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Influence of Integrated Fertilizer Application on Growth and Tuber Yield of Potato (*Solanum tuberosum* L.) in Haramaya District, Eastern Ethiopia

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Abstract: A research was conducted on a fluvisols during the main rainy season in 2012 at Rare research station of Haramaya University. The aim of the study was to evaluate the effect of integrated application of mineral NP fertilizer and cattle manure on the growth, yield and yield components of potato (*Solanum tuberosum* L.). The treatment consisted of three rates of nitrogen (0, 55 and 110 kg ha^{-1} of N), three rates of phosphorus (0, 46 and 92 kg P_2O_5 ha^{-1}) and three rates of cattle manure (0, 7.5 and 15 t ha^{-1}). The experiment was laid out as a randomized complete block design (RCBD) with a factorial arrangement and replicated three times. The results revealed that the main effects of N, P and CM and their interaction were found to be highly significant on total tuber yield, total tuber number, marketable tuber yield, marketable tuber number, large-sized tuber yield, medium-sized tuber yield, days to maturity and plant height. Simple linear correlation analysis showed that total tuber yield significantly and positively correlated with marketable and total tuber numbers, marketable tuber yield and total tuber yield, tuber size/large and medium, average tuber weight, days to 50% maturity, fresh total biomass, dry total biomass, plant height and leaf area index. In this research the economic analysis revealed that, the highest marginal rate of return had treatment from 110 kg N ha^{-1} x 46 kg P_2O_5 ha^{-1} x 15 t CM ha^{-1} shift to110 kg N ha^{-1} x 92 kg P_2O_5 ha^{-1} x 7.5 t CM ha^{-1}. Therefore, treatment 110 kg N ha^{-1} x 92 kg P_2O_5 ha^{-1} x 7.5 t CM ha^{-1} had the highest net benefit and the highest marginal rate of return (6785.00 %) which is above the minimum required acceptable rate of return since the producer can expect to recover Birr one invested plus an additional return of Birr 67.85 birr. Therefore, potato growers can practice supplementing inorganic fertilizer with organic manure is the most appropriate option for sustainable potato production.

Key words: Haramya · Fertilizer · Potato · Yield

INTRODUCTION

The Irish potato (*Solanum tuberosum* L.), is an important food and cash crop in eastern and central Africa, playing a major role in national food security and nutrition, poverty alleviation and income generation and provides employment in the production, processing and marketing sub-sectors [1]. The annual production of potato in Ethiopia is about 785,800 tonnes, from a total area of 69,784 ha and the national average yield is 11.2 t ha^{-1} which is very low compared to the world's average of 17.43 t ha^{-1} [2]. This low productivity is attributed to little or input like fertilizer applied to increase productivity of potato to its potential.

The integrated nutrient management is a strategy that incorporates both organic and inorganic plant nutrients to attain higher crop productivity, prevent soil degradation and thereby help meet future food supply needs due to positive complementarities. This is due to practical reasons as fertilizer or organic resources alone may not provide sufficient amounts of nutrients or may be unsuitable for alleviating specific constraints to crop

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production [3]. The use of both organic and inorganic fertilizers responds positively to improve output markets and crop prices. The profitability of alternative nutrient input sources depends not only on yield gains but also on market conditions. Many studies have found that the poor farmers' inability to access mineral fertilizers have adverse consequences on soil fertility and incomes [4]. Therefore, there is an urgent need to develop low cost input technology to get higher production from intensive cropping apart from maintaining soil fertility. Hence, the combined use of different nutrient sources is one alternative way of replenishing and maintaining soil fertility. In this regard, integrating organic fertilizers with inorganic fertilizers is one of the promising techniques for improving soil fertility and increasing potato yield [5].

Integrated nutrient management (INM) may harness such discrepancies through maintenance or adjustment of soil fertility/productivity and of optimal plant nutrient supply for sustaining the desired level of crop productivity [2]. Supplementation of fertilizers through manures and inorganic fertilizers were observed to augment yield and productivity [6 -8] of potato through improvement of soil health and fertility in a sustainable manner [8 -10]. INM can thus be considered an effective agricultural paradigm to ensure food security [8] and improve environmental quality worldwide, especially in countries with rapidly developing economies.

Potato is a gross feeder of fertilizer and excessive use of mineral fertilizers alone has caused adverse effect on soil nutrient balances and, thus reduced plant growth performance. Therefore, application of mineral fertilizers in combination with organic manure is essential to sustain high yields, better quality and more profit. Farmers apply animal manure and chemical fertilizers such as DAP (Diammonium Phosphate) and Urea to improve soil fertility and increase production. The use of animal manure is common in the study area and animal manure is transported from homestead to the field mostly during the dry season and spread in the field. Although there is some aggregation errors due to the small area allocated to the vegetables, the fertilizer application rate appears to be high [11].

In addition to well-adapted high yielding local cultivars, farmers in eastern Ethiopia cultivate improved potato cultivars which have been released by Haramaya University. Farmers in the study area are aware of the response of potato and other related crops to applied nutrients and raise the crop in homesteads using cattle manure, household wastes etc. However, they do not know the rate of manure and its combined effect with inorganic fertilizers (nitrogen and phosphorus) for high production of the crop. So far no information is available and no research has been done on the combined effects of chemical and organic fertilizer requirement and management on the new improved potato cultivar (Bubu) for maximum tuber yield production. In view of this fact, the release of new potato cultivar (Bubu) necessitates a systematic investigation to develop most appropriate recommendations using commercial fertilizers like nitrogen, phosphorus and locally available, accessible and affordable animal manure is of paramount importance for increasing yield and yield components of potato. Therefore this study was initiated with the objective of evaluating the effect of integrated nutrient management on yield and yield components of an improved potato variety.

MATERIALS AND METHODS

Description of the Study Site: The experiment was conducted on the field research station on the main campus of Haramaya University during the 2012/2013 main growing season under rain-fed condition. The research site is located at 42°3' E longitude, 9° 26' N latitude and at an altitude of 2015 meters above sea level. The site has a bimodal rainfall distribution and is representative of a sub-humid mid-altitude agro-climatic zone. The short rainy season extends from March to April and constitutes about 25% of the annual rainfall whereas the long rainy season extends from June to October and accounts for about 45% of the total rainfall [12].The mean annual rainfall and temperature of the area are 760 mm and 17°C, respectively. The type of soil on which the experiment was conducted is fluvisol. Soil analysis results before planting showed that the soil is clayey in texture with clay (54 %), sand (10 %) and silt (36 %) contents and it is moderately alkaline in reaction with a pH value of 8.07.

Before planting, physical and chemical properties of the experimental soil were determined. For pre-planting, representative soil samples were collected from the experimental field randomly in a zigzag pattern to a depth of 30 cm before planting using an auger. The soil samples were composited and a one kg sample was taken as a working sample. The soil has an organic matter content of 1.21 %, total nitrogen and available phosphorus of 0.15 % and 8.11mg kg^{-1}, respectively. In addition, the exchangeable bases, namely, Ca, Mg, Na and K contents in cmol (+) kg^{-1} soil are 33.43, 7.55, 0.1 and 1.0

respectively and the cation exchange capacity is 43.7. According to [13] the levels organic carbon and total nitrogen are very low; the level of phosphorus is medium whereas that of exchangeable potassium is very high; the exchangeable bases as well as the total cation exchange capacity of the soil are high. The results show that the soil requires application of external phosphorus and nitrogen to sustain production of potato. This is because external available phosphorus is medium whereas the organic carbon content, which is a surrogate of mineral nitrogen in the soil for plant uptake [14], is very low.

The results of the laboratory analysis of some selected physiochemical properties of the soil of experimental site are presented in Appendix Table 1.

Experimental Material: The improved potato variety Bubu, which was released by Haramaya University in 2011, was used for the experiment. Urea [CO $(NH_2)_2$] was used as a source of nitrogen whereas triple superphosphate (TSP) was used as a source of phosphate. Well decomposed cattle manure was obtained from the university cattle farm and was used as an organic fertilizer.

Treatments and Experimental Design: The treatments consisted of three levels of nitrogen (0, 55 and 110 kg N ha^{-1}), three rates of phosphorus (0, 46 and 92 kg P_2O_5 ha^{-1}) and three rates of cattle manure (0, 7.5 and 15 t CM ha^{-1}). The experiment was laid out as a randomized complete block design (RCBD) in a 3 x 3 x 3 factorial arrangement and replicated three times.

Experimental Procedures: The experimental field was ploughed by a tractor. The lay out was done as per the experimental plan. The ridge planting was done manually on July 18, 2012 using medium-sized tubers bearing 2-3 cm long sprouts. Well-decomposed cattle manure was applied about one month before planting as per the treatment and incorporated into the soil. Application of the entire rates of phosphorus was done by banding the granules of the fertilizers at the depth of 10 cm below and around the seed tuber at planting. Nitrogen was applied in three splits [1/4th at planting, ½ at mid-stage of vegetative growth (about 40 days after planting) and 1/4th before tuber initiation where as phosphorus was applied once at the time of planting. Weeding and hoeing were done at the appropriate time to facilitate root, stolon and tuber growth. Earthing up was first done when the plants reached the height of 15 cm and then repeated as required.. Two weeks before harvesting, the haulms of the potato plants were mowed using a sickle to toughen the periderm and avoid skinning and bruising of the tubers during harvesting and handling. Harvesting was done manually 107 days after planting using hoes.

Plant Tissue Sampling Analysis: Mature non-necrotic and healthy leaves with petioles were stripped-off randomly from plants per treatment just prior to tuber initiation. 60 leaves with petioles were taken as a sample from each plot. The leaves were dried in an oven at 65°C until a constant weight was attained. The dried and ground shoot of the plant was ashed at the temperature of 480°C. The ashed plant material was treated with a solution of 1volume of nitric acid (HNO_3) diluted in 3 volume of distilled water. The concentrations of nitrogen in the leaf tissues were determined by the micro-Kjeldhal digestion and distillation method. The laboratory analysis of nitrogen and phosphorus in plant tissue were presented.

Data Collection and Measurements: The data on phonological, growth and yield variables were be collected from the central three rows and subjected to analysis of variance (ANOVA) using the Generalized Linear Model of the SAS statistical package [15] version 9.1. All pairs of treatment means were compared using the Least Significant Difference (LSD) test at 5% level of significance. Correlation analysis was performed to determine simple correlation coefficients among response variables as affected by the supply of the nutrient.

Economic Analysis: To strengthen the statistical analysis of the agronomic data, economic analysis was done for each treatment. An economic analysis of on farm experiment is calculated the costs that vary for each treatment. The 27 treatment combinations were subjected to discrete economic analysis using the procedure recommended by CIMMYT [16]. It was important to take consideration all inputs that are affected in any way by changing from one treatment to another. The field price of 1 kg of tubers that farmers receive for sale of the crop was taken as 4.50 Birr based on the market price of tuber yield at Haramaya town near the experimental site. N was applied as urea and its price was 14 Birr kg^{-1}. The applied P was converted in to DAP equivalents and price of DAP was 16 birr kg^{-1} ETB. The value of FYM was considered in the budget including the personal expense for collection of cattle manure 20 birr qt^{-1}. Since farmers are using family labour to perform most of activities, other costs like ploughing, weeding, harvesting, etc were not considered in the variable costs. The recommended level of 10% was reduced from all treatments in order to attain the adjusted yield. Then, gross benefit was calculated as average adjusted tuber yield (kg ha^{-1}) x field price that farmers receive for the sale of the crop (4.50 birr kg^{-1}). Total variable cost was calculated as the sum of all cost that is variable or specific to a treatment. Net benefit was calculated by subtracting total variable cost from the gross benefit.

RESULTS AND DISCUSSION

Phonological Parameter

Days to 50% Emergence**:** The interaction effect of N, P and CM was highly significant on 50% emergence (Table 1). The results generally revealed that farmyard manure hastened tuber emergence from the soil when combined with higher rates of nitrogen and/or phosphorus. Nutrients had no significant effect on the days to emergency throughout the emergence period because emergence was largely dependent on the utilization of reserve material and metabolites in the mother tubers [17-19]. However, the present result revealed that FYM interacted with N and P to significantly hasten days to 50% emergence. This may be attributed to the fact that organic manure contained in the manure imparts the soil with high capacity to hold moisture to promote growth. The increment of soil temperature and moisture availability due to the presence of manure may have increased the metabolic activity of the tuber seed for using stored food, thereby hastening days to 50% emergence.

Days to 50% Maturity: The interaction effect of N, P and CM significantly influenced days to reach 50% physiological maturity (Table 2). Maturity was generally prolonged when higher rates of nitrogen were combined with higher rates of phosphorus and manure. At nil rate of nitrogen combined with all rates of the other fertilizers, maturity tended to be hastened. The data also showed that increasing the rate of nitrogen significantly prolonged crop maturity under all phosphorus and manure levels. Similar trend was also obtained in case of manure under all the interactions with nitrogen and phosphorus rates. The prolonged maturity under higher rates of application of the fertilizers might be due to extended physiological activity of the plant, accumulation and eventual partitioning of photo assimilates, thereby continuing photosynthesis and growth. The application of nitrogen and manure might have also created favourable conditions for the supply of nutrients. Moreover, it could be due to the improvement of soil water holding capacity as mentioned earlier byRoeand Cornforth [20]. In addition, organic manure activates many species of living organisms, which release phytohormones and may stimulate the plant growth and absorption of nutrients [21]. Such organisms need nitrogen for multiplication. This may be a possible reason that the use of organic manure with inorganic fertilizer led to increased leaf area which may have increased the amount of solar radiation intercepted, thereby increasing days to physiological maturity [22, 23].

Growth Parameter

Plant Height: The interaction effect of N, P and CM had a significant effect on plant height (Table 3). The lowest plant height was recorded under the control treatment

Table 1: Interaction effect of N, P and CM on days to 50% emergence of potato variety (Bubu)

	P_2O_5 (kg ha^{-1})									
	0			46			92			
	CM (t ha^{-1})									
N(kg ha^{-1})	0	7.5	15	0	7.5	15	0	7.5	15	Mean
0	19.0^{bcd}	18.7^{cde}	18.3^{de}	20.0^{a}	19.7^{ab}	19.7^{ab}	19.7^{ab}	18.7^{cde}	18.3^{de}	19.12
55	20.0^{a}	20.0^{a}	18.0^{e}	19.7^{ab}	19.0^{bcd}	18^{e}	19.3^{abc}	19.0^{bcd}	19.7^{ab}	19.19
110	20.0^{a}	19.7^{ab}	19.0^{bcd}	19.7^{ab}	18.7^{cde}	18.7^{cde}	20.0^{a}	18.7^{cde}	18.0^{e}	19.17
Mean	19.67	19.47	18.43	19.80	19.13	18.80	19.67	18.80	18.67	
SE ±			0.4911							
LSD (N x P_2O_5 x CM) (5%)			0.9795							
CV (%)			3.1							

Means followed by the same letters are not significantly different at 5% level of significance; CM = Cattle manure; LSD = Least significant difference; CV = Coefficient of variation.

Table 2: Interaction effect of N, P and CM on days to 50% maturity of potato variety (Bubu)

	P_2O_5 (kg ha^{-1})									
	0			46			92			
	CM (t ha^{-1})									
N (kg ha^{-1})	0	7.5	15	0	7.5	15	0	7.5	15	Mean
0	92.0^{m}	96.3^{ij}	98.3^{fg}	94.0^{k}	96.7^{hij}	98.7^{fg}	92.3^{lm}	96.0^{j}	98.7^{fg}	95.89
55	98.3^{fg}	98.33gh	98.33gh	98.33gh	98.33gh	99.0^{f}	101.3^{de}	97.0^{jk}	98.0^{gh}	99.0^{f}
110	100.6^{e}	104.0^{c}	105.0^{b}	98.3^{fg}	100.7^{e}	103.7^{c}	97.3^{hi}	103.7^{cd}	107.3^{a}	102.29
Mean	96.97	99.77	101.53	96.43	98.47	100.47	95.30	99.47	102.57	
SE ±					0.4237					
LSD (N x P_2O_5 x CM) (5%)					0.8501					
CV(%)					0.5					

Means followed by the same letters are not significantly different at 5% level of significance; CM = Cattle manure; LSD = Least significant difference; CV = Coefficient of variation.

Table 3: Interaction effect of N, P and CM on plant height (cm) of potato variety (Bubu)

	P_2O_5 (kg ha^{-1})									
	0			46			92			
	CM (t ha^{-1})									
N(kg ha^{-1})	0	7.5	15	0	7.5	15	0	7.5	15	Mean
0	53.8°	59.5^{kl}	63.4^{efgh}	54.6^{no}	56.7^{mn}	59.9^{jkl}	67.6^{bc}	$60.4i^{jkl}$	63.0^{fgh}	59.88
55	56.5^{mn}	61.9^{hij}	64.1^{efg}	58.7^{lm}	61.4^{hijk}	64.2^{defg}	60.2^{ijkl}	63.2^{fgh}	65.1^{def}	61.70
110	68.6^{b}	65.5^{de}	69.00^{b}	62.13^{ghi}	63.3^{fgh}	66.3^{cd}	68.6^{b}	72.4^{a}	72.4^{a}	67.58
Mean	59.63	62.30	65.50	58.48	60.47	63.47	65.47	65.33	66.83	
SE ±				1.066						
LSD(N x P_2O_5 x CM) (5%)				2.139						
CV(%)				2.1						

Means followed by the same letter are not significantly different at 5 % level of significance; CM= Cattle manure; LSD =Least significant difference; CV = Coefficient of variation.

which was in statistical parity with the height of plants observed in response to applying 46 kg P_2O_5 ha^{-1} in the absence of nitrogen and manure application. The tallest plants were obtained in response to applying the highest rates of nitrogen (110 kg N ha^{-1}) and the highest rate of phosphate (92 kg P_2O_5 ha^{-1}) combined with 7.5 or 15 t CM ha^{-1}. Thus, the heights of plants grown in these treatments exceeded the heights of plants grown in the absence of application of all three fertilizers (control treatment) by about 35%. In general, plant height tended to increase with the increased rate of CM application up to 46 kg P_2O_5 ha^{-1} while at 92 kg N ha^{-1}, it showed an inconsistent trend. However, the plants attained the maximum height with the interaction effect of 110 kg N ha^{-1} with a significant variation over other interactions. The increased plant height observed in response to the increased application rates of the fertilizers may be attributed to enhanced growth due to increased supply of plant nutrients. Consistent with the results of this study, Gonzalez, Avarez and Matheus [24] reported that organic manure and inorganic fertilizers supplied all the essential nutrients at seedling stage resulting in increase of measured variables like the plant height. Generally it was observed that treatments that received higher rates of organic manure, nitrogen and phosphorus fertilizer produced plants with more height as compared to plants in the absolute control treatment. The results of this experiment confirm that of Najm *et al.* [25] who reported that combined application of organic and inorganic fertilizer significantly enhanced plant height.

Leaf Area Index: The results also revealed that the interaction effects of N x CM and P x CM were significant on leaf area index (Table 4). Leaf area index increased linearly in response to increasing the rate of manure application together with increased application of either phosphorus or nitrogen. The lowest leaf area index was obtained at the nil application rates of N or P and manure. On the other hand, the highest leaf area index was obtained in response to increasing the rate of manure from

Table 4: Interaction effect of N x CM and P x CM on leaf area index of potato variety (Bubu)

	CM(t ha^{-1})					CM(t ha^{-1})			
N(kg ha^{-1})	0	7.5	15	Mean	P_2O_5 (kg ha^{-1})	0	7.5	15	Mean
0	2.79^{c}	5.23^{a}	5.01^{a}	4.34	0	2.58^{d}	5.06^{ab}	4.96^{b}	4.20
55	4.18^{b}	5.15^{a}	5.32^{a}	4.88	46	4.33^{c}	5.06^{ab}	5.18^{ab}	4.86
110	4.36^{b}	5.10^{a}	5.20^{a}	4.99	92	4.42^{c}	5.36^{ab}	5.39^{a}	5.06
Mean	3.78	5.16	5.18			3.78	5.16	5.18	
SE ±				0.2059					
LSD (N x CM) or (P_2O_5 x CM) (5%)				0.4132					
CV(%)				9.3					

Means followed by the same letters do not differ significantly at the 5 % of level of the LSD test; CM = Cattle manure; LSD = Least significant difference; CV = Coefficient of variation.

Table 5: Interaction effect of N, P and CM on marketable tuber number per hill of potato variety (Bubu)

	P_2O_5 (kg ha^{-1})									
	0			46			92			
	CM (t ha^{-1})									
N (kg h^{-1})	0	7.5	15	0	7.5	15	0	7.5	15	Mean
0	5.51^{l}	5.66^{kl}	5.71^{k}	5.74^{k}	6.43^{ij}	6.45^{i}	5.81^{k}	6.48^{hi}	6.68^{g}	6.05
55	6.28^{j}	6.74^{g}	7.01^{f}	7.63^{d}	7.76^{bcd}	7.79^{bcd}	7.66^{cd}	7.80^{bc}	7.85^{ab}	7.39
110	6.63^{gh}	7.00^{f}	7.24^{e}	7.62^{d}	7.82^{abc}	7.92^{ab}	7.66^{cd}	7.84^{ab}	7.99^{a}	7.50
Mean	6.14	6.47	6.58	7.00	7.34	7.39	7.04	7.37	7.51	
SE ±					0.845					
LSD(N x P_2O_5 x CM)(5%)					0.172					
CV(%)					11.5					

Means followed by the same letters do not differ significantly at the 5 % level of significance. CM = Cattle manure; LSD = Least significant difference; CV = Coefficient of variation.

nil to 7.5 t ha^{-1} with any of the other two fertilizers. Thus, in both cases, keeping the level of manure 0 and increasing the rates of either phosphorus or nitrogen even to the highest levels did not markedly increase leaf area index (Table 4). However, when the rate of manure was increased from 0 to 7.5 t ha^{-1} and then to 15 t ha^{-1}, leaf area index increased significantly. This shows that manure application had a huge synergistic effect when combined with either of the two nutrients in enhancing leaf area index.

The optimum leaf area index for high yield of potato ranges between 4.0 to 6.0 [26, 27]. This shows that all leaf are indices except the one obtained from the combined nil application of nitrogen and manure or phosphate and manure were in optimum range and could enable to obtain optimum growth and tuber yields of the crop. Therefore, it could be argued that integrated use of nitrogen, phosphorus and manure enhance potato tuber yield thorough promoting leaf growth and for efficient photosynthesis.

Stem Number: Although stem density is one of the most important yield components in potato, the results of the present study showed that the influences of N, P and CM and their interaction effect on stem number did not show significant effect on main stem number of the potato crop. This could be due to the fact that the trait is much influenced by the inheritance of the potato crop. This trait is not significantly influenced much by mineral nutrients, possibly because stem number may be influenced by other factors such as storage condition of tubers, number of viable sprouts at planting, sprout damage at the time of planting and growing conditions [28] physiological age of the seed tuber [29], variety [30] and tuber size [31].

Yield and Yield Components Parameter

Marketable, Unmarketable and Total Tuber Numbers: Two-way interaction of N x P x FYM highly significantly influenced both total and marketable tuber numbers (Table 5 and 6). The results showed that increasing the combined rates of the three fertilizers markedly increased

Table 6: Interaction effect of N x P and P x CM on average tuber weight per hill of potato variety (Bubu)

	P_2O_5 (kg ha^{-1})					CM (t ha^{-1})			
N(kg ha^{-1})	0	46	92	Mean	P_2O_5(kg ha^{-1})	0	7.5	15	Mean
0	69.09^{d}	67.67^{d}	75.24^{c}	70.67	0	67.65^{e}	72.21^{d}	83.74^{ab}	74.53
55	76.99^{c}	75.56^{c}	83.42^{b}	78.66	46	68.86^{de}	79.25^{c}	80.50^{bc}	76.20
110	77.53^{c}	85.39^{b}	92.75^{a}	85.22	92	79.58^{c}	84.62^{a}	87.21^{a}	83.80
Mean	74.54	76.21	83.80		Mean	72.03	78.69	83.82	
SE ±					1.967				
LSD(N x P_2O_5) or (P_2O_5 x CM) (5%)					3.947				
CV(%)					5.3				

Means followed by the same letters do not differ significantly at the 5 % level of significance. CM = Cattle manure; LSD =least significant difference; CV = coefficient of variation.

Table 7: Effects of N, P and CM on total biomass yield (t ha^{-1}) of potato variety (Bubu)

	Fresh	Dry
N (kg ha^{-1})		
0	48.63^{c}	10.35^{b}
55	56.60^{b}	12.55^{a}
110	59.88^{a}	12.82^{a}
P_2O_5 (kg ha^{-1})		
0	51.28^{b}	10.91^{b}
46	55.83^{b}	11.80^{b}
92	57.99^{a}	13.01^{a}
CM (t ha^{-1})		
0	50.86^{c}	10.35^{b}
7.5	55.71^{b}	12.57^{a}
15	58.53^{a}	12.80^{a}
SE ±	2.049	1.623
LSD(5%)	2.374	1.556
CV (%)	7.9	23.92

Means within the same column followed by the same letters do not differ significantly at the 5 % of level of significance. CM = Cattle manure; LSD =Least significant difference; CV = Coefficient of variation.

tuber numbers. However, increasing the rate of farmyard manure had evidently a more prominent role in enhancing the production of marketable tubers than either of the two other fertilizers. This may be attributed to the role manure plays in enhancing tuber setting of the plant. The profound interaction effect of manure with the other fertilizers in enhancing tuber numbers may be attributed to its effect on raising the organic carbon content of the soil, which was very low (1.21 %). This suggestion is corroborated by that of Sanchez *et al.* [32] that cattle manures contain all essential nutrients plus C, the source of energy for soil biota. The present results are in conformity with that of Daniel Mekonnen [33], Gezachew Abate[34] who reported that both marketable and total tuber numbers increased in response to the interaction effect of organic and inorganic fertilizer.

The observed non-significant and inconsistent effect of the three nutrients on unmarketable tuber number might probably indicate the difficulties of manipulating this plant parameter by the use of mineral nutrients. This could be attributed to other biotic and abiotic factors and is not necessarily dependent on nutrient supply in the soil. However, contradicting results were reported regarding the effects of P and N on the tuber number.

Average Tuber Weight: The heaviest tubers were produced in response to applying phosphorus and nitrogen at the highest rates (i.e., 110 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1}). In addition, combining nitrogen at 110 kg ha^{-1} with manure at 7.5 t ha^{-1} and 15 t ha^{-1} resulted in the production of the heaviest tubers. However, keeping the rate of phosphorus at nil but increasing the rate of manure to 15 t ha^{-1} led to the production of tubers with the highest weight. This result shows the prominence of manure in increasing tuber size over nitrogen and phosphorus. The lightest tubers were produced in response to applying zero and 46 kg P_2O_5 ha^{-1} combined with nil tonne of manure ha^{-1} (Table 7). This result revealed that in the absence of any of the two fertilizers, tuber weights cannot be enhanced. Also the lightest tubers were produced in response to applying zero kg N ha^{-1} interact with 0 and 46 kg P_2O_5 ha^{-1}.The increased size and duration of the haulm stemming from improved supply of nutrients might have favoured tuber weight [35].

Fresh and Dry Total Biomass: Nitrogen, phosphorus and manure had statistically significant effect on fresh total biomass (Table 8). The fresh total biomass yield was increased significantly with the increase in nitrogen application. The increase in fresh yield was 16.4 and 5.8 % with the successive increase in nitrogen rates.

The main effects of N, P and CM were highly significant on dry total biomass (Table 8). The increase in total dry biomass was 23.8 and 2.2 % with the application of 110 kg N ha^{-1} over the control treatment and 55kg N ha^{-1}, respectively. Although, phosphorus application

Table 8: Interaction effect of P x CM on fresh total biomass (t ha^{-1}) of potato variety (Bubu)

P_2O_5 (kg ha^{-1})	CM (t ha^{-1}) 0	7.5	15	Mean
0	43.70^{d}	52.02^{c}	58.13^{a}	51.28
46	52.99^{bc}	56.13^{ab}	58.37^{a}	55.83
92	55.88^{abc}	58.98^{a}	59.10^{a}	57.99
Mean	50.86	55.71	58.53	
SE ±			2.049	
LSD (P_2O_5 x CM) (5%)			4.111	
CV(%)			7.9	

Means followed by the same letters do not differ significantly at the 5 % level of significance. CM =Cattle manure; LSD = Least significant difference; CV = Coefficient of variation.

Table 9: Effect of N and P on harvest index of potato variety (Bubu)

N (kg ha^{-1})	
0	0.81^{a}
55	0.74^{b}
110	0.67^{c}
P_2O_5 (kg ha^{-1})	
0	0.76^{a}
46	0.74^{a}
92	0.72^{b}
CM (t ha^{-1})	
0	0.74^{a}
7.5	0.73^{a}
15	0.73^{a}
SE ±	0.00365
LSD (5%)	0.0176
CV (%)	4.55

Means within the same column followed by the same letters do not differ significantly at the 5 % level of significance. CM = Cattle manure; LSD = Least significant difference; CV = Coefficient of variation.

also resulted in an increase in total dry biomass with the increase in application rates but no significant difference was observed between the control treatment and 46 P_2O_5 ha^{-1}, both of which resulted in significantly lower total dry biomass yield than 92 kg P_2O_5 ha^{-1}. The results obtained in this study support the findings of Millard and Marshall [36] where a significant increment in canopy dry matter yield of potato was reported as N application was increased. Total dry biomass of potato significantly increased with the increase in the manure rates from 0 to 7.5 and 15.0 t CM ha^{-1}, which were in statistical parity. The additional increases in total dry biomass were 21.4 and 23.7 % with the application of 7.5 and 15.0 t ha^{-1} over the control treatment, respectively.

The interaction effect of P with CM was also significant on fresh total biomass (Table 9). The data showed that the highest fresh total biomass yield was obtained with the interaction of 92 kg P_2O_5 ha^{-1} and 15.0 t CM ha^{-1} but significant increases occurred for the control treatment, 7.5 t CM ha^{-1} and 46 kg P_2O_5 ha^{-1}. The increase in fresh total biomass yield was 35.2, 13.6 and 11.5 %, respectively. In line with this result,Powon, Aguyoh and Mwaja [37] in Kenya found positive response to total fresh biomass of potato to the combined application of CM and P_2O_5.

Harvest Index: The harvest index decreased significantly and linearly with the increase in the rate of nitrogen application (Table 10). This decrease was about 9.5% with each successive increase in the rate of nitrogen application. Similar to the effect of N, the increase in P application also resulted in a significant decrease in harvest index of potato and this decrease was 2.7 % with each successive increase in the rate of P application.

The reduction in harvest index due to N and P_2O_5 did not appear to be associated with a decrease in total tuber yield. This is because the total biomass increased more than the harvestable portion in response to the application of N and P. Therefore, the yield advantage obtained through the use of N and P fertilizers might not be attributed to its effect on the increment in harvest index; rather a parallel increase in both harvestable and non-harvestable parts was apparent. Therefore, even though harvest index is commonly used as a one of plant parameters contributing to yield, it may not be necessarily correlated with high yield [38].

Marketable and Total Tuber Yields: Increasing the rates of the three fertilizers increased both total and marketable tuber yields. The analysis of the data showed that combining the three fertilizers at higher rates markedly increased tuber yields. Thus, the highest total as well as marketable tuber yield was obtained at the combined application of the highest rates of N and P and half of the highest rate of CM, i.e., 110 kg N ha^{-1} + 7.5 t CM ha^{-1} + 92 kg P_2O_5 ha^{-1} as well as at the highest rates of the three fertilizers i.e., 110 kg N ha^{-1} + 15 t CM ha^{-1} + 92 kg P_2O_5 ha^{-1} (Tables 11 and 12). The lowest total as well as marketable tuber yields were obtained at nil combined rates of all three fertilizers. The total and marketable tuber yields obtained at the combined rates of 110 kg N ha^{-1} + 7.5 t CM ha^{-1} + 92 kg P_2O_5 ha^{-1} exceeded the total and marketable yields obtained at nil rates of the three fertilizers by 115 and 122%, in the order mentioned here. The result of this study also revealed that applying only half (7.5 t) of the highest rate of CM applied in this experiment (15 t ha^{-1}) is sufficient to lead to optimum potato tuber yield when combined with 92 kg P_2O_5 and 110 kg N ha^{-1}.

Table 10: Interaction effect of N, P,and CM on Marketable tuber yield (t ha^{-1}) of potato variety (Bubu).

	P_2O_5 (kg ha^{-1})									
	0			46			92			
	CM (t ha^{-1})									
N (kg ha^{-1})	0	7.5	15	0	7.5	15	0	7.5	15	Mean
0	14.40^{q}	16.63^{p}	18.78^{n}	14.50^{q}	19.51^{mn}	19.88^{lmn}	17.02^{op}	21.11^{kl}	23.26^{ij}	18.34
55	18.38^{no}	22.35^{jk}	25.78^{gh}	24.71^{hi}	26.72^{fg}	27.55^{def}	26.93^{efg}	28.47^{cde}	28.77^{bcd}	25.52
110	20.67^{lm}	21.27^{kl}	27.97^{cdef}	26.73^{fg}	29.50^{bc}	30.27^{b}	29.30^{bc}	31.97^{a}	33.50^{a}	27.91
Mean	17.82	20.08	24.18	21.98	25.24	25.90	24.42	27.18	28.51	
SE ±					0.769					
LSD (N x P_2O_5 x CM) (5%)					1.543					
CV(%)					3.9					

Means followed by the same letters do not differ significantly at the 5 % level of significance. CM = Cattle manure; LSD =Least significant difference; CV = Coefficient of variation.

Table 11: Interaction effect of N, P and CM on total tuber yield (t ha^{-1}) of potato variety (Bubu)

	P_2O_5 (kg ha^{-1})									
	0			46			92			
	CM (t ha^{-1})									
N (kg ha^{-1})	0	7.5	15	0	7.5	15	0	7.5	15	Mean
0	15.33^{o}	17.48^{mn}	19.74^{jkl}	15.51^{no}	20.51^{ijk}	20.81^{ijk}	18.04^{lm}	22.08^{ghi}	24.22^{g}	19.30
55	19.29^{klm}	23.36^{gh}	26.79^{f}	22.33^{ghi}	27.69^{ef}	28.52^{def}	27.93^{ef}	29.46^{cde}	29.77^{cde}	26.13
110	21.60^{hij}	22.23^{ghi}	28.94^{de}	27.74^{ef}	30.51^{cd}	31.24^{bc}	30.31^{cd}	32.94^{ab}	34.46^{a}	28.89
Mean	18.74	21.02	25.16	21.86	26.24	26.86	25.43	28.16	29.48	
SE ±					1.068					
LSD (N x P_2O_5 x CM) (5%)					2.143					
CV(%)					5.3					

Means followed by the same letters do not differ significantly at the 5 % level of significance. CM = Cattle manure; LSD =Least significant difference; CV = Coefficient of variation.

Table 12: Effect of N on specific gravity of potato variety (Bubu)

N (kg ha^{-1})	
0	1.09^{a}
55	1.06^{b}
110	1.06^{b}
P_2O_5 (kg ha^{-1})	
0	1.07^{a}
46	1.07^{a}
92	1.08^{a}
CM (t ha^{-1})	
0	1.07^{a}
7.5	1.07^{a}
15	1.07^{a}
SE ±	0.0245
LSD(5%)	0.0103
CV(%)	1.8

Means within the same column followed by the same letters do not differ significantly at the 5 % level of significance. CM=Cattle manure, LSD = least significant difference; CV = coefficient of variation.

Table 13: Interaction effect of N x P and N x CM on tuber dry matter content (%) of potato variety (Bubu)

	P_2O_5(kg ha^{-1})					CM(t ha^{-1})			
N (kg ha^{-1})	0	46	92	Mean	N (kg ha^{-1})	0	7.5	15	Mean
0	23.95^{cde}	23.52^{de}	24.35^{abc}	23.94	0	24.09^{bc}	23.79^{bcd}	23.93^{bcd}	23.94
55	23.35^{de}	24.98^{a}	24.41^{abc}	24.25	55	23.50^{cd}	24.09^{bc}	25.15^{a}	24.25
110	23.22^{e}	24.07^{bcd}	24.79^{ab}	24.03	110	23.27^{d}	24.29^{bc}	24.51^{ab}	24.02
Mean	23.51	24.19	24.52			23.62	24.06	24.53	
SE ±					0.4027				
LSD (N x P_2O_5) or (N x CM) (5%)					0.8080				
CV(%)					3.5				

Means followed by the same letters do not differ significantly at the 5 % level of significance. CM = Cattle manure; LSD = Least significant difference; CV = Coefficient of variation.

The results of this study showed that combining the three fertilizers resulted in profoundly enhanced tuber yield than applying either sole or combining only two of the three fertilizers. In line with this suggestion, Murage *et al.* [14] stated that soil organic matter is the best surrogate for soil quality and enhanced productivity of crops. The results obtained in this study also confirm the findings [4, 39] who suggested that organic and inorganic mineral inputs cannot be substituted entirely by one another and are both required for sustainable crop production. Sanchez and Jama [3] attributed this to practical reasons that fertilizer or organic resources alone may not provide sufficient amounts of nutrients or may be unsuitable for alleviating specific constraints to crop production.

The results of this study are corroborated also by those of Sibale and Smith [40] who reported a significant increase in tuber yields with increasing the rates of organic manure and mineral fertilizers applied, which they attributed to higher nutrient availability and uptake with higher rates of both fertilizer rates. Apart from supplying nutrients, manure provides valuable organic matter to help improve soil physical properties and increase the activity of beneficial soil microbes [41]. Charreauand Murwira, Swift and Frost [42, 43] also stated that higher crop yields are achieved with the same amount of nutrients when supplied through combined use of organic and inorganic fertilizers than mineral fertilizer alone. The interaction effect of small amounts of inorganic fertilizer and organic materials could meet the mineral fertilizer requirements of crops for maximum yields. Many studies in zimbabwe indicated that manure alone generally produced low crop yields [44].

The results of this experiment also confirm the observations of Sanchez and Jama [3] who reported that integration of organic and inorganic inputs sustains crop production due to positive interaction and complementarities between them. it has been observed that addition of manure increases soil water holding capacity and this means that nutrient would be made available to crops where manure has been added to the soil [45]. Fuchs, Rauche, Wicke [46] also reported that nutrients from mineral fertilizers enhance the establishment of crops while those from mineralization of organic manure promoted yield when both fertilizers were combined.Murwira and Kirchman [47] observed that nutrient use efficiency might be increased through the combination of manure and mineral fertilizer.

Quality Parameter

Specific Gravity and Tuber Dry Matter Content: Increasing the rate of nitrogen from nil to 55 kg ha^{-1} decreased tuber specific gravity by about 2.4%. However, increasing the rate of N beyond the level of 55 kg ha^{-1} did not further decrease tuber specific gravity (Table 14). Consistent with the result of this study, Zelalem, Tekalign and Nigussie [48] found a decrease in specific gravity of potato tubers in response to increasing the rate of N application from 0 to 207kg N/ha on vertisol of Debre Berhan area.

In general, increasing the combined application rates of nitrogen and phosphorus as well as nitrogen and manure significantly enhanced tuber dry matter contents. Thus, it was at the highest rates of combined application of either nitrogen and phosphorus or nitrogen and manure that the highest tuber dry matter contents were attained (Table 15). This result indicates the synergic roles the fertilizers play when combined in enhancing starch production and accumulation in the tubers. The data on the interaction effect of N and P_2O_5 revealed that combined application of 55 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} resulted in the highest tuber dry matter content, which was in statistical parity with the tuber dry matter content obtained with combined application of 92 kg P_2O_5 ha^{-1}, 55 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1} and 110 kg N ha^{-1} with either 46 kg or 92 kg P_2O_5 ha^{-1}. The highest tuber dry

Table 14: Interaction effect of N, P and CM on the concentration of nitrogen (%) in potato variety (Bubu) leaf

	P_2O_5 (kg ha^{-1})									
	0			46			92			
	CM (t ha^{-1})									
N (kg ha^{-1})	0	7.5	15	0	7.5	15	0	7.5	15	Mean
0	3.95^{g}	4.50^{d}	4.56^{cd}	4.50^{d}	4.02^{fg}	4.47^{d}	4.51^{cd}	4.16^{ef}	4.19^{e}	4.32
55	4.54^{cd}	4.54^{ef}	4.19^{e}	4.61^{bcd}	4.53^{cd}	4.59^{bcd}	4.57^{bcd}	4.46^{d}	4.57^{bcd}	4.51
110	4.52^{cd}	4.56^{cd}	4.82^{a}	4.55^{cd}	4.47^{d}	4.67^{fgh}	4.74^{ab}	4.49^{d}	4.79^{a}	4.62
Mean	4.34	4.53	4.52	4.55	4.34	4.58	4.61	4.37	4.52	
SE ±					0.235					
LSD (N x P_2O_5 x CM) (5%)					0.1675					
CV (%)					2.3					

Means followed by the same letters do not differ significantly at the 5 % level of significance. CM = Cattle manure; LSD =Least significance difference; CV= Coefficient of variation.

Table 15: Non dominated treatment for Marginal Rate of Return analysis

Treatments	Marketable yield (Average tuber yield)	Gross field Benefit for Adjusted yield	Total cost	Net benefit	Change in total cost	Change in total benefit	Marginal rate of return (MRR%)
0N x 0P x 0CM	14.4	58320	0	58320			
0N x 0P x 7.5CM	16.63	67352	1500	65852	1500	7531	502.10
55N x 0P x 0CM	18.38	74439	1680	72759	180	6908	3837.50
0N x 0P x 15CM	18.78	76059	3000	73059	1320	300	22.73
0N x 46P x 7.5CM	19.51	79016	3100	75916	100	2857	2856.50
55N x 46P x 7.5CM	26.72	108216	4780	103436	4780	103436	2163.93
55N x 92P x 0CM	26.93	109067	4880	104187	100	751	750.50
55N x 46P x 15CM	27.55	111578	6280	105298	1400	1111	79.36
110N x 0P x 15CM	27.97	113279	6360	106919	80	1621	2026.25
110N x 46P x15CM	30.27	122594	7960	114634	7960	114634	1440.12
110N x 92P x 7.5CM	31.97	129479	8060	121419	100	6785	6785.00
110N x 92P x15CM	33.5	135675	9560	126115	1500	4697	313.10

Nitrogen (0 kg N ha^{-1}, 55 kg N ha^{-1}, 110 kg N ha^{-1} or 0, 120, 240 kg urea ha^{-1}); Phosphorus (0 kg P_2O_5 ha^{-1}, 46 kg P_2O_5 ha^{-1}, 92 kg P_2O_5 ha^{-1}or 0, 100, 200 kg DAP ha^{-1}); Cattle manure (0, 7.5, 15 ton ha^{-1}).

matter was obtained when 55 kg N ha^{-1} was applied combined with 15.0 t CM ha^{-1}, which was in statistical parity with the tuber dry matter content obtained in response to applying 110 kg N ha^{-1} and 15.0 t CM ha^{-1}. The lowest tuber dry matter contents were recorded at the lowest combined rates of either of the two fertilizers. High dry matter content has been reported to be desirable because of less sugar accumulation and water content [49]. Storey and Davies [50] observed that tubers with high dry matter content required less energy input during frying or dehydration to remove water; resulting in greater product yield per unit fresh weight than tubers with lower solid content and also absorbed less oil during frying. For the purpose of potato processing, tuber quality should be emphasised. Therefore, a special consideration should be given to the application of nutrients since tuber specific gravity and dry matter contents are a good indicator of potato tuber quality and are affected by nutrient supply [51]. In general, tubers with lower specific gravity are not suited for processing. Consistent with this suggestion, Gould [52] described that dry matter concentration is a critical component of efficiency in making chips and French fries and noted that the cut-off below which factory deliveries are not acceptable is 19.5% dry matter (SG = 1.077) for French fries and 20% dry matter (SG = 1.079) for chips. The author further states that upper limits do not apply, though penalties may be incurred for >25% dry matter (SG = 1.103) in French fry manufacture. This is because too high specific gravity and/or dry matter concentration can yield French fries that are too hard and dry [53]. Therefore, potatoes meant for processing should be fertilized with nitrogen cautiously.

Concentration of N in Potato Leaf Tissue: The three factors interacted to significantly influence the concentration of nitrogen in the leaf tissue of the crop. The highest concentrations of nitrogen in the leaf tissue of the crop plant occurred in response to applying the highest rates of nitrogen (110 kg ha^{-1}) in combination with the highest rate of manure (15 t ha^{-1}), regardless of the rate of phosphate combined (Table 16). This may be attributed to the fact that application of the nitrogen and manure fertilizers enhanced availability of the nutrient in the soil and enhanced its uptake by the plants.

The present finding is similar with the results of the investigations carried out by Gezachew Abate [34] on potato, which revealed that the interaction effect of organic (compost) and inorganic N and P fertilizers significantly affected leaf N concentration. In addition [54] reported that potato leaf N and phosphorus concentrations were significantly increased by the application of inorganic N and P fertilizers. This could be due to the fact that application of N, P and FYM increased the levels of available N and P in the soil which in turn may have enhanced uptake of the nutrients by the plants and improved plant growth and development thereby increasing the amount of nutrients assimilated in tuber tissue and in the whole plants.

The critical concentration of a nutrient in plant tissues is the concentration of the nutrient in a particular plant part usually a mature leaf sampled at a given growth stage (usually just before flowering or tuber initiation for potato) below which plant growth and yield are suppressed by 5 to 10% [55]. Sufficient nutrient concentration in the leaf tissue is the one that leads to optimum yields [26]. Sufficient concentrations of nitrogen in the dry matter of potato leaf blade sampled just before tuber initiation ranges between 5.0 and 6.5 [56]. The results of this experiment showed that plants grown in the treatments with the highest combined nitrogen and manure rates concentrations of nitrogen in the leaf tissue that approximated the range indicated above. However, plants that had sufficient range of N in the leaf tissue did not necessarily produce maximum yields, for example, 110 kg N ha^{-1} combined with 15 t ha^{-1}. This shows the importance of applying phosphate also to synergize and enhance growth of the potato crop and its tuber yield and the need for balanced nutrition for increasing productivity of the crop.

Correlation Analysis: Results from the simple linear correlation analysis showed that total tuber yield is highly positive correlated with marketable tuber number (r = 0.91), total tuber number (r = 0.93), marketable tuber yield (r = 0.97), large-sized tuber yield (r = 0.97), medium-sized tuber yields (r = 97), average tuber weight (r = 0.94), days to 50%maturity (r = 0.69), fresh total biomass (r = 0.64), dry total biomass (r = 0.50), plant height (r = 0.67), leaf area index (r = 0.58).

It is also interesting to note that the experimental confirmation of simple linear correlation analysis showed that leaf N concentration had a positively significant correlation between most agronomic traits like total and marketable tuber yields, total and marketable tuber number, large and medium-sized yield, average tuber weight, fresh total and dry total biomass, plant height, stem number, leaf area index, dry tubers matter percentage and days to 50% maturity of potato (r = 0.44^{**}, 0.43^{**}, 0.42^{**}, 0.43^{**}, 0.43^{**}, 0.44^{**}, 0.38^{**}, 0.29^{**}, 0.22^{*}, 0.47^{**}, 0.11^{ns}, 0.19^{ns}, 0.11^{ns}, 0.45^{**}), respectively.

The results which depicted highly significant positive correlation may indicate that enhancing the performance of one good correlated parameter may increase the performance of the other. For example, enhancing the production of large or medium-sized tubers through nitrogen application may also enhance total tuber yields. Similarly, increasing leaf area index through enhanced fertilizer application may also enhance tuber yields. However, negative correlations indicate that enhancing one parameter of the plant through agronomic practices may decrease the performance of the other parameter.

Partial Budget Analysis: The economic analysis revealed that highest net benefit was recorded from the treatment that received 110 kg N ha^{-1} x 92 kg P_2O_5 ha^{-1} x 15 t CM ha^{-1}, followed by 92 kg P_2O_5 ha^{-1} x 7.5 t CM ha^{-1} and 110 kg N ha^{-1} x 46 kg P_2O_5 ha^{-1} x 7.5 t CM ha^{-1}, respectively(Table 17). However, the lowest net return was received with the treatment of 46 kg P_2O_5 ha^{-1} without N and CM (Appendix Table 2).That is why net benefit is not enough for economic analysis and it is better to make dominance analysis and marginal rate of return (MRR%).

By observing the marginal rate of return from Table 19, the highest MRR% occurred for the treatment with 110 kg N ha^{-1}, 92 kg P_2O_5 ha^{-1} and 7.5 t CM ha^{-1}. Usually the minimum acceptable marginal rate of return for fertilizer trial is 100%. In this experiment, the highest marginal rate of return had treatment from 110 kg N ha^{-1} x 46 kg P_2O_5 ha^{-1} x 15 t CM ha^{-1} shift to110 kg N ha^{-1} x 92 kg P_2O_5 ha^{-1} x 7.5 t CM ha^{-1}. Therefore, treatment 110 kg N ha^{-1} x 92 kg P_2O_5 ha^{-1} x 7.5 t CM ha^{-1} had the highest net benefit and the highest marginal rate of return (6785.00 %) which is above the minimum required acceptable rate of return since the producer can expect to recover Birr one invested plus an additional return of Birr 67.85 birr (Table 17). The highest tuber yield treatment was recorded similar with the above recommended treatment.

CONCLUSION

This study revealed that combined application of mineral and organic fertilizers resulted in markedly enhanced growth and yield of the potato crop compared to the growth and yield that would be attained through sole application of either of the fertilizers. This is attributed to the synergistic role organic fertilizers have on the uptake of nutrients as well as in supplying balanced nutrition to plants. In this study, the optimum marketable tuber yield was obtained in response to the application of 110 kg N ha^{-1}, 92 kg P_2O_5 ha^{-1} and 7.5 t FYM ha^{-1}.However, assessing the cost-benefit of application of the fertilizers revealed that applying110 kg N ha^{-1} + 92 kg P_2O_5 ha^{-1} + 15 t FYM ha^{-1} resulted in the highest marginal rate of return. Therefore, farmers in the study area are recommended to apply applying110 kg N ha^{-1} + 92 kg P_2O_5 ha^{-1} + 15 t FYM ha^{-1} to obtain the highest marketable tuber yield. However, it is too early to reach a conclusive recommendation since the experiment was conducted only with one variety in one location for one season. Hence, future studies must be done by including the current variety and other improved ones in different agro-ecology and soil type to develop fertilizer recommendations for improving production and productivity of the potato crop in Eastern Ethiopia so as to enhance household food security and cash income of smallholder farmers in the region.

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Appendices:

Appendix Table 1: Soil chemical and physical properties of the study area prior to fertilization at Haramaya during 2012 the main growing season.

Characteristics (parameter)	Result (value)
Soil pH	8.07
Soil moisture (%)	6.77
Total nitrogen (%)	0.15
Available Phosphorus (ppm)	8.11
Organic carbon (%)	1.21
Cat ion exchangeable capacity (cmol(+)/kg)	43.7
Exchangeable K (cmol(+)/kg)	1.0
Exchangeable Ca (cmol(+)/kg)	33.43
Exchangeable Mg (cmol(+)/kg)	7.55
Exchangeable Na (cmol(+)/kg)	0.1
Electrical conductivity (mS/cm)	0.16
Textural class of soil	clay
Sand (%)	10
Silt (%)	36
Clay (%)	54

Appendix Table 2: Treatments with cost and benefit items in Partial budget analysis influenced by integrated nutrient management

				Variable cost (Birr/ha)				Benefit type (Birr/ha)	
No	Treatment	Average yield (t/ha)	Adjusted yield (t/ha)	N	P	FYM	Total Cost (Birr/ha)	Gross field benefit	Net benefit
1	0 N x 0 P x 0 FYM	14.4	12.96	0	0	0	0	38880	38880
2	0N x 0P x 7.5 FYM	16.63	14.97	0	0	375	375	44901	44526
3	0N x 0P x 15 FYM	18.78	16.90	0	0	750	750	50706	49956
4	0N x 46P x 0 FYM	14.5	13.05	0	1300	0	1300	39150	37850
5	0N x 46P x 7.5 FYM	19.51	17.56	0	1300	375	1675	52677	51002
6	0N x 46P x 15 FYM	19.88	17.89	0	1300	750	2050	53676	51626
7	0N x 92P x 0 FYM	17.02	15.32	0	2600	0	2600	45954	43354
8	0N x 92P x 7.5 FYM	21.11	19.00	0	2600	375	2975	56997	54022
9	0N x 92P x 15 FYM	23.26	20.93	0	2600	750	3350	62802	59452
10	55N x 0P x 0 FYM	18.38	16.54	1320	0	0	1320	49626	48306
11	55N x 0P x 7.5 FYM	22.35	20.12	1320	0	375	1695	60345	58650
12	55N x 0P x 15 FYM	25.78	23.20	1320	0	750	2070	69606	67536
13	55N x 46P x 0 FYM	24.71	22.24	1320	1300	0	2620	66717	64097
14	55N x 46P x 7.5 FYM	26.72	24.05	1320	1300	375	2995	72144	69149
15	55N x 46P x 15 FYM	27.55	24.80	1320	1300	750	3370	74385	71015
16	55N x 92P x 0 FYM	26.93	24.24	1320	2600	0	3920	72711	68791
17	55N x 92P x 7.5 FYM	28.47	25.62	1320	2600	375	4295	76869	72574
18	55N x 92P x 15 FYM	28.77	25.89	1320	2600	750	4670	77679	73009
19	110N x 0P x 0 FYM	20.67	18.60	2640	0	0	2640	55809	53169
20	110N x 0P x 7.5 FYM	21.27	19.14	2640	0	375	3015	57429	54414
21	110N x 0P x 15 FYM	27.97	25.17	2640	0	750	3390	75519	72129
22	110N x 46P x 0 FYM	26.73	24.06	2640	1300	0	3940	72171	68231
23	110Nx46P x 7.5 FYM	29.5	26.55	2640	1300	375	4315	79650	75335
24	110Nx 46P x 15 FYM	30.27	27.24	2640	1300	750	4690	81729	77039
25	110N x92P x 0 FYM	29.3	26.37	2640	2600	0	5240	79110	73870
26	110Nx92P x 7.5 FYM	31.97	28.77	2640	2600	375	5615	86319	80704
27	110Nx 92P x 15 FYM	33.5	30.15	2640	2600	750	5990	90450	84460

Nitrogen (0 kg N ha^{-1}, 55 kg N ha^{-1}, 110 kg N ha^{-1} or 0, 120, 240 kg urea ha^{-1}).
Phosphorus (0 kg P_2O_5 ha^{-1}, 46 kg P_2O_5 ha^{-1}, 92 kg P_2O_5 ha^{-1} or 0, 100, 200 kg DAP ha^{-1}).
Farm yard manure (0, 7.5, 15 ton ha^{-1}).