PRODUCTIVITY AND PROCESSING QUALITY OF POTATO AS INFLUENCED BY GROWTH DURATION, TIME OF NITROGEN APPLICATION AND INTRA-ROW SPACING

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CERTIFICATE

This is to certify that the thesis titled, ***"PRODUCTIVITY AND PROCESSING QUALITY OF POTATO AS INFLUENCED BY GROWTH DURATION, TIME OF NITROGEN APPLICATION AND INTRA-ROW SPACING"*** *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* ***PAROMA RANI SAHA, Registration No. 11-04654*** *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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The Author

PRODUCTIVITY AND PROCESSING QUALITY OF POTATO AS INFLUENCED BY GROWTH DURATION, TIME OF NITROGEN APPLICATION AND INTRA-ROW SPACING

ABSTRACT

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 growth duration, time of nitrogen application and intra-row spacing on the productivity and processing quality of potato. Variety “Asterix” was used as planting material under present study. The present experiment was comprised of three different factors as treatments namely, factor A: growth duration (G): G_1 = Harvested at 90 days after planting (DAP) and G_2 = Harvested at 100 DAP; factor B: time of nitrogen application (T): T_1 = 135 kg N ha^{-1} (at planting) + 135 kg N ha^{-1} (at first earthing up, 35 DAP), T_2 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 67.5 kg N ha^{-1} (at second earthing up, 50 DAP), T_3 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP and T_4 = 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP and factor C: intra-row spacing (S): S_1 = 60 cm X 20 cm and S_2 = 60 cm X 25 cm. The experiment was laid out in a 3 factors split-split-plot design with three replications, where the growth duration assigned to main plots; time of nitrogen application to sub-plots and intra-row spacing to sub-sub-plots. Results demonstrated that most of the parameters studied under present experiment had significantly influenced by growth duration, time of nitrogen application and intra-row spacing. Result revealed that weight of tuber $hill^{-1}$ (g), average weight of tuber (g) and tuber yield (t ha^{-1}) was found the highest (382.29 g, 55.87 g and 37.68 t ha^{-1}) under $G_1T_3S_2$ *i.e.*, 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP, wider spacing (60 cm × 25 cm) in combination with earlier growth duration (at 90 DAP) is the best for improving the tuber yield of potato whereas $G_2T_1S_1$ showed the lowest one. On the other hand, in case of quality traits such as specific gravity, dry matter (%) and starch content (mg g^{-1} FW) of potato tuber $G_1T_4S_2$ *i.e.*, 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP, wider spacing in combination with earlier growth duration (90 DAP) exhibited the better (1.11, 22.92 % and 24.01 mg) performance which was statistically similar to $G_1T_3S_2$ *i.e.*, 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP, wider spacing (60 cm × 25 cm) in combination with early growth duration (at 90 DAP). From this study, it may be concluded that from the standpoint of yield and quality considerations, an advantages of earlier growth duration, split applications of nitrogen as soil and foliar spray under wider intra-row spacing may put remarkable influence for improving the yield and processing quality of potato tuber for the betterment of farming community.

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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
G	Growth duration
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
Nat.	Natural
Nutr.	Nutrition
Physiol.	Physiological
Res.	Research
S	Intra-row spacing
SAU	Sher-e-Bangla Agricultural University
Sci.	Science
Soc.	Society
t ha^{-1}	Ton per hectare
T	Time of nitrogen application
viz	*videlicet* (L.), Namely

Chapter I

Introduction

CHAPTER I

INTRODUCTION

Among the starchy tuber crops potato (*Solanum tuberosum* L.) is one of the most widely grown in the world and contributes immensely to human nutrition and food security and it has more potentiality to earn huge money by exporting processing and export quality standard produce to especially European countries (Karim *et al*., 2010). Bangladesh is the 8th potato producing country in the world, 3rd biggest in Asia and in Bangladesh; it ranks 2nd 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 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). Although approx. 1.00 crore MT potato is produced in Bangladesh during fiscal year/2016-2017 (FAOSTAT, 2016) but at present two-thirds of the total produce did not find any space in the cold storage and a part of which is consumed (about 65 lacs MT) shortly after harvest and the rest is kept in traditional storage at home under room temperature and humidity at farm level. So, the surplus (about 35 lacs MT) has the potentiality to export to abroad. In most cases the excess production goes to waste. In Bangladesh most of the potatoes consumed is unprocessed. Only 2% of the potatoes are processed mainly in the form of chips and crackers. But the majority of Bangladesh's potato production is used for direct consumption. The varieties used for table potatoes are not appropriate for processing (the dry matter content, specific gravity is too low and more reducing sugar content) or export (foreign consumers have different tastes). Moreover, the quality of the potato seed also is an influencing factor, the formal sector seed potato production is only 5-9% of the total requirement. Both private and public sector together supply only 5% quality seed of the total requirement (Khandker and Basak (2017).

Remaining 95% is the low quality seed potato which is produced by the farmers themselves. Potato produced on the basis of low quality seeds and sub-optimal management (such as non-proper harvesting time, high uses of inorganic fertilizer, non-proper planting density and non-proper growth duration for tuber quality) for cultivation is not preferred for processing and export. Though the record amount of potato is produced, the quantity of export is insignificant. On the other hand, contribution of this sector to the GDP is dwindling though it has a potential to contribute to the economy (Khandker and Basak (2017). The overproduction of potato is not a threat; rather it could be turned into an opportunity by utilizing the resources in the processing and export industry. The increasing demand for processed food products may drive the proper utilization of the excess potato which may lead to product diversification (such as potato soup, hash brown, mashed potato, french fry and chips etc.) in Bangladesh as a whole.

Growth duration can influence the biomass accumulation in potato tuber. The location, cultivar, date of harvest and tuber curing influences the, physical and biochemical changes in the structural growth duration of tuber gives economic support to the farmers but it affects the processing quality Marwaha *et al*. (2005). Tuber harvested at full maturity stage contains maximum dry matter and protein content and have higher specific gravities than immature ones (Misra *et al*., 1993). The potato has the affinity to the macronutrients. Among these, Nitrogen management is 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. The imbalance of N hampered the production of tuber of potato (Hailu *et al*., 2017). Even under best management practices, approximately 30-50% of applied nitrogen is lost through different agencies and, hence, the farmer is compelled to apply more than what the crop needs to compensate for losses through leaching, volatilization, and denitrification making the nutrient unavailable during the critical stages of crop growth (Ahmed *et al*., 2017).

Especially rate and time of application of nitrogen affect the crop growth period and invariably increases yield, tuber plant^{-1}, tuber size as well as tuber numbers. A significant improvement for N fertilizer used efficiency results from split N fertilizer applications according to potato growth needs (Rens *et al.*, 2015a; Datta *et al.*, 2015). Foliar sprays of urea provide a means of fertilizing the crop late on in the season and can increase tuber yield and qualities also (Ayyub *et al.*, 2006). Intra-row spacing means inter and intra arrangement of 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 plant size and yield plant^{-1}. This effect is due to increased inter-plant competition for water, light and nutrients (Masarirambi *et al.*, 2012). It is therefore, essential to understand how individual plants interact with each other and the environment and to possibly come up with the ideal crop density levels to optimize yields.

In Bangladesh, potato farmers have been lacking on the proper information of appropriate potato harvesting time and quality aspects. Hardly any study has been conducted in Bangladesh to determine the optimum doses for fertilization correlating with growth and yield of potato cultivars. But research works with growth duration, time of nitrogen application and intra-row spacing of potato is not well flourish to us. Under such situations, there is need to develop an optimum quality potato production technology for maximizing yield and quality of potato tubers. From these perspectives the field experiment was conducted to fulfill the following objective:

–To standardize the optimum growth duration, the time of nitrogen application and intra-row spacing for getting maximum yield and higher proportion of processing grade tubers.

Chapter II

Review of literature

CHAPTER II

REVIEW OF LITERATURE

Potato playing a major role in many developed country as a staple starchy food crop and it is mostly popular supplemental food crop in Bangladesh. Improvement of productivity and quality attributes of potato is much more important for growing hungry people around the world through processing and exporting industry. Yield of potato tuber is much lower than in Bangladesh compared to the other major potato growing developed countries. Due to the plastic nature of potato, the yield potential of potato could be changed by nutritional management including varying growth behaviors and mediated new cultivation systems. The research on fertilizer applications on potato are more or less availed in our country but research on the optimum growth duration, time of N application and intra-row spacing for better quality seed potato tuber is not well known to us. Some more related research findings regarding production of potato against growth duration, time of N application and intra-row spacing have been reviewed under this chapter.

Ahmed *et al*. (2017) reported that unbalanced use of chemical fertilizer is a problem in the intensive cropping systems on the central part of Bangladesh. Proper nutrient management is essential to maximize potato production and sustain agricultural production while minimizing negative impacts on the soil fertility. So, the study was conducted to evaluate the effect of spilt application of N, potato yields and soil fertility in response to environmental impact. Six treatments *viz*., T_1= control (no urea), T_2= Two splits (1/2 nitrogen at 10 DAP and 1/2at the 30 DAP), T_3= Two splits (1/2 nitrogen at 15 DAP and 1/2at the 45 DAP), T_4 =Three splits (1/3 nitrogen at 10 DAP , 1/3 at the 30 DAP and 1/3 at the 50 DAP), T_5=Four splits (1/4 nitrogen at 5 DAP , 1/4 at the 20 DAP, 1/4 at the 35 DAP and 1/4 at the 50 DAP) along with T_6= existing practice (FRG, 2012 of two splits) were evaluated for this purpose.

The result indicated that the highest tuber yield (35.75 t ha^{-1}) was found from T_5= Four splits (1/4 nitrogen at 5 DAP, 1/4 at the 20 DAP, 1/4 at the 35 DAP and 1/4 at the 50 DAP) treatment. The lowest tuber yield was obtained from control treatment.

Ayyub *et al*. (2017) conducted a series of experiments to find out the optimum dose and efficacy of nitrogen to fulfill the requirements of potato plant at each level by making split doses. Being most important macro nutrient, afield trial was conducted to study the effect of without applying nitrogen (control) single nitrogen (N) application at planting time on yield and nitrogen uptake of potato in comparison to various split applications. Data were collected about plants vegetative growth, total yield and qualitative factors (TSS, nitrogen, phosphorus, potassium and protein percentage in tuber). Overall, qualitative characters of tubers and yield enhanced with split nitrogen application as compared to all nitrogen applied once at planting time whereas, there was no significant difference between tuber nitrogen, potassium, phosphorus and protein contents.

Haymanot *et al*. (2017) pointed out the findings of an experiment that the total N uptake and concentration in above ground part were raised by two and three folds, respectively with application of 230 kg N ha^{-1} that had increased N concentration in tuber by 57.17% and soils after harvest by 20.87% as compared to the control. Generally, the highest values of total dry matter, above ground biomass, total plant dry matter and medium size tubers were found at the 184 kg N ha^{-1} rate. However, the maximum amounts of agronomic and physiological N efficiencies were recorded at 46 kg N ha^{-1} that had the highest percent of apparent N recovery and N harvest index. The finding of this study had also revealed that N had significant impact on production of quality potato tubers and nitrogen use efficiency. Generally, 184 kg N ha^{-1} showed the highest dry matter accumulation with good apparent nitrogen recovery and agronomic nitrogen use efficiency, beyond which there were poor efficiency and non-significant difference.

Kumar *et al.* (2017) carried out an investigation to evaluate the "Nitrogen management in potato (*Solanum tuberosum* L.)" and to identify a carefully controlled nitrogen application rate and better synchronization between applied nitrogen and potato nitrogen uptake. The findings of investigation revealed that the performance of potato crop was significantly influenced by different split nitrogen doses. Among all treatments, treatment T_4 (50% basal N + 25% top dressing at 25 DAP + one foliar spray@ 2% urea at 40 DAP) was found best with respect to overall plant growth, yield and quality parameters with a total yield (32.73 t ha^{-1} and 37.23 t ha^{-1}) and benefit: cost ratio (1.81 and 3.08) during both year respectively. The treatment T_4 (50% basal N + 25% top dressing at 25 DAP + one foliar spray@ 2% urea at 40 DAP) not only recorded 18.09 % and 43.48 % more yield over the RDF treatment T_1 (RDF: 50% basal N + 50% top dressing at 25 DAP) and T_9 (No application of nitrogen) respectively but also saves 22 % nitrogen and thus reducing N losses to the environment. Based on overall performance, they concluded that under prevalent climatic conditions, 50% basal N + 25% top dressing N at 25 DAP + one foliar spray@ 2% urea at 40 DAP is the best in terms of higher and economic yield of potato than RDF (50% basal N + 50% top dressing N at 25 DAP) and also in reducing N losses to the environment.

Zerga *et al.* (2017) conducted an experiment on the effects of the intra-intra-row spacing on the yield and yield components of potato cultivars. The treatments include three intra-intra-row spacing (20 cm, 30 cm and 40, 50 cm). The treatments were arranged in the randomized complete block design (RCBD) replicated three times. Data was collected on number of leaves $plant^{-1}$, number of stem, leaf length, above ground fresh weight. Among the studied characters leaf length, number of leaf $plant^{-1}$ and above ground fresh weight were statistically different. However, number of branches $plant^{-1}$, number of stem $plant^{-1}$ and plant length were not statistically different. Cultivar at 50 cm was shown significantly higher leaf length, number of leaf $plant^{-1}$ and above ground fresh weight.

Generally there was no significant effect number of branches plant^{-1}, number of stem plant^{-1} and plant length of the cultivar.

Alam *et al*. (2016) reported that crop intra-row spacing had great influence on economically important characteristics such as total yield, processing grade yield, tuber size distribution and tuber quality. So, the experiment was conducted to develop suitable crop spacing for the production of higher processing grade yield and quality of potato tubers. The treatment consisted of three levels of inter intra-row spacing (60, 67.5 and 75 cm) and four levels of intra intra-row spacing (20, 25, 30 and 35 cm). Crop spacing significantly influenced growth, yield contributing characters, tuber size distribution and yield of potato. The highest chips, french fry grade tubers and total potato tuber yield were found in 67.5 cm × 25 cm spacing without affecting processing quality but all were in the highly acceptable range. Intra intra-row spacing of 25 cm showed the maximum processing quality tubers closely followed by 30 cm. The highest gross and net returns with benefit cost ratio (1.75) were recorded in 67.5 cm × 25 cm crop spacing. Therefore, 67.5 cm × 25 cm crop spacing can be recommended for higher potato tuber yield and processing grade tubers as well as higher economic return.

Xing *et al*. (2016) conducted an experiment to evaluate N fertilization effects on potato (*Solanum tuberosum* L.) tuber yields and quality as well as soil nitrate leaching. Eight N fertilizer treatments were examined, including three N sources (i.e. conventional, controlled-release and organic fertilizers) at two application rates (100 and 200 kg N ha^{-1}), a split application of conventional fertilizer at the high rate and a zero N fertilizer input as control. Application of N-fertilizer significantly increased tuber yield (by 76% maximum) and quality over the unfertilized treatments whereas differences between the two N fertilizer application rates were non-significant. Fertilizer use efficiency varied from 16% to 56% over treatments and years. Low application rates resulted in lower seasonal soil and soil solution NO3- concentrations than high application rates.

The controlled-release and organic form of fertilizer both reduced seasonal mean soil and soil solution N concentrations than conventional fertilizer, with low leaching potential.

Rens *et al*. (2016) carried out a research study to develop management recommendations that enhance fertilizer use by minimizing N losses. In this study, the N-fertilizer uptake efficiency (FNUE) of two chipping potato (*Solanum tuberosum* L.) varieties ('Atlantic' and 'FL1867') under three typical fertilizer application timings was investigated. All treatments received total 225 kg ha^{-1} of N throughout the season, split into three applications of 75 kg ha^{-1} as ammonium nitrate (NH_4NO_3) applied at pre-plant, plant emergence and tuber initiation FNUE at each application time was evaluated by the substitution of conventional N-fertilizer by isotope labeled ammonium nitrate ($15NH_415NO_3$). Total tuber yield was similar between the two varieties at 48.8 and 37.5 Mg ha^{-1} in 2013 and 2014, respectively. Likewise, the overall FNUE was also similar at 45 % across both varieties and years. FNUE was 11 % for the pre-plant application, while 62 % for the applications at emergence and tuber initiation stages. Since a small fraction of the N applied at pre-plant was recovered in the plant, N fertilizer application closer to the potato planting may increase the FNUE.

Assefa *et al*. (2015) carried out a field experiment on tomato to evaluate the effect of four inter-intra-row spacing's (70, 80, 90, and 100 cm) and three intra-intra-row spacing (20, 30 and 40 cm) on yield and yield components of fresh market (Bishola) and processing (Cochoro) tomato cultivars. The treatments were arranged in 2x4x3 factorial in a split-split plot design in three replications. Data were collected on plant canopy width, above ground dry biomass as well total, marketable and nonmarketable fruit yield and on quality parameters such as TSS, fruit length and diameter were analyzed. The results indicated that inter and inter-intra-row spacing had a significant effect on plan canopy width, above ground dry biomass, total, marketable, unmarketable fruit yield, TSS, fruit length and diameter.

The highest canopy width of Bishola (77.08 cm) was recorded at 40 cm x 100 cm whereas for Cochoro (71.30 cm) at 40 cm x 90 cm. Maximum fruit TSS (3.72) was recorded at 40 cm intra-intra-row spacing and this was not significantly different from 30 cm (3.68). The highest total fruit yield of 100.45 and 92.55 t ha^{-1} were recorded for closer inter and intra-intra-row spacing of 70 and 20 cm, respectively. However, the highest marketable yield was obtained at 90 cm (51.48 t ha^{-1}) inter-intra-row spacing and at 30 cm (45.78 t ha^{-1}) intra intra-row spacing and this was not significantly different from 40 cm. The study suggest that 30 cm x 90 cm or 40 cm x 90 intra-inter intra-row spacing combination was suitable for obtaining higher marketable yield and good quality fruit.

Getie *et al*. (2015) investigated the effect of nitrogen fertilizer and planting density on yield and yield components of potato crop. Treatments included quantity of nitrogen fertilizer (0, 110, 165 and 220 kg N ha^{-1}) and planting density (4.17 plant m^{-2} (80 cm x 30 cm), 4.44 plant m^{-2} (75 cm x 30 cm), 5.56 plant m^{-2} (60 cm x 30 cm), 6.67 plant m^{-2} (60 cm x 25 cm) and 8 plant m^{-2} (50 cm x 25 cm)). Increasing nitrogen level up to110 kg N ha^{-1} lead to more tuber yield, highest stem number, plant length, total dry biomass, total tuber number, large-sized tuber yield (59.01%) and marketable tuber yield. The highest foliar N concentration was recorded at 165 kg N ha^{-1}. Increasing planting density resulted in higher tuber yield; total tuber number, total dry biomass yield (%), marketable tuber yield and small-sized tuber yield (16.92%). Highest foliar N concentration was found at the lower planting densities of 4.17 and 4.44 plant m^{-2}. Yield of tuber per hectare was significantly and positively correlated with leaf area index, total tuber number, days to physiological maturity and total dry biomass yield.

In conclusion, results of the experiment revealed that 110 kg N ha^{-1} and planting density of 6.67 plant m^{-2} resulted in optimum total and marketable tuber yields (35.50 and 35.66 t ha^{-1}, respectively).

Mangani *et al.* (2015) studied a review of on how growth, yield and quality responded to plant spacing in Irish potato. A number of parameters were considered: stem length, stem number, tuber numbers, tuber size categories, total yield, marketable yield, dry matter content and specific gravity. Some contradictions were exposed showing the need for further researches concerning how spacing interacts with the environment and other production practices including varietal choices. This information will help producers to optimize productivity.

Rens *et al*. (2015 a) conducted an experiment to determine the effect of N fertilizer rate and application timing strategy on biomass accumulation, marketable yield, and tuber quality of chipping potato cultivar in two consecutive years. All plots received 56 kg ha^{-1} of N before potato planting. Nitrogen fertilizer treatments were 0, 56, 112, or 168 kg ha^{-1} at plant emergence combined with 56 or 112 kg ha^{-1} of N applied as side dress at tuber initiation. Aboveground plant biomass showed no response to increasing N at emergence or tuber initiation. Low yield and poor tuber quality were a result of intense rainfall patterns in the first year. For the other two seasons, marketable yield ranged from 28.7 to 36.1 Mg ha^{-1}.Nitrogen treatments at emergence were not correlated to an increase in potato yield during the second year indicating that under the conditions of these experiments there was no N limitation. Total N applications over 280 kg ha^{-1} did not increase yield or quality and N tuber init above 56 kg ha^{-1} had no impact on plant biomass or tuber yield on any farm in any year of this study.

Rens *et al*. (2015 b) carried out an experiment to determine the effect of N-fertilizer rate and timing of application on plant biomass, tuber marketable yield and quality of chipping potato irrigated by sub-irrigation. All experimental plots received 56 kg ha^{-1} of N as ammonium nitrate approximately 40 days before planting, a common grower practice.

Nitrogen fertilizer treatments were 0, 56, 112 or 168 kg ha^{-1} applied at plant emergence combined with 56 or 112 kg ha^{-1} of N applied as a side dress at tuber initiation. The two years of this study were characterized by low rainfall conditions, reducing the risk of N leaching and runoff. Under these conditions, the N treatments rarely increased potato aboveground biomass. Mean marketable tuber yield across all sites ranged from 19.2 to 39.7 Mg ha^{-1} with the lowest yield when a large amount of rainfall occurred prior to harvest at one site. Marketable yield responded quadratically to increase N-fertilizer rates applied at plant emergence, with optimum yield calculated at N rate between 88 and 113 kg ha^{-1}. Applying >56 kg ha^{-1} of N at tuber initiation did not increase marketable yield, tuber specific gravity or tuber quality on any farm in either year. Nitrogen rate treatments above 112 kg ha^{-1} at emergence, and 56 kg ha^{-1} at tuber initiation did not improve potato marketable yield or tuber quality. The contribution of 56 kg ha^{-1} applied at pre-plant to potato yield is still unknown, and may be more beneficial to move this application closer to planting.

Shaw (2015) conducted an experiment to compare combinations of source, timing, and application methods of different synthetic N fertilizers on yield and quality of irrigated processing potato. Source, timing, and application method combinations were examined to provide a range of N availability over the growing season. Split applications of granular urea or Super-U, addition of ESN, a nitrogenous fertilizer at planting and split application of granular urea at planting and fertigation were the most consistent treatments for highest marketable yield and nitrogen use efficiency. ESN was advantageous in wet site conditions. The results indicate split application of granular urea and split granular urea and fertigation that growers of processing irrigated potato primarily use in Manitoba are sound management practices.

Zotarelli *et al*. (2015) carried out the experiment to determine the effect of the N fertilizer rate and timing of application on the N use efficiency (NUE) and yield of chipping potato 'FL1867' in two consecutive years. All treatments received 56 kg ha^{-1} of N as ammonium nitrate applied as a band approximately 40 days before planting (N). Liquid urea ammonium nitrate was then band applied at 0, 56, 112, or 168 kg ha^{-1} at plant emergence (N) followed by 56 or 112 kg ha^{-1} applied as a side-dress at tuber initiation stage (N). The treatments were arranged in a factorial design with four replicates. The total amount of N fertilizer applied ranged from 112 to 336 kg ha^{-1}. Maximum daily N uptake by the potato crop occurred between 55 and 65 days after planting, coinciding with the onset of the tuber bulking stage. Heavy rainfall prior to planting during the first year crop reduced soil N availability from pre-plant applied N fertilizer indicating the high susceptibility of that application timing to leaching. Average tuber yield ranged from 25.6 to 47.2 Mg ha^{-1}, with the lowest yields occurring when heavy rainfall close to harvest increased yield loss to decay. While higher N rates at emergence increased soil inorganic N, tuber yield was either not affected by N application or responded quadratically peaking N at emergence levels between 95 and 125 kg ha^{-1}. N application rates above this range decreased yield and NUE while increasing soil residual N at the end of the season. Plant N uptake and tuber yield did not increase with N rate at tuber initiation above 56 kg ha^{-1} and it was associated with lower NUE and also higher residual soil N.

Akassa *et al*. (2014) conducted a research study to determine the effect of inter and intra intra-row spacing on potato (*Solanum tuberosum* L.) seed and ware tuber emergence and subsequent growth. Six levels of inter: 60, 65, 70, 75, 80 and 85cm and three levels of intra intra-row spacing’s: 20, 30 and 40cm were used under study. Most of the variables collected in this experiment were significantly affected by inter, intra and/or their interactions except the number of main stem which did not show any change as the result to change of these treatments.

Though most of the variables considered require wider spacing, it was observed that an indefinite increase in the space between plants and rows did not result to an increase in any of the variables apart from extending days to flowering and maturity. For the optimum emergence and successful growth of potato tubers for seed and ware, spacing of 70-75 and 20-30 cm between plants and rows, respectively were identified as the best combinations to be used in the study are.

Banjare *et al*. (2014) carried out a field investigation to study the effect of different nitrogen levels on growth and yield parameters in potato var. Kufri Surya. The experiment was laid out in a randomized block design with treatments consisting of six nitrogen levels replicated four times. Growth parameters like plant length, number of leaves plant^{-1}, number of shoot plant^{-1}, fresh and dry weight of shoot plant^{-1} and yield attributing parameters like number of stolon, fresh and dry weight of tuber plant^{-1} increased with an increase in nitrogen levels with maximum values being obtained on application of highest nitrogen level (375 kg N ha^{-1}). However, the highest values for number of tubers plant^{-1} and plot^{-1} as well as tuber yield plot^{-1} and ha^{-1} were recorded on application of 225 kg N ha^{-1}. The highest net returns (Rs. 117323) and maximum B: C ratio (1.42) was recorded on application of 225 kg N ha^{-1}.

Kumar *et al*. (2014) conducted a field study two processing varieties Kufri Himsona and Kufri Chipsona-3 in main plot and five crop intra-row spacing 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 intra-row spacing. Tuber number plant^{-1}, percent processing grade tuber and average processing grade tuber weight steadily increased with increased intra-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 intra-row spacing. 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 percent 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 intra-row spacing 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.

Zotarelli *et al*. (2014) carried out an experiment to determine the effect of N fertilizer rate, applied at the plant emergence and tuber initiation stages, on N use efficiency and yield of cultivar Atlantic chipping potato. Fertilizer rates of 0, 56, 112, 168 kg ha^{-1} were applied at plant emergence, and 56 and 112 kg ha^{-1} were applied at tuber initiation as a side-dress in a factorial randomized complete block design with four replicates in three consecutive years at three commercial farms. All treatments received 56 kg ha^{-1} of N at pre-plant. Total N fertilizer applied ranged from 112 to 370 kg ha^{-1}. Applied N rates influenced the levels of soil inorganic N. The maximum daily N uptake occurred between 55 and 70 d after planting, coinciding with the onset of the tuber bulking stage. Potato yield was similar between N rates applied at emergence with the exception of one farm in 2010 due to high precipitation. Average tuber yield ranged from 15 to 33, 29 to 41, and 33 to 39 Mg ha^{-1} first, second and third year, respectively. Tuber yield and plant N uptake were similar with N rates above 56 kg ha^{-1} applied-at tuber initiation. There was an increased residual concentration of soil N at harvest with higher N application; however, this did not correlate to an increase in potato yield.

Tarkalson *et al*. (2011) conducted an experiment to evaluate the effect of in-row plant spacing and planting configuration on yield of potatoes under sprinkler irrigation. For the three cultivars, the effect of in-row plant spacing (three spacing treatments) for each planting configuration (4 row conventional ridged-row [4RC], 5 row bed [5RB], and 7 row bed [7RB]), and the effect of planting configuration at a uniform population on total tuber yield, U.S. No. 1 tuber yield, tubers per ha, average size (by weight), and large tuber yield were investigated. The greatest influence of in-row plant spacing was on average size and tubers per ha. In general, as in-row plant spacing increased (plant population decreased) the average tuber size increased and tubers ha^{-1} decreased. There was little influence of in-intra-row spacing on measured production variables under the bed planting configurations except for tubers ha^{-1} which generally increased with narrower plant spacing.

For Russet Norkotah and Ranger Russet there were few differences in measured production variables between planting configuration treatments. For Russet Burbank, the 4RC planting configuration had 14.6% significantly greater total tuber yield than the 7RB planting configuration, 20.2% greater U.S. No. 1 tuber yield than both bed planting configurations, and 25.2 and 29.9% greater large tuber yield than the 5RB and 7RB planting configurations.

Sogut and Ozturk (2011) investigated the effect of harvesting time was on yield and quality traits for spring season production in different maturing potato (*Solanum tuberosum* L.) cultivars. The cultivars tested were adora (early), carrera (early), felsina (mid-early), marfona (mid-early), mondial (mid-late) and vangogh (mid-late). Samples of tubers were harvested at 75, 90, 105 and 120 days after planting (DAP) in spring crop. Early cultivars carrera and felsina gave more than 2 t ha^{-1} tuber yield at 120 DAP. However, vangogh and mondial (mid-late cultivars) proved to be superior cultivars in relation to dry matter, specific gravity or starch content at 105 DAP.

Ayyub *et al*. (2006) conducted a research experiment with a promising red potato variety 'Symphonia' was taken to explore for various nitrogen application techniques like broadcast (BC), side dressing (SO) and foliar application. Optimal recommended dose of nitrogen (250 kg ha^{-1}) were supplied from urea applied at planting and later on. Tuber emergence percentage, number of aerial stems, leaves $plant^{-1}$, plant length, number of tubers, foliage and tuber fresh and dried weight $plant^{-1}$ and tuber yield ha^{-1} were found to be better in case of T_1O= BC+SO, followed by T_7 = BC+BC, T_{11} = SO+BC and T_4 = SO after 30 days of planting. Similarly, some of the tuber qualitative characters like TSS, specific gravity, dry matter contents were also better comparatively in case of initially broadcasted or later on side dressed nitrogen as compared to full basal dose (broadcasted or side dressed) and foliar application of nitrogen.

On the other hand some qualitative characteristics like tuber's moisture, nitrogen, phosphorus, potassium and crude protein contents were improved in case of foliar application of nitrogen, followed by initially side dressed or full basal single dose of nitrogen as compared to better performing treatments for all other quantitative characters.

Kumar and Lal (2006) conducted a field experiment to evaluate the effects of planting geometry, N and P levels and haulms 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 intra-row 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 haulms 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.

Kawakami *et al*. (2004) carried out a study to clarify the field performance of plants grown from directly planted micro-tubers of cultivars with different maturity periods, with a special attention to early cultivars. The experiments were conducted at Hokkaldo University, Japan, over four years.

Micro-tubers and conventional seed tubers of the early cultivar Kitaakari, late cultivars Konafubuki and Norin-1, and very late breeding line IWA-1 were planted, and the plant growth and tuber yields were analyzed. The micro-tuber plants of Kitaakari had a lower initial increase in leaf area index than conventional seed tuber plants, but at the maximum shoot growth had the same leaf area index. This pattern was also observed in the other cultivars. Tuber initiation and tuber bulking occurred on average five days later in micro-tuber plants than in conventional seed tuber plants of cultivar Kitaakari. At maximum shoot growth, micro-tuber plants had on average 65% of tuber dry weight of conventional seed tuber plants, with small variation among cultivars. Irrespective of maturity period, micro-tuber plants showed a higher tuber increase after maximum shoot growth, achieving around 86% of tuber dry weight of conventional seed tuber plants at harvest. From the results of this study we conclude that micro-tuber plants of early and late cultivars have a similar yield potential relative to conventional seed tuber plants, and micro-tubers of both early and late cultivars might be used as an alternative seed tuber source for potato production, if necessary.

El khider (2003) conducted an experiment with two types of urea fertilizer were added to potato plant in the form of granules (N_g) and in the form of solution (N_s) (urea dissolved in water) in different seasons. In different quantities (0, 1.7, 3.3 and 5.0 g) to the individual plant. The fertilizer was added in two doses; the first dose was added one month after sowing, and the second at earthing up (after irrigation). All treatments had a clear response when compared to the control. The third treatment (N_{3g}) gave better results when compared to the other treatments and had a higher significant effect on the measurements of vegetative growth and yield gave a higher significant effect. The first treatment of fertilizer (N_{1s}) (solution) gave the lowest effect, and was no significant when compared to other treatments.

The third season gave better results in growth attributes when compared to first and second seasons, while the second season gave results in yield same as the third and better of the first season.

Chowdhury *et al*. (2002) conducted an experiment to find out the proper methods of urea application for maximizing the production of potato. All the studied parameters (days required to 80% emergence, plant length, foliage coverage (%) hill^{-1}, number of stem hill^{-1}, fresh weight and dry weight of haulm, dry weight (%) of tuber, number of tuber hill^{-1}, yield of tuber hill^{-1} and yield of tuber plot^{-1} were differed significantly ($P<0.01$) among the methods of urea application. Application of urea as 50 % basal + 50% top dressing produced the best result among the methods and it was found to be the most cost effective (1.99). It might be concluded that split application of urea (50% basal + 50% top dressing in two installment at 30 and 50 DAP) is the effective way to avoid the detrimental effect of urea on plant emergence and to maximize the tuber yield in Bangladesh.

Vos (1999) conducted an experiment to evaluate the effects of single nitrogen (N) applications at planting on yield and nitrogen uptake of potato (*Solanum tuberosum* L.) that's was compared with two or three split applications. The total amount of N applied was an experimental factor in three of the experiments. In two experiments, sequential observations were made during the growing season. Generally, splitting applications (up to 58 days after emergence) did not affect dry matter (DM) yield at maturity and tended to result in slightly lower DM concentration of tubers, whereas it slightly improved the utilization of nitrogen. Maximum haulm dry weight and N content were lower when less nitrogen was applied during the first 50 days after emergence (DAE).

Millard and Robinson (1990) carried out an experiment to evaluate the effect of the timing of N fertilizer application on the uptake and partitioning of N within the crop and the yield of potato tubers.

Fertilizer N was applied either at planting, around the time of tuber initiation or half at planting and the remainder in four foliar sprays of urea during tuber bulking. 15N labeled fertilizer was applied to measure the recovery of fertilizer N in the crops. Applying the N at tuber initiation delayed and reduced the accumulation of N in the canopy compared with crops receiving all their fertilizer at planting. Foliar sprays of urea slightly increased both tuber yields and tuber N contents when compared to a single application at planting. The proportion of the fertilizer N recovered in the crop was little affected by the rate of N application, but a greater proportion of foliar-applied N was recovered than N broadcast at planting, due partly to pre-emergence losses of nitrate in 1986. It is suggested that late applications of N was foliar sprays can be of benefit to crops with a long growing season and reduce environmental losses of N.

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

Materials and methods

CHAPTER III

MATERIALS AND METHODS

A brief description about experimental site, climatic condition, planting materials, treatments, experimental design and layout, crop growing procedure, intercultural operations, data collection and statistical analysis were described details in this chapter.

3.1 Experimental period and site

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. The experimental area was belonged to 23^o7'N latitude and 93^oE' longitude at an altitude of 8.6 meter 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

The experimental site characterized by winter with a significant monsoon climate with sub-tropical cropping zone during the months from November, 2015 to March, 2016 (*Rabi* season). The soil above the sub-surface soil are termed as “Surface soil” which was characterized by silty clay with slight sandy loam in texture, olive-slight grayish white with common fine to medium distinct dark whitish brownish-light brown mottles was seen on the top soil. The soil was also characterized by pH-5.62 and organic carbon-0.459%. 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

The potato variety "Asterix" was used as test crop under present study which was released and developed by Tuber Crops Research Centre (TCRC), Bangladesh Agricultural research Institute, Gazipur. For improving the income status of farming communities of potato in Bangladesh as a whole this variety was selected as it is more popular under processing and export quality attributes.

3.4 Treatments

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

Factor A: Growth duration (G)

$\mathbf{G_1}$ = Harvested at 90 days after planting (DAP)

$\mathbf{G_2}$ = Harvested at 100 DAP

Factor B: Time of nitrogen application (T)

$\mathbf{T_1}$ = 135 kg N ha^{-1} (at planting) + 135 kg N ha^{-1} (at first earthing up, 35 DAP)

$\mathbf{T_2}$ = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 67.5 kg N ha^{-1} (at second earthing up, 50 DAP)

$\mathbf{T_3}$ = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP

$\mathbf{T_4}$ = 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP

Factor C: Intra-row spacing (S)

$\mathbf{S_1}$ = 60 cm X 20 cm

$\mathbf{S_2}$ = 60 cm X 25 cm

There were total sixteen treatment combinations was used under study are as follows:-

$G_1T_1S_1$, $G_1T_1S_2$, $G_1T_2S_1$, $G_1T_2S_2$, $G_1T_3S_1$, $G_1T_3S_2$, $G_1T_4S_1$, $G_1T_4S_2$

$G_2T_1S_1$, $G_2T_1S_2$, $G_2T_2S_1$, $G_2T_2S_2$, $G_2T_3S_1$, $G_2T_3S_2$, $G_2T_4S_1$, $G_2T_4S_2$

3.5 Experimental design and layout

The experiment was laid out in a 3 factors split-split-plot design with three replications, where the growth duration assigned to main plots; time of nitrogen application to sub-plots and intra-row spacing to sub-sub plots. The total numbers of unit plots were 48. The size of unit plot was 2.0 m × 1.5 m. The final layout of the experimental plots was shown in Appendix-III.

3.6 Preparation of seed

Tubers of uniform size (50-60 g) were used for planting and kept in room temperature to facilitate good sprouting. Finally full sprouted potato tubers were used as planting material in a pit of allocated plot.

3.7 Land preparation

The land of the experimental site was first opened in the second week of November with power tiller and to obtain the desirable tilth the land was ploughed and cross-ploughed four times followed by laddering. Weeds and stubbles were removed from the corners of field using spade. The land was finally prepared on 22 November 2015 three days before of the planting of whole seed tuber. In order to avoid water logging due to rainfall during the study period, drainage channels were made around the land. The soil was treated with Furadan 5G @ 20 kg ha when the plot was finally ploughed to protect the young plant from the attack of cut worm.

3.8 Fertilizer application

The crop was fertilized as per treatments and recommended dose of fertilizers at the rate of 44-132-15-2-5 kg ha^{-1} of P-K-S-B-Zn, respectively, as TSP, MoP, gypsum, boric acid and zinc sulphate were applied in the field during final land preparation (Mondal *et al*., 2013). Nitrogen was used @ 270 kg ha^{-1} in the form of urea and applied at different installments as per treatment. During planting of tuber the fertilizers were applied in furrow as per required as treatment.

3.9 Planting of seed tuber

The well sprouted healthy and uniform sized potato tubers of "Asterix was planted according to desired. Seed potatoes were planted at a depth of 5-6 cm on November 25, 2015.

3.10 Intercultural operations

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

First weeding was done two weeks after emergence. Another weeding was done before 2nd top dressing of urea. It was also done as and 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

Three irrigations were provided throughout the growing period in controlled way. The first irrigation was given at 35 DAP. Subsequently, another two irrigations were given at 50 and 65 DAP. Top dressing of fertilizers was followed by irrigation for proper utilization of fertilizers.

3.10.4 Control of insects and diseases

All possible phytosanitary measures were adopted to keep plant healthy. 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. At moist condition of weather Ridomil Gold MZ @ 1g $litre^{-1}$ was applied before incidence of late blight of potato at an interval of 7 days.

3.11 Haulm cutting

Haulm cutting was done at February 18, 2016, when 60-70% plants showed senescence for treatment G_1 and these potatoes were harvested 7 days after of haulms cutting for skin hardening and tuber bulking. On the other hand, for treatment G_2, haulm cutting was done at March 04, 2016 and these potatoes were harvested 7 days after of haulms 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

Different types of data were collected on the basis of the aims of the present study. Some of the parameters were taken after harvesting of tuber 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

All the plots were keenly observed daily to see the emergence of tuber from soil. 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

All the plots were keenly observed daily to see the emergence of tuber from soil. 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 at stolonization stage

Ten randomly selected potato hills were considered for taking the plant length. 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

All the potato ridges in each plot were keenly observed daily to see the initiation of stolon from the soil. 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

The relative content of leaf chlorophyll could be known from the SPAD value. So, SPAD-502 electrical device was used under present study which was manufactured by Minolta Camera Co., Ltd, Osaka, Japan. (1989). Ten randomly selected hills were taken to take the SPAD values 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}

Five hills were selected from each plot. The entire tuber was counted from five hills and then the mean values of tuber per hill were calculated.

ii. Weight of tubers hill^{-1}

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

iii. Average weight of tuber

Five hills were selected from each plot. The entire tuber (>20g) was counted and weighted from five hills by using an electronic balance. Then to calculate the average tuber weight, the weight of total tuber hill was divided by the numbers of tuber per hill and then means were taken in gram unit.

iv. Tuber yield

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

3.12.3 Quality traits

i. Specific gravity

Specific gravity was measured by using the following formula (Gould, 1995). Five tubers were taken from each plot after harvest of treatment and then the means were taken.

$$\text{Specicifc gravity} = \frac{\text{Weight of tuber (g) in air}}{\text{Weight of tuber (g) in fresh water at 4 degree centigrade}}$$

ii. Dry matter content (DMC)

The potato tuber samples were kept in separated envelopes for each plot and five potato tubers were taken after harvest to calculate the DMC and were oven dried at 70^0C for 72 hours. Dry weight was determined with a digital balance and means were calculated in percent unit.

$$\textbf{DMC=} \frac{\text{□□□ □□□□□□□}}{\text{□□□□□ □□□□□□□}} \times 100$$

iii. Total soluble solid

TSS of harvested tubers was determined after harvest in a drop of potato juice by using Hand Sugar Refractometer "ERMA" Japan, Range: 0-32% according to (AOAC, 1990) and recorded as ^{o}brix from direct reading of the instrument.

iv. Starch content

Starch content of tubers was determined after harvest by Somogyi-Nelson method (Nelson, 1944). Phosphate buffer solution was prepared through diluted 0.74g $NaH_2PO_4 \cdot 2H_2O$ and 0.09g $Na_2HPO_4 \cdot 12H_2O$ into 100 ml Distilled water. Added 0.1 g Enzyme (Amyloglucosidase) and mixed well. Kept at-20^{o}C for the preservation. The residue remained after extraction for sugar was washed for several times with water to ensure that there was no more soluble sugar in the residues. After that using tap water and mark up to 250 ml beaker. Stirred well on a magnetic stirrer. Then 0.5 mL solution was taken from the beaker during stirring into 3 test tubes. Boil the test tubes for 10 min at 100˚C. Add 1 ml Amyloglucosidase solution, mix well, and heat at 50-60˚C for 2 hours in hot water. After cooling, add 0.5 ml Copper solution, mix well, heat at 100^{o}C for 10 min., cool in tap water, add 0.5 ml Nelson solution, mix well, add 7 ml distilled water, mix well (Final volume = 9.5 ml), and measure the absorbance at 660 nm (Abs). Starch content was calculated using the glucose standard curve.

v. Reducing sugar

For the analysis of sugar content like reducing sugar glucose potato flesh was extracted. For each extraction, 1 g fresh sample of chopped potato was taken from uniform tuber samples and smashed well in a motor. Sugar was extracted using 5 ml of 80% ethanol heat at 80°c for 30 min using a dry block heat bath and the extracts was centrifuged at 5000 rpm for 10 min and decanted the supernatant. 8 mL 80% EtOH, was added and it was repeated 4 and 5 times in total. All the supernatants were mixed well and the final volume was made up to 25 mL using 80% EtOH. The residue is used for sugar analysis. Reducing sugar was estimated by the photometric adaptation of the Somogyi method (Nelson, 1944) with some modification. Copper solution and Nelson reagent and standard glucose solution (0.5 mL) were used. 3 mL sample solution was put into a small glass container. Then it was completely dried up on an electric heater, 3 mL distilled water was added and then mixed well.

Then 0.5 ml solution was taken from that, two times and was put in different test tubes. In one test tube, 0.5 mL Copper solution was added and was boiled (100° C) for 10 min. After boiling, immediately the test tube was cooled in tap water. 0.5 mL Nelson reagent in the test tube was added, and mixed them well. After 20 min, 8 mL distilled water was added and mixed well (Total volume = 9.5 mL). After that the absorbance at 660 nm (Abs1) was measured and the reducing sugar content was calculated.

3.13 Correlation coefficient (r)

Correlation coefficient between different growth, yield and quality contributing traits were calculated by using the MS excel spread sheet.

3.14 Statistical Analysis

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

Chapter IV

Results and discussion

CHAPTER IV

RESULTS AND DISCUSSION

The present study was aimed to investigate the effects of growth duration, time of nitrogen application and intra-row spacing on the production of quality potato tuber. In this chapter; figures, tables and appendices have been used to present, discuss and compare the findings obtained from the present study. The ANOVA (analysis of variance) of data in aspects of all the visual and measurable characteristics 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

In aspect of days to first emergence of potato plant a no variation was noted (Table-1 and Appendix IV) against growth duration of potato. In respects of days to first emergence of potato plant a remarkable variation was noted (Table-2 and Appendix IV) against different time of nitrogen applications. The maximum period (13.82 days) was required for the plant produced from T_1 treatment and the minimum (12.39 days) was in T_4. In case of days to first emergence of potato plant a remarkable variation was noted (Table-3 and Appendix IV) against intra-row spacing. The maximum period (13.22 days) was required for the plant produced from S_1 treatment and the minimum (12.53 days) was in S_2. Combindly, a remarkable variation was found (Table-4 and Appendix IV) among the treatment against days to first emergence from the soil surface. The maximum period (14.58 days) was required for the plant produced from $G_1T_1S_2$ treatment followed by $G_2T_1S_1$ and the minimum (9.14 days) was in $G_1T_3S_2$. At higher spacing the potato mother tuber get a full growing condition without imparting the stored materials to others and also there is lower competition at higher spacing than that of lower spacing in respect of light, air and water. Emergence was largely dependent on the utilization of reserve material and metabolites in the mother tuber.

Optimum seed tubers had slightly longer and thicker sprouts at planting time and this contributed to earlier germination and crop establishment. 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 (Kabir *et al*., 2004). Results are supported by Masome and Kazemi (2014). He explained that, number of days to seed emergence of tomato influenced significantly by urea, a nitrogenous fertilizer. The result of present study showed that, more absorption of nitrogen was exhibited from split application of nitrogen with 1 foliar spray resulting a better reduction of days required for first emergence of potato from field.

4.2 Days to 100% emergence

In aspect of days to 100% emergence of potato plant no variation was noted (Table-1 and Appendix IV) against growth duration potato tubers. In respects of days to 100% emergence of potato plant a remarkable variation was noted (Table-2 and Appendix IV) against different time of nitrogen applications. The maximum period (16.34 days) was required for the plant produced from T_1 treatment and the minimum (14.91 days) was in T_4. In case of days to 100% emergence of potato plant a remarkable variation was noted (Table-3 and Appendix IV) against intra-row spacing. The maximum period (15.74 days) was required for the plant produced from S_1 treatment and the minimum 15.05 days) was in S_4. Combindly, a remarkable variation was found (Table-4 and Appendix IV) among the treatment against days to 100% emergence from the soil surface (Table-4 and Appendix IV). The maximum period (17.10 days) was required for the plant produced from $G_1T_1S_2$ treatment followed by $G_2T_1S_1$ and the minimum (11.66 days) was in $G_1T_3S_2$. At higher spacing the potato mother tuber get a full growing condition without imparting the stored materials to others and also there is lower competition at higher spacing than that of lower spacing in respect of light, air and water.

Emergence was largely dependent on the utilization of reserve material and metabolites in the mother tuber. Optimum seed tubers had slightly longer and thicker sprouts at planting time and this contributed to earlier germination and crop establishment. 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 (Kabir *et al*., 2004). Results are supported by Masome and Kazemi (2014). He explained that, number of days to seed emergence of tomato influenced significantly by urea, a nitrogenous fertilizer. The result of present study showed that, more absorption of nitrogen was exhibited from split application of nitrogen with 1 foliar spray resulting a better reduction of days required for 100% emergence from field.

Table 1. Effect of growth duration on days to first emergence and 100% emergence of potato

Growth duration	Days to first emergence	Days to 100% emergence
G_1	12.86	15.38
G_2	12.89	15.41
CV (%)	2.22	1.86
LSD (0.05)	----	----
F-test	NS	NS

NS= non-significant

G_1 = Harvested at 90 days after planting (DAP) and G_2 = Harvested at 100 DAP

Table 2. Effect of time of nitrogen application on days to first emergence and 100% emergence of potato

Time of nitrogen application	Days to first emergence	Days to 100% emergence
T_1	13.82 a	16.34 a
T_2	13.28 b	15.80 b
T_3	12.02 d	14.54 d
T_4	12.39 c	14.91 c
CV (%)	2.58	2.16
LSD (0.05)	0.295	0.311
F-test	**	**

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

T_1 = 135 kg N ha^{-1} (at planting) + 135 kg N ha^{-1} (at first earthing up, 35 DAP), T_2 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 67.5 kg N ha^{-1} (at second earthing up, 50 DAP), T_3 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP and T_4 = 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP

** indicates significant at 1% level of probability

Table 3. Effect of intra-row spacing on days to first emergence and 100% emergence of potato

Intra-row spacing	Days to first emergence	Days to 100% emergence
S_1	13.22 a	15.74 a
S_2	12.53 b	15.05 b
CV (%)	8.86	7.41
LSD (0.05)	0.568	0.591
F-test	*	*

Values with common letter (s) within a column do not differ significantly at 5% level of probability
S_1 = 60 cm X 20 cm and S_2 = 60 cm X 25 cm
* indicates significant at 5% level of probability

Table 4. Combined effect of growth duration, time of nitrogen application and intra-row spacing on days to first emergence and 100% emergence of potato

Combination	Days to first emergence	Days to 100% emergence
$G_1T_1S_1$	14.20 a-c	16.72 a-c
$G_1T_1S_2$	14.58 a	17.10 a
$G_1T_2S_1$	14.00 a-c	16.52 a-c
$G_1T_2S_2$	13.94 a-c	16.46 a-c
$G_1T_3S_1$	13.51 a-d	16.03 a-d
$G_1T_3S_2$	9.14 f	11.66 f
$G_1T_4S_1$	11.21 e	13.73 e
$G_1T_4S_2$	12.28 de	14.80 de
$G_2T_1S_1$	14.41 ab	16.93 ab
$G_2T_1S_2$	12.08 de	14.60 de
$G_2T_2S_1$	12.32 de	14.84 de
$G_2T_2S_2$	12.85 cd	15.37 cd
$G_2T_3S_1$	13.00 b-d	15.52 b-d
$G_2T_3S_2$	12.41 de	14.93 de
$G_2T_4S_1$	13.11 a-d	15.63 a-d
$G_2T_4S_2$	12.97 b-d	15.49 b-d
CV (%)	8.86	7.41
LSD (0.05)	1.4758	1.5158
F-test	**	**
G × T	NS	NS
G × S	NS	NS
T × S	*	*

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

Note: G_1 = Harvested at 90 days after planting (DAP) and G_2 = Harvested at 100 DAP
T_1 = 135 kg N ha^{-1} (at planting) + 135 kg N ha^{-1} (at first earthing up, 35 DAP), T_2 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 67.5 kg N ha^{-1} (at second earthing up, 50 DAP), T_3 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP and T_4 = 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP
S_1 = 60 cm X 20 cm and S_2 = 60 cm X 25 cm
*, ** indicate significant at 5 and 1% level of probability
NS=Non-significant

4.3 Plant length at first stolonization stage

No variation was noted in case of length of potato plant (Table-5 and Appendix V) against growth duration of potato. Remarkable variation was noted in case of length of potato plant (Table-6 and Appendix V) against different time of nitrogen applications. The tallest plant (58.11 cm) was found for the plant produced from T_3 treatment and the smallest (51.42 cm) was in T_1. In case of potato plant length a remarkable variation was noted (Table-7 and Appendix V) against intra-row spacing. The tallest plant (55.97 cm) was found for the plant produced from S_2 treatment and the smallest (53.15 cm) was in S_1. Combindly, no variation was found (Table-8 and Appendix V) among the treatment against length of potato plant, except, in the combination of growth duration and time of nitrogen application a significant variation (Table-8 and Appendix V) was noted on this parameter. At lower intra-row spacing, the competition between plants to plant is higher than that of the higher intra-row spacing. 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. The finding also supported by Marschner (1995). He reported that, 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.

4.4 Days to stolon initiation

Days to stolon initiation of potato plant was not varied (Table-5 and Appendix V) by growth duration of potato tubers. In respects of days to stolon initiation of potato plant a remarkable variation was noted (Table-6 and Appendix V) against different time of nitrogen applications. The maximum period (41.90 days) was required for the plant produced from T_1 treatment and the minimum (36.44 days) was T_4. In case of days to stolon initiation of potato plant a remarkable variation was noted (Table-7 and Appendix V) against intra-row spacing.

The maximum period (39.32 days) was required for the plant produced from S_1 treatment and the minimum (37.40 days) was in S_2. Combindly, no variation was found (Table-8 and Appendix V) among the treatment against days to stolon initiation. Thicker sprouts with higher intra-row spacing at planting time and this contributed to earlier germination and crop establishment. 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 (Kabir *et al*., 2004). More nitrogen induces the mother tuber of potato to initiate stolon by increasing the cell division with a vigorous tuber where at higher N accumulation by the plant also get more time to accumulate the nutrients from the soil for tuber development which induces the early reproductive growth than that of the tuber planting with lower N uptake (Regassa *et al*., 2016). Lowered nutrient level also led to a reduction in the number of nodes bearing stolons, 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

The SPAD value of leaf was found non-significant (Table-5 and Appendix VI) against growth duration of potato. In respects of SPAD value of potato leaf a remarkable variation was noted (Table-6 and Appendix VI) against different time of nitrogen application. The maximum SPAD value (43.78) was found from T_3 treatment which was statistically similar to T_4 and the minimum (35.73) was in T_1. In case of SPAD value of potato leaf no remarkable variation was noted (Table-7 and Appendix VI) against intra-row spacing. Combindly, no variation was found (Table-8 and Appendix VI) among the treatment against SPAD value of potato leaf. At higher intra-row spacing, the mother tuber gets more nutrients than that of the tuber placed at lower spacing.

Regassa *et al*. (2016) also said that, with the increasing of nitrogen accumulation by the plants it tends to enhance the partitioning of more green pigments into the plants through photosynthesis. Chlorophyll content is approximately proportional to leaf nitrogen content and at the advent of stolonization of potato tuber, the vegetative growth was stopped to patron the sink to reproductive part as a whole. As a result, the SPAD value was varied among the treatment at this stage of potato plant.

Table 5. Effect of growth duration on plant length, days to stolon initiation and SPAD value of potato

Growth duration	Plant length (cm)	Days to stolon initiation	SPAD value of leaf
G_1	55.20	38.41	41.83
G_2	53.98	38.31	37.98
CV (%)	0.75	0.25	9.36
LSD (0.05)	-----	------	------
F-test	NS	NS	NS

G_1 = Harvested at 90 days after planting (DAP) and G_2 = Harvested at 100 DAP
NS= Non-significant

Table 6. Effect of time of nitrogen application on plant length, days to stolon initiation and SPAD value of potato

Time of nitrogen application	Plant length (cm)	Days to stolon initiation	SPAD value of leaf
T_1	51.42 d	41.90 a	35.73 b
T_2	56.35 b	37.86 b	37.72 b
T_3	58.11 a	36.44 d	43.78 a
T_4	52.36 c	37.24 c	42.40 a
CV (%)	0.78	0.65	12.54
LSD (0.05)	0.377	0.221	4.450
F-test	**	**	**

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

T_1 = 135 kg N ha^{-1} (at planting) + 135 kg N ha^{-1} (at first earthing up, 35 DAP), T_2 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 67.5 kg N ha^{-1} (at second earthing up, 50 DAP), T_3 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP and T_4 = 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP

** indicates significant at 1% level of probability

Table 7. Effect of intra-row spacing on plant length, days to stolon initiation and SPAD value of potato

Intra-row spacing	Plant length (cm)	Days to stolon initiation	SPAD value of leaf
S_1	53.15 b	39.32 a	39.61
S_2	55.97 a	37.40 b	40.20
CV (%)	7.71	7.99	11.20
LSD (0.05)	2.573	1.875	------
F-test	*	*	NS

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

S_1 = 60 cm X 20 cm and S_2 = 60 cm X 25 cm
* indicates significant at 5% level of probability
NS= Non-significant

Table 8. Combined effect of growth duration, time of nitrogen application and intra-row spacing on plant length, days to stolon initiation and SPAD value of potato

Combination	Plant length (cm)	Days to stolon initiation	SPAD value of leaf
$G_1T_1S_1$	54.10	44.24	35.54
$G_1T_1S_2$	56.20	39.00	37.88
$G_1T_2S_1$	58.10	38.61	37.98
$G_1T_2S_2$	60.04	38.97	38.00
$G_1T_3S_1$	60.11	37.41	48.38
$G_1T_3S_2$	65.12	34.20	50.80
$G_1T_4S_1$	51.11	36.14	42.86
$G_1T_4S_2$	52.84	38.71	43.22
$G_2T_1S_1$	43.11	47.25	34.16
$G_2T_1S_2$	52.28	37.10	35.32
$G_2T_2S_1$	53.24	36.85	37.41
$G_2T_2S_2$	54.01	37.00	37.47
$G_2T_3S_1$	53.20	36.94	38.41
$G_2T_3S_2$	54.00	37.21	37.51
$G_2T_4S_1$	52.22	37.12	42.11
$G_2T_4S_2$	53.26	36.97	41.40
CV (%)	7.71	7.99	11.20
LSD (0.05)	------	---------	------
F-test	NS	NS	NS
G × T	**	**	*
G × S	NS	NS	NS
T × S	NS	**	NS

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

Note: G_1 = Harvested at 90 days after planting (DAP) and G_2 = Harvested at 100 DAP
T_1 = 135 kg N ha^{-1} (at planting) + 135 kg N ha^{-1} (at first earthing up, 35 DAP), T_2 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 67.5 kg N ha^{-1} (at second earthing up, 50 DAP), T_3 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP and T_4 = 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP
S_1 = 60 cm X 20 cm and S_2 = 60 cm X 25 cm
*, ** indicate significant at 5 and 1% level of probability
NS=Non-significant

4.6 Number of tubers hill^{-1}

Number of tubers was found non-significant (Table-9 and Appendix VI) against growth duration of potato tubers. In respects of number of potato tubers a remarkable variation was noted (Table-10 and Appendix VI) against different time of nitrogen appllications. The maximum (10.72) number of tuber was found from T_1 treatment and the minimum (8.91) was T_3 which was statistically similar to T_4. In case of number of potato tubers a remarkable variation was noted (Table-11 and Appendix VI) against intra-row spacing. The maximum (9.80) number of tuber was found from S_1 treatment and the minimum (9.17) was in S_2. Combindly, significant variation was found (Table-12 and Appendix VI) among the treatment against number of potato tubers. The maximum (13.18) number of tuber was found from $G_2T_1S_1$ treatment and the minimum (7.97) was in $G_1T_3S_2$ which was statistically similar to $G_1T_4S_1$. Tuber numbers were significantly affected by plant population density (Masarirambi *et al.*, 2012). The greater the space, the higher the number of tubers formed (Arioglu, 2009). But the result of present study is antagonistic of the findings of above researcher. The results showed that close spacing leads to higher proportion of small tubers than wider spacing (Kumar *et al.*, 2001). However, the result of present study is in agreement with (Mahmud *et al.*, 2009). They said that, number of tubers is not related to growth durations because tuber formation in potato is almost completed within 50 days.

4.7 Weight of tubers hill^{-1}

Weight of tubers was found significant (Table-9 and Appendix VII) against growth duration of potato. The highest weight (400.93 g) of tuber/hill was found from G_1 treatment and the lowest (366.89 g) was in G_2. In respects of weight of potato tubers a remarkable variation was noted (Table-10 and Appendix VII) against different time of nitrogen applications. The highest weight (402.67 g) of tuber was found from T_3 treatment and the lowest (360.72 g) was in T_1.

In respects of weight of potato tubers a remarkable variation was noted (Table-11 and Appendix VII) against intra-row spacing. The highest weight (393.49 g) of tuber was found from S_2 treatment and the lowest (374.32 g) was found from S_1. Combindly, a significant variation was found (Table-12 and Appendix VII) among the treatment against weight of potato tubers. The highest weight (452.25 g) of tuber was found from $G_1T_4S_1$ treatment combination which was statistically similar to $G_1T_3S_2$ and the lowest (274.23 g) was in $G_2T_1S_1$ treatment combination. Since, at higher intra-row spacing the number of tuber was higher but the weight of tuber was higher due to that, at higher spacing the potato tuber gets more spaces to enlarge by size and shape with more accumulation of soil nutrients than that of tuber placed at lower intra-row spacing (Kumar *et al*., 2004). More absorption of soil nitrogen by plant through more protein partitioning into the growing tubers may be the main reason for higher weight of tuber $hill^{-1}$. The tuber weight per hill increased with age, which is obvious up to 80 days under the tropical climatic condition of Bangladesh. Under this climatic conditions, potato crop mature within 85 to 95 days. With the rise of temperature in the month of late February or March, potato storage food used in reverse order from tuber to foliage (Mahmud *et al*., 2009).

4.8 Average weight of tuber

Average weight of tubers was found significant (Table-9 and Appendix VII) against growth duration of potato. The highest average weight (49.01 g) of tuber was found from G_1 treatment and the lowest (39.88 g) was in G_2. In respects of average weight of potato tubers a remarkable variation was noted (Table-10 and Appendix VII) against different times of nitrogen applications. The highest average weight (47.96 g) of tuber was found from T_3 treatment and the lowest (37.57 g) was in T_1. In respects of average weight of potato tubers a remarkable variation was noted (Table-11 and Appendix VII) against intra-row spacing. The highest average weight (45.82 g) of tuber was found from S_2 treatment and the lowest (43.07 g) was in S_1.

Combindly, a significant variation was found (Table-12 and Appendix VII) among the treatment against average weight of potato tubers. The highest average weight (60.20 g) of tuber was found from $G_1T_4S_1$ treatment combination which was statistically similar to $G_1T_3S_2$ and the lowest (24.97 g) was in $G_2T_1S_1$ treatment combination. Kumar *et al*. (2004) showed that, increased intra-specific competition at higher plant densities/closer spacing's reduced the average individual tuber wt for total and all tuber size categories. More absorption of soil nitrogen induced more protein partitioning into the growing tubers may be the main reason for higher average weight of tuber hill^{-1}. Average tuber weight progressively increased with increasing split nitrogen application with foliar spraying (Belachew, 2016). The average tuber weight hill^{-1} also increased with age, which is obvious up to 80 days under the tropical climatic condition of Bangladesh. Under this climatic conditions, potato crop mature within 85 to 95 days. With the rise of temperature in the month of late February or March, potato storage food used in reverse order from tuber to foliage (Mahmud *et al*., 2009).

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

Growth duration	Number of tubers hill^{-1}	Weight of tubers hill^{-1} (g)	Average weight of tuber (g)
G_1	9.45	400.93 a	49.01 a
G_2	9.53	366.89 b	39.88 b
CV (%)	1.06	0.31	0.20
LSD (0.05)	--------	1.468	0.111
F-test	NS	**	**

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

G_1 = Harvested at 90 days after planting (DAP) and G_2 = Harvested at 100 DAP

** indicates significant at 1% level of probability

NS= Non-significant

Table 10. Effect of time of nitrogen application on number and weight of tuber hill^{-1}, average tuber weight of potato

Time of nitrogen application	Number of tubers hill^{-1}	Weight of tubers hill^{-1} (g)	Average weight of tuber (g)
T_1	10.72 a	360.72 d	37.57 d
T_2	9.42 b	391.88 b	45.81 c
T_3	8.91 c	402.67 a	47.96 a
T_4	8.90 c	380.36 c	46.44 b
CV (%)	1.06	0.54	0.82
LSD (0.05)	0.089	1.840	0.322
F-test	**	**	**

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

T_1 = 135 kg N ha^{-1} (at planting) + 135 kg N ha^{-1} (at first earthing up, 35 DAP), T_2 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 67.5 kg N ha^{-1} (at second earthing up, 50 DAP), T_3 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP and T_4 = 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP

** indicates significant at 1% level of probability

Table 11. Effect of intra-row spacing on number and weight of tubers hill^{-1}, average tuber weight of potato

Intra-row spacing	Number of tubers hill^{-1}	Weight of tubers hill^{-1} (g)	Average weight of tuber (g)
S_1	9.80 a	374.32 b	43.07 b
S_2	9.17 b	393.49 a	45.82 a
CV (%)	11.15	7.87	7.93
LSD (0.05)	0.5380	18.487	2.156
F-test	*	*	**

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

S_1 = 60 cm X 20 cm and S_2 = 60 cm X 25 cm

*, ** indicate significant at 5 and 1% level of probability

Table 12. Combined effect of growth duration, time of nitrogen application and intra-row spacing on number and weight of tuber hill^{-1}, average tuber weight of potato

Combination	Number of tubers hill^{-1}	Weight of tubers hill^{-1} (g)	Average weight of tuber (g)
$G_1T_1S_1$	10.01 bc	385.21 d	40.00 d
$G_1T_1S_2$	10.46 b	403.12 b	43.20 b
$G_1T_2S_1$	10.11 bc	402.15 b	48.707 b
$G_1T_2S_2$	9.95 b-d	400.11 b	49.10 b
$G_1T_3S_1$	9.547 b-e	401.12 bc	47.51 bc
$G_1T_3S_2$	7.97 e	382.29 a	55.87 a
$G_1T_4S_1$	8.51 e	452.25 a	60.20 a
$G_1T_4S_2$	9.00 c-e	381.18 bc	47.50 bc
$G_2T_1S_1$	13.18 a	274.23 e	24.97 e
$G_2T_1S_2$	9.22 b-e	380.32 d	42.11 d
$G_2T_2S_1$	8.97 c-e	385.12 d	42.31 d
$G_2T_2S_2$	8.66 de	380.15 d	43.11 d
$G_2T_3S_1$	9.11 c-e	382.21 d	41.01 d
$G_2T_3S_2$	9.01 c-e	375.12 d	43.11 d
$G_2T_4S_1$	8.97 c-e	382.29 cd	44.20 cd
$G_2T_4S_2$	9.10 c-e	375.68 d	38.19 d
CV (%)	11.15	7.87	7.93
LSD (0.05)	1.305	37.064	4.331
F-test	*	*	**
G × T	**	**	**
G × S	NS	NS	NS
T × S	NS	*	**

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

Note: G_1 = Harvested at 90 days after planting (DAP) and G_2 = Harvested at 100 DAP

T_1 = 135 kg N ha^{-1} (at planting) + 135 kg N ha^{-1} (at first earthing up, 35 DAP), T_2 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 67.5 kg N ha^{-1} (at second earthing up, 50 DAP), T_3 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP and T_4 = 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP

S_1 = 60 cm X 20 cm and S_2 = 60 cm X 25 cm

*, ** indicate significant at 5 and 1% level of probability

NS=Non-significant

4.9 Tuber yield

Yield of tubers was found significant (Table-13 and Appendix VIII) against growth duration of potato. The highest (33.41 t ha^{-1}) tuber yield was found from G_1 treatment and the lowest (30.28 t ha^{-1}) was in G_2. In respects of yield of potato tubers a remarkable variation was noted (Table-14 and Appendix VIII) against different time of nitrogen applications. The highest tuber yield (33.55 t ha^{-1}) was found from T_3 treatment and the lowest (29.89 t ha^{-1}) was in T_1. In case of yield of potato tubers no variation was noted (Table-15 and Appendix VIII) against intra-row spacing. Combindly, a significant variation was found (Table-16 and Appendix VIII) among the treatment against yield of potato tubers. The highest tuber yield (37.68 t ha^{-1}) was found from $G_1T_3S_2$ treatment combination and the lowest (22.18 t ha^{-1}) was in $G_2T_1S_1$. The higher weight of tuber $hill^{-1}$ and higher average weight of tuber might be the main reason for higher tuber yield $hectare^{-1}$ (Verma *et al*., 2016). Zelalem *et al*. (2009) and Guler (2009) have reported highly significant increases in total tuber yield in response to increased level of nitrogen application. The increase in average tuber weight of potato with the supply of fertilizer nutrients 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 (Belachew, 2016).

Table 13. Effect of growth duration on tuber yield of potato

Growth duration	Tuber Yield (t ha^{-1})
G_1	33.41 a
G_2	30.28 b
CV (%)	1.82
LSD (0.05)	0.743
F-test	**

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

G_1 = Harvested at 90 days after planting (DAP) and G_2 = Harvested at 100 DAP

** indicates significant at 1% level of probability

Table 14. Effect of time of nitrogen application on tuber yield of potato

Time of nitrogen application	Tuber yield (t ha^{-1})
T_1	29.89 d
T_2	32.65 b
T_3	33.55 a
T_4	31.28 c
CV (%)	2.27
LSD (0.05)	0.641
F-test	**

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

T_1 = 135 kg N ha^{-1} (at planting) + 135 kg N ha^{-1} (at first earthing up, 35 DAP), T_2 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 67.5 kg N ha^{-1} (at second earthing up, 50 DAP), T_3 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP and T_4 = 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP

** indicates significant at 1% level of probability

Table 15. Effect of intra-row spacing on tuber yield of potato

Intra-row spacing	Tuber yield (t ha^{-1})
S_1	32.58
S_2	31.11
CV (%)	7.89
LSD (0.05)	---------
F-test	NS

S_1 = 60 cm X 20 cm and S_2 = 60 cm X 25 cm

NS= Non-significant

Table 16. Combined effect of growth duration, time of nitrogen application and intra-row spacing on tuber yield of potato

Combination	Tuber yield (t ha^{-1})
$G_1T_1S_1$	32.10 d
$G_1T_1S_2$	33.59 b
$G_1T_2S_1$	33.51 b
$G_1T_2S_2$	33.34 b
$G_1T_3S_1$	33.42 bc
$G_1T_3S_2$	37.68 a
$G_1T_4S_1$	31.85 d
$G_1T_4S_2$	31.76 bc
$G_2T_1S_1$	22.18 e
$G_2T_1S_2$	31.69 d
$G_2T_2S_1$	32.09 d
$G_2T_2S_2$	31.67 d
$G_2T_3S_1$	31.85 d
$G_2T_3S_2$	31.26 d
$G_2T_4S_1$	31.85 cd
$G_2T_4S_2$	29.67 d
CV (%)	7.89
LSD (0.05)	3.251
F-test	*
G × T	**
G × S	NS
T × S	*

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

Note: G_1 = Harvested at 90 days after planting (DAP) and G_2 = Harvested at 100 DAP

T_1 = 135 kg N ha^{-1} (at planting) + 135 kg N ha^{-1} (at first earthing up, 35 DAP), T_2 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 67.5 kg N ha^{-1} (at second earthing up, 50 DAP), T_3 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP and T_4 = 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP

S_1 = 60 cm X 20 cm and S_2 = 60 cm X 25 cm

*, ** indicate significant at 5 and 1% level of probability

NS=Non-significant

4.10 Specific gravity

In aspect of specific gravity of potato tuber was found significant (Table-17 and Appendix VIII) against growth duration. The highest specific gravity (1.07) of potato was found from G_1 treatment and the lowest (0.97) was in G_2. In respects of specific gravity of potato tuber a remarkable variation was noted (Table-18 and Appendix VIII) against different time of nitrogen applications. The highest specific gravity (1.07) of potato tuber was found from T_4 treatment and the lowest (0.99) was in T_1. In respects of specific gravity of potato tuber no variation was noted (Table-19 and Appendix VIII) against intra-row spacing. Combindly, a significant variation was found (Table-20 and Appendix VIII) among the treatment against specific gravity of potato tubers. The highest specific gravity (1.11) of potato tuber was found from $G_1T_4S_2$ treatment combination which was statistically similar to $G_1T_3S_2$ (1.10) and the lowest (0.79) was in $G_2T_1S_1$.

4.11 Dry matter content

In aspect of dry matter content of potato tuber was found significant (Table-17 and Appendix VIII) against growth duration. The highest dry matter (18.48 %) of potato was found from G_1 treatment and the lowest (15.96 %) was in G_2. In respects of dry matter of potato tuber a remarkable variation was noted (Table-18 and Appendix VIII) against different time of nitrogen applications. The highest dry matter (18.14 %) of potato tuber was found from T_3 treatment and the lowest (16.31 %) was in T_1. In respects of dry matter of potato tuber remarkable variation was noted (Table-19 and Appendix VIII) against intra-row spacing. The highest dry matter (17.99 %) of potato tuber was found from S_2 treatment and the lowest (16.46 %) was in S_1. Combindly, a significant variation was found (Table-20 and Appendix VIII) among the treatment against dry matter of potato tubers. The highest dry matter (22.92 %) of potato tuber was found from $G_1T_4S_2$ treatment combination which was statistically similar to $G_1T_3S_2$ (21.95 %) and the lowest (14.20 %) was in $G_2T_1S_1$.

4.12 Total soluble solid

In aspect of total soluble solid (TSS) of potato tuber was found non-significant (Table-17 and Appendix IX) against growth duration. In respects of TSS of potato tuber a remarkable variation was noted (Table-18 and Appendix IX) against different time of nitrogen applications. The highest TSS (5.96^o) of potato tuber was found from T_1 treatment identical with T_2 and the lowest (5.39^o) was in T_4. In respects of TSS of potato tuber remarkable variation was noted (Table-19 and Appendix IX) against intra-row spacing. The highest TSS (5.73^o) of potato tuber was found from S_1 treatment and the lowest (5.50^o) was in S_2. Combindly, a significant variation was found (Table-20 and Appendix IX) among the treatment against TSS of potato tubers. The highest TSS (7.22^o) of potato tuber was found from G_2T_1S treatment combination and the lowest (4.59^o) was in $G_1T_3S_2$. Joshi *et al*. (2015) reported that, more nitrogen uptake by the tuber lowering the rate of TSS in tuber.

Table 17. Effect of growth duration on specific gravity, dry matter and total soluble solid content of potato tuber

Growth duration	Specific gravity	Dry matter content (%)	Total soluble solid (TSS, ^{o} brix)
G_1	1.07 a	18.48 a	5.51
G_2	0.97 b	15.96 b	5.71
CV (%)	0.44	1.32	9.55
LSD (0.05)	0.024	0.282	--------
F-test	**	**	NS

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

G_1 = Harvested at 90 days after planting (DAP) and G_2 = Harvested at 100 DAP

** indicates significant at 1% level of probability

NS= Non-significant

Table 18. Effect of time of nitrogen application on specific gravity, dry matter and total soluble solid content of potato tuber

Time of nitrogen application	Specific gravity	Dry matter content (%)	Total soluble solid (TSS, ^{o}brix)
T_1	0.99 c	16.31 d	5.96 a
T_2	0.99 c	16.60 c	5.70 a
T_3	1.03 b	18.14 a	5.41 b
T_4	1.07 a	17.83 b	5.39 b
CV (%)	0.81	0.90	5.44
LSD (0.05)	0.022	0.138	0.271
F-test	**	**	**

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

T_1 = 135 kg N ha^{-1} (at planting) + 135 kg N ha^{-1} (at first earthing up, 35 DAP), T_2 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 67.5 kg N ha^{-1} (at second earthing up, 50 DAP), T_3 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP and T_4 = 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP

** indicates significant at 5% level of probability

Table 19. Effect of intra-row spacing on specific gravity, dry matter and total soluble solid content of potato tuber

Intra-row spacing	Specific gravity	Dry matter content (%)	Total soluble solid (TSS, ^{o}brix)
S_1	0.99	16.46 b	5.73 a
S_2	1.05	17.99 a	5.50 b
CV (%)	10.99	12.52	6.81
LSD (0.05)	------	1.319	0.234
F-test	NS	*	*

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

S_1 = 60 cm X 20 cm and S_2 = 60 cm X 25 cm

* indicates significant at 5% level of probability

NS= Non-significant

Table 20. Combined effect of growth duration, time of nitrogen application and intra-row spacing on specific gravity, dry matter and total soluble solid content of potato tuber

Combination	Specific gravity	Dry matter content (%)	Total soluble solid (TSS, ^{o}brix)
$G_1T_1S_1$	1.05 ab	16.52 cd	5.30 bc
$G_1T_1S_2$	1.06 ab	17.42 cd	6.23 ab
$G_1T_2S_1$	1.06 ab	17.20 cd	5.96 b
$G_1T_2S_2$	1.06 ab	17.23 cd	6.20 ab
$G_1T_3S_1$	1.05 ab	18.08 bc	6.01 ab
$G_1T_3S_2$	1.10 a	21.95 ab	4.59 c
$G_1T_4S_1$	1.06 ab	16.52 cd	5.01 bc
$G_1T_4S_2$	1.11 a	22.92 a	4.81 c
$G_2T_1S_1$	0.79 c	14.20 e	7.22 a
$G_2T_1S_2$	1.05 ab	17.11 cd	5.08 bc
$G_2T_2S_1$	0.80 c	16.13 cd	5.14 bc
$G_2T_2S_2$	1.06 ab	15.85 cd	5.48 bc
$G_2T_3S_1$	1.06 ab	16.12 cd	5.20 bc
$G_2T_3S_2$	0.90 bc	16.40 d	5.85 bc
$G_2T_4S_1$	1.06 ab	16.87 cd	6.00 ab
$G_2T_4S_2$	1.04 ab	15.00 cd	5.73 b
CV (%)	10.99	12.52	6.81
LSD (0.05)	0.138	2.655	0.830
F-test	*	*	**
G × T	**	**	**
G × S	NS	*	NS
T × S	NS	NS	NS

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

Note: G_1 = Harvested at 90 days after planting (DAP) and G_2 = Harvested at 100 DAP

T_1 = 135 kg N ha^{-1} (at planting) + 135 kg N ha^{-1} (at first earthing up, 35 DAP), T_2 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 67.5 kg N ha^{-1} (at second earthing up, 50 DAP), T_3 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP and T_4 = 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP

S_1 = 60 cm X 20 cm and S_2 = 60 cm X 25 cm

*, ** indicate significant at 5 and 1% level of probability

NS=Non-significant

4.13 Starch

Starch content of potato tuber was found significant (Table-21 and Appendix IX) against growth duration. The highest starch (20.53 mg g^{-1} FW) of potato tuber was found from G_1 treatment and the lowest (17.56 mg g^{-1} FW) was in G_2. In respects of starch content of potato tuber a remarkable variation was noted (Table-22 and Appendix IX) against different time of nitrogen applications. The highest starch content (19.94 mg g^{-1} FW) of potato tuber was found from T_3 treatment followed by T_4 and the lowest (17.53 mg g^{-1} FW) was in T_1. In respects of starch content of potato tuber remarkable variation was noted (Table-23 and Appendix IX) against intra-row spacing. The highest starch content (19.98 mg g^{-1} FW) of potato tuber was found from S_2 treatment and the lowest (18.12 mg g^{-1} FW) was in S_1. Combindly, a significant variation was found (Table-24 and Appendix IX) among the treatment against starch content of potato tubers. The highest starch content (24.01 mg g^{-1} FW) of potato tuber was found from $G_1T_4S_2$ treatment combination which was statistically similar to $G_1T_3S_2$ (23.74 mg g^{-1} FW) and the lowest (13.21 mg g^{-1} FW) was in $G_2T_1S_1$.

4.14 Reducing sugar

In aspect of reducing sugar content of potato tuber was found significant (Table-21 and Appendix IX) against growth duration. The highest reducing sugar content (0.41 mg g^{-1} FW) of potato tuber was found from G_2 treatment and the lowest (0.34 mg g^{-1} FW) was in G_1. In respects of reducing sugar content of potato tuber a remarkable variation was noted (Table-22 and Appendix IX) against different time of nitrogen applications. The highest reducing sugar content (0.43 mg g^{-1} FW) of potato tuber was found from T_1 and the lowest (0.35 mg g^{-1} FW) was in T_4 which was statistically similar to T_3. In respects of reducing sugar content of potato tuber remarkable variation was noted (Table-23 and Appendix IX) against intra-row spacing. The highest reducing sugar content (0.39 mg g^{-1} FW) of potato tuber was found from S_1 treatment and the lowest (0.36 mg g^{-1} FW) was in S_2.

Combindly, a significant variation was found (Table-24 and Appendix IX) among the treatment against reducing sugar content of potato tubers. The highest reducing sugar content (0.58 mg g^{-1} FW) of potato tuber was found from $G_2T_1S_1$ treatment combination and the lowest (0.29 mg g^{-1} FW) was in $G_1T_4S_1$ which was statistically similar to $G_1T_3S_2$. At higher temperature during later part of March may increase the internal respiration of potato stored matter as starch due to that, at later crop duration the reducing sugar was greater by breaking the starch into more reducing sugars than that of earlier duration (Mahmud *et al*. 2009).

Table 21. Effect of growth duration on starch and reducing sugar of potato

Growth duration	**Starch (mg g^{-1} FW)**	**Reducing sugar (mg g^{-1} FW)**
G_1	20.53 a	0.34 b
G_2	17.56 b	0.41 a
CV (%)	0.60	3.19
LSD (0.05)	0.143	0.015
F-test	**	**

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

G_1 = Harvested at 90 days after planting (DAP) and G_2 = Harvested at 100 DAP

** indicates significant at 1% level of probability

Table 22. Effect of time of nitrogen application on starch and reducing sugar of potato

Time of nitrogen application	Starch (mg g^{-1} FW)	Reducing sugar (mg g^{-1} FW)
T_1	17.53 d	0.43 a
T_2	19.14 c	0.38 b
T_3	19.94 a	0.36 c
T_4	19.57 b	0.35 c
CV (%)	0.98	3.65
LSD (0.05)	0.165	0.012
F-test	**	**

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

T_1 = 135 kg N ha^{-1} (at planting) + 135 kg N ha^{-1} (at first earthing up, 35 DAP), T_2 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 67.5 kg N ha^{-1} (at second earthing up, 50 DAP), T_3 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP and T_4 = 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP

** indicates significant at 1% level of probability

Table 23. Effect of intra-row spacing on starch and reducing sugar of potato

Intra-row spacing	Starch (mg g^{-1} FW)	Reducing sugar (mg g^{-1} FW)
S_1	18.12 b	0.39 a
S_2	19.98 a	0.36 b
CV (%)	12.49	9.09
LSD (0.05)	1.456	0.021
F-test	**	**

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

S_1 = 60 cm X 20 cm and S_2 = 60 cm X 25 cm

** indicates significant at 1% level of probability

Table 24. Combined effect of growth duration, time of nitrogen application and intra-row spacing on starch and reducing sugar of potato

Combination	Starch (mg g^{-1} FW)	Reducing sugar (mg g^{-1} FW)
$G_1T_1S_1$	18.71 cd	0.41 b
$G_1T_1S_2$	19.08 cd	0.35 c
$G_1T_2S_1$	19.84 cd	0.36 c
$G_1T_2S_2$	20.10 cd	0.40 bc
$G_1T_3S_1$	20.58 bc	0.35 c
$G_1T_3S_2$	23.74 ab	0.29 e
$G_1T_4S_1$	18.18 cd	0.29 e
$G_1T_4S_2$	24.01 a	0.31 d
$G_2T_1S_1$	13.21 e	0.58 a
$G_2T_1S_2$	19.10 cd	0.37 bc
$G_2T_2S_1$	18.52 cd	0.37 bc
$G_2T_2S_2$	18.08 cd	0.38 bc
$G_2T_3S_1$	17.87 cd	0.38 bc
$G_2T_3S_2$	17.58 d	0.40 bc
$G_2T_4S_1$	18.00 cd	0.39 bc
$G_2T_4S_2$	18.10 cd	0.39 bc
CV (%)	12.49	9.09
LSD (0.05)	2.921	0.046
F-test	*	**
G × T	**	**
G × S	NS	NS
T × S	NS	**

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

Note: G_1 = Harvested at 90 days after planting (DAP) and G_2 = Harvested at 100 DAP

T_1 = 135 kg N ha^{-1} (at planting) + 135 kg N ha^{-1} (at first earthing up, 35 DAP), T_2 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 67.5 kg N ha^{-1} (at second earthing up, 50 DAP), T_3 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP and T_4 = 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP

S_1 = 60 cm X 20 cm and S_2 = 60 cm X 25 cm

*, ** indicate significant at 5 and 1% level of probability

NS=Non-significant

4.15 Correlation coefficient (r)

The uses of growth duration, time of nitrogen application and intra-row spacing 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, yield and quality traits. A negative relation ($r=-0.53^{NS}$) was exhibited between SPAD value of potato leaf and number of tuber hill^{-1} (Figure-1). A negative relation ($r=-0.74^{NS}$) 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=0.85**) was found between weight of tuber hill^{-1} and average weight of potato. In figure-4, there was present a positive and strong linear relation (r=0.86**) between average tuber weight and tuber yield (t ha^{-1}) of potato. A positive and strong linear relation (r=0.61*) was present between average tuber weight and specific gravity of potato (Figure-5). A positive and strong linear relation (r=0.65*) was present between leaf SPAD value and dry matter content of potato tuber (Figure-6). A positive linear relation (r=0.53*) was present between specific gravity and dry matter content of potato tuber (Figure-7). About 50 to 86 % of tuber yield of potato was depended on different yield contributing traits and all of these characters had significant contribution on tuber yield and quality could be increased by improving these yield attributes for the wellbeing of the farming community.

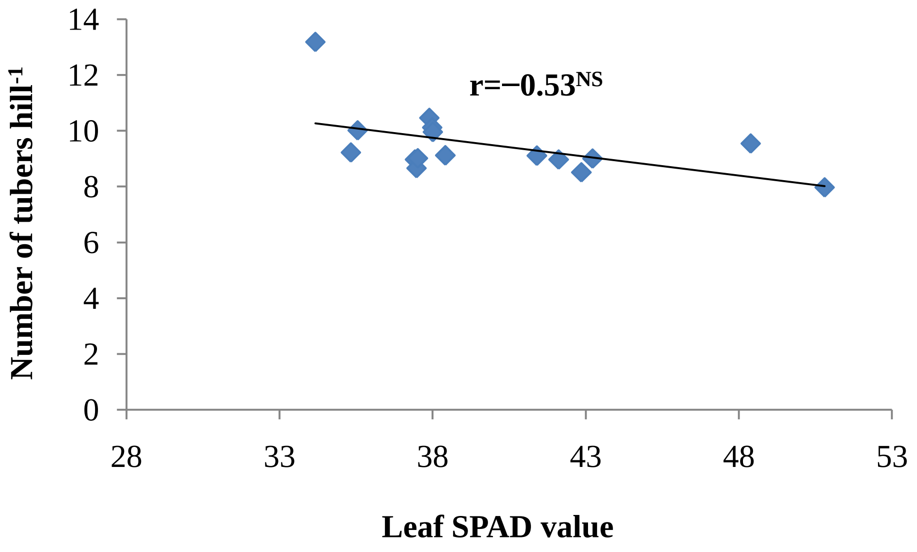

Figure 1. Relationship between SPAD value of leaf and number of tubers hill^{-1} of potato

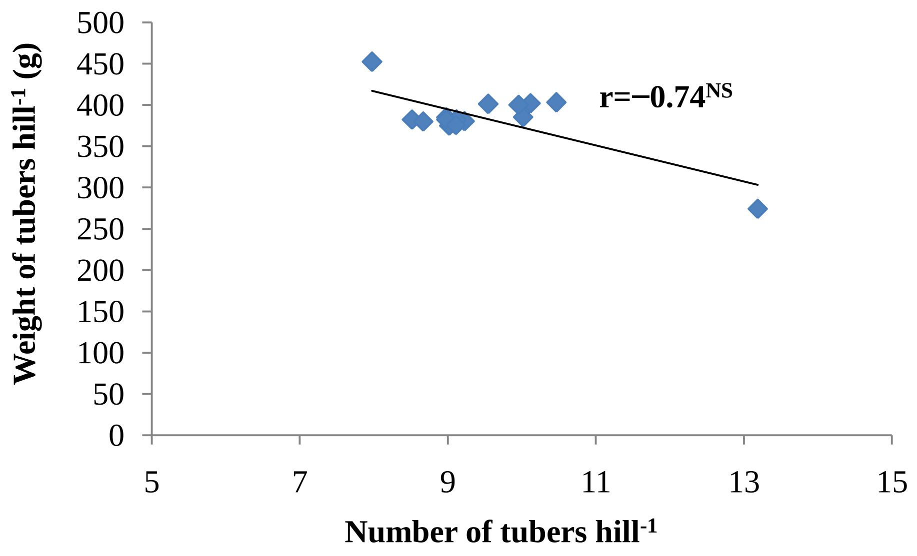

Figure 2. Relationship between number of tubers hill^{-1} and weight of tubers hill^{-1}(g) of potato

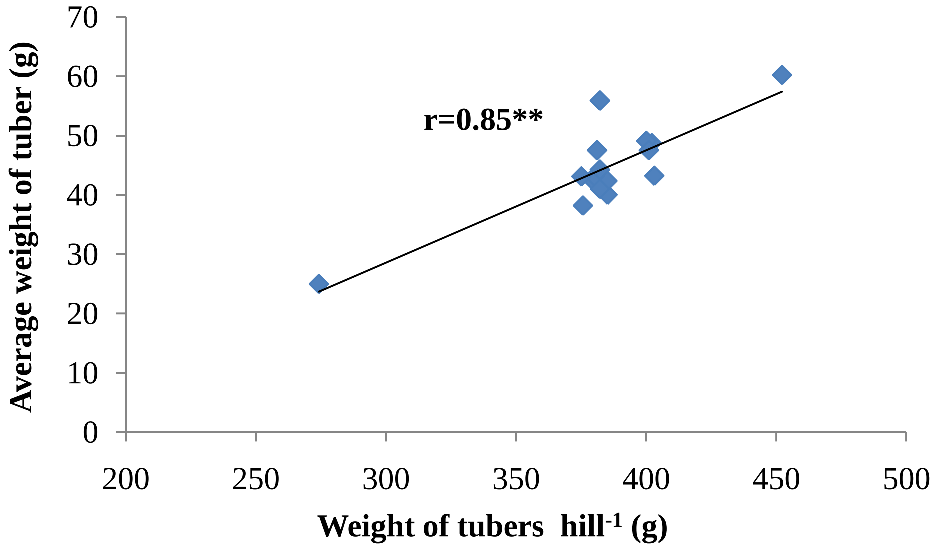

Figure 3. Relationship between weight (g) of tubers hill^{-1} and average tuber weight (g) of potato

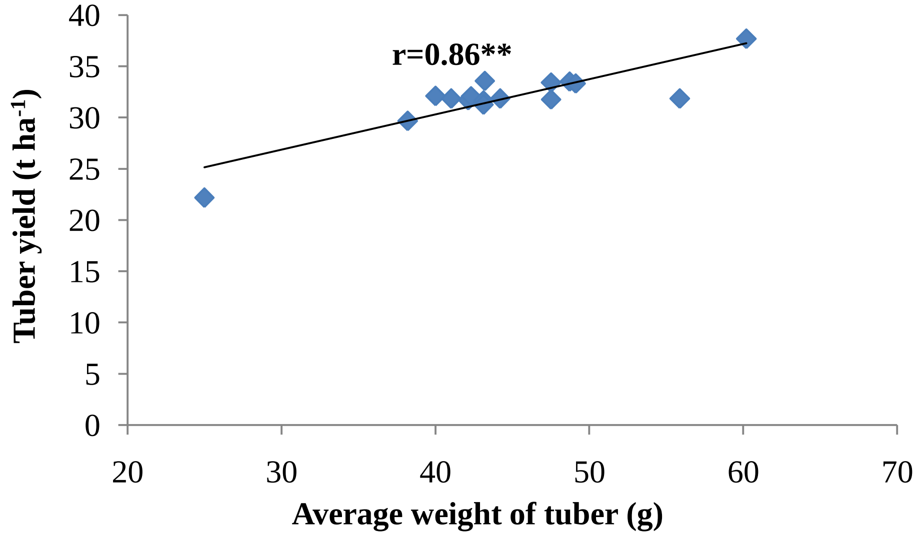

Figure 4. Relationship between average tuber weight (g) and tuber yield (t ha^{-1}) of potato

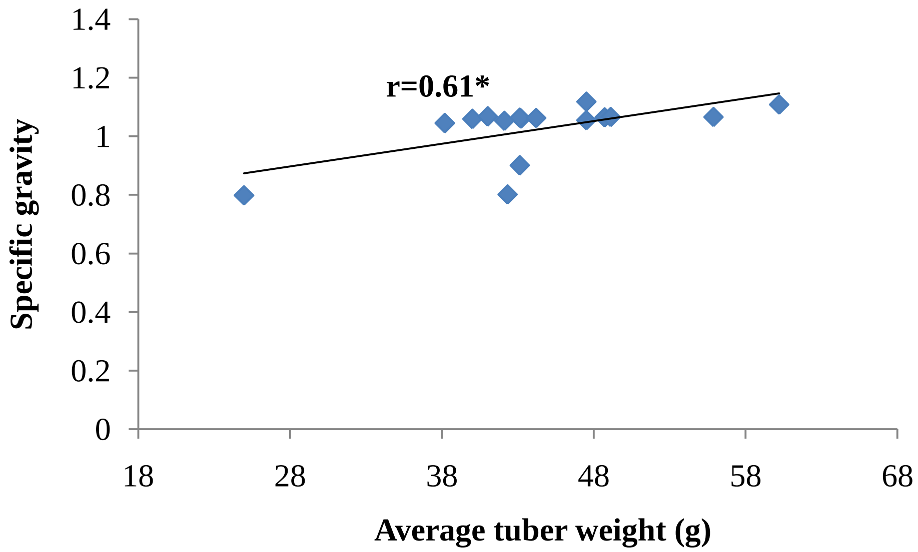

Figure 5. Relationship between average tuber weight (g) and specific gravity of potato tuber

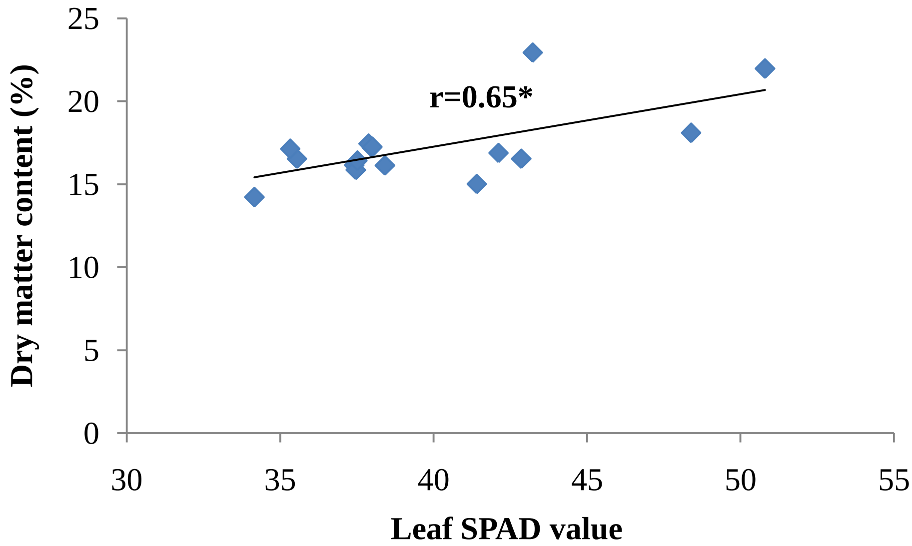

Figure 6. Relationship between leaf SPAD value and dry matter content (%) of potato tuber

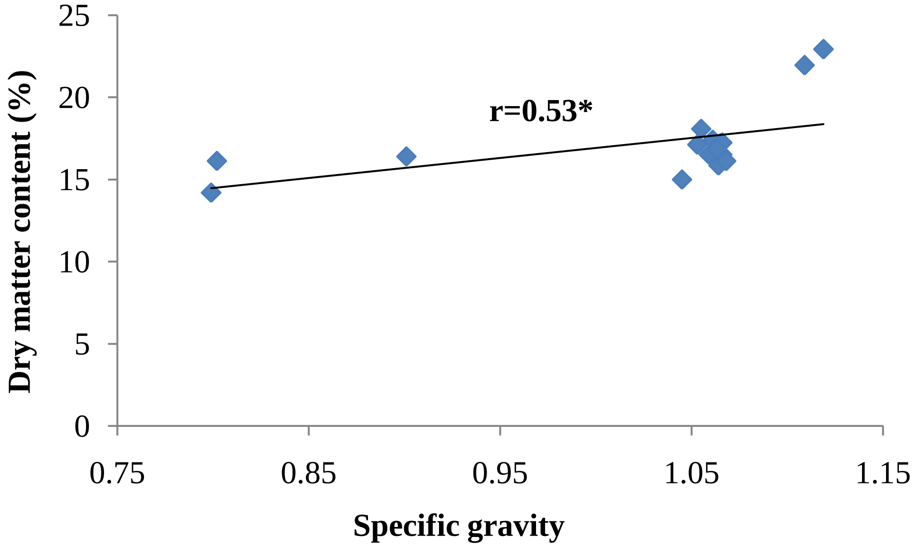

Figure 7. Relationship between specific gravity and dry matter content (%) of potato tuber

Chapter V

Summary and conclusion

CHAPTER V

SUMMARY 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 growth duration, time of nitrogen application and intra-row spacing on the productivity and processing quality of potato. “Asterix” was used as planting material under present study. The present experiment was comprised of three different factors as treatments namely, factor A: growth duration (G): G_1 = Harvested at 90 days after planting (DAP) and G_2 = Harvested at 100 DAP; factor B: time of nitrogen application (T): T_1 = 135 kg N ha^{-1} (at planting) + 135 kg N ha^{-1} (at first earthing up, 35 DAP), T_2 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 67.5 kg N ha^{-1} (at second earthing up, 50 DAP), T_3 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP and T_4 = 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP and factor C: intra-row spacing (S): S_1 = 60 cm X 20 cm and S_2 = 60 cm X 25 cm. The experiment was laid out in a 3 factors split-split-plot design with three replications, where the growth duration was assigned to main plots; time of nitrogen application to sub-plots and intra-row spacing to sub-sub-plots. The total numbers of unit plots were 48. The size of unit plot was 2.0 m × 1.5 m. The spacing was used under present study as per treatment. Uniform size (50-60 g) tubers were used for planting. Seed potatoes were planted at a depth of 5-6 cm on November 25, 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 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}, average weight of tuber, tuber yield. Data on quality traits such as specific gravity, dry matter content, total soluble solid, starch content, reducing sugar were taken and correlation coefficient (r) was calculated. Results demonstrated that, most of the parameters were significantly influenced by growth duration, time of nitrogen application and intra-row spacing studied under present experiment. In case of growth parameters growth duration had not showed any significant result. Plant length and SPAD value of leaf showed the significantly highest result under T_3 treatment and lowest was in T_1 whereas days to first tuber emergence, 100% tuber emergence and days to stolon initiation showed delay in their responses under T_1 treatment and earlier was in T_3. The intra-row spacing had performed a significant influence on growth parameters. In case combination, $G_2T_1S_1$ showed delay in their responses on days to first tuber emergence, 100% tuber emergence and days to stolon initiation and earlier was in $G_1T_3S_2$. Except, on plant length, days to stolon intitiation and SPAD value of leaf no significant variation was found among the treatment combinations. Yield traits such as, weight of tubers hill^{-1} (g), average tuber weight (g) and tuber yield (t ha^{-1}) showed the better result under earlier growth duration *i.e.*, 90 DAP than that of 100 DAP. The yield traits also highest result under T_3 treatment *i.e.*, 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP than that of T_1.

Wider intra-row spacing gave the better performance on most of the yield traits studied under present experiment than that of closer spacing. The highest (452.25 g) weight of tuber was found from $G_1T_4S_1$ treatment combination which was statistically similar to $G_1T_3S_2$ and the lowest (274.23 g) was in $G_2T_1S_1$ treatment combination. The highest (60.20 g) weight of tuber was found from $G_1T_4S_1$ treatment combination which was statistically similar to $G_1T_3S_2$ and the lowest (24.97 g) was in $G_2T_1S_1$ treatment combination. The highest (37.68 t ha^{-1}) tuber yield was found from $G_1T_3S_2$ treatment combination and the lowest (22.18 t ha^{-1}) was in $G_2T_1S_1$. But, in case of number of tubers $hill^{-1}$, the maximum (13.18) number of tuber was found from $G_2T_1S_1$ treatment and the minimum (7.97) was in $G_1T_3S_2$ which was statistically similar to $G_1T_4S_1$. Quality traits such as, specific gravity, dry matter content (%) and starch content of potato tuber (mg g^{-1} FW) showed better result under earlier growth duration *i.e.*, 90 DAP than that of later duration. But TSS and reducing sugar performed the highest under later duration of potato. The treatment, T_3 = 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP exhibited the best for specific gravity, dry matter content and starch content of potato tuber whereas treatment, T_1 = 135 kg N (at planting) + 135kg N (at first earthing up, 35 DAP) was the worst one.

But, TSS and reducing sugar showed the highest value under T_1 = 135 kg N (at planting) + 135 kg N (at first earthing up, 35 DAP) treatment. The wider intra-row spacing showed the better performance on dry matter and starch content of tuber. The highest (1.11) specific gravity of potato tuber was found from $G_1T_4S_2$ treatment combination which was statistically similar to $G_1T_3S_2$ (1.10) and the lowest (0.79) was in $G_2T_1S_1$. The highest (22.92 %) dry matter of potato tuber was found from $G_1T_4S_2$ treatment combination which was statistically similar to $G_1T_3S_2$ (21.95 %) and the lowest (14.20 %) was in $G_2T_1S_1$.

The highest (24.01 mg) starch content of potato tuber was found from $G_1T_4S_2$ treatment combination which was statistically similar to $G_1T_3S_2$ (23.74 mg) and the lowest (13.21 mg) was in $G_2T_1S_1$. The highest (7.22^o) TSS of potato tuber was found from G_2T_1S treatment combination and the lowest (4.59^o) was in $G_1T_3S_2$. The highest (0.58 mg g^{-1} FW) reducing sugar content of potato tuber was found from $G_2T_1S_1$ treatment combination and the lowest (0.29 mg g^{-1} FW) was in $G_1T_4S_1$ which was statistically similar to $G_1T_3S_2$. About 50 to 86% 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.

From the present study it may be concluded that, $G_1T_3S_2$ *i.e.*, 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) + 58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP, wider spacing (60 cm × 25 cm) in combination with early growth duration (at 90 DAP) is the best for improving the tuber yield of potato. On the other hand; although, $G_1T_4S_2$ *i.e.*, 126 kg N ha^{-1} (at planting) + 126 kg N ha^{-1} (at first earthing up, 35 DAP) + 18 kg N ha^{-1} as 2 foliar spray (2% urea) where first 9 kg N ha^{-1} applied at 50 DAP and second 9 kg N ha^{-1} applied at 60 DAP, wider spacing in combination earlier growth duration (90 DAP) showed the better performance on quality traits such as specific gravity, dry matter and starch content of potato tuber but, was statistically similar to $G_1T_3S_2$ *i.e.*, 135 kg N ha^{-1} (at planting) + 67.5 kg N ha^{-1} (at first earthing up, 35 DAP) +58.5 kg N ha^{-1} (at second earthing up, 50 DAP) + 9 kg N ha^{-1} as 1 foliar spray (2% urea) at 60 DAP, wider spacing (60 cm × 25 cm) in combination with early growth duration (at 90 DAP).

Recommendations

1. If, potato growers harvest the potato tuber at earlier time than that of their conventional non-conscious time of growth duration as found from the present study so that, it might be improved the yield and quality of potato tuber by increasing the skin hardening and tuber bulkening.

2. If, potato growers apply nitrogen as higher split application ha^{-1} than that of their conventional nitrogen application system it might be improved the yield and quality of potato tuber.

3. Usually the potato growers use recommended spacing *i.e.*, 50 cm × 25 cm or 60 cm × 10 cm on their crop field but, the higher spacing as 60 cm × 25 cm which was found best from present study might be improved the yield and quality of potato tuber.

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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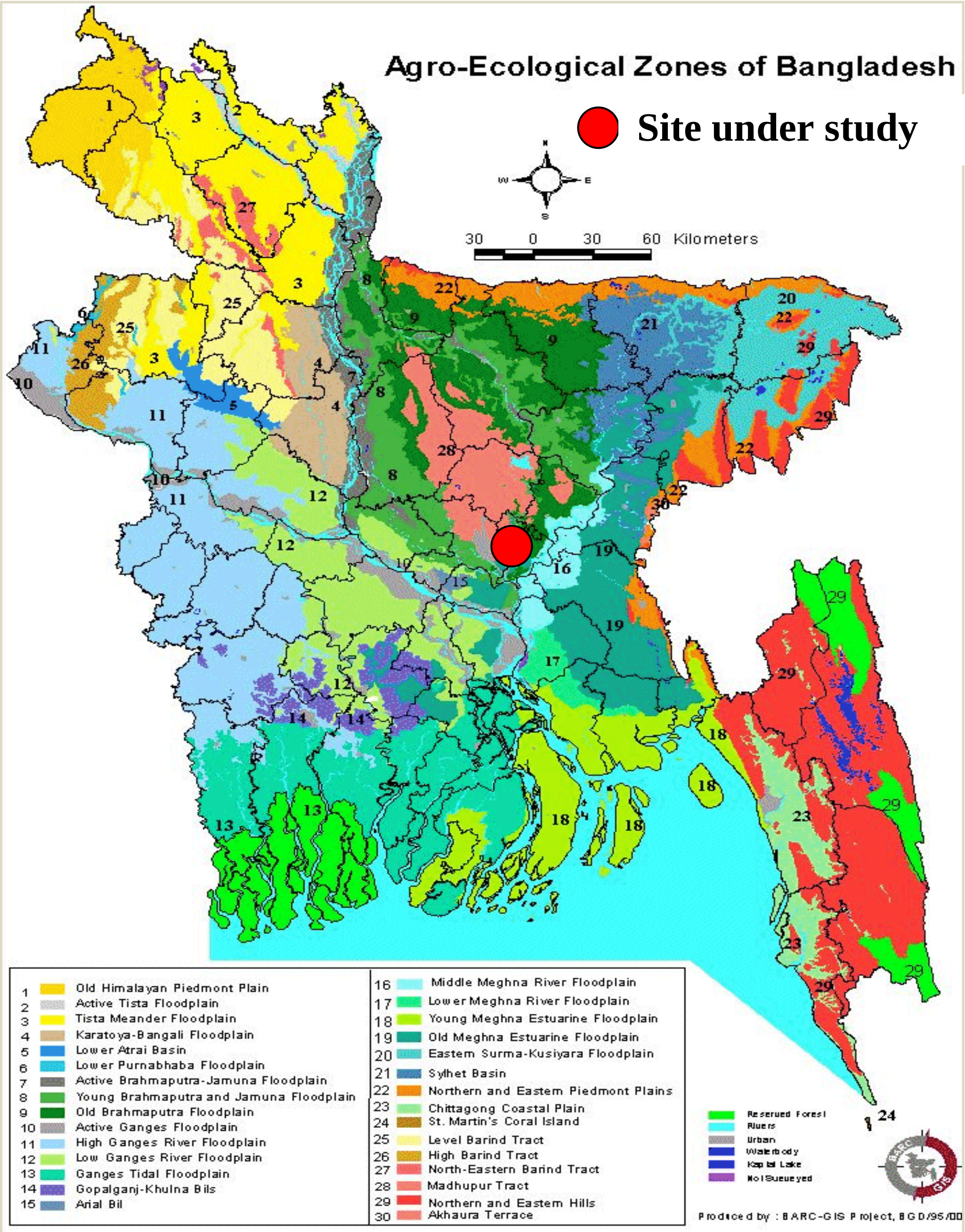
Appendices

APPENDICES

Appendix I. Map showing the site used for present study

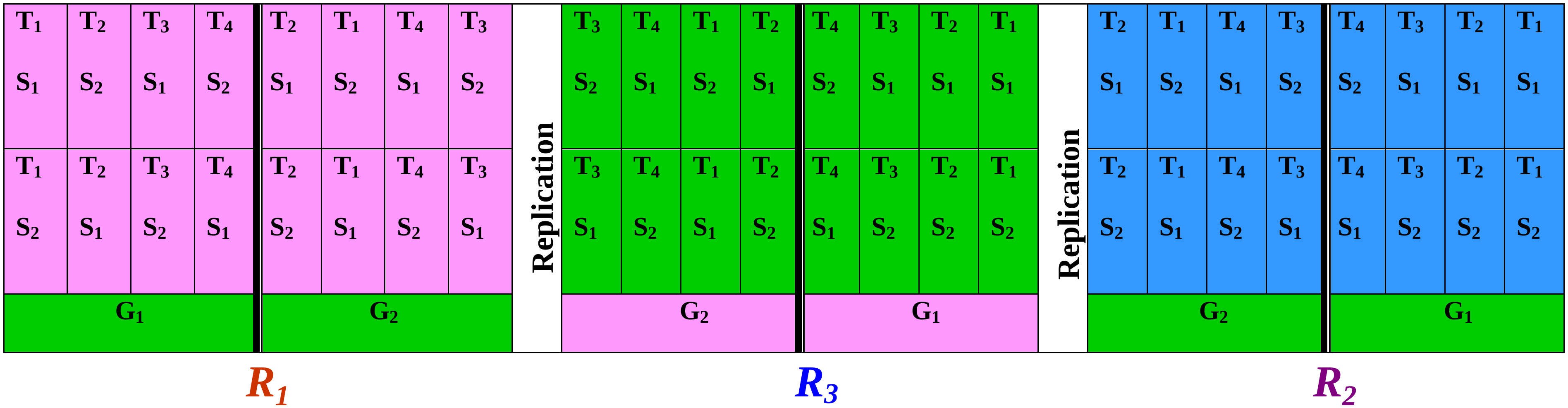


Appendix II. Monthly meteorological information during the period from November, 2015 to March, 2016

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



Length of plot: 2.0 m
Width of plot: 1.5 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: 2.0 m × 1.5 m (3.0 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)	2	0.13411	0.13411
Growth duration (G)	1	0.01470^{NS}	0.01470^{NS}
Error (A×G**)**	2	0.08170	0.08170
Time of nitrogen application (T)	3	8.08406**	8.08406**
G×T	3	6.80882^{NS}	6.80882^{NS}
Error (A× G×T**)**	12	0.11019	0.11019
Row spacing (S)	1	5.67188*	5.67188*
G×S	1	0.03968^{NS}	0.03967^{NS}
T×S	3	5.46710*	5.46710*
G×T×S	3	5.84523**	5.84523**
Error (A× G×T×S**)**	16	1.30390	1.30390
Total			

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

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

Source of variation	**df**	**Plant height at stolonization stage**	**Days to stolon initiation**
Replication (A)	2	0.471	0.0121
Growth duration (G)	1	335.492^{NS}	0.1365^{NS}
Error (A×G**)**	2	0.169	0.0094
Time of nitrogen application (T)	3	121.899**	70.9142**
G×T	3	55.250**	5.4921**
Error (A× G×T**)**	12	0.180	0.0622
Row spacing (S)	1	95.429*	44.4675*
G×S	1	0.187^{NS}	3.5643^{NS}
T×S	3	12.137^{NS}	48.0984*
G×T×S	3	17.326^{NS}	9.7065^{NS}
Error (A× G×T×S**)**	16	17.691	9.3946
Total			

*, ** indicate significant at 5 and 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)	2	17.607	0.00535
Growth duration (G)	1	178.641^{NS}	0.08417^{NS}
Error (A×G**)**	2	13.946	0.01013
Time of nitrogen application (T)	3	173.802**	8.81827**
G×T	3	81.501*	2.55082**
Error (A× G×T**)**	12	25.029	0.01013
Row spacing (S)	1	4.225^{NS}	4.74392*
G×S	1	5.755^{NS}	2.23172^{NS}
T×S	3	2.260^{NS}	2.34727^{NS}
G×T×S	3	1.470^{NS}	4.69637*
Error (A× G×T×S**)**	16	19.986	1.12119
Total			

*, ** indicate significant at 5 and 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)	2	5.7	0.09
Growth duration (G)	1	13902.6**	1001.10**
Error (A×G**)**	2	1.4	0.01
Time of nitrogen application (T)	3	3864.3**	261.73**
G×T	3	2495.5**	18.74**
Error (A× G×T**)**	12	4.3	0.13
Row spacing (S)	1	4407.6*	90.34*
G×S	1	87.0^{NS}	7.00^{NS}
T×S	3	2886.8*	180.06**
G×T×S	3	2772.0*	75.72**
Error (A× G×T×S**)**	16	912.6	12.41
Total			

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

Appendix VIII. Mean sum square values for yield specific gravity and dry matter content of potato tuber

Source of variation	df	Total yield	Specific gravity	Dry matter content
Replication (A)	2	0.196	0.00007	0.0717
Growth duration (G)	1	110.240**	0.12150**	76.2048**
Error (A×G**)**	2	0.337	0.00002	0.0518
Time of nitrogen application (T)	3	30.563**	0.01633**	9.6629**
G×T	3	14.430**	0.00600**	6.2545**
Error (A× G×T**)**	12	0.521	0.00007	0.0241
Row spacing (S)	1	24.604^{NS}	0.03647^{NS}	28.0908*
G×S	1	0.120^{NS}	0.00916^{NS}	19.3548*
T×S	3	24.846*	0.02502^{NS}	3.7169^{NS}
G×T×S	3	22.734*	0.04332*	14.9027*
Error (A× G×T×S**)**	16	6.314	0.01269	4.6497
Total				

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

Appendix IX. Mean sum square values for total soluble solid, starch and reducing sugar content of potato tuber

Source of variation	**df**	**TSS**	**Starch content**	**Reducing sugar content**
Replication (A)	2	0.01431	0.119	0.00034
Growth duration (G)	1	0.47601^{NS}	105.970**	0.04914**
Error (A×G**)**	2	0.28765	0.013	0.00015
Time of nitrogen application (T)	3	0.86558**	13.602**	0.01614**
G×T	3	1.54968**	3.894**	0.00612**
Error (A× G×T**)**	12	0.09337	0.035	0.00019
Row spacing (S)	1	0.65801*	41.552**	0.01286**
G×S	1	0.17041^{NS}	3.575^{NS}	0.00326^{NS}
T×S	3	0.43308^{NS}	6.824^{NS}	0.01375**
G×T×S	3	3.36738**	17.751*	0.00669**
Error (A× G×T×S**)**	16	0.14640	5.660	0.00120
Total				

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

Plate 1: Overall view of experimental plot

Plate 2: Supervisor visiting experimental plot

Plate 3: Weighing of potato tuber