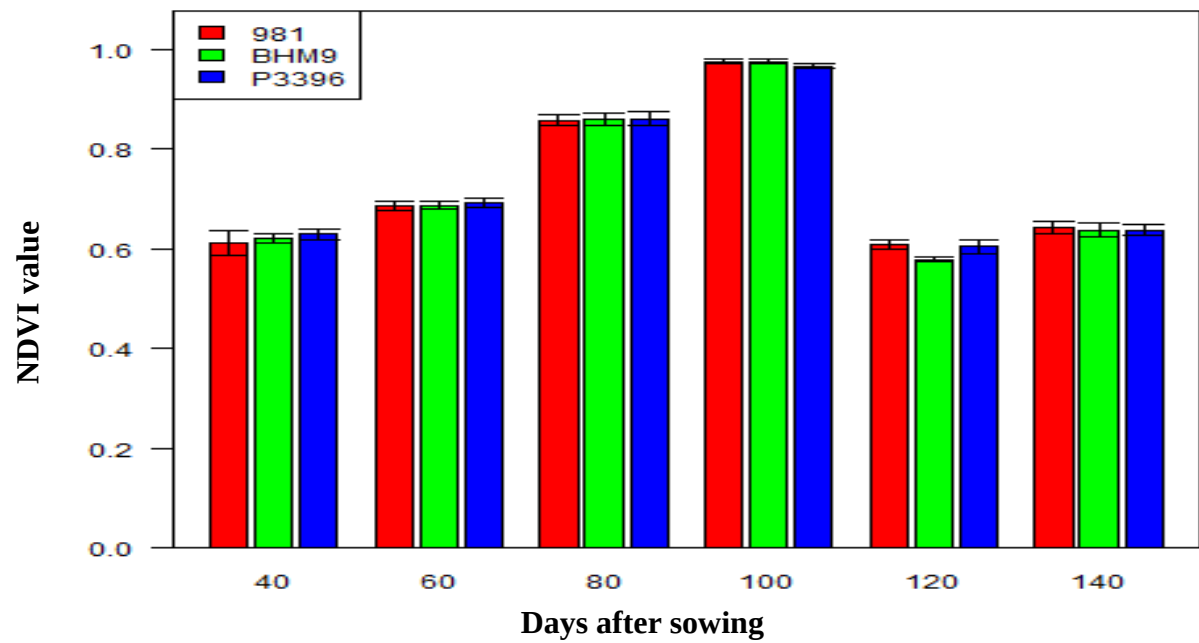


Figure 3.2.9: Effect of hybrid maize varieties on NDVI at different days after sowing during 2016-17.

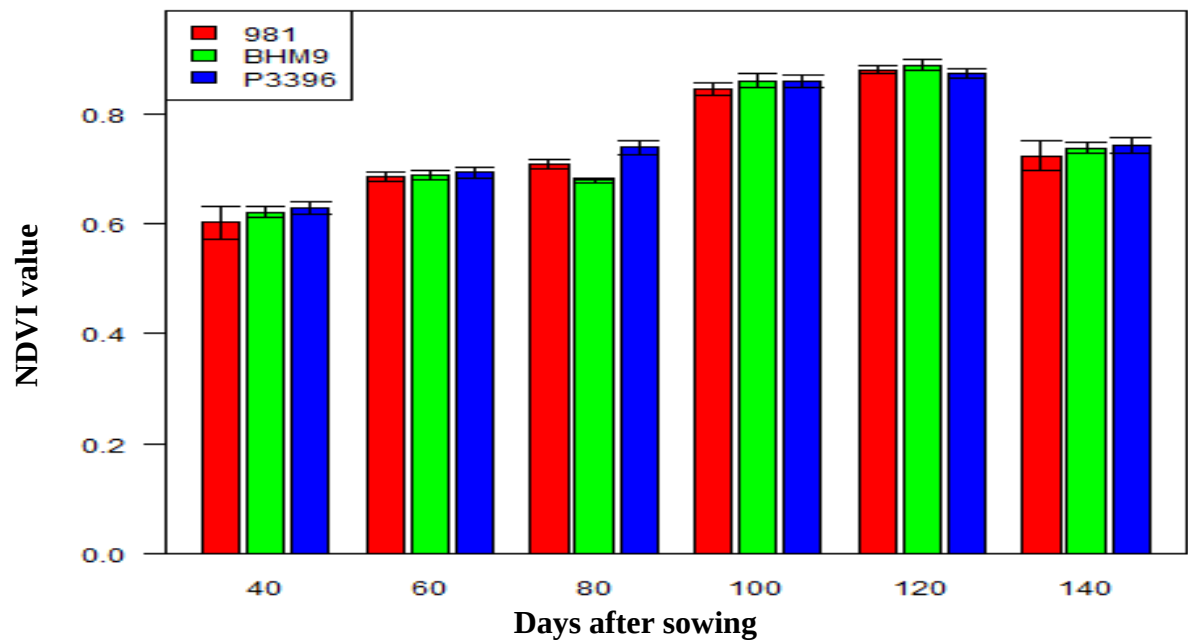


Figure 3.2.10: Effect of hybrid maize variety on NDVI at different days after sowing during 2017-18.

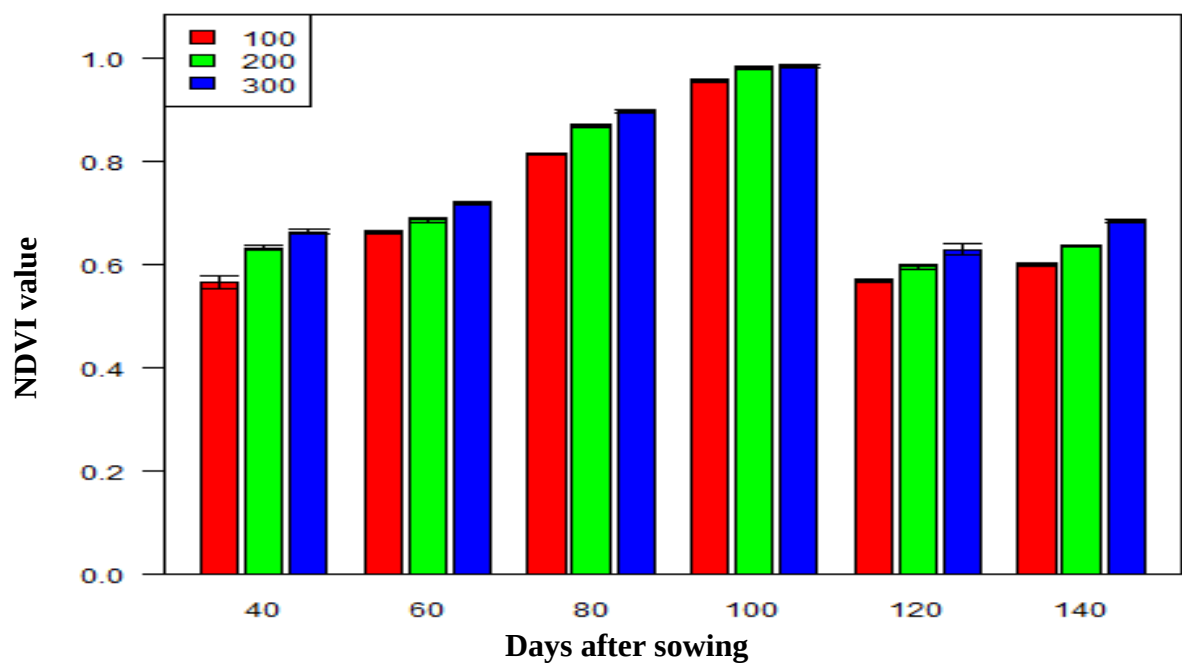


Figure 3.2.11: Effect of nitrogen on NDVI of hybrid maize at different days after sowing during 2016-17.

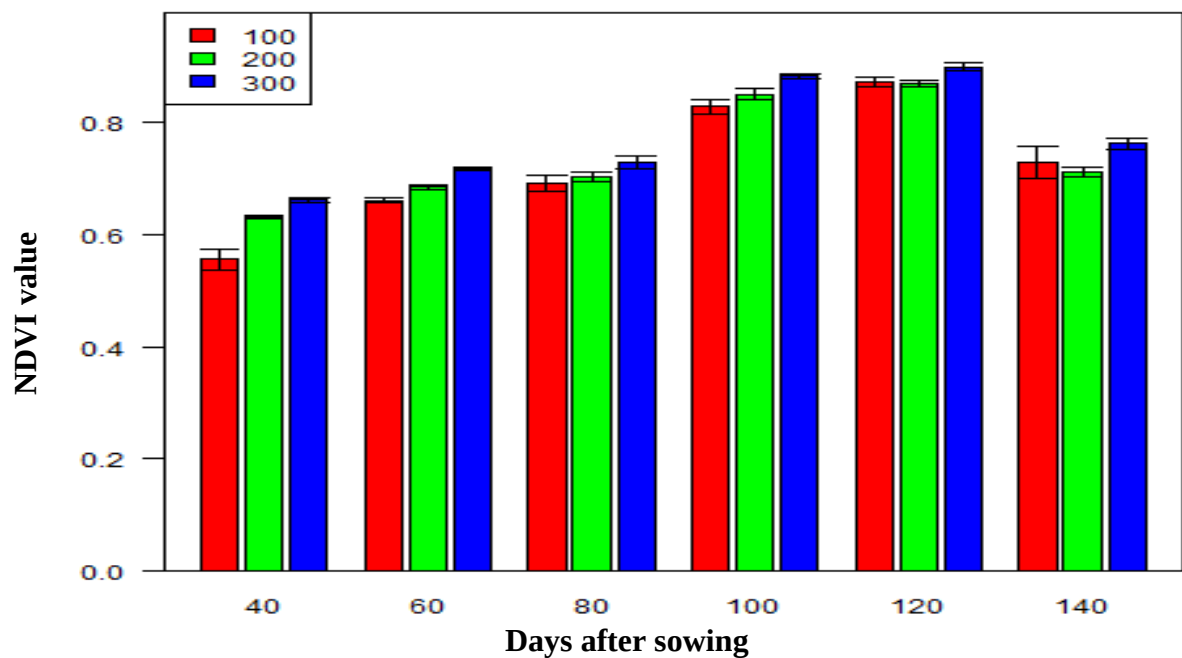


Figure 3.2.12: Effect of nitrogen on NDVI of hybrid maize at different days after sowing during 2017-18.

Table 3.2.7. Interaction effect of varieties and nitrogen levels on NDVI at different days after sowing of hybrid maize during 2016-17

V×N	Days After Sowing (DAS)					
Interaction	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	0.52	0.65	0.82	0.96	0.68	0.61
981×200	0.64	0.69	0.86	0.98	0.71	0.64
981×300	0.68	0.72	0.89	0.99	0.74	0.69
BHM9×100	0.59	0.66	0.81	0.96	0.67	0.60
BHM9×200	0.62	0.69	0.87	0.98	0.68	0.63
BHM9×300	0.65	0.72	0.89	0.99	0.79	0.69
P3396×100	0.59	0.67	0.81	0.95	0.66	0.60
P3396×200	0.64	0.68	0.87	0.97	0.70	0.64
P3396×300	0.66	0.72	0.90	0.98	0.76	0.68
LSD (0.05)	0.01	0.02	0.01	0.01	0.01	0.01

Table 3.2.8. Interaction effect of varieties and nitrogen levels on NDVI at different days after sowing of hybrid maize during 2017-18

V×N	Days After Sowing (DAS)					
Interaction	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	0.49	0.65	0.68	0.88	0.80	0.75
981×200	0.64	0.69	0.71	0.87	0.85	0.68
981×300	0.68	0.72	0.74	0.89	0.88	0.74
BHM9×100	0.59	0.66	0.67	0.87	0.84	0.72
BHM9×200	0.62	0.69	0.68	0.88	0.85	0.73
BHM9×300	0.60	0.67	0.69	0.92	0.88	0.77
P3396×100	0.59	0.67	0.73	0.87	0.84	0.73
P3396×200	0.64	0.68	0.73	0.86	0.85	0.72
P3396×300	0.66	0.72	0.76	0.89	0.89	0.78
LSD (0.05)	0.04	0.01	0.04	0.04	0.05	0.10

3.2.3.1.4 Canopy cover (CC) value

Effect of hybrid maize varieties on canopy cover (CC) value

The CC value of different hybrid maize varieties at different growth stages highly significantly differs at different days after sowing (DAS) is shown in Appendix 3.2.7, Figure 3.2.13 for 2016-17 and Appendix 3.2.8, Figure 3.2.14 for 2017-18, respectively. CC increased slowly up to 50 DAS and then increased rapidly up to 100 DAS and decreased with the advancement of growing period of all the varieties for both the years. Regardless of treatment differences, CC increased progressively up to 100 DAS. The CC values varied from 0.48 to 0.73 during 2016-17 and from 0.46 to 0.72 during 2017- 2018. Different hybrid varieties showed different CC at different growth stages and finally the variety BARI Hybrid Maize 9 produced the highest CC (0.50, 0.54, 0.57, 0.73, 0.67 and 0.62 at 60, 80, 100, 120 and 140 DAS, respectively) which was insignificant from all other varieties during 2016-17. The hybrid 981 also produced the maximum CC (0.57, 0.59, 0.60, 0.62, 0.62 and 0.63 at 40, 60, 80, 100, 120 and 140 DAS, respectively) which was superior than other varieties during 2017-18. Lowest CC was found from the hybrid P3396 produce dwarf plant during the both seasons. As expected, the canopy cover increased progressively with growing stage and peaked at the anthesis among the varieties (Yanli *et al.*, 2007). They reported that differences in leaf spatial distribution resulted in different canopy cover between the two varietal groups. however, differences in canopy spectral reflectance between groups decreased with the growing stage.

Effect of nitrogen on CC of hybrid maize

Effect of N levels revealed that a highly significant variation on CC for all growth stages of hybrid maize (Figure 3.2.15 & Appendix 3.2.7 for 2016-17 and Figure 3.2.16 & Appendix 3.2.8 for 2017-18). Nevertheless, of treatment differences, CC increased progressively up to 75 DAS after that it was gradually decreased. The CC values varied from 0.57 to 0.98 during 2016-17 and from 0.56 to 0.90 during 2017- 2018 which were in good agreement with the measurements of Lawal *et al.*, (2018) they reported that nitrogen levels significantly influenced the CC values throughout the growing period varied from 0.25 to 0.56 among the N levels. It was found that the maximum CC was obtained from the 300 kg N ha⁻¹ treatment at all growth stages (0.66, 0.72, 0.90, 0.98, 0.63 and 0.68 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17

and the maximum CC also was obtained from the N₃₀₀ (300 kg N ha⁻¹) treatment at all growth stages (0.63, 0.69, 0.74, 0.86, 0.87 and 0.74 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the minimum CC was found in N₁₀₀ (100 kg N ha⁻¹) treatment (0.57, 0.66, 0.81, 0.95, 0.57 and 0.60 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the minimum CC also was observed in N₁₀₀ (100 kg N ha⁻¹) treatment (0.56, 0.66, 0.69, 0.83, 0.87 and 0.73 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. Increasing nitrogen level from 100 kg N ha⁻¹ to 300 kg N ha⁻¹ also increased the CC of hybrid maize varieties which were in good agreement with the measurements of Ahmed *et al.* (2018), they reported that due to nitrogen fertilizer treatment, canopy efficiency departed widely at 90 days after sowing. The highest canopy cover (82.04%) was attained from 550kg urea/ha which was 14.63% and 36.12% higher than 413kg urea/ha and 275kg urea/ha treatment respectively.

Interaction effect of hybrid maize varieties and nitrogen on CC

The interaction effect of varieties and nitrogen levels on CC at different growth stage of hybrid maize was statistically significant during 2016-17 (Table 3.2.9 and appendix 3.2.7 for 2016-17) and during 2017-18 (Table 3.2.10 and appendix 3.2.8 for 2017-18). The interaction of between nitrogen rates and cultivars for CC score increased from 0.43 to 0.80 during 2016-17 and from 0.45 to 0.82 during 2017- 2018 by increasing N level which were in good agreement with the measurements of Aparicio *et al.*, (2000) they reported that CC values consistently increased with crop growth stages in early season and it reached a plateau when the ground surface was completely covered by the canopy. Results showed that the maximum CC was obtained from combination of BHM9×300 (0.51, 0.59, 0.61, 0.80, 0.72 and 0.68 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the maximum CC also was obtained from combination of BHM9×300 (0.52, 0.60, 0.63, 0.82, 0.76 and 0.68 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the minimum CC was obtained from hybrid 981×100 combination during both years which were in good agreement with the measurements of Ahmad *et al.*, (2018) they reported that the highest CC (57.07%) value recorded at 60 days after sowing (DAS) and CC (82.04%) value recorded at 120 days after sowing.

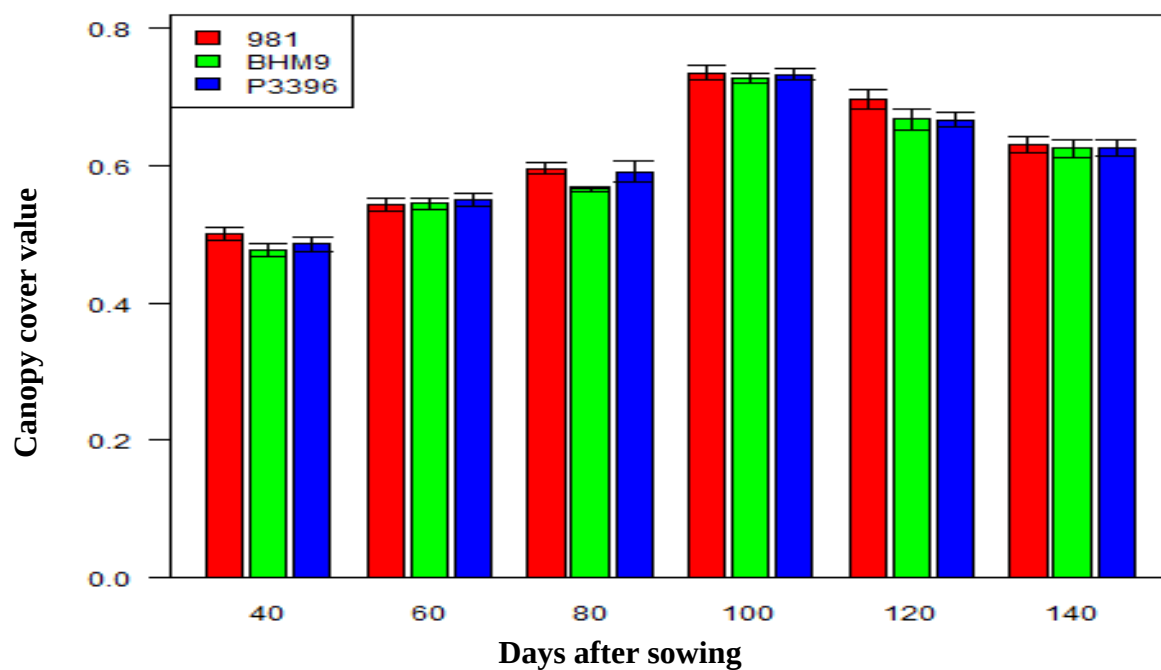


Figure 3.2.13: Effect of hybrid maize varieties on CC at different days after sowing during 2016-17.

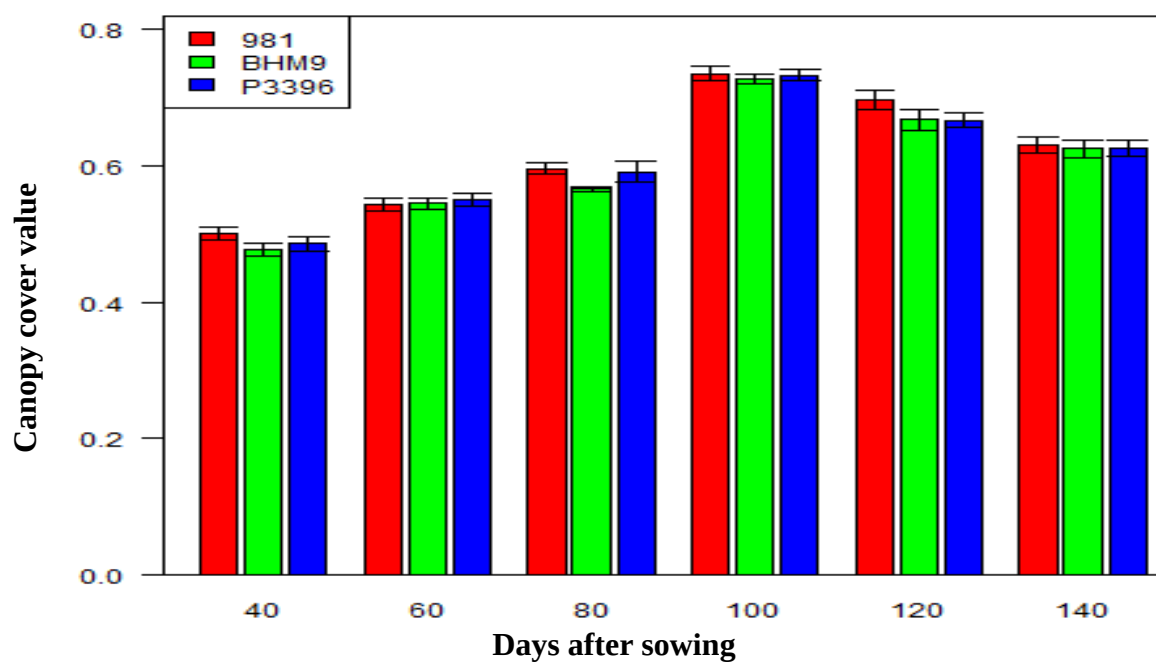


Figure 3.2.14: Effect of hybrid maize variety on CC at different days after sowing during 2017-18..

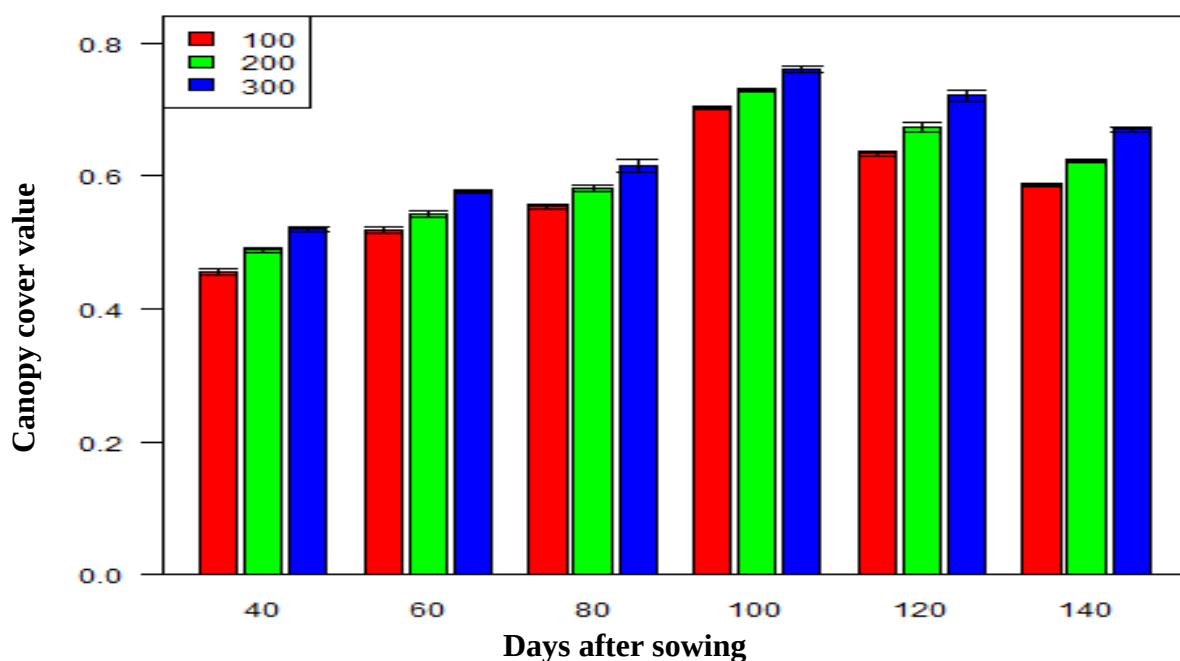


Figure 3.2.15: Effect of nitrogen on canopy cover of hybrid maize at different days after sowing during 2016-17.

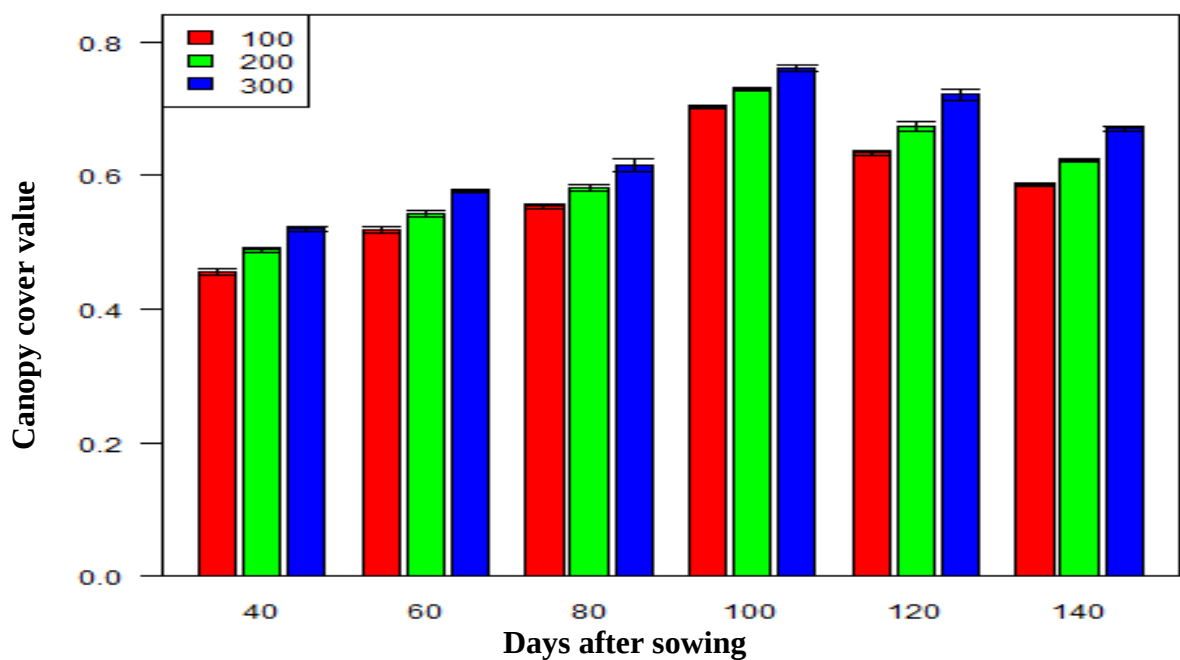


Figure 3.2.16: Effect of nitrogen on canopy cover of hybrid maize at different days after sowing during 2017-18.

Table 3.2.9. Interaction effect of varieties and nitrogen levels on CC at different days after sowing of hybrid maize during 2016-17

V×N	Days After Sowing (DAS)					
Interaction	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	0.43	0.51	0.57	0.70	0.65	0.59
981×200	0.50	0.54	0.59	0.73	0.70	0.62
981×300	0.53	0.57	0.63	0.77	0.74	0.67
BHM9×100	0.45	0.52	0.55	0.70	0.62	0.58
BHM9×200	0.48	0.54	0.57	0.73	0.66	0.62
BHM9×300	0.51	0.59	0.61	0.80	0.72	0.68
P3396×100	0.45	0.53	0.54	0.70	0.63	0.58
P3396×200	0.49	0.54	0.59	0.73	0.66	0.63
P3396×300	0.52	0.58	0.64	0.76	0.70	0.66
LSD (0.05)	0.01	0.02	0.01	0.02	0.02	0.01

Table 3.2.10. Interaction effect of varieties and nitrogen levels on CC at different days after sowing of hybrid maize during 2017-18

V×N	Days After Sowing (DAS)					
Interaction	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	0.47	0.51	0.57	0.70	0.65	0.59
981×200	0.50	0.54	0.59	0.73	0.70	0.62
981×300	0.53	0.57	0.63	0.77	0.74	0.67
BHM9×100	0.45	0.52	0.55	0.71	0.62	0.58
BHM9×200	0.48	0.54	0.57	0.79	0.66	0.62
BHM9×300	0.52	0.60	0.63	0.82	0.76	0.68
P3396×100	0.45	0.53	0.54	0.70	0.63	0.58
P3396×200	0.49	0.54	0.59	0.73	0.66	0.63
P3396×300	0.52	0.58	0.64	0.76	0.70	0.66
LSD (0.05)	0.01	0.02	0.01	0.02	0.02	0.01

3.2.3.1.5 Total Dry Matter (TDM) accumulation

Effect of hybrid maize varieties on total dry matter accumulation

The total dry matter (TDM) accumulation of different hybrid maize varieties at different growth stages highly significantly differs at different days after sowing (DAS) is shown in Appendix 3.2.9, Figure 3.2.20 for 2016-17 and Appendix 3.2.10, Figure 3.2.21 for 2017-18, respectively. TDM accumulation increased gradually up to harvest of all the varieties for both the years. Regardless of varietal differences, TDM accumulation increased progressively up to harvest. The TDM accumulation varied from 443.02 to 1932.18 g m⁻² during 2016-17 and from 525.83 to 1990.56 g m⁻² during 2017- 2018. Different hybrid varieties showed different TDM at different growth stages and finally the hybrid P3396 variety produced the highest TDM (443.02, 514.70, 671.00, 984.04, 1282.01 and 1932.18 at 60, 80, 100, 120 and 140 DAS, respectively) which was insignificant from all other varieties during 2016-17. The hybrid 981 also produced the maximum TDM (0.57, 0.59, 0.60, 0.62, 0.62 and 0.63 at 40,60, 80, 100, 120 and 140 DAS, respectively) which was superior than other varieties during 2017-18. This result is also in agreement with the findings of Raj (2016) reported that among the maize cultivars, CMH 08-350 recorded significantly higher dry matter production than CMH 08-292, PMH-3, CMH 08-287, PMH-1 and HQPM-1at maturity which might be due higher leaf area index resulting in higher photosynthetic efficiency and ultimately higher photosynthate accumulation. Ashok. (2013) also reported significant variation in dry matter accumulation among the different maize hybrid tested.

Effect of nitrogen on TDM accumulation of hybrid maize

Effect of N levels revealed that a highly significant variation on TDM accumulation for all growth stages (Figure 3.2.19 & Appendix 3.2.9 for 2016-17 and Figure 3.2.20 & Appendix 3.2.10 for 2017-18). Nevertheless, of treatment differences, TDM accumulation increased progressively up to 75 DAS after that it was gradually decreased. The TDM values varied from 0.57 to 0.98 during 2016-17 and from 0.56 to 0.90 during 2017- 2018 which were in good agreement with the measurements of Lawal *et al.*, (2018) they reported that nitrogen levels significantly influenced the TDM values throughout the growing period varied from 0.25 to 0.56 among the N levels. It was found that the maximum TDM was obtained from the 300 kg N ha⁻¹

¹ treatment at all growth stages (0.66, 0.72, 0.90, 0.98, 0.63 and 0.68 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the maximum TDM also was obtained from the N₃₀₀ (300 kg N ha⁻¹) treatment at all growth stages (0.63, 0.69, 0.74, 0.86, 0.87 and 0.74 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the minimum TDM was found in N₁₀₀ (100 kg N ha⁻¹) treatment (0.57, 0.66, 0.81, 0.95, 0.57 and 0.60 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the minimum TDM also was observed in N₁₀₀ (100 kg N ha⁻¹) treatment (0.56, 0.66, 0.69, 0.83, 0.87 and 0.73 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. Increasing nitrogen level from 100 kg N ha⁻¹ to 300 kg N ha⁻¹ also increased the TDM of hybrid maize varieties which were in good agreement with the measurements of Ahmed *et al.* (2018), they described that total dry matter production increased progressively with the increase of nitrogen fertilizer rate. Highest TDM of 45.86, 203.89 and 536.20 gm⁻² was noted for maximum urea application at 30, 60 and 90 days after sowing

Interaction effect of hybrid maize varieties and nitrogen on TDM (gm⁻²)

The combined effect of varieties and nitrogen levels on TDM was statistically significant except 100 DAS during 2016-17 (Table 3.2.11) and 25 DAS during 2017-18 (Table 3.2.12 and appendix 3.2.10), respectively. Results showed that the highest dry matter accumulation was obtained from combination of P3396×300 (528.64, 591.36, 725.76, 1090.92, 1430.48, 2245.38 gm⁻² at 40, 60, 80, 100, 120 and 140 DAS, respectively) which was identical with P3396×300 and BHM 9×300 during 2016-17 and the maximum TDM accumulation also was obtained from combination of P3396×300 (619.50, 703.00, 950.50, 1036.00, 1670.00 and 2333.33 gm⁻² at 40, 60, 80, 100, 120 and 140 DAS, respectively) which was identical with 981×300 and BHM 9×300 during 2017-18. According to Pandey *et al.* (2000), maize genotypes differ in their ability to maintain aboveground dry matter production at different levels of N supply.

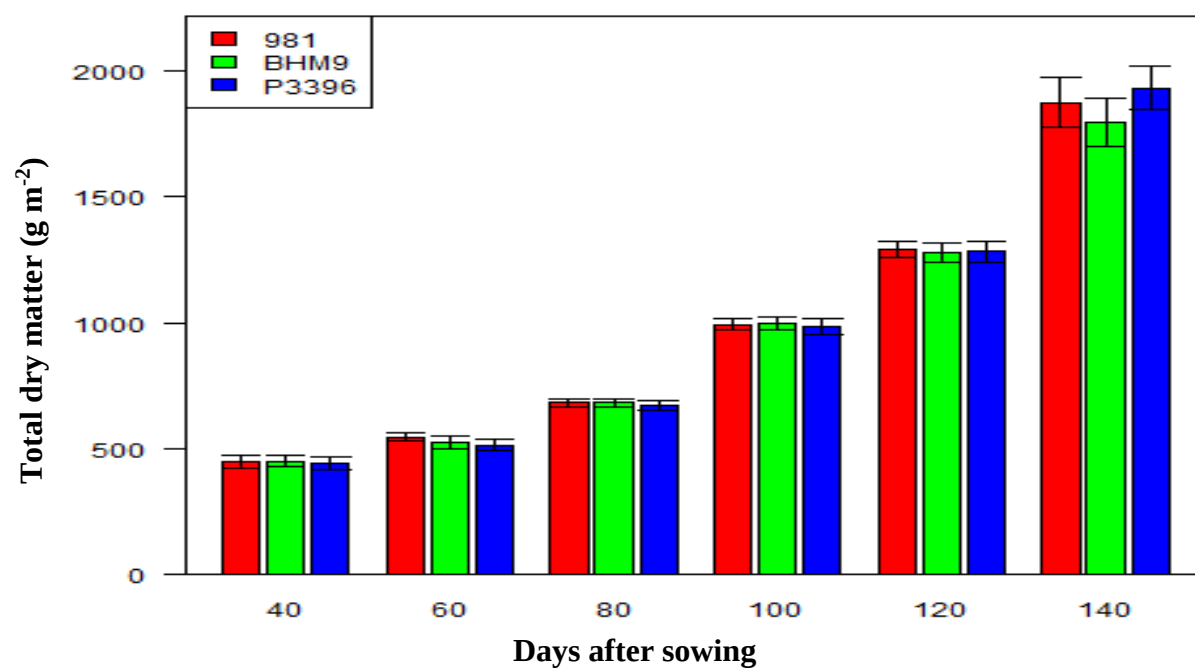


Figure 3.2.17: Effect of hybrid maize varieties on total dry matter accumulation³ at different days after sowing during 2016-17.

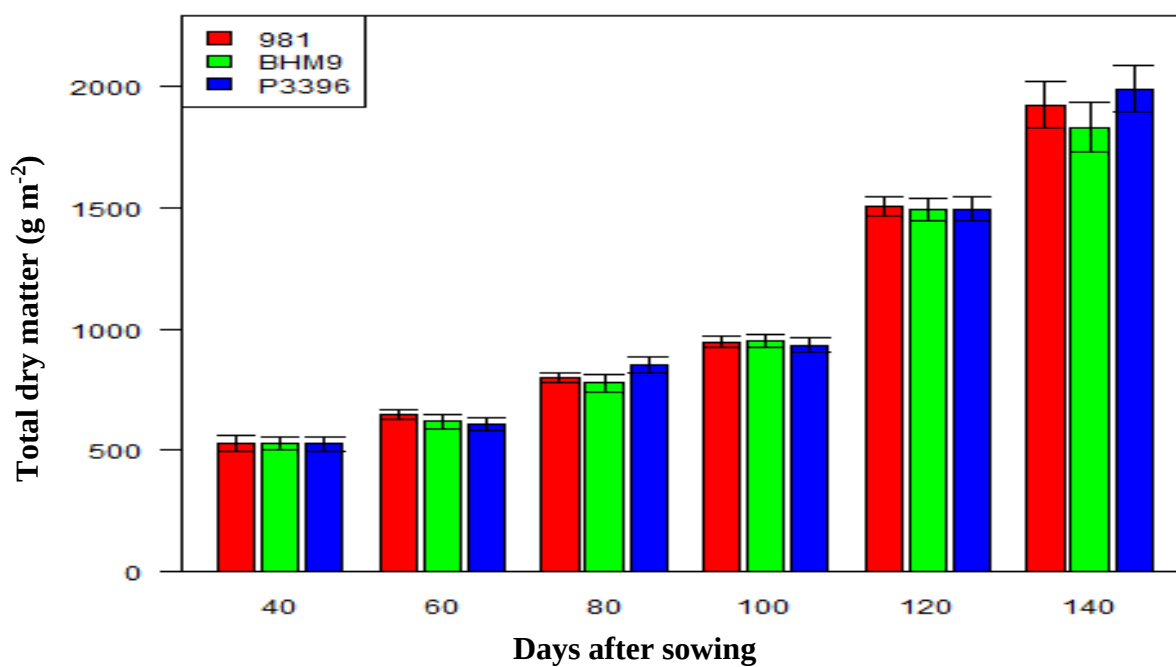


Figure 3.2.18: Effect of hybrid maize variety on total dry matter at different days after sowing during 2017-18.

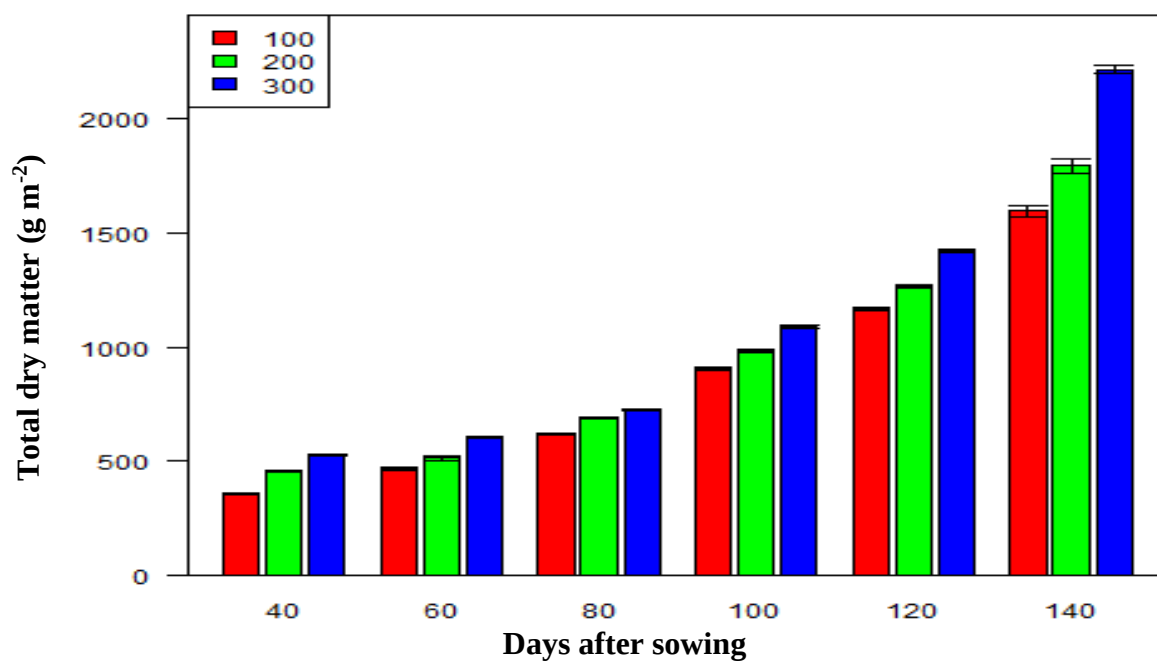


Figure 3.2.19: Effect of nitrogen on total dry matter of hybrid maize at different days after sowing during 2016-17.

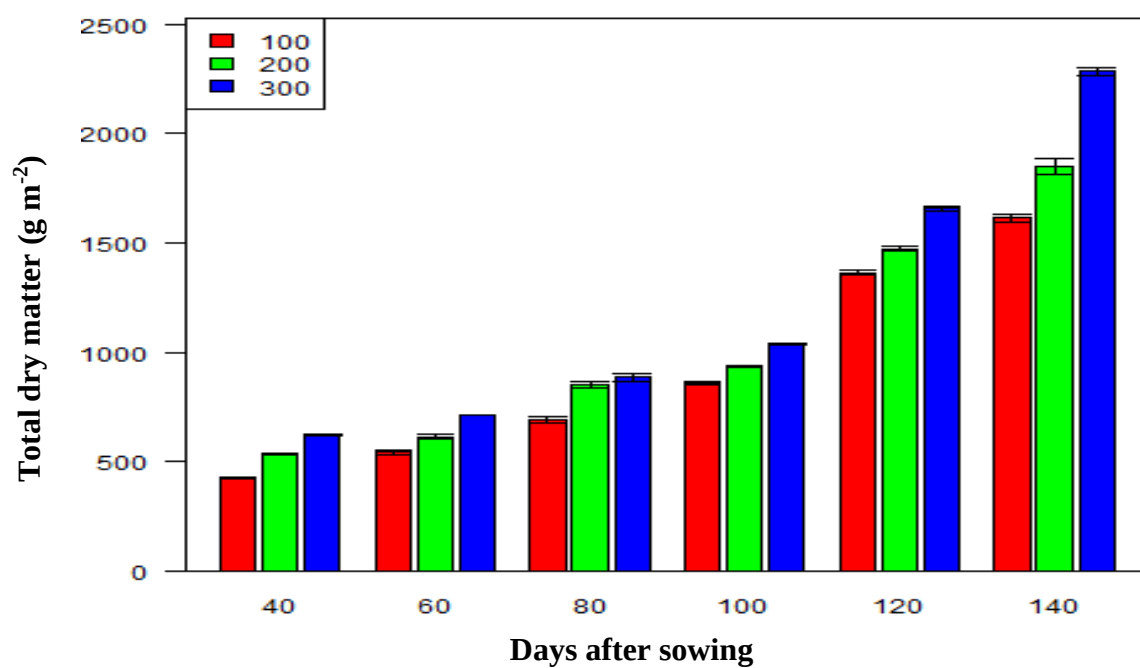


Figure 3.2.20: Effect of nitrogen on total dry matter accumulation of hybrid maize at different days after sowing during 2017-18.

Table 3.2.11. Interaction effect of varieties and nitrogen on TDM at different days after sowing of hybrid maize during 2016-17

V×N Interaction	Days After Sowing (DAS)					
	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	351.39	480.85	624.21	914.02	1194.92	1591.89
981×200	468.91	552.53	698.88	987.73	1267.73	1787.82
981×300	528.64	606.29	722.77	1079.87	1409.07	2243.48
BHM9×100	373.33	442.03	627.20	917.70	1156.38	1542.91
BHM9×200	456.96	507.73	689.92	984.04	1263.45	1689.86
BHM9×300	519.68	618.24	731.73	1094.61	1421.92	2155.18
P3396×100	355.41	471.89	609.28	884.53	1156.38	1650.67
P3396×200	445.01	480.85	677.97	976.67	1259.17	1900.48
P3396×300	528.64	591.36	725.76	1090.92	1430.48	2245.38
LSD (0.05)	19.70	28.78	19.88	16.50	45.18	101.40

Table 3.2.12. Interaction effect of varieties and nitrogen on TDM at different days after sowing of hybrid maize during 2017-18

V×N Interaction	Days After Sowing (DAS)					
	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	419.50	580.17	724.83	871.33	1395.00	1645.00
981×200	539.50	647.50	829.00	941.33	1480.00	1840.00
981×300	629.50	713.83	850.33	1028.83	1645.00	2286.67
BHM9×100	437.50	523.33	635.00	871.50	1350.00	1535.00
BHM9×200	535.50	611.67	841.83	942.17	1475.00	1732.33
BHM9×300	619.00	724.50	857.50	1046.17	1660.00	2233.33
P3396×100	426.50	526.33	724.00	840.00	1350.00	1665.00
P3396×200	531.50	586.83	884.50	927.50	1470.00	1973.33
P3396×300	619.50	703.00	950.50	1036.00	1670.00	2333.33
LSD (0.05)	12.35	8.09	31.37	17.73	50.50	32.19

3.2.3.2 Physiological traits of maize

3.2.3.2.1 SPAD value

Effect of hybrid maize varieties on SPAD value

The SPAD value of different hybrid maize varieties at different growth stage significantly differs at different days after sowing (DAS) during 2016-17 is shown in Figure 3.2.21 for 2016-17 and Figure 3.2.22 for 2017-18, respectively. SPAD value increased gradually up to 100 DAS and decreased with the advancement of growing period of all the varieties for both the years. Regardless of variety differences, SPAD value increased progressively up to 100 DAS. Among the hybrid maize varieties SPAD value ranged from 43.19 to 67.63 during 2016-17 and from 42.10 to 68.30 during 2017- 2018 at different DAS. Different hybrid maize varieties showed different SPAD value at different growth stages and finally the variety hybrid P3396 produced the highest SPAD value (44.32, 45.39, 48.29, 54.47, 67.63 and 61.03 at 60, 80, 100, 120 and 140 DAS, respectively) which was significant from all other varieties during 2016-17. The hybrid P3396 also produced the maximum (43.74, 46.40, 50.12, 68.30, 60.00 and 56.30 at 40, 60, 80, 100, 120 and 140 DAS, respectively) which was superior than other varieties during 2017-18. Production of highest SPAD value at different DAS of hybrid P3396 might be due to its genetically governed traits. Lowest SPAD value was found from the hybrid P3396 produce (43.62, 45.16, 51.58, 65.90, 60.93 and 55.46 at 60, 80, 100, 120 and 140 DAS, respectively) during the both seasons.

Effect of nitrogen on SPAD value of hybrid maize

Effect of N levels revealed that a highly significant variation on SPAD for all growth stages (Figure 3.2.23 for 2016-17 and Figure 3.2.24 for 2017-18). Irrespective of treatment differences, SPAD value increased rapidly up to 120 DAS after that it was slowly decreased. Among the N level SPAD value ranged from 36.99 to 71.86 during 2016-17 and from 37.40 to 71.90 during 2017- 2018 at different DAS. It was found that the maximum SPAD value was obtained from the 300 kg N ha⁻¹ treatment at all growth stages (50.83, 51.83, 55.69, 60.41, 71.86 and 67.71 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the maximum SPAD value also was obtained from the N₃₀₀ (300 kg N ha⁻¹) treatment at all growth stages (50.83, 51.83, 55.69, 71.63, 67.71 and 60.41 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-

18. On the other hand, the minimum SPAD value was found in N₁₀₀ (100 kg N ha⁻¹) treatment (36.99, 39.74, 43.90, 49.64, 61.73 and 55.97 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the minimum SPAD value also was observed in N₁₀₀ (100 kg N ha⁻¹) treatment (36.99, 39.74, 43.90, 61.51, 55.97 and 49.64 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. Increasing nitrogen level from 100 kg N ha⁻¹ to 300 kg N ha⁻¹ also increased the SPAD value of hybrid maize varieties. Generally, an increasing trend in SPAD value was observed with increased N application rates. Similar to this finding, Haghighi *et al.* (2010) on maize reported an increasing trend in SPAD on maize due to an increase in N fertilizer application rates.

Interaction effect of hybrid maize varieties and nitrogen on SPAD

The combined effect of hybrid varieties and nitrogen levels on SPAD value was statistically significant for all the growth stage during both years, respectively (Table 3.2.13 for 2016-17 and Table 3.2.14 for 2017-18). The interaction of between nitrogen rates and hybrid varieties for SPAD value increased from 50.10 to 72.90 during 2016-17 and from 51.75 to 73.15 during 2017- 2018 at different DAS by increasing N level which were in good agreement with the measurements of Aparicio *et al.*, (2000) they reported that SPAD values consistently increased with crop growth stages in early season and it reached a plateau when the ground surface was completely covered by the canopy. Results showed that the maximum SPAD value was obtained from combination of P3396×300 (51.23, 52.30, 55.07, 72.87, 66.23, 60.40 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the maximum SPAD value also was obtained from combination of P3396×300 (51.75, 54.10, 57.54, 73.15, 67.40 and 61.00 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the minimum SPAD value was obtained from hybrid 981×100 combination during both years which were in good agreement with the measurements of Lawal *et al.*, (2018) they reported that the highest SPAD value recorded at 2 WAP (0.31) was recorded on LY1001-22 at 80 kg N ha⁻¹.

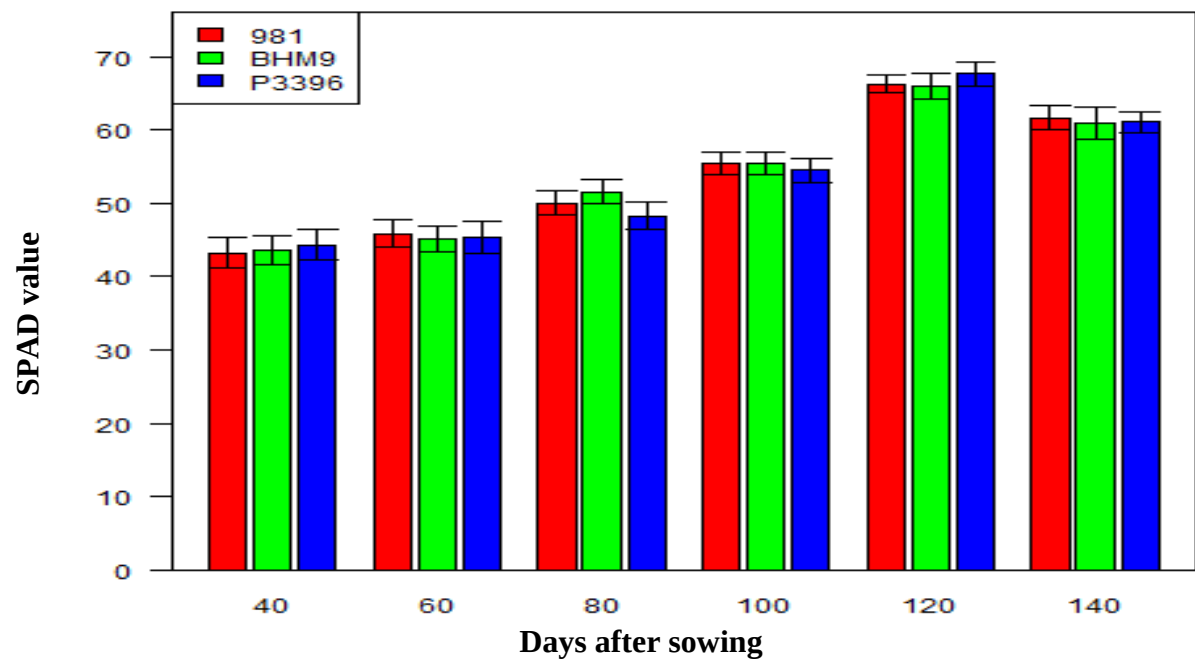


Figure 3.2.21: Effect of hybrid maize varieties on SPAD value at different days after sowing (2016-17).

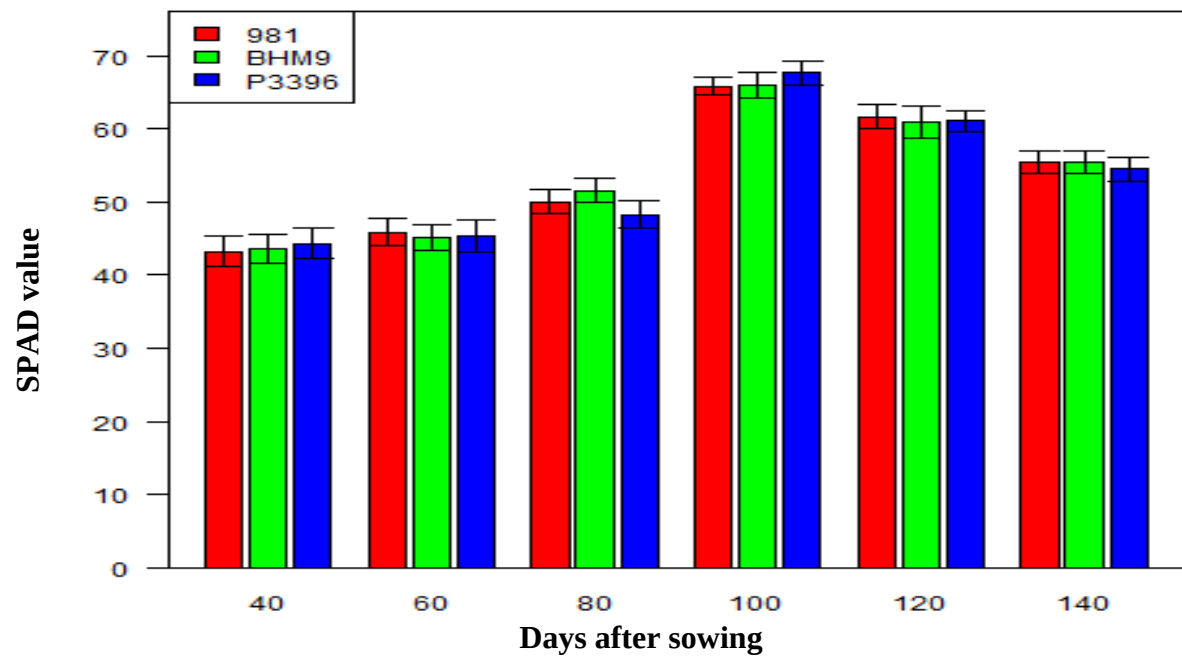


Figure 3.2.22: Effect of hybrid maize variety on SPAD at different days after sowing during 2017-18.

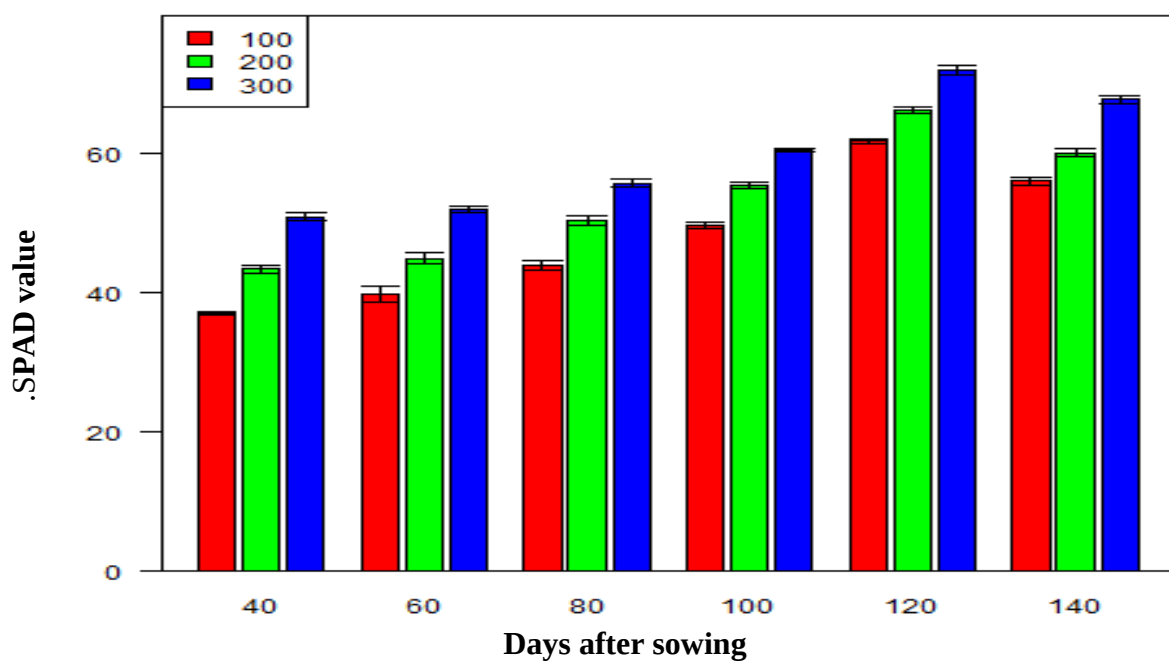


Figure 3.2.23: Effect of nitrogen on SPAD value of hybrid maize at different days after sowing during 2016-17.

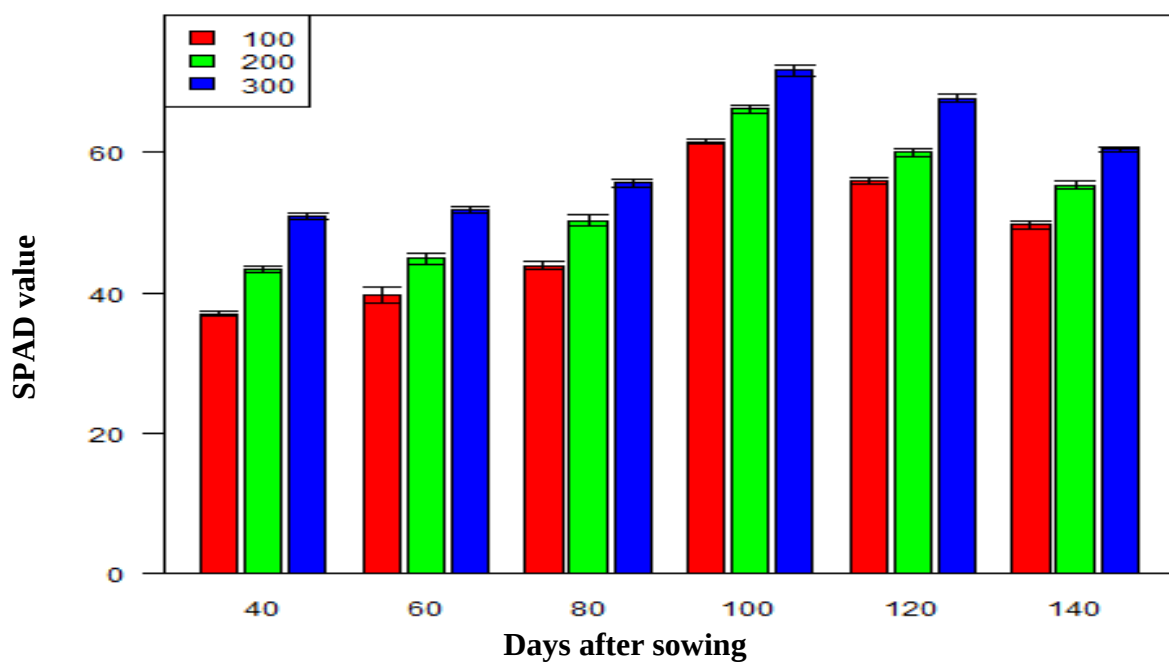


Figure 3.2.24: Effect of nitrogen on SPAD value of hybrid maize at different days after sowing during 2017-18.

Table 3.2.13. Interaction effect of varieties (V) and nitrogen (N) levels on SPAD at different days after sowing of hybrid maize during 2016-17

V×N	Days After Sowing (DAS)					
Interaction	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	36.53	39.60	44.20	62.50	56.27	49.77
981×200	42.37	46.43	50.77	65.57	61.40	56.37
981×300	50.67	51.60	55.10	70.53	67.37	60.23
BHM9×100	37.53	39.30	45.43	60.57	55.07	50.37
BHM9×200	42.73	44.57	52.40	64.97	58.20	55.40
BHM9×300	50.60	51.60	56.90	72.17	69.53	60.60
P3396×100	36.90	40.33	42.07	62.13	56.57	48.80
P3396×200	44.83	43.53	47.73	67.90	60.30	54.20
P3396×300	51.23	52.30	55.07	72.87	66.23	60.40
LSD (0.05)	2.42	3.74	2.65	2.54	2.31	2.63

Table 3.2.14. Interaction effect of varieties and nitrogen levels on SPAD at different days after sowing of hybrid maize during 2017-18

V×N	Days After Sowing (DAS)					
Interaction	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	36.53	39.60	44.20	61.83	56.27	49.77
981×200	42.37	46.43	50.77	65.57	61.40	56.37
981×300	50.67	51.60	55.10	69.87	67.37	60.23
BHM9×100	37.53	39.30	45.43	60.57	55.07	50.37
BHM9×200	42.73	44.57	52.40	64.97	58.20	55.40
BHM9×300	50.60	51.60	56.90	72.17	69.53	60.60
P3396×100	36.90	40.33	42.07	62.13	56.57	48.80
P3396×200	44.83	43.53	47.73	67.90	60.30	54.20
P3396×300	51.75	54.10	57.54	73.15	67.40	61.00
LSD (0.05)	2.29	4.83	2.54	2.44	2.17	2.29

3.2.3.2.2 Leaf Chlorophyll a (Chl a) content (mg g⁻¹)

Effect of hybrid maize varieties on Chl a content (mg g⁻¹)

The Chl a content of different hybrid maize varieties at different growth stages significantly differs at different days after sowing (DAS) is shown in Figure 3.2.25 for 2016-17 and Figure 3.2.26 for 2017-18, respectively. Irrespective of variety differences, Chl a content increased progressively up to 100 DAS. Among the hybrid maize varieties Chl a content ranged from 0.90 to 1.19 during 2016-17 and from 0.89 to 1.15 during 2017- 2018 at different DAS. Different hybrid varieties showed different Chl a content at different growth stages and finally the variety P3396 produced the highest Chl a content (0.95, 1.11, 1.14, 1.19, 1.09 and 0.98 mg g⁻¹ at 60, 80, 100, 120 and 140 DAS, respectively) which was insignificant from all other varieties during 2016-17. P3396 also produced the maximum (0.95, 1.03, 1.03, 1.15, 0.92 and 0.91 mg g⁻¹ at 40, 60, 80, 100, 120 and 140 DAS, respectively) which was superior than other varieties during 2017-18. Production of highest Chl a content at different DAS of P3396 might be due to its genetically governed traits. Lowest Chl a content was found from the hybrid P3396 during the both seasons. According to Pandey *et al.* (2000), maize genotypes differ in their ability to maintain leaf area, Chl a content. Nasab (2001) reported that both grain and biomass yield in maize are correlated with vegetative and reproductive phase duration. Leaf area influences interception and utilization of solar radiation of maize crop canopies and, consequently, maize dry matter accumulation and grain yield. Leaf area and number are important factors in the estimation of canopy photosynthesis in crop growth simulation models that compute dry matter accumulation from temporal integration of canopy photosynthesis (Boote *et al.*, 1996).

Effect of nitrogen chlorophyll a (Chl a) content (mg g⁻¹)

Effect of N levels revealed that a highly significant variation on Chl a content for all growth stages (Figure 3.2.27 for 2016-17 and Figure 3.2.28 for 2017-18). Irrespective of treatment differences, Chl a content increased rapidly up to 100 DAS after that it was slowly decreased. Among the N levels treatments Chl a content ranged from 0.91 to 1.16 mg g⁻¹ during 2016-17 and from 0.95 to 1.17 mg g⁻¹ during 2017- 2018 at different DAS. It was found that the maximum Chl a content was obtained from the 300 kg N ha⁻¹ treatment at all growth stages (0.91, 1.10, 1.10, 1.16, 1.12, 0.96 mg g⁻¹ at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-

17 and the maximum Chl a content also was obtained from the N₃₀₀ (300 kg N ha⁻¹) treatment at all growth stages (0.95, 1.03, 1.03, 1.17, 0.99 and 0.91 mg g⁻¹ at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the minimum Chl a content was found in N₁₀₀ (100 kg N ha⁻¹) treatment during both the years. Increasing nitrogen level from 100 kg N ha⁻¹ to 300 kg N ha⁻¹ also increased the Chl a content of hybrid maize varieties. Generally, an increasing trend in Chl a content was observed with increased N application rates. The increase in Chl a content was possibly due to the improved leaf expansion in plants by giving optimum nitrogenous fertilizers. Similar to this finding, Haghighi *et al.* (2010) on maize reported an increasing trend in Chl a content on maize due to an increase in N fertilizer application rates.

Interaction effect of hybrid maize varieties and nitrogen on Chl a content (mg g⁻¹)

The interaction effect of varieties and nitrogen levels on Chl a content was statistically significant except 75 DAS during 2017-18 (Table 3.2.15 for 2016-17) and 25 DAS & 75 DAS during 2017-18 (Table 3.2.16 for 2017-18). The interaction of between nitrogen rates and cultivars for Chl a content increased from 0.52 to 0.99 during 2016-17 and from 0.49 to 0.92 during 2017- 2018 by increasing N level which were in good agreement with the measurements of Aparicio *et al.*, (2000) they reported that Chl a content consistently increased with crop growth stages in early season and it reached a plateau when the ground surface was completely covered by the canopy. Results showed that the maximum Chl a content was obtained from combination of BHM9×300 (0.65, 0.72, 0.89, 0.99, 0.79 and 0.69 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the maximum Chl a content also was obtained from combination of BHM9×300 (0.60, 0.67, 0.69, 0.92, 0.88 and 0.77 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the minimum Chl a content was obtained from hybrid 981×100 combination during both years which were in good agreement with the measurements of Lawal *et al.*, (2018) they reported that the highest Chl a content recorded at 2 WAP (0.31) was recorded on LY1001-22 at 80 kg N ha⁻¹. At 3 WAP, however, there was no consistency in the expression of the vegetative index, LY1001-23 had the highest vegetative index (0.46) under application of 120 kg N ha⁻¹.

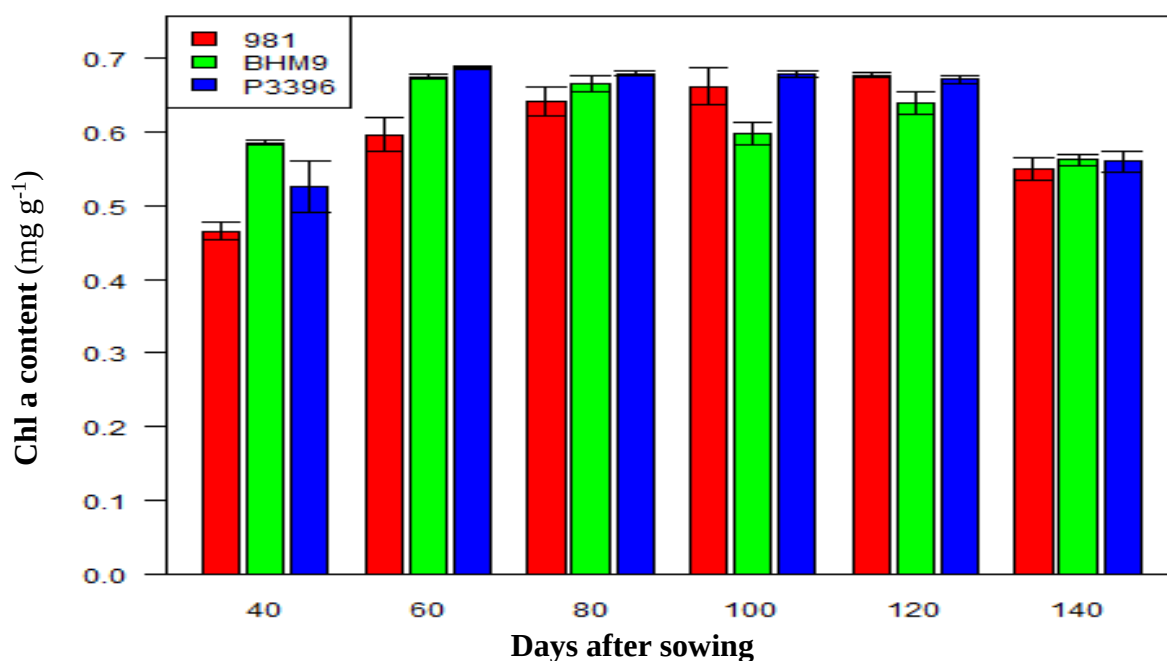


Figure 3.2.25: Effect of hybrid maize varieties on Chl a content at different days after sowing during 2016-17.

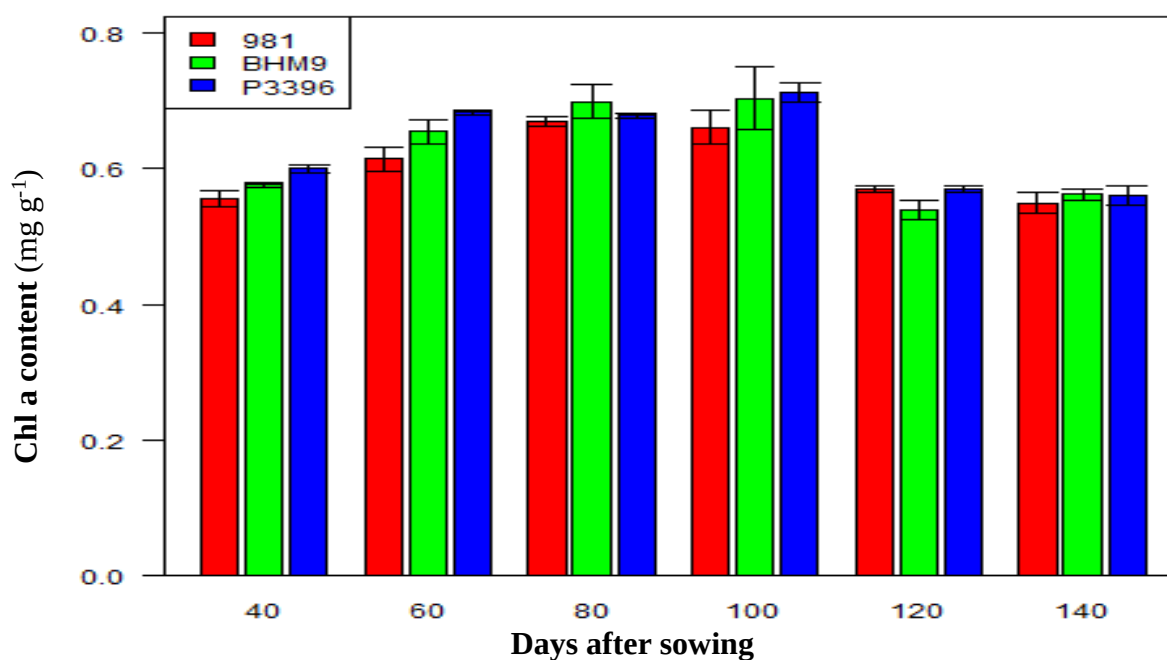


Figure 3.2.26: Effect of hybrid maize variety on Chl a content at different days after sowing during 2017-18. Vertical bars indicate $\pm$ SE value.

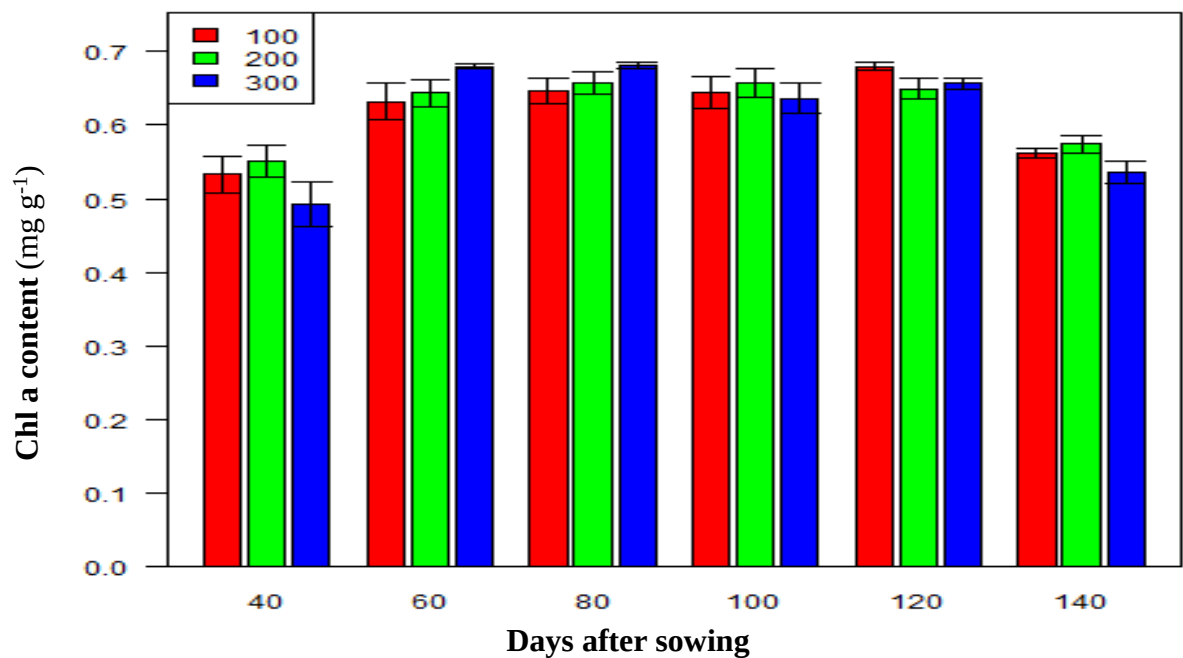


Figure 3.2.27: Effect of nitrogen on Chl a content of hybrid maize at different days after sowing during 2016-17.

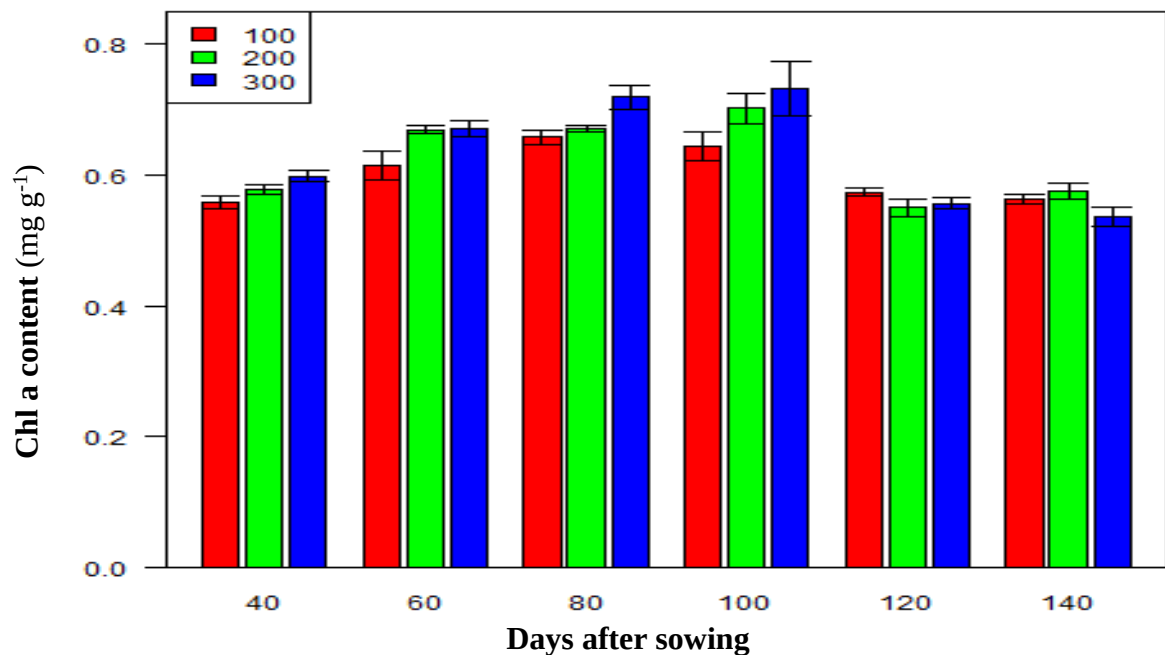


Figure 3.2.28: Effect of nitrogen on Chl a content of hybrid maize at different days after sowing during 2017-18.

Table 3.2.15. Interaction effect of varieties and nitrogen levels on Chl a content at different days after sowing of hybrid maize during 2016-17

V×N	Days After Sowing (DAS)					
Interaction	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	0.86	0.95	1.07	1.11	1.11	1.00
981×200	0.89	1.00	1.04	1.13	1.09	0.98
981×300	0.92	1.10	1.09	1.01	1.10	0.93
BHM9×100	1.00	1.10	1.05	0.98	1.11	0.96
BHM9×200	1.11	1.09	1.10	1.00	1.02	1.00
BHM9×300	1.21	1.09	1.11	1.08	1.05	1.00
P3396×100	1.01	1.11	1.09	1.11	1.09	0.99
P3396×200	1.02	1.10	1.10	1.11	1.11	1.01
P3396×300	0.81	1.12	1.11	1.09	1.09	0.94
LSD (0.05)	0.03	0.04	0.07	0.06	0.02	0.06

Table 3.2.16. Interaction effect of varieties and nitrogen levels on Chl a content at different days after sowing of hybrid maize during 2017-18

V×N	Days After Sowing (DAS)					
Interaction	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	0.87	0.90	1.00	1.04	0.92	0.93
981×200	0.90	1.00	1.02	1.05	0.92	0.91
981×300	0.94	1.19	1.15	0.94	0.93	0.86
BHM9×100	0.92	0.95	0.98	0.91	0.94	0.88
BHM9×200	0.93	1.02	1.03	1.06	0.85	0.93
BHM9×300	0.93	1.14	1.14	1.19	0.88	0.92
P3396×100	0.93	1.03	1.02	1.03	0.91	0.92
P3396×200	0.95	1.10	1.03	1.03	0.93	0.94
P3396×300	0.97	1.13	1.24	1.32	0.91	0.87
LSD (0.05)	0.03	0.06	0.03	0.10	0.02	0.05

3.2.3.2.3 Leaf Chlorophyll b (Chl b) content (mg g⁻¹)

Effect of hybrid maize varieties on Chl b content (mg g⁻¹)

The Chl b content of different hybrid maize varieties at different growth stages highly significantly differs at different days after sowing (DAS) is shown in Figure 3.2.29 for 2016-17 and Figure 3.2.30 for 2017-18, respectively. Chl b content increased gradually up to 100 DAS, then increased up to 100 DAS and decreased with the advancement of growing period of all the varieties for both the years. Irrespective of variety differences, Chl b content increased progressively up to 100 DAS. Among the hybrid maize varieties Chl b content ranged from 0.77 to 1.17 mg g⁻¹ during 2016-17 and from 0.79 to 1.19 mg g⁻¹ during 2017- 2018 at different DAS. Different hybrid varieties showed different Chl b at different growth stages and finally the variety BARI Hybrid Maize 9 produced the highest Chl b (0.84, 1.02, 1.02, 0.96, 1.13 and 1.04 mg g⁻¹ at 60, 80, 100, 120 and 140 DAS, respectively) which was insignificant from all other varieties during 2016-17. BARI Hybrid Maize 9 also produced the maximum (0.89, 0.94, 1.04, 1.19, 0.89 and 0.84 at 40,60, 80, 100, 120 and 140 DAS, respectively) which was superior than other varieties during 2017-18. Production of highest Chl b at different DAS of BARI Hybrid Maize 9 might be due to its genetically governed traits. Lowest Chl b was found from the hybrid P3396 during the both seasons. According to Pandey *et al.* (2000), maize genotypes differ in their ability to maintain leaf area, Chl b.

Effect of nitrogen on Chl b content (mg g⁻¹)

Effect of N levels revealed that a highly significant variation on Chl b content for all growth stages (Figure 3.2.33 for 2016-17 and Figure 3.2.34 for 2017-18). Irrespective of treatment differences, Chl b content increased rapidly up to 100 DAS after that it was slowly decreased. Among the N levels treatments Chl b content ranged from 0.89 to 1.15 mg g⁻¹ during 2016-17 and from 0.78 to 1.14 mg g⁻¹ during 2017- 2018 at different DAS. It was found that the maximum Chl b was obtained from the 300 kg N ha⁻¹ treatment at all growth stages (0.96, 1.07, 1.10, 1.15, 1.05 and 0.99 mg g⁻¹ at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the maximum Chl b also was obtained from the N₃₀₀ (300 kg N ha⁻¹) treatment at all growth stages (0.93, 1.04, 1.05, 1.14, 0.88 and 0.82 mg g⁻¹ at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the minimum Chl b was found in N₁₀₀ (100 kg N ha⁻¹)

treatment during both years. Increasing nitrogen level from 100 kg N ha⁻¹ to 300 kg N ha⁻¹ also increased the Chl b of hybrid maize varieties. Generally, an increasing trend in Chl b was observed with increased N application rates. The increase in Chl b was possibly due to the improved leaf expansion in plants by giving optimum nitrogenous fertilizers. Similar to this finding, Haghighi *et al.* (2010) on maize reported an increasing trend in Chl b on maize due to an increase in N fertilizer application rates.

Interaction effect of hybrid maize varieties and nitrogen on Chl b content (mg g⁻¹)

The interaction effect of varieties and nitrogen levels on Chl b content was statistically significant except 75 DAS during 2017-18 (Table 3.2.17 for 2016-17) and 25 DAS & 75 DAS during 2017-18 (Table 3.2.18 for 2017-18). The interaction of between nitrogen rates and cultivars for Chl b score increased from 0.87 to 1.11 mg g⁻¹ during 2016-17 and from 0.89 to 1.23 mg g⁻¹ during 2017- 2018 by increasing N level which were in good agreement with the measurements of Aparicio *et al.*, (2000) they reported that Chl b values consistently increased with crop growth stages in early season and it reached a plateau when the ground surface was completely covered by the canopy. Results showed that the maximum Chl b was obtained from combination of P3396×300 (0.98, 1.00, 1.09, 1.11 and 1.10, 0.95 mg g⁻¹ at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the maximum Chl b also was obtained from combination of P3396×300 (0.95, 0.97, 1.07, 1.23, 0.93 and 0.78 mg g⁻¹ at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the minimum Chl b was obtained from hybrid 981×100 combination during both years.

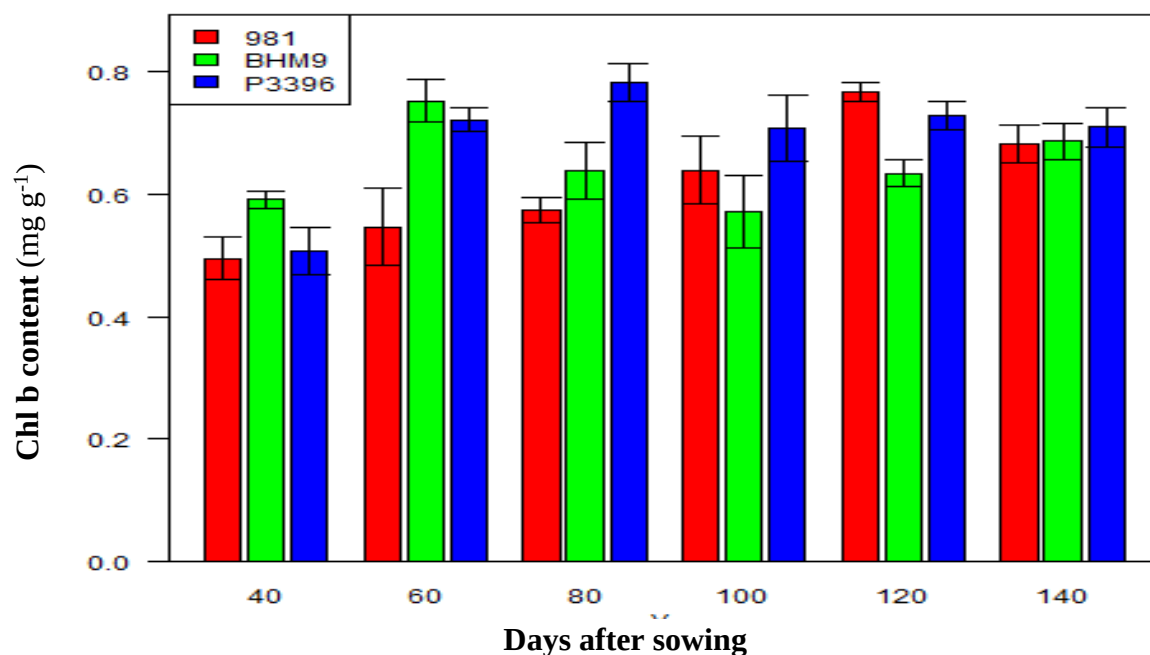


Figure 3.2.29: Effect of hybrid maize varieties on Chl b content at different days after sowing during 2016-17.

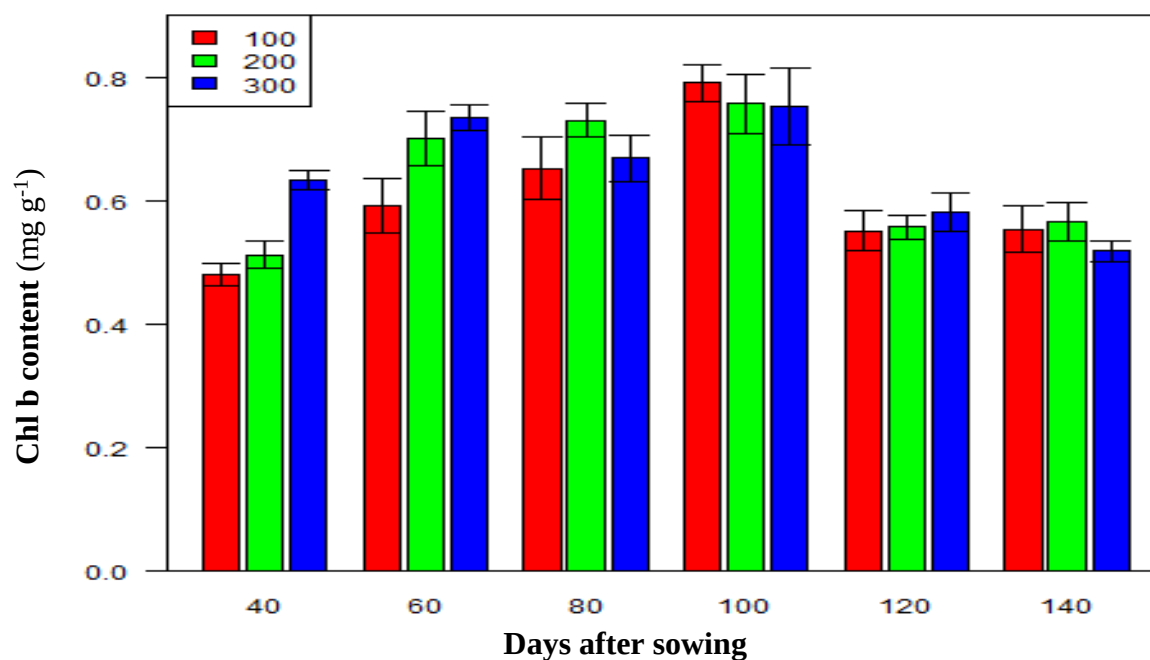


Figure 3.2.30: Effect of hybrid maize variety on Chl b content at different days after sowing (2017-18). Vertical bars indicate $\pm$ SE value.

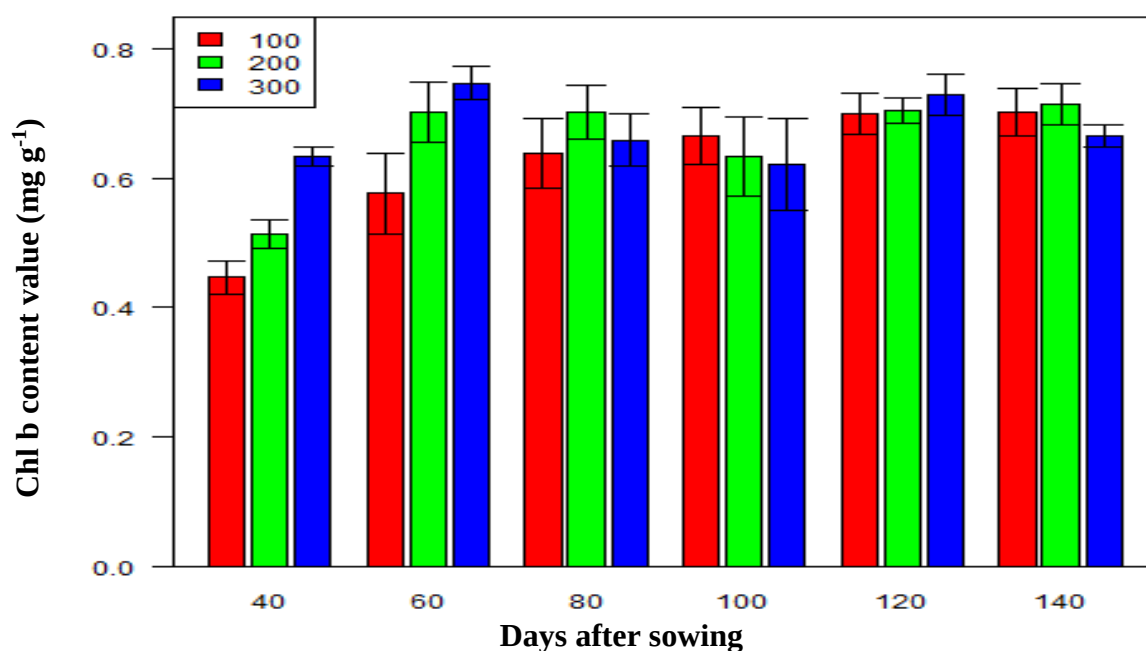


Figure 3.2.31: Effect of nitrogen on Chl b content on hybrid maize at different days after sowing during 2016-17.

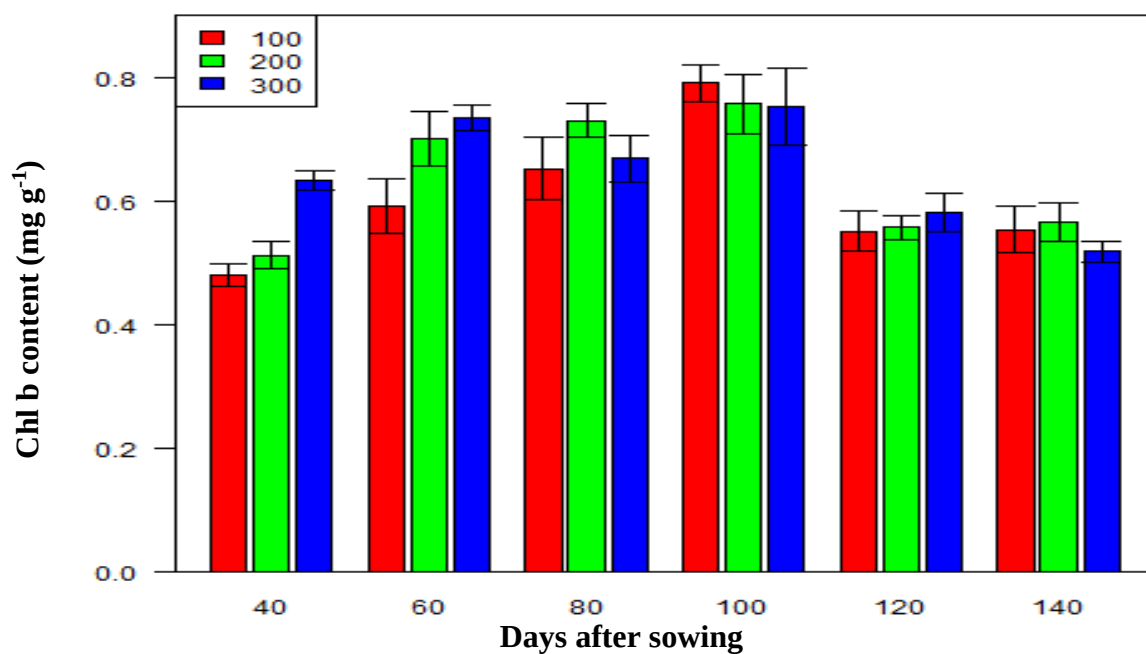


Figure 3.2.32: Effect of nitrogen on Chl b content on hybrid maize at different days after sowing during 2017-18.

Table 3.2.17. Interaction effect of varieties and nitrogen levels on Chl b content at different days after sowing of hybrid maize during 2016-17

V×N	Days After Sowing (DAS)					
Interaction	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	0.72	0.67	0.93	1.00	1.08	1.05
981×200	0.80	0.87	0.88	1.09	1.07	1.00
981×300	0.93	1.08	0.88	0.81	1.12	0.97
BHM9×100	0.87	1.00	0.81	0.95	0.98	0.92
BHM9×200	0.92	1.10	1.11	0.81	0.97	1.07
BHM9×300	0.96	1.14	0.97	0.92	0.93	1.05
P3396×100	0.72	1.03	1.14	1.02	1.01	1.11
P3396×200	0.79	1.11	1.09	0.97	1.05	1.04
P3396×300	0.98	1.00	1.09	1.11	1.10	0.95
LSD (0.05)	0.04	0.14	0.15	0.29	0.12	0.16

Table 3.2.18. Interaction effect of varieties and nitrogen levels on Chl b content at different days after sowing of hybrid maize during 2017-18

V×N	Days After Sowing (DAS)					
Interaction	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	0.76	0.72	0.96	1.12	0.91	0.88
981×200	0.78	0.84	0.94	1.14	0.90	0.83
981×300	0.91	1.05	0.90	0.93	0.95	0.80
BHM9×100	0.84	0.95	0.79	1.08	0.81	0.75
BHM9×200	0.89	1.08	1.08	0.94	0.80	0.90
BHM9×300	0.94	1.08	0.94	1.90	0.76	0.88
P3396×100	0.73	1.01	1.11	1.08	0.84	0.94
P3396×200	0.77	1.09	1.07	1.09	0.88	0.87
P3396×300	0.95	0.97	1.07	1.23	0.93	0.78
LSD (0.05)	0.06	0.08	0.13	3.01	0.11	0.14

3.2.3.2.4 Leaf Carotenoid Content (LCC)

Effect of hybrid maize varieties on Leaf Carotenoid Content (mg g⁻¹)

The leaf carotenoid content (LCC) value of different hybrid maize varieties at different growth stages significantly differed at different days after sowing (DAS) is shown in Figure 3.2.35 for 2016-17 and Figure 3.2.36 for 2017-18, respectively. Carotenoid increased gradually up to 100 DAS and decreased with the advancement of growing period of all the varieties for both the years. Regardless of variety differences, leaf carotenoid content increased progressively up to 100 DAS. Among the hybrid maize varieties LCC content ranged from 0.16 to 0.26 mg g⁻¹ during 2016-17 and from 0.32 to 0.41 mg g⁻¹ during 2017- 2018 at different DAS. Different hybrid varieties showed different leaf carotenoid content at different growth stages and finally the variety BARI Hybrid Maize 9 produced the highest leaf carotenoid content (0.19, 0.19, 0.17, 0.24, 0.21 and 0.22 mg g⁻¹ at 60, 80, 100, 120 and 140 DAS, respectively) which was insignificant from all other varieties during 2016-17. BARI Hybrid Maize 9 also produced the maximum (0.35, 0.35, 0.36, 0.37, 0.41, 0.36 and 0.37 mg g⁻¹ at 40,60, 80, 100, 120 and 140 DAS, respectively) which was superior than other varieties during 2017-18. Production of highest leaf carotenoid content at different DAS of BARI Hybrid Maize 9 might be due to its genetically governed traits. Lowest leaf carotenoid content was found from the hybrid P3396 during the both seasons.

Effect of nitrogen on carotenoid (mg g⁻¹)

Effect of N levels revealed that a highly significant variation on LCC for all growth stages (Figure 3.2.37 for 2016-17 and Figure 3.2.38 for 2017-18). Irrespective of treatment differences, leaf carotenoid content increased rapidly up to 100 DAS after that it was slowly decreased. Among the hybrid maize varieties LCC content ranged from 0.16 to 0.24 mg g⁻¹ during 2016-17 and from 0.32 to 0.42 mg g⁻¹ during 2017- 2018 at different DAS. It was found that the maximum leaf carotenoid content was obtained from the 300 kg N ha⁻¹ treatment at all growth stages (0.19, 0.20, 0.22, 0.24, 0.19 and 0.20 mg g⁻¹ at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the maximum leaf carotenoid content also was obtained from the N₃₀₀ (300 kg N ha⁻¹) treatment at all growth stages (0.37, 0.39, 0.42, 0.42, 0.35 and 0.36 mg g⁻¹ at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the

minimum leaf carotenoid content was found in N₁₀₀ (100 kg N ha⁻¹) treatment (0.95, 1.41, 1.63, 2.51, 2.26 and 1.93 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the minimum leaf carotenoid content also was observed in N₁₀₀ (100 kg N ha⁻¹) treatment (0.96, 1.41, 1.63, 2.59, 2.26 and 2.34 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. Increasing nitrogen level from 100 kg N ha⁻¹ to 300 kg N ha⁻¹ also increased the leaf carotenoid content of hybrid maize varieties. Generally, an increasing trend in leaf carotenoid content was observed with increased N application rates. The increase in leaf carotenoid content was possibly due to the improved leaf expansion in plants by giving optimum nitrogenous fertilizers. Similar to this finding, Haghighi *et al.* (2010) on maize reported an increasing trend in leaf carotenoid content on maize due to an increase in N fertilizer application rates.

Interaction effect of hybrid maize varieties and nitrogen on leaf carotenoid content

The interaction effect of varieties and nitrogen levels on leaf carotenoid content was statistically significant except 100 DAS during 2016-17 (Table 3.2.19 for 2016-17) and during 2017-18 (Table 3.2.20 for 2017-18). The interaction of between nitrogen rates and cultivars for leaf carotenoid content score increased from 0.32 to 0.49 mg g⁻¹ during 2016-17 and from 0.30 to 0.44 mg g⁻¹ during 2017- 2018. Results showed that the maximum leaf carotenoid content was obtained from combination of BHM 9×300 (0.44, 0.45, 0.41, 0.49, 0.48 and 0.45 mg g⁻¹ at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the maximum leaf carotenoid content also was obtained from combination of BMH 9×300 (0.38, 0.36, 0.37, 0.44, 0.38 and 0.39 mg g⁻¹ at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the minimum leaf carotenoid content was obtained from hybrid 981×100 combination during both years.

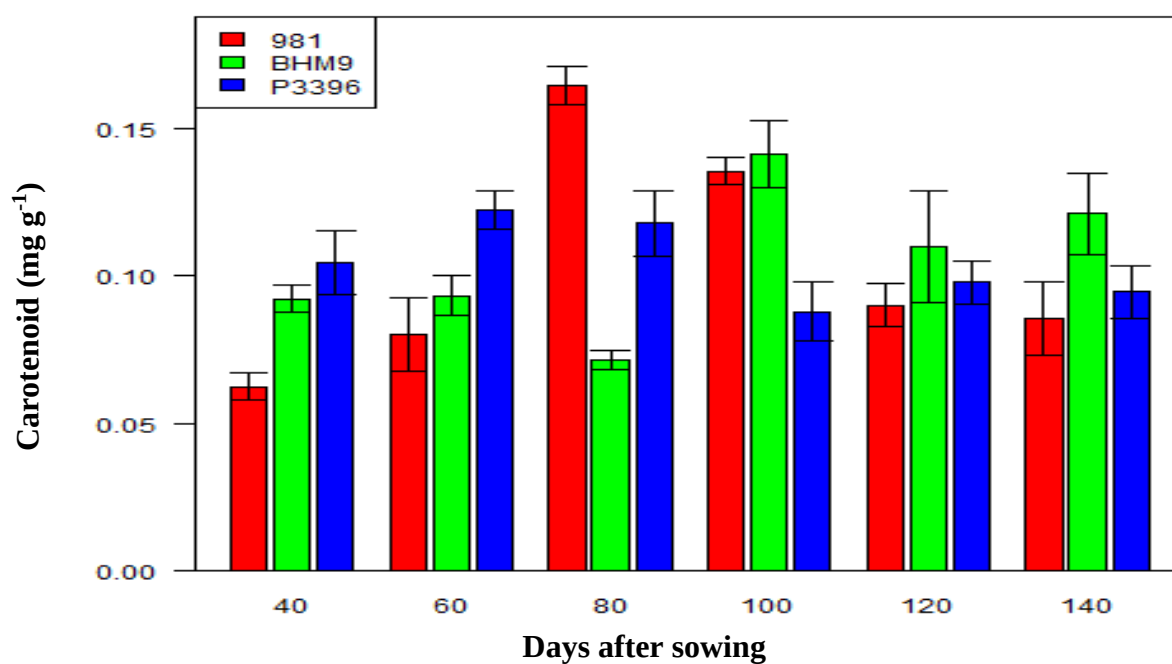


Figure 3.2.33: Effect of hybrid maize varieties on carotenoid at different days after sowing during 2016-17.

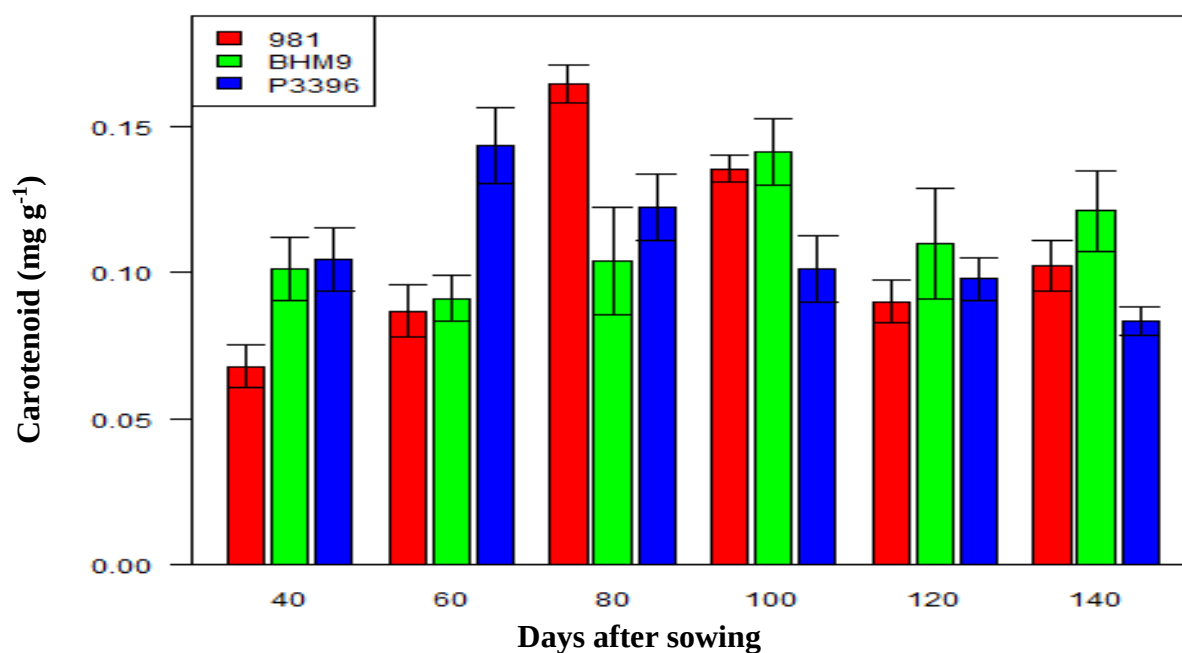


Figure 3.2.34: Effect of hybrid maize variety on carotenoid at different days after sowing during 2017-18. Vertical bars indicate $\pm$ SE value.

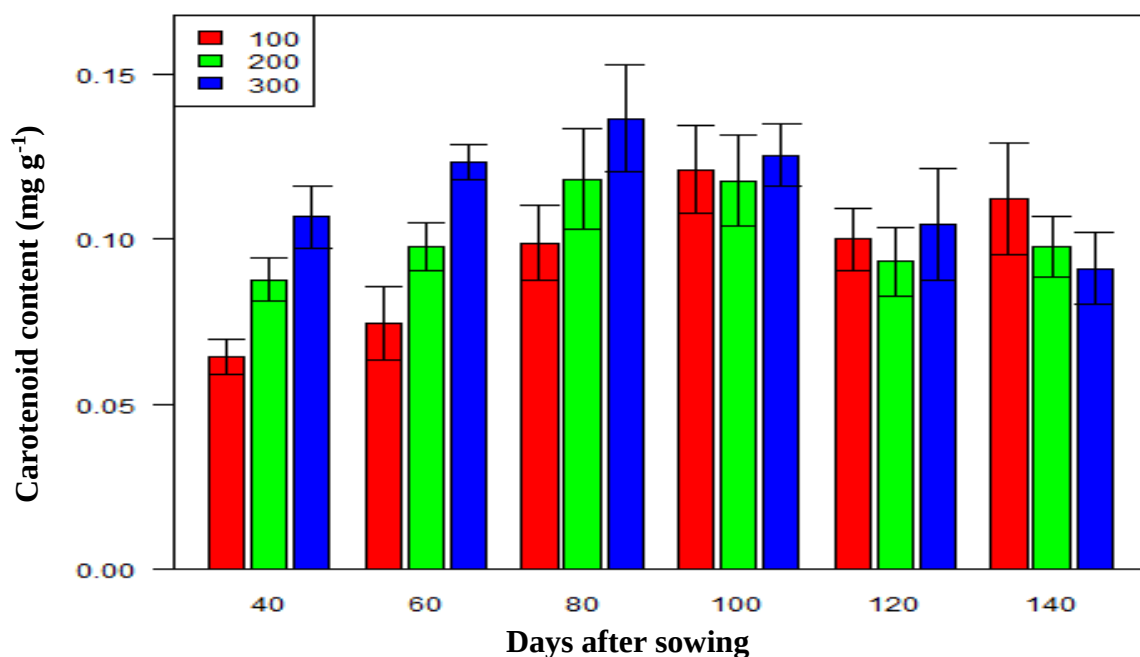


Figure 3.2.35: Effect of nitrogen on carotenoid on hybrid maize at different days after sowing during 2016-17.

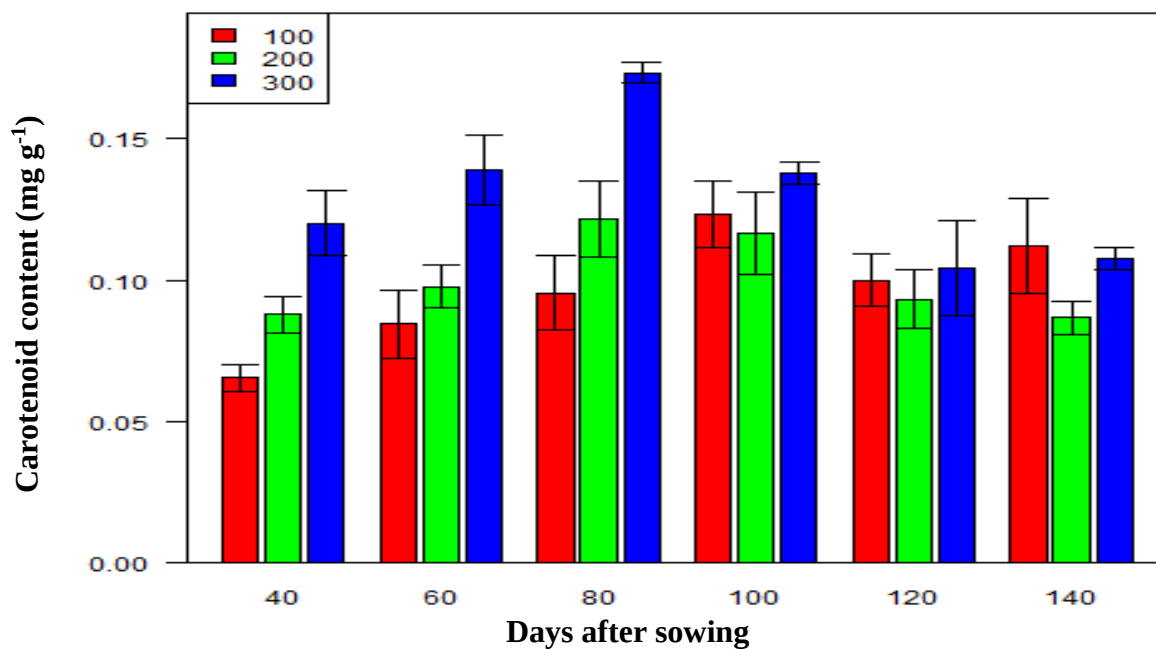


Figure 3.2.36: Effect of nitrogen on carotenoid on hybrid maize at different days after sowing during 2017-18.

Table 3.2.19. Interaction effect of varieties and nitrogen levels on LCC at different days after sowing of hybrid maize during 2016-17

V×N Interaction	Days After Sowing (DAS)					
	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	0.38	0.38	0.48	0.46	0.42	0.41
981×200	0.40	0.41	0.50	0.47	0.44	0.43
981×300	0.41	0.45	0.52	0.48	0.41	0.39
BHM9×100	0.41	0.40	0.41	0.48	0.45	0.45
BHM9×200	0.43	0.43	0.40	0.48	0.40	0.40
BHM9×300	0.44	0.45	0.41	0.49	0.48	0.45
P3396×100	0.40	0.44	0.41	0.43	0.43	0.41
P3396×200	0.44	0.45	0.46	0.40	0.43	0.41
P3396×300	0.47	0.47	0.48	0.43	0.43	0.43
LSD (0.05)	0.01	0.02	0.02	0.05	0.07	0.05

Table 3.2.20. Interaction effect of varieties and nitrogen levels on LCC at different days after sowing of hybrid maize during 2017-18

V×N Interaction	Days After Sowing (DAS)					
	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	0.30	0.31	0.35	0.39	0.37	0.34
981×200	0.31	0.33	0.34	0.42	0.38	0.36
981×300	0.34	0.37	0.36	0.43	0.40	0.32
BHM9×100	0.33	0.31	0.41	0.31	0.39	0.37
BHM9×200	0.35	0.35	0.34	0.33	0.40	0.32
BHM9×300	0.38	0.36	0.37	0.44	0.38	0.39
P3396×100	0.32	0.38	0.33	0.34	0.35	0.35
P3396×200	0.35	0.37	0.33	0.37	0.32	0.35
P3396×300	0.39	0.44	0.35	0.41	0.38	0.35
LSD (0.05)	0.03	0.03	0.05	0.02	0.04	0.06

3.2.3.2.5 Leaf Nitrogen Content (LNC)

Effect of hybrid maize varieties on LNC (ppm)

The LNC content of different hybrid maize varieties at different growth stages shows insignificant at different days after sowing (DAS) is shown in Figure 3.2.37 for 2016-17 and Figure 3.2.38 for 2017-18, respectively. LNC increased gradually up to 100 DAS, then decreased with the advancement of growing period of all the varieties for both the years. Regardless of variety differences, LNC increased progressively up to 100 DAS. Among the hybrid maize varieties LNC content ranged from 1189 to 1724 ppm during 2016-17 and from 1206 to 1713 ppm during 2017- 2018 at different DAS. Different hybrid varieties showed different LNC at different growth stages and finally the variety BARI Hybrid Maize 9 produced the highest LNC (1292, 1451, 1333, 1724, 1633 and 1406 ppm at 60, 80, 100, 120 and 140 DAS, respectively) which was insignificant from all other varieties during 2016-17. BARI Hybrid Maize 9 also produced the maximum (1239, 1429, 1311, 1713, 1626 and 1492 ppm at 40, 60, 80, 100, 120 and 140 DAS, respectively) which was superior than other varieties during 2017-18. Production of highest LNC at different DAS of BARI Hybrid Maize 9 might be due to its genetically governed traits. Lowest LNC was found from the hybrid P3396 during the both seasons. According to Pandey *et al.* (2000), maize genotypes differ in their ability to maintain leaf area, LNC.

Effect of nitrogen on LNC content (ppm)

Effect of nitrogen treatments revealed that a highly significant variation on LNC for all growth stages (Figure 3.2.39 for 2016-17 and Figure 3.2.40 for 2017-18). Irrespective of treatment differences, LNC increased rapidly up to 50 DAS after that it was gradually decreased. Among the hybrid maize varieties LNC content ranged from 1059 to 1757 ppm during 2016-17 and from 1068 to 1740 ppm during 2017- 2018 at different DAS. It was found that the maximum LNC was obtained from the 300 kg N ha⁻¹ treatment at all growth stages (1528, 1537, 1551, 1637, 1642 and 1757 ppm at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the maximum LNC also was obtained from the N₃₀₀ (300 kg N ha⁻¹) treatment at all growth stages (1391, 1514, 1520, 1740, 1642 and 1508 ppm at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the minimum LNC was found in N₁₀₀ (100 kg

N ha⁻¹) treatment during both years. Increasing nitrogen level from 100 kg N ha⁻¹ to 300 kg N ha⁻¹ also increased the LNC of hybrid maize varieties. Generally, an increasing trend in LNC was observed with increased N application rates. The increase in LNC was possibly due to the improved leaf expansion in plants by giving optimum nitrogenous fertilizers. Similar to this finding, Haghighi *et al.* (2010) on maize reported an increasing trend in LNC on maize due to an increase in N fertilizer application rates

Interaction effect of hybrid maize varieties and nitrogen level on LNC (ppm)

The interaction effect of varieties and nitrogen levels on LNC was statistically significant except 100 DAS during 2016-17 (Table 3.2.21 for 2016-17) and during 2017-18 (Table 3.2.22 for 2017-18). The interaction of between nitrogen rates and cultivars for LNC score increased from 1076 to 1830 ppm during 2016-17 and from 1070 to 1813 ppm during 2017- 2018 by increasing N level which were in good agreement with the measurements of Aparicio *et al.*, (2000) they reported that LNC values consistently increased with crop growth stages in early season and it reached a plateau when the ground surface was completely covered by the canopy. Results showed that the maximum LNC was obtained from combination of BHM 9×300 (1533, 1553, 1430, 1830, 1713 and 1493. ppm at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and the maximum LNC also was obtained from combination of BHM 9×300 (1390, 1520, 1413, 1813, 1713 and 1579 ppm at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. On the other hand, the minimum LNC was obtained from hybrid 981×100 combination during both years which were in good agreement with the measurements of Lawal *et al.*, (2018) they reported that the highest LNC value recorded at 2 WAP (0.31) was recorded on LY1001-22 at 80 kg N ha⁻¹. At 3 WAP, however, there was no consistency in the expression of the vegetative index, LY1001-23 had the highest vegetative index (0.46) under application of 120 kg N ha⁻¹ while the least LNC value (0.33) was obtained from EXL 01 x EXL 05. At 4 WAP, higher LNC values that were not significantly different from one another were recorded.

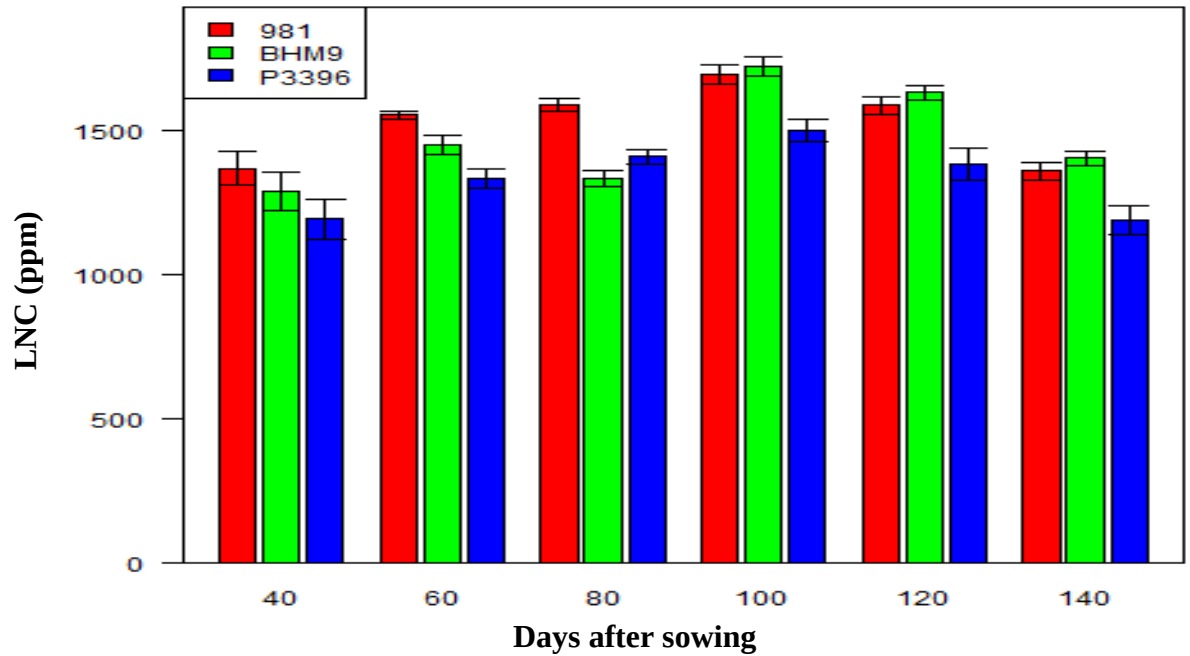


Figure 3.2.37: Effect of hybrid maize varieties on LNC at different days after sowing during 2016-17.

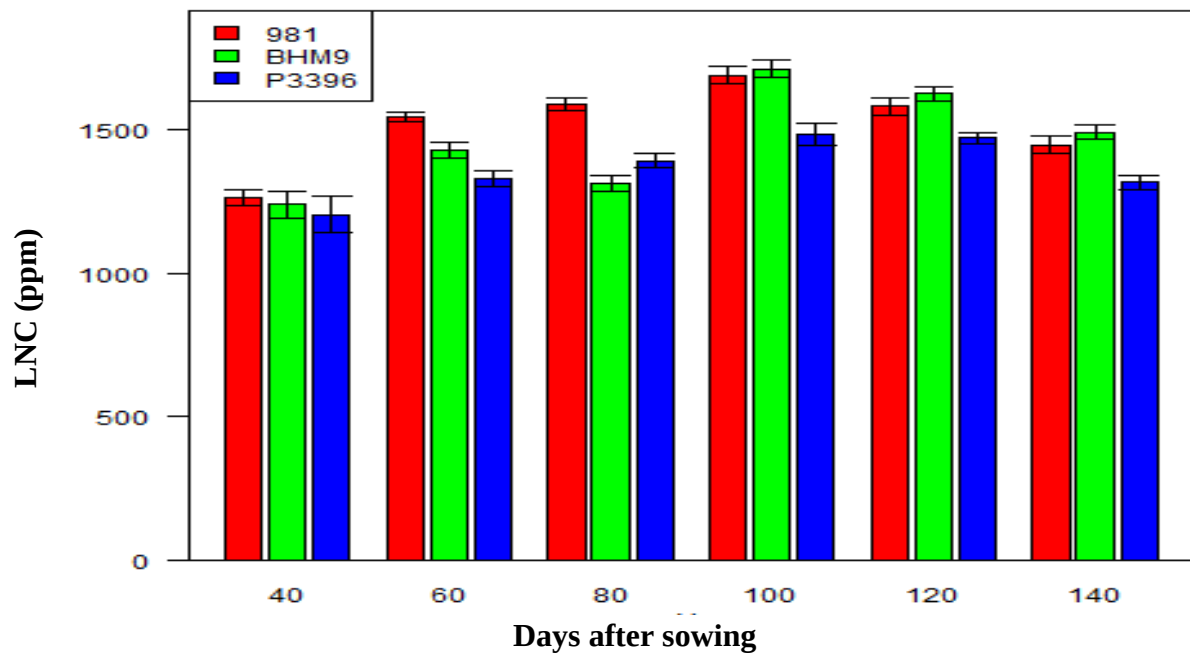


Figure 3.2.38: Effect of hybrid maize variety on LNC at different days after sowing during 2017-18. Vertical bars indicate $\pm$ SE value.

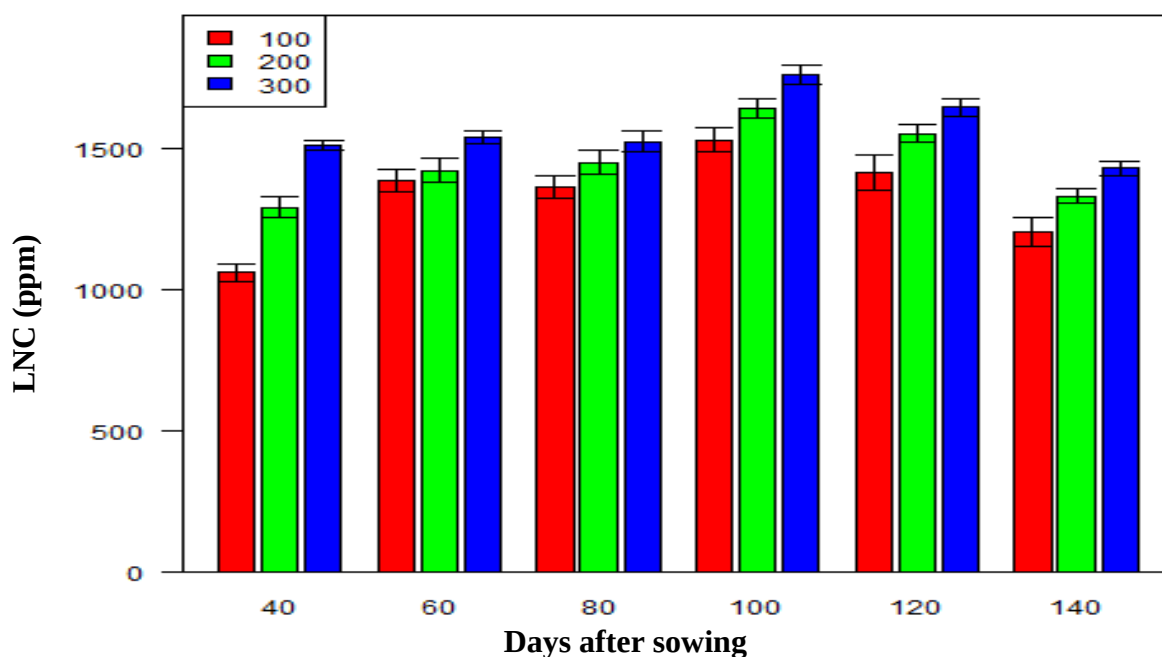


Figure 3.2.39: Effect of nitrogen on LNC on hybrid maize at different days after sowing (2016-17).

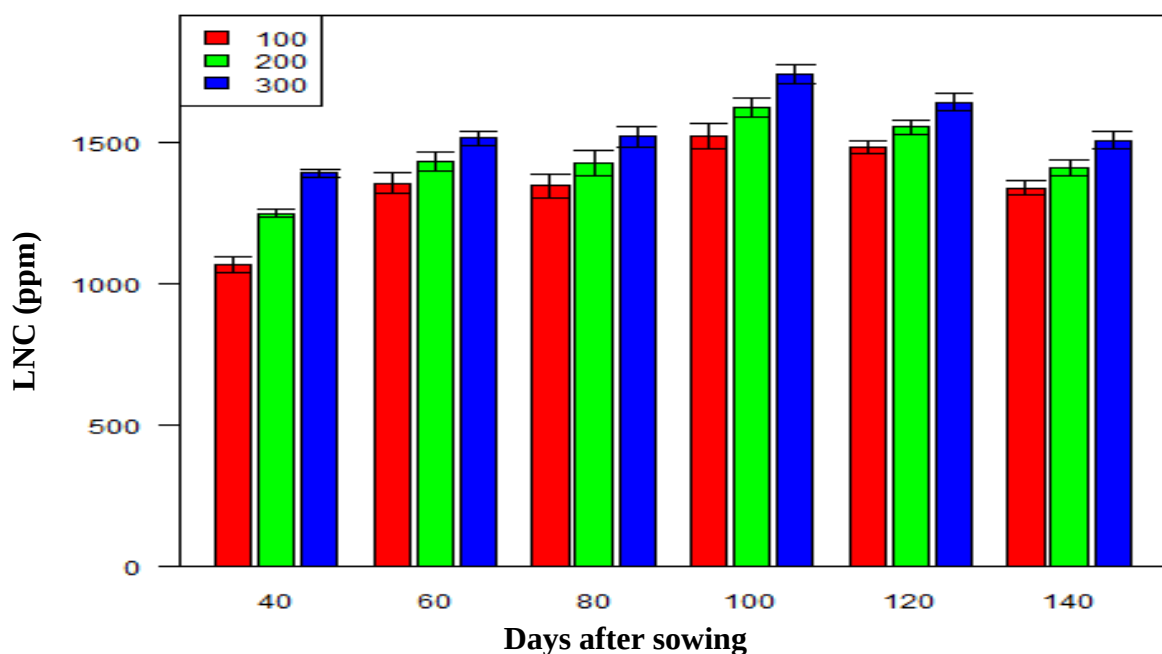


Figure 3.2.40: Effect of nitrogen on LNC on hybrid maize at different days after sowing during 2017-18.

Table 3.2.21. Interaction effect of varieties and nitrogen levels on LNC at different days after sowing of hybrid maize during 2016-17

V×N Interaction	Days After Sowing (DAS)					
	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	1149.67	1520.00	1513.33	1606.67	1503.33	1263.33
981×200	1413.00	1546.67	1586.67	1670.00	1580.00	1360.00
981×300	1549.67	1596.67	1666.67	1810.00	1680.00	1460.00
BHM9×100	1076.33	1366.67	1250.00	1613.33	1553.33	1333.33
BHM9×200	1266.33	1433.33	1320.00	1730.00	1633.33	1390.00
BHM9×300	1533.00	1553.33	1430.00	1830.00	1713.33	1493.33
P3396×100	949.67	1266.67	1326.67	1363.33	1180.00	1003.33
P3396×200	1189.67	1280.00	1440.00	1510.00	1440.00	1233.33
P3396×300	1439.67	1460.00	1466.67	1630.00	1533.33	1330.00
LSD (0.05)	60.23	87.56	44.84	70.17	83.79	57.65

Table 3.2.22. Interaction effect of varieties and nitrogen levels on LNC at different days after sowing of hybrid maize during 2017-18

V×N Interaction	Days After Sowing (DAS)					
	40 DAS	60 DAS	80 DAS	100 DAS	120 DAS	140 DAS
981×100	1163.33	1486.67	1413.33	1406.67	1483.33	1349.33
981×200	1260.00	1546.67	1586.67	1670.00	1580.00	1446.00
981×300	1367.33	1596.67	1666.67	1793.33	1680.00	1546.00
BHM9×100	1057.00	1333.33	1233.33	1613.33	1553.33	1419.33
BHM9×200	1270.00	1433.33	1486.67	1713.33	1610.00	1476.00
BHM9×300	1390.00	1520.00	1413.33	1813.33	1713.33	1579.33
P3396×100	983.33	1243.33	1293.33	1346.67	1413.33	1249.33
P3396×200	1216.67	1320.00	1406.67	1493.33	1470.00	1306.00
P3396×300	1416.67	1426.67	1480.00	1613.33	1533.33	1399.33
LSD (0.05)	65.55	41.76	35.56	59.33	53.54	58.78

3.2.3.3 Yield and yield contributing traits of maize

3.2.3.3.1 Plant height at harvesting stage

Plant height (cm) at harvesting stage as influenced by the hybrid maize varieties, nitrogen levels and interaction between hybrid maize varieties, nitrogen levels are presented in Table 3.2.23.

Effect of hybrid variety on plant height at harvest stage

Results revealed that among the hybrid maize, BARI hybrid maize 9 (BHM 9) had the tallest plant (241.86 cm) and shorter plant (190.84 cm) was found from hybrid 981. The trend of plant height was in order of BHM 9 > P3396 > 981 at harvesting stage (Table 3.2.23). The variation in plant height among the maize hybrid was also reported by Kumar *et.al.* (2014).

Effect of nitrogen on plant height at harvest stage

It was found that the maximum plant height at harvest stage (227.45 cm) was observed with N₃ treatment (300 kg N ha⁻¹) which was significantly differed from other treatments. Minimum plant height (204.97 cm) was found with N₁ treatment (100 kg N ha⁻¹). The tendency of plant height was in order of N₃ > N₂ > N₁ at harvesting stage (Table 3.2.23).

Interaction effect of variety and nitrogen on plant height at harvesting stage

The taller plant (251.68 cm) was recorded by the interaction of V₂ N₃ (BHM 9 and 300 kg N ha⁻¹) which was statistically at par with V₂N₂ (BHM 9 and 100 kg N ha⁻¹) and V₃N₃ (P3396 and 300 kg N ha⁻¹). Shorter plant (181.85 cm) was obtained from V₁N₁ (hybrid 981 and 100 kg N ha⁻¹) at harvesting stage (Table 3.2.23).

3.2.3.3.2 Ear height (EH) at harvest stage

Ear height (cm) at harvesting stage significantly differed by the hybrid maize varieties, nitrogen levels and interaction between hybrid maize varieties, nitrogen levels are presented in Table 3.2.23.

Effect of hybrid variety on ear height at harvest stage

Results revealed that among the maize hybrids, BHM 9 had the maximum ear height (80.22 cm) and minimum ear height (79.22 cm) was found from hybrid P3396 which was statistically identical with hybrid 981. The trend of ear height was in order of BHM 9 > 981 > P3396 at harvesting stage (Table 3.2.23).

Effect of nitrogen on ear height at harvest stage

It was found that the maximum ear height (91.78 cm) at harvest stage from N_3 treatment (300 kg N ha⁻¹) which was significantly differed from other treatments. Minimum ear height (71.00 cm) was found with N_1 treatment (100 kg N ha⁻¹). The tendency of ear height was in order of $N_3 > N_2 > N_1$ at harvesting stage (Table 3.2.23).

Interaction effect of variety and nitrogen on ear height at harvesting stage

Maximum ear height (94.33 cm) was recorded by the interaction of V_2N_3 (BHM 9 and 300 kg N ha⁻¹) which was statistically at par with V_2N_2 (BHM 9 and 200 kg N ha⁻¹) and V_3N_3 (P3396 and 300 kg N ha⁻¹). Minimum ear height (70.00 cm) was obtained from V_1N_1 (hybrid 981 and 100 kg N ha⁻¹) at harvesting stage (Table 3.2.23).

3.2.3.3 Days to fifty percent tasseling (DFT)

Days to fifty percent tasseling (DFT) had significantly differed by the hybrid maize varieties, nitrogen levels and interaction between hybrid maize varieties, nitrogen levels are presented in Table 3.2.23.

Effect of hybrid variety on days to fifty percent tasseling (day)

Results revealed that among the maize hybrids, BHM 9 had the maximum DFT (86.44) and minimum DFT (76.11) was found from hybrid 981 which was statistically identical with hybrid P3396. The trend of DFT was in order of $BHM\ 9 > P3396 > 981$ (Table 3.2.23).

Effect of nitrogen on days to fifty percent tasseling (day)

It was found that the maximum DFT (94.22) from N_3 treatment (300 kg N ha⁻¹) which was significantly differed from other treatments. Minimum DFT (75.56) was found with N_1 treatment (100 kg N ha⁻¹). The tendency of DFT was in order of $N_3 > N_2 > N_1$ (Table 3.2.23).

Interaction effect of variety and nitrogen on days to fifty percent tasseling (day)

Maximum DFT (97.67) was recorded by the interaction of V_3N_3 (P3396 and 300 kg N ha⁻¹) which was statistically at par with V_2N_3 (BHM 9 and 300 kg N ha⁻¹) and V_1N_3 (hybrid 981 and 300 kg N ha⁻¹). Minimum DFT (66.33) was obtained from V_1N_1 (hybrid 981 and 100 kg N ha⁻¹) (Table 3.2.23).

3.2.3.3.4 Days to fifty percent Silking (DFS)

Days to fifty percent silking (DFS) had significantly differed by the hybrid maize varieties, nitrogen levels and interaction between hybrid maize varieties, nitrogen levels are presented in Table 3.2.23.

Effect of hybrid variety on days to fifty percent silking (day)

Results revealed that among the maize hybrids, BHM 9 had the maximum DFS (92.56) and minimum DFS (84.15) was found from hybrid 981 which was statistically identical with hybrid P3396. The trend of DFS was in order of BHM 9 > P3396 > 981 (Table 3.2.23).

Effect of nitrogen on days to fifty percent tasseling (day)

It was found that the maximum DFS (98.86) from N_3 treatment (300 kg N ha⁻¹) which was significantly differed from other treatments. Minimum DFS (83.26) was found with N_1 treatment (100 kg N ha⁻¹). The tendency of DFS was in order of $N_3 > N_2 > N_1$ (Table 3.2.23).

Interaction effect of variety and nitrogen on days to fifty percent tasseling (day)

Maximum DFS (101.67) was recorded by the interaction of V_3N_3 (P3396 and 300 kg N ha⁻¹) which was statistically identical with V_2N_3 (BHM 9 and 300 kg N ha⁻¹) and V_1N_3 (hybrid 981 and 300 kg N ha⁻¹). Minimum DFS (74.67) was obtained from V_1N_1 (hybrid 981 and 100 kg N ha⁻¹).

Table 3.2.23. Effect of variety, nitrogen and their interaction on yield contributing characters of hybrid maize

Treatments	Plant height (cm)	Ear height (cm)	Days to 50% tasseling	Days to 50% silking	Number of plant m⁻²	Number of cob m⁻²
Effect of variety						
V ₁ =981	190.84	80.89	76.11	84.15	12.44	16.45
V ₂ =BHM9	241.86	90.22	86.44	92.67	12.67	16.68
V ₃ =P3396	218.91	79.44	84.89	88.76	13.56	17.67
LSD (0.05)	2.97	1.56	2.48	1.53	1.65	1.60
CV (a)%	4.23	2.43	2.13	4.96	2.15	1.23
Effect of nitrogen						
N ₁ (100 Kg N ha ⁻¹)	204.97	71.00	75.56	83.26	10.00	14.03
N ₂ (200 Kg N ha ⁻¹)	219.18	78.78	81.67	86.56	12.67	16.72
N ₃ (300 Kg N ha ⁻¹)	227.45	91.78	94.22	98.86	15.89	19.95
LSD (0.05)	3.10	2.49	2.19	1.98	1.16	2.14
Interaction effect of variety and nitrogen						
981×100	181.85	70.00	66.33	74.67	9.33	13.37
981×200	193.35	81.00	74.33	80.17	12.00	16.01
981×300	197.32	91.67	87.67	91.33	16.00	20.05
BHM9×100	226.22	71.67	75.00	83.00	9.67	13.72
BHM9×200	247.68	77.67	87.00	93.00	12.33	16.37
BHM9×300	251.68	94.33	97.33	101.67	15.67	19.79
P3396×100	206.85	71.33	73.33	81.40	11.00	15.08
P3396×200	216.52	77.67	83.67	89.33	13.67	17.75
P3396×300	233.35	89.33	97.67	101.67	16.00	20.04
LSD (0.05)	11.77	4.32	3.80	2.70	1.83	1.75
CV (b)%	5.15	3.65	4.23	5.86	3.24	4.93

Table 3.2.24. Effect of variety, nitrogen and their interaction on yield and yield contributing characters of hybrid maize

Treatments	Cob length (cm)	No. of row cob ⁻¹	No. of seed row ⁻¹	No. of seed cob ⁻¹	Thousand seed weight (g)	Grain yield (t ha ⁻¹)
Effect of variety						
V ₁ =981	17.67	16.00	36.22	614.33	348.00	13.80
V ₂ =BHM9	17.33	14.78	35.00	577.22	357.22	12.47
V ₃ =P3396	18.56	16.78	35.78	662.33	343.44	13.76
LSD (0.05)	1.96	1.33	1.23	33.78	9.67	2.32
CV (a)%	2.81	2.86	1.36	3.03	3.75	8.25
Effect of nitrogen						
N ₁ (100 Kg N ha ⁻¹)	13.67	13.11	29.89	495.67	279.56	9.76
N ₂ (200 Kg N ha ⁻¹)	18.00	16.00	36.22	625.67	359.44	12.45
N ₃ (300 Kg N ha ⁻¹)	21.89	18.44	40.89	732.56	389.67	13.84
LSD (0.05)	0.83	0.88	1.40	32.90	24.39	1.29
Interaction effect of variety and nitrogen						
981×100	13.67	13.33	31.00	468.00	279.67	10.68
981×200	17.67	16.00	36.33	631.00	357.33	12.73
981×300	21.67	18.67	41.33	744.00	407.00	13.00
BHM9×100	12.67	13.33	28.67	559.67	285.33	7.95
BHM9×200	18.33	16.00	36.67	673.00	371.00	11.59
BHM9×300	21.00	18.00	39.67	754.33	415.33	13.88
P3396×100	14.67	12.67	30.00	459.33	273.67	10.65
P3396×200	18.00	16.00	35.67	573.00	350.67	13.19
P3396×300	23.00	18.67	41.67	699.33	406.00	14.45
LSD (0.05)	1.43	1.53	2.42	56.99	42.24	2.23
CV (b)%	4.42	3.74	2.85	5.49	6.43	9.54

3.2.3.3.5 Number of plant m⁻² (NPPM)

Number of plant m⁻² (NPPM) had significantly differed by the hybrid maize varieties, nitrogen levels and interaction between hybrid maize varieties, nitrogen levels are presented in Table 3.2.23.

Effect of hybrid variety on number of plant m⁻²

Results revealed that among the maize hybrids, P3396 had the maximum NPPM (13.56) and minimum NPPM (12.44) was found form hybrid 981 which was statistically identical with hybrid 981. The trend of NPPM was in order of P3396> BHM 9> 981 (Table 3.2.23).

Effect of nitrogen on number of plant m⁻²

It was found that the maximum NPPM (15.89) from N₃ treatment (300 kg N ha⁻¹) which was significantly differed from other treatments. Minimum NPPM (10.00) was found with N₁ treatment (100 kg N ha⁻¹). The tendency of NPPM was in order of N₃> N₂>N₁ (Table 3.2.23).

Interaction effect of variety and nitrogen on number of plant m⁻²

Maximum NPPM (16.00) was recorded by the interaction of V₃N₃ (P3396 and 300 kg N ha⁻¹) which was statistically identical with V₂N₃ (BHM 9 and 300 kg N ha⁻¹) and V₁N₃ (hybrid 981 and 300 kg N ha⁻¹). Minimum NPPM (9.33) was obtained from V₁N₁ (hybrid 981 and 100 kg N ha⁻¹).

3.2.3.3.6 Number of cob m⁻² (NCPM)

Number of plant m⁻² (NCPM) had significantly differed by the hybrid maize varieties, nitrogen levels and interaction between hybrid maize varieties, nitrogen levels are presented in Table 3.2.23.

Effect of hybrid variety on number of plant m⁻²

Results revealed that among the maize hybrids, P3396 had the maximum NCPM (17.60) and minimum NCPM (16.40) was found form hybrid 981 which was statistically identical with hybrid 981. The trend of NCPM was in order of P3396> BHM 9> 981 (Table 3.2.23).

Effect of nitrogen on number of plant m⁻²

It was found that the maximum NCPM (19.90) from N₃ treatment (300 kg N ha⁻¹) which was significantly differed from other treatments. Minimum NCPM (14.00) was found with N₁ treatment (100 kg N ha⁻¹). The tendency of NCPM was in order of N₃> N₂>N₁ (Table 3.2.23).

Interaction effect of variety and nitrogen on number of plant m⁻²

Maximum NCPM (20.00) was recorded by the interaction of V₃N₃ (P3396 and 300 kg N ha⁻¹) which was statistically identical with V₂N₃ (BHM 9 and 300 kg N ha⁻¹) and V₁N₃ (hybrid 981 and 300 kg N ha⁻¹). Minimum NCPM (13.33) was obtained from V₁N₁ (hybrid 981 and 100 kg N ha⁻¹).

3.2.3.3.7 Cob length (CL)

Cob length (cm) had significantly differed by the hybrid maize varieties, nitrogen levels and interaction between hybrid maize varieties, nitrogen levels are presented in Table 3.2.24.

Effect of hybrid variety on cob length (cm)

Results revealed that among the maize hybrids, P3396 had the maximum CL (18.56 cm) and minimum CL (17.67 cm) was found form hybrid 981 which was statistically identical with hybrid 981. The trend of CL was in order of P3396> BHM 9> 981 (Table 3.2.24).

Effect of nitrogen on cob length (cm)

It was found that the maximum CL (21.89 cm) from N₃ treatment (300 kg N ha⁻¹) which was significantly differed from other treatments. Minimum CL (13.67 cm) was found with N₁ treatment (100 kg N ha⁻¹). The tendency of CL was in order of N₃> N₂>N₁ (Table 3.2.24).

Interaction effect of variety and nitrogen on cob length (cm)

Maximum CL (23.00 cm) was recorded by the interaction of V₃N₃ (P3396 and 300 kg N ha⁻¹) which was statistically identical with V₂N₃ (BHM 9 and 300 kg N ha⁻¹) and V₁N₃ (hybrid 981 and 300 kg N ha⁻¹). Minimum CL (12.67 cm) was obtained from V₁N₁ (hybrid 981 and 100 kg N ha⁻¹).

3.2.3.3.8 Number of rows cob⁻¹ (NRPC)

Number of rows cob⁻¹ (NRPC) had significantly differed by the hybrid maize varieties, nitrogen levels and interaction between hybrid maize varieties, nitrogen levels are presented in Table 3.2.24.

Effect of hybrid variety on number of rows cob⁻¹

Results revealed that among the maize hybrids, P3396 had the maximum NRPC (16.78) which was statistically identical with hybrid 981 and minimum NRPC (14.78) was found form BHM 9. The trend of NRPC was in order of P3396> 981> BHM 9 (Table 3.2.24).

Effect of nitrogen on number of rows cob⁻¹

It was found that the maximum NRPC (18.44) from N₃ treatment (300 kg N ha⁻¹) which was significantly differed from other treatments. Minimum NRPC (13.11) was found with N₁ treatment (100 kg N ha⁻¹). The tendency of NRPC was in order of N₃> N₂>N₁ (Table 3.2.24).

Interaction effect of variety and nitrogen on number of rows cob⁻¹

Maximum NRPC (18.67) was recorded by the interaction of V₃N₃ (P3396 and 300 kg N ha⁻¹) which was statistically identical with V₂N₃ (BHM 9 and 300 kg N ha⁻¹) and V₁N₃ (hybrid 981 and 300 kg N ha⁻¹). Minimum NRPC (13.33) was obtained from V₁N₁ (BHM 9 and 100 kg N ha⁻¹).

3.2.3.3.9 Number of seed row⁻¹ (NSPR)

Number of seed row⁻¹ (NSPR) had significantly differed by the hybrid maize varieties, nitrogen levels and interaction between hybrid maize varieties, nitrogen levels are presented in Table 3.2.24.

Effect of hybrid variety on number of seed row⁻¹ (NSPR)

Results revealed that among the maize hybrids, P3396 had the maximum NSPC (36.22) which was identical with Hybrid 981 and minimum NSPC (35.00) was found form BHM 9. The trend of NSPC was in order of P3396> 981> BHM 9 (Table 3.2.24).

Effect of nitrogen on number of seed row⁻¹ (NSPR)

It was found that the maximum NSPC (40.89) from N₃ treatment (300 kg N ha⁻¹) which was significantly differed from other treatments. Minimum NSPC (29.89) was found with N₁ treatment (100 kg N ha⁻¹). The tendency of NSPC was in order of N₃> N₂>N₁ (Table 3.2.24).

Interaction effect of variety and nitrogen on number of seed row⁻¹ (NSPR)

Maximum NSPC (41.67) was recorded by the interaction of V₃N₃ (P3396 and 300 kg N ha⁻¹) which was statistically identical with V₂N₃ (BHM 9 and 300 kg N ha⁻¹) and V₁N₃ (hybrid 981 and 300 kg N ha⁻¹). Minimum NSPC (28.67) was obtained from V₁N₁ (BHM 9 and 100 kg N ha⁻¹).

3.2.3.3.10 Number of seed cob⁻¹ (NSPC)

Number of seed cob⁻¹ (NSPC) had significantly differed by the hybrid maize varieties, nitrogen levels and interaction between hybrid maize varieties, nitrogen levels are presented in Table 3.2.24.

Effect of hybrid variety on number of seed cob⁻¹ (NSPC)

Results revealed that among the maize hybrids, P3396 had the maximum NSPC (662.33) which was statistically identical with hybrid 981 and minimum NSPC (577.22) was found form BHM 9. The trend of NSPC was in order of 981> P3396> BHM 9 (Table 3.2.24).

Effect of nitrogen on number of seed cob⁻¹ (NSPC)

It was found that the maximum NSPC (732.56) from N₃ treatment (300 kg N ha⁻¹) which was significantly differed from other treatments. Minimum NSPC (495.67) was found with N₁ treatment (100 kg N ha⁻¹). The tendency of NSPC was in order of N₃> N₂>N₁ (Table 3.2.24). This result agrees with the findings of Chun *et al. et al.*, (2005) they reported that efficient maize hybrids, the number of kernels per ear is much higher than in N inefficient hybrids, even when their above ground vegetative biomass is similar (Chen *et al.*, 2006). Gallais and Hirel (2004) reported that, among the yield components, kernel number was the most affected (32%) while kernel weight was reduced by only 9% and the decline in yield due to the reduction of N caused ovule abortion after fertilization.

Interaction effect of variety and nitrogen on number of seed cob⁻¹ (NSPC)

Maximum NSPC (754.33) was recorded by the interaction of V₃N₃ (P3396 and 300 kg N ha⁻¹) which was statistically identical with V₂N₃ (BHM 9 and 300 kg N ha⁻¹) and V₁N₃ (hybrid 981 and 300 kg N ha⁻¹). Minimum NSPC (459.33) was obtained from V₃N₁ (P3396 and 100 kg N ha⁻¹). It was found that yield reduction at low N stress is largely due to increased kernel abortion and formation of fewer kernels per ear (Below, 2002). It appears that N metabolism in kernels has a direct effect on kernel development and productivity since the provision of N to developing maize kernels can increase their capacity to synthesize protein and to utilize sugars for the biosynthesis of starch (Singletary and Below 1990). Modern cultivars usually achieve higher yields than the old cultivars not only at high N but also under low N supply. Modern cultivars are, therefore, more N efficient because the physiological traits related to yield formation and resistance are comprehensively improved in modern cultivars. However, this does not mean that the physiological and morphological traits in a modern high yielding cultivar have been optimized for adaptation to low N conditions. These cultivars still show large variations in yield formation in low N stress conditions, indicating the possibility that NUE can be further improved by plant breeding endeavors.

3.2.3.3.11 Thousand seed weight (g)

Thousand seed weight (TSW) had significantly differed by the hybrid maize varieties, nitrogen levels and interaction between hybrid maize varieties, nitrogen levels are presented in Table 3.2.24.

Effect of hybrid variety on thousand seed weight (g)

Results revealed that among the maize hybrids, P3396 had the maximum TSW (357.22 g) which was statistically identical with hybrid 981 and minimum TSW (343.44 g) was found form BHM 9. The trend of TSW was in order of P3396 > 981 > BHM 9 (Table 3.2.24). This result agrees with the findings of Ahmad *et al.*, (2018) they reported that the effect of cultivars on thousand grain weight was significant. Highest thousand grain weight was observed in Jalal variety as compared to Azam variety.

Effect of nitrogen on thousand seed weight (g)

It was found that the maximum TSW (389.67 g) from N_3 treatment (300 kg N ha⁻¹) which was significantly differed from other treatments. Minimum TSW (279.56 g) was found with N_1 treatment (100 kg N ha⁻¹). The tendency of TSW was in order of $N_3 > N_2 > N_1$ (Table 3.2.24). The results are in agreement with those Muhammad *et al.*, (2009) and Ahmad *et al.*, (2018) they found that N when applied at the rate of 180 kg ha⁻¹ significantly increases the thousand grain weight.

Interaction effect of variety and nitrogen on thousand seed weight (g)

Maximum TSW (415.33 g) was recorded by the interaction of V_3N_3 (P3396 and 300 kg N ha⁻¹) which was statistically identical with V_2N_3 (BHM 9 and 300 kg N ha⁻¹) and V_1N_3 (hybrid 981 and 300 kg N ha⁻¹). Minimum TSW (273.67) was obtained from V_1N_1 (hybrid 981 and 100 kg N ha⁻¹). This result agrees with the findings of Ahmad *et al.*, (2018) they reported that thousand grain weights were significantly affected by cultivars and nitrogen levels. The interaction between cultivars and nitrogen levels was significant. Maximum thousand grain weights (264.96 g) with application of 180 kg N ha⁻¹, followed by 150 kg N ha⁻¹ (257.18 g)

3.2.3.3.12 Grain yield (t ha⁻¹)

Grain yield (GY) had significantly differed by the hybrid maize varieties, nitrogen levels and interaction between hybrid maize varieties, nitrogen levels are presented in Table 3.2.24.

Effect of hybrid variety on grain yield (t ha⁻¹)

Results revealed that among the maize hybrids maize, 981 had the maximum grain yield (13.80 t ha⁻¹) which was statistically identical with hybrid P3396 and minimum grain yield (12.47 t ha⁻¹) was found from BHM9. The trend of grain yield was in order of 981 > P3396 > BHM 9 (Table 3.2.24). These differences may be due to the genetic differences between the three maize hybrids. Also, the differences in 1000-kernel weight might be attributed to the variation in translocation rate of photosynthetic from leaves to the storing organs, i.e. the kernels. This result agrees with the findings of Hosary *et al.*, (2019) they reported that the superiority of S.C. 30K8 maize hybrid in grain yield/fed over the other maize hybrids might be due to the increase in yield components, namely, No. of plants carried two ears/fed, No. of ears/fed, No. of rows/ear, No. of kernels/row, No. of kernels/ear, grain yield/plant and harvest index.

Effect of nitrogen on grain yield (t ha⁻¹)

It was found that the maximum grain yield (13.84 t ha⁻¹) from N₃ treatment (300 kg N ha⁻¹) which was significantly differed from other treatments. Minimum grain yield (9.76 t ha⁻¹) was found with N₁ treatment (100 kg N ha⁻¹). The tendency of grain yield was in order of N₃ > N₂ > N₁ (Table 3.2.24). Nitrogen levels significantly increase the grain yield. Yield varying between 4744.8 kg ha⁻¹ in no nitrogen application and 7355.5 kg N ha⁻¹ with application of 225 kg N/ha have been reported by Ali and Raouf (2012). A similar trend in yield differences across nitrogen rates have been reported by Zeidan *et al.* (2006) and Lawrence *et al.* (2008). Bundy and Carter (1988) and Sanjeev and Bangarwa (1997) reported that grain yield increased with increasing nitrogen rate. Hammad *et al.* (2011) concluded that yield components, Nitrogen use efficiency –Agronomic efficiency and economic yield of maize crop increased with the application of N up to 250 kg ha⁻¹ and there was no further significant increase in economic yield beyond this level. In contrast the biological yield increased up to 300 kg N ha⁻¹. Application of various N levels also significantly influenced seed protein content and it was increased up to 300 kg N ha⁻¹ application without application of N, grain yield and quality was extremely decreased.

Interaction effect of variety and nitrogen on grain yield (t ha⁻¹)

Maximum grain yield (14.45 t ha⁻¹) was recorded by the interaction of V₃N₃ (P3396 and 300 kg N ha⁻¹) which was statistically identical with V₂N₃ (BHM 9 and 300 kg N ha⁻¹) which was identical with V₁N₃ (hybrid 981 and 300 kg N ha⁻¹) and V₃N₃ (P3396 and 200 kg N ha⁻¹). It may be due to maximum DFT (97.67); DFS (101.67); NPPM (16.00); NCPM (20.00); CL (23.00 cm); NRPC (18.67); NSPC (41.67); NSPC (754.33); TSW (415.33 g) was recorded by the interaction of V₃N₃ (P3396 and 300 kg N ha⁻¹) but Minimum grain yield (7.95 t ha⁻¹) was obtained from V₁N₁ (hybrid 981 and 100 kg N ha⁻¹) it may be due to leaf senescence as a result the LA become low. This result agrees with the findings of Hosary *et al.*, (2019) they reported that almost traits of maize under study, were significantly increased by increasing nitrogen fertilizer rates in the both seasons, application of 150 kg N/fed significantly gave the maximum values of studied traits except, No. of days to 50 % tasseling and tasseling as well as No. of barren plants/fed which were significantly decreased with increasing nitrogen rates in the both seasons. White single cross (S.C.) hybrids of maize were significantly differed in all maize traits

under study in the both seasons. S.C. 30K8 was significantly surpassed S.C. 7071 and S.C. 2031 in mean values of No. of plants carried two ears/fed, No. of ears/fed, No. of rows/ear, No. of kernels/row, No. of kernels/ear, grain yield/fed, grain yield/plant and harvest index as well as gave the lowest mean values of No. of barren plants/fed and the shortest period from planting to 50 % tasseling or silking in the both seasons. Moreover, S.C. 2031 surpassed the other two maize hybrids in mean values of leaf area/plant, ear weight, 100-kernel weight, ear yield/fed, biological yield/fed, kernels nitrogen content, kernels crude protein content, kernels nitrogen uptake/fed and protein yield/fed in the two seasons. Meanwhile, S.C. 7071 recorded the highest mean values of No. of green leaves/plant, plant height, ear height, shelling % and stover yield/fed in the two seasons.

Maize yield increases with increase in plant density and N rate (Gaurkar and Bharad, 1998). Increase in biological yield for maize under various N rates has been reported by other researchers (Cox *et al.*, 1993). In a study by Hammad *et al.* (2011), biological yield increased by application of N up to 300 kg/ ha. These results are also supported by the findings of Khaliq *et al.* (2009) who achieved 17.61 t/ha mean biological yields with the application of different N rates. Nitrogen levels significantly increase the maize grain yield. Yield varying between 4744.8 kg ha⁻¹ in no nitrogen application and 7355.5 kg N ha⁻¹ with application of 225 kg N/ha have been reported by Ali and Raouf (2012). A similar trend in yield differences across nitrogen rates have been reported by Zeidan *et al.* (2006) and Lawrence *et al.* (2008). Bundy and Carter (1988) and Sanjeev and Bangarwa (1997) reported that grain yield increased with increasing nitrogen rate.

These results are also in agreement with those obtained by Sallah *et al.*, 2009; Szulc *et al.*, 2009; Bamuaafa *et al.*, 2010; Hokmalipour and Darbandi 2011; Dawadi and Sah 2012; Karasu 2012; Li *et al.*, 2012; Kandil 2013; Radma and Dagash 2013; Adeniyani 2014; Ahmadu 2014; Delibaltova 2014; Khan *et al.*, 2014; Rehman *et al.*, 2014; Hafez and Abdelaal 2015; Majid *et al.*, 2017; Marković *et al.*, 2017 and Ahmad *et al.*, 2018 they found that growth, yield components, yield and chemical properties of maize were significantly affected by the interaction between nitrogen fertilizer rates and maize hybrids.

3.2.3.4 Correlation matrix of different traits of hybrid maize

3.2.3.4.1 Genotypic (r_g) and phenotypic (r_p) correlation matrix among the morpho-physiological trait of hybrid maize

The phenotypic and genotypic correlation matrix among the morpho-physiological traits of different DAS combined are presented in Table 25 & Table 26. Genotypic correlation coefficients were higher than their corresponding phenotypic correlation in most of the cases which indicated that the association was largely due to genetic factors.

Highly significant positive genotypic and phenotypic correlation was observed for plant height with LAI ($r_g = 0.79$, $r_p = 0.75$), NDVI ($r_g = 0.56$, $r_p = 0.50$), CC ($r_g = 0.64$, $r_p = 0.60$), SPAD ($r_g = 0.64$, $r_p = 0.57$), Chl a ($r_g = 0.30$, $r_p = -0.21$), Chl b ($r_g = 0.04^{ns}$, $r_p = 0.03^{ns}$), LNC ($r_g = 0.42$, $r_p = 0.38$), and TDM ($r_g = 0.91$, $r_p = 0.89$) (Table 3.2.25 and Table 3.2.26). These results indicated that LAI, NDVI, CC, LNC and TDM would be increased with increasing of plant height

Leaf area index (LAI) had positive and significant correlation with NDVI ($r_g = 0.88$, $r_p = 0.81$), CC ($r_g = 0.96$, $r_p = 0.94$), SPAD ($r_g = 0.96$, $r_p = 0.91$), Chl a ($r_g = 0.34$, $r_p = 0.19$), Chl b ($r_g = 0.66$, $r_p = 0.18$), Car ($r_g = 0.29$, $r_p = 0.20$), LNC ($r_g = 0.75$, $r_p = 0.71$), and TDM ($r_g = 0.70$, $r_p = 0.69$) (Table 3.2.25 and Table 3.2.26).

Significant positive genotypic and phenotypic correlation was observed for NDVI with CC ($r_g = 0.93$, $r_p = 0.88$), SPAD ($r_g = 0.91$, $r_p = 0.84$), Chl a ($r_g = 0.28$, $r_p = 0.18$), Chl b ($r_g = 0.70$, $r_p = 0.15$), Car ($r_g = 0.29$, $r_p = 0.19$), LNC ($r_g = 0.80$, $r_p = 0.70$), and TDM ($r_g = 0.51$, $r_p = 0.49$) (Table 3.2.25 and Table 3.2.26). The assorted results might be indicating the plausible involvement of microclimatic factors.

Significant positive genotypic and phenotypic correlation was observed for CC with SPAD ($r_g = 0.97$, $r_p = 0.94$), Chl a ($r_g = 0.18$, $r_p = 0.15$), Chl b ($r_g = 0.84$, $r_p = 0.18$), Car ($r_g = 0.38$, $r_p = 0.30$), LNC ($r_g = 0.83$, $r_p = 0.78$), and TDM ($r_g = 0.55$, $r_p = 0.54$) (Table 3.2.25 and Table 3.2.26). The results showed that the genotypic correlation value was higher than the phenotypic correlation of CC which is indicated that CC is highly influenced by environment.

Table 3.2.25. Genotypic (r_g) correlation matrix of morpho-physiological trait of hybrid maize

	PH	LAI	NDVI	CC	SPAD	Chla	Chlb	Car	LNC	TDM
PH	1									
LAI	0.79**	1								
NDVI	0.56**	0.88**	1							
CC	0.64**	0.96**	0.93**	1						
SPAD	0.64**	0.96**	0.91**	0.97**	1					
Chla	0.30**	0.34**	0.28**	0.18*	0.35**	1				
Chlb	0.04 ^{NS}	0.66**	0.70**	0.84**	0.85**	0.50**	1			
Car	0.08 ^{NS}	0.29**	0.29**	0.38**	0.31**	0.61**	0.65**	1		
LNC	0.42**	0.75**	0.80**	0.83**	0.77**	0.35*	0.53**	0.54**	1	
TDM	0.91**	0.70**	0.51**	0.55**	0.54**	0.50**	0.35**	-0.14 ^{NS}	0.63**	1

NS: Non-Significant at 5%, *: Significant at 5%, **: Highly Significant at 1%

PH = Plant height (cm), LAI= Leaf Area Index, NDVI= Normalized Difference Vegetative Index, CC= Canopy Cover, SPAD= Soil Plant Analysis Development, LNC= Leaf Nitrogen Content (ppm), Chl a= Chlorophyll a content (mg g⁻¹), Chl b= Chlorophyll b content (mg g⁻¹), Car= Carotenoid Content (mg g⁻¹), TDM= Total Dry Matter (gm⁻²)

Table 3.2.26. Phenotypic (r_p) correlation matrix of morpho-physiological trait of hybrid maize

	PH	LAI	NDVI	CC	SPAD	Chla	Chlb	Car	LNC	TDM
PH	1									
LAI	0.75**	1								
NDVI	0.50**	0.81**	1							
CC	0.60**	0.94**	0.88**	1						
SPAD	0.57**	0.91**	0.84**	0.94**	1					
Chla	-0.21**	0.19*	0.18*	0.15*	0.16*	1				
Chlb	0.03 ^{NS}	0.18*	0.15*	0.18*	0.18*	0.35**	1			
Car	0.05 ^{NS}	0.20**	0.19*	0.27**	0.30**	0.32**	0.15*	1		
LNC	0.38**	0.71**	0.70**	0.78**	0.76**	0.20*	0.19*	0.43**	1	
TDM	0.89**	0.69**	0.49**	0.54**	0.53**	0.39**	0.14 ^{NS}	-0.01 ^{NS}	0.33**	1

NS: Non-Significant at 5%, *: Significant at 5%, **: Highly Significant at 1%

PH = Plant height (cm), LAI= Leaf Area Index, NDVI= Normalized Difference Vegetative Index, CC= Canopy Cover, SPAD= Soil Plant Analysis Development, LNC= Leaf Nitrogen Content (ppm), Chl a= Chlorophyll a content (mg g⁻¹), Chl b= Chlorophyll b content (mg g⁻¹), Car= Carotenoid Content (mg g⁻¹), TDM= Total Dry Matter (gm⁻²)

SPAD value had positive and significant correlation with Chl a ($r_g=0.35$, $r_p=0.16$), Chl b ($r_g=0.85$, $r_p=0.18$), Car ($r_g=0.31$, $r_p=0.30$), LNC ($r_g=0.77$, $r_p=0.76$) and TDM ($r_g=0.54$, $r_p=0.53$) (Table 3.2.25 and Table 3.2.26). This result suggested that increase in the SPAD value increases the LNC and TDM of hybrid maize. Parvizi *et al.* (2004) observed that the SPAD meter reading correlated well ($r=0.92^*$) with dry matter yield in hybrid maize. In general, such relationship become stronger at the reproductive phase of crops. Ramesh *et al.* (2002) observed highly significant correlations of SPAD readings with the grain yield of direct wet seeded rice at 79 DAS. Many studies using the SPAD to assess N status have shown reliable indication of N stress and relationship to relative yield (Earl and Tollenaar, 1997; Fox *et al.*, 2001). SPAD reading was found closely related to grain yield reported by Blackmer and Schepers, (1995); Maiti *et al.*, (2004); Boggs *et al.*, (2003).

Chl a had positive and significant correlation with Chl b ($r_g=0.50$, $r_p=0.35$), Car ($r_g=0.61$, $r_p=-0.32$), LNC ($r_g=0.35$, $r_p=0.20$) and TDM ($r_g=0.50$, $r_p=0.39$). Chl b also had positive and significant correlation with Car ($r_g=0.65$, $r_p=0.15$), LNC ($r_g=0.53$, $r_p=0.19$) and TDM ($r_g=0.35$, $r_p=0.14^{ns}$).

Highly significant positive genotypic and phenotypic correlation was observed for LNC with Car ($r_g=0.54$, $r_p=0.43$) and TDM ($r_g=0.63$, $r_p=0.33$) (Table 3.2.25 and Table 3.2.26). Spaner *et al.* (2005) and Shukla *et al.* (2004) have successfully used leaf chlorophyll concentrations estimated by SPAD meter for assessing the N status in hybrid maize.

Both genotypic and phenotypic correlation co-efficient analyses carried in this study suggested that plant height (PH), leaf area index (LAI), normalized difference vegetative index (NDVI), canopy cover (CC), soil plant analysis development (SPAD), leaf nitrogen content (LNC), chlorophyll a content (Chl a) are major components of total dry matter (TDM). The correlation coefficient analysis of hybrid maize varieties and nitrogen levels interaction indicated that the physiological traits NDVI, CC, SPAD and LNC were directly correlated with TDM at 75 DAS, which would be effective trait for improvement of dry matter accumulation as well as yield of hybrid maize.

3.2.3.5 Regression analysis of different morpho-physiological trait of hybrid maize with different nitrogen levels

The regression analysis of some morpho-physiological traits of hybrid maize at different nitrogen levels for combined both the year was carried out and the results is present in Figure 3.2.41-3.2.45 for 120 DAS.

3.2.3.5.1 Response of plant height against different nitrogen levels

The response of plant height against different nitrogen levels at 120 DAS were linear and positively significant for all the hybrid varieties. This showed that increasing different nitrogen level significantly increased plant height of different variety of hybrid maize (Figure 3.2.41). The linear models had an R^2 value of 0.97 for hybrid 981, 0.98 for BHM 9 and 0.99 for hybrid P3396 which indicating that higher doses of nitrogen provided taller plant. The linear equations were $y(981) = 17x + 120$, $y(BMH\ 9) = 26x + 170$ and $y(P3396) = 0.12x + 120$, respectively.

3.2.3.5.2 Response of Leaf Area index (LAI) against different nitrogen levels

Response on LAI of hybrid maize varieties at different doses of nitrogen presented in Figure 3.2.42. The relationship between LAI and different nitrogen levels were linear and positively significant for all the varieties. The linear models had an R^2 value of 0.96 for hybrid 981, 0.96 for BHM 9 and 0.98 for hybrid P3396, respectively which indicating that higher doses of nitrogen provided higher LAI. The linear equations were $y(981) = 0.0039x + 2.1$, $y(BMH\ 9) = 0.004x + 2$ and $y(P3396) = 0.0054x + 1.5$, respectively.

3.2.3.5.3 Response of NDVI against different nitrogen levels

Response on NDVI of hybrid maize varieties at different doses of nitrogen presented in Figure 3.2.43. The relationship between NDVI and different nitrogen levels were linear and positively significant for all the hybrid varieties. The linear models had an R^2 value of 0.93 for hybrid 981, 0.99 for BHM 9 and 0.95 for hybrid P3396, respectively which indicating that higher doses of nitrogen provided higher NDVI. The linear equations were $y(981) = 0.00023x + 0.83$, $y(BMH\ 9) = 0.00045x + 0.81$ and $y(P3396) = 0.00023x + 0.83$, respectively.

3.2.3.5.4 Response of Canopy Cover (CC) against different nitrogen levels

The response of CC against different nitrogen levels were linear and positively significant for all the varieties. This showed that increasing different nitrogen level significantly increased CC of different variety of hybrid maize (Figure 3.2.44). The linear models had an R^2 value of 0.99 for hybrid 981, 0.94 for BHM 9 and 0.95 for hybrid P3396, respectively which indicating that higher doses of nitrogen provided higher CC. The linear equations were y (981) = $0.00048x + 0.6$, y (BMH 9) = $0.00047x + 0.57$ and y (P3396) = $0.00035x + 0.6$, respectively.

3.2.3.5.5 Response of total dry matter (TDM) against different nitrogen levels

Response on TDM accumulation of hybrid maize varieties at different doses of nitrogen presented in Figure 3.2.45. The relationship between TDM and different nitrogen levels were linear and positively significant for all the varieties. The linear models had an R^2 value of 0.95 for hybrid 981, 0.99 for BHM 9 and 0.97 for hybrid P3396, respectively which indicating that higher doses of nitrogen provided higher TDM. The linear equations were y (981) = $1.3x + 1300$, y (BMH 9) = $1.6x + 1200$ and y (P3396) = $1.6x + 1200$, respectively.

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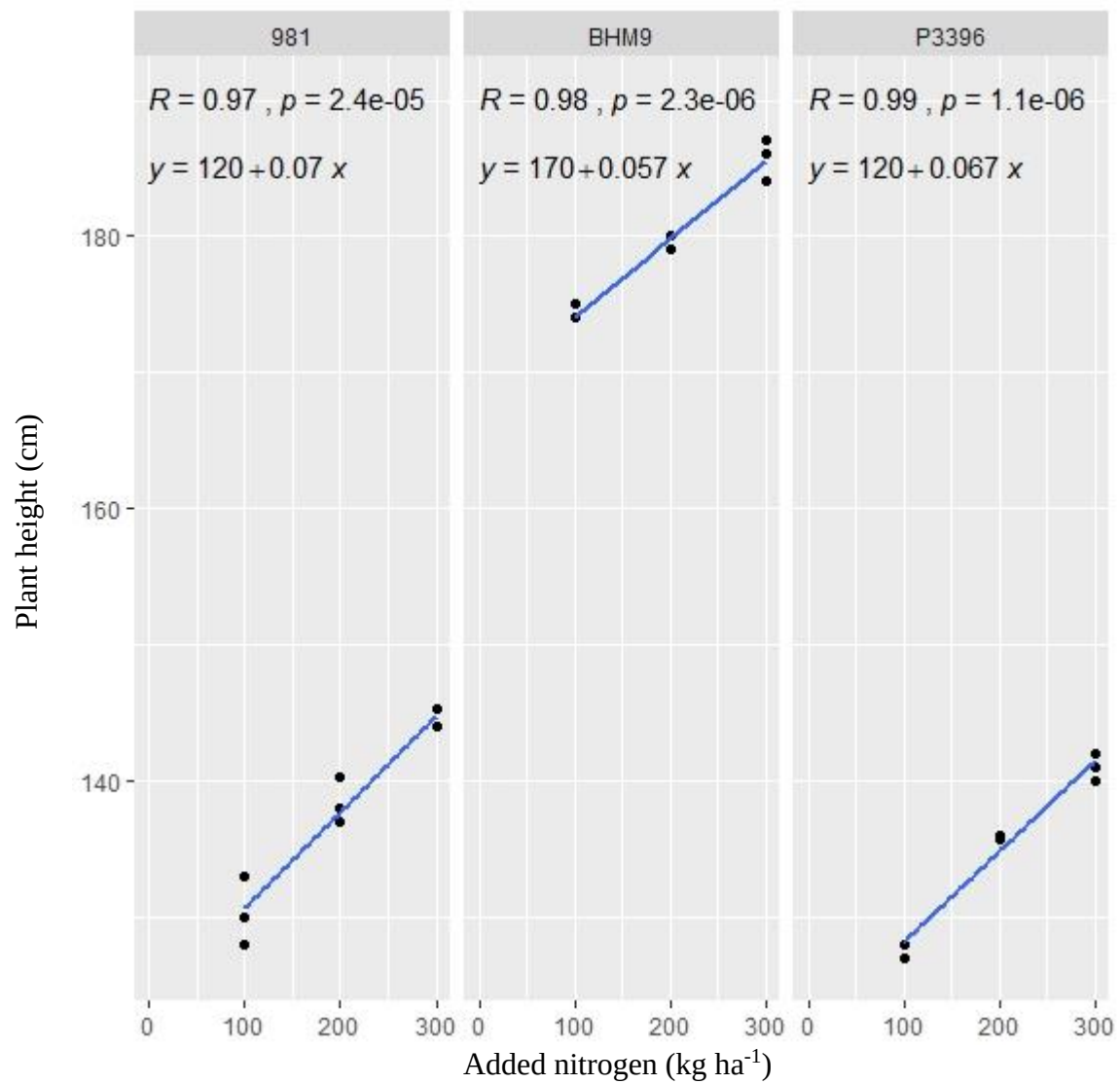


Figure 3.2.41: Response on plant height (PH) of hybrid maize varieties at different doses of nitrogen.

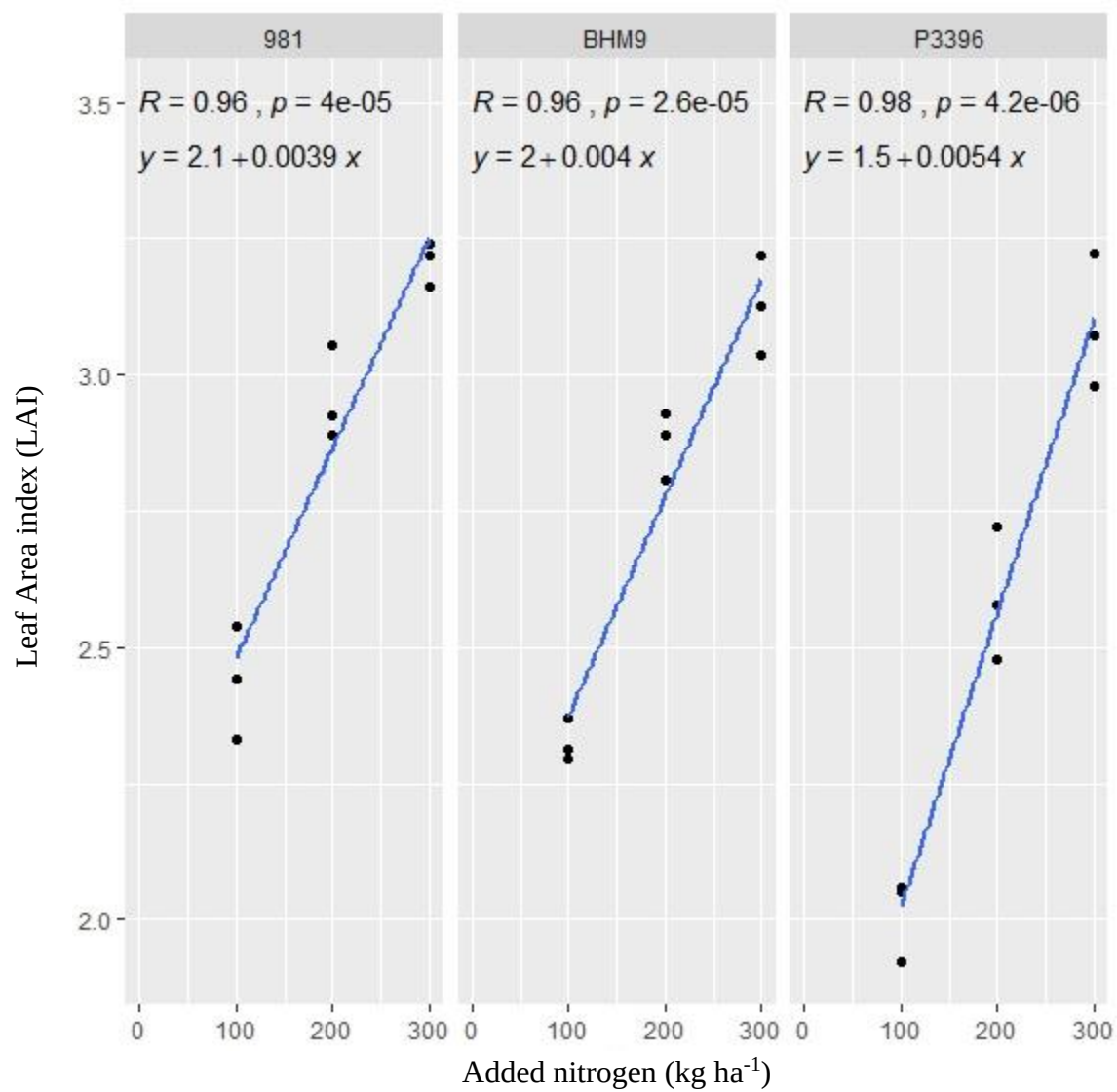


Figure 3.2.42: Response on Leaf Area index (LAI) of hybrid maize varieties at different doses of nitrogen.

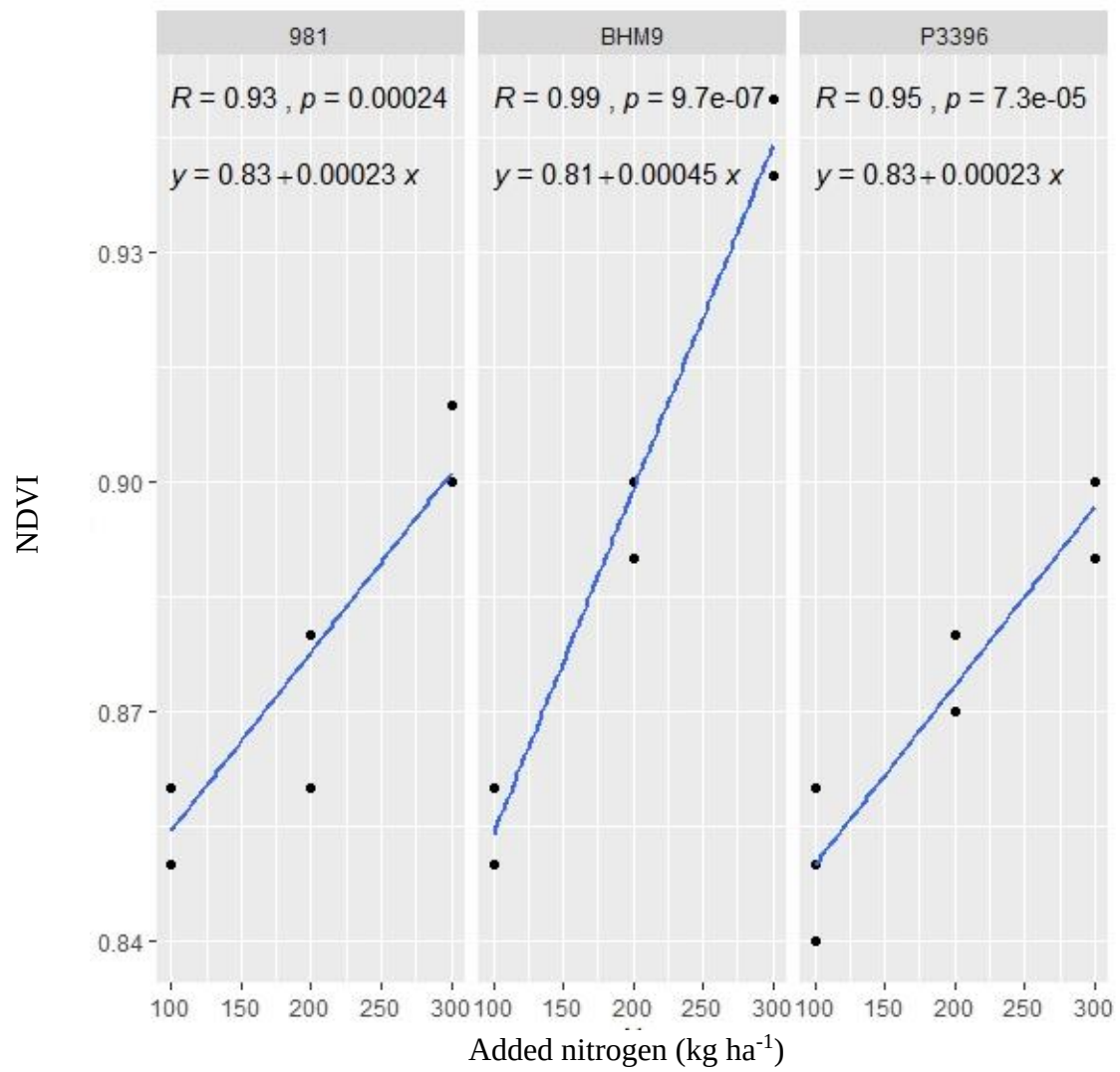


Figure 3.2.43: Response on NDVI of hybrid maize varieties at different doses of nitrogen.

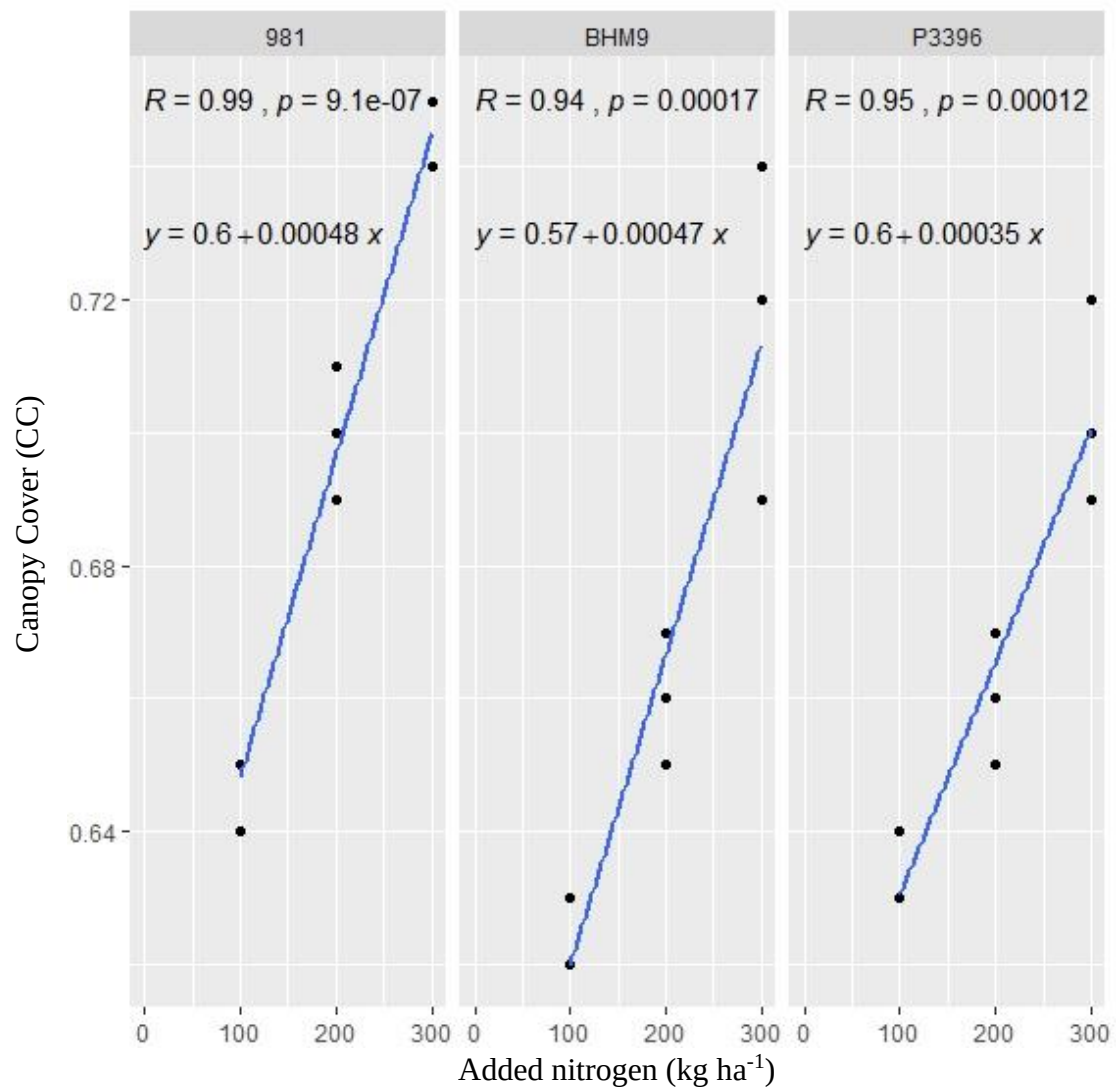


Figure 3.2.44: Response on Canopy Cover (CC) of hybrid maize varieties at different doses of nitrogen.

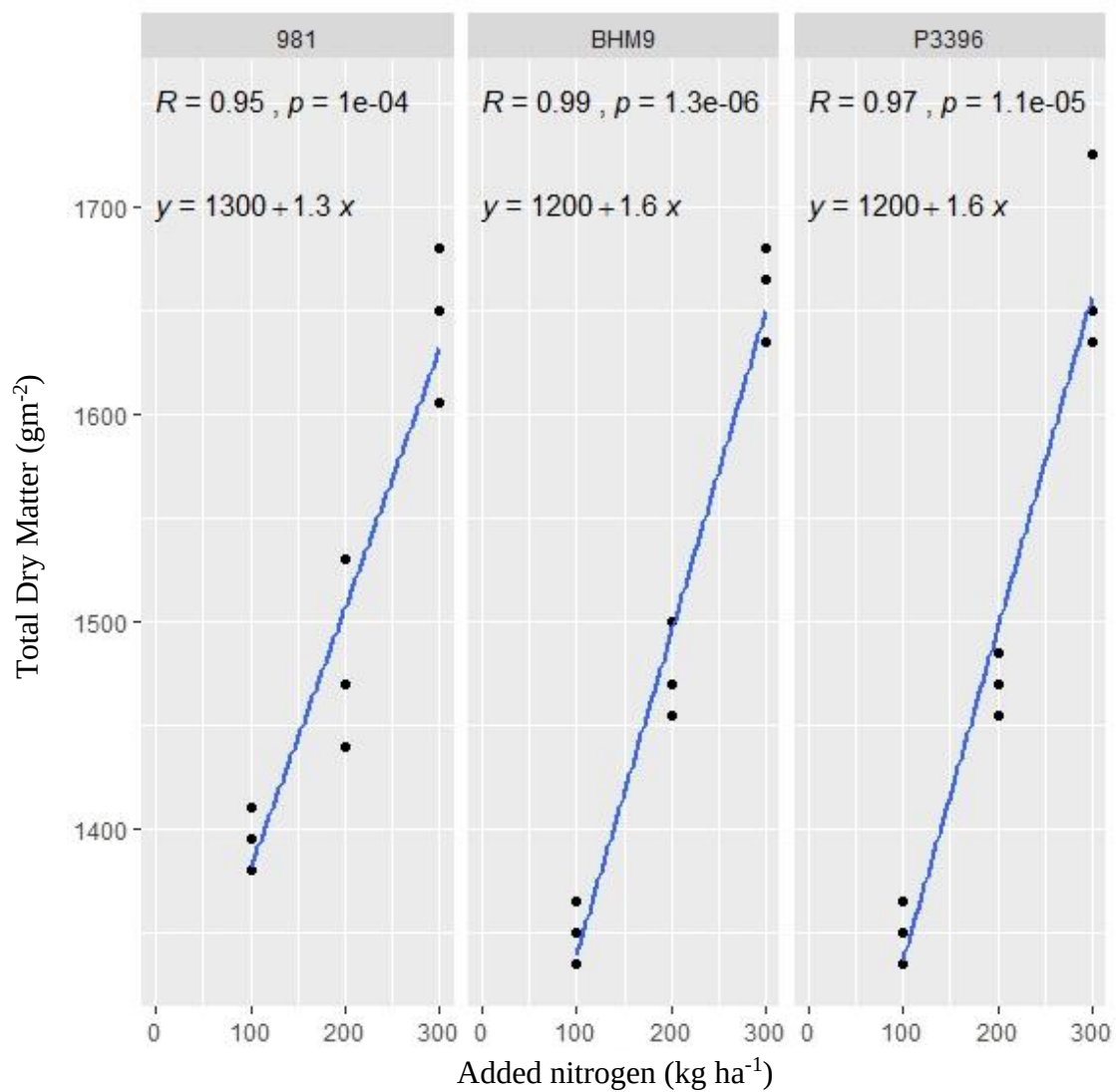


Figure 3.2.45: Response on Total Dry Matter (gm⁻²) of hybrid maize varieties at different doses of nitroge.

3.2.3.6 Relationship of different morpho-physiological trait of hybrid maize

Regression was used to further investigate the relationship between some morpho-physiological characters to total dry matter (TDM) accumulation of different hybrid maize varieties at 120 DAS presented in Figure 3.2.46-3.2.54.

3.2.3.6.1 Relationship between plant height and TDM accumulation

The relationship between plant height and TDM accumulation was linear and positively significant (Figure 3.2.46). The linear models had an R^2 value of 0.99 for hybrid 981, 0.94 for BHM 9 and 0.95 for hybrid P3396, respectively. The positive relationship indicated that TDM increased with the increasing of PH depression for each variety. The linear equations were y (981) = $0.0039x + 2.1$, y (BMH 9) = $0.004x + 2$ and y (P3396) = $0.0054x + 1.5$, respectively.

3.2.3.6.2 Relationship between LAI and TDM accumulation

The relationship between LAI and TDM accumulation was linear and positively significant (Figure 3.2.47). The linear models had an R^2 value of 0.90 for hybrid 981, 0.91 for BHM 9 and 0.97 for hybrid P3396, respectively. The positive relationship indicated that TDM increased with the increasing of LAI depression for each variety. The linear equations were y (981) = $300x + 650$, y (BMH 9) = $350x + 530$ and y (P3396) = $290x + 759$, respectively. The multiple R-squared value was found 0.90 and adjusted R-squared value was found 0.89. The R^2 values for over all varieties indicated that the 90% increase in average TDM.

3.2.3.6.3 Relationship between NDVI and TDM accumulation

The relationship between NDVI and TDM accumulation was linear and positively significant (Figure 3.2.48). The linear models had an R^2 value of 0.93 for hybrid 981, 0.98 for BHM 9 and 0.94 for hybrid P3396, respectively. The positive relationship indicated that TDM increased with the increasing of NDVI depression for each variety. The linear equations were y (981) = $4900x + 2800$, y (BMH 9) = $3400x + 1500$ and y (P3396) = $6300x + 4000$, respectively. The multiple R-squared value was found 0.81 and adjusted R-squared value was found 0.75. The R^2 values for over all varieties indicated that the 75% increase in average TDM.

3.2.3.6.4 Relationship between CC and TDM accumulation

The relationship between CC and TDM accumulation was linear and positively significant (Figure 3.2.49). The linear models had an R^2 value of 0.93 for hybrid 981, 0.95 for BHM 9 and 0.92 for hybrid P3396, respectively. The positive relationship indicated that TDM increased with the increasing of CC depression for each variety. The linear equations were $y(981) = 2500x + 240$, $y(BMH\ 9) = 3000x + 510$ and $y(P3396) = 4100x + 1200$, respectively. The multiple R-squared value was found 0.79 and adjusted R-squared value was found 0.73. The R^2 values for over all varieties indicated that the 72% increase in average TDM.

3.2.3.6.5 Relationship between SPAD and TDM accumulation

The relationship between SPAD and TDM accumulation was linear and positively significant (Figure 3.2.50). The linear models had an R^2 value of 0.96 for hybrid 981, 0.99 for BHM 9 and 0.96 for hybrid P3396, respectively. The positive relationship indicated that TDM increased with the increasing of SPAD depression for each variety. The linear equations were $y(981) = 17x + 460$, $y(BMH\ 9) = 17x + 490$ and $y(P3396) = 23x + 63$, respectively. The multiple R-squared value was found 0.75 and adjusted R-squared value was found 0.70. The R^2 values for over all varieties indicated that the 70% increase in average TDM.

3.2.3.6.6 Relationship between LNC (ppm) and TDM accumulation

The relationship between LNC and TDM accumulation was linear and positively significant (Figure 3.2.51). The linear models had an R^2 value of 0.93 for hybrid 981, 0.92 for BHM 9 and 0.90 for hybrid P3396, respectively. The positive relationship indicated that TDM increased with the increasing of LNC depression for each variety. The linear equations were $y(981) = 1.2x - 360$, $y(BMH\ 9) = 1.6x - 1200$ and $y(P3396) = 2.3x - 1800$, respectively. The multiple R-squared value was found 0.74 and adjusted R-squared value was found 0.70. The R^2 values for over all varieties indicated that the 69% increase in average TDM.

3.2.3.6.7 Relationship between Chl a and TDM accumulation

The relationship between leaf Chl a and TDM accumulation was linear and positively significant (Figure 3.2.52). The linear models had an R^2 value of 0.96 for hybrid 981, 0.96 for BHM 9 and 0.98 for hybrid P3396, respectively. The positive relationship indicated that TDM increased with the increasing of Chl a depression for each variety. The linear equations were $y(981) = 810x + 900$, $y(BMH\ 9) = 890x + 770$ and $y(P3396) = 1200x + 600$, respectively. The multiple R-squared value was found 0.82 and adjusted R-squared value was found 0.80. The R^2 values for over all varieties indicated that the 79% increase in average TDM.

3.2.3.6.8 Relationship between leaf Chl b and TDM accumulation

The relationship between leaf Chl b and TDM accumulation was linear and positively insignificant (Figure 3.2.53). The linear models had an R^2 value of 0.93 for hybrid 981, 0.86 for BHM 9 and 0.92 for hybrid P3396, respectively. The positive relationship indicated that TDM increased with the increasing of Chl b depression for each variety. The linear equations were $y(981) = 1200x + 530$, $y(BMH\ 9) = 2800x - 690$ and $y(P3396) = 1300x + 430$, respectively. The multiple R-squared value was found 0.70 and adjusted R-squared value was found 0.64. The R^2 values for over all varieties indicated that the 62% increase in average TDM.

3.2.3.6.9 Relationship between Car and TDM accumulation

The relationship between leaf Car and TDM accumulation was linear and positively significant (Figure 3.2.54). The linear models had an R^2 value of 0.90 for hybrid 981, 0.96 for BHM 9 and 0.86 for hybrid P3396, respectively. The positive relationship indicated that TDM increased with the increasing of Car depression for each variety. The linear equations were $y(981) = 3100x + 390$, $y(BMH\ 9) = 2700x + 480$ and $y(P3396) = 5400x + 450$, respectively. The multiple R-squared value was found 0.86 and adjusted R-squared value was found 0.80. The R^2 values for over all varieties indicated that the 81% increase in average TDM.

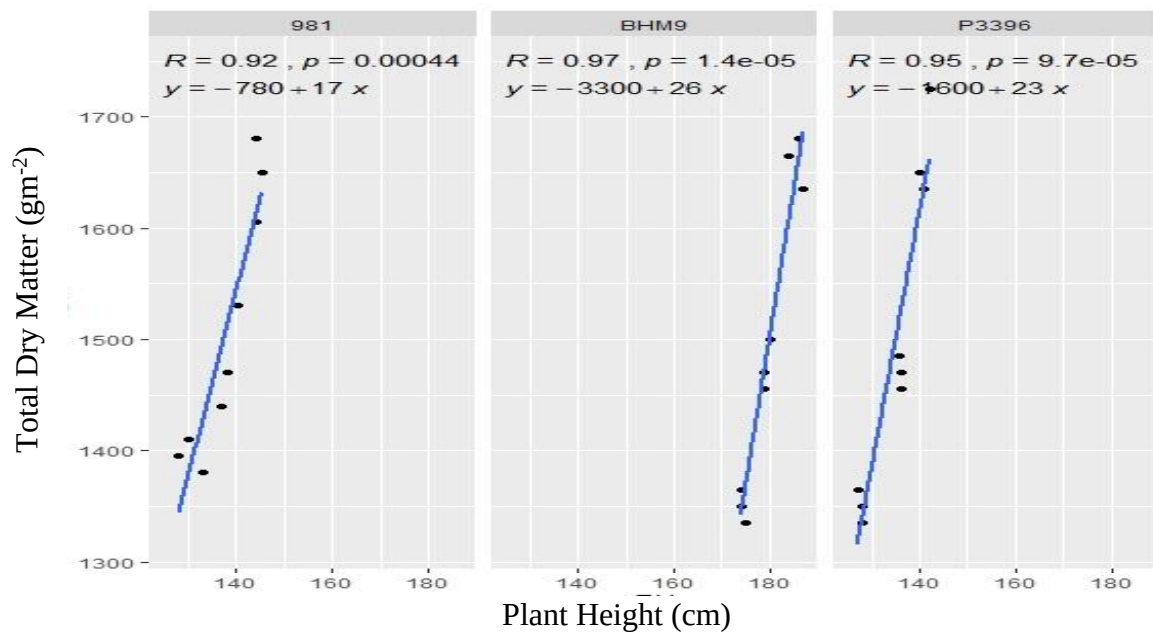


Figure 3.2.46: Relationship between total dry matter (gm^{-2}) and plant height (cm) of hybrid maize varieties.

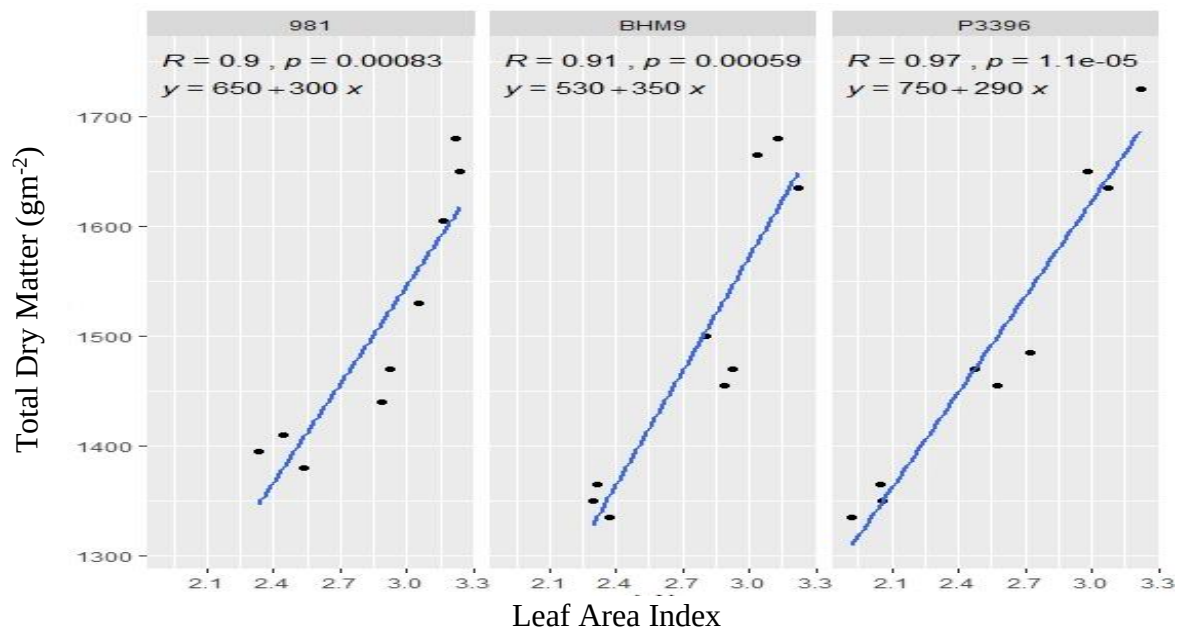


Figure 3.2.47: Relationship between total dry matter (gm^{-2}) and LAI of hybrid maize varieties.

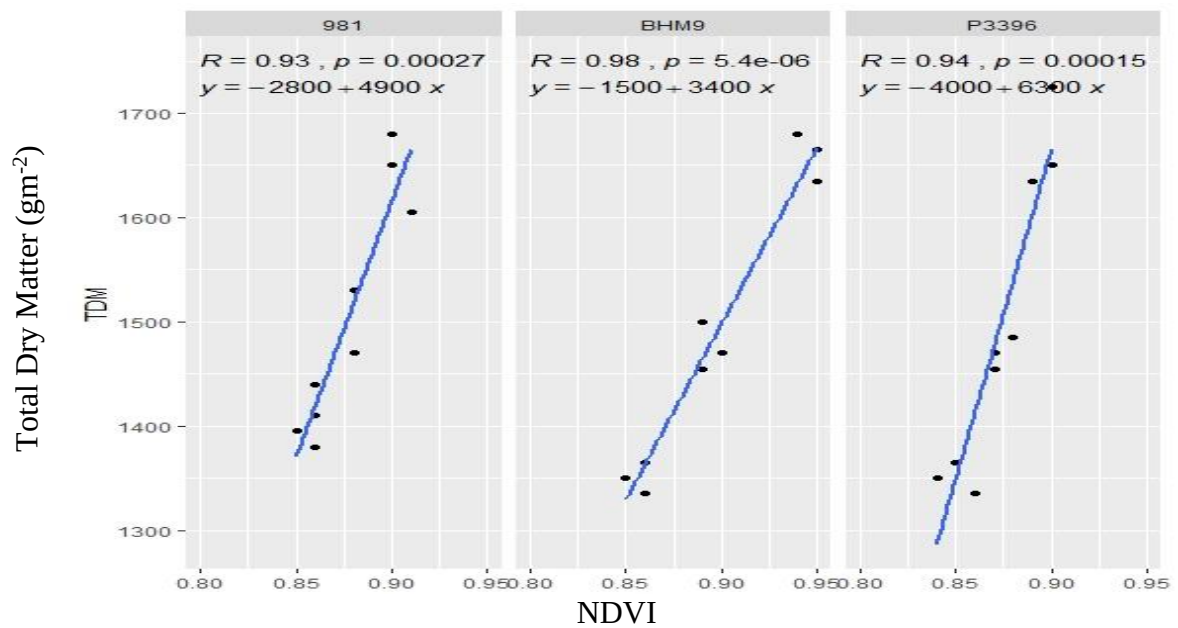


Figure 3.2.48: Relationship between total dry matter (gm⁻²) and NDVI of hybrid maize varieties .

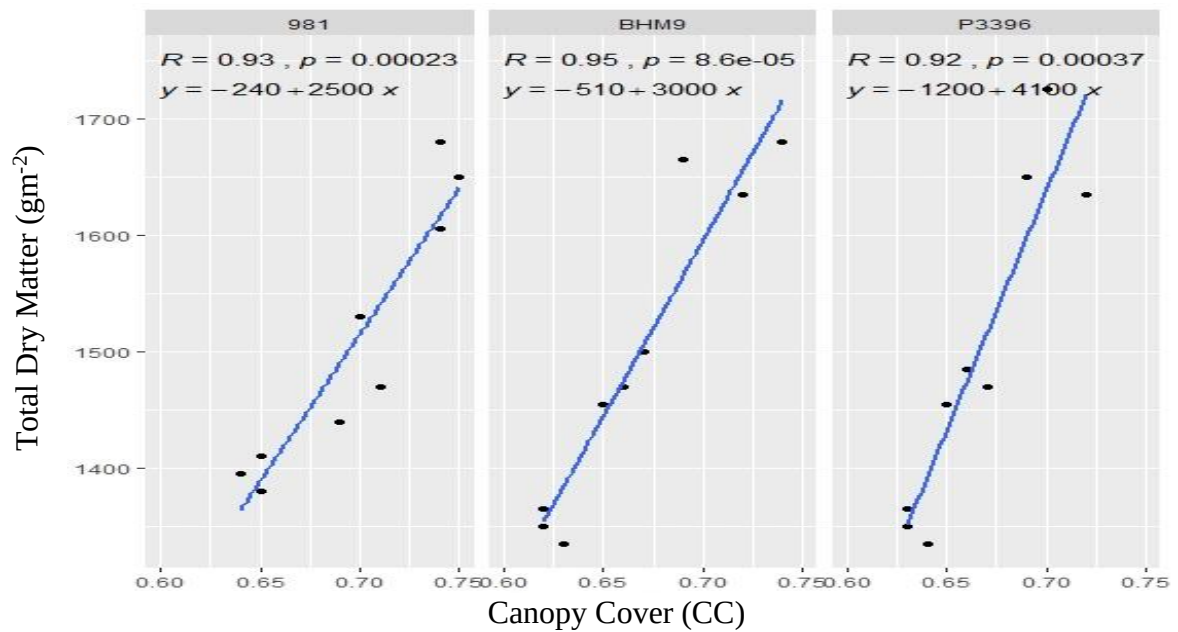


Figure 3.2.49: Relationship between total dry matter (gm⁻²) and CC of hybrid maize varieties.

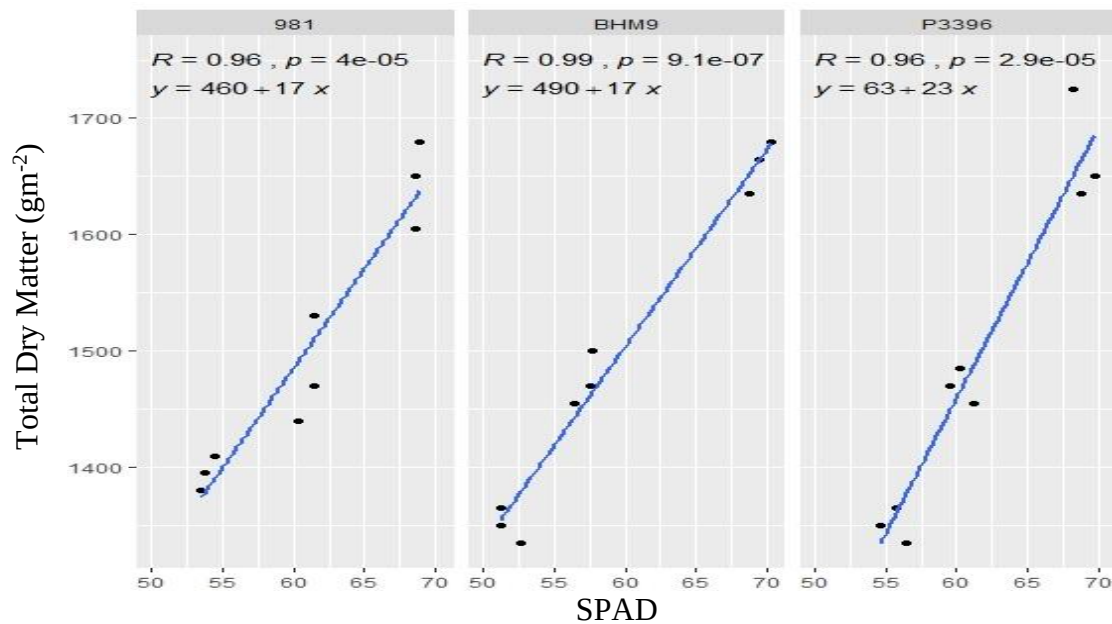


Figure 3.2.50: Relationship between total dry matter (gm⁻²) and SPAD of hybrid maize varieties .

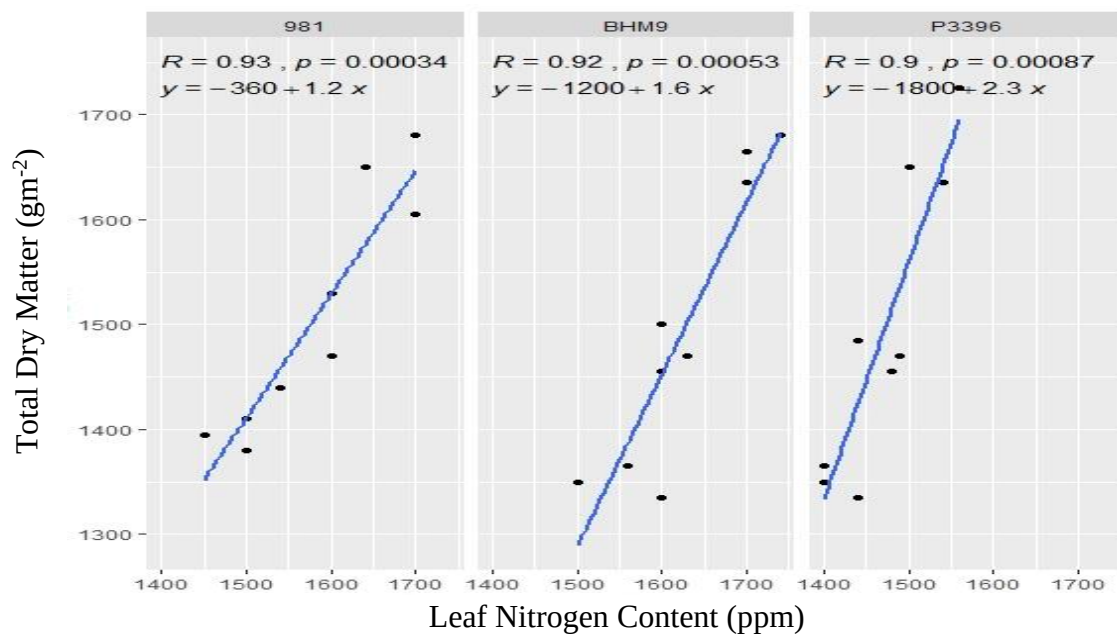


Figure 3.2.51: Relationship between total dry matter (gm⁻²) and NDVI of hybrid maize varieties .

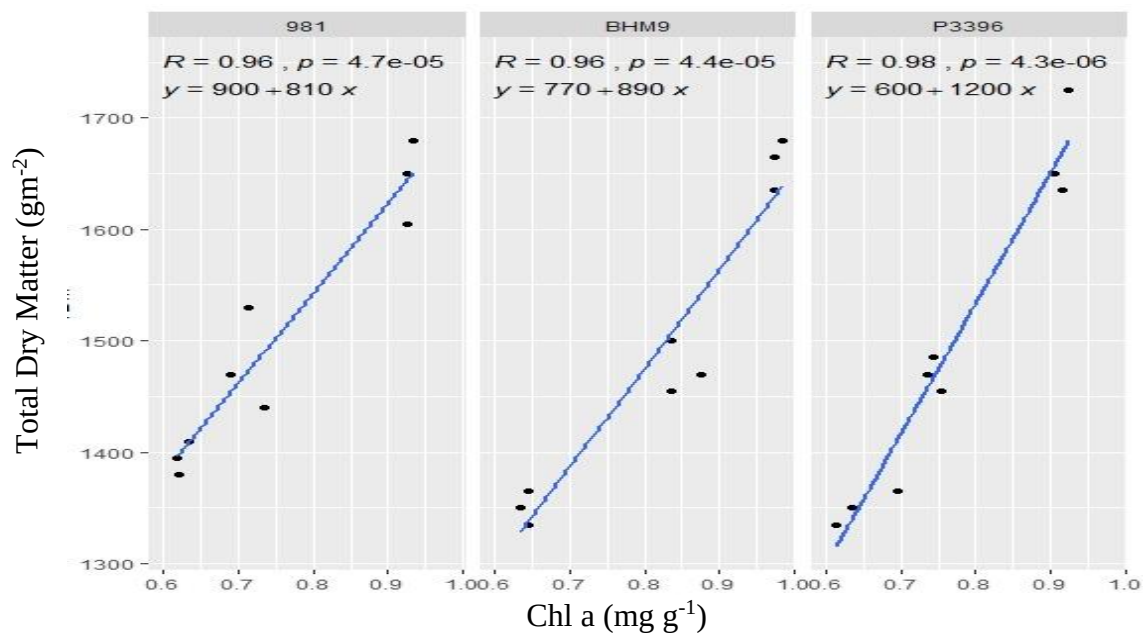


Figure 3.2.52: Relationship between total dry matter (gm⁻²) and Chl a of hybrid maize varieties.

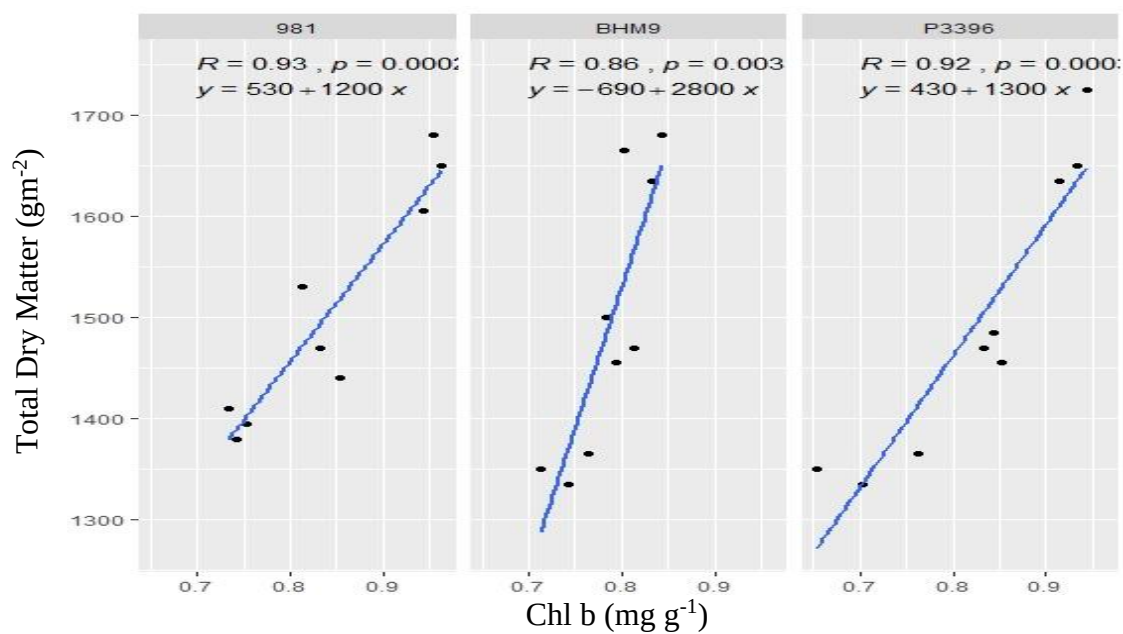


Figure 3.2.53: Relationship between total dry matter (gm⁻²) and Chl b of hybrid maize varieties.

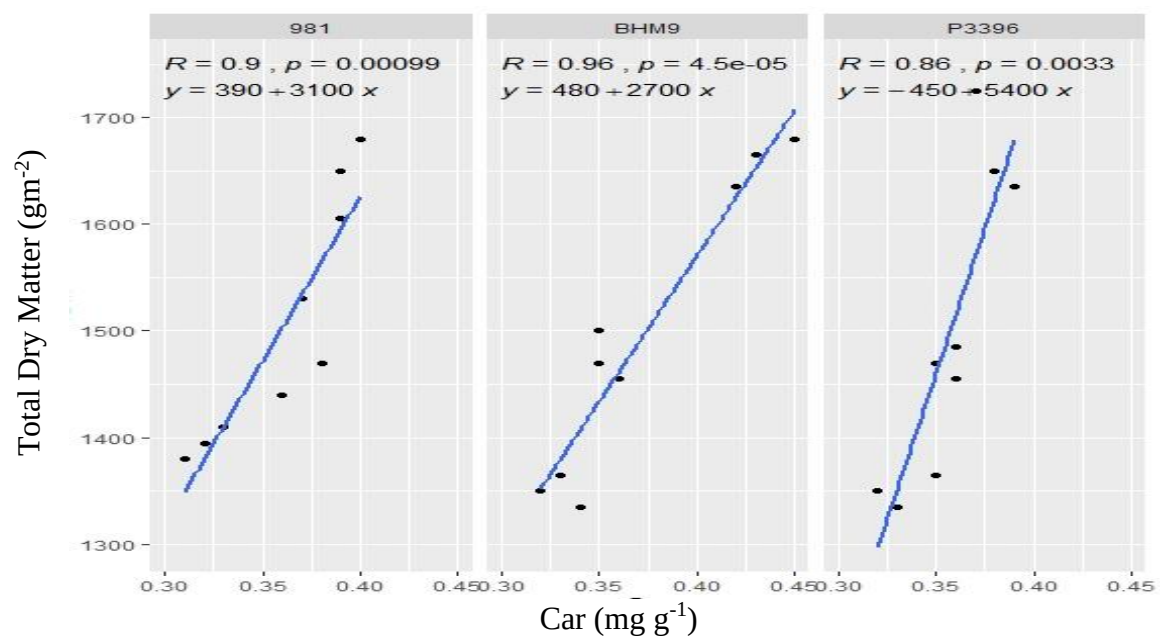


Figure 3.2.54: Relationship between total dry matter (gm⁻²) and Car of hybrid maize varieties.

3.2.3.7 Multivariate analysis of hybrid maize

3.2.3.7.1 Biplot analysis (Treatments $\times$ Traits)

Using all trait values, a $T \times T$ biplot was constructed from a two-way matrix of 15 traits (including morpho-physiological, yield & yield contributing and digitally extract trait) by 9 treatments in Figure 3.2.55. The plot condensed the information from this matrix into PCs, the first two of which comprised 85.06% of the total variation within the dataset. This comparatively high percentage reveals the complication of the relations among the treatments and the evaluated different traits. The treatments 9 and 8 that fall in the quadrant and coincided with as a $9=N_3 \times V_3$, and $8=N_3 \times V_3$ treatment scored significantly the highest values compared to other. As a treatment $8=N_2 \times V_3$, and $9=N_3 \times V_2$ for LNC scored the highest values (Figure 3.2.55).

The plot shows the relationship between traits. The cosine of the angle between vectors connecting traits to the origin is proportional to the correlation coefficient between those traits (Yan and Kang, 2003). Thus, traits on opposite sides of the origin are negatively correlated, traits near each other are positively correlated and traits at 90° to each other with respect to the origin are not correlated. The $T \times T$ biplot showed superior treatment with relatively greater expression of combinations of favorable traits.

Again, biplot analysis showed the trait profiles of the treatments, especially, those treatments positioned far away from the origin and the results indicated correlation between traits with treatments. Biplot revealed that treatment 9 and 8 was performed better for YTPH, Chl a, NCPM, SPAD LNC and NPPM (Figure 3.2.55). The results suggest that YTPH, Chl a, SPAD, LNC, TDM, LAI and yield could be used to identify superior treatment from this study.

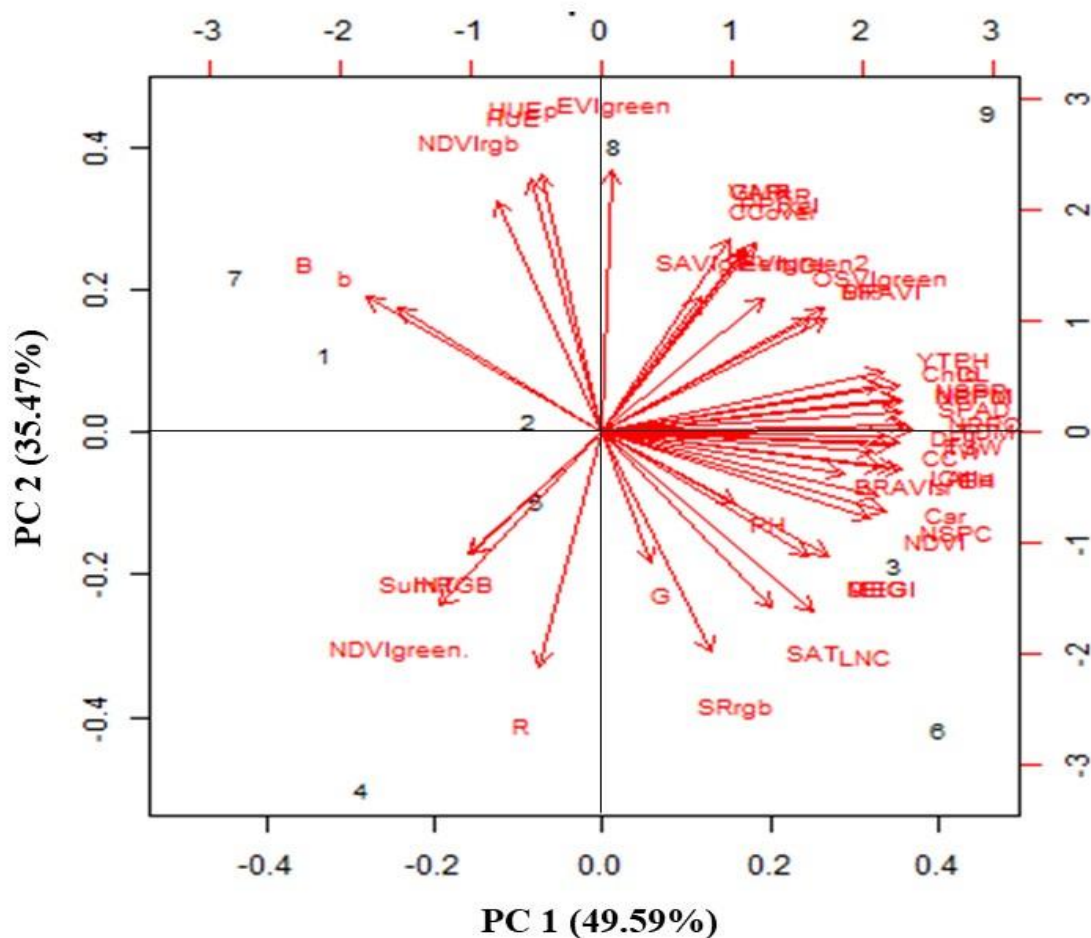


Figure 3.2.55: Ordination of treatment by trait biplots of principal component analysis output.

Treatments in black colour and traits in red colour. 1= $N_1 \times V_1$, 2= $N_2 \times V_1$, 3= $N_3 \times V_1$, 4= $N_1 \times V_2$, 5= $N_2 \times V_2$, 6= $N_3 \times V_2$, 7= $N_1 \times V_3$, 8= $N_2 \times V_3$, 9= $N_3 \times V_3$, (V_1 = 981, V_2 = BMH 9, and V_3 = P3396 and N_1 = 100 kg N ha⁻¹, N_2 = 200 kg N ha⁻¹, N_3 = 300 kg N ha⁻¹); PH = Plant height (cm), LAI= Leaf Area Index, NDVI= Normalized Difference Vegetative Index, CC= Canopy Cover, SPAD= Soil Plant Analysis Development, LNC= Leaf Nitrogen Content (ppm), Chl a= Chlorophyll a content (mg g⁻¹), Chl b= Chlorophyll b content (mg g⁻¹), Car= Carotenoid Content (mg g⁻¹), TDM= Total Dry Matter (gm⁻²),

3.2.3.7.2 Heatmap analysis

Heatmap explored the performances of the interaction between hybrid maize variety and nitrogen doses regarding their morpho-physiological, yield and yield contributing traits. It shows the highest and lowest values of each treatment in different colors against all the traits. The intensity of the color indicates the degree of high or low of the traits. Amber color indicates higher value while white color indicates lower value. Heat map displaying the relationship matrix among 9 treatments of hybrid maize varieties and nitrogen interaction. The amber diagonal represents a perfect relationship of each treatment with itself. The symmetric off-diagonal elements represent the relationship measures for pairs of treatments. The white of warmer colors on the diagonal show clusters of closely related treatments.

Hierarchical clustering based on the morpho-physiological, yield and yield contributing traits of the treatments (Interaction of variety and Nitrogen doses) studied revealed four clusters namely Cluster A, Cluster B, Cluster C, and Cluster D in Figure 3.2.3.56 all cluster accommodated two treatments but cluster B accommodated three treatments. It is clear that the treatments having similarity in their morpho-physiological, yield and yield contributing traits composition were grouped together (Figure 3.2.3.56). However, the heatmap also revealed the overall performance of each treatment regarding the observed traits.

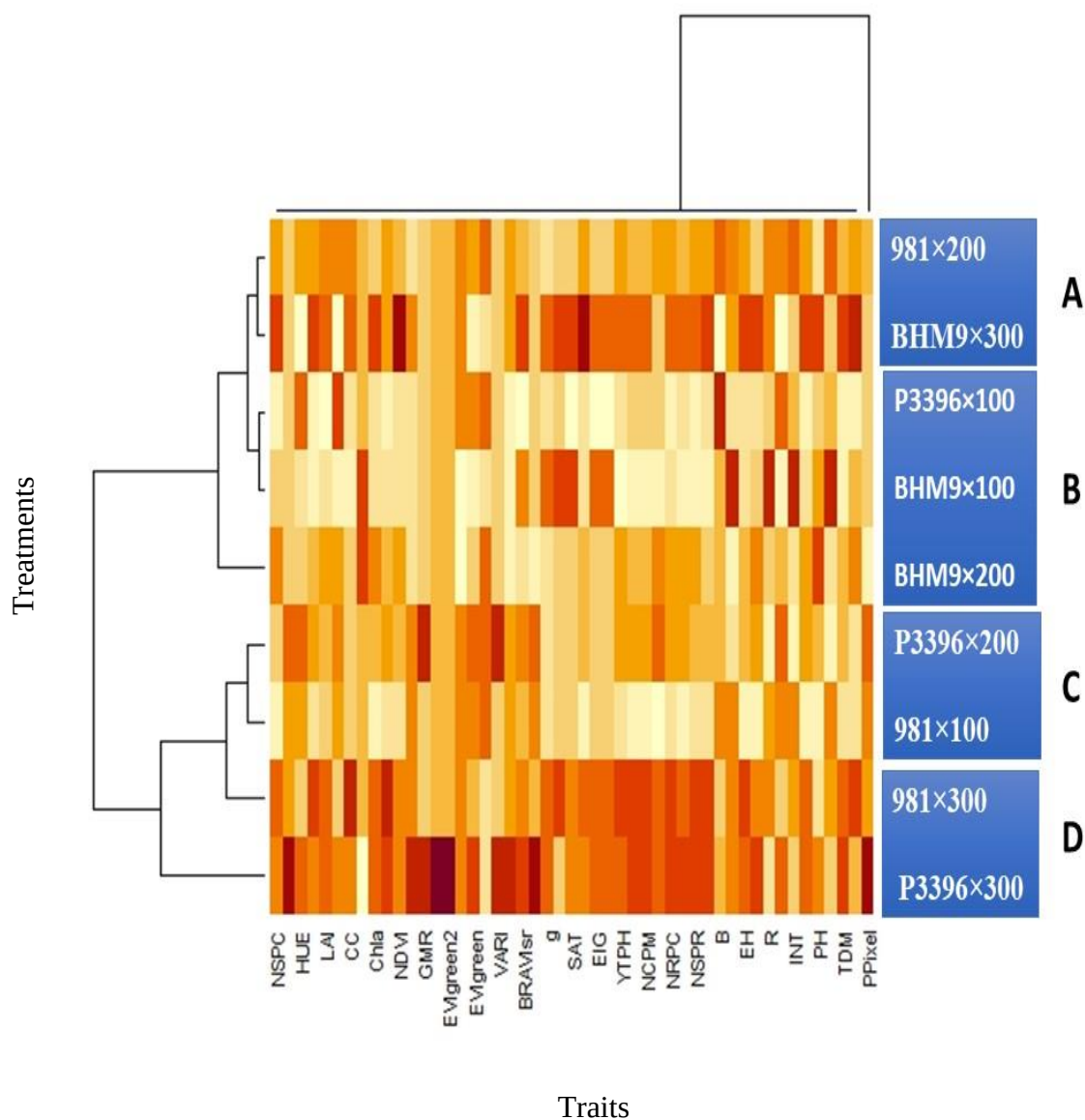


Figure 3.2.56: Heatmap showing the clustering pattern of 9 treatments of hybrid maize varieties and nitrogen interaction with 51 morpho-physiological traits.

Heat map displaying the relationship matrix among 9 treatments of hybrid maize varieties and nitrogen interaction. The amber diagonal represents a perfect relationship of each treatments with itself. The symmetric off-diagonal elements represent the relationship measures for pairs of treatments. The white of warmer colors on the diagonal show clusters of closely related treatments.

3.2.3.8 Image Processing and Modeling of hybrid maize

3.2.3.8.1 Image acquisition

Canon camera and Android mobile phone were utilized for image acquisition. Images were stored in the JPG format. Substantial effort was made develop a standard imaging protocol to ensure imaging consistency and quality. Tefash function was kept of and an umbrella was always used to shade the area under the camera view in order to minimize illumination discrepancies between images. A light/color calibration protocol was also followed. An image of a color calibration chart (X-Rite Color Checker Color Rendition Chart) was taken at the beginning of imaging operations, and every 20 min thereafter or whenever light condition changes (cloud cover, etc.). While taking pictures, the whole canopy was in the field of view of the camera. Weed control was practiced consistent with research plots and commercial farms; however, due to the small size of the field weed removal was done manually. Weeds in the view of camera were removed for enhanced efficiency of subsequent image processing. Images were taken across several days (at several times of the day) under various illumination conditions. Finally, the imaging protocol was chosen so that the imaging window and the camera resolution resulted in images with at least 6 pixels/mm, ensuring that the approach is transferable to other cameras that use an appropriate imaging window to get this resolution.

3.2.3.8.2 Image analysis

MCCBARI description

MCCBARI is automatic color threshold (ACT) image analysis software developed in the JAVA programming language using color values in the red, green, blue (RGB) system. MCCBARI analyzes and classifies all pixels in the image. The analysis is based on the selection of pixels according to ratios of R/G, B/G and the excess green index. The result of the analysis is a binary image where white pixels correspond to the pixels that satisfied the selection criteria (green canopy) and black pixels correspond to the pixels that did not meet the selection criteria (not green canopy). Fractional green canopy cover ranges from 0 (no green canopy cover) to 1 (100% green canopy cover). The classification of green canopy is based on the following criteria:

$$R/G < X1 \text{ and } B/G < X2 \text{ and } 2G-R-B > X3$$

where X1 and X2 are parameters that typically have a value near 1 to classify pixels that are predominantly in the green band (~500–570 nm), and X3 is a parameter that sets the minimum excess green index, which typically has a value around 20 to select green vegetation (Meyer and Neto, 2008; Richardson *et al.*, 2007). The default parameter values for MCCBARI are X1 = 0.89, X2 = 0.89, and X3 = 25.

The threshold value for the excess green index was set constant at a value of 20. The excess green index effectively classifies dark or gray pixels that cannot be adequately discriminated using the R/G and B/G ratios alone. MCCBARI also has the capability to reduce noise by removing isolated green pixels. Isolated pixels that meet the color ratio specifications can sometimes occur in other objects and are not exclusively part of green canopy. For instance, some isolated pixels in residue shadows may have R/G and B/G ratios similar to those found in green canopies. MCCBARI can remove these pixels or small clusters of pixels (e.g., small weeds in a row crop) by analyzing connected neighboring pixels. MCCBARI saves a text file which can be opened in spreadsheet (Microsoft Excel format). MCC_BARI saves the image file name, picture taken date and time, total plant pixel, plant pixel percentage values, intensity, saturation, CC value etc. The supported image formats are .jpeg (Joint Photographic Experts Group), .png (Portable Network Graphic).

Digital photo provides spectral information in the red, green, and blue wave lengths (Reiko and Hiroyuki 2010). RGB color component has 256 levels, numbered 0 to 255, and in total, 256, 3 colors can be represented, with black shown as 0, 0, 0 and white shown as 255, 255, 255 (Gonzalez *et al.* 1987). Digital images were analyzed with a computer program (Image Analysis of Fertilizer) written in Microsoft visual basic 6.0 for the present study. The program extracts red, green, and blue (RGB) features from the digital camera image files and computes color indices.

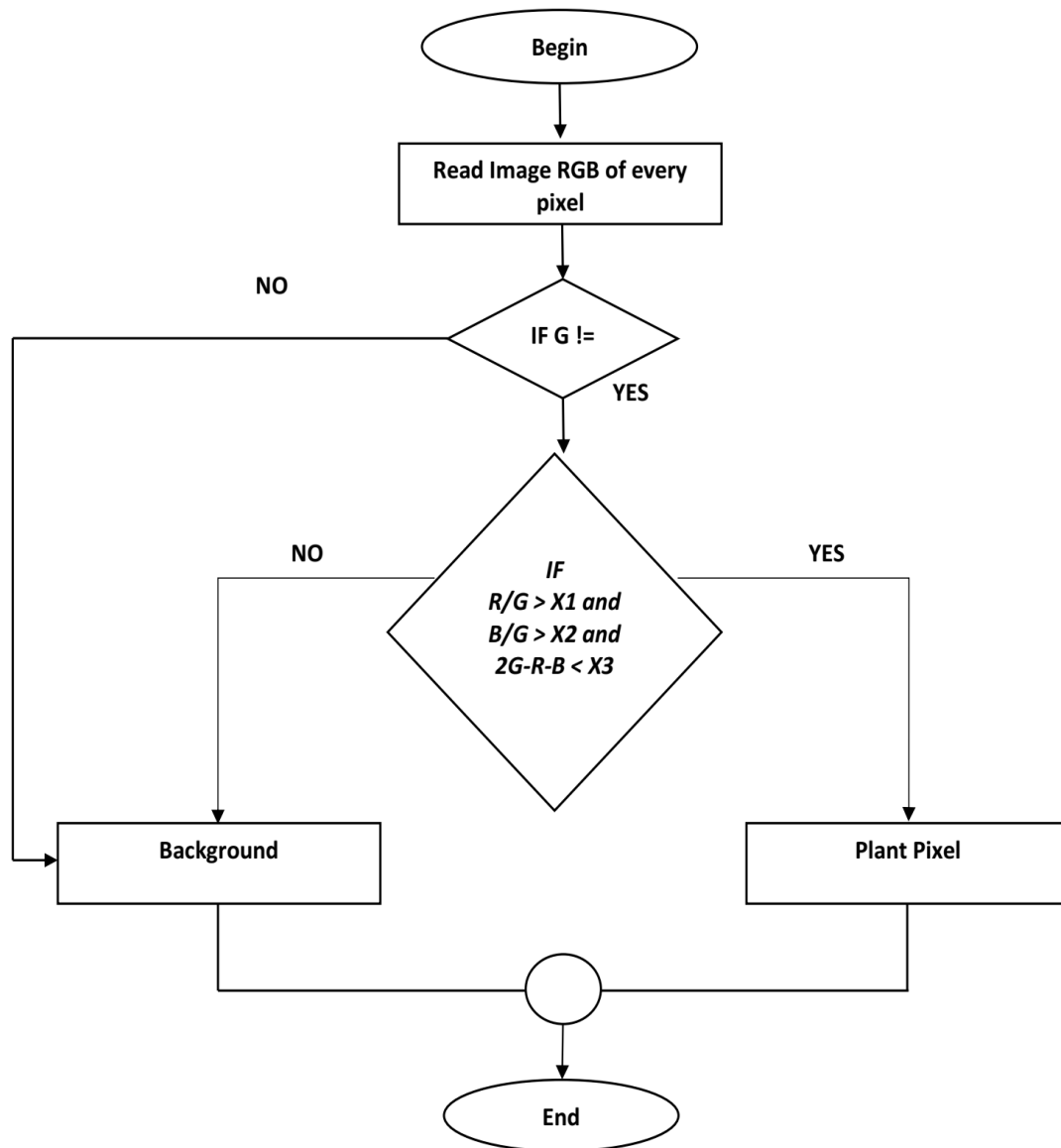


Figure 3.2.57. Flowchart algorithm of the overall methodology and modeling

3.2.3.8.4 Correlation matrix of morpho-physiological, digitally extract traits, yield and yield contributing traits of maize

Pearson's correlation coefficients (lower diagonal) among 43 morpho-physiological, digitally extract, yield, and yield contributing attributes of maize varieties grown under different level of nitrogen fertilizer treatments are shown in Figure 3.1.58. There was noted a significant correlation between grain yield and most of the studied traits, i.e., YTPH, EH, NCPM, NDVI, LAI, NGS, Chl a, PH, Chl b, SPAD, HUEp, SAT, NDVIrgb, EIG, HUE, LNC, CC and DCC which are highly positively associated with one another.

The correlation matrix of digitally extracted trait and morpho-physiological traits results agree with a number of previous studies on the use of spectral indices to estimate the N-nutrition status (Mistele and Schmidhalter, 2010; Erdle *et al.*, 2011, Baresel *et al.*, 2017). There are differences in the ranking of correlation coefficients in various studies. Due to the large confidence intervals correlation coefficients usually have, many of the reported differences may be statistically not significant and should not be over-interpreted. Furthermore, the results concerning the SPAD-measurements coincide with those from previous studies (Uddling *et al.*, 2007), confirming the suitability of the method, and indicating, that the method has been applied correctly.

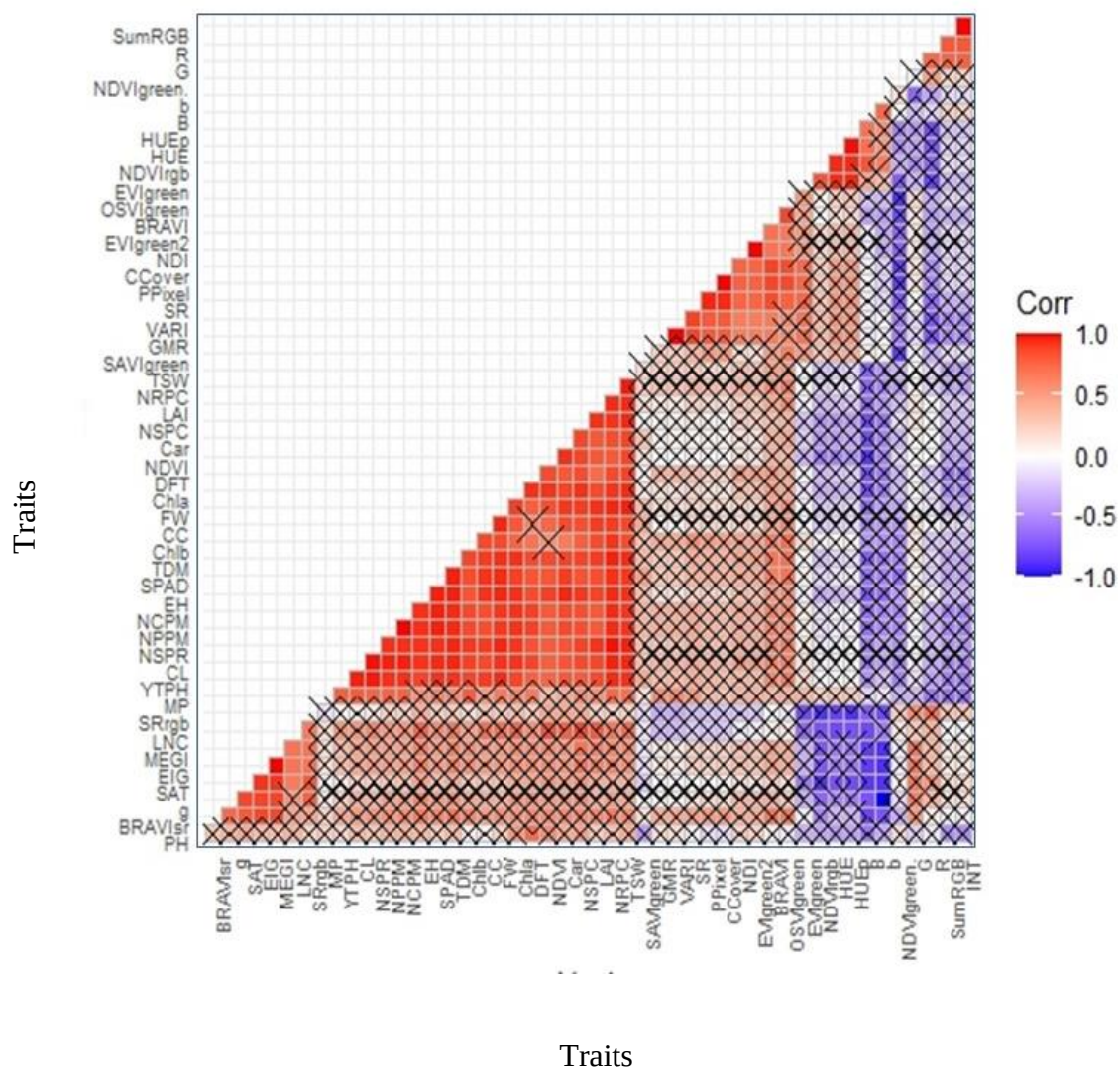


Figure 3.1.58: Heatmap showing the Correlation matrix of 43 morpho-physiological, digitally extract traits, yield and yield contributing traits.

Heat map displaying the relationship matrix among 43 maize traits. The red colour diagonal represents a perfect positive relationship between two traits with itself and blue colour diagonal represents a perfect negative correlation between two traits. ×= Non Significant at 5%

CHAPTER IV

4. SUMMARY AND CONCLUSION

Digital image analysis systems have been increasingly utilized for the assessment of plant growth and nitrogen nutrient requirement for decades. Sustaining soil and soil fertility in intensive cropping systems for higher yields and better quality can be achieved through optimum levels of fertilizer application. Thus, information on fertility status of soils and crop response to different soil fertility management is very crucial to come up with profitable and sustainable crop production. Accordingly, four experiments were conducted in two successive years at Seed Technology Division, Bangladesh Agriculture Research Institute (BARI), Gazipur-1701 during 2016-17 and 2017-18 to study the effect nitrogen on morpho-physiological traits of wheat and maize; to use digital image and software for assessment of leaf nitrogen of wheat and maize at different stages of growth and to establish a relationship between morpho-physiological parameters with image parameters of wheat and maize.

4.1 Summary

4.1.1 Summary of the wheat experiment during 2016-17 and 2017-18

The experiment comprised of four wheat varieties viz. (i) V_1 = BARI Gom 26, (ii) V_2 = BARI Gom 28, (iii) V_3 = BARI Gom 29 and (iv) V_4 = BARI Gom 30 and four nitrogen levels viz. (i) N_0 = Control (0.0 kg N ha^{-1}), (ii) N_1 = 50 kg N ha^{-1} , (iii) N_2 = 100 kg N ha^{-1} , (iv) N_3 = 150 kg N ha^{-1} during 2016-17 and in the next year (2017-18) the experiment comprised of three wheat varieties viz. (i) V_1 = BARI Gom 26, (ii) V_2 = BARI Gom 28 and (iii) V_3 = BARI Gom 30 and five nitrogen levels viz. (i) N_0 = Control (0.0 kg N ha^{-1}), (ii) N_1 = 60 kg N ha^{-1} , (iii) N_2 = 100 kg N ha^{-1} , (iv) N_3 = 120 kg N ha^{-1} and (v) N_4 = 140 kg N ha^{-1} . The experiment was laid out in a split-plot design with three replications.

Different wheat varieties (V), different levels of nitrogen (N) and interaction effect of $V \times N$ showed the significant variation on maximum morpho-physiological traits, digitally extract traits, yield and yield contributing traits during both the years at different growth stage. Results revealed that the tallest plant (46.71, 74.42, 89.77 and 97.15 cm at 30 DAS, 60 DAS, 90 DAS and at harvest, respectively) was obtained by the treatment combination of N_3V_1 (150 kg N ha^{-1} and BARI Gom 26) which during 2016-17, on the other hand, tallest plant (62.67, 79.00,

96.67 and 102.33 cm at 30 DAS, 60 DAS, 90 DAS and at harvest, respectively) was found with treatment combination N₄V₂ (140 kg N ha⁻¹ and BARI Gom 28) during 2017-18.

Maximum leaf area index (0.87, 2.22, 3.47 and 2.51 at 25, 50, 75 and 100 DAS, respectively) was found from interaction of N₃V₁ (150 kg N ha⁻¹ and BARI Gom 26) during 2016-17, on the other hand highest LAI (0.71, 3.13, 2.03 and 1.95 at 25, 50, 75 and 100 DAS and at harvest, respectively) which was identical with treatment combination of N₃V₂ (150.0 kg N ha⁻¹ and BARI Gom 28)

Highest NDVI (0.81) was resulted by the interaction of N₂V₄ (100 kg N ha⁻¹ and BARI Gom 30) during 2016-17 where the highest NDVI (0.97) was found from the treatment interaction of N₄V₂ (140 kg N ha⁻¹ and BARI Gom 28) at 50 DAS during 2017-18 at 50 DAS.

At 75 DAS, maximum CC (0.99) was found from interaction of N₃V₃ (150 kg N ha⁻¹ and BARI Gom 29) during 2016-17 where the maximum CC (0.97) was found with treatment combination N₄V₂ (140 kg N ha⁻¹ and BARI Gom 28) which was statically non-significant from other treatment combinations during 2017-18.

At harvest, the highest TDM (1499.91 gm⁻²) was recorded by the interaction of N₃V₂ (150 kg N ha⁻¹ and BARI Gom 28) which was statistically insignificant with other treatment combinations during 2016-17 where the maximum TDM (1676.5 gm⁻²) was found with treatment combination N₃V₂ (120 kg N ha⁻¹ and BARI Gom 28) during 2017-18.

For SPAD value maximum (52.23) was found from treatment interaction of N₃V₃ (150 kg N ha⁻¹ and BARI Gom 29) during 2016-17 but maximum SPAD value (74.70) was observed from treatment interaction of N₄V₃ (140 kg N ha⁻¹ and BARI Gom 30) during 2017-18 .

At 75 DAS, the maximum Chl a content (0.57) was recorded by the interaction of N₃V₁ (150 kg N ha⁻¹ and BARI Gom 26) during 2016-17 where the maximum Chl a content (0.67) was found with treatment combination N₄V₃ (140 kg N ha⁻¹ and BARI Gom 30) during 2017-18.

At 50 DAS, highest Chl b content (0.81) was resulted by the interaction of N₂V₄ (100 kg N ha⁻¹ and BARI Gom 30) during 2016-17 where the highest Chl b content (0.99) was found from the treatment interaction of N₄V₂ (140 kg N ha⁻¹ and BARI Gom 28 during 2017-18.

At 50 DAS, highest LCC (0.81) was resulted by the interaction of N₂V₄ (100 kg N ha⁻¹ and BARI Gom 30) during 2016-17 but the highest LCC (0.99) was found from the treatment interaction of N₄V₂ (140 kg N ha⁻¹ and BARI Gom 28) during 2017-18.

At 50 DAS, highest LNC (2367 ppm) was resulted by the interaction of N₃V₁ (150 kg N ha⁻¹ and BARI Gom 26) during 2016-17 where the highest LNC (2370 ppm) was found from the treatment interaction of N₄V₁ (140 kg N ha⁻¹ and BARI Gom 26) during 2017-18.

It was found that the maximum number of spikelets spike⁻¹ (21.13) by the interaction of N₃V₃ (150 kg N ha⁻¹ and BARI Gom 29) during 2016-17 but the maximum number of spikelets spike⁻¹ (19.67) was found with treatment combination N₄V₁ (140 kg N ha⁻¹ and BARI Gom 26) during 2017-18.

The maximum number of number of grains spike⁻¹ (46.51) was recorded by the interaction of N₂V₁ (100 kg N ha⁻¹ and BARI Gom 26) during 2016-17 where the maximum number of number of grains spike⁻¹ (59.00) was found with treatment combination N₄V₃ (140 kg N ha⁻¹ and BARI Gom 30) during 2017-18.

The maximum spike length (16.60 cm) was recorded by the interaction of N₂V₁ (100 kg N ha⁻¹ and BARI Gom 26) during 2016-17 but the maximum spike length (2135 ppm) was found with treatment combination N₄V₂ (140 kg N ha⁻¹ and BARI Gom 28) during 2017-18.

The maximum straw yield (3.90 tons ha⁻¹) was recorded by the interaction of N₃V₂ (150 kg N ha⁻¹ and BARI Gom 28) during 2016-17 nevertheless the maximum straw yield (5.38 tons ha⁻¹) was found with treatment combination N₄V₃ (140 kg N ha⁻¹ and BARI Gom 30) during 2017-18.

The maximum harvest index (45.39%) was recorded by the interaction of N₃V₁ (150 kg N ha⁻¹ and BARI Gom 26) during 2016-17 where the maximum harvest index (49.76%) was found with treatment combination N₄V₂ (140 kg N ha⁻¹ and BARI Gom 28) during 2017-18.

Results revealed that, the maximum grain yield (3.97 t ha⁻¹) was recorded by the interaction of N₃V₄ (150 kg N ha⁻¹ and BARI Gom 30) during 2016-17 where the maximum grain yield (3.94 t ha⁻¹) was found with treatment combination N₃V₁ (120 kg N ha⁻¹ and BARI Gom 26) during 2017-18.

Both genotypic and phenotypic correlation co-efficient analyses carried in this study suggested that plant height (PH), leaf area index (LAI), normalized difference vegetative index (NDVI), canopy cover (CC), soil plant analysis development (SPAD), leaf nitrogen content (LNC), chlorophyll a content (Chl a) are major components of total dry matter (TDM). The correlation coefficient analysis of wheat varieties and nitrogen levels interaction indicated that the physiological traits NDVI, CC, SPAD and LNC were directly correlated with TDM at 75 DAS, which would be effective trait for improvement of dry matter accumulation as well as yield of wheat.

The regression analysis of some morpho-physiological traits of wheat at different nitrogen levels for the year of 2016-17 and 2017-18 The response of morpho-physiological traits against different nitrogen levels in both the years were linear and positively significant for all the varieties. The relationship between plant height and TDM accumulation in both years was linear and positively significant. The response of grain yield and added nitrogen in both the years were quadratic significant for all the varieties of wheat

Using all trait values, a T×T biplot was constructed from a two-way matrix of 16 traits by 16 Treatments during 2016-17 and a two-way matrix of 16 traits by 15 Treatments during 2017-18. The plot condensed the information from this matrix into PCs, the first two of which comprised 89.71% during 2016-17 and 87.59% during 2017-18 of the total variation within the dataset. This comparatively high percentage reveals the complication of the relations among the treatments and the evaluated morpho-physiological traits. The treatments 16 and 8 that very closed to x-axis and coincided with as a $16=N_3 \times V_4$, and $8=N_3 \times V_2$ treatment scored significantly the highest values compared to other. As a treatment $16=N_3 \times V_4$, and $8=N_3 \times V_2$ for LNC and HI scored the highest values during 2016-17 (Figure 3.1.73). The treatments 14 and 7 that very closed to x-axis and coincided with as a $14=N_3 \times V_3$, and $7=N_2 \times V_2$ treatment scored significantly the highest values compared to other. As a treatment $14=N_3 \times V_3$, and $7=N_2 \times V_2$ for TDM, Yield and SPAD scored the highest values during 2017-18.

Heatmap displaying the relationship matrix among 16 treatments of wheat varieties and nitrogen interaction. The amber diagonal represents a perfect relationship of each treatment with itself. The symmetric off-diagonal elements represent the relationship measures for pairs

of treatments. The white or warmer colors on the diagonal show clusters of closely related treatments. Hierarchical clustering based on the morpho-physiological, yield and yield contributing traits of the treatments (Interaction of variety and Nitrogen doses) studied revealed four clusters namely Cluster A, Cluster B, Cluster C, and Cluster D. Pearson's correlation coefficients (lower diagonal) among 43 morpho-physiological, digitally extracted, yield and yield contributing attributes of wheat varieties grown under different levels of nitrogen fertilizer treatments. There was noted a significant correlation between grain yield and most of the studied traits, i.e., NDVI, LAI, NGS, Chl a, PH, Chl b, SPAD, HUEp, SAT, NDVI_{rgb}, EIG, HUE, LNC, HI, CC and DCC which are highly positively associated with one another.

4.1.2 Summary of maize experiment during 2016-17 and 2017-18

The experiment comprised of three hybrid maize varieties viz. (i) $V_1 = 981$, (ii) $V_2 = \text{BARI Hybrid Maize 9 (BHM 9)}$ and (iii) $V_3 = \text{P3396}$ and three nitrogen levels viz. (i) $N_1 = 100 \text{ kg N ha}^{-1}$, (ii) $N_2 = 200 \text{ kg N ha}^{-1}$ and (iii) $N_3 = 300 \text{ kg N ha}^{-1}$ during 2016-17 in two successive years. The experiment was laid out in a split-plot design with three replications.

Different morpho-physiological parameters were significantly influenced by combined effect of different hybrid varieties and nitrogen levels. The treatment $V_2 N_3$ (BHM9 $\times$ N₃₀₀) registered the tallest plant (58.33, 78.33, 138.67, 165.00, 185.67 and 243.33 cm at 40, 60, 80, 100, 120 cm and 140 DAS, respectively) were observed during 2016-17 and 60.33, 78.33, 138.67, 165.00, 185.67 and 253.33 cm at 40, 60, 80, 100, 120 and 140 DAS, respectively during 2017-18. Maximum LAI (2.06, 3.85 and 3.13 at 80, 100 and 120 DAS, respectively) during 2016-17 and 1.35, 1.75, 2.10, 3.51, 3.09 and 2.73 at 40, 60, 80, 100, 120 and 140 DAS, respectively during 2017-18. Maximum NDVI (0.72, 0.89, 0.99, 0.79 and 0.69 at 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and 0.60, 0.67, 0.69, 0.92, 0.88 and 0.77 at 40, 60, 80, 100, 120 and 140 DAS, respectively during 2017-18. Maximum CC (0.51, 0.59, 0.61, 0.80, 0.72 and 0.68 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and 0.52, 0.60, 0.63, 0.82, 0.76 and 0.68 at 40, 60, 80, 100, 120 and 140 DAS, respectively during 2017-18. Maximum Chl a content (0.65, 0.72, 0.89, 0.99, 0.79 and 0.69 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and 0.60, 0.67, 0.69, 0.92, 0.88 and 0.77 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18. Maximum leaf carotenoid content (0.44, 0.45, 0.41, 0.49, 0.48 and 0.45 mg g⁻¹ at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and 0.38, 0.36, 0.37, 0.44, 0.38 and 0.39 mg g⁻¹ at 40, 60, 80, 100, 120 and 140 DAS, respectively during 2017-18. Maximum LNC (1533, 1553, 1430, 1830, 1713 and 1493. ppm at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and 1390, 1520, 1413, 1813, 1713 and 1579 ppm at 40, 60, 80, 100, 120 and 140 DAS, respectively during 2017-18.

The combined effect of varieties and nitrogen levels on TDM accumulation results showed that the highest TDM obtained from combination of P3396 $\times$ N₃₀₀ (528.64, 591.36, 725.76, 1090.92, 1430.48, 2245.38 gm⁻² at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and maximum TDM (619.50, 703.00, 950.50, 1036.00, 1670.00 and 2333.33 gm⁻² at

40, 60, 80, 100, 120 and 140 DAS, respectively) during 2017-18; maximum SPAD (51.23, 52.30, 55.07, 72.87, 66.23, 60.40 at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and 51.75, 54.10, 57.54, 73.15, 67.40 and 61.00 at 40, 60, 80, 100, 120 and 140 DAS, respectively during 2017-18; maximum Chl b content (0.98, 1.00, 1.09, 1.11 and 1.10, 0.95 mg g⁻¹ at 40, 60, 80, 100, 120 and 140 DAS, respectively) during 2016-17 and 0.95, 0.97, 1.07, 1.23, 0.93 and 0.78 mg g⁻¹ at 40, 60, 80, 100, 120 and 140 DAS, respectively during 2017-18.

The both years pooled or combined analysis different yield contributing traits and grain yield was influenced significantly due to the interaction effect of different hybrid maize varieties (V) and nitrogen levels (N). Results indicated that the taller plant (251.68 cm) was recorded by the interaction of V₂ N₃ (BHM 9 and 300 kg N ha⁻¹) and maximum ear height (94.33 cm) at harvesting stage;

Results indicated that the maximum DFT (97.67); DFS (101.67); NPPM (16.00); NCPM (20.00); CL (23.00 cm); NRPC (18.67); NSPC (41.67); NSPC (754.33); TSW (415.33 g); grain yield (14.45 t ha⁻¹) was recorded by the interaction of V₃N₃ (P3396 and 300 kg N ha⁻¹)

The correlation coefficient analysis of hybrid maize varieties and nitrogen levels interaction indicated that the physiological traits NDVI, CC, SPAD and LNC were directly correlated with TDM at 120 DAS, which would be effective trait for improvement of dry matter accumulation as well as grain yield of hybrid maize.

The response of plant height, LAI, NDVI, CC, TDM against different nitrogen levels at 120 DAS were linear and positively significant for all the hybrid varieties. This showed that increasing different nitrogen level significantly increased plant height of different variety of hybrid maize. The linear models had an R² value varies from 0.97 for hybrid 981, 0.98 for BHM 9 and 0.99 for hybrid P3396 which indicating that higher doses of nitrogen provided taller plant.

Regression was used to further investigate the relationship between some morpho-physiological characters to total dry matter (TDM) accumulation of different hybrid maize varieties at 120 DAS. The relationship between plant height, LAI, NDVI, CC, SPAD, LNC, Chl a, Chl b and Car with TDM accumulation was linear and positively significant. The linear models had an R² value ranged from 0.90 for hybrid 981, 0.91 for BHM 9 and 0.97 for hybrid

P3396, respectively. The positive relationship indicated that TDM increased with the increasing of LAI depression for each variety. Both genotypic and phenotypic correlation coefficient analyses carried in this study suggested that plant height (PH), leaf area index (LAI), normalized difference vegetative index (NDVI), canopy cover (CC), soil plant analysis development (SPAD), leaf nitrogen content (LNC), chlorophyll a content (Chl a) are major components of total dry matter (TDM). The correlation coefficient analysis of maize varieties and nitrogen levels interaction indicated that the physiological traits NDVI, CC, SPAD and LNC were directly correlated with TDM at 120 DAS, which would be effective trait for improvement of dry matter accumulation as well as yield of hybrid maize.

The response of morpho-physiological traits against different nitrogen levels in both the years were linear and positively significant for all the hybrid maize varieties. The relationship between plant height and TDM accumulation was linear and positively significant. The response of grain yield and added nitrogen in both the years were quadratic significant for all the varieties of maize

Using all trait values, a T×T biplot was constructed from a two-way matrix of 50 traits (including morpho-physiological, yield & yield contributing and digitally extract trait) by 9 treatments. The plot condensed the information from this matrix into PCs, the first two of which comprised 85.06% of the total variation within the dataset. This comparatively high percentage reveals the complication of the relations among the treatments and the evaluated morpho-physiological traits. The treatments 9 and 8 that fall in the quadrant and coincided with as a $9=N_3 \times V_3$, and $8=N_3 \times V_3$ treatment scored significantly the highest values compared to other. As a treatment $8=N_2 \times V_3$, and $9=N_3 \times V_2$ for LNC scored the highest values

Hierarchical clustering based on the morpho-physiological, yield and yield contributing traits of the treatments studied revealed four clusters namely Cluster A, Cluster B, Cluster C, and Cluster D all cluster accommodated four treatments but cluster A accommodated five treatments, while cluster B and D composed of three treatments and cluster C consisted four treatments. It is clear that the treatments having similarity in their morpho-physiological, yield and yield contributing traits composition were grouped together. However, the heatmap also revealed the overall performance of each treatment regarding the observed traits.

4.1.3 Conclusions

From the above findings, the conducted wheat experiment revealed the variety BARI Gom 30 gave the highest grain yield that was statistically similar with variety BARI Gom 26. So, both the varieties may be recommended for wheat cultivation for obtaining the maximum yield.

Among the different nitrogen levels, the highest grain yield was obtained from the 150 kg N ha⁻¹ during 2016-17 and 140 kg N ha⁻¹ during 2017-18, respectively. So, the 140 kg N ha⁻¹ may be recommended for the extensive wheat cultivation for obtaining the highest yield.

Among the interaction treatments, maximum grain yield 3.97 t ha⁻¹ was recorded by the interaction of 150 kg N ha⁻¹ and BARI Gom 30 which was statistically similar with 100 kg N ha⁻¹ and BARI Gom 29, 100 kg N ha⁻¹ and BARI Gom 28 during 2016-17 where the maximum grain yield 3.94 t ha⁻¹ was found with treatment combination 120 kg N ha⁻¹ and BARI Gom 26 which was statistically similar with 120 kg N ha⁻¹ and BARI Gom 30, 120 kg N ha⁻¹ and BARI Gom 28 during 2017-18. So, the treatment nitrogen 130 kg N ha⁻¹ with combination of variety BARI Gom 26 or BARI Gom 30 can be considered as an economically the best treatment for wheat production.

For maize experiment, it is concluded that among the maize varieties, 981 had the maximum grain yield (13.80 t ha⁻¹) which was statistically identical with Hybrid P3396 and minimum grain yield (12.47 t ha⁻¹) was found from BHM9. So, both the hybrid varieties may be recommended for wheat cultivation for obtaining the maximum yield.

It was found that the maximum grain yield (13.84 t ha⁻¹) from N₃ treatment (300 kg N ha⁻¹) which was significantly differed from other treatments. So, the 300 kg N ha⁻¹ may be recommended for the extensive hybrid maize cultivation for obtaining the highest yield.

Among the interaction effect of variety and nitrogen level, Maximum grain yield (14.45 t ha^{-1}) was recorded by the interaction of P3396 and 300 kg N ha^{-1} which was statistically identical with BHM 9 and 300 kg N ha^{-1} . So, the treatment nitrogen 300 kg N ha^{-1} with combination of variety P3396 or BARI Hybrid Maize 9 of can be considered as an economically the best treatment for hybrid maize production.

A strong relationship between NDVI, SPAD, CC and LNC across the wheat and maize varieties was observed. The results also suggest that because of NDVI, SPAD and CC saturation, NDVI and CC could accurately predict nitrogen requirements for wheat and maize.

It could be concluded that under the conditions of the current experiment, application of nitrogen fertilizer has positive effects on physiological parameter of wheat and maize variety.

The results of this study partially supported the hypothesis that digital image traits measured by image processing software (WCC and MCC) can identify and differentiate variations in nitrogen use in wheat and maize crops.

Continuous crop N monitoring may help to understand the transition of N from the soil into the crop, to help farmers to improve their farm management and to alert growers about potential shortfalls, thus guiding real-time or long-term fertilizer management plan modifications for future production years. In this way, overfertilization could be reduced preventing harmful effects on the environment, while at the same time a sustainable use of production resources can be maintained. The outcomes of study propose that a new era of N sensing also beyond agricultural research and applications could be initiated.

4.1.4 Recommendations

The following recommendations/suggestions are made based on the findings of the study-

- Among the interaction effect of wheat variety and nitrogen level, the highest grain yield (3.97 t ha^{-1}) was found from the 150 kg N ha^{-1} and BARI Gom 30 during 2016-17 where the maximum grain yield (3.94 t ha^{-1}) was found with treatment combination (120 kg N ha^{-1} and BARI Gom 26) during 2017-18. So, the treatment nitrogen 130 kg N ha^{-1} with combination of variety BARI Gom 26 or BARI Gom 30 of can be considered as an economically the best treatment for wheat production.
- Among the interaction effect of variety and nitrogen level, Maximum grain yield (14.45 t ha^{-1}) was recorded by the interaction of P3396 and 300 kg N ha^{-1} which was statistically identical with BARI Hybrid Maize 9 and 300 kg N ha^{-1} . So, the treatment 300 kg N ha^{-1} nitrogen with combination of variety P3396 or BARI Hybrid Maize 9 of can be considered as a best treatment for hybrid maize production.
- The relationship between SPAD readings and N content per leaf area is profoundly affected by environmental factors and leaf features of crop species. The results suggest that the time of SPAD measurements, environmental irradiance and species must be considered to precisely monitor leaf N status with chlorophyll meters.
- Potential use of digital image as a tool combined with software to make nitrogen fertilizer recommendation.

CHAPTER V

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APPENDIX

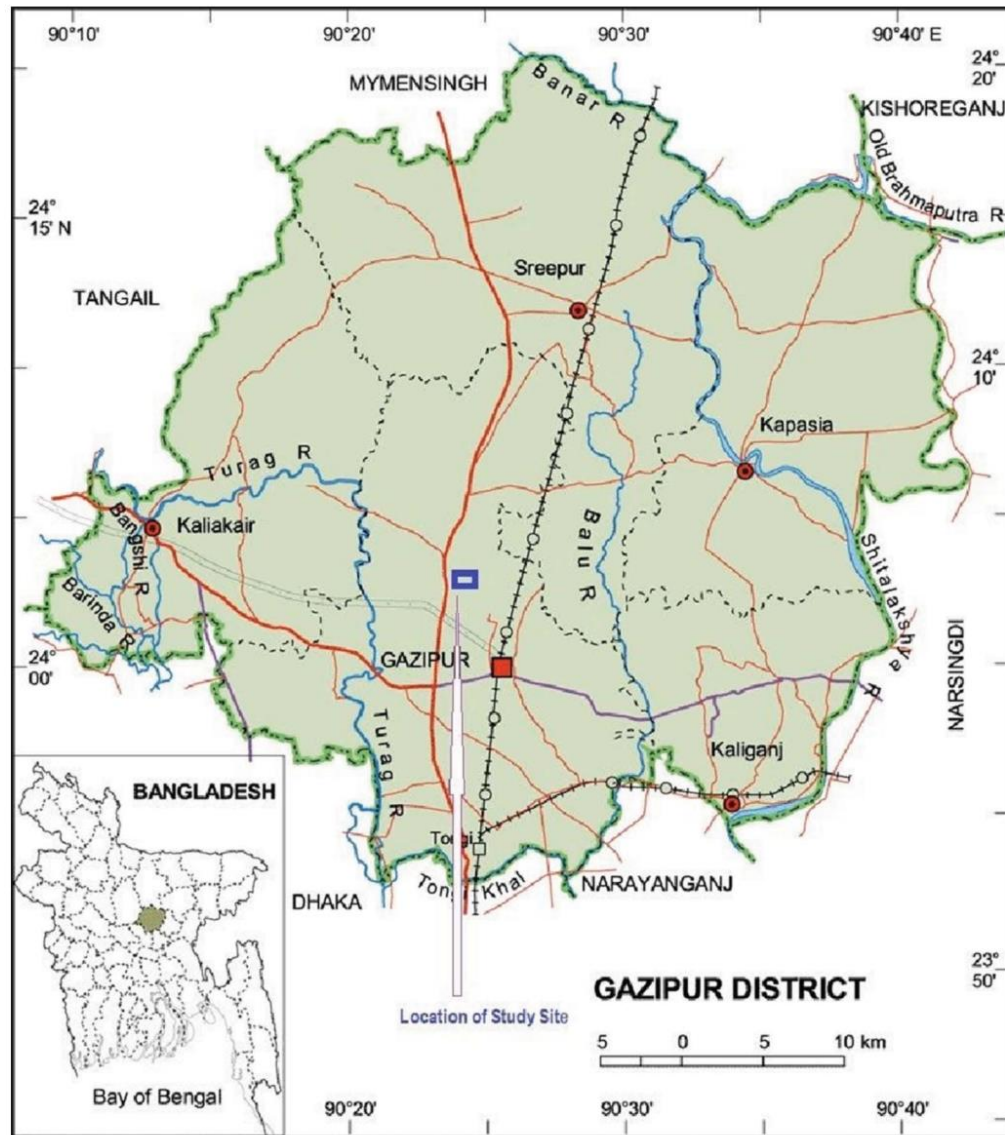


Figure 3.1.1 Map of Gazipur District, Bangladesh, showing study area

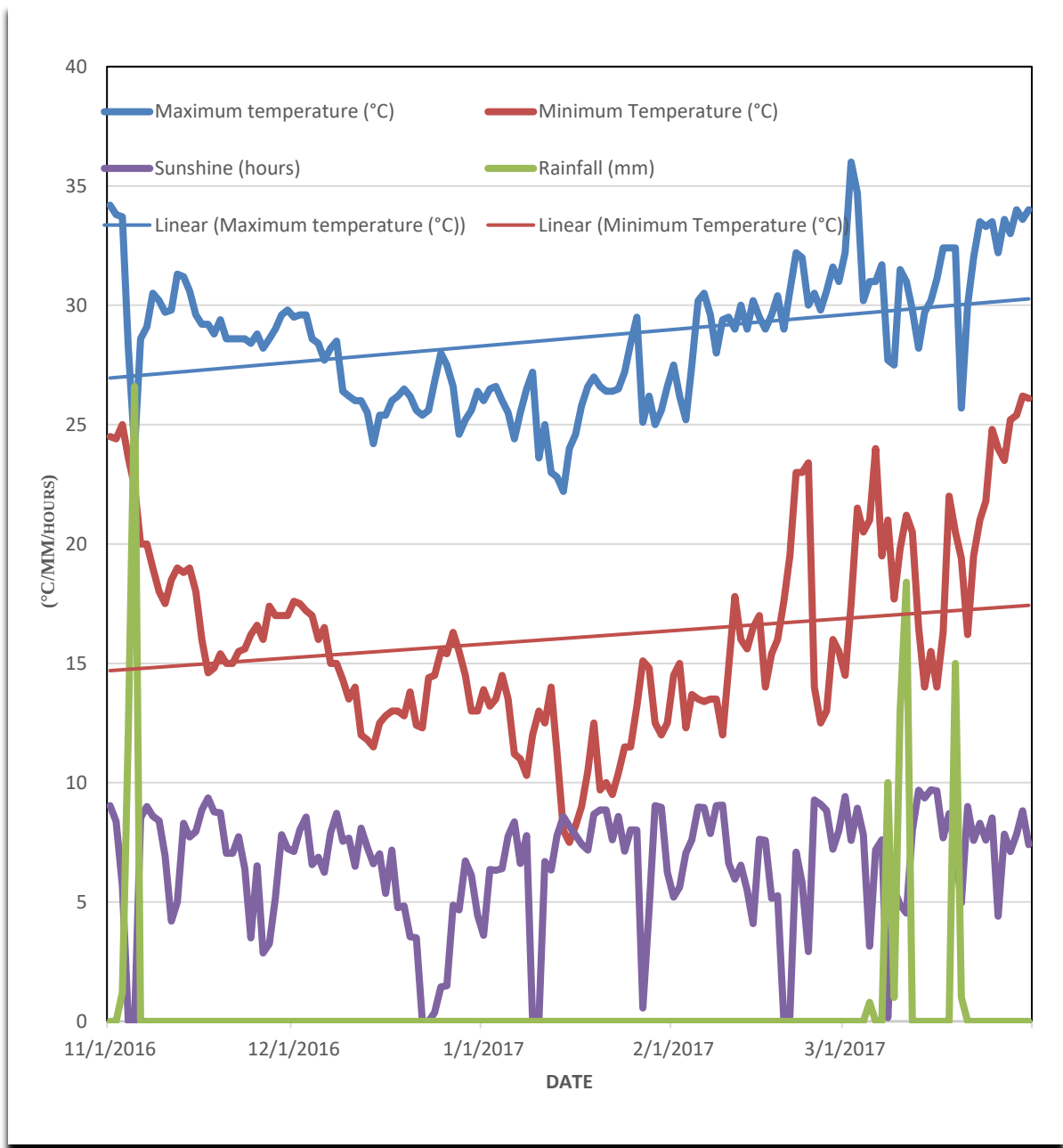


Figure 3.1 2 Weather information of Gazipur during wheat growing season

Table 3.1.1: ANOVA for plant height at different DAS of wheat during 2016-17

Sources of variation	df	Means square values of plant height at different DAS			
		30 DAS	60 DAS	90 DAS	Harvest
Replication	2	1.18	0.71	0.85	0.06
Variety (V)	3	6.34 ^{NS}	179.92**	75.06**	43.76**
Error (a)	6	0.98	2.32	0.48	0.97
Nitrogen (N)	3	666.87**	978.43**	1058.33**	689.11**
V: N	9	2.57*	7.80**	35.35**	14.37**
Error (b)	24	0.63	0.16	0.40	0.45

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.2: ANOVA for plant height at different DAS of wheat during 2017-18

Sources of variation	df	Means square values of plant height at different DAS			
		30 DAS	60 DAS	90 DAS	Harvest
Replication	2	1.18	0.71	0.85	0.06
Variety (V)	2	6.34*	179.92**	75.06**	43.76**
Error (a)	4	0.98	2.32	0.48	0.97
Nitrogen (N)	4	666.87**	978.43**	1058.33**	689.11**
V: N	8	2.57*	7.80**	35.35**	14.37**
Error (b)	24	0.63	0.16	0.40	0.45

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.3. ANOVA for leaf area index at different DAS of wheat during 2016-17

Sources of variation	df	Means square values of leaf area index at different DAS			
		25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	0.0004	0.01	0.0041	0.0213
Variety (V)	3	0.0089**	0.1219**	0.0786*	0.2406**
Error (a)	6	0.0002	0.0007	0.0063	0.0085
Nitrogen (N)	3	0.3651**	5.6378**	8.0716**	4.7402**
V: N	9	0.0248**	0.0557**	0.1542**	0.1733**
Error (b)	24	0.0009	0.0009	0.0025	0.0164

*Significant at 5% level and **Significant at 1% level

Table 3.1.4. ANOVA for leaf area index at different DAS of wheat during 2017-18

Sources of variation	Means square values of leaf area index at different DAS				
	df	25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	0.0002	0.0201	0.0062	0.0076
Variety (V)	2	0.0094**	0.6447**	0.2705**	0.4698**
Error (a)	4	0.0007	0.027	0.0484	0.0028
Nitrogen (N)	4	0.0396**	5.4212**	1.2806**	0.4156**
V: N	8	0.0056**	0.0364 ^{ns}	0.0554 ^{ns}	0.0153*
Error (b)	24	0.0021	0.0225	0.0469	0.0049

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.5. ANOVA for NDVI at different DAS of wheat during 2016-17

Sources of variation	Means square values of NDVI at different DAS				
	df	25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	0.0001	0.0001	0.0024	0.0003
Variety (V)	3	0.0080*	0.001**	0.0001 ^{ns}	0.0036*
Error(a)	6	0.0006	0.00001	0.0006	0.0012
Nitrogen (N)	3	0.0373**	0.1628**	0.048**	0.0031*
V: N	9	0.0055**	0.0011*	0.0011 ^{ns}	0.0054**
Error(b)	24	0.0002	0.0003	0.0008	0.0011

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.6. ANOVA for NDVI at different DAS of wheat during 2017-18

Sources of variation	Means square values of NDVI at different DAS				
	df	25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	0.0085	0.0039	0.0045	0.0034
Variety (V)	2	0.053**	0.034**	0.0139**	0.0058**
Error(a)	4	0.0011	0.0003	0.0008	0.0002
Nitrogen (N)	4	0.1099**	0.271**	0.0943**	0.0416**
V: N	8	0.0007 ^{ns}	0.0010*	0.0004 ^{ns}	0.0012*
Error(b)	24	0.0004	0.0003	0.0005	0.0005

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.7. ANOVA for canopy cover at different DAS of wheat during 2016-17

Sources of variation	Means square values of CC at different DAS				
	df	25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	0.0001	0.0001	0.0024	0.0003
Variety (V)	3	0.0080*	0.001**	0.0001 ^{ns}	0.0036*
Error(a)	6	0.0006	0.00001	0.0006	0.0012
Nitrogen (N)	3	0.0373**	0.1628**	0.048**	0.0031*
V: N	9	0.0055**	0.0011*	0.0011 ^{ns}	0.0054**
Error(b)	24	0.0002	0.0003	0.0008	0.0011

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.8. ANOVA for canopy cover at different DAS of wheat during 2017-18

Sources of variation	Means square values of CC at different DAS				
	df	25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	0.0085	0.0039	0.0045	0.0034
Variety (V)	2	0.053**	0.034**	0.0139**	0.0058**
Error(a)	4	0.0011	0.0003	0.0008	0.0002
Nitrogen (N)	4	0.1099**	0.271**	0.0943**	0.0416**
V: N	8	0.0007 ^{ns}	0.0010*	0.0004 ^{ns}	0.0012*
Error(b)	24	0.0004	0.0003	0.0005	0.0005

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.9. ANOVA for TDM at different DAS of wheat during 2016-17

Sources of variation	Means square values of TDM at different DAS				
	df	25 DAS	50 DAS	75 DAS	At harvest
Replication	2	213.78	10.1	270.5	259.9
Variety (V)	3	1679.16*	10331.4**	7858.1**	2883.0**
Error(a)	6	174.04	17.2	411.5	341.4
Nitrogen (N)	3	56224.6**	67301.1**	55058.7**	476457.9**
V: N	9	3582.40**	8950.9**	2144.9**	1421.4 ^{ns}
Error(b)	24	94.67	53.2	105.2	2059.3

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.10. ANOVA for TDM at different DAS of wheat during 2017-18

Sources of variation	Means square values of TDM at different DAS				
	df	25 DAS	50 DAS	75 DAS	At harvest
Replication	2	2378.3	1953.9	2750.3	2334.6
Variety (V)	2	18535.5**	105802.4**	24191.9**	9624.4**
Error(a)	4	2421.4	578.2	1070.5	721.3
Nitrogen (N)	4	36112.0**	597487.8**	558254.9**	806871.7**
V: N	8	9010.8*	7098.4**	14182.5**	11756.9**
Error(b)	24	4196.6	721.2	1978.8	3256.9

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.11. ANOVA for SPAD at different DAS of wheat during 2016-17

Sources of variation	Means square values of SPAD at different DAS				
	df	25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	24.5	41.9	2.4	2.1
Variety (V)	3	27.2**	1.8 ^{ns}	6.3 ^{ns}	17.9*
Error(a)	6	3.3	25.1	5.6	9.1
Nitrogen (N)	3	100.2**	309.0**	41.2**	205.2**
V: N	9	20.8**	6.7 ^{ns}	20.5*	12.7*
Error(b)	24	4.1806	17.5	7.2	5.6

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.12. ANOVA for SPAD at different DAS of wheat during 2017-18

Sources of variation	Means square values of SPAD at different DAS				
	df	25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	24.00	45.9	2.35	3.25
Variety (V)	2	27.2**	1.8 ^{ns}	6.3 ^{ns}	17.9*
Error(a)	4	3.3	25.1	5.6	9.1
Nitrogen (N)	4	100.2**	309.0**	41.2**	205.2**
V: N	8	20.8**	6.7 ^{ns}	20.5*	12.7*
Error(b)	24	4.1806	17.5	7.2	5.6

*Significant at 5% level, **Significant at 1% level and ns=Non-Significant

Table 3.1.13. ANOVA for chlorophyll a at different DAS of wheat during 2016-17

Sources of variation	Means square values of chlorophyll a at different DAS				
	df	25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	0.0001	0.0001	0.0001	0.0013
Variety (V)	3	0.0008 ^{ns}	0.0012*	0.0031*	0.0113**
Error(a)	6	0.0002	0.0001	0.0001	0.0002
Nitrogen (N)	3	0.0362**	0.0202**	0.0166**	0.0322**
V: N	9	0.0013**	0.0012*	0.0032*	0.0010*
Error(b)	24	0.0001	0.0002	0.0001	0.0003

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.14. ANOVA for chlorophyll a at different DAS of wheat during 2017-18

Sources of variation	Means square values of chlorophyll a at different DAS				
	df	25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	0.0005	0.0026	0.0003	0.0071
Variety (V)	2	0.0019 ^{ns}	0.0006	0.0004	0.0019
Error(a)	4	0.0051	0.0004	0.0005	0.0016
Nitrogen (N)	4	0.0440**	0.0703	0.0436	0.0122
V: N	8	0.00121*	0.0005	0.0106	0.0245
Error(b)	24	0.0046	0.0008	0.0023	0.0072

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.15. ANOVA for chlorophyll b at different DAS of wheat during 2016-17

Sources of variation	Means square values of chlorophyll b at different DAS				
	df	25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	24.5	41.9	2.4	2.1
Variety (V)	3	27.2**	1.8 ^{ns}	6.3 ^{ns}	17.9*
Error(a)	6	3.3	25.1	5.6	9.1
Nitrogen (N)	3	100.2**	309.0**	41.2**	205.2**
V: N	9	20.8**	6.7 ^{ns}	20.5*	12.7*
Error(b)	24	4.1806	17.5	7.2	5.6

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.16. ANOVA for chlorophyll b at different DAS of wheat during 2017-18

Sources of variation	Means square values of chlorophyll b at different DAS				
	df	25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	0.0002	0.0013	0.0082	0.0181
Variety (V)	2	0.0212	0.118	0.0273	0.0216
Error(a)	4	0.0031	0.0069	0.026	0.0062
Nitrogen (N)	4	0.0118	0.0547	0.0251	0.0647
V: N	8	0.1416	0.101	0.1186	0.0155
Error(b)	24	0.0118	0.0121	0.0184	0.0322

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.17. ANOVA for carotenoid at different DAS of wheat during 2016-17

Sources of variation	Means square values of carotenoid at different DAS				
	df	25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	0.0002	0.0001	0.0003	0.0003
Variety (V)	3	0.0006	0.0002	0.0014	0.0002
Error(a)	6	0.0001	0.0005	0.0004	0.0006
Nitrogen (N)	3	0.0013	0.002	0.0007	0.0039
V: N	9	0.0013	0.0016	0.0006	0.001
Error(b)	24	0.0018	0.0011	0.0008	0.0011

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.18. ANOVA for carotenoid at different DAS of wheat during 2017-18

Sources of variation	Means square values of carotenoid at different DAS				
	df	25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	0.0002	0.0001	0.0003	0.0003
Variety (V)	2	0.0006	0.0002	0.0014	0.0002
Error(a)	4	0.0001	0.0005	0.0004	0.0006
Nitrogen (N)	4	0.0013	0.002	0.0007	0.0039
V: N	8	0.0013	0.0016	0.0006	0.001
Error(b)	24	0.0018	0.0011	0.0008	0.0011

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.19. ANOVA for LNC at different DAS of wheat during 2016-17

Sources of variation	Means square values of LNC at different DAS				
	df	25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	27708.3	8125.0	11025.0	1631.0
Variety (V)	3	6875.0 ^{ns}	1666.7 ^{ns}	22119.4 ^{ns}	13560.1 ^{ns}
Error(a)	6	6875.0	625.0	11286.1	4222.0
Nitrogen (N)	3	1907430.6**	2615000.0**	2624969.4**	12506.3**
V: N	9	12245.4*	210370.4*	114413.9*	1280.4*
Error(b)	24	6250.0	4444.4	16056.9	271.3

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

Table 3.1.20. ANOVA for LNC at different DAS of wheat during 2017-18

Sources of variation	Means square values of LNC at different DAS				
	df	25 DAS	50 DAS	75 DAS	100 DAS
Replication	2	24222.2	8222.2	6720.0	531.4
Variety (V)	2	5575.6 ^{ns}	4222.2 ^{ns}	33020.0 ^{ns}	3311.6 ^{ns}
Error(a)	4	6555.6	2888.9	12660.0	1636.4
Nitrogen (N)	4	1196333.3**	1697000.0**	1705272.2**	3336.5 ^{ns}
V: N	8	55000.0*	29500.0*	414217.2*	1185.0 ^{ns}
Error(b)	24	7444.4	4666.7	14810.6	2372.0

*Significant at 5% level, **Significant at 1% level and ns=Non Significant

LIST OF PLATES



Plate 1: Field view of wheat experiment



Plate 2: Field visit of wheat experiment by Co-supervisor and Supervisor



Plate 3: Field view and data collection of wheat experiment



Plate 4: Field view of wheat experiment with contrast of treatment



Plate 5: Field visit of maize experiment by Co-supervisor and Supervisor



Plate 6: Field view of maize experiment



Plate 7: Field view and data collection of maize experiment



Plate 8: Modified selfie stick camera controlled by blue tooth connection with mobile phone