PERFORMANCE OF POTATO UNDER MANGO BASED AGROFORESTRY SYSTEM INFLUENCED BY PLANTING SPACINGS

A THESIS
BY

SHEWLY KHATUN
Student No. 1805341
Session: 2018
Semester: January- June, 2020

MASTER OF SCIENCE (M.S.)

IN

AGROFORESTRY AND ENVIRONMENT

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENT

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY
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Submitted to the Department of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur in partial fulfillment to the requirement of the degree of

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Approved as to style and contents by

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Prof. Dr. Md. Shafiqul Bari	**Prof. Dr. Md. Shoaibur Rahman**
Supervisor	**Co-supervisor**

…………………………………………….

Prof. Dr. Md. Shoaibur Rahman
Chairman
Examination committee
and
CHAIRMAN, DEPARTMENT OF AGROFORESTRY AND ENVIRONMEN

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY
DINAJPUR-5200

JUNE 2020

Dedicated

To

My Beloved Parents

DECLARATION

I hereby declare that the work presented in this thesis titled "PERFORMANCE OF POTATO UNDER MANGO BASED AGROFORESTRY SYSTEM INFLUENCED BY PLANTING SPACINGS" has been carried out by myself and that it has not been submitted for any previous degree. All quotations have been distinguished by quotation marks and all sources of information specifically acknowladged by references to the author.

Examination Roll No. **1805341**
Name. Shewly khatun
M.S. Session: 2018
Department of Agroforestry and Environment
Hajee Mohammad Danesh Science and Technology University,
Dinajpur-5200, Bangladesh

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PERFORMANCE OF POTATO UNDER MANGO BASED AGROFORESTRY SYSTEM INFLUENCED BY PLANTING SPACINGS

ABSTRACT

A field experiment was carried out at the research farm of the department of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh during November 2018 to March 2019 to evaluate the performance of different planting spacing's on the growth and yield of potato under mango based agroforestry system in comparison with sole cropping. The experiment was laid out with factorial Randomized Complete Block Design (RCBD) following three replications. The two factors were, factor A: two production systems viz, mango + potato based agroforestry system (P_1) and sole cropping of potato (P_2). Factor B: four planting spacing's of potato seeds viz, S_1 (50 cm × 25 cm), S_2 (60 cm × 20 cm), S_3 (60 cm × 25 cm) and S_4 (60 cm × 30 cm). The result of the experiment revealed that in case of main effect of production system, the initial germination percentages were not significantly varied but later stage i.e. at 28 days , significantly the highest percentage of germination (72.97 %) was recorded in sole cropping. Interestingly plant height of potato was the highest under mango orchard. However, except plant height all other growth parameters of potato including tuber yield were significantly highest in open condition. The highest (22,77 t\ha) and the lowest tuber yield (8.59 t\h) were found in s0le cropping mango + potato based agroforestry system. Again, in case of main effects of potato seed tuber spacing's, the highest tuber yield (15.76 t/h) was recorded in that plot where 60 cm×30 cm spacing was followed. On the other hand, in case of interaction effect of production systems and planting spacing of potato seeds, it was found that open condition with close spacing i.e. 50 cm × 25 cm gave highest yield (22.01 t/h). Therefore, the suitability of proper spacing for the cultivation of potato under mango based Agroforestry systems may be ranked as 50 cm × 25 cm > 60 cm × 20 cm >60 cm X 25 cm > 60 cm × 30 cm. Finally, it may be concluded that closing spacing gave maximum potato yield at the floor of Mango due to more number of plants in a unit area.

Key words: Agroforestry, Mango, Potato, Spacing and Yield.

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ABBREVIATION AND ACRONYMS

AEZ	:	Agro-ecological zone
AFS	:	Agroforestry System
ANOVA	:	Analysis of Variance
BBS	:	Bangladesh Bureau of Statistics
BCR	:	Benefit Cost Ration
cm	:	Centimeter
DAP	:	Days after planting
DAS	:	Days after sowing
e.g	:	For example
g	:	Gram
i.e.	:	That is
kg	:	Kilogram
m	:	Meter
MOP	:	Muriate of Potash
N	:	Nitrogen
RCBD	:	Randomized Complete Block Design
t/ha	:	ton/hectare
TSP	:	Triple Super phosphate

CHAPTER 1

INTRODUCTION

Bangladesh is one of the densely populated countries of the world having an agro-based economy which situated in the North-Eastern part of South Asia with a tropical to sub-tropical climate. Now, the population of Bangladesh is about 166,280,712 in the area of 130,168 sq. kilometers and population growth rate is 1.6% per annum (BBS, 2016). To feed this huge population and for national food security land use should be changed and required new sustainable land use options. Under this circumstance various agroforestry systems like forest, fruit tree or vegetable based agroforestry system can address the stress of the day to considerable extents. The agroforestry technology also play role in the light of combating hunger, poverty, diseases, environmental degradation (Garrity, 2004).

Agroforestry as a land use system that integrates trees, crops and animals in a way that is scientifically sound, ecologically desirable, practically feasible and socially acceptable to the farmers (Nair, 1979). Indeed the fruit based Agro forestry system can utilize the interspaces between tree rows for intercropping with agricultural crops and this doesn't impair the growth and development of trees but enable farmers to benefit accrued from the use of fuel and timber from the trees (Singh *et al.*, 2001).

Potato (*Solanum tuberosum* L.) is a perennial tuber crop. It is an herbaceous, succulent and dicotylentous plant with alternate stolons underground as well as alternate leaves on the steam above ground. Potatoes are the world's fourth largest crop, following rice, wheat and maize .This vegetable is one of the leading food crops and occupies the first position in both acreage and production among the total vegetable crop in Bangladesh (BBS, 2014).

During 2014-2015, the production of potato was 8950024 MT from an area of 462032ha which is 4.03% higher than previous year and average yield are 19.371MTh (BBS, 2015).The crop can be used both as human food and as seed tuber (Khurana *et al.*, 2003).To provide balance diet there would be no alternative to produce vegetable, as this would also provide vitamins and minerals. But the scope of horizontal increase in production of potato is limited in the country mainly due to shortage of land and hence shady places like the floor of orchard or tree woodlots can be used as an effective tool.

Despite among global production of potato over the past two decades has expanded from 267 to 375 million tons, and market opportunities are emerging to respond to the potato as a popular source of affordable food for growing urban populations. A highly dependable food security crop, potato offers important advantages over major food grains for the major developing for many countries including Bangladesh. Potato produces more food per unit area than the other major food crop. It generates more employment in the farm economy than other crops and serves as a source of cash income for low-income farm households through access to higher value markets along the potato value chain. Finally yet importantly, potato is not prone to speculative commodities trading on global markets, instead, prices are more likely set by local supply and demand conditions (USAID, 2013). Additionally, Potato has been considered as a strategic crop by the government aiming at enhancing food security and economic benefits to the country. As the population grows rapidly, increased productivity of potatoes can improve the livelihood of smallholder potato producers and is required to meet the growing demand (SCA, 2014). According the Uganda is listed among the countries with the lowest crop yields per unit area in the world, in spite of its relatively favorable agro-climatic environment (Wang *et al.*, 2015). To reduce food insecurity and poverty at household level, the government of Uganda has initiated various liberalization policies to revitalize agricultural production and improve rural household income. Subsequently, the government has urged farmers to embrace agricultural modernization and produce for the market (Adong, 2014). At the same time, Potato has emerged as high yielding cash crop in Pakistan during the last decade and the area under its cultivation has increased rapidly since independence. The total estimated production is 2.63 million tons from an area of 138 thousand hectares. However, per hectare average yield is very low (16 to 19 tons/ha) as compared to developed potato grown countries (45 to 50 tons/ha) (MINFAL, 2007). Pakistan has very unique climate in the world for the cultivation of potato crop. Irrigation system combined with climatic condition allowing the cultivation of three crops round the year in various agro-ecological zones from sea level to 3000 m altitude. Autumn crop in plains and in southern Punjab, plains of Balochistan and Sindh, spring crop is cultivated in the plains and lower hills of Balochistan, North-West-Frontier Province; and one summer crop is cultivated in the high hilly northern areas (Din *et al*., 2007). Bulk of the production comes from Okara, Sahiwal, Sialkot, Lahore, Kasur and Jhang districts Bangladesh is one of the densely populated countries of the world having an agro-based economy system. And the population of Bangladesh is about 166,280,712 in the area of 130,168sq.Kilometers and growth rate is 1.6%per annum (BBS, 2014).But only 6% or a total of 0.769 million hectares land of the territory has actual tree coverage (Anonymous, 1999). For getting benefit it should have at least 25% covered with forest. Due to over population and greater affluence exert pressures to convert forest to agricultural or residential land. Land use changes and require new sustainable land use options for both livelihood security and environmental protection. And for this reason people find suitable method to adapt to the natural environment in which they live. Under these fatal situations, various agroforestry systems like forest or fruit tree based agroforestry system can address the stress of the day to considerable extents (BBS, 2014).

Plant density in potato affects some of important plant traits such as total yield, marketable tuber number, unmarketable tuber number and quality. So it might argued that increase in mean tuber weight and increase in the number of tuber and yield per unit area (Marguerite *et al.,* 2006). (Georgakis *et al*., 1997) concluded that by increasing plant density, the tuber yield was increased. An optimal plant density of a particular variety grown using its optimum spacing requirement manifests its performance by showing optimal growth through efficient utilization of moisture, nutrients and light, and also high tuber high yield (Doughari *et al*., 2008). According to (Khisa *et al*., 2001), a suitable in-row spacing for an adaptable variety in a locality increases tuber yield by 50%.Depending on the level of production as well as farming implements being used, different in-row spacing are being used across the world, impacting differently on the growth rate and yield of Irish potato. In general, the commonly used in-row spacing for Irish potato in Zimbabwe is varied but ranges between 25 cm and 40 cm, while inter-row spacing is less varied. The optimum in-row spacing and the best variety in terms of the highest tuber yield produced remain unknown in Nyanga, as the varieties and the variables under consideration are strongly affected by environmental factors such as rainfall, soil type and agronomic practices.

On the other hand, mango (*Mangifera indica*) is regarded as one of the kings of sub-tropical fruits and it is good source of Vitamin A, B_6, E, K and C. It contains rich in fiber and prevents night blindness and dry eyes. It decreases risk of cancer. Further research is still ongoing but some studies have already revealed that mangoes are a great natural remedy for diabetics. Now mango orchards are increasing day by day in the northern part of Bangladesh. The owners of mango orchard also using the floor of young orchard for different vegetables and spices cultivation. But usually they are using traditional vegetable cultivation practice under mango based agroforestry system. Whereas, there are huge scope of high value vegetable like potato production at the floor of young mango orchard using appropriate technology. Information regarding potato production in a suitable tuber seed planting spacing under mango based agroforestry system is very scant in Bangladesh and also all over the world. So, considering the above circumstances the propose study will be conducted in order to investigate proper potato tuber seed planting spacing for better potato yield under mango based agroforestry system.

Objectives

i. To investigate the performance of potato in association with Mango tree.
ii. To identify the suitable planting spacing of potato for Mango based agro forestry system.
iii. To increase the land use efficiency by intercropping of Potato in Mango orchard.

CHAPTER 2

REVIEW OF LITERATURES

Agroforestry provides an effective land management system that can ensure more production in a balanced ecological environment. It helps to overcome short comings of traditional agriculture that are often characterized by low output at the cost them of relatively high investment, resulting in a deterioration of environment. This chapter presents a brief review of the post studies and opinion of researchers having relevance to this investigation which were gathered from different sources like literature, journals, thesis, reports, newspaper, CD search and periodicals. The literatures were collected and compiled for better and clear understanding of the present studies. Keeping this in view, an attempt has been made to review findings on agroforestry practices with particular emphasis on the impact of fertilizer and manure applications on potato cultivation in association with mango tree. The relevant literatures pertaining to the present study have been reviewed in this chapter under the following heads.

2.1 Concept and Benefit from agroforestry system

2.2 Mango based agroforestry system

2.3Agroforestry system based on fruit tree

2.4 Impact of light and temperature on potato production

2.5 Effect of planting spacing on potato

2.6 Performance of potato in agroforestry systems

2.1 Concept and Benefit from Agroforestry System

Dagar and Minhas (2016) stated that cultivation of trees and agricultural crops in intimate combination with one another is an ancient practice that farmers have used throught out the world, but agroforestry as a science has a recent origin. Agroforestry now has come of age during the past 35 years. During the earlier stages of this period, traditional practices involving numerous indigenous forms of trees and crops with and without animals were dominant and explained in emerging literature of agroforestry.

Nair *et al*., (2016) recently have shown the concern that over the years the emphasis on the study of such indigenous agroforestry systems (AFS) has been slide lined or ignored. Such location specific, time-tasted, indigenous systems that have been passed or ignored by "modern" agroforestry research have a lot to contribute to the development of improved agroforestry systems and practices.

Nair *et al*., (2016) also stated that today, agroforestry represents the modern, science based approach to harness the sustainability attributes and production benefits of such time tasted practices, and its demonstrated role in sustaining crop yields ,diversifying farm production, realizing ecosystem services, and ensuring environmental integrity in land use in receiving increasing attention in development programs including climate change around the world.

Pandit *et al*., (2014) stated that agroforestry has been recognized as one of the important systems for supporting the livelihoods of a large number of rural farmers in the Nepalese hills. However, its conversation and socio economic values have received little attention. This resulted in increased livelihood benefits to local people .Production of goat meat and buffalo milk has increased considerably .The high economic benefits are mainly associated with the introduction of various fodder trees and grasses in private farm land. It is concluded that the various divers of the Agroforestry system need to be carefully attended so as to improve both positive conservation and livelihood outcomes. Enabling policy and practices are needed to initiate and support farming cooperatives in the commercialization of Agroforestry products and market the conservation values in a changing climate.

Korwar *et al.,* (2014) stated that Agroforestry in rainfed areas increases livelihood security through simultaneous production of food, fodder, and firewood, and an increase in total productivity per unit area of land. To enhance rural livelihood security among the dry land farmers, several improved Agroforestry systems, commercial plantations and biofuels and bioenergy systems came into being for adoption. Agroforestry plantation-based success stories reveal livelihood security of small, marginal, and landless farmers. Steps to promote basic and promotional Agroforestry research in dry land agriculture and appropriate policy responses with extension outreach may potentially deliver better results in rainfed agriculture. Rainfed Agroforestry for livelihood security reflects the positive way in utilization of rainfed area resources.

Rahman *et al.,* (2012) stated that in the Padma floodplain of Bangladesh, the traditional system of agriculture has become unsustainable due to high population growth. Mango based Agroforestry which has been practiced by the farmers since the 1990's, is a promising alternative and is considered as one of the few options to lift farmers out of poverty and improve livelihood security. Farmers with the least land were found to allocate a higher percentage of their land to Agroforestry and the increased income from Agroforestry compared to other agricultural systems helps reduce relative poverty. This income maintains basic household needs, providing food security and fuel wood, and contributes to healthcare, housing and sanitation conditions, and meeting educational expenses.

Brodt *et al.,* (2009) stated that although hedgerows, windbreaks, and other biodiversity enhancing farm edge features offer the potential for ecosystem benefits without occupying much crop space, relatively few farms in California, USA include such features. We also identified social, economic, and agronomic incentives and constraints to installing biodiversity-enhancing edge features. More than one-third of the study farmers had installed native hedgerows, windbreaks, and/or grassed edges. Interviews demonstrated the importance of socially influential farmers working in tandem with public and private agencies to build initial interest in these practices. However, these features occupied less than four percent of all possible edge length. Constraints to increasing adoption included high costs, fear of harboring weeds and rodents, and lack of certainty about ecosystems benefits, highlighting the need for cost-share programs and more regionally-focused agro-ecological research.

Gupta R.K and Ajay Gulati (2009) stated that two Agroforestry systems were established on reclaimed mine sites in NE-Germany (Lusatia) and Central Germany (Helmstedt). The yield potential and the sustainability of yields were studied for different clones of poplar (Populus spp.), willow (*Salix viminalis* L.), and black locust (*Robinia pseudoacacia* L.), considering different rotation periods (3-, 6-, and 9-year-rotation) and approaches of soil amelioration (mineral fertilizer, compost). In the Agroforestry system in Lusatia, special emphasis was given to the interaction between trees (*R. pseudoacacia*) and crops (*Medicago sativa* L.). Considering the land equivalent ratio (LER), *R. pseudoacacia* hedge rows have practically no negative influence on yields of *M. sativa*. Hence, with regard to an increasing demand for woody biomass, alley cropping with *R.*

pseudoacaci and crops such as *M. sativa* may provide a promising alternative for future land use in the temperate zone.

Batish and Daizy (2008) stated that perhaps the greatest benefit of AF systems (especially in the developing world) is their use in weed and pest management. Weeds and pests interfere with primary crop productivity, and can have huge impacts on harvest levels. Use of pesticides and herbicides in the west to control weeds has led to many unintended effects on non-target organisms, environmental degradation, and reduced sustainability of crop land. Pesticides are also relatively affordable in the west, but prohibitively expensive in much of the developing world. Although there have been contrasting studies on both sides of the issue, the general consensus is that AF crops reduce weed population due to shading. They also decrease insect attacks by providing a physical barrier to airborne pests and pathogens.

ICRAF (2008) showed that agroforestry helps in diversifying and sustaining production of the broad spectrum of agricultural commodities for enhanced economic, environmental, and social benefits by integrating trees on farms and in the agricultural landscape.

Batish and Daizy (2008) according to ("Ecological interactions in AGF overview") stated that the United Nations has set a list of Millennium Development Goals (MDG) aimed at: eradicating poverty and hunger, bettering health, nutrition, and education to people, gender equality, and environmental sustainability, particularly in the developing world. AF is substantially assisting the UN in meeting these goals.

Economic gain has been identified as the primary motivating factor in the adoption of Agroforestry in the US. Agroforestry practices must offer at least as much income potential without increasing risk, compared to current farming practices, and better scenarios for solving conservation problems than the current farming practice for adoption to take place. Incentives for Agroforestry can be implemented to provide economic or ecological benefits to the landowner and entice them to adopt practices that may have been too risky or foreign to them prior to the incentives.

National Agroforestry Center investigated the funding incentives available through the federal, state and non-governmental organizations (NGO) for the five Agroforestry practices. Cost sharing was found to be the most commonly used incentive. Other incentives such as producer grants, land rental payments, financial incentive payments and technical assistance were also identified. Most federal funding available for Agroforestry practices is distributed through the United States Department of Agriculture (USDA), while the state of Missouri funding is available through the Missouri Department of Agriculture (MDA).

Groot and Van der (2010) stated that agroforestry is a land use option that increase livelihood security and reduce vulnerability to climate and environmental change .Regarding agroforestry systems very few studies are being conducted have estimated the economic values of local goods and services provided by planted forests in selected villages in northern India. Moreover, the agroforestry systems that have been traditionally practicing only return the subsistence need of the local people and from this subsistence return; the socioeconomic status has not been uplifted. The present need is the commercial and semi-commercial return from their productions and the resources. Keeping these facts, the study was carried out with objective of to identify the existing agroforestry practices and impacts of the agroforestry practices on their socio-economic conditions.

Garrity (2004) stated that agroforestry systems, composed by trees, agricultural crops and/or animal production have the potential to enhance soil fertility, reduce soil erosion, improve water quality, enhance biodiversity, maintain and increase aesthetics and sequester carbon. Other rural spaces with non-agricultural land uses, for example wetlands and woodlands, also deliver multiple services including habitat provision, pollinators and recreation.

Dixon and Pagiola (1998) stated that value (TEV) has become a framework widely used for quantifying the utilitarian value of ecosystems (Barbier, 2007). This framework normally dis-aggregates TEV into two categories: use values and non-use values. Use values comprise three elements: direct use, indirect use and option values. It is also known as the extractive, consumptive or structural use value and derives mainly from goods that can be extracted, consumed or enjoyed directly ,Indirect use value is also known as the non-extractive use value or functional value and derives mainly from the services provided by the environment . Option value is the value attached to maintaining the option to take advantage of the use value of something at a later time.

Adekunle and Bakare (2004) stated that agroforestry has many potential, such as enhance the overall (biomass) productivity, soil fertility improvement, soil conservation, nutrient recycling, micro climate improvement, carbon sequestration, bio drainage, bio energy and bio fuel etc. Now day's agroforestry has gained popularity among farmers, researchers, policy makers and other for its ability to contribute significantly in meeting deficit of tree products, socio economic and environmental benefits. Variety of agroforestry systems for environmental sustainability taungya Farming: This system has been used as a method of establishing forestry plantation. This consists of growing annual agricultural crops along with the forestry species during the early years of establishment of the forestry plantation. Usually the land belongs to the forestry department or their large scale leases, who allow the subsistence farmers to raise their crops. The farmers are required to tend the forestry seedlings and, in return, retain a part or all of the agricultural produce. It is an agreement that will last for two or three years, during which time the forestry species would grow and expand its canopy (Adekunle and Bakare, 2004). It was described as a way of completely utilization of forest soil for increase agricultural production in developing nations. It is an avenue for farmers to participate in tree planting and be directly involved in afforestation project of the government. (Otegbeye and Famuyide 2005) also indicated that, taungya farming was widely adopted in the arid and semi- arid land of Nigeria, as a method of reforestation.

Kang (1993) stated that rural people have been discovered to have a wealth of indigenous knowledge and have incorporated trees in production systems in areas where they lived for a very long period of time. Agroforestry has both protective and social-economic benefit. Besides direct agricultural benefit, trees exhibit social - economic values. The benefit of the tree components derived by farmers from agroforestry was evaluated from a social economic and ecological perspective (Anderson and Sinclair, 1993). The social - economic benefits of agroforestry can be evaluated in terms of productivity, stability and sustainability.

Singh *et al.,* (2013) stated that soil fertility in their AF plots has increased particularly after the planted trees have grown up and their crop yields have improved. This is in agreement with (Buresh and Tian 1998) who noted that trees improve soil properties in various ways and via several processes. Generally, agroforestry practices increases the soil organic matter through leaf litter addition. It maintains the population dynamics of beneficial microorganism and improves biological nitrogen fixation in soil. All microbiological activity in soil contributes to cycling of nutrient and other ecosystem functions and all soil functions contributes to ecosystem services. Recycling in natural system is one of the many ecosystem services that sustain and contribute to the wellbeing of human society (Jhariya and Raj, 2014). The valuation of ecosystem services has been receiving increasing attention from various society sectors as a way of providing more concrete data on the value and importance of biodiversity and ecosystems to populaces (Groot and Van der, 2010) The quantification of economic values can, and regularly does, provide useful information for public decisions, especially when the limitations as well as the strengths of the values are recognized (Barbier, 2009). Accurate estimation of ecosystem service values allows the incorporation of otherwise un-quantified values into dominant decision-making frameworks such as benefit cost analysis, economic impact assessments and regulatory impact statements, along with more readily quantified financial costs and benefits (Groot and Van der, 2010).Increased productivity, improved soil fertility, nutrient cycling, soil conservation are the major positive effects of interactions and competition is the main negative effect of interaction, which substantially reduces the crop yield. It may be for space, light, nutrients and moisture. Ecological sustainability and success of any agroforestry system depends on the inter-play and complementarily between negative and positive interactions. It can yield positive results only if positive interactions outweigh the negative interactions.

Tayeb and Osman (2011) reported that in the early year of the agroforestry system, the intercrop of annual crops helps to increase vegetation cover over land (35 20 29). Fuel wood is the most common source of energy that farmers in the study site use for cooking as in other parts of the region. It was estimated that the average annual household consumption is about 19 M3 of wood for provision of energy and building material. Participants mentioned that fuel wood is obtained from many sources, including trees in own plots, natural forests, buying from private sources.

Groot and van der (2010) stated that in addition to maintaining ecosystem (and biosphere) health, they provide many services with direct and indirect benefits to humans such as clean air, water and soil, nutrient regulation, disturbance prevention, biological control and pollination; 3) Information functions (or cultural services) are those services that contribute to human mental well-being. Major categories of cultural services associated with forests are aesthetic and recreational use, spiritual and religious services and importance to cultural heritage, and 4) Habitat functions (or supporting services) relate to the importance of ecosystems to provide habitat for various stages in the life cycles of wild plants and animals, which, in turn, maintain biological and genetic diversity and evolutionary processes. The valuation of ecosystem services has been receiving increasing attention from various society sectors as a way of providing more concrete data on the value and importance of biodiversity and ecosystems to populaces .The quantification of economic values can, and regularly does, provide useful information for public decisions, especially when the limitations as well as the strengths of the values are recognized.

Nair *et al.,* (2009) stated that agroforestry for CO_2 mitigation Climate change is a burning issue of the world. Rise in CO_2 level accelerate the global warming which necessitated the sink and sequestration of carbon. These problems are mitigated through plantation of valuable tree and crop either singly or simultaneously on same piece of land through agroforestry system. As per under the agroforestry system carbon sequestration has potential to mitigate the greenhouse gases because of greater efficiency of resource (nutrients light and water) capture and utilization.

Oboho (1989) stated that mixed farming system practiced by majority of the farming communities indicated the existence of traditional agroforestry system common in the semi-arid zones of Nigeria (Oboho, 1989). Integration of trees into farming system and subsequent modification of the system could be easy with earlier understanding of the importance of trees in the farming system. Similarly, the practice of animal production could make the intensification of fodder bank system an easily acceptable agroforestry model.

Sudha *et al.,* (2007) stated that reforestation and agro-forestry systems offer perhaps the greatest potential to remove large quantities of carbon from the atmosphere. However, agroforestry is an attractive option for climate change mitigation as it sequesters carbon in vegetation and soil, produces wood, serving as substitute for similar products that are unsustainably harvested from natural forests, and also contributes to farmers' income.

Kursten (2000) stated that agroforestry can, arguably, increase the amount of C stored in lands devoted to agriculture, while still allowing for the growing of food crops. Socioeconomic development Agro-forestry as a land use system that integrates trees, crops and animals in a way that is scientifically sound, ecologically desirable, practically feasible and socially acceptable to the farmers (Nair, 1979). It can improve the livelihoods of smallholder farmers as by providing fruit and nuts, fuel wood, timber, medicine, fodder for livestock, green fertilizers, additional diversified income agroforestry models for different site conditions have to be developed and demonstrated under different agro-ecological regions in the country (WAC, 2010).

Singh *et al.,* (2013).tree crop interaction under the agroforestry system the interaction between tree and crop are studied in positive, negative and neutral way. This interaction are depends upon the type of model including varying species, their nature and composition. Further, interaction is defined as the effect of one component of a system on the performance of another component and/or the overall system (Nair, 1993). Various interactions take place between the tree and herbaceous plants (crops and pasture), which are referred to as the tree-crop interface. Studying tree crop interaction in agroforestry would help to devise appropriate ways to increase overall productivity of land. Increased productivity, improved soil fertility, nutrient cycling, soil conservation are the major positive effects of interactions and competition is the main negative effect of interaction, which substantially reduces the crop yield. It may be for space, light, nutrients and moisture. Ecological sustainability and success of any agroforestry system depends on the inter-play and complementarily between negative and positive interactions. It can yield positive results only if positive interactions outweigh the negative interactions.

Shakoor *et al.,* (2011) stated that the role of agroforestry in protecting the environment and providing a number of ecosystem services is promoted as a key benefit of integrating trees into farming systems. As traditionally employed in India, these benefits were intuitive to the farmers and landowners that managed agroforestry systems, although the scientific evidence to support such benefits is only now coming to light the impact of agroforestry on the environment occurs at a range of spatial and temporal scales; from fine-scale impacts on soil structure and quality to impacts on the environment and society at regional or global scales. Agroforestry can improve the resilience of agricultural production to current climate variability as well as long-term climate change through the use of trees for intensification, diversification and buffering of farming systems.

Sun *et al.,* (2008) stated that the economics of hedgerow systems have been studied, and results look very promising. Most studies cite the number one initial effect of hedgerow systems being an increase in productivity from the start. This is achieved through a stabilized moisture regime, and the 23 increased soil fertility has benefits alluded to previously. One study showed yields of maize increasing up to 22 percent without fertilizer addition, and up to 70 percent increase with fertilizer use.

Dorr (2006) found a lifestyle attitude that is represented as “loss of trees as a problem” to be interested in the Agroforestry practices except for windbreaks where it was found not significant. These result shows that attitudes are not the most important factor influencing conservation practices but play an important role in whether there is interest in new practices.

Singh *et al.,* (2005) stated that increased food production can be achieved in different ways by an increase in the area of land, devoted to farming or by increasing the productivity of land already farmed. The most suitable land has already been used for farming and even the area of this land is being reduced by urban demands for more houses and roads, more industrial development and more amenity areas. So the next available alternative of raising productivity of land already farmed has gained momentum through adoption of Agroforestry practices. In a changing scenario of decreasing availability of good arable land for agriculture, degradation of soil and water resources, increasing environmental pollution, the new approaches in farming systems have made rapid strides in the last two decades. Making the country self-sufficient in food, fodder, fiber, firewood and timber production deliberate inclusion of trees in the existing farming/cropping systems and adoption of Agroforestry approaches on all kinds of land is one of the viable options to achieve sustainability while optimizing productivity. The most important factor responsible for such an achievement is the widespread adoption of Agroforestry technology.

Brandle *et al.,* (2004) listed the following economic benefits of Agroforestry:

1. When various species are included in the design, they can contribute directly to the production of nuts, fruits, timber and other wood products. This helps to diversify and increase farming income while also providing a stock of capital in valuable timber.
2. When used in livestock production systems, they improve animal health, improve feed efficiency and contribute to the economic returns of producers.

3. The practices can also help to reduce energy consumption by the farm and improved working conditions within the farm area, which helps to save cost and increases productivity.
4. Agroforestry technology can reduce costs of production, increase productivity and provide multiple outputs.

Puri and Nair (2004) observed the value and assessed the social, cultural and economic benefits of various tangible and intangible benefits of Agroforestry, but the socioeconomic processes involved in the success and failure of Agroforestry have not been investigated. On the other hand, the success stories of wasteland reclamation and poplar-based Agroforestry have shown that the technologies are widely adopted when their scientific principles are understood and socio-economic benefits are convincing.

Alavalapati *et al.,* (2004) stated that Agroforestry systems (AFS) provide a mix of market goods and nonmarket goods and services. We postulate that if nonmarket goods and services can be internalized to the benefit of landowners, the adoption of AFS will increase. It has been found that the profitability of silvopasture would increase, relative to conventional ranching, if environmental services are included. Estimates of public willingness to pay for environmental services associated with silvopasture and estimates of ranchers' willingness to accept for the adoption of silvopasture will provide a scientific basis for policy development.

King (1987) after tracing the history of agroforestry stated that in Europe, until the Middle Ages, it was the general custom to clear-fell degraded forest, burn the slash, cultivate food crops for varying periods on the cleared area, and plant or sow trees before, along with, or after sowing agricultural crops.

Conklin (1957) stated that in Southeast Asia, the Human of the Philippines practiced a complex and somewhat sophisticated type of shifting cultivation. While clearing the forest for agricultural use, they deliberately spared certain trees which, by the end of the rice growing season, provided partial canopy of new foliage to prevent the excessive exposure of the soil to the sun. Trees were an indispensable part of this farming system to provide food, medicines, construction wood, and cosmetics.

2.2 Mango based agroforestry system

Nair (1989) stated that mango is an important component of agroforestry systems in many parts of the world. Mango offers great advantage in agroforestry due to the spatial advantage it provides for intercropping, as it is generally planted at wide spacing to accommodate the large crowns that are needed to support the fruit yield. Wider spacing of the trees ensures large gaps in the canopy up to 30% of the land area. They also offer ample scope for exploitation of soil depth due to spatially differential root distribution of component crops in the system ensuring a higher nutrient and water use efficiency. Root abundance of plants is usually highest at the topsoil (Canadell *et al.,* 1996). Tree crops are not an exception and often have their maximum root length density stretching from shallow organic litter layer to several meters depth. However, root distribution is primarily function of the tree species or the genotype which is often modified by cropping system and stand management practices. Shaded tree crops such as coffee and cacao tend to have a shallower root activity than the grown fruit trees (Lehmann, 2003). Mango has a long taproot that can often reach up to 6 m soil depth. Bulk of the root activity (75 %) in mango was found to be at a shallow depth (47.3 cm) in an 18 year old tree while it was estimated to be as deep as 215.9 cm in an 8 year old tree. This wide variation in root activity provides scope for effective integration of other crops.

Alam *et. al.,* (2005) stated that mango (*Mangifera indica*) is the predominant fruit tree crop in the tropics. Apart from its delicious fruits, mango is grown for multiple uses like small timber, firewood, poles, pepper support, organic matter for soil amendment, living fence post, shade, soil conservation and cattle feed in homesteads. Mangoes are planted at wider spacing to accommodate large crowns for higher fruit yields and provide ample scope for intercropping. During the early non–competitive establishment phase of mango, variety of intercrops can be cultivated. On account of its versatility, mango forms a potential component in many agroforestry systems. As well as wild grown mangoes have a potential to grow as tall as 30 m to occupy the top canopy in forests. However, mangoes when cultivated are pruned Mango in agroforestry 3 to a level less than 10 m to enable well spreading of crown and ease of harvest. The trees generally branch at a height of 0.6–2 m above ground level. Mangoes do not make a good over story tree for cropping shade– tolerant species as their dense canopy produces heavy shade due to low branching and evergreen dense foliage. This poses serious limitations to intercropping with shade intolerant crops. However, mango orchards in their early stages of development offer ample scope for intercropping.

Alum *et al.,* (2010) stated that fruit tree proportion in traditional homesteads is higher (>75% of trees species) of which probably mango forms the most integral component. Mango is more often encountered as a component of home gardens, where they are allowed to grow taller and leaving space for the incorporation of components beneath its canopy. Farmers had strong preference for fruit species over timber yielding ones in homesteads of Bangladesh because of better growth and among fruit trees mango was the most popular species.

Gebauer (2005) stated that long rotation fruit trees such as mango constitute dominant horticultural crop in tropical agroforestry system. Mango based agri-horticultural systems consist of three main components viz. main crop, filler crop and inter crops which occupy three different tiers in space of the production system. The main crop (mango) in the system is planted at a wider spacing of 10m x 10m to 12m x 12 m providing enough space in the early period for incorporation of inter crops. Mango with its large crown constitutes the upper most layer of the multitier system. As mangoes seldom utilize the full site potential before 15–20 years, it can be safely intercropped with compatible crops up to 10 years. The filler crops are usually short statured crops with small crown and non–competitive nature. Mango based alley cropping is popular and widely followed in many parts of the world (Rahman *et al.,* 2008). Since mango takes several years to grow to its full size, intercropping to utilize the interspaces is desirable. Mango trees are planted in rows. Paddy, wheat, sugarcane, papaya, banana, ginger, turmeric and different types of vegetables like potato, dolichos bean, and lady's finger are intercropped in between the hedge rows of mango trees to provide a cash flow – particularly in the early years after the mangoes have been planted but have yet to yield. Quiet often the alleys are wide enough (10 or 12m) to accommodate a variety of agricultural crops. However, one has to be careful in choosing (Zaman *et al.,* 2010).

Musvoto *et al.,* (2000) reported that mango is often managed as multipurpose tree grown in association with herbaceous crops. They also said that although intercropping mangoes and herbaceous crops is a widespread practice in Zimbabwe, mango trees are generally perceived as having negative effects on crop growth and yield. The authors point out that although maize is the staple food crop and the most important source of income for farmers, it is still widely intercropped with mangoes despite the farmers' awareness of the negative effects mangoes have on crop yields. The value of mango trees as a source of fruit for households may be sufficiently high that farmers are prepared to sacrifice some maize yield for mango production. This is in consistent with results from research on tree–crop associations (Ralhan *et al.,* 1992; Farrell, 1990). Mango based agri–horticulture system is an important agroforestry system in Andhra Pradesh state of India (Sreemannarayana and Prasadini.2007). Mango offer good scope for growing many shade tolerant medicinal crops. Like other plants, light demanding medicinal plants could be incorporated in mango orchards early in its development stage. The compatible crop combinations (Alum, 2011). Fruit crops like mango and guava constitute a major share of area expansion programme under fruit crops in the region. Long juvenile period, heavy mortality of the plants during the summer season due to grazing and lack of irrigation are two major factors which discourage the farmers to take up mango orchard. Again, low productivity of mango under the uplands of this region makes mango cultivation, unprofitable under the eastern plateau and hill region. Hence, development of a profitable mango based production system with income from the first year onwards can help in alluring the farmers to take up mango orchard. Integration of a precocious bearing filler plants in a multitier system can address to the need for income from the initial years of orchard establishment in mango.

Swain (2006) stated that mango has become naturalized and adapted throughout the tropics and subtropics. Mango plays an important part in the diet and cuisine of many diverse cultures. This delicious fruit is particularly rich in nutrients such as protein, vitamin A, fiber, thiamine, ascorbic acid etc. The fruit is eaten as green, processed pickles, pulps, jams and is frozen or dried. Mango trees are usually between 3 and 10 m (10 - 33 ft.) tall but can reach up to 30 m (100 ft.) in some forest situation. The canopy is evergreen. Mango trees are recognized as national tree of Bangladesh, and eaten throughout the world. Mango covered 78,196 acres area under garden having total production of 304,187 metric tons in 2007-2008.

Musvoto *et al.,* (2000) stated that, mango litter decomposes at slower rate compared to many tropical trees. Moreover, have quantity and quality of litter production is an important characteristic of a tree useful for agroforestry systems. Small holding farmers often substitute high cost mineral fertilizers with plant litter as a plant nutritional source. Plant litter also helps in maintaining soil physical properties such as, aggregate stability and water–holding capacity. Trees in agroforestry systems can be an important source of such plant residues. Accumulation of organic matter in soils too depends mainly on inputs and decomposition rates of organic material. This in turn results in enhanced biological activity in the system leading to ecological stability in the rhizosphere.

Swaminathan *et al.*, (1999) stated that mature mangoes can be successfully mixed with other similarly vigorous species such as jackfruit, avocado, breadfruit, coconut, guava, or rambutan. About increase in height growth of mango was registered when mango was inter planted with leucaena .The authors identified casuarinas and leucaena as two nitrogen fixing trees ideal for inter planting with the mango in early establishment period. The same author at a later stage observed a 12% reduction in the growth of mango when co– planted with casuarinas or leucaena. Further it was also revealed that eucalyptus was incompatible with mango, potato + pumpkin, pumpkin after potato, vegetable pea, pumpkin after vegetable pea, garlic and onion after potato in association with mango were also observed. Productivity of crops under mango soil fertile in rainfed condition is low and unstable; and often optimum yield cannot be achieved because of aberrant monsoon behavior and erosion prone. Therefore, some alternate land use systems are to be developed for such lands. Fruit-based agroforestry system is an alternative land use system that integrates the cultivation of arable crops, fruit trees and silvi components.

2.3 Agroforestry system based on fruit tree

Mondal *et al*., (2012) reported that monoculture produced the highest yields of individual crops but in intercropping system the highest groundnut equivalent yield (10.63 t/h and 11.10 t/ha) was obtained from two rows of carrot in between two rows of groundnut. The maximum land equivalent ratio (1.67 and 1.74), the highest gross return (Tk.212600/ha and Tk. 248400/ha) and net return (Tk.184881/ha and Tk.211680) were also obtained from the intercropping treatment with two rows carrot in between two normal rows of groundnut. But due to higher cost in this treatment, maximum benefit cost ratio (7.09 and 7.01) was obtained from the intercropping treatment with one row carrot in between two normal rows of groundnut in both the years.

Hasanuzzaman *et al.*, (2014) stated that cropland agroforestry is an important production system in the southwest region of Bangladesh. This study focused on the floristic composition and management of existing cropland agroforests. A total of 313 cropland agroforests were surveyed and 83% respondents practiced pure agroforestry while the remaining 17% practiced agroforestry with fisheries. A total of 18 forest trees and 2 shrubs were recorded from 11 families and 59 species of agricultural crops were from 28 families. A higher proportion (79%) of cropland agroforests were occupied small land areas (0.12–0.80 ha). About 63% of respondents planted trees for fruit production and 47% for timber production, and 35% of respondents engaged in commercial production (35%). *Swietenia macrophylla* was the most prevalent species (relative prevalence 20.83) followed by *Mangifera indica* (relative prevalence 15.57) and *Cocos nucifera* (relative prevalence 7.08).Shorter spacing was used for timber and fuel wood species and wider spacing for fruit trees. A wide range of rotation periods, from 5 to 25 years, was observed for both cases.

Dhakal *et al.,* (2012) stated that agroforestry-based farming systems evolved in the Dhanusha district of Nepal following the conversion of forest into agriculture during the early 1950s. The experts' discussion resulted in a scale to differentiate the prevailing farming systems in the study area considering five key components of agroforestry: agricultural crops, livestock, forest tree crops, fruit tree crops and vegetable crops. The study reveals that land use had generally changed from very simple agriculture to agroforestry, triggered by infrastructure development, technological innovations, institutional support (subsidies and buy-back guarantees) and extension programs. The three types of agroforestry systems, which are the focus of this study, varied significantly in terms of farm size, cropping intensity, use of farm inputs, tree species diversity, tree density, home to forest distance and agricultural labour force.

Rahman *et al.,* (2010) conducted a field experiment at the Bangladesh Agricultural University germplasm center, fruit tree improvement project (FTIP), Department of Horticulture, Bangladesh Agricultural University, Mymensingh, during July to November, 2008 to find out the performances of tomato under different multistoried agroforestry production system and open field condition. Different multistoried agroforestry system such as Amloki + Guava based agrofrestry system (T1), Horitaki + Lemon based agroforestry system (T2) and Bohera+lemon based agroforestry system (T3) were investigated in the study. Tomato was grown following the RCBD design with three replications. The study showed that except plant height all others morphological characters viz. Number of branches per plant, number of leaves per plant, number of fruits per plant, fruit length, fruit diameter and single fruit weight were highest in open field condition among the different agroforestry systems (Multistoried vegetation), highest yield was obtained in Horitaki + lemon + tomato based agroforestry system, which was 16.67% lower than open field condition.

Ali *et al.,* (2010) conducted a field experiment to evaluate the performance of four Cane species under different multipurpose tree species. The treatments were three tree species viz. Mehogony, Deshi neem and Eucalyptus, which were used as the upper storey. There was also a control (Open field) treatment. Four cane species namely Bhudum beth, Udum beth, Jali beth and Golla beth were used as the middle storey non-woody perennial. His aim of the experiments was to study the growth performance and selection of potential cane species under different multipurpose tree based Agroforestry system. Considering cane species, jali beth was the best performer compared to other cane species. Udum beth + Deshi Neem were found as the best combination followed by Udum beth + Mehogony combination and Udum beth + Eucalyptus combination. Significantly the lowest performance was found in open field irrespective of cane species. While the tree effects, Mehogony was the best one followed by Deshi neem and significantly the poorest performance was found in the open field.

Singh (2007) studied that pure guava cultivation was an old concept; utilization of its interspace with traditional cropping system was profitable in Gangetic region of Uttar Pradesh. The farm families of Mainpuri, Etah, Budaun, Hardoi, Farrukhabad, Kannauj, Unnao, Kanpur Nagar, Lucknow, Sitapur and Allahabad adopted the cultivation of wheat, potato, vegetable pea, cucurbits, onion, summer moong, summer urd, okra, sweet potato and barley as parallel crops in association of guava plantation. At the initial stage, guava fruits was 150-250 q/ha while, wheat, potato, vegetable pea, cucurbits, onion, summer urd/moong, okra, sweet potato and barley yielded 30, 220, 95, 180, 235, 6, 80, 190 and 32 q/ha, respectively, with protective irrigation.

Islam (2005) conducted an experiment to investigated the performance of lemon and guava grown under coconut multistoried agroforestry system and observed a significant influence on yield, yield attributing and quality parameters of lemon as well as guava. The best yield of lemon was found in the coconut + lemon based agroforestry system while the highest yield of guava was obtained from the open conditions.

Bellow and Nair (2003) surprisingly found in comparison to other types of trees, the research conducted on fruit trees in the areas such as tree-crop interactions and the appropriate horticultural and agronomic management regimes needed to optimize total yields of mixed systems in particular biophysical and social environments are extremely scarce. An exception is for those fruit trees such as *Coffea* spp. or *Theobroma* spp. Grown as understory species where the tree is treated more like the annual crop component and the tree component is more frequently from the timber category. Research similar to historical agronomic and horticultural research is needed to identify optimal stand densities, fertilization regimes, and planting and management practices in fruit-tree based agroforestry systems in order to maximize the benefits that these systems will produce.

McDonald *et al.,* (2003) study the farmers in Jamaica's Blue Mountains reported interest in planting trees on their farms; their preferred trees were described as multipurpose trees with fruit as one of their products and the majority of existing trees were fruit trees.

Briggs and Twomlow (2002) study in Southern Uganda, *Musa* spp. was the dominant perennial managed on farms and farmers generally allocated land to this herbaceous perennial in a ratio of 2:1 versus annual crops such as maize (*Zea mays* L.) and bean (*Vigna* and *Phaseolus* spp.).

Osei *et al.,* (2002) have undertaken an experiment to compare the merits of four cacao-coconut intercropping systems with the traditional cultivation of cacao under *Gliricidia sepium* shade at the Cocoa Research Institute of Ghana. Cacao seedling girth was not affected when intercropped with coconut but was significantly (P=0.01) reduced when intercropped with *G. sepium*. High density cacao facilitated better early canopy formation. Yield of cacao spaced at 2.5 m triangular (1739 plants ha-1) with coconut at 9.8 m triangular (105 plants ha-1) was significantly higher (P=0.05) than from the other treatments during 1993/94 to 1995/96. Widely spaced coconuts intercropped with cacao spaced at 3 m × 3 m showed better flowering and gave higher coconut yields, but cacao spaced at 2.5 m triangular under coconuts spaced at 9.8 m triangular was more profitable than the other treatments. Moisture stress was the greatest in cacao system with *G. sepium* shade and this could be responsible for the low yield of cacao in that treatment. It is suggested that properly arranged high density cacao under widely spaced coconuts can be a profitable intercrop system for adoption by cacao farmers in Ghana.

Bellow (2004) mentioned that Worldwide, fruit-tree-based agroforestry systems have been only modestly studied, especially in terms of the quantification of biophysical interactions occurring in mixtures of fruit trees and crops. Agroforestry systems based on apple (*Malus spp*.), peach (*Prunus spp*.), and pear (*Pyrus spp*.) are common in northwest Guatemala as low intensity home gardens. The first portion of the study evaluated the productivity of mixed cropping of fruit trees with annual crops as influenced by biophysical mechanisms. The second portion of the study investigated the potential for adoption of fruit-tree-based agroforestry by resource limited farmers in the region using ethnographic investigation and linear programming simulations. The on-station experiment included the following: sole crops and additive intercrops of maize (*Zea mays*) and fava (*Vicia faba* major), and clean weeding without crops as understory treatments, and eight-year-old pear trees or artificial shade structures as over story treatments. Growth and yields of all components were measured during 2002 and 2003. Mixed cropping of fruit trees + annuals showed significant yield advantages over maize + fava intercropping, which was superior to sole cropping of the same species. Annual-crop yields were generally unaffected by over story treatments making fruit yields an additive benefit. Pear + fava mixed cropping improved yields of top-grade pears with no reductions in fruit quality. The results suggest small farm productivity and fruit quality can be increased through careful association of fruit trees with annual crops. Increased capture of growth resources (radiation and precipitation) by the fruit-tree + crop mixture suggests that the resources are not efficiently used by the sole crop stand and the increased resource use was at least partially responsible for the realized gains. On-farm studies indicated that fruit-tree-based agroforestry was potentially more attractive to relatively prosperous families or those with larger land holdings. The inability to meet annual food security needs, poor fruit quality, and lack of market infrastructure were identified as factors that limit adoption. The complementarily of production with the dominant maize crop, home consumption of fruit, and the potential to generate additional cash on limited land holdings were identified as promoting adoption of fruit-tree-based-agroforestry within some groups.

Rahman *et al*., (2010) conducted a field experiment at the Bangladesh Agricultural University germplasm center, fruit tree improvement project (FTIP), Department of Horticulture, Bangladesh Agricultural University, Mymensingh, during July to November, 2008 to find out the performances of tomato under different multistoried agroforestry production system and open field condition. Different multistoried agroforestry system such as Amloki + Guava based agrofrestry system (T1), Horitaki +

Lemon based agroforestry system (T2) and Bohera + lemon based agroforestry system (T3) were investigated in the study. Tomato was grown following the RCBD design with three replications. The study showed that except plant height all others morphological characters viz. Number of branches per plant, number of leaves per plant, number of fruits per plant, fruit length, fruit diameter and single fruit weight were highest in open field condition among the different agroforestry systems (Multistoried vegetation), highest yield was obtained in Horitaki + lemon + tomato based agroforestry system, which was 16.67% lower than open field condition.

Ceccolini (2002) study in Soqotra Island, a remote location near the Yemeni coast, the presence of fruit trees appeared to be most closely related to subsistence, as opposed to market gardening. The number of large fruit trees declined as the importance of crops destined for the market increased, highlighting the potential importance of the income generating aspects of fruit-tree management and the relative value of the various products.

Mendez *et al.,* (2001) found that Nicaraguan home gardens had 37% of their total space allocated to fruit producing species, on average; moreover, 85% of the fruits so produced were for home consumption and the remainder for marketing. When farmers in Jamaica were questioned as to the importance of trees, fruit was given as the second most important product following timber.

Quartieria *et al.,* (2002) investigated the competition effects with fruit trees, it is important to take into account the multi-year nature of growth cycles and responses. For pear, it was shown 32 that N taken up at or after harvest was preferentially used during the following year for growth and fruiting.

Korikanthimath *et al.,* (2000) conducted an experiment at Sirsi, Karnataka during 1992-95 to explore the possibility of cultivating cardamom (*Elettaria cardamomum* Maton) as a mixed crop with coconut. The average size of coconut holdings is as low as 0.22 ha and 98% of the holdings are below 2 ha. The results revealed that tall coconuts and short cardamom plants with varying rooting patterns and spacings intercepted solar energy at different vertical heights, and their roots (rhizosphere) absorbed nutrients and soil moisture at different depths and lateral distances. The coconut canopy provided adequate shade for shade-loving cardamom in this multi-strayed cropping system. Intercropping with cardamom reduced coconut yield compared with coconuts in monoculture (mean values of 85.7 compared with 91.3 nuts/palm), but intercropping with high value cardamom increased overall profits (cardamom yields in 1993-94 and 1994-95 were 15.66 and 554.2 kg/ha, respectively).

Salam *et al.,* (2000) investigated the food production from trees was categorized as "not important" by only 15.1 % of farmers in this study while generation of household income was cited as very important by 87.8 %; ecological functions of trees in the landscape were scarcely considered. The availability of labor to establish and care for trees and the potential conflict between agricultural production and tree establishment were noted as important constraints.

In a field trial conducted during 1994-95 and 1995-96 by Hegde *et al.,* (2000) to investigate the performance of ginger cv. Suprabha grown as intercrop in an adult arecanut plantation (30-year-old) at the Agricultural Research Station (Pepper), Sirsi, Karnataka, India, and its performance was compared with those planted under open conditions. Ginger plants grown as intercrop were significantly taller than those under open conditions (pure crop) when measured 200 days after planting and had significantly lower number of functional leaves and tillers per clump. Interceptions of photo synthetically active radiation (PAR) by ginger was maximum at 110 DAP, both in open conditions (1.088 ly/min) and in the intercrop (0.788 ly/min). Percentage of PAR intercepted by ginger out of total PAR was the lowest at 170 DAP in both open (74.4%) and under arecanut shade (56.41%). Mean duration of ginger crop grown in open conditions was 184.5 days, while it was 198.5 days when grown as intercrop. Per plant yield of ginger under arecanut plantation was significantly higher (154.5 g) when compared to open conditions (118.8 g/plant). Individual rhizomes of ginger grown in arecanut plantation were slightly bigger (4.5 g/rhizome) than the crop grown in open (3.4 g/rhizome). Yield of arecanut was not affected due to intercropping with ginger during the two years study. However, there was slight improvement in the yield of arecanut (3.20 kg chali/palm) when compared to mono cropping of arecanut (2.59 kg Chali/palm).

2.4 Impact of light and temperature on potato production

Reynolds and Ewing (1989) stated that the effects of climate change on crop production can be complex. Depending on the temperature regime and the crop, high temperatures can lead to low yields due to increased development rates and higher respiration. However, a short growth cycle can also be beneficial, e.g., to escape drought or frost, and the use of late-maturing cultivars could offset the effect of high development rates. In environments where low temperatures now limit production, global warming could lead to a beneficial lengthening of the growing season and temperatures close to optimal for assimilation. Moreover, global warming is related to the increase of atmospheric CO, concentration, which is likely to increase crop yields, particularly when water limits crop production. Potato is grown in many different environments, but it is best adapted to temperate climates (Haverkort 1990). At high temperatures above 17 C. tuberization diminishes.

Delden *et al.,* (2001) stated that the temperature profoundly influences the growth and development of the potato canopy. Leaf appearance, expansion, and senescence, leaf orientation and physiological age and stem elongation and branching are significantly correlated with temperature. The leaf-level photosynthetic rate also varies with temperature; however, few whole-canopy gas exchange studies have been conducted (Thornton *et al.,* 1996). Most potato models are included; subs or and lentil potato those are represent the canopy as a single large stem and homogenous leaf layer (Shaykewich *et al.,* 1998). Increases in canopy leaf area are simulated as an exponential or nonlinear function of temperature. Canopy leaf area is used to estimate the interception of PAR (photo synthetically active radiation). Increases in plant mass (grams per plant) are computed by multiplying light interception by a constant value for radiation use efficiency (grams of biomass per mega joule of intercepted PAR. Potato models can be improved by including more detailed canopy responses to temperature (Vos, 1995). More sophisticated modeling approaches that estimate canopy photosynthetic rate by integrating gas exchange from different leaf layers in the canopy have been developed to improve accuracy in other crop models (Boote and Pickering, 1994). Knowledge of potato leaf and branch distribution at different canopy depths and their contribution to plant growth rate is needed to adopt these approaches for potato. Potato is an indeterminate crop with regard to its growth habit (Vos, 1995), vegetative growth can continue well after floral and tuber initiation. Potato main stems terminate in an inflorescence, at which point typically two apical, or upper, axillary stems develop from the axils of the second and third leaf below the inflorescence.

Sudha *et al.,* (2007) stated that agroforestry is an attractive option for climate change mitigation as it sequesters carbon in vegetation and soil, produces wood, serving as substitute for similar products that are unsustainably harvested from natural forests, and also contributes to farmers' income Climate change is a burning issue of the world. Rise in CO2 level accelerate the global warming which necessitated the sink and sequestration of carbon. These problems are mitigated through plantation of valuable tree and crop either singly or simultaneously on same piece of land through agroforestry system. As per Nair *et al.,* (2009) under the agroforestry system carbon sequestration has potential to mitigate the greenhouse gases because of greater efficiency of resource (nutrients light and water) capture and utilization. Moreover, reforestation and agro-forestry systems offer perhaps the greatest potential to remove large quantities of carbon from the atmosphere. Similarly, according to (Kursten 2000) agroforestry can, arguably, increase the amount of C stored in lands devoted to agriculture, while still allowing for the growing of food crops.

Thornton *et al.,* (1996) stated that warmer temperatures reduce the net photosynthetic rate; however, it is difficult to extrapolate leaf-level measurements to the whole canopy. The manner in which potato branches and leaves are distributed throughout the canopy and their corresponding contribution to photosynthetic rate has not been quantified. Growth temperatures 258C produce plants with elongated stems, smaller leaves, increased internodes number, and inhibited tuber development; (Struik *et al.,* 1989). Optimum photo synthetically active radiation; PAR, photo synthetically active radiation; PPF, photosynthetic (Thornton *et al.,* 1996). Differences in canopy composition according to basal, apical, and main-stem branches and leaves would be expected at different growth temperatures and these differences may influence whole canopy gas exchange.

Wolf *et al.,* (1990) stated that it is well known that the carbohydrate synthesis and translocation are affected by temperature. In potato plants, there are some reports concerning high temperature effects on carbohydrate metabolism, suggesting the reduction of carbohydrate synthesis and translocation from source leaf to the tubers and reduced the yield (Mohabir and John, 1988). Even in natural conditions, temperature fluctuation sometimes observed in the potato growing areas which may be happened in the different growth stages during the growing season and can influenced the growth and yield of potato. For that we are mixed different temperature treatments at different growth stages (Lafta and Lorenzen, 1995).

FAO (2008) stated that heat stress due to increased temperature is an agricultural problem in many areas in the world. Transitory or constant high temperatures cause an array of morph anatomical, physiological and biochemical changes in plants, which affect plant growth and development and may lead to a drastic reduction in economic yield .The adverse effects of heat stress can be mitigated by developing crop plants with improved thermo tolerance using various genetic approaches. For this purpose, however, a thorough understanding of physiological responses of plants to high temperature is imperative. Potato it is grown in more than 100 countries, mainly in Asia and Europe. The potato is a plant mainly of typical temperate climate. The crop grows best in cool but frost-free seasons and does not perform well in heat (Haverkort and Verhagen 2008). It is characterized by specific temperature requirements. The limits and optimal values for the growth of the above-ground part of the potato plant and for the tubers are different.

Rykaczewska (2004) stated that potato plantations and periodic action of heat stress under conditions of good soil moisture, in some studies the impact of high temperature on potato plants was separated from the impact of drought. It is not clear if the whole growing period is important for potato or if the time between maximum leaf area, coinciding with the stage of flowering and harvest, is the most sensitive period. Therefore, decreasing arable land in Bangladesh, together with increasing population and changing climatic conditions, make this challenge more acute. Most of the agriculture production is carried out on small pieces of lands. Bangladesh's population is increasing at a rate of two million every year. Besides that, in order to feed the ever increasing population, the government of Bangladesh emphasized cereal crops production with the introduction of high-yielding varieties of rice and wheat since independence.

2.5 Effect of planting spacings on growth of potato

Some studies, for example those by Fonseka *et al.*, (1996), Ifenkwe and Allen (1978), in which the relation between plant spacing and growth were examined, the results showed an increase in plant spacing to be accompanied by an increased stem length. The increased branching at the wider spacing did not compensate for fewer plants/m^2. They attributed increased branching at wider spacing to the availability of more space at lower plant densities. More space meant that plants were able to exploit the available nutrients in the soil and the photosynthetic active radiation for growth than plants at close spacing.

In other words, the growth rate was increased. Vander Zaag *et al*., (1990) studied the response to plant population under two different sites; one temperate and the other tropical. At the temperate site, closer spacing increased plant height. At the tropical site, closer spacing decreased plant height when canopy cover did not reach 100%. Other studies have examined the effect of planting population on stem number. Bussan *et al.,* (2007) showed that stem density (number of stems emerging from all planted tubers) increased linearly with increasing plant density (number of seed tubers planted per unity area), but the response differed across years. They highlighted that the linear response indicated that the stems per plant were not influenced by plant density. Stems per plant were not influenced by plant density but by physiological factors resulting from the management of the seed. Masarirambi *et al.,* (2012), however, found population density to have a highly significant influence on the subsequent development of secondary stems. Stem numbers were reduced at high plant density level and increased significantly at lower densities. This is likely due to intense competition for light, water and nutrients at high densities. Wurr *et al*., (1993) attributed the reduction in stem number and development at the high-density spacing levels to the limited space for root and tuber expansion. Masarirambi *et al.,* (2012) found out that plant population density (E) had an impact on above ground biomass production, specifically leaf area production, with plants grown at a spacing of 90 by 45 cm exhibiting highest haulm growth. The least values of leaf area production were recorded at 90 by 15 cm. Masarirambi *et al.*, (2012) also found a lower leaf area at highest crop density (90 × 15 cm) than at 90 × 30 cm. Ifenkwe and Allen (1978) found that increasing planting density reduced number of axillary branches and their leaves per plant, dry weight of leaf, stem, underground parts and tubers per plant, but increased stem length. Almekinders (1993) showed that increasing plant density resulted in cessation of shoot growth at an earlier stage and concentrated inflorescence and flower production at primary positions of early-flowering shoots. He worked on spacing but using different cultivars. With cultivars Renacimiento and Yungay, a higher plant density increased the percentage of flowers produced in the first three weeks of the flowering period but with cultivar Atzimba, the effect of plant density on the distribution of flower production was off-set by a slower stem development.

Güllüoglu and Arioglu (2009) revealed that major yield components; mean tuber weight and tuber yield per plant, significantly decreased as planting distance got closer due to increasing interplant competition. Rykbost and Maxwell (1993) showed that only one out of seven varieties showed reduced total yield at low populations. Contrastingly, reports of increased yield at high plant population are available (Güllüoglu and Arioglu, 2009) to increased number of plants/unit area and more tubers/plant. Masarirambi *et al*., (2012), yield was not affected by population density although they did not examine the tuber size distribution which would have shown an increase in smaller tuber reduced plant population was reported to increase yield (Arsenault and Malone, 1999; Vander Zaag *et al.*, 1990) .

Getachew *et al*., (2013) stated that plant spacing has been manipulated in the production of seed sizes that can satisfy the targeted market. Farmers that produce tubers for seed tend to produce smaller tubers because that is what the market demands whereas for processing markets bigger tubers are required. A number of researches have been carried out to investigate the effect of plant spacing on tuber size category. Tuber bulking of individuals at close spacing was reduced resulting in small tubers. Khalafalla (2001) also showed that closer spacing resulted in smaller tubers. In a similar studies but using different varieties, Rieman *et al*., (1953) showed that the cultivar Russet Burbank had a tendency to produce many tubers of small size implying a genetic influence on tuber size. Getachew *et al*., (2013) found that a larger proportion of large sized tubers occurred when a wider spacing was used. Getachew *et al.*, (2013) attributed this to the presence of fewer sinks that were available per unit area. That in turn resulted in less competition between the individuals. Other researchers also supported the same findings (Yenagi *et al*., 2010; Essah, 2004).

Entz and LaCroix (1984) in their research where they studied the effect of row spacing and seed type on yield and quality found that those plants grown from large seed pieces produced higher marketable yield also found marketable yield to respond negatively to an increased plant density terms of the marketable yield, the results from researches carried out by a number of researchers are also contrasting. Khalafalla (2001) carried out his studies on 2 different sites namely Shehainab and Shambat. He found marketable yield to increase as the spacing was reduced except when the research was carried out again in another year. At Shambat marketable yield significantly ($P<0.05$) increased with close spacing and out-yielded wider (35 cm) spacing by 26%. Used different varieties and when tested on different plant spacing that were used, responded differently with regard to marketable yield. Variety Ranger Russet produced higher marketable yield at narrowest spacing than Russet Burbank whilst variety Frontier Russet was intermediate .

Fonseka *et al.,* (1996) also observed a fall in specific gravity as the plant spacing was increased from 30 to 35 cm drawing the same conclusion as Getachew *et al*., (2013). Besides these numerous studies showed that increasing plant spacing resulted in an increase in specific gravity (Vander *et al*., 1990; Burton, 1948). Getachew *et al.,* (2013) attributed this to the resultant less intra-plant competition associated with reduced plant population. Rykbost and Maxwell (1993) however, found plant population not to have an effect on the specific gravity of all the varieties they studied.

Getachew *et al.,* (2013) found high plant population to be associated with low dry matter content. It then rose to a peak at 30 but then fell with a further increase in plant spacing. He thought that at low plant spacing, there was a high competition for light and other important resources. This then led to a few resources being channeled to each sink. Low dry matter content at the widest plant spacing was due to the high photosynthetic rate thus a relatively high vegetative growth at the expense of the tubers. Dry matter partitioning to the tubers was less. Many other studies showed increased dry matter with decreasing plant population Burton, (1948); Vander Zaag *et al.,* (1990).

2.6 Performance of potato in Agroforestry systems

Dieme and Ourèyesy (2013) stated that the micro tuber is considered one of the most effective means of spreading basic materials, as well as transporting and preserving potato germplasm varieties. To define the optimal conditions for the potato micro tuber in vitro germination of Aida, Atlas and Odessa varieties, the effects of temperature, physiological age and grade (size) were evaluated. The study conducted at three different temperature levels has demonstrated that the most favorable temperature for micro tuber germination at a higher and faster germination rate was 25°C, regardless of the variety.

In addition, micro tubers of large caliber, greater than 4 mm, germinate more quickly, with a higher germination rate, than smaller size ones (less than 4 mm) for all genotypes. For Atlas, Aida and Odessa varieties, a germination rate equal to 86.66%, 70% and 70% respectively, was obtained for micro tubers with a caliber superior to 4 mm. Physiological age influences micro tuber germination. The mean length of sprouts, reached after a 7 week incubation period, was more marked at multiple sprouts and branched sprout" stages than at a "monosprout" stage. The average length was 2.35 cm, 2.48 cm and 1.5 cm, respectively. Thus, it is necessary to plant micro tubers at a multiple sprouts.

Tuber yield in potato was affected by genotype /environment relations. In North Gujarat, Kufri Pukhraj established good in wide range of environment, and where as other two varieties were adapted to suitable environment only. As a main season crop, Kufri Badshah was preferably suitable for a wide range of environment Patel *et al., (*2008).

Avasthe *et al.,* (2007) observed that nine major agroforestry systems are in practice in the sub-tropical and mid-hill temperate zones of Sikkim, India. Among them only agri horticultural (potato) are found to be more viable and economically feasible than other system. The economics revealed that the potato cultivation generated almost Rs. 48 000/- per hectare.

Calstellani and Prevosta (1961) stated that the yield reduction of crops was higher during the rainy season than winter season. During the rainy season, turmeric gave maximum relative yield while in winter season, both berseem and wheat were equally compatible with poplar at all the spacings, however, potato also proved promising for poplar based agroforestry system but inferred that poplar planted in rows in any direction had no significant effect on yields of crops alongside up to fourth year after plantation.

Nandal and hooda (2005) stated that the effect of different spacing of poplar (5x4m, 10x2.5m, 15x2.5m) on the performance of intercrops was investigated in Hisar, Haryana, India. They cultivated different agricultural crops viz., sorghum, cowpea, dhincha, mungbean, groundnut, turmeric, wheat, oats, berseem, lentil and potato for seven consecutive years under poplar plantation. Results showed that yield of all crops decreased with increasing age of poplar.The yield of all crops increased with increasing poplar spacing, however, a spacing of 10mx2.5m seems to be the pedal for getting optimum growth and yield of agricultural crops. The yield reduction of crops was higher during the rainy season than winter season. During the rainy season, turmeric give maximum relative yield while in winter season, both season wheat were equally compatible with poplar at all the spacing, however, potato also proved promising for poplar based agroforestry system but (Calstellani and Prevosta 1961) inferred that poplar planted in rows in any direction had no significant effect on yield of crops alongside up to fourth year after plantation.

Dhyani *et al.,* (1995) conducted a field experiment to study the effect of lopping on biomass production of Eucalyptus globulus and yield of potato and oats in agroforestry system. Trees which were not lopped up to the 10th year produced the highest total biomass of 436.63 t ha-1 whereas those lopped in alternate years and every year from the 4th year produced 218.29 and 140.76 t/ha, respectively. The reduction in intercrop yield of potato was 12.4-15.6% in agroforestry system as compared to sole crop but potato was the most profitable option, and, therefore, recommended for higher production, profitability and protection of sloping lands in the Nilgiri hills.

Dagar and Singh (2002) suggested that tuber crops are feasible to grow under partial shade with *Casurina equisitifolia*. Tuber yield (turmeric, potato and taro) was higher under partial shade when the crops were grown during the second year compared with control (without tree) but was reduced markedly under complete shade. During the third year, the turmeric yield increased in partial shade while potato and taro yields declined slightly. Potato is a weather sensitive crop; its growth and production are obviously affected by environmental conditions Patel *et al.,* (2000a). Temperature above 18-20oC tend to increase haulm growth and lower tuber yield.

Okonkwo (2002) found that the best time to introduce soya bean into potato to obtain maximum production from the intercrop is 20 days after planting potato, when potato is intercropped with soybean.

Dagar (2001) suggested that tuber crops are feasible to grow under partial shade with Casurina equisitifolia. Tuber yield (turmeric, potato, taro) was higher under partial shade when the crops were grown during the second year compared with control (without trees), but was reduced markedly under complete shade. During the third year, the turmeric yield increased in partial shade while potato and taro yields declined slightly. Increasing shading and planting density and delaying planting reduced the number of lateral and branch stolons and the frequency of their tuberization but there were no effects on number of primary stolons or their tuberization. Consequently, at Cambridge a similar number of tubers were born on primary stolons in shaded and unshaded crops.

Agarwal *et al.,* (1995) reported that intercropping of black wattle with potato were more economically efficient in the first year of cultivation in Nilgiris in Tamil Nadu than compared to its sole stand but the yield of potato decrease as cultivation goes on.

CHAPTER 3

MATERIALS AND METHODS

In this chapter the materials and methods have been presented which include brief description of location of the experimental site, soil, climate, materials used and methods followed in the experiment. The details of this section are described below in the flowing subheadings:

3.1 Description of Experiential Site

3.1.1 Location

The experimental site was selected in the existing mango orchard of the Agroforestry and Environment Research Farm, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh. The geographical location of the site was between $25^{0}13^{'}$ latitude and $88^{0}23^{'}$ longitude and about 37.5 m above the sea level.

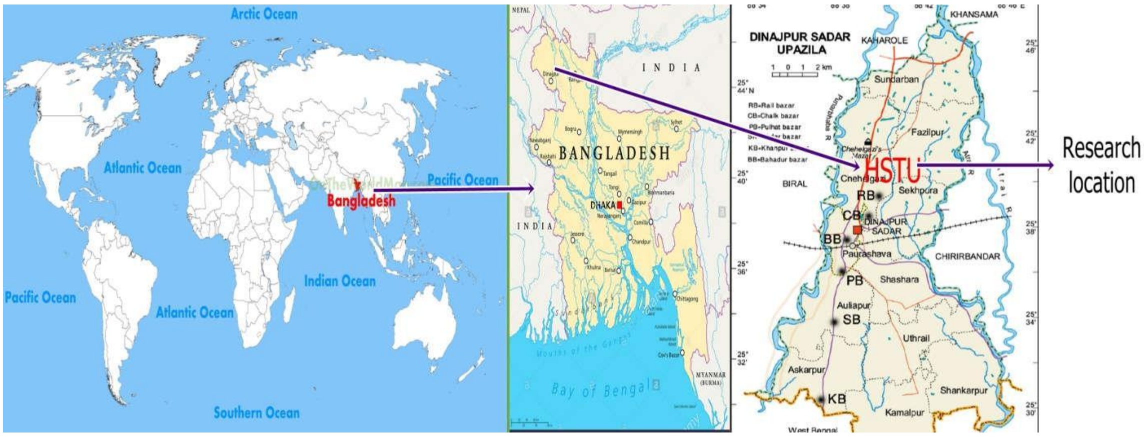

Figure 1: Map of the research location (HSTU campus, Dinajpur, Bangladesh).

3.1.2 Soil Characteristics

The experiment plot was situated in a medium high land belonging to the old Himalayan Piedmont Plain area (AEZ 01). Land was well-drained as drainage system was well developed. The soil texture was sandy loam in nature. The soil p^{H} was 5.35. The details soil properties are presented in Appendix-I.

3.1.3 Climate and weather

The experimental site was situated under the tropical climate characterized by heavy rainfall from July to August and scanty rainfall the rest period of the year. Monthly maximum and minimum temperatures, rainfall and relative humidity recorded during the experimental period (November, 2018 to March 2019. (Appendix-II)

3.2 Experimental period

Duration of the experiential period was from November 2019 to March 2020.

3.3 Seed collection

Seed potato tubers were collected from Bangladesh Agricultural Development Cooperation (BADC), Naishipur, Dinajpur, Bangladesh.

3.4 Experimental Design

The experiment was laid out following a two factorial Randomized Complete Block Design (RCBD) with three replications. Among them, total numbers of experimental plots were 24. 12 plots were open condition and the rest 12 plots were at the floor of mango orchard. The size of each unit in open condition was 2m×2m= 4m^2 and at the floor of mango orchard was 3m×2m = 6m^2.

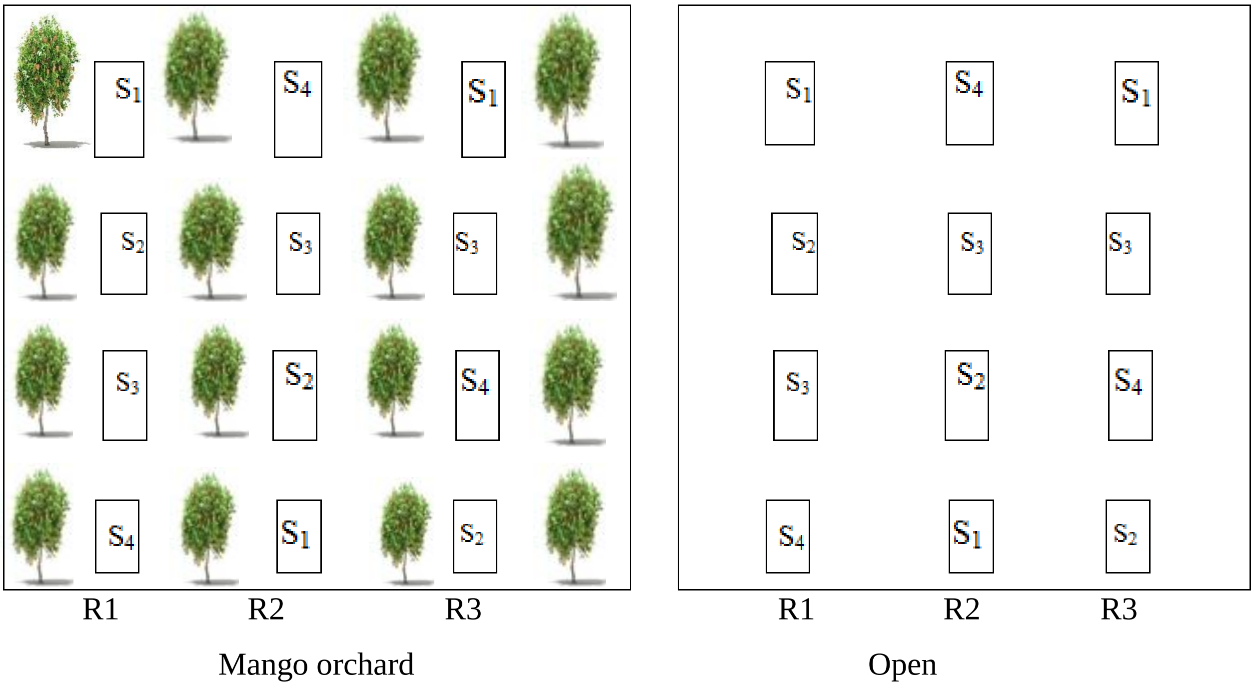

Figure 2: Experimental Layout for potato cultivation.

3.5 Experiential Treatment

The experiential consist 2 (two) production systems with 5 (five) spacings

Factor A: (two production systems)

- P_1= Mango+ Potato i.e. Mango based agroforestry system.
- P_2= Potato as sole cropping i.e. in open condition as control

Factor B: (Planting Spacing's)

- S_1= 50cm × 25cm
- S_2= 60cm × 20cm
- S_3= 60cm × 25cm
- S_4= 60cm × 30cm

Treatments Combinations:

- P_1S_1 = mango + S_1 (50cm × 25cm)
- P_1S_2= mango + S_2 (60cm × 20cm)
- P_1S_3 = mango + S_3 (60cm × 25cm)
- P_1S_4 = mango + S_4 (60cm × 30cm)
- P_2 S_1 = mango + S_1 (50cm × 25cm)
- P_2 S_2 = mango + S_2 (60cm × 20cm)
- P_2 S_3 = mango + S_3 (60cm × 25cm)
- P_2 S_4 = mango + S_4 (60cm × 30cm)

3.6 Structural Description of Mango garden

Spacing : 6m × 6m

Orientation : East- West

Average height : 6.11 m (during experimental period)

Average canopy sizes : N-S × E-W

2.5m × 2.6m (during experimental period)

Scientific name: *Mangifera indica,*

Family name: Anacardiaceae

Common name: Amm.

Variety: Amropali.

Distribution:

The mango is now cultivated in most frost-free tropical and warmer subtropical climates; almost half of the world's mangoes are cultivated in India alone, with the second-largest source being China. Mangoes are also grown in Andalusia, Spain (mainly in Málaga province), as its coastal subtropical climate is one of the few places in mainland Europe that permits the growth of tropical plants and fruit trees.

Soil:

Mangos can be grown on a wide range of soil types, from light sandy loams to red clay soils.

Size:

Mango trees grow to 35–40 m (115–131 ft) tall, with a crown radius of 10 m (33 ft). The trees are long-lived, as some specimens still fruit after 300 years. In deep soil, the taproot descends to a depth of 6 m (20 ft), with profuse, wide-spreading feeder roots and anchor roots penetrating deeply into the soil. The leaves are evergreen, alternate, simple, 15–35 cm (5.9–13.8 in) long, and 6–16 cm (2.4–6.3 in) broad; when the leaves are young they are orange-pink, rapidly changing to a dark, glossy red, then dark green as they mature. The flowers are produced in terminal panicles 10–40 cm (3.9–15.7 in) long; each flower is small and white with five petals 5–10 mm (0.20–0.39 in) long, with a mild, sweet fragrance. Over 500 varieties of mangoes are known, many of which ripen in summer, while some give a double crop (Noratto *et al*., 2010). The fruit takes four to five months from flowering to ripen.

The ripe fruit varies in size, shape, color, sweetness, and eating quality. Cultivars are variously yellow, orange, red, or green, and carry a single flat, oblong pit that can be fibrous or hairy on the surface, and which does not separate easily from the pulp. The fruits may be somewhat round, oval, or kidney-shaped, ranging from 5–25 centimetres (2–10 in) in length and from 140 grams (5 oz) to 2 kilograms (5 lb) in weight per individual fruit. The skin is leather-like, waxy, smooth, and fragrant, with color ranging from green to yellow, yellow-orange, yellow-red, or blushed with various shades of red, purple, pink or yellow when fully ripe. (Morton and Dowling, 1987).

Habitat:

Mango trees or predominant in hot **tropical** or **subtropical** regions of the world with mild rainfall. *Mengifera indica* is native to India and then spread to Burma, Indonesia and other countries.

Main Agroforestry uses:

Home gardens.

Main uses:

Fruit, flavoring, medicinal, timber.

Health benefit:

Mango fruit is rich in pre-biotic dietary fiber, vitamins, minerals, and *poly-phenolic flavonoid* antioxidant compounds. According to new research study, mango fruit has been found to protect from colon, breast, leukemia and prostate cancers. Several trial studies suggest that *polyphenolic antioxidant* compounds in mango are known to offer protection against breast and colon cancers. Mango fruit is an excellent source of Vitamin-A and flavonoids like β-carotene, α-carotene, and β-cryptoxanthin. 100 g of fresh fruit provides 180 IU (54 µg) or 6% of recommended daily levels of vitamin-A. Together; these compounds have been known to have antioxidant properties and are essential for vision. Vitamin-A also required for maintaining healthy mucosa and skin. Consumption of natural fruits rich in carotenes is known to protect from lung and oral cavity cancers. Fresh mango is a good source of potassium. 100 g fruit provides 156 mg of potassium while just 1 mg of sodium. Potassium is an important component of cell and body fluids that helps controlling heart rate and blood pressure.

Yield:

Typically, yields are often 5 mt/ha but can reach 20-30mt/ha; single mature tree can produce 200-300 kg of fruit in heavy cropping years and so low as 4 kg in bad years.

3.7 Land preparation

The land of experimental plot was opened in the last week of November 2018 with a power tiller and it was made ready for planting on first 5th December 2018. The corner of the land was spaded and visible larger clods were hammered to break into small pieces. All weeds and stubbles were removed from the field. The layout was done as per experimental design. All basal dosages of fertilizers and manure as per schedule of the experiment were incorporated in the soil and finally the plots were made ready for planting.

3.8 Application of fertilizers and Manures

Cowdung was applied during the land preparation. Half of urea and full doses of cow dung, TSP, MP, were applied as the basal dose in furrows made on both sides of the seed rows and mixed properly with soil at planting for the chemically fertilized plots. On the other hand, the remaining urea was applied at 40 DAP during the second earthling-up at the side of the rows and covered with soil for the same plots. The fertilizer doses for the chemically fertilized plots were followed as per FRG (2012).

Fertilizer	Nutrients	Nutrient dose (kg ha^{-1})
Urea	N	135
TSP	P_2O_5	30
MP	K_2O	90
Gypsum	S	10
Zinc Sulfate	Zn	2
Borax	B	1.5

3.9 Planting of tubers

The well-sprouted seed tubers were planted on the 5th December 2018 at a depth of 10 cm in furrows.

3.10 Intercultural operations Weeding and mulching

Manual weeding was done as and when necessary to keep the plots completely free from all weeds. After irrigation, the soil was mulched by breaking the crust for aeration and to conserve soil moisture.

Earthing-up

Earthing-up was made twice during the growing period at 25 days and 40 days after planting.

The second one was preceded by top dressing of the remaining half of urea.

Irrigation

Two irrigations were provided throughout the growing period. The first one was done at 30 days after planting and the second irrigation were given at after 20 days of first irrigation.

Plant protection measures

Furadan 5G @10 kg/ha was applied during the final land preparation to control ant, mite, cutworm and other soil borne insects in only chemically treated plots. As a preventive measure against late blight Melody Duo 66.8 WP (Iprovelicarb 5.5%, propineb 61.3%) was sprayed at the rate of 2.5 g litre^{-1} when the weather was cloudy in the same chemically treated plots. But remaining other plots, no chemical pesticides were applied except 2% neem oil as bio-pesticide was applied three times.

3.11 Harvesting

The crop was harvested on 5th March 2019 at 90 days after planting when 90% plants showed leaf senescence. At first ten sample plants were harvested from each plot and later on the rest plants were harvested.

3.12 Sampling and data collection

The experimental plots were observed frequently to record various changes in plant characteristics at different stages of their growth. Ten plants were selected at random from each unit plot to collect experimental data. The plants in the outer rows and at the extreme end of the two middle rows were excluded to avoid the border effects. The observations were made on the following parameters during plant growth phase and harvest, which were noted for different treatments of the experiment.

Plant height (cm):The heights were measured from the ground level to the tip of the longest shoot at an interval of 15 days starting from 30, 45, 60 and 75 DAP.

Number of leafs per plant: It was recorded with at an interval of 15 days starting from 30, 45, 60 and 75 DAP.

Number of shoots per hill: It was recorded with at 15 days starting from 30, 45, 60 and 75 DAP.

Canopy Size per plant (cm^2): It was recorded with at 45, 60 and 75 DAP

Fresh weight of haulm per hill (g): It was recorded during the harvesting time

Number of tubers per hill: It was recorded at the time of final harvest. It was recorded as the average of the 10 plants selected at random at harvest from each unit per plot.

Weight of tubers per hill: It was recorded at the time of final harvest.

Yield of tubers (ton/ha): This trait was recorded from the harvested tubers of all plants of each plot including the sample plants. The yield of tuber plot $^{-1}$ was converted to the yield per hectare.

Dry matter contents (%) of tubers: A sample weight (100g) of freshly harvested tubers was taken and the tubers were cut into small pieces and firstly, air-dried in the laboratory. Air-dried sample was then oven dried for 48 hours at 700C± 2 0 C in an oven. After drying it was weighted in an electric balance having a sensitivity of 0.1mg

Tuber grades

G-A (>55mm): The middle girth of this grade of tuber was above >55mm

G-B (46-55mm): The middle girth of this grade of tuber was between46-55mm

G-C (36-45mm): The middle girth of this grade of tuber was between 36-45mm

G-D (28~35mm): The middle girth of this grade of tuber was between 28~36mm G-E (<28mm) the middle girth of this grade of tuber was between <28mm

3.13 Total cost of production

The cost of cultivation of mango was worked out on the basis of per hectare. The initial plantation cost of the mango sapling was included in this study. The management cost of mango tree was also included. The total cost included the cost items like human labour and mechanical power costs, materials cost (including cost of seeds, fertilizers and manures, pesticide, bamboos, ropes etc.), land use cost and interest on operating capital.

3.14 Gross return

Gross return is the monetary value of total product and by-product. Per hectare gross returns from potato tuber was calculated by multiplying the total amount of production by their respective market prices.

3.15 Net return

Net return usually means the profit of the enterprises. Net return was calculated by deducting the total cost of production from the gross return.

Net return= Gross return (Tk.ha^{-1}) - Total cost of production (Tk.ha^{-1})

3.16 Benefit-cost ratio (BCR)

Benefit-cost ratio is the ratio of gross return with total cost of production. It was calculating by using the flowing formula Islam *et al.,* (2004)

Benefit-cost ratio= Gross return (Tk.ha^{-1})/ Total cost of production (Tk.ha^{-1})

3.17 Statistical analysis

Data were statistically analyzed using the "Analysis of Variance" (ANOVA) technique with the help of computer package R-studio. The mean difference was adjudged by Duncan's Multiple Range Test (DMRT) (Gomez, 1984).

CHAPTER 4

RESULTS AND DISCUSSION

The results of the performance of potato cultivated under mango based agroforestry system and open condition influenced by planting spacing are presented in Table1 to 18 and 2 to 7 figures. Moreover, in this chapter the findings of the study and interpretation of the results under different critical sections comprising growth, yield contributing characteristics, yield and quality parameters and cost-effective analysis are presented and also discussed under the following sub-headings to achieve the objective of the study.

4.1 Effect of production systems on growth, yield contributing characters and yield of potato

4.1.1 Germination percentages

The germination percentages were significantly different due to the impact of different production systems. The initial germination at 14 DAP and 21 DAP were varied but statistically not significant. At 30 DAP the highest germination (2.32 %) was observed in mango + potato based agroforestry system and the lowest germination (1.52%) was observed in potato sole cropping (P_2). At 21 DAP, the highest germination (28.98 %) was observed in mango + potato (P_2) based agroforestry system. Here also the germination percentage was varied but this was not statistically significant. However, at 28 DAP, the germination (%) was statistically significant and the highest germination (72.97 %) was observed in potato sole condition and the lowest germination (51.12 %) was observed in mango potato based agroforestry system (Table -1).Because, in open condition potato get more favorable condition for their germination. This finding was in agreement with the findings of Dieme and Qureyesy (2013).

Table 1: Main effect of production systems on the germination percentages (%) of potato

P. systems	Germination Percentages (%)		
	14 DAP	**21 DAP**	**28 DAP**
Mango + Potato (P_1)	2.319	28.98	51.12 b
Potato sole (P_2)	1.518	20.77	72.97 a
CV (%)	20.72	47.67	20.23

In a column, figure having similar letter(s) do not differ significantly whereas figure's bearing different letter(s) differ significantly (as per DMRT).

4.1.2 Plant height (cm)

Plant growth under mango based agroforestry system was more vigorous than those grown in sole cropping at the initial growth stage (Table 2). However, at the 30 DAP; there was no statistically significant variation of plant height between the two production systems like potato at the floor of mango and potato as sole cropping. At 30 DAP, the tallest plant (20.04 cm) was recorded in mango + potato based agroforestry system (P_1). On the other hand, the shortest plant (13.71 cm) was observed in open cropping of potato (P_2). Again at 45 DAP, the shortest plant (30.46 cm) was observed in open cropping of potato (P_2) whereas, the tallest plant (36.20 cm) was recorded in mango + potato based agroforestry system (P_1).Similarly at 60 DAP, the shortest plant (39.87 cm) was observed in open cropping of potato (P_2) and the tallest plant (44.43 cm) recorded in mango + potato based agroforestry system (P_1). Finally, at 75 DAP, the shortest plant (46.38 cm) was observed in open cropping of potato (P_2). On the other hand the tallest plant height(49.59 cm) recorded in mango + potato based agroforestry system (P_1).The present study revealed that the plant height increased with the decrease of light levels at the initial growth stage but later open condition i.e. full sunlight increase the potato plant height. Plant height depends on a number of factors such as availability of required quality of water, mineral nutrients, quantity, quality and duration of light, temperature area of growing space and genetic set-up of the plants. Hillman (1984) reported that those grown in high light environment resulting in taller plants than shade condition.

Table 2: Effect of production systems on the plant height (cm) of potato

P. systems	Plant Height (cm)			
	30 DAP	45 DAP	60 DAP	75 DAP
Mango + Potato (P_1)	20.08 a	36.20 a	44.43 a	46.38
Potato sole (P_2)	13.71 b	30.46 b	39.87 b	49.59
CV (%)	22.72	9.67	9.29	11.92

In a column, figure having similar letter(s) do not differ significantly whereas figure's bearing different letter(s) differ significantly (as per DMRT).

4.1.3 Number of shoot

The number of shoots was also varied significantly due to the impact of different production systems. Open condition i.e. sole cropping of potato gave more shoot whereas mango+potato based agroforestry system gave less number of shoots per hill (Table 3).

At 30 DAP, the maximum number of shoots (4.025) was observed in open cropping of potato (P_2), whereas minimum number of shoot (3.675) was observed in mango + potato based agroforestry system (P_1). Similarly, at 45 DAP, maximum number of shoots (4.317) was observed in open cropping of potato (P_2) and the minimum number of shoots (3.842) was observed in mango + potato based agroforestry system (P_1).Again at the 60 DAP, the maximum number of shoots (4.267) was observed in open cropping of potato (P_2). On the other hand, minimum number of shoots (3.980) was recorded mango + potato based agroforestry system (P_1). Finally at 75 DAP, maximum number of shoots (4.150), was observed in open cropping of potato (P_2) and the minimum number of shoots (3.983) was observed in mango + potato based agroforestry system (P_1). At 30 DAP and 45 DAP, the number of shoot per hill were not varied significantly but at 60 DAP and 75 DAP the variation were significant. Interesting that number of shoot were increased gradually in open condition but gradually decreased in mango+potato based agroforestry production system. This result was close conformity of O'Brien and Allen (1992).

Table 3: Effect of production systems on number of shoot per hill of potato

P. systems	Number of shoot per hill of potato			
	30 DAP	45 DAP	60 DAP	75 DAP
Mango + Potato (P_1)	3.675	3.842	3.980b	3.983b
Potato sole (P_2)	4.025	4.317	4.267 a	4.150 a
CV (%)	12.17	10.95	11.56	11.83

In a column, figure having similar letter(s) do not differ significantly whereas figure's bearing different letter(s) differ significantly (as per DMRT).

4.1.4 Number of leaves per plant

Numbers of leaves per plant of potato were also significantly disposed by the different production systems (Table 4). At 30 DAP, the maximum number of leaves (21.58) was observed in open cropping of potato (P_2), whereas the minimum number of leaves (19.75) was observed in mango + potato based agroforestry system (P_1). At 45 DAP, maximum number of leaves per plant (29.69) was also observed in open cropping of potato (P_2). Again at 45 DAP, the minimum number of leaves per plant (27.07) was observed in mango + potato based agroforestry system (P_1). Similarly, at the 60 DAP, the maximum number of leaves per plant (44.52) was observed in open cropping of potato (P_2). On the other hand, minimum number of leaves per plant (34.92) was observed in mango + potato based agroforestry system (P_1). Again at 75 DAP, maximum number of leaves per plant (43.99)was observed in sole cropping of potato (P_2) and minimum number of leaves per plant (37.41) was observed in mango + potato based agroforestry system (P_1). At 30 DAP and 75 DAP the number of leaves were not statistically significant but at 45 DAP and 60 DAP the variation were significant. The highest number of leaves was due to the effect of temperature pressure. Many researchers (Kirk and Marshall, 1992) reported that temperature profoundly influences the growth and development of the potato canopy leaf performance, expansion, and senescence, leaf orientation and physiological properties. The leaf-level photosynthetic rate also varies with temperature; air temperature at 23^0 C and above increase the number of axillaries branches and the leaf appearance and senescence rates Manrique *et al., (*1989). This finding was in agreement with the findings of Benoit *et al.,* (1986) who stated that, cooler temperatures promote lower number of total leaf and numbers of branches.

Table 4: Effect of production systems on number of leaves per plant of potato

P. systems	**Number of leaves per plant**			
	30 DAP	**45 DAP**	**60 DAP**	**75 DAP**
Mango + Potato (P_1)	19.75	27.07 b	34.92b	37.41
Potato sole (P_2)	21.58	29.69 a	44.52a	43.99
CV (%)	13.65	10.11	11.36	18.96

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.1.5 Canopy size per plant (cm^2)

The canopy size of the potato plant was significantly influenced by the different production systems. At 45 DAP, the highest canopy size (1047 cm^2)was observed in open cropping of potato (P_2) and the lowest canopy size (866.1 cm^2) was observed in mango + potato based agroforestry system (P_1). Again at 60 DAP, the highest canopy size (1916 cm^2) was observed in open cropping of potato (P_2). On the other hand, the lowest canopy size (1447 cm^2) was observed in mango + potato based agroforestry system **(**P_1). Finally, at 75 DAP the highest canopy size (2638 cm^2) was observed in open cropping of potato (P_2). Again, the lowest canopy size (1729 cm^2) was recorded in mango + potato based agroforestry system (P_1). Canopy size was increased gradually with the increase of plant growth stages and this increase was rapid in case of open condition. Indeed, in open condition, the potato plant got favorable environment and less competition for growth .The results was collaborating in findings by Dhyani *et al.*, (1995).

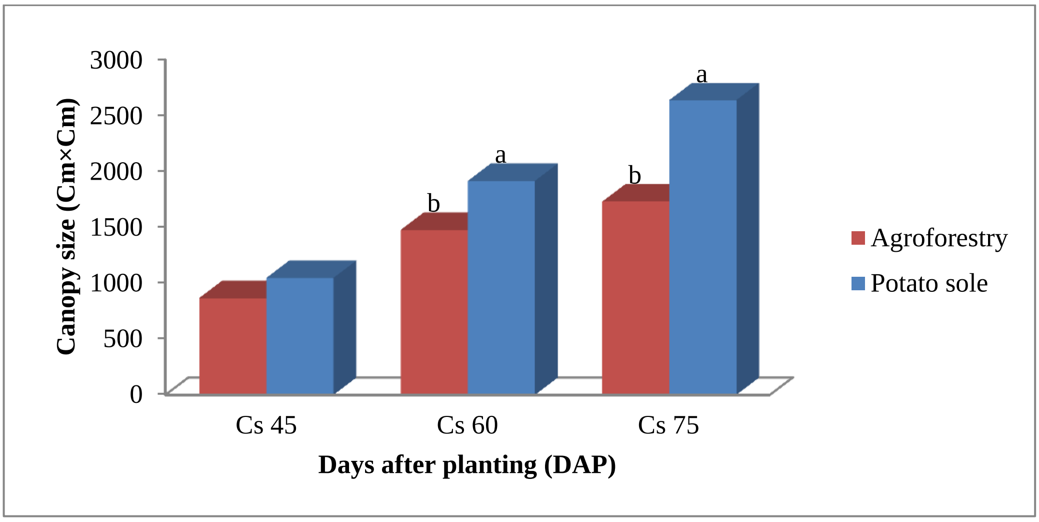

Figure 3: Effect of production systems on canopy size per plant (cm^2).

4.1.6 Tuber grades per plot

- **Grade-A (>55 mm):** The grade of tuber was significantly influenced by the different production systems (Table 6). The highest (0.9167) number of Grade-A tuber (>55mm) was recorded in open cropping of potato (P_2) and the lowest (0.00) was recorded in mango + potato based agroforestry system (P_1).
- **Grade-B (46-55 mm):** The tuber Grade-B (46-55 mm) was not significantly varied by the different production systems (Table 6). However, the highest number of grade-B tuber (0.5333) was recorded in open cropping of potato (P_2) and lowest (0.1167) was recorded in mango + potato based agroforestry system (P_1).
- **Grade-C (36-45 mm):** The tuber Grade-C (36-45 mm) was significantly varied due to the impact of the different production systems (Table 6). The highest (2.692) number of grade-C tubers were recorded in open cropping of potato (P_2) whereas the lowest (1.700) was recorded in mango + potato based agroforestry system (P_1).
- **Grade-D (28-35 mm):** Tuber grade-D (28-35mm**)** was significantly varied by the different production systems. The highest (5.942) number of grade-D tuber was recorded in open cropping of potato (P_2). On the other hand, the lowest (4.042) D-grade tuber was recorded in mango + potato based agroforestry system (P_1).

- **Grade E (<28mm):** Tuber grade-E (<28mm) was significantly varied by the different production systems .The highest (4.233) number of Grade-E tuber was recorded in mango + potato based agroforestry system (P_1). On the other hand the lowest (3.375) number of Grade E tuber was recorded in open cropping of potato (P_2).

Table 5: Main effect of production systems on the grades of potato tubers

P. systems	Grades of tubers				
	A	B	C	D	E
Mango + Potato (P_1)	0.00 b	0.1167	1.700 b	4.042 b	4.233 a
Potato sole (P_2)	0.9167 a	0.5333	2.692 a	5.942 a	3.375 b
CV (%)	23.26	14.87	29.95	30.31	49.06

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.1.7 Effect of production systems on the dry weight of potato tuber

Percent dry weights of tubers were not significantly influenced by the production system. However, the maximum dry weight (15.71 g) was recorded in open cropping of potato (P_2) due to the height photosynthesis rate resulting in more food materials deposited of potato in open condition. On the other hand, the minimum of dry weight (14.88 g) was recorded in mango + potato based agroforestry system (P_1).Similar result was found from Habib *et al*., (2012).

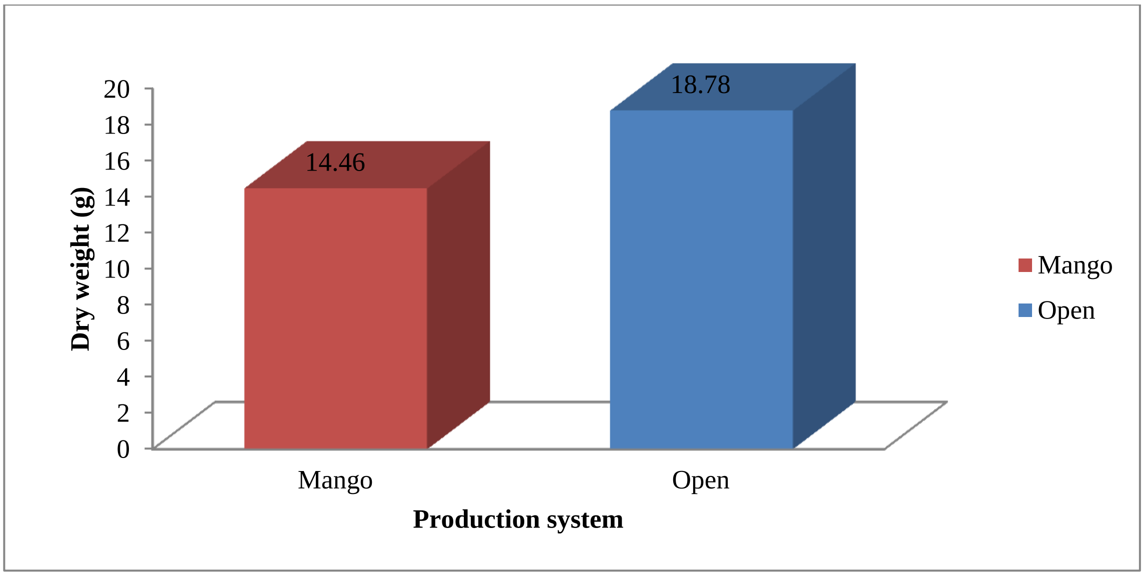

Figure 4: Effect of production system on dry weight of tuber.

4.1.8 Number of tuber per plant

Number of tuber per plant was significantly influenced due to the different production systems (Table 7). The maximum number of tuber (12.75 g) was recorded in open cropping of potato (P_2). On the other hand, the minimum number of tuber (9.817 g) was recorded in mango + potato based agroforestry system (P_1). More sun light gave more photosynthesis produce more carbohydrates accumulated in potato tuber. Corroboratory results from Nandal and Hooda (2005) reported that, the main growth and yield attributing character responsible for lower yield under poplar were number of tuber and weight of tuber .The lower number of tuber was found where plant was not get enough light, air and other resources. This agreement was close conformity to Basak *et al*., (2009).

4.1.9 Weight of tuber per plant (g)

Weight of tuber per plant was also significantly influenced due to the different production systems (Table 7). The maximum weight of tuber (348.7 g) was recorded in open cropping of potato (P_2). On the other hand, the minimum number of weight of tuber (252.9 g) was observed in mango + potato based agroforestry system (P_1).The maximum weight of tuber per plant was due to the increase in photosynthesis rate resulting in more food material deposited in fruit of potato .Significantly, the minimum weight of potato per plant (252.9 g) was recorded under mango based agroforestry system (AF).This finding is similar to that of Hanif *et al*., (2010).

Table 6: Effect of production systems on number of tubers per plant, weight of tuber per plant, weight of tuber per plot and yield (t/ha)

P. Systems	Number of tubers per plant	Weight of tubers per plant(g)	Weight of tubers per plot (g)	Yield (t/ha)
Mango + Potato (P_1)	9.817 b	252.9 b	5.150 b	8.586 b
Potato sole (P_2)	12.75 a	348.7 a	8.330 a	20.77 a
CV (%)	15.99	27.12	17.68	17.64

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT)

4.1.10 Weight of tubers per plot (g)

The result showed that tuber yield (g/plot) of potato was significantly influenced due to the different production systems (Table 7). The highest tuber yield (8.330 kg/plot) was recorded in open cropping of potato (P_2), whereas the lowest tuber yield (5.150 kg/plot) was observed in mango + potato based agroforestry system (P_1).The maximum weight of tuber per plot was found in open condition as there was no competition for nutrient light and other components. This result is in experiment with Rao *et al.*, (1998)

4.1.11 Yield (ton/ha)

The yield of potato (ton/ha) was significantly affected by the different production systems (Table 7). Significantly the highest tuber yield (20.77 t/ha) was recorded in open cropping of potato (P_2), whereas the lowest tuber yield (8.586 t/ha) was observed in mango + potato based agroforestry system (P_1).Generally it is said that understory crop yield reduced in agroforestry system as compare to open condition. This potato yield was reduced under shade of mango tree .This result is related to the result of Rao *et al*., (1998) and Hanif *et al., (*2010).

4.2 Effect of different planting spacing on growth, yield contributing characters and yield of potato

4.2.1 Germination percentages

Number of germination percentages of plant was also significantly varied by the different planting spacings. At 14 DAP, the maximum number of germination (2.850 %) was recorded in S_1 (50cm×25cm) which was followed by S_2 (60cm × 20cm) and S_3 (60cm × 25cm), respectively and the minimum number germination percentages (1.250) was recorded in S_4 (60cm × 30cm) which was statistically significant. Secondly, 21 DAP, maximum number of germination (26.04 %) was recorded in S_1 (50cmX25cm). On the other hand, at 21 DAP; the minimum number of germination (19.79 %) was recorded in S4 (60cm × 30cm) which was statistically significant. Again at 28 DAP, the maximum number of germination (67.58%) was recorded in S_1 (50cm×25cm) which was followed by S_2 (60cm × 20cm) and S_3(60cm × 25cm), respectively and the minimum number germination (1.25 %) was recorded in S_4(60cm × 30cm) and it was significantly followed whereas minimum number of germination (58.29 %) was recorded in S_4 (60cm×30cm).Here in closest spacing more number of tuber are planted than widest spacing that's why the germination percentage are more in closest spacing .This result was close conformity in the findings of(Wurr *et al.*,1995).

Table 7: Effect of different planting spacing systems on number of germination Percentages (%) of potato

Treatment Spacing	Germination Percentages (%)		
	14 DAP	**21 DAP**	**28 DAP**
S_1(50cm× 25cm)	2.850 a	26.04 a	67.58 a
S_2(60cm× 20cm)	1.910 b	22.50 a	61.80 a
S_3 (60cmx× 25cm)	1.665 b	21.17 a	60.50 a
S_4 (60cm× 30cm)	1.250 b	19.79 b	58.29 b
CV %	20.29	57.67	20.23

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.2.2 Plant Height (cm)

Plant height of potato was recorded from the ground surface to the tip of the leaf in all the treatments. At different Days after Planting (DAP), plant height not found significantly influenced by the different planting spacings (Table 9). At 30 DAS, the tallest plant height (17.75 cm) was recorded in S_1 (50cm × 25cm) which was followed by S_2 (60cm × 20cm) and S_3 (60cm × 25cm), respectively whereas the shortest plant height (16.17 cm) was recorded in S_4 (60cm × 30cm). Similarly, at 45 DAS, the tallest plant height (34.75 cm) was recorded in S_1 (50cm × 25cm), which was followed by S_2 (60cm × 20cm) and S_3 (60cm × 25cm), respectively. And the shortest plant height (31.93 cm) was recorded in S_4 (60cm × 30cm). Again, at 60 DAS, the tallest plant height (43.33 cm) was recorded in S_1 (50cm × 25cm), which was followed by S_2 (60cm × 20cm) and S_3 (60cm × 25cm), respectively. However, the shortest plant height (41.35 cm) was recorded in S_4 (60cm × 30cm). Finally at 75 DAP, the tallest plant (49.03 cm) was recorded in S_1 (50cm×25cm) which was not significantly followed. Conversely, the lowest plant height (47.47 cm) was observed in S_4 (60cm×30cm). In all stages the shortest plant height was found in widest spacing i.e. S_4 (60cm×30cm). This result is exactly similar to the result of Rajendra *et al.*, (2013) who stated that widest spacing gives shortest plant than closest spacing.

Table 8: Effect of different planting spacing on number of plant height (cm) of potato

Treatment Spacing	Plant height (cm)			
	30 DAP	45 DAP	60 DAP	75 DAP
S_1(50cm× 25cm)	17.75	34.75	43.33	49.33
S_2(60cm× 20cm)	17.33	33.53	42.17	47.58
S_3 (60cm× 25cm)	16.31	33.10	41.75	47.55
S_4 (60cm× 30cm)	16.17	31.93	41.35	47.47
CV %	22.72	9.67	9.29	11.92

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.2.3 Number of shoots per plant

Number of shoots per plant was also significantly varied at different DAS due to different spacing effects (Table-9). At 30 DAP, the maximum number of shoots (4.100) was recorded in S_4 (60cm×30cm) and the minimum number of shoots (3.517) were recorded in S_1 (50cm×25cm) which was statistically significant. Again at 45 DAP, maximum number of shoots (4.33) was recorded in S_4 (60cm×30cm) it was also statistically significant. On the other hand, at 45 DAP, the minimum number of shoots (3.867) was recorded in S_1 (50cm×25cm). Again at 60 DAP, maximum number of shoots (4.467) was recorded in S_4 (60cm×30cm) and the minimum number of shoots (3.850) was recorded in S_1 (50cm×25cm). Finally at 75 DAP, maximum number of shoots (4.350) was recorded in S_4 (60cm×30cm) and the minimum number of shoots (3.800) was recorded in S_1 (50cm×25cm). Reduction in stem number in densely populated area might be due to increased number of plants per unit area. This increased number of plants per unit area exerted competition among plants for nutrient and light that caused a reduction in branch number similar result was also reported by yenagi *et al.*, (2002) in potato.

Table 9: Effect of different planting spacing on number of shoot of potato

Treatment Spacing	Number of shoot			
	30 DAP	45 DAP	60 DAP	75 DAP
S_1(50cm× 25cm)	3.517 b	3.867 b	3.850 b	3.800 b
S_2(60cm× 20cm)	3.850 b	3.867 b	4.050 a	3.983 b
S_3 (60cm× 25cm)	3.933 b	4.250 a	4.183 a	4.133 a
S_4 (60cm× 30cm)	4.100 a	4.333 a	4.467 a	4.350 a
CV %	12.17	10.95	11.56	11.83

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.2.4 Number of leaves per plant

Numbers of leaves per plant were significantly varied due to the impact of different planting spacings (Table 10). At 30 DAP, the maximum number of leaves per plant (21.35) was recorded in S_1 (50cm × 25cm) which was followed by S_2 (60cm × 20cm) and S_3 (60cm × 25cm), respectively and the lowest number of leaves (19.77) was recorded in S_4 (60cm × 30cm). Again at 45 DAP, the maximum number of leaves per plant (30.07) was recorded in S_1 (50cm × 25cm) which was followed by S_2 (60cm × 20cm) and S_3 (60cm × 25cm), respectively and the lowest number of leaves (27.03) was recorded in S_4 (60cm × 30cm). Again at 60 DAP, the maximum number of leaves per plant (40.00) was recorded in S_1 (50cm × 25cm) which was statistically significant and followed by S_2 (60cm × 20cm) and S_3 (60cm × 25cm), respectively. On the other hand at 60 DAP, the lowest number of leaves (36.96) was recorded in S_4 (60cm × 30cm). Finally at 75 DAP, the maximum number of leaves per plant (42.15) was recorded in S_1 (50cm × 25cm) which was statistically significant and followed by S_2 (60cm × 20cm) and S_3 (60cm × 25cm), respectively. On the other hand at 75 DAP, the lowest number of leaves (39.18) was recorded in S_4 (60cm × 30cm). In the widest spacing the minimum numbers of leaves were found as there was leaf size per plant was more. Therefore big leaves but the number was prevailed in widest spacing. This result was close conformity that of Miah *et al*., (1996).

Table 10: Effect of different planting spacing on number of leaves of potato

Treatment Spacing	Number of leaves			
	30 DAP	**45 DAP**	**60 DAP**	**75 DAP**
S_1(50cm× 25cm)	21.35 a	30.07 a	40.00 a	42.15 a
S_2(60cm× 20cm)	20.92 a	28.23 b	42.28 a	41.63 a
S_3 (60cm× 25cm)	20.62 a	28.18 b	39.63 b	39.83 b
S_4 (60cm× 30cm)	19.77 b	27.03 b	36.96 c	39.18 b
CV %	13.65	10.11	11.36	18.96

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.2.5 Effect of different planting spacing on canopy size (cm^2)

The canopy size of the potato plant was significantly influenced by the planting spacing. At 45 DAP, the highest canopy size (1010.0cm^2) was recorded in S_4 (60cm×30cm) and it was not statistically significant and the lowest canopy size was recorded (914.03 cm^2) in S_1 (50cm×25cm). Again at 60 DAP, the highest canopy size (1871.0 cm^2) was recorded in S_4 (60cm×30cm) and it was not statistically significant and the lowest canopy size was recorded (1483.0 cm^2) in S_1 (50cm×25cm). Finally at 75 DAP, the highest canopy size (2406.0cm^2) was recorded in S_4 (60cm×30cm) and it was statistically significant and the lowest canopy size was recorded (1867.0 cm^2) in S_1 (50cm×25cm). However there was gradual decrease in all the canopy parameter with the decrease in planting density which was collaborating in Nair *et al*., (2016).

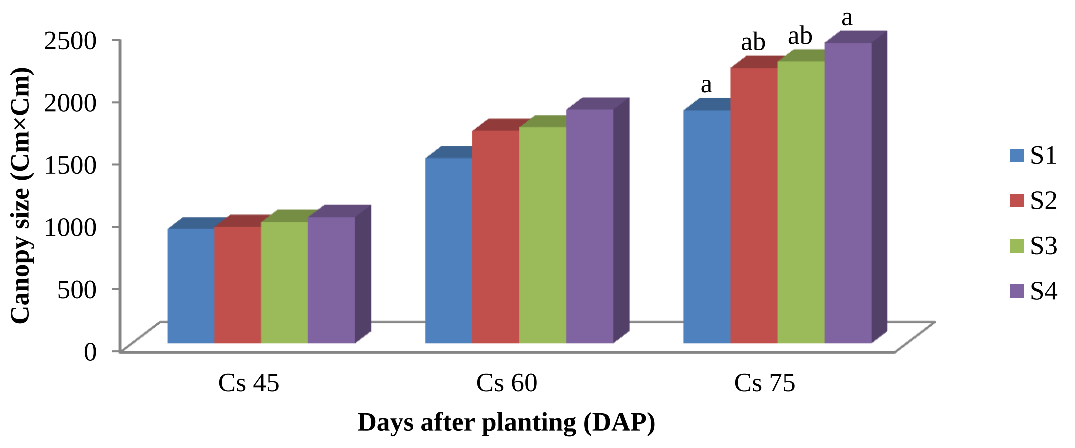

Figure 5: Effect of different planting spacing on canopy size (cm^2).

Here, S_1= 50cm × 25cm ,S_2 = 60cm × 20cm, S_3 = 60cm × 25cm,S_4 = 60cm × 30cm
In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.2.5 Tuber grades per plot

- **Grade-A (>55 mm):** The grade of tuber was not significantly influenced by different spacing (Table 12). The highest (0.833) number of Grade-A tuber (>55mm) was recorded in S_4 (60cm×30cm) it was not statistically significant. Again, the lowest (0.166) number of Grade-A tuber (>55mm) was recorded in S_1 (50cm×25cm).

- **Grade-B (46-55 mm):** The grade of tuber was not significantly influenced by different spacing (Table 12). The highest (0.4500) number of Grade-B tuber (46-55 mm) was recorded in S_4 (60cm×30cm) it was not statistically significant. Again, the lowest (0.233) number of Grade-B tuber (>55mm) was recorded in S_1 (50cm×25cm).

- **Grade-C (36-45 mm):** The grade of tuber was significantly influenced by different spacing (Table 12). The highest (2.633) number of Grade-C tuber (36-45 mm) was recorded in S_4 (60cm×30cm) it was statistically significant. Again, the lowest (1.750) number of Grade-C tuber (36-45 mm) was recorded in S_1 (50cm×25cm).

- **Grade-D (28-35 mm):** The grade of tuber was not significantly influenced by different spacing (Table 12). The highest (2.633) number of Grade-D tuber (28-35 mm) was recorded in S_4 (60cm×30cm) it was not statistically significant. Again, the lowest (1.750) number of Grade-D tuber (28-35 mm) was recorded in S_1 (50cm×25cm).

- **Grade-E (<28 mm):** The grade of tuber was not significantly influenced by different spacing (Table 12). The highest (4.083) number of Grade-D tuber (<28 mm) was recorded in S_4 (60cm×30cm) it was not statistically significant. Again, the lowest (3.450) number of Grade-D tuber (<28 mm) was recorded in S_1 (50cm×25cm).

Table 11: Effect of different planting spacing on the grade of tuber of potato

Treatment Spacing	Grade of Tuber				
	Grade A	Grade B	Grade C	Grade D	Grade E
S_1(50cm×25cm)	0.1667	0.2333	1.750 b	4.400	4.083
S_2(60cm×20cm)	0.3333	0.2833	2.133 a	4.933	3.867
S_3(60cm×25cm)	0.5000	0.3333	2.267 ab	5.250	3.817
S_4(60cm×30cm)	0.8333	0.4500	2.633 ab	5.383	3.450
CV %	23.26	14.87	29.95	30.31	49.06

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.2.6 Number of tuber per plant

The number of tuber per plant was not found significantly varied by the different planting spacing (Table 13). The maximum number of tubers (11.98) was recorded in S_4 (60cm×30cm) it was statistically significant On the other hand, the minimum number of tuber (10.58) was recorded in S_1 (50cm×25cm).This findings was close conformity to Georgakis *et al*., (1997) who states that number of tuber are increased with the increasing of planting density.

4.2.7 Weight of tuber per plant (g/plant)

Weight of tuber per plant was also influenced by planting spacing (Table 13). The maximum weight of tuber (314.4 g) was recorded in S_4 (60cm×30cm) it was statistically significant. Significantly, the minimum weight of tuber (291.7 g) was recorded in S_1 (50cm×25cm). Tuber weight was increased with the increasing in plant density that’s findings are similar to Marguerite *et al.,* (2006).

4.2.8 Weight of tubers per plot (kg/plot)

The result showed that tuber yield (kg/plot) was found significant variation by planting spacing(Table 13).The highest tuber yield (7.255 kg) per plot was recorded in S_1(50cm×25cm). It was statistically significant. On other hand, the lowest tuber yield (6.288 kg) was recorded in S_4 (60cm×30cm). The maximum weight of tuber per plot was found in closer spacing due the highest plant density which gives highest number of tuber on the other hand, minimum weight of tuber per plot was recorded in widest spacing. However this finding was also close conformity to the result of palanisamy and Ramaswamy (1993).

4.2.9 Yield (ton/ha)

The yield of potato (ton/ha) was also significantly varied by planting spacing's (Table 13). Significantly the highest tuber yield (15.76 t/ha) was recorded in S_1 (50cm×25cm). It was statistically significant. Again, the lowest tuber yield (13.69 t/ha) was recorded in S_4 (60cm×30cm). The closest spacing caused highest yield, as it gives more plant and more tuber per unit area. This result was in the agreement of Absar and Siddique (1982) who stated that higher yield of tuber is reported from close spacing.

Table 12: Effect of planting spacing on number of tubers per plant, weight of tuber per plant, weight of tuber per plot and yield (t/ha)

Treatment Spacing	Number of tuber of Tuber/Plant	Weight of Tuber/Plant(g)	Weight of Tuber/Plot(kg)	Yield (ton/ha)
S_1(50cm×25cm)	10.58 b	291.7 b	7.255 a	15.76 a
S_2(60cm×20cm)	11.22 a	295.6 b	7.073 a	15.09 a
S_3 (60cm×25cm)	11.35 a	301.5 a	6.405 b	14.16 b
S_4 (60cm×30cm)	11.98 a	314.4 a	6.228 b	13.69 c
CV %	15.99	27.12	17.68	17.64

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.2.10 Effect of planting spacing on the dry weight of potato tuber

Percent dry weights of potato tubers were not significantly varied by different plating spacings and. However, the maximum dry weights of tubers of potato (17.00 g) were recorded inS_4 (60cm×30cm). Again, the minimum number dry weights of tubers of potato (13.13 g) were recorded in S_1 (50cm×25cm). At low plant spacing, there was a high competition for light and other important resources. Low dry matter content at the widest plant spacing was due to the high photosynthetic rate thus a relatively high vegetative growth at the expense of the tubers. Dry matter partitioning to the tubers was less. Many other studies showed increased dry matter with decreasing plant population (Burton, 1948; Vander Zaag *et al*., 1990).

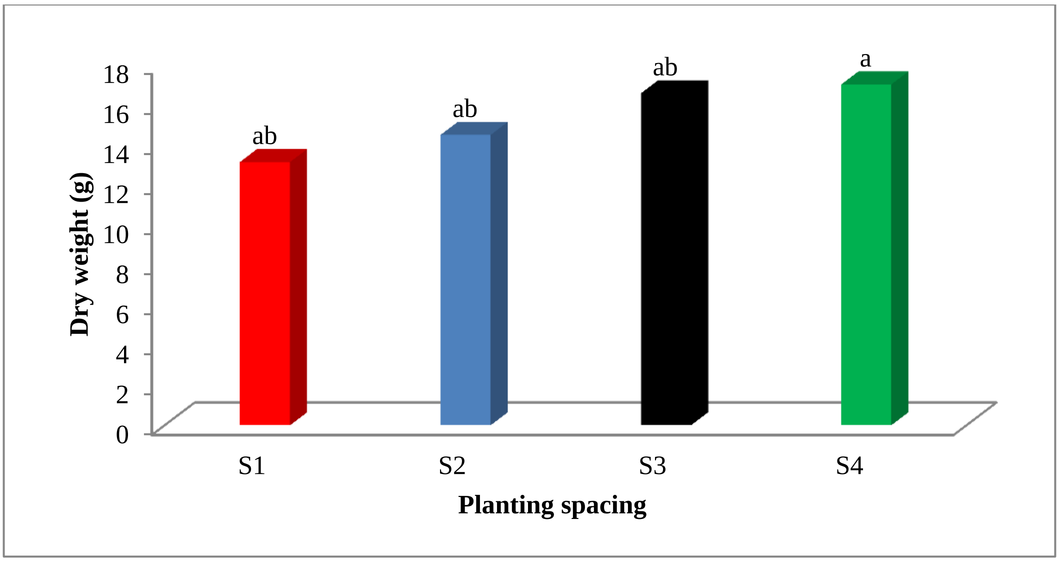

Figure 6: Effect of planting spacing on the dry weight of potato tuber.

Here, S_1 = 50cm × 25cm , S_2 = 60cm × 20cm , S_3 = 60cm × 25cm, S_4 = 60cm × 30cm
In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.3 Interaction effect of production systems and different planting spacing on growth, yield contributing characters and yield of potato

4.3.1 Germination percentages (%)

The interaction effect of spacing and production systems on the number of germination of potato was found significant at different days after planting (Table 14). At 14 DAP, the highest number of germination percentage of potato (4.667) was recorded in treatment P_2S_1 (potato sole with spacing 50cm×25cm). On the other hand, the lowest number of germination (0.833) was recorded in P_1S_4 (Mango+potato with spacing 60cm×30cm). Again at 21 DAP, the highest number of germination percentage of potato (39.58) was recorded in treatment P_2S_1 (potato sole with spacing 50cm×25cm). On the other hand, the lowest number of germination (8.33) was recorded in P_1S_4 (Mango+potato with spacing 60cm×30cm). It was statistically significant. Finally at 28 DAP, the highest number of germination plant of potato (79.17) was recorded in treatment P_2S_1 (potato sole with spacing 50cm×25cm). On the other hand, the lowest number of germination (47.50) was recorded in P_1S_4 (Mango+potato with spacing 60cm×30cm). It was statistically significant. This finding was close conformity in (Marguerity *et al.*, 2006)

Table 13: Interaction effect of production systems and planting spacing on germination (%) of potato

Treatments	Germination Percentages (%)		
	14 DAP	21 DAP	28 DAP
P_1S_1	1.043	21.00 abc	56.00 ab
P_1S_2	1.033	18.33 abc	50.97 b
P_1S_3	1.000	12.50 bc	50.00 b
P_1S_4	0.833	8.333 c	47.50 b
P_2S_1	4.667	39.58 a	79.17 a
P_2S_2	2.777	34.00 ab	76.09 a
P_2S_3	2.497	24.00 abc	71.00 ab
P_2S_4	1.500	21.25 abc	65.62 ab
CV %	20.29	57.67	20.23

Here,

P_1S_1= mango+potato with (50cm × 25cm), P_1S_2 = mango+potato with (60cm × 20cm), P_1S_3 = mango+potato with (60cm × 25cm), P_1S_4 = mango+potato with (60cm × 30cm), P_2S_1 = potato sole with (50cm × 25cm), P_2S_2 = potato sole with (60cm × 20cm), P_2S_3 = potato sole with (60cm × 25cm), P_2S_4 = potato sole with (60cm × 30cm)

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.3.2 Plant height (cm)

The interaction effect of spacing and production systems on the plant height of potato was found significant at different days after planting (Table 15). At 30 DAP, the tallest plant of potato (23.28 cm) was recorded in treatment P_2S_1 (potato sole with 50cm×25cm). On the other hand, the shortest plant height (12.22 cm) was recorded in P_1S_4 (mango +potato with 60cm×30cm). Again at 45 DAP, the tallest plant of potato (38.20 cm) was recorded in treatment P_2S_1 (potato sole with 50cm×25cm). On the other hand, the shortest plant height (28.87 cm) was recorded in P_1S_4 (mango +potato with 60cm×30cm) and It was statistically significant .Again at 60 DAP, the tallest plant of potato (46.83 cm) was recorded in treatment P_2S_1 (potato sole with 50cm×25cm). On the other hand, the shortest plant height (38.43 cm) was recorded in P_1S_4 (mango +potato with 60cm×30cm) and It was statistically significant. Finally at 75 DAP, the tallest plant of potato (51.10 cm) was recorded in treatment P_2S_1 (potato sole with 50cm×25cm). On the other hand, the shortest plant height (44.70 cm) was recorded in P_1S_4 (mango +potato with 60cm×30cm) and It was statistically significant .The tallest plant was found P_2S_1

(potato sole with 50cm×25cm) because it was in open condition which help to get more light, water and other nutrient components and closer spacing gives tallest plant. The present result is in agreement with the findings of Alam *et al*., (2012) and Rajendra *et al*., (2013), they reported open condition potato gives tallest plant as there was on competition between crop and plant, which in closer spacing tallest plant was found.

Table 14: Interaction effect of production systems and planting spacing on plant height (cm) of potato

Treatments	Plant Height (cm)			
	30 DAP	**45 DAP**	**60 DAP**	**75 DAP**
P_1S_1	14.85 bc	34.17 abc	42.07 ab	47.57
P_1S_2	14.57 bc	29.70 bc	39.83 ab	47.30
P_1S_3	13.20 c	29.10 bc	38.93 b	45.43
P_1S_4	12.22 c	28.87 c	38.43 b	44.70
P_2S_1	23.28 a	38.20 a	46.83 a	51.10
P_2S_2	21.47 ab	37.10 a	44.57 ab	50.47
P_2S_3	18.05 abc	35.33 ab	44.27 ab	49.50
P_2S_4	17.50 abc	34.17 abc	44.27 ab	47.80
CV %	22.72	9.67	9.29	11.92

Here,

P_1S_1= mango+potato with (50cm × 25cm), P_1S_2 = mango+potato with (60cm × 20cm), P_1S_3 = mango+potato with (60cm × 25cm), P_1S_4 = mango+potato with (60cm × 30cm) ,P_2S_1 = potato sole with (50cm × 25cm), P_2S_2 = potato sole with (60cm × 20cm) ,P_2S_3 = potato sole with (60cm × 25cm), P_2S_4 = potato sole with (60cm × 30cm)

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.3.3 Number of Shoots

The interaction effect of spacing and production systems on number of shoots per plant was found significant at different days after planting (Table 16). At 30 DAP, the maximum number of shoots (4.367) was recorded in the treatment P_2S_4 (potato sole with 60cm×30cm) which was statistically significant. On the other hand, the minimum number of shoots per plant (4.33) was recorded in P_1S_1 (mango+potato with 50cm×25cm). Again at 45 DAP, the maximum number of shoots (4.700) was recorded in the treatment P_2S_4 (potato sole with 60cm×30cm) which was statistically significant. On the other hand, the minimum number of shoots per plant (3.567) was recorded in P_1S_1

(mango +potato with 50cm×25cm). Again at 60 DAP, the maximum number of shoots (4.600) was recorded in the treatment P_2S_4 (potato sole with 60cm×30cm) which was statistically significant. On the other hand, the minimum number of shoots per plant (3.833) was recorded in P_1S_1 (mango +potato with 50cm×25cm). Finally at 75 DAP, the maximum number of shoots (4.500) was recorded in the treatment P_2S_4 (potato sole with 60cm×30cm) which was statistically significant. On the other hand, the minimum number of shoots per plant (3.767) was recorded in P_1S_1 (mango +potato with 50cm×25cm).This result was also reported by Yenagi *et al.*, (2010).

Table 15: Interaction effect of production systems and planting spacing on number of shoot of potato

Treatments	Number of Shoot			
	30 DAP	**45 DAP**	**60 DAP**	**75 DAP**
P_1S_1	3.433 b	3.567 c	3.833	3.767
P_1S_2	3.533 ab	3.80 abc	3.833	3.833
P_1S_3	3.600 a	3.800 abc	3.867	3.900
P_1S_4	3.733 ab	3.933abc	4.000	3.967
P_2S_1	3.833 ab	4.067 abc	4.100	4.000
P_2S_2	4.133 ab	4.167 ab	4.333	4.200
P_2S_3	4.167 ab	4.600 ab	4.533	4.367
P_2S_4	4.367 a	4.700 a	4.600	4.500
CV %	12.17	10.95	11.56	11.83

Here,

P_1S_1= mango+potato with (50cm × 25cm), P_1S_2 = mango+potato with (60cm × 20cm). P_1S_3 = mango+potato with (60cm × 25cm), P_1S_4 = mango+potato with (60cm × 30cm) ,P_2S_1 = potato sole with (50cm × 25cm), P_2S_2 = potato sole with (60cm × 20cm) ,P_2S_3 = potato sole with (60cm × 25cm), P_2S_4 = potato sole with (60cm × 30cm)

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.3.4 Number of leaves per plant

Numbers of leaves per shoot of potato were also significantly influenced by planting spacing and production system at the different day after planting (Table 17). At 30 DAP, the maximum number of leaves (23.87) was recorded in P_2S_1 (potato sole 50cm×25cm) which was statistically significant. On the other hand the minimum number of leaves per plant (18.83) was recorded in P_1S_4 (Mango+potato with 60cm×30cm). Again at 45 DAP, the maximum number of leaves (32.13) was recorded in P_2S_1 (potato sole 50cm×25cm) which was statistically significant. On the other hand the minimum number of leaves per plant (26.37) was recorded in P_1S_4 (Mango+potato with 60cm×30cm). Again at 60 DAP, the maximum number of leaves (32.69) was recorded in P_2S_1 (potato sole 50cm×25cm) which was statistically significant. On the other hand the minimum number of leaves per plant (48.27) was recorded in P_1S_4 (Mango+potato with 60cm×30cm). Finally 75 DAP, the maximum number of leaves (35.70) was recorded in P_2S_1 (potato sole 50cm×25cm) which was statistically significant. On the other hand the minimum number of leaves per plant (48.60) was recorded in P_1S_4 (Mango+potato with 60cm×30cm). As in P_2S_1 (potato sole with 50cm×25cm) was highest number of plant so it gives the highest number of leaves per plant as well. This result close conformity that of Miah *et al*., (1999).

Table 16: Interaction effect of production systems and planting spacing on number of leaves of potato

Treatments	Number of Leaves			
	30 DAP	**45 DAP**	**60 DAP**	**75 DAP**
P_1S_1	20.30	27.70 ab	37.10 bc	39.47
P_1S_2	20.17	27.13 ab	36.30 bc	38.60
P_1S_3	19.37	26.77 ab	33.60 c	35.87
P_1S_4	18.83	26.37 ab	32.69 c	35.70
P_2S_1	23.87	32.13 a	48.27 a	48.60
P_2S_2	21.33	29.70 ab	45.67 a	43.80
P_2S_3	20.93	29.23 ab	42.90 ab	43.80
P_2S_4	20.50	28.00 ab	41.23 abc	39.77
CV %	13.65	10.11	11.36	18.96

Here,

P_1S_1= mango+potato with (50cm × 25cm), P_1S_2 = mango+potato with (60cm × 20cm), P_1S_3 = mango+potato with (60cm × 25cm), P_1S_4 = mango+potato with (60cm × 30cm), P_2S_1 = potato sole with (50cm × 25cm), P_2S_2 = potato sole with (60cm × 20cm), P_2S_3 = potato sole with (60cm × 25cm), P_2S_4 = potato sole with (60cm × 30cm)

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.3.5 Interaction effect of production systems and spacing canopy size of per plant (cm)

The canopy size of the potato plant was significantly influenced by different planting spacing and production systems at the different day after planting. At 45 DAP, the highest canopy size (1180 cm^2) was recorded in P_2S_4 (potato sole with 60cm×30cm) which was not statistically significant. Again, the lowest canopy size (852.8 cm^2) was recorded in P_1S_1 (Mango+potato with 50cm×25cm). On the other hand at 60 DAP, the highest canopy size (2080 cm^2) was recorded in P_2S_4 (potato sole with 60cm×30cm) which was statistically significant. Again, the lowest canopy size (1210 cm^2) was recorded in P_1S_1 (Mango+potato with 50cm×25cm). Finally 75 DAP, the highest canopy size (3086 cm^2) was recorded in P_2S_4 (potato sole with 60cm×30cm) which was statistically significant. Again, the lowest canopy size (1515 cm^2) was recorded in P_1S_1 (Mango+potato with 50cm×25cm). These result was contradictory with the findings of chundawat *et al*., (1992) and Nawaz *et al.*, (2007) they reported that in closer spacing plants having the tendency to grow tall with less lateral growth and plant become columnar in shape due to poor light interception or shading effect and in wider spacing had optimum space for lateral growth hence balanced growth.

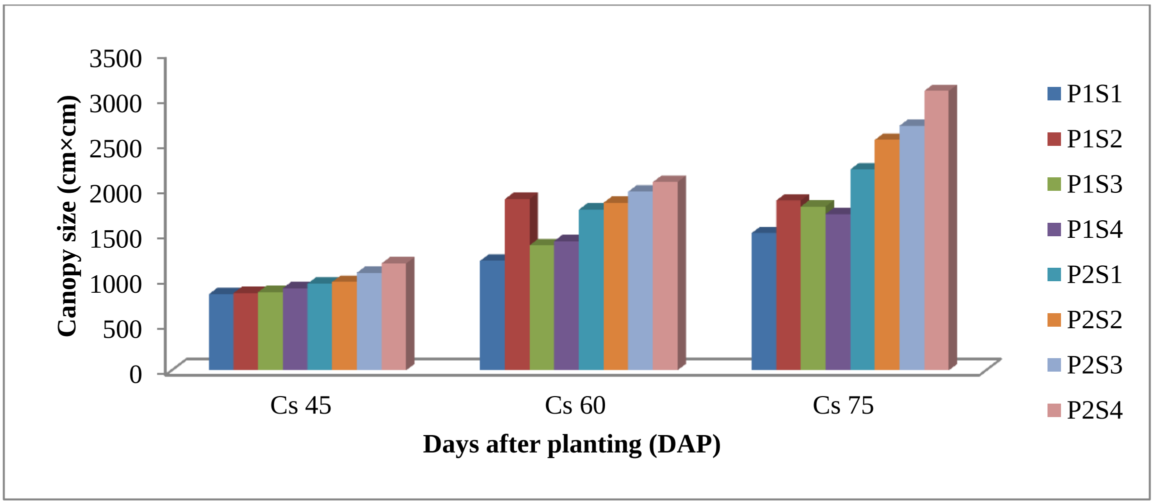

Figure 7: Interaction effect of production systems and planting spacing on the canopy size (cm^2) of potato

Here,

P_1S_1= mango+potato with (50cm × 25cm) P_1S_2 = mango+potato with (60cm × 20cm), P_1S_3 = mango+potato with (60cm × 25cm), P_1S_4 = mango+potato with (60cm × 30cm), P_2S_1 = potato sole with (50cm × 25cm), P_2S_2 = potato sole with (60cm × 20cm), P_2S_3 = potato sole with (60cm × 25cm), P_2S_4 = potato sole with (60cm × 30cm)

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.3.6 Tuber grades per plant

- **Grade-A (>55 mm):** The grades of tuber were significantly influenced by different planting spacing and production systems (Table-19). The highest (0.66) number of Grade-A tuber (>55mm) was recorded in P_2S_4 (potato sole with 60cm×30cm) which was not statistically significant. Again the lowest (0.00) number of Grade-A tuber (>55mm) was recorded in P_1S_1 (Mango+potato with 50cm×25cm).
- **Grade-B (46-55 mm):** The grades of tuber were significantly influenced by different planting spacing and production systems (Table-19). The highest (0.900) number of Grade-B tuber (46-55mm) was recorded in P_2S_4 (potato sole with 60cm×30cm) which was statistically significant. Again the lowest (0.00) number of Grade-B tuber (46-55mm) was recorded in P_1S_1 (Mango+potato with 50cm×25cm).
- **Grade-C (36-45 mm):** The grades of tuber were significantly influenced by different planting spacing and production systems (Table-19). The highest (2.867) number of Grade-C tuber (36-45mm) was recorded in P_2S_4 (potato sole with 60cm×30cm) which was statistically significant. Again the lowest (0.9667) number of Grade-C tuber (36-45mm) was recorded in P_1S_1 (Mango+potato with 50cm×25cm).
- **Grade-D (28-35 mm):** The grades of tuber were significantly influenced by different planting spacing and production systems (Table-19). The highest (6.867) number of Grade-D tuber (28-35 mm) was recorded in P_2S_4 (potato sole with 60cm×30cm) which was statistically significant. Again the lowest (3.733) number of Grade-D tuber (28-35 mm) was recorded in P_1S_1 (Mango+potato with 50cm×25cm).
- **Grade-E (<28mm):** The grades of tuber were significantly influenced by different planting spacing and production system (Table-19). The highest (4.733) number of Grade-E tuber (<28 mm) was recorded in P_1S_1 (Mango+potato with 50cm×25cm) which was statistically significant. Again the lowest (2.767) number of Grade-E tuber (<28 mm) was recorded in P_2S_4 (potato sole with 60cm×30cm).

Table 17: Interaction effect of production systems and planting spacing on the grade of tuber of potato

Treatment Spacing	Grade of Tuber				
	Grade A	Grade B	Grade C	Grade D	Grade E
P_1S_1	0.000	0.0000	0.9667 b	3.733 ab	4.733
P_1S_2	0.000	0.1000	2.567 a	4.500 ab	3.833
P_1S_3	0.000	0.03333	1.600 ab	4.033 b	4.233
P_1S_4	0.000	0.3333	1.667 ab	3.900 ab	4.133
P_2S_1	1.667	0.3333	2.533 a	4.767 ab	3.433
P_2S_2	0.3333	0.3667	2.700 a	6.000 ab	3.800
P_2S_3	1.000	0.5333	2.667 a	6.133 ab	3.500
P_2S_4	0.6667	0.9000	2.867 a	6.867 a	2.767
CV %	23.26	14.87	29.95	30.31	49.06

Here,

P_1S_1= mango+potato with (50cm × 25cm) P_1S_2 = mango+potato with (60cm × 20cm), P_1S_3 = mango+potato with (60cm × 25cm), P_1S_4 = mango+potato with (60cm × 30cm), P_2S_1 = potato sole with (50cm × 25cm), P_2S_2 = potato sole with (60cm × 20cm), P_2S_3 = potato sole with (60cm × 25cm), P_2S_4 = potato sole with (60cm × 30cm)

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.3.7 Interaction effect of production systems and spacing dry weight of tuber of potato

Percent dry weight of tubers was significantly inclined by different planting spacing and the production systems. There was no significant difference. The maximum dry weight (18.36 g) was recorded in P_2S_4 (potato sole with 60cm×30cm) which was statistically significant and the minimum number dry weights of tubers of potato (12.12 g) was observed in P_1S_1 (Mango+potato with 50cm×25cm). This findings is similar with Habib *et al.*, (2012); Burton, (1948); Vander Zaag *et al.*, (1990).

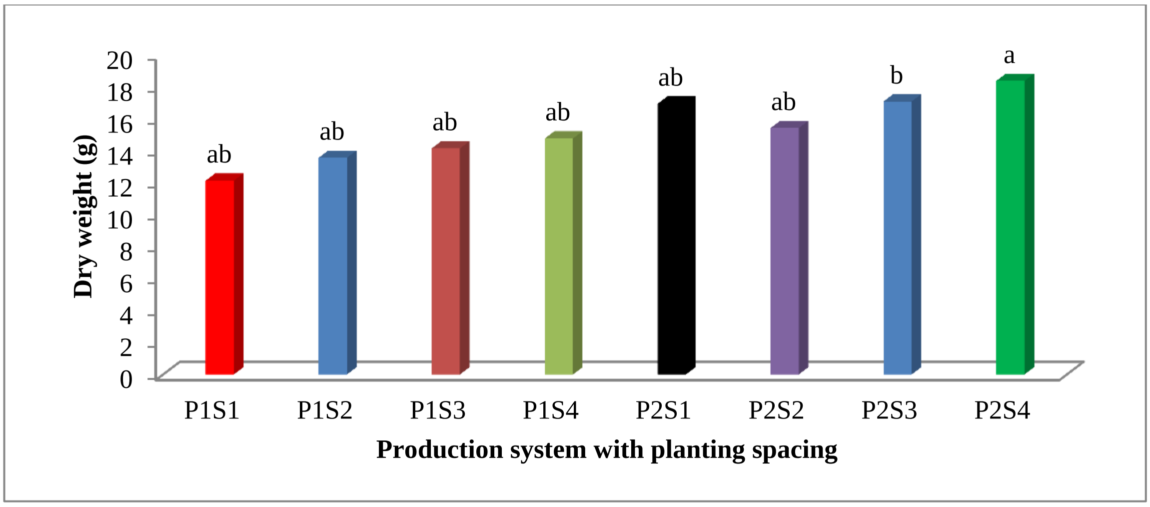

Figure 8: Interaction effect of production system and planting spacing on the dry weight of tuber

Here,

P_1S_1= mango+potato with (50cm × 25cm), P_1S_2 = mango+potato with (60cm × 20cm), P_1S_3 = mango+potato with (60cm × 25cm), P_1S_4 = mango+potato with (60cm × 30cm), P_2S_1 = potato sole with (50cm × 25cm), P_2S_2 = potato sole with (60cm × 20cm), P_2S_3 = potato sole with (60cm × 25cm), P_2S_4 = potato sole with (60cm × 30cm)

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.3.8 Number of tuber per/plant

The number of tuber per plant of potato was found significantly different inclined by the spacing and production system levels (Table 20). The maximum number of tuber (13.27) was recorded in P_2S_4 (potato sole with 60cm×30cm) which was statistically significant. On the other hand, the minimum number of tuber (8.667) was observed in P_1S_1 (Mango+potato with 50cm×25cm).This finding was close conformity to Georgakis *et al*., (1997).

4.3.9 Weight of tuber per/plant (g/plant)

The tuber weight per plant of potato was found significantly different inclined by the spacing and production system levels (Table 20). The maximum weight of tuber (362.4 g) was recorded in P_2S_4 (potato sole with 60cm×30cm) which was statistically significant. Significantly, the minimum weight of tuber (225.3g) was observed in P_1S_1

(Mango+potato with 50cm×25cm).Tuber weight was increased with the increasing in plant density in open condition that's findings are similar to Marguerite *et al.,* (2006).

4.3.10 Weight of tubers per plot (kg/plot)

The result showed that tuber yield (kg/plot) was found significant variation by the spacing and production system (Table 20) the highest tuber yield (8.805kg/plot^{-1}) was recorded in P_2S_1 (potato sole with 50cm×25cm spacing) which was statistically significant. Again, the lowest tuber yield (4.445 kg/plot^{-1}) was observed in P_1S_4 (mango+potato with 60cm×30cm spacing).By this way the result was also close conformity to the result of Palanisamy Ramaswamy(1993) and Rao *et al., (*1998).

4.3.11 Yield (ton/ha)

The yield of potato (ton/ha) was found significantly by the spacing varied and production system (Table-20) significantly the highest tuber yield (22.01 t/ha) was recorded in P_2S_1 (potato sole with 50cm×25cm spacing) which was statistically significant. On the other hand, the lowest tuber yield (7.407 t/ha) was observed in P_1S_4 (mango+potato with 60cm×30cm spacing).This findings of Rao *et al.* (1998) and Hanif *et al*., (2010) who found that under shade and in agroforestry system component yield gradually reduced. Significantly, the lowest yield of tuber (7.407 t/ha) was recorded in P_1S_4 (mango+potato with 60cm×30cm spacing under mango).

Table 18: Interaction effect of production systems and planting spacing number of tubers per plant, weight of tuber per plant, weight of tuber per plot and yield t/ha

Treatments	Number of tuber of Tuber/Plant	Weight of Tuber/Plant(g)	Weight of tuber/plot(g) of Tuber/Plot(kg)	Yield (ton/ha)
P_1S_1	8.667 c	225.3	5.927 c	9.892 b
P_1S_2	10.23 abc	288.9	5.706 bc	9.510 b
P_1S_3	9.667 bc	268.7	4.524 c	7.537 b
P_1S_4	10.70 abc	228.9	4.445 c	7.407 b
P_2S_1	12.50 ab	334.4	8.805 a	22.01 a
P_2S_2	12.47 ab	340.0	8.219 a	20.92 a
P_2S_3	12.77 ab	358.1	8.365 a	20.30 a
P_2S_4	13.27 a	362.4	7.932 ab	19.84 a
CV %	15.99	27.12	17.68	17.64

Here,

P_1S_1= mango+potato with (50cm × 25cm), P_1S_2 = mango+potato with (60cm × 20cm), P_1S_3 = mango+potato with (60cm × 25cm), P_1S_4 = mango+potato with (60cm × 30cm), P_2S_1 = potato sole with (50cm × 25cm), P_2S_2 = potato sole with (60cm × 20cm), P_2S_3 = potato sole with (60cm × 25cm), P_2S_4 = potato sole with (60cm × 30cm)

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

4.4 Economic analysis

Profitability of growing potato as inter-crop in mango based agroforestry system was calculated based on local market rate prevailed during experimentation. The cost of production of potato and cost of production of tree plantation and management of trees have been summarized in appendix V. The return of produce and the profit per taka i.e. Benefit Cost Ratio (BCR) have also been presented in Table 18.

4.4.1 Total cost of production

The values in Table 15 indicate that the total cost of production was maximum (147617 Tk. /ha) in mango+ potato based agroforestry system (p_1) in 50cm×25cm spacing whereas the minimum cost of production (125339 Tk./ha) was recorded from the sole cropping of potato (p_2) i.e. potato grown in open field in 60cm×30cm spacing .

4.4.2 Gross return

Gross return is an important indicator whether crop cultivation is profitable or not. It is vary with the variety of potato and production system of potato. The values in Table 18 indicate that the highest value of gross return (437680 Tk. /ha) was obtained from mango + potato based Agroforestry system (p_1) in 50cm×25cm spacing. On the other hand, the lowest value of gross return (297600 Tk. /ha) was obtained from sole cropping of potato (p_2) in 60cm×30cm spacing.

4.4.3 Net return

Results presented in the Table 18 show that net return (290063 TK /ha) was comparatively higher in producing potato under mango + potato based agroforestry system in 50cm×25cm spacing. At the same time, the lowest net return (174670 Tk. /ha) was received from the sole cropping of potato in 60cm×30cm spacing. Higher net return was the result of higher gross return from the mango + potato based agroforestry system with closest spacing.

4.4.4 Benefit-cost ratio (BCR)

The values in Table 18 indicate that the highest benefit-cost ratio (3.24) was recorded from mango + potato based agroforestry system in 60cm×20cm spacing. On the other hand the lowest benefit-cost ratio (2.37) was observed in sole cropping of potato in 60cm×30cm spacing. So, potato can profitably be cultivated in mango based agroforestry systems. Thus, it may be advocated that such type of speculation will be beneficial to the farmer as because such project provides cash money to the farmer and gradually can enrich the soil nutritionally.

Table 19: Economics analysis of potato production under Mango based Agroforestry system (ha^{-1} $year^{-1}$)

Production system	Outcome (Tk./ha)		Total cost of Production (Tk./ha)	Gross Return (Tk./ha)	Net Return (Tk./ha))	BCR
	Mango	potato				
P_1S_1	289300	148380	147617	437680	290063	2.96
P_1S_2	289300	142600	133305	431950	298645	3.24
P_1S_3	289300	113055	132175	402355	270180	3.04
P_1S_4	289300	111105	131045	400405	269360	3.05
P_2S_1	-	330150	128729	330150	206845	2.56
P_2S_2	-	304500	127599	304500	190644	2.38
P_2S_3	-	313800	126469	313800	181231	2.48
P_2S_4	-	297600	125339	297600	174670	2.37

Here,

P_1S_1= mango+potato with (50cm × 25cm), P_1S_2 = mango+potato with (60cm × 20cm), P_1S_3 = mango+potato with (60cm × 25cm), P_1S_4 = mango+potato with (60cm × 30cm), P_2S_1 = potato sole with (50cm × 25cm), P_2S_2 = potato sole with (60cm × 20cm), P_2S_3 = potato sole with (60cm × 25cm), P_2S_4 = potato sole with (60cm × 30cm).

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per DMRT).

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CHAPTER 5

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The present investigation was conducted at the Agroforestry and Environment Farm of the Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, during the period from November 2018 to March 2019, to screen different spacing treatments on Potato under Mango based agroforestry systems. The experiment consisted of two production systems viz., P_1 (under Mango based agroforestry system), P_2 (open field). Each treatment was replicated three times in a two factor Randomized Complete Block Design (RCBD). The experiment included four treatment spacing viz, S_1 (50cm×25cm), S_2 (60cm×20cm), S_3 (60cm×25cm), S_4 (60cm×30cm). The land of experimental plots was started in the first week of November 2018 with a power tiller and it was made ready for transplanting. The size of each unit plot was 3m×2m under mango orchard and 2m×2m in open condition. . From each plots 10 plants were randomly selected for collection of data on yield components and fruit yields. The parameters studied were height of plant, Number of leaves per plants, number of fruits per plots, fruit yields per plots. The data was recorded on two broad heads, 1) growth stage 2) harvesting stage. The data were analyzed statistically MSTATC software. The results of the experiments have been summarized below:

In case of the main effect of different spacing application on the growth, yield contributing characters and yield of Potato, the results were found that the number of tuber per plant, tuber weight and yield were significantly different. The maximum number of tuber per plant was recorded from S_4 (60cm×30cm) whereas minimum number of tuber per plant was obtained from closest spacing S_1 (50cm×25cm). The big grade tuber per plant was observed from widest spacing S_4 (60cm×30cm) and the lowest size tuber per plant was recorded from closest spacing S_1 (50cm×25cm). The maximum weight of tuber per plant (7.25 kg) was recorded closest spacing (S_1). And the minimum weight of tuber per plot (6.22 kg) was recorded from widest spacing (S_4) on other hand the result of this study showed that the main effects of production system were significant different in number of tuber per plant, weight of tuber, tuber diameter and tuber yield due to different production systems. The maximum number of tuber per plant was observed in sole cropping of Potato (P_2) whereas the minimum number of tuber per plant was obtained in Mango + Potato based on agroforestry system (P_1) due to the shortage of sunlight. Diameter of tuber was also influenced by the different production system. The maximum diameter of tuber per plant i.e. big grade tuber was recorded in sole cropping Potato (P_2) whereas the minimum of tuber diameter per plant was obtained in Mango + Potato based on agroforestry system (P_1). Weight of tuber per plant was also influenced by different production systems. The maximum weight of tuber was recorded in sole cropping Potato (P_2), and the minimum weight of tuber was observed in Mango + Potato based on agroforestry system (P_1). Yield of tuber ton per hector was also influenced by different production systems. The highest yield was recorded in sole cropping Potato (P_2), and the lowest yield was observed in Mango + Potato based on agroforestry system (P_1).

Interaction effect of different planting spacing and production system on the growth, yield contribution characters and yield of Potato were observed that the number of tuber per plant, diameter of tuber, weight of tuber and yield were also significantly influenced by different planting spacing and production system. The maximum number of tuber was observed in P_2S_4 (13.27) (Sole cropping + widest spacing) and the minimum number of tuber was recorded in P_1S_1 (Mango + closest spacing). Diameter of tuber was not significantly influenced by the spacing and production system. The maximum diameter of tuber was recorded in P_2S_4 (Sole cropping in 60cm×30cm spacing) and the minimum of tuber diameter was found in P_1S_1 (Mango + 50cm×25cm spacing). Tuber per plant was also influenced by the spacing treatments and production system. The maximum weight of tuber per was recorded in P_2S_4 362.4 g (Sole cropping in 60cm×30cm spacing) and the minimum weight of tuber per plant was observed in P_1S_1 225.3 g (Mango + 50cm×25cm). The yield of Potato (t ha^{-1}) was significantly affected by the spacing and production system. The highest tuber yield was observed in P_2S_1 20.01t/ha (Sole cropping in 50cm×25cm spacing), whereas the lowest tuber yield was observed in P_1S_4 7.407t/ha (mango in 60cm×30cm spacing). The highest yield was obtained from closest spacing because the rest weight of potato was obtained from closest spacing.

Again, in case of economic analysis, the total cost of production was maximum in Potato cultivation under Mango based Agroforestry system. But the highest benefit cost ratio was recorded from the Potato under Mango based Agroforestry system.

5.2 Conclusion

The findings of the present investigation indicate that diversification of farming system and growing potato as inter layers crops with appropriate spacing in mango tree orchard is a viable option for increasing income of farmers. However, foregoing discussion, it is clear that open field is so good for potato production but at the floor of young mango orchard (up to 10 years), it can be also grown successfully. In case of planting spacing, medium spacing i.e. 50cm×25cm or 60cm×20cm is good for optimum yield under mango based agroforestry system.

5.3 Recommendations

1. Potato production at the flour of young mango orchard is a good agroforestry system.
2. The developed model should be applied in the mango fruit tree plantation of Bangladesh using low aged garden with the space for potato 50cm×25cm
3. The experiment was conducted in a single season and using a single 10 (ten) years aged mango orchard. So, to get the valid recommendation the experiment should be repeated in different location of the country using different aged mango orchard.

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APPENDICES

Appendix I: The soil properties of mango field of Agroforestry and Environment farm HSTU, Dinajpur

Soil Characters	Physical and Chemical Properties
Texture	
Sand (%)	65.6
Silt (%)	22
Clay (%)	12.4
Textural Class	Sandy loam
p^H	5.78
Organic carbon (%)	0.31
Organic matter (%)	0.55
Total nitrogen (%)	0.014
Sodium (mg/100g)	1.87
Calcium (mg)	50
Magnesium (mg)	2.43
Potassium (mg/100g)	0.94
Phosphorus (ppm)	1.0
Sulphur (ppm)	4.0
Zinc (µg/g)	0.63
Boron (µg/g)	0.15
Iron (µg/g)	63.44

Sources: Soil Resources Development Institute, Noshipur, Dinajpur

Appendix II: Monthly records of different weather data at the period from November- 2019 to March-2020

Months	**Air Temperature (^{0}C)			*Rainfall (mm)	**Relative Humidity (%)
	Maximum	Minimum	Average		
May	35.1	23.0	29.5	176.0	78
June	37.0	25.3	31.2	211.4	70
July	36.0	26.3	31.2	142.0	82
August	36.3	25.4	31.3	254.6	84
September	36.9	26.3	31.2	98.2	80
October	35.4	20.6	28.0	06.0	62
November	33.8	15.0	24.4	00.0	70
December	28.9	10.6	19.8	01.0	66
January	26.7	9.6	18.15	00.0	77

*Monthly total

****** Monthly average

Sources: Meteorological Station, Wheat Research Center, Noshipur, Dinajpur

Appendix III: Cost of production for potato under mango based agro forestry system

Treatments	Input cost										Total input cost (Tk/ha)	Over head cost			Total cost of production ((Tk/ha)
	Non material cost (Tk/ha)			Material cost (Tk/ha)								Interest of input cost 8% for the crop season (Tk/ha)	Interest of the value of land (tk. 300000/ha) 8% for the crop season (Tk/ha)	Miscellaneous cost 5% of the input cost (Tk/ha)	
	Fruit tree	Potato	Total non-material cost	Seedling	Fertilizer	Pesticide	Irrigation	Maintenance cost of trees	Initial Plantation cost of trees	Total material cost					
P_1S_1	15000	20000	35000	26666	13232	8000	2800	6000	1389	58087	104087	8326	30000	5204	147617
P_1S_2	15000	20000	35000	25666	13232	8000	2800	6000	1389	57087	91421	7313	30000	4571	133305
P_1S_3	15000	20000	35000	24666	13232	8000	2800	6000	1389	56087	90421	7233	30000	4521	132175
P_1S_4	15000	22000	35000	23666	13232	8000	2800	6000	1389	55087	89421	7153	30000	4471	131045
P_2S_1	-	18000	18000	33332	16540	10000	3500	6000	0	69372	87372	6989	30000	4368	128729
P_2S_2	-	18000	18000	32332	16540	10000	3500	6000	0	68372	86372	6909	30000	4318	127599
P_2S_3	-	18000	18000	31332	16540	10000	3500	6000	0	67372	85372	6829	30000	4268	126469
P_2S_4	-	18000	18000	30332		10000	3500	6000	0	66372	84372	6749	30000	4218	125339

Note: Cow dung 600Tk./ton; Urea 16 Tk./kg, TSP 26 Tk./kg; MP 16 Tk./kg, Gypsum 9 Tk/kg, $ZnSO_4$ 130 Tk./kg, Labour 400Tk./day, Plantation cost for Mango tree were 150 Tk./tree. Rotation year for Mango tree were 30 years.

Appendix IV: Some plates of the research activities

Plate 1: Planting the potato in row

Plate 2: Tagging at the experimental plot of potato

Plate 3: Counting number shoots leaves of potato

Plate 4: Collecting the harvested potato

Plate 5: Harvested potato

Plate 6: Placing the potato in the oven to dry

Plate 7: Taking the dry weight of potato