EFFECT OF PLANTING GEOMETRY, NITROGEN-PHOSPHORUS RATIO AND HAULM CUTTING ON THE PRODUCTION OF SEED POTATO

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CERTIFICATE

This is to certify that the thesis titled, ***"EFFECT OF PLANTING GEOMETRY, NITROGEN- PHOSPHORUS RATIO AND HAULM CUTTING ON THE PRODUCTION OF SEED POTATO"*** *submitted to the* ***DEPARTMENT OF AGRONOMY,*** *Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE (MS)*** *in* ***AGRONOMY*** *embodies the result of a piece of bona fide research work carried out by* ***TITUN BISWAS, Reg. No. 11-04553*** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged by the Author.

Dated:
Place: Dhaka, Bangladesh

(Professor Dr. Tuhin Suvra Roy)
Supervisor

Dedicated to

"My Beloved Parents"

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ABSTRACT

Production of maximum number of seed-sized tubers should be the main component of seed potato *(Solanum tuberosum* L.) production programme in Bangladesh to improve the tuber yield. From this perspective a field experiment was carried out in the research field of Sher-e-Bangla Agricultural University (SAU), Dhaka-1207, during November, 2015 to March, 2016 to investigate the effects of planting geometry, nitrogen and phosphorus ratio and haulm cutting on the production of seed potato. “Courage” was used as planting material under present study. The experiment comprised of three different factors as treatments namely, factor A: Planting geometry: S_1 = 60 × 20 cm and S_2 = 60 × 15 cm; factor B: Ratio of nitrogen (N): phosphorus (P): L_1 =100:40 and L_2= 150:50 and factor C: Period of haulm cutting: H_1= at 80 DAP (days after planting) and H_2= at 90 DAP. The experiment was laid out in a 3 factors split-split-plot design with four replications, where the planting geometry assigned to main plots; ratio of nitrogen and phosphorus to sub-plots and periods of haulm cutting to sub-sub plots. Results demonstrated that most of the parameters were significantly influenced by planting geometry, nitrogen and phosphorus ratio and haulms cutting period. In case of growth parameters, only the combination of planting geometry and fertilizer ratio noted a significant variation. Haulm cutting period had no effect on growth parameters. In aspect of yield components, the highest weight of tuber hill^{-1}(g), average tuber weight (g), tuber yield (t ha^{-1}) and seed potato yield (t ha^{-1}) was found under higher planting geometry, higher ratio of N: P and late haulm cutting. In case of combination, the highest weight of tuber hill^{-1} (455.62 g), average tuber weight (54.54 g), tuber yield (37.96 t ha^{-1}) and seed potato yield (30.06 t ha^{-1}) were exhibited from $S_1L_2H_2$ treatment *i.e.*, the wider planting geometry (60cm × 20cm), higher nitrogen and phosphorus (150:50 kg ha^{-1}) in combination with late haulm cutting (at 90 DAP) whereas $S_2L_2H_2$ treatment combination was the worst one. From this study, it may be concluded that the best combination of planting system from the present study may put remarkable contribution for minimizing the seed scarcity to improve the tuber yield for the betterment of farming community.

LIST OF CONTENTS

CONTENTS (Cont'd)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Cont'd)

LIST OF APPENDICES

LIST OF PLATES

LIST OF ACCRONYMS AND ABBREVIATIONS

AEZ	Agro-Ecological Zone
%	Percentage
@	At the rate of
Agric.	Agriculture
Agril.	Agricultural
Agron.	Agronomy
Appl.	Applied
Biol.	Biology
Chem.	Chemistry
cm	Centi-meter
CV	Coefficient of Variance
DAP	Days After Planting
Ecol.	Ecology
Environ.	Environmental
et al	et alii, And Others
Exptl.	Experimental
g	Gram
H	Haulm cutting
i.e.	*id est* (L), that is
J.	Journal
kg	Kilogram
L	Ratio of nitrogen and phosphorus
LSD	Least Significant Difference
M.S.	Master of Science
m^2	Meter squares
mg	Milligram
Nutr.	Nutrition
Physiol.	Physiological
Res.	Research
S	Spaing
SAU	Sher-e-Bangla Agricultural University
Sci.	Science
Soc.	Society
t ha^{-1}	Ton per hectare
viz	*videlicet* (L.), Namely

CHAPTER I

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most widely grown tuber crop in the world and contributes immensely to human nutrition and food security (Karim *et al.*, 2010). Bangladesh is the 8th potato producing country in the world and in Bangladesh; it ranks second after rice in production. The total acreage, production and yield of Bangladesh is 0.47 million hectares, 0.947 crore MT and 19.91 t ha^{-1}, respectively (FAOSTAT, 2016). The potato yield is increasing day by day in Bangladesh but the average yield is very much low compared to other major potato producing countries *viz.*, USA (47.15 t ha^{-1}), France (27.76 t ha^{-1}) (FAOSTAT, 2016). The seed production in Bangladesh is not as good as developed countries. In potato production, seed alone accounts for 40-50% of the total cost of cultivation due to higher seed rate per unit area (Singh, 2005). Bangladesh is sub-tropical country so the seed potato production is a highly technical matter which needs careful attention in all stages like date of planting, planting geometry, fertilization, irrigation, weeding, earthing up, spraying of pesticides, date of dehaulming, harvesting etc. The existing ratio of seed potato yield to total yield is about 0.6:1.0 which could be improved through agronomic management (Mahmud *et al.*, 2009).

Planting geometry means row to row and plant to plant distance, plays a vital role in the production of tuber crops under irrigated condition. Sub-optimal planting geometry, wider rows and plant spacing lead to low population which in turn fail to compensate the yield obtained in optimum plant stand while narrower row and plant spacing increase the inter- and intra-plant competition leading to poor growth and development and dry matter accumulation resulting in poor yield (Pandey *et al.*, 2015).

As plant density increases, there is a marked decrease in yield plant^{-1}. This effect is due to increased inter-plant competition for water, light and nutrients which may impact optimization of yields. Planting geometry is considered a very important tool for better production of potato seed. It was revealed that even small size (5-10g and 20-30g) tubers planted at closer row and plant spacing (60×15 cm and 70×15 cm) produced medium size tubers (33-55 mm). Whereas, wider spacing (70×20 cm, 50×20 cm) produced relatively higher number of large size tubers (Verma *et al*., 2016). The differences in the emergence count of tuber might be attributed to the improved soil moisture maintained by closer ridge spacing due to reduced exposure of soil surface to evaporation (Kumar *et al*., 2001).

The potato has the affinity to the nitrogen (N), phosphorus (P) and potassium (K). Among these, N and P are most crucial for potato seed tuber production. Nitrogen is the relative measures of leaf chlorophyll content which resulted in more photosynthate for the crop improvement through more dry mater production. In soil, the P has the capacity to synergist N. The imbalance of N and P has hampered the production of tuber of potato (Hailu *et al*., 2017).

Haulm cutting is the removal of haulm by hand tools or light machine and it can be used to advance harvesting, reduce foliage mass, obtain a suitable tuber size, strengthen tuber skins before harvesting and prevent plant pathogens from spreading amongst the foliage and crop. Early haulm killing decreases crop yield but, on the other hand, haulm killing carried out too late increases the risk of pathogens and potato diseases (Struik and Wiersema, 1999). Delayed dehaulming increased the potato yield of all the grades. Higher yield at 80 days after planting might be attributed to the continuous translocation of photosynthates from ·tops to tubers over a longer period of time which increased the size as well as number of tubers (Kumar *et al*., 2001). The interaction among spacing, farmyard manure and dehaulming time on different potato parameters was non-significant (Kumar *et al*., 2001).

But research works with planting geometry, N and P rate and haulm cutting on potato is not well flourish to us in Bangladesh. Under such situations, there is need to develop an optimum seed potato production technology for maximizing yield and number of seed potato tubers.

From the above discussion optimum planting geometry, N and P rate and haulm cutting may contribute to produce higher and quality seed potato. Therefore, the field experiment was conducted with the following objectives:-

i) To determine the optimum planting geometry for maximizing the seed potato yield,

ii) To find out the optimum ratio of N and P application for maximizing the seed potato yield and

iii) To standardize the optimum period of haulm cutting for maximizing the seed potato yield.

CHAPTER II

REVIEW OF LITERATURE

As a staple starchy food crops, potato playing a major role in many developed country mostly in Bangladesh. Improvement of growth, yield and quality attributes of potato is much more important for growing hungry people around the world through processing and exporting industry. In Bangladesh the yield of seed potato tuber is much lower than other major potato growing developed countries. But, the yield potential of potato is plastic nature those could be changed by nutritional management including mediated new cultivation systems. The research on fertilizer applications on potato are more or less availed in our country but research on the optimum planting geometry, N and P rate and haulm cutting for better quality seed potato tuber is not well known to us. Some more related research findings regarding production of seed potato against planting geometry, N and P rate and haulm cutting have been reviewed under this chapter.

Belachew (2016) conducted an experiment to study the effect of different Nitrogen (N) and Phosphorus (P) levels on growth, yield and quality of potato. Treatments consisted of four levels of N (0, 55, 110 and 165 kg N ha^{-1}) and four levels of P (0, 45, 90 and 135 kg P ha^{-1}) which was laid out in Randomized Complete Block Design (RCBD) in a 4x4 factorial arrangement with three replications. Data were collected on growth and yield parameters and analyzed using SAS 9.2 software. Results revealed that application of N and P fertilizer significantly ($P < 0.05$) influenced plant length, days to 50% flowering, main stem number, days to physiological maturity, total tuber number, marketable tuber number, total tuber yield, marketable tuber yield, average tuber weight and tuber dry matter percentage.

The highest total tuber yield was recorded for combined application of 165 kg N and 135kg P ha^{-1} (42.27 t ha^{-1}) and the lowest (12.91 t ha^{-1}) was obtained at the control plot. Combined application of 165 kg and 135 kg P ha^{-1} gave the highest marketable tuber yield (36.13 t ha^{-1}) and the lowest value (19.18 t ha^{-1}) was recorded for the control. The highest average tuber weight (78.97g) was observed for 165 kg N ha^{-1} while the lowest (52.45g) was obtained from the control. The highest dry matter (27.27%) percentage of potato tuber was recorded from plots that received the combination of N 110 kg ha^{-1} and P 90 kg ha^{-1}, while the lowest (22.17%) tuber dry matter percentage was obtained at the combination of highest (165 kg ha^{-1}) level of nitrogen and zero level of Phosphorus.

Regassa *et al.* (2016) undertaken an experiment at Bule hora district, Eastern Guji zone, southern Ethiopia in 2016 to study the effect of different NP rates on the yield and yield components of Irish potato to determine biological and economic optimum NP rate at the area. Adapted and recommended variety of Irish potato variety (Gudane) was used for the experiment under rainfall. The treatment consisted of combination of five levels of N (0, 50, 80, 110 and 140 kg N ha^{-1}) and four levels of P (0, 45, 90 and 135 kg P ha^{-1}). Data were collected on parameters like plant length, number of branch $hill^{-1}$, tuber weight, marketable yield $hectare^{-1}$, non-marketable yield $hectare^{-1}$ and total yield $hectare^{-1}$. Tuber yield was significantly affected by both P and N levels. There was also a significant N and P interaction effect on tuber yield. The maximum total tuber yield (195.06 qt ha^{-1}) was obtained when 50 kg N ha^{-1} and 135 kg P ha^{-1} were combined, and closely followed by 193.21 qt ha^{-1} obtained at 110-90 kg ha^{-1} NP combinations, resulting in grain yield benefit of 361 and 358% over the control, respectively. Almost all collected parameters were significantly affected by P rate but did not respond to N rate. Based on this experiment, 110-90 Kg ha^{-1} NP combination was found profitable and recommended for Irish potato farmers of Bule hora district and similar areas.

Shunka *et al.* (2016) conducted a field experiment at Holetta and Jeldu Agricultural Research Station in the central highlands of Ethiopia to determine the rates of Nitrogen (N) and Potassium (K) fertilizers on growth, yield and yield components of potato. 4×3^2 factorial treatment was arranged in completely randomized block design with three replications on plot size of 3 m × 3 m during 2014-2015 cropping season. Nitrogen (87 kg, 110 kg and 133 kg ha^{-1}), Potassium (0, 34.5 kg, 69 kg and 103.5 kg ha^{-1}) and potato varieties (Betete, Gudenie and Jalenie) were used. The interaction effect of potassium and nitrogen fertilizers did affect marketable tuber number and plant length significantly. Gudenie produced the highest marketable yield (30.53 t ha^{-1}) in 2015 with application of 69 kg/ha potassium and 110 kg ha^{-1} nitrogen rates while lowest marketable yield (16.67 t ha^{-1}) was obtained from Belete variety at 0 kg ha^{-1} potassium rate and 87 kg ha^{-1} nitrogen rate. From these results, it can be concluded that interaction of nitrogen and potassium rates affected significantly plant length and marketable tuber numbers. Therefore, it is better to apply 69 kg ha^{-1} potassium and 110 kg ha^{-1} nitrogen for potato production to obtain reasonable economic yield at sites similar to experimental locations.

Verma *et al.* (2016) carried out an experiment on the effect of mulching and planting geometry to improve the yield and quality of seeds in vegetables. Numerous workers have given reasonable proof that mulches provide many advantages for the user, such as higher yields, better fruit quality, earlier harvest, better moisture retention, inhibition of weed growth, reduced fertilizer leaching, decreased soil compaction, fruit protection from soil deposits and from soil microorganisms. One of the main objectives of using plastic mulch is to increase soil temperature in the rootzone. The favourable root-zone temperature promotes the uptake of water and mineral nutrients, which in turn promotes better foliage, growth and fruit set.

Planting geometry determines the plant distribution in the field and thereby affects competition among crop plants for minerals, nutrients and also important to facilitate aeration and light penetration into crop canopy. Plant arrangement has received relatively little attention particularly in bell pepper. In theory, equidistant spacing of plants within the row and between rows (an arrangement approaching a square) should maximize the yield per plant by optimizing canopy exposure to light and by providing a more uniform area for water and mineral uptake by the roots. Plant biomass production per unit area of land is directly related to solar radiation interception. Solar radiation interception depends on leaf area index, which is strongly determined by plant density and arrangement.

Rostami *et al.* (2015) conducted an experiment to study the effects of nitrogen fertilizer and plant density on yield characteristics of potatoes (CV. Sante. The experimental design was factorial based on randomized complete blocks design with four replications. In this experiment, densities were in 80, 100 and 130 thousand plants in hectare and nitrogen fertilizer was tested at four levels (Nitroxin, Nytrazhyn, Azotobacter and urea). After harvesting potatoes on number of tubers per plant, tuber weight, tuber yield, harvest index, density and percent nitrogen gland tubers were measured and the results of analysis of variance. The results showed that the density and type of nitrogen fertilizer was significant on all traits. The density of 80 thousand plants per hectare than other treatments were superior in many characteristics between the treatments of different types of nitrogen fertilizer urea fertilizer for most traits were statistically significantly better. Also, in different types of nitrogen fertilizer urea fertilizer was better statistically significantly for most traits. The interaction between plant density and nitrogen fertilizer were statistically significant for most traits. So most of the potato tuber yield (4584.9), the density of the tuber (1.44 cm^3) and harvest index (56.33) was conducted from application of urea and planting 80 thousand plants per hectare.

Therefore it is suggested to use density of 80 thousand plants per hectare and application of urea fertilizer in this study has shown the best results. Also yield difference between 80 and 100 thousand plant density was not significant in any of the applied fertilizers.

Kumar *et al*. (2014) conducted a field study at Central Potato Research Institute Campus, Modipuram, India during with two processing varieties Kufri Himsona and Kufri Chipsona-3 in main plot and five crop geometry treatments (67.5 × 20, 67.5 × 22.5, 67.5 × 25, 67.5 × 27.5 and 67.5 × 30 cm). Growth traits, processing grade tuber number and yield and processing quality parameters were not influenced by crop geometry. Tuber number/plant, percent processing grade tuber and average processing grade tuber weight steadily increased with increased intra-row spacing from 22 to 30 cm. Net returns (` 126,000 ha^{-1}) and B:C ratio (2.69) was highest at 67.5 × 30 cm crop geometry. Processing grade tuber number and yield, net returns, B:C ratio was higher for cv. Kufri Chipsona-3 than Kufri Himsona. Tuber number $plant^{-1}$, tuber dry matter and chip yield was higher and oil per cent in chips were lower in cv. Kufri Himsona compared to Kufri Chipsona-3. Tuber dry matter yield, chip colour score and glucose content were statistically similar in both the cultivars. Study suggests that cv. Kufri Chipsona 3 and Kufri Himsona may be raised at 67.5 × 30 cm crop geometry for higher tuber yield, net returns and better processing quality.

Roy *et al.* (2014) conducted an experiment to observe the response of seedling tuber weight and plant spacing on yield and economic analysis of potato. Four weight of seedling tubers *viz.*, 40 ± 2, 30 ± 2, 20 ± 2 and 10 ± 2 g and three plant spacing *viz.*, 60 cm × 25 cm, 60 cm × 20 cm and 60 cm × 15 cm were used as treatment and laid out in Randomized Complete Block Design (RCBD) with three replications.

Results revealed that in general yield attributes such as tubers hill^{-1} and tuber weight and tuber yield of gross, marketable and non-marketable were significantly influenced by seedling tuber weight and plant spacing .The highest tuber yield ha^{-1} both gross and marketable was recorded in the tuber weight of 30 ± 2 g due to increased number of tubers hill^{-1} and tuber yield hill^{-1} and the lowest from smaller seedling tuber of 10 ± 2 g. Results showed that tubers hill^{-1}, single tuber weight and tuber weight hill^{-1} increased with increasing plant spacing. The highest gross and marketable tuber yield ha^{-1} was observed in the plant spacing of 60 cm × 20 cm and the lowest from closer spacing of 60 cm × 15 cm. For combined effect of seedling tuber weight and plant spacing, the highest gross and marketable tuber yield was observed in the treatment combination of 40 ± 2 g seed tuber with the plant spacing of 60 cm × 25 cm. But economic point of view with high yield performance, the seedling tuber size of 30 ± 2 g with plant spacing of 60 cm × 20 cm was more profitable than those of other treatment combinations.

Sharma *et al*. (2014) carried out an experiment at Central Potato Research Station, Kufri (Shimla) to find out the suitable method of planting the potato micro-plants with appropriate plant density for obtaining optimum number and size of mini-tubers. Three week old micro-plants of potato cultivar Kufri Himalini were planted in two different methods *viz*., flat bed and ridge-furrow system in combination with two plantlet densities, *viz*., 33 and 50 hills m^{-2}, achieved by planting at two spacings *viz*., 30 x 10 cm and 20 x 10 cm respectively. Two plantlets were planted hill^{-1}. Higher number and yield of mini-tubers were obtained under flat bed (232.6 and 2.23 kg m^{-2} respectively) than ridge-furrow method (221.4 and 1.85 kg m^{-2} respectively). Higher plant density (20 x 10 cm) resulted in more number of mini-tubers (237.7 m^{-2}) than low density (216.2 m^{-2}). Plant density did not influence the yield of mini-tubers significantly.

Planting at low density (30 x 10 cm) was better in improving the size of mini-tubers and reducing the proportion of <3g mini-tubers over higher density (20 x 10 cm). Flat bed method of planting was also superior to ridge-furrow method in reducing the proportion of extremely small sized (<3g) mini-tubers.

Virtanen and Seppanen (2014) carried out a field study to observe the response of haulm killing is used in seed potato production primarily to regulate tuber size. The most common haulm killing method is mechanical-chemical. We studied the effects of mechanical and mechanical-chemical haulm killing methods on seed potato quality, comparing to natural haulm senescence (control). The timing of haulm killing (when no more than 5% of the crop tubers were over 50 mm in size) and the time between destruction and harvest (21–26 days) were similar to practices followed in seed-potato production. Matilda was the cultivar used. In this study, haulm killing clearly increased plant disease pressure, as black scurf (*Rhizoctonia solani*) could be seen in tubers whose haulm had been destroyed. Black scurf was also observed in mechanical haulm killing. The yield from naturally senesced haulm had less black scurf than the other treatments. In addition, when haulm senescence occurred naturally, crop yield and starch content were highest compared to other treatments.

Diengdoh *et al.* (2012) Plant spacing and tuber size are important for potato seed production due to their effects on plant development and yield of the crop. The effects of different spacing (30 x 15 cm and 40 x 15 cm) and grading (<3 g, 3-6 g and >6 g seed) were studied at Central Potato Research Station, Shillong during 2009 & 2010 autumn planting season under net-house conditions using the cultivar Kufri Himalini. Data was recorded on germination, plant length, no. of stem m^{-2}, no. of leaves m^{-2}, no. of tubers $plant^{-1}$ and yield $plant^{-1}$.

It was determined that closer spacing increased the number of tubers, however reduction in the size of the tubers was observed. Planting larger sized mini-tubers positively affected all the growth and yield parameters during the planting period. Our findings indicated that the size of the mini-tuber seed has further importance for growth and total yield aspects in potato production system. Also, since in a mini-tuber production programme, the tuber number vis-a-vis to its size is more preferable. Thus, the overall finding indicated that lowering the spacing is more suited for mini-tuber multiplication.

Kumar and Lal (2012) conducted a field experiment at Patna in randomized block design with nine treatments and four replications to show the effects of two planting space, two levels of nutrients and two crop durations. In control treatment, the crop was raised through seed plot technique. Yield as well as number of small tubers (10 40 g) increased significantly with closer planting space (60 x 10 cm) and lower level of nutrients (100, 35 and 67 kg N, P and K), while the yield and number of bigger size tubers were significantly higher at wider spacing and higher level of nutrients. Yield and number of total tubers were increased significantly with decrease in planting space. Total tuber yield was increased significantly from 219.4 q ha^{-1} to 237.8 q ha^{-1} due to increase in N & P level from 100 and 35 to 150 and 52 kg ha^{-1}, respectively. Yield of small and total tubers were recorded significantly higher when duration of crop was increased from 70 to 80 days. Number of small tubers (10-40g) and total tubers were also increased due to increase in crop duration but the difference was non-significant. Seed multiplication rate as well as benefit cost ratio was recorded higher at wider planting space, higher nutrients level and at longer crop duration. The maximum benefit cost ratio of 1.88 was received in control treatment.

Masarirambi *et al.* (2012) carried out a field study with the potato (*Solanum tuberosum* L.) variety BP1 to determine the influence of plant population density and seed tuber size on the crop's physiological growth components and yield performance under optimal field conditions. Two factors considered were seed tuber size and population density. The first factor involved four seed sizes; S_1 (small), 200-350 mm in diameter; S_2 (medium), 350-450 mm in diameter; S_3 (large), 450-550 mm in diameter and S_4 (very large), greater than 550 mm in diameter. The second factor was population density (E) and it was at three levels; level 1 (E_1) at 90 by 15 cm, level 2 (E_2) at 90 by 30 cm, level 3 (E_3) at 90 by 45 cm spacing. Parameters measured included shoot emergence (germination), haulm growth and yield. There were significant differences in mean percentage germination at 9, 10, 11 and 12 days after planting across the four seed sizes. Large and very large seed potato tubers exhibited greater overall resource use efficiency of allocation o metabolites as measured by growth components and yield at all plant density levels compared to small and medium sized seed tubers. At the same time, plant population density had no significant effect on the number of days to emergence.

Khan *et al.* (2010) carried out an experiment to determine the suitable planting geometry for better yield from TPS mini tubers. It was revealed that even small size (5- 20g, 20-30g) tubers planted at closer row and plant spacing (60cm x 15cm,70cm x 15 cm) produced 31.00%, 31.33% and 28.33%, 32.33% medium size tubers (35-55 mm size). Whereas wider spacing (70cm x 20cm, 50cm x 20cm) produced relatively higher number of large size tubers.

Arioglu (2009) carried out an experiment to optimize the plant density and seed size are the most important subjects of early potato production systems in mediterranean-type environments due to their effects on seed cost, plant development, yield and quality of the crop.

The effects of different in-row spacing (20, 25, 30 and 35 cm) and seed size (small, medium and large) treatments on yield components and tuber yield of early potato were studied in Adana, where is situated in the east mediterranean region of Turkey, during 2006 and 2007 growing seasons. It was determined that closer spacing reduced tuber number hill^{-1}, average tuber weight, tuber yield hill^{-1} and percentages of large and medium size tubers. Total yields increased as increasing planting density up to 20 cm spacing. Planting larger seeds positively affected all growth and yield components in both years. Tuber yield ha^{-1} was increased up to certain stem density and then started to decline at all seed sizes. The optimum stem density increased with increasing seed size. Hence it was concluded that using larger tubers had an advantage for vigorous early growth and for obtain high tuber yield in early potato production in the mediterranean-type environments. Seed size should be considered during recommendation for planting density in potato production.

Mahmud *et al*. (2009) carried out an experiment to investigate the effects of seed tuber size on five standard potato cultivars (Cardinal, Multa, Ailsa, Heera, and Dheera) in relation to dates of dehaulming (65, 70, and 80 days after planting) in a Seed Potato Production Farm, Debijong, Panchagarh during 1996-97 and 1997-98. Dehaulming at 70 days gave maximum seed size tubers (19.75 t ha^{-1} ≈ 76%) but identical to 75 days (19.56 t ha^{-1} ≈ 70%) and 80 days (18.69 t ha^{-1} ≈ 63%).Considering all the parameters studied, the performance of Heera proved to be best among the cultivars grown. Among the cultivars, the maximum seed tuber yield was recorded from Cardinal at 80 DAP followed by Heera and Cardinal at 70 DAP, Dheera and Ailsa at 75 DAP. In general, most of the cultivars gave the maximum seed tuber yield when the crop was dehaulmed at 70 and 80 DAP and the lowest from 65 DAP.

Bussan *et al*. (2007) conducted a study to optimize the tuber size to maximize crop value Potato (*Solanum tuberosum*) for in-row spacings ranging from 15 to 40 cm. Production goals require. Also the goal was to evaluate the effect of plant, stem, and tuber density on stem and tuber set, potato yield, tuber size distribution, and other quality factors. Research plots were established within a 20-ha commercial production field and analysis was done with linear and nonlinear regression. Plant density decreased with increasing in-row plant spacing. Stem density increased linearly with increasing plant density, but response differed across years. Tuber density increased to a maximum of 190 tubers m^{-2} in response to plant and stem density, with stem density more accurately predicting tuber set. Yield was related to plant, stem, and tuber density using nonlinear regression, more accurately predicted by stem and tuber density than by plant density. Average tuber size was related to stem and tuber density using the inverse yield law and estimated maximum average tuber size of >200 g. Modeling tuber size distribution over different stem densities provides a mechanism for future economic analysis to optimize management and conduct sensitivity analysis to determine the most important factors influencing crop value.

Kumar and Lal (2006) conducted a field experiment to evaluate the effects of planting geometry, N and P levels and haulm cutting on the production of small size tubers of potato at the Central Potato Research Station, Patna (Bihar), with variety Kufri Ashoka in randomized block design with four replications. The treatments consisted of two plant spacing's (60 x 15 and 60 x 10 cm), two levels of nitrogen and phosphorus (100 and 35, and 150 and 52 kg ha^{-1} of N and P) and two schedules of haulm cutting at 70 and 80 days after planting. The level of potassium (83 kg ha^{-1}) was uniform for both the levels of N and P.

A control treatment having 60 x 20 cm planting geometry was planted with 150, 35 and 83 kg ha^{-1} of N, P and K and haulm cutting was done at the appearance of critical level. Number of stems m^{-2} decreased significantly with the increase in plant spacing from 60 x 10 cm to 60 x 15 cm. Yield of small sized tubers (up to 40g) and total tubers increased significantly with closer plant spacing, while the yield of bigger size tubers (>40g) increased with wider planting geometry. Number of small sized tubers (up to 40g) as well as total tubers increased significantly at closer planting geometry, while the number of larger size tubers (>40g) increased with wider planting geometry. Multiplication rate on the basis of yield decreased from 7.8 times to 4.21 times with a decrease in plant spacing. The effect of different doses of nitrogen and phosphorus on the number of stems m^{-2} was not-significant.

Singh and Singh (2005) conducted a field experiments, one each for N (0, 80, 120, 160 and 200 kg ha^{-1}), P_2O_5 (0, 50, 100, 150 and 200 kg ha^{-1}) and K_2O (0, 50, 100, 150 and 200 kg ha^{-1}) were carried out, with other two incorporated as standard dose (N: 120, P_2O_5: 60 and K_2O: 80 kg ha^{-1}) at Varanasi to find out the best NPK combination for eastern Uttar Pradesh. Increasing doses of N, P and K up to 200 kg ha^{-1} improved tuber yield. However, tuber yield and related yield traits significantly improved only up to 120, 100 and 100 kg ha^{-1} of N, P_2O_5 and K_2O, respectively. Percent dry matter and starch content were significantly higher at lower levels of N and K.

Kumar *et al.* (2004) conducted a field experiment on sandy loam soils at Central Potato Research Institute Campus, Monirampur research farm in west-central plains to optimize best crop geometry for obtaining maximum chipping size grade yield in two recently released potato cultivars Kufri Chipsona-l and Kufri Chipsona-2.

Planting geometry did not affect the plant growth parameters (plant length, compound leaf number plant^{-1} and stem number) and processing quality parameters like specific gravity, dry matter content, Chips color and reducing sugars. In cv. Kufri Chipsona-l the maximum processing grade tuber number and Yield (242.42 thousand ha^{-1} and 235q ha^{-1}) were recorded at 66 x 20 cm, spacing, while these yield attributes remained unaffected due to vanable crop geometry commotions in cv Kufri Chlpsona-2. In view of problem of greening of tubers ridges, abrupt changes in soil moisture and temperature during tuber development and at maturity due to weather variations, It may be concluded that the spacing of 66 x 20 cm could be recommended for growing Chipsona cultivars for chipping purpose in this region.

Khalafalla (2001) carried out an experiment to evaluate the effect of size of seed tuber (whole, ½ seed and farmer's seed piece) and intra-row spacing (15, 25, 35 cm) on growth and yield of potato was studied during three winter seasons in Khartoum State, Sudan at two locations, namely Shambat Research Farm and Shehainab Isand representing two soil types. Yield decreased with decrease in seed size and increase in spacing at both locations. Close spacing of 15 - 25 cm was better than wide spacing 35 cm. Seed size affected some yield parameters, i.e., marketable tubers plant^{-1}, marketable tuber weight, number of marketable tubers plant^{-1} and number of stems plant^{-1}. These parameters were also affected by plant spacing except number of stems.

Kumar *et al.* (2001) conducted a field experiment on light-textured soil at Modipuram to develop potato-seed technology for producing maximum number of seed-sized tubers <40 g) by testing 2 inter row planting spacings,3 levels of farmyard manure and 3 dehaulming time schedules in potato *(Solanum tuberosum* L.).

The number of tubers increased with decrease in planting spacing from 50 cm x 15 cm to 50 cm x 10 cm spacing and delay in dehaulming time from 60 to 80 days after planting, Farmyard manure up to 20 t ha^{-1} had no significant effect on tubers <40 g) but increased the number as well as yield of tubers weighing > 40 g. The crop with haulm-cut (dehauhued) at 80 days produced tubers up to 40 g size and accounted for 91 % of the produce. The physiological maturity of seed tubers induced by dehaulming the crop at 60, 70 and 80 days did not affect the number of seed-sized tuber. The seed produce of 80 days old haulm cut crop gave about 18% higher yield than the seed produce from 60-70 days old haulm cut crop.

Oliveira (2000) studied the growth and development variables and dry matter characteristics were studied for cultivar Snowden of potato (*Solanum tuberosum* L.) to evaluate nitrogen and plant density influence. Disregarding ending of season plant stress, the average number of actives haulm per plant was five and it was not affected by plant spacing. However, seasonal and final number of active haulm per plant was increased at 200 kg ha^{-1} of nitrogen. Maximum stem elongation was reached quickly with double density and had the tendency to keep constant at the highest and lowest nitrogen levels after 70 days after planting. Specific stem mass defined as mass per unit stem length was established as an indirect measure of stem thickness and load capacity. Specific leaf mass position in plant was higher at upper stem leaves, increased as plant density increased and did not vary markedly over time throughout the season. The rate of leaf appearance increased drastically due to more branching caused by high nitrogen level, and increased above ground dry matter per plant. Canopy growth and development influenced main tuber yield components. The number of active tubers per haulm decreased after 60 days after planting showing that tuberization is reversible. Tuber growth functions were established allowing the estimate of dry biomass partitioning coefficients for each plant organ.

By reviewing the different sources of information regarding the present experiment it was found and taken that, the systems of planting geometry, fertilizer ratio and haulm cutting has the potentiality to response against different traits of potato and other crops. So, different levels of planting geometry, fertilizer ratio in combination with different periods of haulm cutting were taken for the present study to investigate the effects on vegetative growth, tuber yield and seed yield of potato.

CHAPTER III

METERAIALS AND METHODS

Description about experimental site, climatic condition, planting materials, treatments, experimental design and layout, crop husbandry, intercultural operations, data recording and statistical package were described in this chapter. The details of experimental materials and methods are described below:

3.1 Experimental period and site

The experiment was conducted in the Agronomy research field of Sher-e-Bangla Agricultural University (SAU), Dhaka-1207, during November, 2015 to March, 2016. The experimental area was situated between 23^{o}7'N latitude and 93^{o}E' longitude with 8.6 meter altitude of above the sea level (Anon., 2004) and research area was also belonged to agro-ecological zone of "Madhupur Tract", AEZ-28. The experimental site is shown in the map of AEZ of Bangladesh in (Appendix-I).

3.2 Climate and soil

With a significant monsoon climate under sub-tropical cropping zone, the experimental site most probably characterized by winter during the months from November, 2015 to March, 2016 (*Rabi* season). The soil above the sub-surface soil are termed as "Surface/Top soil" which was characterized by silty clay with slight sand in texture, olive-slight brown whitish with common fine to medium distinct dark whitish brownish-grey mottles was seen on the top soil. The soil was also characterized by pH-5.67 and organic carbon-0.462%. The experimental area was medium flat and medium high topography with available easy irrigation and drainage system. The weather data during the study period at the experimental site including maximum and minimum temperature, total rainfall and relative humidity were shown in (Appendix-II).

3.3 Planting material

A popular variety due to have processing and export quality attributes in "Courage" was used as test crop under present study which was released and developed by Tuber Crops Research Centre (TCRC), Bangladesh Agricultural research Institute, Gazipur. The variety was used due to improve the income status of farming communities of potato in Bangladesh as a whole by higher yield.

3.4 Treatments

The present experiment was comprised of three different factors as treatments are as follows:

Factor A: Planting geometry (2)

S_1 = 60 × 20 cm

S_2 = 60 × 15 cm

Factor B: Level of nitrogen: phosphorus (2)

L_1 =100:40

L_2= 150:50

Factor C: Period of haulm cutting (2)

H_1= at 80 DAP

H_2= at 90 DAP

Total eight treatment combinations were used under present study are as follows: $S_1L_1H_1$, $S_1L_1H_2$, $S_1L_2H_1$, $S_1L_2H_2$, $S_2L_1H_1$, $S_2L_1H_2$, $S_2L_2H_1$ and $S_2L_2H_2$

3.5 Experimental design and layout

The experiment was laid out in a 3 factors split-split-plot design with four replications, where the planting geometry assigned to main plots; level of nitrogen and phosphorus to sub plots and periods of haulm cutting to sub-sub plots. The total numbers of unit plots were 32. The size of unit plot was 2.5 m × 2.0 m. The final layout of the experimental plots was shown in Appendix-III.

3.6 Preparation of seed

Uniform size (40-50 g) tubers of potato were used for planting and kept in room temperature to facilitate good sprouting. Finally potato tubers as full sprouted were used as planting material in furrows of allocated plot.

3.7 Land preparation

At first week of November the land of the experimental site was first opened with power tiller and the land was ploughed and cross-ploughed four times followed by laddering to obtain the desirable tilth. Weeds and stubbles were removed from the corners of field using spade. Finally, on 12 November 2015 the land was prepared three days before of the planting of whole seed tuber. Drainage channels were made around the land in order to avoid water logging due to rainfall during the study period. Furadan 5G @ 20 kg ha^{-1} was used as soil treatment when the plot was finally ploughed to protect the young plant from the attack of cut worm.

3.8 Fertilizer application

Recommended dose of common fertilizers at the rate of 132-15-2-5 kg ha^{-1} of K-S-B-Zn, respectively, as MoP, gypsum, boric acid and zinc sulphate were applied in the field during final land preparation (Mondal *et al*., 2013). The crop was fertilized as per treatments. Nitrogen was used @ 100 and 150 kg ha^{-1} from urea and applied in two equal installments where first half at FLP (Final land preparation) and second half at 35 DAP, during first earthing up. Phophorus was applied from TSP @ 40 and 50 kg ha^{-1} during final land preparation.

3.9 Planting of seed tuber

Tuber of “Courage” that was well sprouted, healthy and uniform sized potato planted according to desired planting geometry. Finally, the seed potatoes were planted at a depth of 5-6 cm on November 15, 2015.

3.10 Intercultural Operation

3.10.1 Earthing up

Direct sunlight resulted "Solonization of potato tubers" which is very much harmful and decreased the stolon number and finally reduced the tuber. So, earthing up reduce such problems. Earthing up was done at 35 DAP and second was at 50 DAP with a narrow spade for the development of tubers.

3.10.2 Removal of weed

Two weeks after emergence the first weeding was done and before 2nd top dressing of urea the weeding was done. It was also done additionally as per when required to keep the crop free from weeds and to keep the soil loose for proper aeration and development of tubers.

3.10.3 Watering and drainage

Throughout the growing period three irrigations were provided in a controlled way. The first irrigation was given at 30 DAP. Subsequently, another two irrigations were given at 55 and 65 DAP. Top dressing of fertilizers was followed by irrigation for proper utilization of fertilizers.

3.10.4 Control of insects and diseases

To keep the plant healthy all possible phytosanitary measures were adopted. Dursban @ 7.5 litre ha^{-1} was drenched on both sides of ridges at 30 DAP to control the cutworm. Dimecron 100 EC @ 2% and Admire 200 SL @ 0.5% were applied to control aphid and jassid. Ridomil Gold MZ @ 1g $litre^{-1}$ was applied at an interval of 7 days at moist condition of weather before the incidence of late blight of potato.

3.11 Haulm cutting

When plants showed 60-70% senescence then haulm cutting was done at February 05, 2016, for treatment H_1 and these potatoes were harvested 7 days after of haulm cutting for skin hardening and tuber bulking. On the other hand, for treatment H_2, haulm cutting was done at February 15, 2016 and these potatoes were harvested 7 days after of haulm cutting for skin hardening and tuber bulking. The tuber was harvested, collected, bagged and tagged separately for further data collection.

3.12 Recording of data

On the basis of the aims of the present study different types of data were collected. After harvesting of tuber some of the parameters were taken by using electronic balance, some of the parameters were taken by using plastic scale, digital electronics and means were calculated by using a digital calculator.

3.12.1 Growth traits

i. Days to first emergence (days)

To see the emergence of tuber from soil all the plots were keenly observed daily. The days to first emergence was calculated by deducting the days to observing the first days of emergence from the days of tuber planting.

ii. Days to 100% emergence (days)

To see the emergence of tuber from soil all the plots were keenly observed daily. The days to 100% emergence was calculated by deducting the days to observing the 100% days of emergence from the days of tuber planting.

iii. Plant length (cm) at stolonization stage

For taking the plant length ten randomly selected potato hills were considered. In all time, two stems of potato were considered for taking length. Then the length of stems of potato plant from each ten hills was added and then means were taken in centimeter unit.

iv. Days to stolon initiation (days)

To see the initiation of stolon from the soil all the potato ridges in each plot were keenly observed daily. The days to first initiation was calculated by deducting the first days to observing the stolon from the days of tuber planting.

v. SPAD value of potato leaf at first stolonization stage

SPAD value knows the relative content of chlorophyll in plant leaves. Under present study SPAD-502 an electrical device was used which was manufactured by Minolta Camera Co., Ltd, Osaka, Japan. (1989). To take the SPAD values ten randomly selected hills were considered and in all time the second leaf just beneath the top leaf was considered to take the SPAD reading considering the 3 leaves from each selected hills. Then the mean of 10 hills was taken.

3.12.2 Yield traits

i. Number of tubers hill^{-1}

From each plot five hills were randomly selected. From five hills the entire tuber was counted and then the mean values of tuber number per hill were calculated.

ii. Weight of tubers hill^{-1} (g)

From each plot five hills were randomly selected. By using an electronic balance the entire tuber was weighted from five hills and then the mean values of tuber weight per hill were calculated in gram unit.

iii. Average weight of tuber (g)

From each plot five hills were randomly selected. By using an electronic balance the entire tuber was counted and weighted from five hills. The weight of total tuber hill was divided by the numbers of tuber per hill to calculate the average tuber weight and then means were taken in gram unit.

iv. Tuber yield (t ha^{-1})

The tuber collected from 1 m^2 harvested area of each plot was weighted by an electronic balance. Then the weight of tuber per square meter was converted to per plot and then again converted to t ha^{-1}.

v. Seed potato yield (t ha^{-1})

For seed tuber yield calculation the tubers, those are between 28-55 mm of their size were considered and by using an electronic balance the entire tuber weighted from 1 m^2 harvested area of each plot. Then the means were taken in t ha^{-1} unit.

vi. Non-seed yield (t ha^{-1})

For non-seed tuber yield calculation the tubers, those are not belonged between 28-55 mm of their size were considered and then the entire tuber weighted by using an electronic balance from 1 m^2 harvested area of each plot. Then the means were taken in t ha^{-1} unit.

vii. 'A' grade seed (28 mm-45 mm)

For the calculation of 'A' grade seed yield, the tubers those are between 28-45 mm of their size were considered and then the tuber weighted by using an electronic balance from the total seed yield by separating the size mentioned above against each plot. Then the means were taken in t ha^{-1} unit.

viii. 'B' grade seed (45 mm-55 mm)

For the calculation of 'B' grade seed yield, the tubers those are between 45-55 mm of their size were considered and then the tuber weighted by using an electronic balance from the total seed yield by separating the size mentioned above against each plot. Then the means were taken in t ha^{-1} unit.

3.13 Correlation coefficient (r)

By using the MS excel spread sheet the correlation coefficient between different growth and yield contributing traits were calculated.

3.14 Statistical Analysis

By using the analysis of variance (ANOVA) technique with the help of WASP (Web Agri Stat Package: version-1) computer program the collected data on different parameters were analyzed statistically and mean were adjusted by using LSD (Least Significant Difference) at 5 % level of probability. By using Microsoft excel spread sheet the raw data management and graphical representation were done.

CHAPTER IV

RESULTS AND DISCUSSION

To investigate the effects of planting geometry, nitrogen and phosphorus ratio and haulm cutting on the production of seed potato the present study was conducted in the research field. Different figures, tables and appendices have been used in this chapter to present, discuss and compare the findings obtained from the present study. In aspects of all the visual and measurable traits the mean square values were given in the ANOVA (analysis of variance) which have been presented in Appendix (IV-IX). The all possible reveals and interpretations were given under the following headings:

4.1 Days to first emergence

A remarkable variation was noted among the different planting geometry of potato tubers in aspect of days to first tuber emergence (Table-1 and Appendix IV) against. The longer period (12.29 days) was required for the plant produced from S_2 treatment and the shorter was required for the plant produced from S_1 (9.11 days). A remarkable variation was noted in respects of days to first tuber emergence of potato plant (Table-2 and Appendix IV) against different ratio of nitrogen and phosphorus fertilizers. The longer period (11.08 days) was required for the plant produced from L_1 treatment and the shorter was required for the plant produced from L_2 (10.33 days). Days to first tuber emergence of potato plant was found non-significant (Table-3 and Appendix IV) against different periods of haulm cutting. Combindly, no variation was found (Table-4 and Appendix IV) among the treatment combinations against days to first tuber emergence from the soil surface, except, in the combination of planting geometry and fertilizer ratio a significant variation (Table-4 and Appendix IV) was noted on this parameter. The potato mother tuber get a full growing condition without imparting the light, air and water to others at higher spacing and also at higher spacing there is lower competition than that of lower spacing.

The utilization of reserve materials and metabolites in the mother tuber was largely verifying the emergence. At planting time the optimum seed tubers had slightly longer and thicker sprouts and this contributed to earlier germination and crop establishment. Kabir *et al*. (2004) mentioned that, this enabled tubers to establish faster since the tubers were not yet photosynthesizing but were relying solely on the supply of metabolites from the mother tubers at higher spacing. In tomato the number of days to seed emergence was influenced significantly by urea, a nitrogenous fertilizer with increasing doses in combination with slight phosphate fertilizers (Masome, 2014). More absorption of nitrogen was exhibited by the treatment of 150 kg ha^{-1} resulting a better reduction of days required for first emergence of tuber from field which was showed from the result of present study.

4.2 Days to 100% emergence

Significant variation was noted in aspect of days to 100% tuber emergence of potato plant (Table-1 and Appendix IV) against different planting geometry of potato tubers. The longer period (15.94 days) was required for the plant produced from S_2 treatment and the shorter was required for the plant produced from S_1 (12.90 days). The 100% tuber emergence of potato plant in respects of days was found significant (Table-2 and Appendix IV) against different ratio of nitrogen and phosphorus fertilizers. The longer period (14.65 days) was required for the plant produced from L_1 treatment and the shorter was required for the plant produced from L_2 (14.19 days). In respect of days to 100% tuber emergence of potato plant was found non-significant (Table-3 and Appendix IV) against different periods of haulm cutting. Combindly, a non-significant results was found (Table-4 and Appendix IV) among the treatment against days to 100% tuber emergence from the soil surface, except, in the combination of planting geometry and fertilizer ratio a significant variation (Table-4 and Appendix IV) was noted on this parameter.

The potato mother tuber get a full growing condition without imparting the light, air and water to others at higher spacing and also at higher spacing there is lower competition than that of lower spacing. The utilization of reserve materials and metabolites in the mother tuber was largely verifying the emergence. At planting time the optimum seed tubers had slightly longer and thicker sprouts and this contributed to earlier germination and crop establishment. Kabir *et al*. (2004) mentioned that, this enabled tubers to establish faster since the tubers were not yet photosynthesizing but were relying solely on the supply of metabolites from the mother tubers at higher spacing. In tomato the number of days to seed emergence was influenced significantly by urea, a nitrogenous fertilizer with increasing doses in combination with slight phosphate fertilizers (Masome, 2014). More absorption of nitrogen was exhibited by the treatment of 150 kg ha^{-1} resulting a better reduction of days required for 100% emergence of tuber from field which was showed from the result of present study.

Table 1. Effect of planting geometry on days to first emergence and 100% emergence of potato

Planting Geometry	Days to first emergence	Days to 100% emergence
S_1= 60 × 20 cm	9.11 b	12.90 b
S_2= 60 × 15 cm	12.29 a	15.94 a
CV (%)	0.10	0.22
LSD (0.05)	0.018	0.055
F-test	**	**

Values with common letter (s) within a column do not differ significantly at 5% level of probability

** indicate significant at 1% level of probability

Table 2. Effect of fertilizer ratio on days to first emergence and 100% emergence of potato

Nitrogen: Phosphorus	Days to first emergence	Days to 100% emergence
L_1 =100:40	11.08 a	14.65 a
L_2= 150:50	10.33 b	14.19 b
CV (%)	0.23	0.10
LSD (0.05)	0.028	0.016
F-test	**	**

Values with common letter (s) within a column do not differ significantly at 5% level of probability
** indicate significant at 1% level of probability

Table 3. Effect of haulm cutting period on days to first emergence and 100% emergence of potato

Haulm Cutting	Days to first emergence	Days to 100% emergence
H_1= at 80 DAP	10.40	14.16
H_2= at 90 DAP	11.01	14.68
CV (%)	9.88	12.40
LSD (0.05)	-----	-----
F-test	NS	NS

Values with common letter (s) within a column do not differ significantly at 5% level of probability
NS= Non-significant

Table 4. Combined effect of spacing, fertilizer ratio and haulm cutting period on days to first emergence and 100% emergence of potato

Combination	Days to first emergence	Days to 100% emergence
$S_1L_1H_1$	9.30	13.65
$S_1L_1H_2$	10.18	14.20
$S_1L_2H_1$	8.457	11.85
$S_1L_2H_2$	8.50	11.90
$S_2L_1H_1$	10.58	15.00
$S_2L_1H_2$	11.24	15.76
$S_2L_2H_1$	13.25	16.15
$S_2L_2H_2$	14.10	16.84
CV (%)	9.88	12.40
LSD (0.05)	------	-------
F-test	NS	NS
S × L	**	**
S × H	NS	NS
L × H	NS	NS

Values with common letter (s) within a column do not differ significantly at 5% level of probability

Note: $\mathbf{S_1}$**=** 60 × 20 cm, $\mathbf{S_2}$**=** 60 × 15 cm; L_1 =100:40, L_2= 150:50; H_1= 80 DAP and H_2= 90 DAP

** indicate significant at 1% level of probability

NS= Non-significant

4.3 Plant length (cm) at first stolonization stage

Length of potato plant was found significant against different planting geometry of potato tubers (Table-5 and Appendix V). The taller plant (59.64 cm) was found from S_2 treatment and the smaller was in S_1 (46.72 cm).

In case of length of potato plant a significant variation was noted against different ratio of nitrogen and phosphorus fertilizers (Table-6 and Appendix V). The taller plant (55.549 cm) was found in the plant produced from L_1 treatment and the smaller was in L_2 (50.821 cm). In case of potato plant length a non-significant result was noted against different periods of haulm cutting (Table-7 and Appendix V). Combindly, no variation was found among the treatment against length of potato plant (Table-8 and Appendix V), except, in the combination of planting geometry and fertilizer ratio a significant variation (Table-8 and Appendix V) was noted on this parameter. The competition between plants with plant is higher than that of the higher planting geometry at lower planting geometry. The tuber growth of potato and canopy spreading has been hampered as a result the vegetative growth is increased than that of tuber development at lower planting geometry. The application of high rates of N to potatoes, depending on the variety, generally delays tuber initiation and promotes vegetative growth resulted from higher accumulation of nitrogen in plant cell resulting a increasing trend of plant length (Marschner, 1995).

4.4 Days to stolon initiation

By different planting geometry of potato tubers the days to stolon initiation in potato plant was found significant (Table-5 and Appendix V). The longer (period 41.22 days) was required for the plant to initiate stolon cultivated from S_2 treatment and the shorter was required for the plant cultivated from S_1 (36.08 days). In respects of days to stolon initiation of potato plant a remarkable variation was noted (Table-6 and Appendix V) against different ratio of nitrogen and phosphorus fertilizers. The longer period (39.95 days) was required for the plant produced from L_2 treatment and the shorter was required for the plant produced from L_1 (37.36 days).

Non-significant result was found in the different periods of haulm cutting in case of days to stolon initiation of potato plant (Table-7 and Appendix V). Combindly, no variation was found (Table-8 and Appendix V) among the treatment against days to stolon initiation, except, in the combination of planting geometry and fertilizer ratio a significant variation (Table-8 and Appendix V) was noted on this parameter. Higher planting geometry at planting time with thicker sprouts contributed earlier germination and crop establishment. Kabir *et al*. (2004) reported higher geometry enabled tubers to establish faster since the tubers were not yet photosynthesizing but were relying solely on the supply of metabolites from the mother tubers at higher spacing. Phosphorus increases the uptake of nitrogen in soil. The mother tuber of potato induced by more nitrogen to initiate stolon by increasing the cell division with a vigorous tuber where at higher N:P ratio and for tuber development the plant also get more time to accumulate the nutrients from the soil which induces the early reproductive growth than that of the tuber planting with lower N:P ratio (Regassa *et al*., 2016). A reduction in the number of nodes bearing stolons resulted from lower nutrient level which also led to fewer stolons per node and to reduced stolon growth per mother tuber under soil aside of the increasing of stolon periods (Ewing and Struik, 2010).

4.5 SPAD value of leaf at first stolonization stage

A significant variation was found among the different planting geometry of potato tubers to SPAD value of leaf (Table-5 and Appendix VI). The maximum SPAD value (42.29) was found from S_1 treatment and the minimum was in S_2 (41.83). In respects of SPAD value of potato leaf a significant variation was found against different ratio of nitrogen and phosphorus fertilizers (Table-6 and Appendix VI). The maximum SPAD value (43.852) was found from L_2 treatment and the minimum was in L_1 (40.279).

Due to different periods of haulm cutting the SPAD value of potato leaf was found non-significant (Table-7 and Appendix VI). Combindly, a non-significant result was found among the treatment against SPAD value of potato leaf (Table-8 and Appendix VI), except, in the combination of planting geometry and fertilizer ratio a significant variation (Table-8 and Appendix VI) was noted on this parameter. The mother tuber gets more nutrients at higher plating geometry than that of the tuber paced at lower spacing. With the increasing of nitrogen accumulation by the plants it tends to enhance the partitioning of more green pigments into the plants through photosynthesis (Regassa *et al*. 2016). Who also said that, chlorophyll content is approximately proportional to leaf nitrogen content and the vegetative growth was stopped to patron the sink to reproductive part as a whole at the advent of stolonization of potato tuber. As a result, the SPAD value was varied among the treatment at this stage of potato plant.

Table 5. Effect of planting geometry on length, days to stolon initiation and SPAD value of potato

Planting Geometry	**Plant length (cm)**	**Days to stolon initiation**	**SPAD value of leaf**
S_1= 60 × 20 cm	46.72 b	36.08 b	42.29 a
S_2= 60 × 15 cm	59.64 a	41.22 a	41.83 b
CV (%)	0.36	0.23	0.11
LSD (0.05)	0.332	0.155	0.080
F-test	**	**	**

Values with common letter (s) within a column do not differ significantly at 5% level of probability

** indicate significant at 1% level of probability

Table 6. Effect of fertilizer ratio on length, days to stolon initiation and SPAD value of potato

Nitrogen: Phosphorus	Plant length (cm)	Days to stolon initiation	SPAD value of leaf
L_1 =100:40	50.821 b	37.362 b	40.279 b
L_2= 150:50	55.549 a	39.954 a	43.852 a
CV (%)	0.55	0.02	0.09
LSD (0.05)	0.3297	0.02103	0.0448
F-test	**	**	**

Values with common letter (s) within a column do not differ significantly at 5% level of probability
** indicate significant at 1% level of probability

Table 7. Effect of haulm cutting period on length, days to stolon initiation and SPAD value of potato

Haulm Cutting	Plant length (cm)	Days to stolon initiation	SPAD value of leaf
H_1= at 80 DAP	53.296	37.982	42.199
H_2= at 90 DAP	53.074	39.334	41.932
CV (%)	9.80	11.02	12.60
LSD (0.05)	---	----	---
F-test	NS	NS	NS

Values with common letter (s) within a column do not differ significantly at 5% level of probability
NS= non-significant

Table 8. Combined effect of spacing, fertilizer ratio and haulm cutting period on length, days to stolon initiation and SPAD value of potato

Combination	Plant length (cm)	Days to stolon initiation	SPAD value of leaf
$S_1L_1H_1$	45.983	35.207	38.207
$S_1L_1H_2$	46.987	35.847	38.847
$S_1L_2H_1$	45.817	36.407	46.267
$S_1L_2H_2$	48.117	36.887	45.847
$S_2L_1H_1$	53.237	38.207	42.207
$S_2L_1H_2$	57.077	40.187	41.857
$S_2L_2H_1$	68.147	42.107	42.117
$S_2L_2H_2$	60.117	44.417	41.177
CV (%)	9.80	11.02	12.60
LSD (0.05)	-------	-------	-------
F-test	NS	NS	NS
S × L	**	**	**
S × H	NS	NS	NS
L × H	NS	NS	NS

Values with common letter (s) within a column do not differ significantly at 5% level of probability

Note: S_1= 60 × 20 cm, S_2= 60 × 15 cm; L_1 =100:40, L_2= 150:50; H_1= 80 DAP and H_2= 90 DAP

** indicate significant at 1% level of probability

NS= Non-significant

4.6 Number of tubers hill^{-1}

Due to different planting geometry of potato tubers the Number of tubers was found significant (Table-9 and Appendix VI). The maximum number (10.56) of tubers was found from S_2 treatment and the minimum was in S_1 (7.91).

A significant variation was noted in respects of number of potato tubers against different ratio of nitrogen and phosphorus fertilizers (Table-10 and Appendix VI). The maximum number of tubers (10.20) was found from L_2 treatment and the minimum was in L_1 (8.27). In case of number of potato tubers, a non-significant variation was noted due to different periods of haulm cutting (Table-11 and Appendix VI). Combindly, a non-significant result was found (Table-12 and Appendix VI) among the treatment against number of potato tubers (Table-12 and Appendix VI), except, in the combination of planting geometry and fertilizer ratio a significant variation was noted.

The plant population density significantly affected tuber numbers (Masarirambi *et al*., 2012). Arioglu (2009) said that, the greater the space, the higher the number of tubers formed. But the result of present study is contradictory of the findings of above researcher. But Kumar *et al*. (2001) reported a similar result that, close spacing leads to higher proportion of small tubers than wider spacing. However, the result of present study is also in agreement with Mahmud *et al*. (2009). Who said that, haulm cutting has no role on number of tubers because tuber formation in potato is almost completed within 50 days.

4.7 Weight of tubers hill^{-1} (g)

A significant variation was found among different planting geometry of potato tubers to weight of tubers (Table-9 and Appendix VII). The higher weight (368.03 g) of tuber was found from S_1 treatment and the lower was in S_2 (329.45 g). Weight of potato tubers found significant due to different ratio of nitrogen and phosphorus fertilizers (Table-10 and Appendix VII). The higher weight of tuber (355.46 g) was found from L_2 treatment and the lower was in L_1 (342.03 g). A significant variation was found in weight of potato tubers due to haulm cutting periods (Table-11 and Appendix VII). The higher weight of tuber (365.27 g) was found from H_2 treatment and the lower was in H_1 (332.21 g).

Combindly, the weight of potato tubers was found significant due to the treatment against (Table-12 and Appendix VII). The higher weight of tuber (455.62 g) was found from $S_1L_2H_2$ treatment combination and the lower was in $S_2L_2H_2$ (310.02 g). Since, the number of tuber was higher at higher planting geometry but the weight of tuber was higher due to that, the potato tuber gets more spaces to enlarge by size and shape with more accumulation of soil nutrients at wider spacing than that of tuber placed at closer planting geometry (Kumar *et al*., 2004). With help of phosphorus more absorption of soil nitrogen occurs by the plant resulted more protein partitioning into the growing tubers may be the main reason for higher weight of tuber hill^{-1}. Under the tropical climatic condition as like as Bangladesh, the tuber weight hill^{-1} increased with age, which is obvious up to 80 days. The potato crop matures within 85 to 95 days under this climatic condition. Potato storage food used in reverse order from tuber to foliage with the rise of temperature in the month of late February or March (Mahmud *et al*., 2009).

4.8 Average weight of tuber (g)

Due to different planting geometry of potato tubers the average weight of tubers was found significant (Table-9 and Appendix VII). The higher average weight of tuber (47.16 g) was found from S_1 treatment and the lower was in S_2 (31.91 g). Average weight of potato tubers was found significant against different ratio of nitrogen and phosphorus fertilizers (Table-10 and Appendix VII). The higher average weight of tuber (41.82 g) was found from L_1 treatment and the lower was found from L_2 (37.25 g). In respects of average weight of potato tubers a significant variation was noted against haulm cutting periods (Table-11 and Appendix VII). The higher average weight of tuber (40.99 g) was found from H_2 treatment and the lower was in H_1 (38.08 g).

Combindly, a significant variation was found among the treatment against average weight of potato tubers (Table-12 and Appendix VII). The higher weight of tuber (54.54 g) was found from $S_1L_2H_2$ treatment combination and the lower was in $S_2L_2H_1$ (25.84 g). Kumar *et al*. (2004) showed that, at higher plant densities/closer spacing's the intra-specific competition increased resulting the reduction of the average individual tuber weight for total and all tuber size categories. With help of phosphorus more absorption of soil nitrogen by the plant resulted more protein partitioning into the growing tubers may be the main reason for higher average weight of tuber hill^{-1}. With the increasing of nitrogen rate up to 165 kg ha^{-1} the average tuber weight progressively increased. Similarly, the average tuber weight highly and significantly increased by phosphorus application (Belachew, 2016). Under the tropical climatic condition as like as Bangladesh, the average tuber weight hill^{-1} increased with age, which is obvious up to 80 days. The potato crop matures within 85 to 95 days under this climatic condition. Potato storage food used in reverse order from tuber to foliage with the rise of temperature in the month of late February or March (Mahmud *et al*., 2009).

Table 9. Effect of planting geometry on number and weight of tuber hill^{-1}, average tuber weight of potato

Planting Geometry	Number of tubers hill^{-1}	Weight (g) of tubers hill^{-1}	Average weight of tuber (g)
S_1= 60 × 20 cm	7.917 b	368.03 a	47.164 a
S_2= 60 × 15 cm	10.564 a	329.45 b	31.916 b
CV (%)	0.50	0.74	3.43
LSD (0.05)	0.0807	4.5211	2.3802
F-test	**	**	**

Values with common letter (s) within a column do not differ significantly at 5% level of probability

** indicate significant at 1% level of probability

Table 10. Effect of fertilizer ratio on number and weight of tuber hill^{-1}, average tuber weight of potato

Nitrogen: Phosphorus	Number of tubers hill^{-1}	Weight (g) of tubers hill^{-1}	Average weight of tuber (g)
L_1 =100:40	8.272 b	342.03 b	41.824 a
L_2= 150:50	10.209 a	355.46 a	37.256 b
CV (%)	0.14	0.69	3.08
LSD (0.05)	0.0144	2.7272	1.3802
F-test	**	**	**

Values with common letter (s) within a column do not differ significantly at 5% level of probability

** indicate significant at 1% level of probability

Table 11. Effect of haulm cutting period on number and weight of tuber hill^{-1}, average tuber weight of potato

Haulm Cutting	Number of tubers hill^{-1}	Weight (g) of tubers hill^{-1}	Average weight of tuber (g)
H_1= at 80 DAP	9.1117	332.21 b	38.086 b
H_2= at 90 DAP	9.3692	365.27 a	40.994 a
CV (%)	11.10	9.39	6.75
LSD (0.05)	----	30.823	2.5138
F-test	NS	*	*

Values with common letter (s) within a column do not differ significantly at 5% level of probability

* indicates significant at 5% level of probability

NS= Non-significant

Table 12. Combined effect of spacing, fertilizer ratio and haulm cutting period on number and weight of tuber hill^{-1}, average tuber weight of potato

Combination	Number of tubers hill^{-1}	Weight (g) of tubers hill^{-1}	Average weight of tuber (g)
$S_1L_1H_1$	7.007	331.45 bc	47.281 b
$S_1L_1H_2$	7.647	341.01 bc	44.572 bc
$S_1L_2H_1$	8.137	344.05 bc	42.262 cd
$S_1L_2H_2$	8.877	455.62 a	54.540 a
$S_2L_1H_1$	9.227	341.21 bc	36.962 e
$S_2L_1H_2$	9.207	354.45 b	38.482 de
$S_2L_2H_1$	12.077	312.15 bc	25.840 f
$S_2L_2H_2$	11.747	310.02 c	26.382 f
CV (%)	11.10	9.39	6.75
LSD (0.05)	------	43.857	4.3720
F-test	NS	*	**
S × L	**	**	**
S × H	NS	NS	NS
L × H	NS	NS	**

Values with common letter (s) within a column do not differ significantly at 5% level of probability

Note: S_1= 60 × 20 cm, **S_2=** 60 × 15 cm; L_1 =100:40, L_2= 150:50; H_1= 80 DAP and H_2= 90 DAP

* indicates significant at 5% level of probability

** indicate significant at 1% level of probability

NS= Non-significant

4.9 Tuber yield (t ha^{-1})

A significant variation was found among different planting geometry of potato against yield of tubers (Table-13 and Appendix VIII). The higher tuber yield (30.66 t ha^{-1}) was found from S_1 treatment and the lower was in S_2 (27.45 t ha^{-1}).

A significant variation was noted in respects of yield of potato tubers against different ratio of nitrogen and phosphorus fertilizers (Table-14 and Appendix VIII). The higher tuber yield (29.62 t ha^{-1}) was found from L_2 treatment and the lower was in L_1 (28.50 t ha^{-1}). In case of yield of potato tubers a significant variation was noted against haulm cutting periods (Table-15 and Appendix VIII). The higher tuber yield (30.43 t ha^{-1}) was found from H_2 treatment and the lower was in H_1 (27.68 t ha^{-1}). Combindly, the yield of potato tubers was found significant variation due to the treatment combinations (Table-16 and Appendix VIII). The higher tuber yield (37.96 t ha^{-1}) was found from $S_1L_2H_2$ treatment combination and the lower was in $S_2L_2H_2$ (25.83 t ha^{-1}). Verma *et al.* (2016) said that the higher weight of tuber $hill^{-1}$ and higher average weight of tuber might be the main reason for higher tuber yield ha^{-1}. Highly significant increases in total tuber yield in response to increased level of nitrogen application (Zelalem *et al.*, 2009 and Guler, 2009). Who also said that, the application of phosphorus also highly significantly increased total tuber yield of potato. Belachew (2016) said that, with the supply of fertilizer nutrients the increase in average tuber weight of potato could be due to more luxuriant growth, more foliage and leaf area and higher supply of photosynthesis, which helped in producing bigger tubers, hence resulting in higher yields

4.10 Seed potato yield (t ha^{-1})

A significant variation was found in case of seed yield of potato against different planting geometry of potato tubers (Table-13 and Appendix VIII). The higher seed yield (22.04 t ha^{-1}) of potato was found from S_1 treatment and the lower was in S_2 (19.18 t ha^{-1}). There was a significant variation found in case of seed yield against different ratio of nitrogen and phosphorus fertilizers (Table-14 and Appendix VIII). The higher seed yield (21.37 t ha^{-1}) of potato was found from L_2 treatment and the lower was in L_1 (19.85 t ha^{-1}).

In case of seed yield of potato a remarkable variation was noted (Table-15 and Appendix VIII) against haulm cutting periods. The highest (22.16 t ha^{-1}) seed yield of potato was found from H_2 treatment and the lowest (19.05 t ha^{-1}) was in H_1. Combindly, a significant variation was found (Table-16 and Appendix VIII) among the treatment against seed yield of potato. The highest (30.06 t ha^{-1}) seed yield of potato was in $S_1L_2H_2$ treatment combination and the lowest (17.28 t ha^{-1}) was found from $S_2L_2H_1$. Verma *et al*. (2016) reported that, the higher weight of tuber $hill^{-1}$, higher average weight of tuber and higher total tuber weight might be the main reason for higher seed yield ha^{-1}. In response to increased level of nitrogen and phosphorus reported highly significant increases in seed tuber yield (35-50 mm sized) resulting from the increases total tuber yield of potato (Zelalem *et al*., 2009). These findings are agreement with the results of present study.

4.11 Non-seed yield (t ha^{-1})

Insignificant result was found in case of non-seed yield against different planting geometry of potato tubers (Table-13 and Appendix VIII). But, numerically the higher non-seed yield (8.62 t ha^{-1}) of potato was found from S_1 treatment and the lower was in S_2 (8.27 t ha^{-1}). In respects of non-seed yield of potato non-significant result was noted against different ratio of nitrogen and phosphorus fertilizers (Table-14 and Appendix VIII). But, numerically the higher non-seed yield (8.65 t ha^{-1}) of potato was found from L_1 treatment and the lower was in L_2 (8.24 t ha^{-1}). Non-seed yield was found insignificant against haulm cutting periods (Table-15 and Appendix VIII). The higher non-seed yield (8.62 t ha^{-1}) of potato was found from H_1 treatment and the lower was in H_2 (8.27 t ha^{-1}). Combindly, an insignificant variation was found among the treatment to non-seed yield of potato (Table-16 and Appendix VIII). But, numerically the higher non-seed yield (9.19 t ha^{-1}) of potato was found from $S_1L_2H_2$ treatment combination and the lower was in $S_2L_2H_2$ (7.89 t ha^{-1}).

Table 13. Effect of planting geometry on tuber and seed yield of potato

Planting Geometry	Tuber Yield ($t\ ha^{-1}$)	Seed potato yield ($t\ ha^{-1}$)	Non-seed potato yield ($t\ ha^{-1}$)
S_1= 60 × 20 cm	30.669 a	22.042 a	8.6274
S_2= 60 × 15 cm	27.455 b	19.182 b	8.2728
CV (%)	0.74	3.95	12.16
LSD (0.05)	0.3768	1.4301	----
F-test	**	**	NS

Values with common letter (s) within a column do not differ significantly at 5% level of probability
** indicate significant at 1% level of probability
NS= Non-significant

Table 14. Effect of fertilizer ratio on tuber yield and seed yield of potato

Nitrogen: Phosphorus	Tuber Yield ($t\ ha^{-1}$)	Seed potato yield ($t\ ha^{-1}$)	Non-seed potato yield ($t\ ha^{-1}$)
L_1 =100:40	28.502 b	19.851 b	8.6514
L_2= 150:50	29.621 a	21.373 a	8.2489
CV (%)	0.69	3.82	8.59
LSD (0.05)	0.2273	0.8928	--------
F-test	**	**	**NS**

Values with common letter (s) within a column do not differ significantly at 5% level of probability, ** indicate significant at 1% level of probability, NS= non-significant

Table 15. Effect of haulm cutting period on tuber yield and seed yield of potato

Haulm Cutting	Tuber Yield (t ha^{-1})	Seed potato yield (t ha^{-1})	Non-seed potato yield (t ha^{-1})
H_1= at 80 DAP	27.684 b	19.055 b	8.6293
H_2= at 90 DAP	30.439 a	22.168 a	8.2710
CV (%)	9.39	10.90	7.27
LSD (0.05)	2.5686	2.1155	------
F-test	*	**	**NS**

Values with common letter (s) within a column do not differ significantly at 5% level of probability

* indicates significant at 5% level of probability

** indicate significant at 1% level of probability

NS= Non-significant

Table 16. Combined effect of spacing, fertilizer ratio and haulm cutting period on tuber and seed yield of potato

Combination	Tuber Yield ($t\ ha^{-1}$)	Seed potato yield ($t\ ha^{-1}$)	Non-seed potato yield ($t\ ha^{-1}$)
$S_1L_1H_1$	27.621 bc	18.427 bc	9.1939
$S_1L_1H_2$	28.417 bc	19.470 bc	8.9472
$S_1L_2H_1$	28.671 bc	20.210 bc	8.4606
$S_1L_2H_2$	37.968 a	30.060 a	7.9081
$S_2L_1H_1$	28.434 bc	20.300 bc	8.1339
$S_2L_1H_2$	29.537 b	21.207 b	8.3306
$S_2L_2H_1$	26.012 bc	17.283 c	8.7289
$S_2L_2H_2$	25.835 c	17.937 c	7.8981
CV (%)	9.39	10.90	7.27
LSD (0.05)	3.6547	3.3716	-----
F-test	*	*	**NS**
S × L	**	**	**NS**
S × H	NS	*	**NS**
L × H	NS	*	**NS**

Values with common letter (s) within a column do not differ significantly at 5% level of probability

Note: S_1= 60 × 20 cm, S_2= 60 × 15 cm; L_1 =100:40, L_2= 150:50; H_1= 80 Days after planting (DAP) and H_2= 90 DAP

* indicates significant at 5% level of probability

** indicate significant at 1% level of probability

NS= Non-significant

4.12 'A' grade seed (28 mm-45 mm) (t ha^{-1})

'A' grade seed yield of potato was found significant due to different planting geometry of potato tubers (Table-17 and Appendix IX). The higher 'A' grade seed yield (12.53 t ha^{-1}) of potato was found from S_1 treatment and the lower was in S_2 (9.74 t ha^{-1}). A significant variation was found in respects of 'A' grade seed yield of potato to different ratio of nitrogen and phosphorus fertilizers (Table-18 and Appendix IX. The higher 'A' grade seed yield (11.84 t ha^{-1}) of potato was found from L_2 treatment and the lowest (10.43 t ha^{-1}) was in L_1. 'A' grade seed yield of potato was found significant due to haulm cutting periods (Table-19 and Appendix IX). The higher 'A' grade seed yield (12.37 t ha^{-1}) of potato was found from H_2 treatment and the lowest (9.90 t ha^{-1}) was in H_1. Combindly, 'A' grade seed yield of potato was found significant among the treatment combination (Table-20 and Appendix IX). The higher 'A' grade seed yield (20.29 t ha^{-1}) of potato was found from $S_1L_2H_2$ treatment combination and the lower was in $S_2L_2H_2$ (7.69 t ha^{-1}). Except, the combination of fertilizer ratio and haulm cutting period showed an insignificant variation on this parameter.

4.13 'B' grade seed (45 mm-55 mm) (t ha^{-1})

Insignificant result was found in case of 'B' grade seed yield of potato due to different planting geometry of potato tubers (Table-17 and Appendix IX). But, numerically the higher 'B' grade seed yield (9.50 t ha^{-1}) of potato was found from S_1 treatment and the lower was in S_2 (9.44 t ha^{-1}). An insignificant variation was found in aspects of 'B' grade seed yield of potato due to different ratio of nitrogen and phosphorus fertilizers (Table-18 and Appendix IX). But, numerically the higher 'B' grade seed yield (9.53 t ha^{-1}) of potato was found from L_2 treatment and the lower was in L_1 (9.41 t ha^{-1}). In respect of 'B' grade seed yield of potato a significant result was found due to haulm cutting periods (Table-19 and Appendix IX).

The higher 'B' grade seed yield (9.795 t ha^{-1}) of potato was found from H_2 treatment and the lower was in H_1 (9.15 t ha^{-1}). Combindly, an insignificant variation was found due to the treatment combination to 'B' grade seed yield of potato (Table-20 and Appendix IX). But, numerically the higher 'B' grade seed yield (10.24 t ha^{-1}) of potato was found from $S_2L_2H_2$ treatment combination and the lower was in $S_2L_1H_1$ (8.93 t ha^{-1}).

Table 17. Effect of planting geometry on seed grading of potato

Planting Geometry	**'A' grade seed (28 mm-45 mm) (t ha^{-1})**	**'B' grade seed (45 mm-55 mm) (t ha^{-1})**
S_1= 60 × 20 cm	12.535 a	9.5067
S_2= 60 × 15 cm	9.740 b	9.4417
CV (%)	3.75	5.16
LSD (0.05)	0.7336	-----
F-test	**	NS

Values with common letter (s) within a column do not differ significantly at 5% level of probability
** indicate significant at 1% level of probability
NS= Non-significant

Table 18. Effect of fertilizer ratio on seed grading of potato

Nitrogen: Phosphorus	**'A' grade seed (28 mm-45 mm) (t ha^{-1})**	**'B' grade seed (45 mm-55 mm) (t ha^{-1})**
L_1 =100:40	10.435 b	9.4158
L_2= 150:50	11.840 a	9.5325
CV (%)	10.62	4.36
LSD (0.05)	1.3411	------
F-test	*	NS

Values with common letter (s) within a column do not differ significantly at 5% level of probability
* indicates significant at 5% level of probability, NS= Non-significant

Table 19. Effect of haulm cutting period on seed grading of potato

Haulm Cutting	'A' grade seed (28 mm-45 mm) (t ha^{-1})	'B' grade seed (45 mm-55 mm) (t ha^{-1})
H_1= at 80 DAP	9.902 b	9.1533 b
H_2= at 90 DAP	12.373 a	9.7950 a
CV (%)	21.22	6.27
LSD (0.05)	2.2247	0.5593
F-test	*	*

Values with common letter (s) within a column do not differ significantly at 5% level of probability

* indicates significant at 5% level of probability

Table 20. Combined effect of spacing, fertilizer ratio and haulm cutting period on seed grading of potato

Combination	'A' grade seed (28 mm-45 mm) (t ha^{-1})	'B' grade seed (45 mm-55 mm) (t ha^{-1})
$S_1L_1H_1$	8.860 bc	9.567
$S_1L_1H_2$	9.817 bc	9.653
$S_1L_2H_1$	11.173 b	9.037
$S_1L_2H_2$	20.290 a	9.770
$S_2L_1H_1$	11.367 b	8.933
$S_2L_1H_2$	11.697 b	9.510
$S_2L_2H_1$	8.207 bc	9.077
$S_2L_2H_2$	7.690 c	10.247
CV (%)	21.22	6.27
LSD (0.05)	3.4758	------
F-test	*	NS
S × L	**	NS
S × H	*	NS
L × H	**NS**	NS

Values with common letter (s) within a column do not differ significantly at 5% level of probability

Note: S_1**=** 60 × 20 cm, S_2**=** 60 × 15 cm; L_1 =100:40, L_2= 150:50; H_1= 80 Days after planting (DAP) and H_2= 90 DAP

* indicates significant at 5% level of probability

** indicate significant at 1% level of probability

NS= Non-significant

4.14 Correlation coefficient (r)

The uses of planting geometry, different ratio of nitrogen and phosphorus and haulm cutting period as treatment under study has significantly influenced the different traits of potato plant and tuber and so, the correlation co-efficient (r) was calculated among some growth and yield traits. A weak relation (r=0.15) was exhibited between number of tuber hill^{-1} and SPAD value of potato leaf (Figure-1). A negative linear relation (r=−0.31) was also exhibited between number of tubers hill^{-1} and weight of tubers hill^{-1} of potato (Figure-2). In figure-3, a strong linear relation (r=0.77) was found between weight of tuber hill^{-1} and average weight of potato. In figure-4, there was present a strong linear relation (r=0.79) between average tuber weight and tuber yield (t ha^{-1}) of potato. A strong linear relation (r=0.71) was present between average tuber weight and seed tuber yield (t ha^{-1}) of potato (Figure-5). A very strong linear relation (r=1.00) was present between weight of tuber hill^{-1} and tuber yield (t ha^{-1}) of potato (Figure-6). About 70 to 100% of tuber yield of potato was depended on different yield contributing traits and all of these characters had significant contribution on tuber yield and seed yield could be increased by improving these yield attributes for the wellbeing of the farming community.

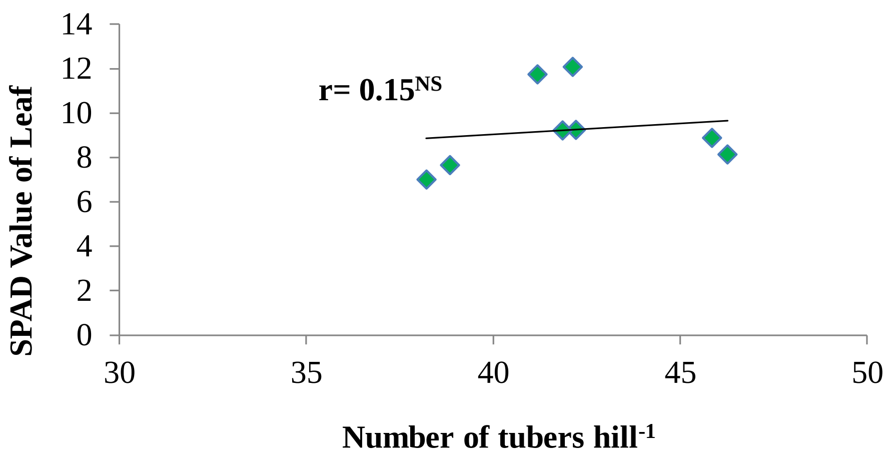

Figure 1. Relationship between SPAD value of leaf and number of tubers hill^{-1} of potato

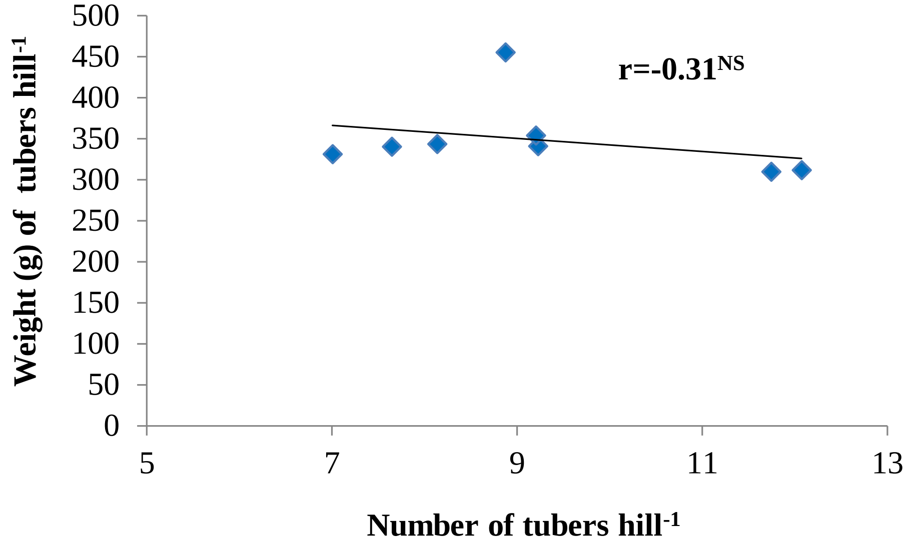

Figure 2. Relationship between number of tubers hill^{-1} and weight (g) of tubers hill^{-1} of potato

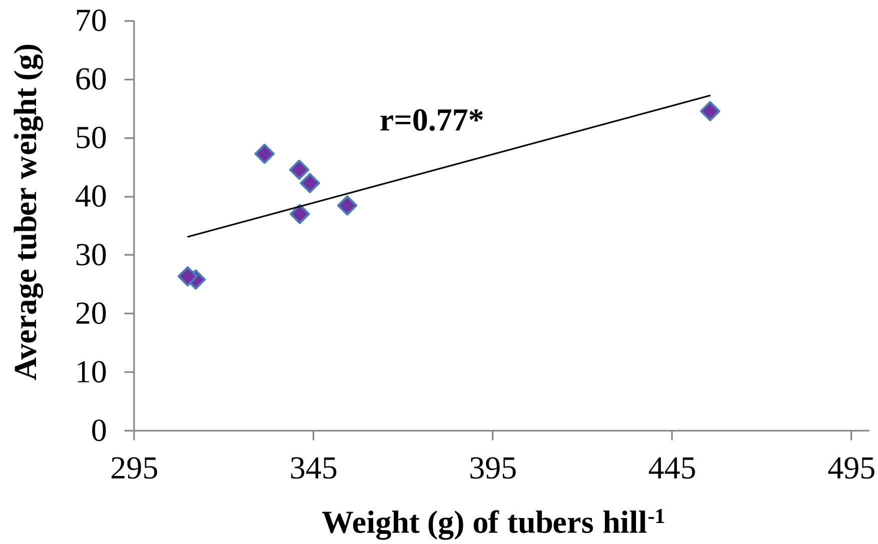

Figure 3. Relationship between weight (g) of tubers hill^{-1} and average tuber weight (g) of potato

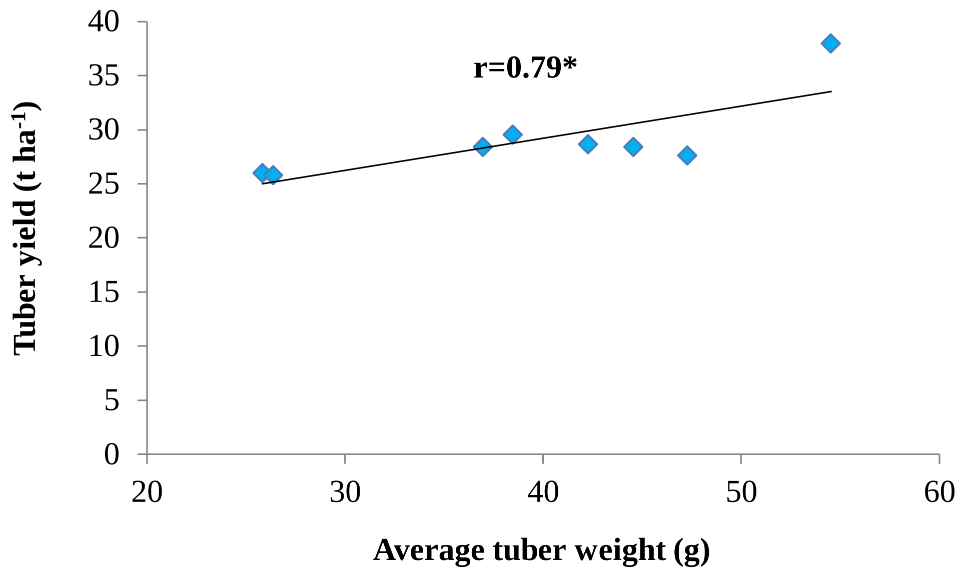

Figure 4. Relationship between average tuber weight (g) and tuber yield (t ha^{-1}) of potato

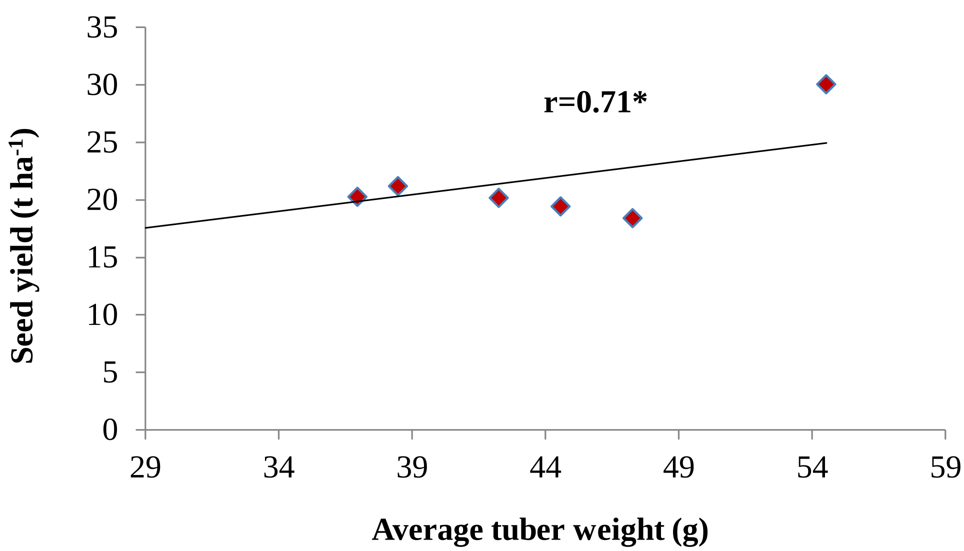

Figure 5. Relationship between average tuber weight (g) and seed yield (t ha^{-1}) of potato

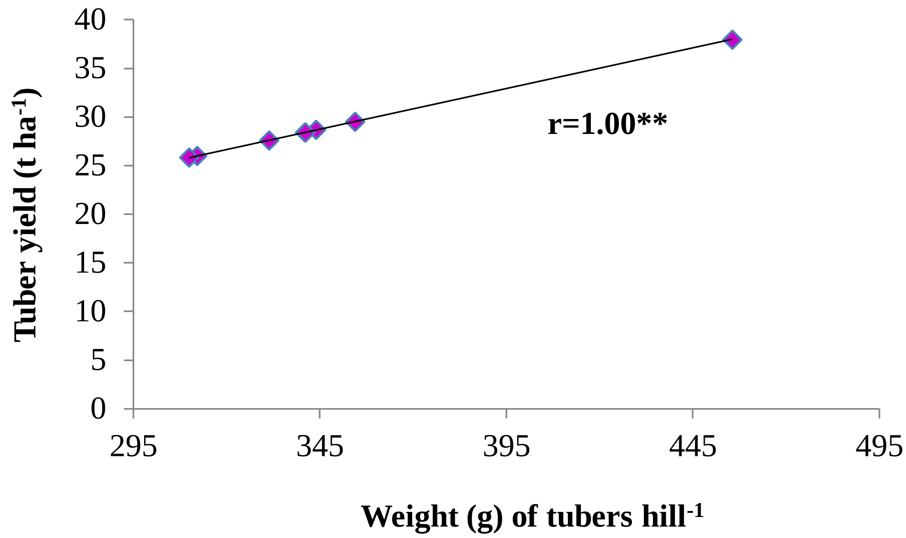

Figure 6. Relationship between weight (g) of tubers hill^{-1} and tuber yield (t ha^{-1}) of potato

CHAPTER V

SUMARRY AND CONCLUSION

The present experiment was carried out in the research field of Sher-e-Bangla Agricultural University (SAU), Dhaka-1207, during November, 2015 to March, 2016 to investigate the effects of planting geometry, nitrogen and phosphorus levels and haulm cutting on the production of seed potato. "Courage" was used as planting material under present study. The present experiment was comprised of three different factors as treatments namely, factor A: Planting geometry (2): S_1 = 60 × 20 cm and S_2 = 60 × 15 cm; factor B: Level of nitrogen: phosphorus (2): L_1 =100:40 and L_2= 150:50 and factor C: Period of haulm cutting (2): H_1= at 80 DAP and H_2= at 90 DAP.

The experiment was laid out in a 3 factors split-split-plot design with four replications, where the planting geometry assigned to main plots; level of nitrogen and phosphorus to sub plots and periods of haulm cutting to sub-sub plots. The total numbers of unit plots were 32. The size of unit plot was 2.5 m × 2.0 m. The spacing was used under present study as per treatment. Uniform size (40-50 g) tubers were used for planting. Seed potatoes were planted at a depth of 5-6 cm on November 15, 2015. Different intercultural operations were done as per when needed. Data on different growth, yield and yield attributes were taken such as, days to first emergence, days to 100% emergence, plant length (cm) at first stolonization stage, days to stolon initiation, SPAD value of potato leaf at first stolonization stage, number of tubers hill^{-1}, weight of tuber hill^{-1} (g), average weight of tuber (g), tuber yield (t ha^{-1}), seed potato yield (t ha^{-1}), non-seed potato yield (t ha^{-1}), 'A' grade seed yield (t ha^{-1}), 'B' grade seed yield (t ha^{-1}) and correlation coefficient (r) was calculated.

Results demonstrated that, most of the parameters were significantly influenced by planting geometry, fertilizer ratio and haulm cutting period studied under present experiment. But, in case of growth parameters only the planting geometry and fertilizer ratio gave the satisfactory results under study. There was no variation found in case of combination among planting geometry, fertilizer ratio and haulm cutting period on growth traits. Results showed that, days to 100% tuber emergence of potato plant was longest (15.94 days) for the plant produced from S_2 treatment and the shortest (12.90 days) was in S_1. Results showed that, days to 100% tuber emergence of potato plant was longest (14.65 days) for the plant produced from L_1 treatment and the shortest (14.19 days) was required for the plant produced from L_2. A remarkable variation was noted in case of length of potato plant against different planting geometry of potato tubers. The tallest (59.64 cm) plant was found S_2 treatment and the smallest (46.72 cm) was required for the plant produced from S_1. Remarkable variation was noted in case of length of potato plant against different ratio of nitrogen and phosphorus fertilizers. The tallest (55.549 cm) period was required for the plant produced from L_2 treatment and the smallest (50.821 cm) was required for the plant produced from L_1. The SPAD value of leaf was found significant against different planting geometry of potato tubers. The maximum (42.29) SPAD value was found from S_1 treatment and the minimum (41.83) was in S_2. In respects of SPAD value of potato leaf a remarkable variation was noted against different ratio of nitrogen and phosphorus fertilizers. The maximum (43.852) SPAD value was found from L_2 treatment and the minimum (40.279) was in L_1. A significant variation was found among the treatment combination against weight of potato tubers. The highest (455.62 g) weight of tuber was found from $S_1L_2H_2$ treatment combination and the lowest (310.02 g) was in $S_2L_2H_2$ treatment combination.

A significant variation was found among the treatment against average weight of potato tubers. The highest (54.54 g) average weight of tuber was found from $S_1L_2H_2$ treatment combination and the lowest (25.84 g) was in $S_2L_2H_1$ treatment combination. Yield of tubers was found significant against different planting geometry of potato tubers. The highest (30.66 t ha^{-1}) tuber yield was found from S_1 treatment and the lowest (27.45 t ha^{-1}) was in S_2. In respects of yield of potato tubers a remarkable variation was noted against different ratio of nitrogen and phosphorus fertilizers. The highest (29.62 t ha^{-1}) tuber yield was found from L_2 treatment and the lowest (28.50 t ha^{-1}) was in L_1. In case of yield of potato tubers a remarkable variation was noted against haulm cutting periods. The highest (30.43 t ha^{-1}) tuber yield was found from H_2 treatment and the lowest (27.68 t ha^{-1}) was in H_1. Combindly, a significant variation was found among the treatment against yield of potato tubers. The highest (37.96 t ha^{-1}) tuber yield was found from $S_1L_2H_2$ treatment combination and the lowest (25.83 t ha^{-1}) was in $S_2L_2H_2$.

Seed yield of potato was found significant against different planting geometry of potato tubers. The highest (22.04 t ha^{-1}) seed yield of potato was found from S_1 treatment and the lowest (19.18 t ha^{-1}) was in S_2. In respects of seed yield of potato a remarkable variation was noted against different ratio of nitrogen and phosphorus fertilizers. The highest (21.37 t ha^{-1}) seed yield of potato was found from L_2 treatment and the lowest (19.85 t ha^{-1}) was in L_1. In case of seed yield of potato a remarkable variation was noted against haulm cutting periods. The highest (22.16 t ha^{-1}) seed yield of potato was found from H_2 treatment and the lowest (19.05 t ha^{-1}) was in H_1. Combindly, a significant variation was found among the treatment against seed yield of potato. The highest (30.06 t ha^{-1}) seed yield of potato was found from $S_1L_2H_2$ treatment combination and the lowest (17.28 t ha^{-1}) was in $S_2L_2H_{1.}$

About 70 to 100% of tuber yield of potato was depended on different yield contributing traits and all of these characters had significant contribution on tuber yield and seed yield could be increased by improving these yield attributes for the wellbeing of the farming community.

On the basis of present study it may be concluded that, $S_1L_2H_2$ *i.e.*, the wider spacing (60cm×20cm), higher doses of nitrogen and phosphorus (150:50 kg ha^{-1}) in combination with late haulm cutting (at 90 DAP) is the best for improving the seed tuber yield of potato.

Recommendations

1. Usually the potato growers use recommended spacing 50cm×25cm on their crop field but, the higher spacing as 60cm×20cm which was found best from present study might be improved the tuber and seed yield of potato tuber.

2. If, potato growers apply higher doses of nitrogen in combination of higher phosphorus per hectare might be improved the tuber and seed yield of potato tuber.

3. If, potato growers cut the haulm at later time than that of their conventional time of haulm cutting as found from the present study so that, it might be improved the tuber and seed yield of potato tuber by increasing the skin hardening and tuber bulkening.

4. Finally, to validate the results of present experiment; more and more research program should be taken at different areas of Bangladesh in combination with other growth and yield modifying traits emphasizing with economic point of view.

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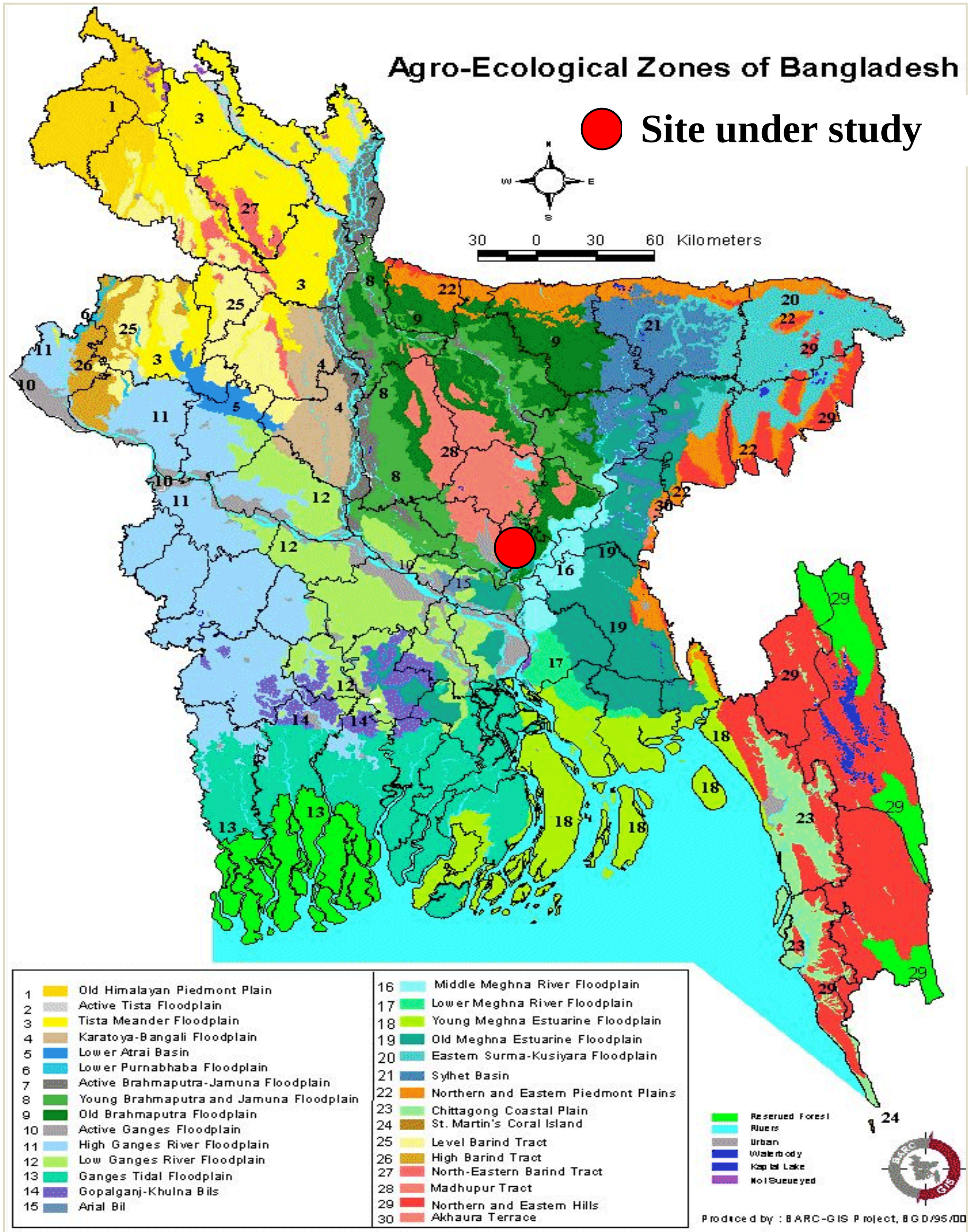
APPENDICES

Appendix I. Map showing the site used for present study



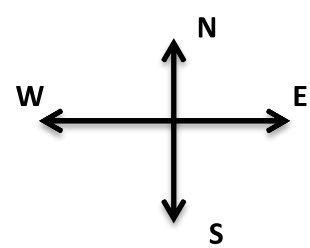
Appendix II. Monthly meteorological information during the period from November, 2015 to March, 2016

Year	Month	Air temperature (^oC)		Relative Humidity (%)	Total rainfall (mm)
		Maximum	Minimum		
2015-2016	November	25.22	9.66	56.52	55
	December	25.03	8.76	66.98	1.29
	January	23.87	9.02	70.49	Trace
	February	25.88	11.88	75.21	Trace
	March	27.51	14.96	65.76	64

Source: Metrological Centre (Climate Division), Agargaon, Dhaka

Appendix III. Layout of experimental plot

L_1 H_2 S_1	L_2 H_1 S_1	L_2 H_2 S_2	L_1 H_1 S_2	L_1 H_2 S_2	L_2 H_1 S_2	L_1 H_2 S_1	L_2 H_1 S_1	L_1 H_2 S_1	L_2 H_1 S_1	L_1 H_2 S_2	L_2 H_1 S_2	L_1 H_2 S_2	L_2 H_1 S_2	L_1 H_2 S_1	L_2 H_1 S_1
L_1 H_1 S_1	L_2 H_2 S_1	H_1 L_2 S_2	H_2 L_1 S_2	L_1 H_1 S_2	L_2 H_2 S_2	H_1 L_1 S_1	H_2 L_2 S_1	L_1 H_1 S_1	L_2 H_2 S_1	H_1 L_1 S_2	H_2 L_2 S_2	L_1 H_1 S_2	L_2 H_2 S_2	H_1 L_1 S_1	H_2 L_2 S_1
R_1				R_4				R_2				R_3			



Treatment combinations:

$S_1L_1H_1$, $S_1L_1H_2$, $S_1L_2H_1$, $S_1L_2H_2$, $S_2L_1H_1$, $S_2L_1H_2$, $S_2L_2H_1$ and $S_2L_2H_2$

Length of plot: 2.5 m
Width of plot: 2.0 m
Replication to replication distance: 0.75 m
Row to row distance maintained as treatment
Plant to plant distance maintained as treatment
Unit plot size: 2.5 m × 2.0 m (5 m^2)

Appendix IV. Mean sum square values for days to emergence of potato tuber

Source of variation	df	Days to first emergence	Days to 100% emergence
Replication (A)	3	0.0037	0.0037
Planting Geometry (S)	1	60.8653**	55.3584**
Error (A×S**)**	3	0.0001	0.0010
Nitrogen: Phosphorus (L)	1	3.3750**	1.3113**
S×L	1	24.3614**	15.0258**
Error (A× S×L**)**	6	0.0006	0.0002
Haulm Cutting (H)	1	2.2326^{NS}	1.5759^{NS}
S×H	1	0.1262^{NS}	0.2709^{NS}
L×H	1	0.1536^{NS}	0.1218^{NS}
S×L×H	1	0.3902^{NS}	0.0693^{NS}
Error (A× S×L×H**)**	12	1.1186	3.2011
Total	31		

**, indicates significant at 1% level of probability, NS, Non-significant

Appendix V. Mean sum square values for days to stolon initiation and length of potato

Source of variation	**df**	**Plant length (cm) at stolonization stage**	**Days to stolon initiation**
Replication (A)	3	0.036875	0.02318
Planting Geometry (S)	1	1001.30**	158.672**
Error (A×S**)**	3	0.03583	0.02218
Nitrogen: Phosphorus (L)	1	134.143**	40.3263**
S×L	1	108.205**	13.0095**
Error (A× S×L**)**	6	0.08463	0.04375
Haulm Cutting (H)	1	0.29482^{NS}	10.9755^{NS}
S×H	1	21.0563^{NS}	3.76834^{NS}
L×H	1	41.9233^{NS}	0.01084^{NS}
S×L×H	1	65.0104^{NS}	0.09004^{NS}
Error (A× S×L×H**)**	12	27.1547	18.1534
Total	31		

**, indicates significant at 1% level of probability, NS, Non-significant

Appendix VI. Mean sum square values for SPAD value of leaf and number of tuber hill^{-1}

Source of variation	**df**	**SPAD value of leaf at stolonization stage**	**Number of tubers hill^{-1}**
Replication (A)	3	0.0011	0.0007
Planting Geometry (S)	1	1.2285**	42.0555**
Error (A×S**)**	3	0.0021	0.0021
Nitrogen: Phosphorus (L)	1	76.5765**	22.5234**
S×L	1	93.9708**	3.4428**
Error (A× S×L**)**	6	0.0016	0.0002
Haulm Cutting (H)	1	0.4293^{NS}	0.3978^{NS}
S×H	1	0.8550^{NS}	1.1223^{NS}
L×H	1	1.0209^{NS}	0.0165^{NS}
S×L×H	1	0.0828^{NS}	0.0630^{NS}
Error (A× S×L×H**)**	12	28.1071	1.0529
Total	31		

**, indicates significant at 1% level of probability, NS, Non-significant

Appendix VII. Mean sum square values for weight of tubers hill^{-1} and average weight of potato tuber

Source of variation	df	Weight of tubers hill^{-1}	Average tuber weight
Replication (A)	3	9.5	1.64
Planting Geometry (S)	1	8928.2**	1394.88**
Error (A×S**)**	3	6.6	1.84
Nitrogen: Phosphorus (L)	1	1082.2**	125.22**
S×L	1	15105.2**	297.62**
Error (A× S×L**)**	6	5.8	1.48
Haulm Cutting (H)	1	6557.8*	50.72*
S×H	1	4539.2^{NS}	21.14^{NS}
L×H	1	2814.9^{NS}	73.59**
S×L×H	1	5166.8*	95.57**
Error (A× S×L×H**)**	12	1072.0	7.13
Total	31		

**, indicates significant at 1% level of probability, *, indicates significant at 5% level of probability, NS, Non-significant

Appendix VIII. Mean sum square values for yield and yield grading of potato tuber

Source of variation	df	Total yield (t ha^{-1})	Seed potato yield (t ha^{-1})	Non-seed potato yield (t ha^{-1})
Replication (A)	3	0.066	0.421	0.54471
Planting Geometry (S)	1	62.001**	49.078**	0.75438^{NS}
Error (A×S**)**	3	0.046	0.663	1.05618
Nitrogen: Phosphorus (L)	1	7.515**	13.893**	0.97204^{NS}
S×L	1	104.897**	130.573**	1.40408^{NS}
Error (A× S×L**)**	6	0.040	0.620	0.52693
Haulm Cutting (H)	1	45.540*	58.157**	0.77042^{NS}
S×H	1	31.522^{NS}	32.667*	0.01021^{NS}
L×H	1	19.548^{NS}	27.435*	0.6666 ^{NS}
S×L×H	1	35.880*	30.781*	0.19530^{NS}
Error (A× S×L×H**)**	12	7.444	5.049	0.37785
Total	31			

**, indicates significant at 1% level of probability, *, indicates significant at 5% level of probability, NS, Non-significant

Appendix IX. Mean sum square values for seed grading of potato tuber

Source of variation	df	'A' grade seed (28 mm-45 mm) (t ha^{-1})	'B' grade seed (45 mm-55 mm) (t ha^{-1})
Replication (A)	3	3.129	1.25608
Planting Geometry (S)	1	46.872**	0.02535^{NS}
Error (A×S**)**	3	0.174	0.23866
Nitrogen: Phosphorus (L)	1	11.844*	0.08167^{NS}
S×L	1	149.301**	0.62727^{NS}
Error (A× S×L**)**	6	1.400	0.17095
Haulm Cutting (H)	1	36.655*	2.47042*
S×H	1	39.475*	0.32202^{NS}
L×H	1	20.057^{NS}	0.57660^{NS}
S×L×H	1	30.420*	0.00107^{NS}
Error (A× S×L×H**)**	12	5.584	0.35296
Total	31		

**, indicates significant at 1% level of probability, *, indicates significant at 5 % level of probability, NS, Non-significant

Plate 1: Overall view of experimental plot

Plate 2: Data collection

Plate 3: Harvesting of potatoes

Plate 4: Weighing of potatoes