ORIGINAL ARTICLE

Potato (*Solanum tuberosum* L.) growth, tuber yield and quality as influenced by blended NPS fertilizer and farmyard manure

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ABSTRACT

Potato is the most important vegetable crop next to Khat in eastern Ethiopia. However, its production is low mainly due to low inherent soil fertility and poor soil fertility management practices. Thus, field experiments were conducted to assess the effect of inorganic NPS fertilizer and farmyard manure on growth, tuber yield and quality of potato in eastern Ethiopia in 2018/19. Six rates of NPS fertilizer (0,100, 150, 200, 250 and 300 kg ha^{-1}) and three rates of FYM (0, 5 and 10 t ha^{-1}) in factorial combinations were evaluated in randomized complete block design with three replications. The results revealed that total number of tubers per hill, marketable and total tuber yields were significantly influenced by the interaction of blended NPS × farmyard manure and location. The combined application of 150 kg NPS with 5 t FYM and 200 kg with 10 t FYM ha^{-1} produced the highest total number of tubers per hill, marketable (28.1; 22.0 t ha^{-1}) and total tuber yields (35.7; 27.0 t ha-1) at Haramaya and Hirna, respectively. Higher dry matter content (24.8%), specific gravity (1.099 g cm^{-3}) and tuber starch content (17.54%) were recorded at 5 t FYM ha^{-1} application at Hirna. Partial budget analysis also affirmed that the combined application of 150 kg NPS with 5 t FYM and 200 kg with 10 t FYM ha^{-1} gave higher net benefit with higher marginal rate of return at Haramaya and Hirna, respectively. Therefore, it is concluded that the combined application of 150 kg NPS ha^{-1} with 5 t FYM and 200 kg NPS ha^{-1} with 10 t FYM ha^{-1} to Bubu potato variety are agronomically optimum and economically feasible fertilizer rates to get higher potato tuber yield at Haramaya and Hirna, respectively. Further, it is recommended to conduct on-farm demonstration trials to verify the results under farmers' field conditions to release technology.

Keywords: Bubu, Tuber dry matter, specific gravity, starch content

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the fundamental vegetable crops that greatly attributing to the world's food security (Karam et al., 2009). It covered nearly around 17,340, 986 hectares in the world (FAOSTAT, 2019). It is also an important food security crop in eastern Ethiopia in particular and in Ethiopia in general (Tewodros and Belay, 2015). In Ethiopia, about 70, 362 hectares covered by potato. However, the national as well eastern Ethiopia average yields of potato are by far lower than the world average yield (FAOSTAT, 2019). Different factors are responsible for low potato production in Ethiopia. Of these, poor agronomic management practices like inappropriate fertilizer application is one of the substantial reasons for decreasing potato production.

The poor soil fertility particularly deficient of nitrogen and phosphorus in most Ethiopian soil including eastern Ethiopia is one of the most important constraint that seriously affect the genetic yield potential of potato (Bezabih and Mengistu, 2011; Haverkort et al., 2012) due to removal of crop residues and animal dung by small scale farmers for fuel purpose. As a result, Ethiopian farmers have been applying these fertilizers for a long time in the form of di-ammonium phosphate (DAP) and urea as blanket recommendation still now without considering soil fertility status and crop requirement. The recent soil mapping report showed that sulfur is deficient in most Ethiopian soils besides to phosphorus and nitrogen (Tegbaru, 2015). Therefore, Ethiopian Ministry of Agriculture recommended and introduced new blended NPS fertilizer (19% N, 38% P_2O_5 and 7% S/100kg NPS) in place of DAP (MoANR, 2013). Sulfur is an essential element for plant growth and development. Previous findings showed that the application of 45 kg ha^{-1} sulfur in potato had a significant effect on tuber yield and tuber qualities (Sharma *et al*., 2011). A research conducted in north east Ethiopia showed that most growth parameters and yield related traits of potato were increased as NPS fertilizer rate increased from 0:0:0 to 55.5: 89.7:16.2 kg ha^{-1} (Mekides *et al*., 2020). However, the effect of sulfur containing NPS fertilizer on tuber quality of potato in eastern Ethiopia was not reported.

In addition, the combined effect of new blended NPS and farm yard manure on potato production has not studied so far in eastern Ethiopia. However, many researches had been done on integrated effect of NP and organic fertilizer on potato production in various Ethiopian corners. Tewodros and Belay (2015 reported that the integrated nutrient management is considered a panacea for maintenance of soil health, high productivity and profitability of the farms. Similarly, the integrated application of organic and inorganic fertilizers is crucially essential to restore soil fertility (Bekunda et al., 2010). The field experiments conducted in western Oromia and northern part of Ethiopia affirmed that the integrated application of organic and inorganic fertilizers increased total tuber number and tuber yield as compared to the separate applications of the two fertilizers (Bewket, 2019). Similarly, a research conducted in north east Ethiopia also showed that application of inorganic NPS and cattle manure increased growth and yield of potato (Masrie et al., 2015). Nevertheless, there is lack of information on the effect of integrated application of farmyard manure and blended NPS fertilizers on growth, tuber yield and tuber quality of potato in eastern Ethiopia. This research was, therefore, conducted to assess the effect of blended NPS fertilizer and farmyard manure on growth, tuber yield and quality of potato in eastern Ethiopia.

MATERIALS AND METHODS

Description of the study areas

The experiments were conducted during the year 2018 / 2019 main cropping season at Hirna and Haramaya University campus research stations. The test locations were selected on the basis of representativeness of the potato environments in East and West Hararghe which are the major potato growing areas of eastern Ethiopia. Hirna is located at 9°12′ North latitude, 41° 4′ East longitude, and at an altitude of 1870 m.a.s.l. The soil texture is sandy clay loamand received 1093.5 mm annual rainfall and its mean maximum and mean minimum temperatures were 26.88 and 11.91°C, respectively.

Haramaya University campus research farm is located at 9°42′32′′N latitude and 42°03′′85′E longitude 2002 m.a.s.l.. The soil is a well-drained deep alluvial with a sub-soil stratified with sandy loam and its total annual rainfall was 1171.2 mm and received the mean maximum and the mean minimum temperatures were 24.51 and 10.20°C, respectively (Tsegaye et al., 2018).

Treatments and experimental design

The treatments consisted of six NPS fertilizer levels (0, 100,150, 200, 250 and 300 kg ha^{-1}) and three farmyard manure (FYM) levels (0, 5 and 10 t ha^{-1}) and used Bubu potato variety as testing material. The experiment was laid out in a randomized complete block design with three replications at each location. Each treatment was assigned to one plot in each replication and six rows with 12 plants. The gross plot size was 16.2 m^2 with spacing of 75 cm between rows and 30 cm between plants, respectively. The spacing of 1.5 m and 1 m was maintained between plots and blocks, respectively. Data were not collected from the two rows at both end of each plot and the experimental plot size was 3 m x 3.6 m.

Experimental procedures

Experimental sites selection was carried out from March to April 2019. Then, the land was ploughed, disked and harrowed by a tractor. The soil samples were collected in diagonal soil sampling method from each field and made one composite sample per field before planting.. The spacing between rows (75 cm) was made by tractor and spacing between plants was done manually. The cattle manure was applied by opening the ridges and burying at the depth of 20 cm into the ridges a month before planting. Field leveling was done manually and inorganic NPS fertilizer was applied as per treatments before planting. The recommended rate of urea (100 kg ha^{-1}) was uniformly applied to all plots in split application at planting and after planting. Medium sized and well sprouted seed tubers of Bubu variety were planted at the sides of the ridges at the end of June. The planting depth was maintained at about 5 to 10 cm. Weeds was controlled by hoeing. Earthling-up was done as required to prevent exposure of tubers to direct sunlight and for promoting tuber bulking and for ease of harvesting.

Soil sample preparation and laboratory analysis

For each experiment, one composite soil sample was prepared from (collected from 0 to 20 cm depths using auger) sub-samples. The composite soil samples were labeled and transported to the laboratory in plastic bags for further processing and analysis and carried out as per standard. Soil pH was measured using a glass combination pH meter in the supernatant of 1:2.5 soil to solution ratio of H_2O and 1 N KCl. They are a measure of the intensity of soil acidity (in soil solution). OM (%) of the soils was determined following the wet digestion method as described by Walkley and Black (1934). Total N of the soil was determined through digestion, distillation and titration procedure of the Kjeldahl method as described by Jackson (1970). Available P content was measured after Bray (1945). Cation exchange capacity (CEC) was measured after leaching the ammonium acetate extracted soil samples with a 10% sodium chloride solution. The amount of ammonium ion in the percolate was determined by the Kjeldahl procedure and reported as CEC (Chapman, 1965).

Data collection and measurements

Growth parameter

Plant height was measured from ten randomly taken plants from the ground of the plant to the apex of the plant using a ruler from four central rows at flowering, and then their average was taken.

Tuber yield and yield components

Total number of tubers per hill: was recorded by counting the total number of tubers from five randomly taken hills per plot and then their average was recorded as total number of tubers per hill.

Marketable tuber yield (t ha^{-1}): the tubers that were sorted and counted from randomly selected plants as marketable were weighted and converted to marketable tuber yield in tons per hectare from the net plot (Zelalem *et al.,* 2009).

Total tuber yield (t ha^{-1}): was calculated as the sum of the weights of marketable and unmarketable tubers from the net plot area and converted to tone per hectare.

Tuber quality parameters

Tuber dry matter content (%): five fresh tubers were randomly selected from each net plot and weighed at harvest and sliced and dried in an oven at 65°C until a constant weight was obtained and dry matter (%) was calculated according to Williams (1968). Dry matter content for each sub-sample was calculated using the following formula (Bonierbale et al. 2006).

Tuber dry matter content (%) =

$$\frac{\text{Weight of sample after drying (g)}}{\text{Initial weight of sample (g)}} \times 100$$

Specific Gravity of Tubers (gcm-3): Tubers of all size categories weighing about five kilogram was randomly taken from each plot and washed with water. Following this step, the 30 sample was first weighed in air and then re-weighed suspended in water. Specific gravity was finally determined as described by Kleinkopf et al. (1987).

$$\text{Specific gravity (g cm}^{-3}\text{)} = \frac{\text{Weight of tubers in air}}{\text{Weight of tubers (in air -in water)}}$$

Tuber starch content (%): was calculated as starch content (%) =17.565 + 199.07 (specific gravity – 1.0988) (Von Scheele equations cited by Hassel et al. (1997).

Data analysis

All data were subjected to analysis of variances with statistical software of Genstat 17th ed. (VSN International, 2012). The F test was done to test homogeneity of error variances of locations'. The F test results showed the homogeneity of error variances for all data and data were subjected to pooled analysis of variances over locations. The mean effect of treatments were compared using the least significant difference (LSD) test at 0.05 probability level of mean separation methods (Gomez and Gomez, 1984).

Partial budget analysis

The economic analysis was done using the partial budget analysis described by CIMMYT (1988). The cost-benefit ratio was calculated by considering the sale of prices of potato at harvesting time (10 ETB/kg) and cost of fertilizers at sowing time (100kg NPS/ 1500.0ETB and 100kg farmyard manure /50.0 ETB) and their application costs per man-days (150.0 ETB/man-days). The mean marketable yield was adjusted by subtracting 10% to approach the real production under farmers' field condition. Then net benefit (NB) was calculated by subtracting total variable cost from gross benefit (GB) and marginal rate of return (MRR%) was also calculated by the change in net benefit/change in total variable cost (TVC) x 100. Thus, the treatment which was non-dominated and having a MRR of greater or equal to 50% with the highest net benefit was taken to be economically profitable.

Goss revenue = Price of potato × marketable tuber yield

Net Benefit= gross revenue – total variable costs

Total variable costs : cost of human labor, cost of seed, FYM, cost of NPS and FYM application.

RESULTS AND DISCUSSION

Soil physical and chemical properties before planting

The textural classes of the Haramaya and Hirna soil were sandy loam and sandy clay loam based on the soil textural triangle of the International Society of Soil Science (ISSS) system respectively, (Rowell, 1994).The pH of experimental sites (Haramaya and Hirna) were 8.39 and 7.95 which are moderately alkaline on the basis of pH limit (7.9 to 8.4) as described by Jones (2003). The available phosphorus at both locations was medium (Cottenie, 1980), but the total N at both locations was low (Tekaligh, 1991). The soil contents of organic matter at Haramaya and Hirna were moderate and high, respectively (Tekalign, 1991) whereas the cation exchange capacity at both locations was high according to Landon (1991) in Table 1.

Table 1. Selected physico-chemical properties of soil at Haramaya and Hirna in eastern Ethiopia during 2018/19 cropping season

	Location				
Physical parameter	**Haramaya**	**Rating**	**Hirna**	**Rating**	References
Sand (%)	63		12		
Silt (%)	19		39		
Clay (%)	18		49		
Textural class		Sandy loam		Sandy clay loam	
Chemical properties					
pH (1:2.5 soil/water)	8.39	Moderately alkaline	7.95	Moderately alkaline	Jones (2003)
Available P (ppm)	16.0	Medium	13.0	Medium	Cottenie (1980)
OM (%)	2.3	Moderate	4.6	High	Tekalign (1991)
Total N (%)	0.11	low	0.10	low	Tekalign (1991)
CEC(meq/100g soil)	39.33	High	37.67	High	Landon (1991)

Effect of blended NPS and farmyard manure on growth parameters of *Bubu* potato variety

Plant height

Plant height was highly ($P < 0.01$) affected by main effects of NPS fertilizer and location but significantly ($P < 0.05$) by farmyard manure. The variable was also highly ($P < 0.01$) influenced by the two way interactions of NPS fertilizer × farmyard manure and NPS fertilizer × location. However, interaction effects of farmyard manure × location as well as NPS fertilizer × farmyard manure and location had no significant effect on plant height (Table 2).

The tallest plant height (78.4 cm) within the treatments was obtained due to the combined application of 150 kg NPS ha^{-1} with 10 t FYM ha^{-1}, however, the height of these plants had non-significant difference with plants supplied with 150 kg ha^{-1} NPS and 5 and 10 t ha^{-1} FYM, 250 kg ha^{-1} NPS and 0, 5 and 10t ha^{-1} FYM, and 300 kg ha^{-1} NPS and 0 and 10 t ha^{-1} FYM (Table 3). The application of 150 kg ha^{-1} NPS with 10 t ha^{-1} FYM increased the plant height of potato variety by 29.8% over control treatment (without fertilizer application). The application of NPS fertilizer alone at higher rates (above 100 kg ha^{-1} NPS) or in combination of FYM tends to increase the plant height of the potato variety though the inconstancy results from application of 200 kg ha^{-1} NPS with all rates of FYM was observed. This could be due to the higher rates N were supplied from higher rates of NPS and FYM fertilizers which is very important for vegetative growth and higher rates of P fertilizer obtained from both fertilizers were also an important primary nutrient for root growth and its extension resulted in the tallest plant height. Besides, it could be due to the improved physical, chemical, and biological properties of the soil that ultimately increased water absorption and nutrient utilization and thus plant heights.

Table 2. Mean squares of combined analyses of variances for growth, tuber yield and tuber quality parameters of *Bubu* potato variety at Haramaya and Hirna in 2018/2019 cropping season

Source of variation	DF	PH (cm)	TTNPH	MTY (t ha^{-1})	TTY (t ha^{-1})	DM (%)	SG (gcm^{-3})	TSC (%)
Replication	2	49.5	0.16	1.47	2	0.8	0.00002	0.6292
Location (L)	1	1981.0**	29.25**	826.7**	1243.7**	11.6**	0.00024**	9.6593**
NPS (kg ha^{-1})	5	370.6**	11.87**	44.3**	54.8**	2.8**	0.00006**	2.3608**
FYM (t ha^{-1})	2	139.5*	2.78NS	39.0 **	57.3**	0.8NS	0.00002NS	0.6634NS
NPS x FYM	10	223.8**	16.25**	45.7**	49..9**	0.9NS	0.00002NS	0.7231NS
NPS x L	5	210.9**	5.82*	49.5**	62.5**	1.0NS	0.00002NS	0.8112NS
FYM x L	2	5.7 NS	8.64*	2.9NS	5.3NS	3.6*	0.00008*	2.9850*
NPS x FYM x L	10	39.9 NS	8.65**	44.6**	44.9**	0.8NS	0.00002NS	0.7009NS
Error	70	41.4	2.26	4.9	5.5	0.8	0.00002	0.6913
CV (%)		9.4	12.6	11.4	9.6	3.8	0.4	4.9

NS, * and **, non significant, significant at P < 0.05 and P < 0.01, respectively. FYM (t ha-^{1})= Farmyard Manure, NPS (kg ha-^{1})= Blended inorganic fertilizer (19% of N, 38% of P2O5 and 7% of S)/100 kg, DF= Degree of Freedom, PH (cm) = Plant Height, TTNPH = Total Tubers Number per Hill, TTY (t ha-^{1}) = Total Tuber Yield tons per Hectare, DM (%)= Tuber Dry Matter, SG (gcm-3)= Tuber Specific Gravity, TSC (%) = Tuber Starch Content and CV (%) = Coefficient of Variation

This result is in line with Alemayehu et al. (2020) who reported that application of 245.1 kg ha^{-1} NPS with 13.5 t ha^{-1} FYM to potato increased plant height by 70% over unfertilized plots. Other findings conducted in eastern Hararghe showed that plant height of potato was increased in response to the increased application rate of N and P fertilizers (Firew et al., 2016). Simon (2019) observed that the maximum plant height (81.6 cm) of potato due to the combined application of 7.5 t ha-^{1} FYM and mineral NP fertilizers (110 kg N ha-^{1} and 90 kg P ha-^{1}). It was also reported that plant height was significantly affected by combined application of NPSZnB and cattle manure (Bewket, 2019). Plant height was increased with the increased use of combined application of organic and inorganic fertilizers (Mama et al., 2016).

Significant variation of plant heights were observed due to interaction effect of NPS fertilizer and location. The tallest plant height was observed at Hirna with the application of 300 kg ha^{-1} NPS fertilizer, but the height of plants had non-significant differences which supplied with 150 and 250 kg ha^{-1} NPS fertilizer at same location. The potato variety had shortest plant height at plot which did not supply fertilizer at both locations. The potato variety had taller plants at Hirna than Haramaya location at all rates of NPS fertilizer (Table 3).This could be due to Hirna had favorable soil and weather conditions and positively interacted with application of higher rates of NPS fertilizer than Haramaya. The effect of location on plant height of potato varieties was aso reported (Tessema et al., 2020). The tallest plant height of potato varieties at favorable location with the application of higher rates of N and P nutrients was also reported (Zelalem et al., 2009; Firew et al., 2016).

Table 3. Interaction effects of farm yard manure and NPS fertilizers and NPS x location on plant height of *Bubu* potato variety at Haramaya and Hirna in eastern Ethiopia during 2018/19 cropping season

Fertilizer	NPS (kg ha^{-1})					
FYM (t ha^{-1})	0	100	150	200	250	300
0	55.0^{f}	67.7^{cde}	60.9^{ef}	63.9^{de}	75.2^{ab}	77.7^{a}
5	61.7^{ef}	65.7^{cde}	76.5^{ab}	69.5^{bcd}	71.5^{abc}	65.1^{cde}
10	69.6^{bcd}	64.2^{cde}	78.4^{a}	64.4^{cde}	71.4^{abc}	75.9^{ab}
LSD (5%)				7.4		
Location						
Haramaya	59.4^{e}	63.6^{de}	66.9^{cd}	63.6^{de}	67.7^{cd}	64.7^{de}
Hirna	60.7^{e}	72.4^{bc}	76.9^{ab}	68.2^{cd}	77.8^{ab}	81.2^{a}
LSD (5%)				6		

Mean values followed by the same letter(s) in each interaction effect had non-significant difference at P < 5% probability level. LSD (5%) = Least Significant Difference at P < 5 % probability level.

Effect of blended NPS and farmyard manure on potato tuber yield and yield related traits

Total number of tubers per hill

Total number of tubers per hill was highly ($P < 0.01$) influenced by main effects of NPS fertilizer and location but it was not affected by main effect of farmyard manure. On the other hand, two –ways interactions of NPS fertilizer × farmyard manure had a high (0.01) and NPS fertilizer × location as well as farmyard manure × location significant ($P < 0.05$) effects on total number of tubers per hill. Besides, it was also highly ($P < 0.01$) influenced by three – way interaction of NPS fertilizer × farmyard manure and location (Table 2).

Table 4. Interaction effects of farmyard manure x NPS x location on total number of tubers per hill for *Bubu* potato variety at Haramaya and Hirna during 2018/19 cropping season

	Fertilizer	NPS (kg ha-1)					
Location	FYM (t ha-1)	0	100	150	200	250	300
Haramaya	0	12.7^{a-i}	11.8^{f-m}	11.1^{g-n}	10.0^{j-n}	14.3^{a-d}	11.5^{f-n}
	5	11.0^{g-n}	10.8^{h-n}	15.6^{a}	13.6^{a-f}	12.3^{b-j}	13.3^{a-g}
	10	13.3^{a-g}	9.4^{m-o}	14.4^{a-d}	14.3^{a-d}	9.3^{no}	14.3^{a-d}
Hirna	0	7.0^{o}	11.8^{f-m}	11.1^{g-n}	10.1^{j-n}	9.8^{k-n}	12.0^{d-k}
	5	10.4^{i-n}	10.4^{i-n}	11.5^{f-n}	13.1^{a-h}	14.4^{a-d}	12.9^{a-h}
	10	10.0^{j-n}	9.5^{l-n}	12.2^{c-k}	15.0^{ab}	11.9^{e-l}	11.8^{f-m}
LSD (5%)					2.4		

Mean values followed by the same letter(s) in rows and columns had non-significant difference at P < 5% probability level. LSD (5%) = Least significant Difference at P < 5% probability level.

The maximum total number of tubers per hill was obtained (15.6) at Haramaya from the combined application of 150 kg NPS ha^{-1} with 5 t farmyard manure ha^{-1} to *Bubu* potato variety and nearly followed (15.0) by the application of 200 kg NPS ha^{-1} with 10 t FYM at Hirna. However, it was at par with the application of 150, 200, 300 kg NPS ha^{-1} with 10 t FYM ha^{-1} as well as 250 kg NPS ha^{-1} and 0 t FYM ha^{-1} (no farmyard manure) at Haramaya and 250 kg NPS ha^{-1} with 5 t FYM ha^{-1} at Hirna. The lowest total numbers of tubers per hill were recorded from unfertilized plot at both locations (Table 4). Obtaining the highest total number of tubers at 150 kg NPS with 5 as well as 200 kg NPS and 10 t FYM ha^{-1} could be due to the presence of adequate growth resources that may contribute to produce more main stems, more leaves and undertake more photosynthesis, then ample organic food (carbohydrates) that is manufactured by green leaves go to the sink or tuber in turn to produce more tuber number per hill. This is in accordance with Ababiya (2018) reported that significantly higher total number of tubers per hill was found from the combined application of 100 kg NPS ha^{-1}+ 30 t cattle manure. Other findings also affirmed that total number of tubers per hill was increased with FYM and NP (Mohammed et al., 2018; Simon, 2019).

Marketable tuber yield

The main effects of NPS fertilizer, farmyard manure and location had a high ($P < 0.01$) significant effect on marketable tuber yield. Similarly, marketable tuber yield was highly ($P < 0.01$) influenced by two-interactions of NPS fertilizer × farmyard manure and NPS fertilizer × location but the interaction of farmyard manure and location had no significant effect on marketable tuber yield. However, the variable was also highly ($P < 0.01$) affected by three-way interaction of NPS fertilizer × farmyard manure and location (Table 2). The mean values of marketable tuber yield showed that the highest marketable tuber yield (28.3 t ha^{-1}) was found where plots treated with 150 kg NPS with 5 t farm yard manure at Haramaya where as the smallest marketable tuber yield (12.0 t ha^{-1}) was obtained from the control at Hirna. Integrated application of 150 kg NPS with 5 t FYM ha^{-1} was produced 51.6% more marketable tuber yield over control at Haramaya (Table 5). On the other hand, the combined application of 200 NPS kg and 10 t FYM ha^{-1} to Hirna soil was increased marketable tuber yield by 45.5% over control. This indicated that the application of both fertilizers is indispensable for maximizing potato production in both locations. Because plant roots get adequate nutrients from both fertilizers that are essential to produce more green leaves to synthesis ample carbohydrates that may attribute to produce more marketable tuber yield. Likewise, organic fertilizers are important to increase water holding capacity of the soil, increase soil fertility, and increase microbes activity. In general, higher marketable tuber yield was produced from Haramaya as compared to Hirna, this is probably due to the presence of good aeration and drainage system at Haramaya due to its soil texture as compared to Hirna.

Table 5. Marketable and total tuber yields *Bubu* potato variety as affected by the interaction effect of NPS × FYM and location

Treatment		MTY (t ha-1)		TTY (t ha-1)	
FYM (t ha-1)	NPS (kg ha-1)	Haramaya	Hirna	Haramaya	Hirna
0	0	13.7^{m-o}	12.0^{o}	19.5^{n-p}	15.2^{q}
	100	23.3^{b-e}	17.9^{g-k}	27.6^{d-g}	21.7^{k-o}
	150	21.0^{d-g}	12.8^{no}	27.5^{d-g}	16.2^{pq}
	200	16.4^{h-n}	19.7^{f-h}	23.6^{h-m}	23.3^{h-m}
	250	23.6^{b-d}	14.3^{k-o}	31.5^{bc}	19.1^{n-p}
	300	24.5^{a-c}	18.0^{g-j}	28.9^{c-g}	21.2^{m-o}
5	0	22.2^{c-f}	14.8^{j-o}	27.0^{e-h}	18.2^{o-q}
	100	16.4^{h-n}	18.1^{g-j}	20.4^{m-o}	23.6^{h-m}
	150	28.3^{a}	12.7^{o}	35.7^{a}	18.0^{o-q}
	200	26.4^{ab}	19.8^{f-h}	30.7^{b-e}	24.5^{f-h}
	250	26.9^{ab}	20.8^{c-f}	32.0^{bc}	26.2^{f-i}
	300	25.5^{a-c}	16.8^{h-m}	30.5^{b-f}	22.3^{j-n}
10	0	23.3^{b-d}	15.4^{i-o}	29.6^{c-g}	19.0^{n-p}
	100	17.8^{g-l}	14.2^{l-o}	21.5^{m-o}	18.4^{o-q}
	150	19.7^{e-h}	19.2^{f-h}	26.8^{f-i}	23.3^{h-m}
	200	18.8^{f-i}	22.0^{c-f}	25.9^{g-j}	27.0^{e-h}
	250	18.7^{f-i}	17.1^{h-m}	23.0^{i-m}	21.6^{m-o}
	300	24.5^{a-c}	17.5^{g-l}	33.8^{ab}	23.2^{h-m}
LSD (5%)		3.6		3.8	

Mean values followed by the same letter(s) in each interaction effect had non significant difference at P < 5% probability level. MTY = Marketable Tuber Yield, TTY = Total Tuber Yield, LSD (5%) = Least Significant Difference at P < 5% probability level.

The result was in line with Bewket (2019) who reported that the highest marketable yield (31.7 t ha-1) was combined from the application of blended 199 kg ha-1 NPSZnB with 30 t ha-1 cattle manure. Additionally, Zelalem *et al*. (2009) also reported that N and P fertilization significantly influenced the productivity of potato measured in terms of marketable and total tuber yields. Firew (2016) and Israel *et al*. (2012) also reported that total tuber yield was highly significantly influenced by nitrogen and phosphorus.

Total tuber yield

Total tuber yield was highly (P < 0.01) influenced by main effects of NPS fertilizer, farmyard manure and location. Similarly, it was also highly (P < 0.01) affected by two – ways interactions of NPS fertilizer × farmyard manure and NPS fertilizer × location, but interaction of farmyard manure × location had no a significant effect on total tuber yield. The variable was highly (P < 0.01) influenced by the three-way interactions of NPS fertilizer ×farmyard manure and location (Table 2). The combined application of 150 kg NPS and 5 t FYM ha-1 to *Bubu* potato variety was produced the maximum total tuber yield (37.1 ha-1) at Haramaya but it was statistically the same with plants provided with the highest combination rates (300 kg NPS ha-1with 10 t FYM ha-1) at the same site (Table 5). Therefore, total tuber yield increased from 19.5 to 37.1 t ha-1 as NPS and FYM increased from (0+0) to 150 kg + 5 t ha-1 at Haramaya. The highest total tuber yield at 150 kg NPS with 5 t FYM ha-1 could be due to the result of the highest total tuber number per hill at 150 kg NPS and 5 t FYMha-1. Besides, possibly this combination had a positive synergetic effect to provide ample nutrients to the plant that could be attributed to produce maximize total tuber number per hill and total tuber yield. On the other hand, the application of 200 kg NPS with 10 t FYM increased the total tuber yield by 44.9% over control at Hirna.

This result is in accordance with Ababiya (2018) who reported that optimum total tuber yield was obtained from the combined application of 150 kg ha-1 NPS blended fertilizer and 20- 30 t ha-1. Bekele (2018) also affirmed that combined application of 199 kg ha-1 blended NPSZnB fertilizer and 30 t ha-1 cattle manure gave the highest total tuber yield (34.1 t ha-1). The highest total tuber yield (36.8 t ha-1) was obtained in response to the application of 150 kg N + 20 t cattle manure ha-1 (Najm et al., 2013). Other scholars like Balemi (2012), Darzi et al. (2012) and Masire (2015) also stated that total tuber yield was significantly influenced by the cattle manure + NP fertilizers. On the other hand, among treatments at Hirna, it was found that the application of 250 kg NPS and 5 t FYM ha-1 gave higher total tuber yield (27.4 t ha-1) but it was less than by 26% as compared to Haramaya. This total tuber yield was not statistically varied from the application of 0NPS kg and 0, 5 FYM ha-1, 100, 200 kg NPSha-1 and 0 FYM ha-1, 150, 200 kg NPS ha-1 and 10 t FYM ha-1 at Haramaya.

Plants which did not receive both organic and inorganic fertilizers gave the lowest total tuber yield (15.1 t ha-1) at Hirna compared to Haramaya. Similarly, Canali et al. (2010) reported that the application of FYM substantially increased the total potato yield by 25% as compared to control. Therefore, an optimum integrated application of organic and inorganic fertilizers is important to balancethe ration of C/N which is resulted in more organic matter build-up, enhanced microbial activity, improvement in soil properties, better root proliferation, sustainable availability and accelerated transport and a higher concentration of plant nutrients to produce more total tuber yield. Overall, it was observed that *Bubu* potato variety gave higher tuber yield at Haramaya compared to Hirna, this variation could be emanated from varied soil textures and weather conditions between two locations.

Effect of inorganic NPS and farmyard Manure on Tuber Quality Traits

Tuber dry matter content, tuber specific gravity and tuber starch content were highly ($P < 0.01$) affected by main effects of NPS fertilizer and location, but main effect of farmyard manure had no a significant effect on these traits. Similarly, two ways interactions of NPS fertilizer × farmyard manure and NPS fertilizer with location as well as three-ways interactions of NPS fertilizer × farmyard manure and location were non-significant. However, the variables were significantly ($P < 0.01$) influenced by the two- way interaction of farmyard manure with location (Table 2).

The highest tuber dry matter content (24.53%), tuber specific gravity (1.097g cm-3) and tuber starch content (17.30%) were obtained where plots treated with 200 kg NPS fertilizer ha-1 while the lowest tuber quality related parameters were found at unfertilized plots (controls). There was no statistical discrepancy of tuber dry matter content due to the application of 0,150 and 250 kg NPS fertilizer ha-1 as well as application of 100, 200 and 250 kg NPS fertilizer ha-1. Similarly, linear increment of starch content was not detected as NPS increased from 0 to 300 kg ha-1. This result was in accordance with Zelalem et al. (2009) and Israel et al. (2012) who reported that high nitrogen level and phosphorus reduces the dry matter content of potato tubers. Both specific gravity and tuber starch content were linearly increased from 1.092 to 1.097 (g cm-3) and 16.26 to 17.30 (%) as inorganic fertilizer (NPS) rate increased from 0 to 200 kg ha-1, respectively. However, specific gravity and tuber starch content tends to slightly reduced from 1.097 to 1.095(g cm-3) and 17.30 to 16.79 (%) when NPS fertilizer rate increased from 200 to 300 kg ha-1, respectively (Table 6). The results were in line with Bewket (2019) who stated that both specific gravity and tuber starch content were reduced as blended NPSZnB increased. The reduction of tuber specific gravity and tuber starch content at high fertilizer; particularly nitrogen could be reducing the dry matter of tuber and increase the water content of tuber. Therefore, the application of 200kg NPS ha-1 to potato variety is an optimum inorganic fertilizer rate to produce higher tuber dry matter content, specific gravity and tuber starch content because it could be enhanced chlorophyll concentration, the photosynthetic rates, the leaf expansion, the total number of leaves, and the dry matter accumulation (Najm et al., 2010). Higher tuber dry matter content, specific gravity and tuber starch content were attained at Hirna as compared to Haramaya (Table 6).

Table 6. Effects of NPS on tuber quality related traits of *Bubu* potato variety at Haramaya and Hirna in eastern Ethiopia during 2018/19 cropping season

NPS (kg ha-1)	DM (%)	SG (g cm-3)	STC (%)
0	23.39c	1.092c	16.26c
100	24.16ab	1.094bc	16.55bc
150	23.7bc	1.096ab	16.96ab
200	24.53a	1.097a	17.30a
250	23.97abc	1.096ab	16.98ab
300	24.18ab	1.095abc	16.79abc
LSD (5%)	0.61	0.003	0.55

Mean values followed by the same letter(s) in each main factor effect had nonsignificant difference at $P < 5\%$ probability level. TDM (%) = Tuber Dry Matter, SG (gcm-3) = Tuber Specific Gravity, STC (%) = Tuber Starch Content, LSD (5%) = Least Significant Difference at $P < 5\%$ probability level.

Significant differences of tuber dry matter content, tuber specific gravity and tuber starch content were observed due to interaction effect of farmyard manure with location. The maximum tuber dry matter content (24.8%) was obtained where plots received with 5 t farmyard manure ha-1 at Hirna but it was at par with the application of 10 t FYM ha-1 at the same site. It was observed that tuber dry matter content was increased by 3.6 and 1.6% as FYM increased from 0 to 5 and 0 to 10 t ha-1, respectively at Hirna, this showed that the application of FYM beyond 5 t ha-1 is not economical (Table 7). Similar trends were also observed at Haramaya. The highest application of organic fertilizer (FYM) (10 t ha-1) rate gave the lowest tuber dry matter content (23.4%) at Haramaya as compared to Hirna.

Similarly, Mohammed et al. (2018) reported that individual application of farmyard manure had a significant effect on tuber dry matter. Other scholars also found that the higher tuber starch and dry mater contents were produced in potato grown without FYM (Baniumiene and Zekaite, 2008). When compared to two locations, higher tuber dry matter content was recorded at Hirna.

The application of 5 t farmyard manure ha^{-1} to *Bubu* potato variety at Hirna was given the highest tuber specific gravity (1.099 g cm^{-3}) and tuber starch content (17.54%) whereas the minimum values of these traits were found from unfertilized plots (controls) at Haramaya. The specific gravity and tuber starch content at Haramaya showed small increments (1.092 to 1.094g $cm^{-3}$and 16.29 to 16.64 %) when FYM increased from 0 to 5t ha^{-1}, then kept constant and slightly declined, respectively. Similarly, in the second location (Hirna) both specific gravity and tuber starch content were increased by 0.30 and 4.67 % as FYM increased from 0 to 5 t FYM ha^{-1} and then declined by 0.27 and 2.8 % when FYM increased from 5 to 10 t FYM ha^{-1}, respectively. Overall, it was found that higher tuber dry matter content, specific gravity and tuber starch content were recorded from 5 t FYM ha^{-1} applications at both locations and good tuber quality parameters were obtained at Hirna compared to Haramaya (Table 7). Similarly, the previous findings confirmed that potato quality related traits were highly influenced by growing environments (Tesfaye et al., 2013; Berhanu and Tewodros, 2016; Tessema et al., 2020).

Table 7. Interaction effect of farm yard manure and location on tuber quality related traits of *Bubu* potato variety at Haramaya and Hirna in eastern Ethiopia during 2018/19 cropping season

	Tuber dry mater (%)		Specific gravity (g cm^{-3})		Starch content (%)	
FYM (t ha^{-1})	Haramaya	Hirna	Haramaya	Hirna	Haramaya	Hirna
0	23.8^{bc}	23.9^{bc}	1.092^{c}	1.095^{bc}	16.29^{c}	16.72^{bc}
5	23.8^{bc}	24.8^{a}	1.094^{bc}	1.099^{a}	16.64^{bc}	17.54^{a}
10	23.4^{c}	24.3^{ab}	1.094^{bc}	1.096^{ab}	16.59^{bc}	17.06^{ab}
LSD (5%)	0.6		0.003		0.55	

Mean values followed by the same letter(s) in each rows and columns of each parameter had non-significant difference at P < 5% probability level. FYM = Farmyard Manure Ton per Hectare and LSD (5%) = Least Significant Difference at P < 5% probability level.

Partial budget analysis

The partial budget analysis was applied on the average marketable yields to assess the most economically feasible rates of NPS and farmyard manure according to the procedure described by CIMMYT (1988). Based on partial economic analysis, the application of 150 kg NPS with 5 t FYM gave the highest net benefit (246950.0 ETB) with the highest marginal rate of return (14180 %) at Haramaya. Similarly, the highest net benefit (187000.0 ETB) with highest marginal rate of return (1893%) was recorded from the combined application of 200 kg NPS with 10 t FYM at Hirna. It is clearly observed that a combined application of organic with inorganic fertilizer rates are economically more feasible as compared to plots which are not fertilized.

CONCLUSIONS

Integrated application of organic and inorganic fertilizers is considered as remedy measure to rehabilitee the poor soil fertility and increases the yields of crops in Ethiopia. Results showed that the highest marketable tuber numbers per hill, marketable and total tuber yields were obtained from the combined application of 150 kg NPS with 5 t FYM ha^{-1} at Haramaya. Whereas the combined application of 200 kg NPS with 10 t FYM produced the maximum marketable tuber numbers per hill, marketable and total tuber yields at Hirna. Overall, higher marketable and total tuber yields were obtained at Haramaya as compared to Hirna. On the other hand, relatively higher tuber quality related traits were recorded at Hirna as compared to Haramaya. Based on partial budget analysis, the combined application of 150 kg NPS with 5 t FYM gave the highest net benefit (246950. 0 ETB) with the highest marginal rate of return (14180 %) at Haramaya. The highest net benefit (187000.0 ETB) with highest marginal rate of return (1893%) was recorded from the combined application of 200 kg NPS with 10 t FYM at Hirna. Finally, it is concluded that the combined application of 150 kg NPS ha^{-1} with 5 t FYM ha^{-1} at Haramaya and the application of 200 kg NPS ha^{-1} with 10 t FYM ha^{-1} at Hirna to Bubu potato variety are agronomically optimum fertilizer rates to get higher potato tuber yield with acceptable quality. Further, it is recommended to conduct on-farm demonstration trials to verify the results under farmers' field conditions to release technology.

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