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The Effects of Combined Application of Cattle Manure and NP Fertilizers on Yield and Nutrient Uptake of Potato in North-Eastern Ethiopia

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Abstract

Potato (*Solanum tuberosum* L.) is a short season crop that thrives best under sufficient nutrient supply. However, in Ethiopia the yield of potato is quite low as it is produced with little or inappropriate rates of fertilizer application. Therefore, a field experiment was conducted for two seasons (2012 and 2013) at Kobo substation of Sirinka Agricultural Research Centre to elucidate the combined effects of cattle manure (CM) and NP fertilizers on growth, yield components, yield and nutrient uptake of the crop. The treatments consisted of three rates each of CM (0, 15 and 30 t ha^{-1}), nitrogen (0, 60 and 120 kg N ha^{-1}) and phosphorus (0, 46 and 92 kg P_2O_5 ha^{-1}), combined factorially and laid out in randomized complete block design with three replications. Growth parameters (growth rate, and leaf area), average tuber weight and marketable and total tuber yield of potato were significantly ($P \leq 0.05$) influenced by the interaction effects of chemical and organic fertilizers. Uptake of N and P were higher with treatments in which 30 t ha^{-1} CM was applied combined with 120 kg N and 92 kg P_2O_5 ha^{-1} as compared to the control treatment. Harvest index, total tuber yield, N uptake and P uptake were significantly increased by 134%, 257%, 2446% and 1186%, respectively, over the control treatment in response to the combined application of 120 kg N, 92 kg P_2O_5 ha^{-1} and 30 t ha^{-1} CM. In conclusion, the results revealed that integrated application of chemical and organic fertilizers could be the best strategy to restore highly depleted soils and to enhance economical production of potato in Kobo district and similar agroecologies.

Key words: Average tuber weight; Leaf Area Index; Tuber yield.

Introduction

Potato *(Solanum tuberosum L.)* is one of the most widely grown tuber crops in the high and mid altitude areas of Ethiopia (Berga *et al*, 2009). It is regarded as a high-potential food security crop due to its ability to provide a high quality yield per unit input within a short cycle (FAO, 2008; Hirpa *et al*., 2010; Balemi, 2012). Regardless of its importance, the productivity of this crop in the country is as low as 11.5 t ha^{-1} (CSA, 2013), which is far from the world's average productivity of 17.7 t ha^{-1} (FAOSTAT, 2012). The major causes of low yields are unavailability and high prices of quality seed tubers, lack of improved varieties, poor soil fertility, low market value at the time of harvesting, diseases, and postharvest losses (Tsegaw, 2006; Fuglie, 2007). Of these potato production constraints, poor soil fertility is a wide spread problem in Ethiopia.

Soil fertility depletion owing to high rates of erosion is considered to be the fundamental biophysical root cause for declining per capita food production in Africa, including Ethiopia in smallholders' fields (Sanchez *et al*., 2002; Tesfaye *et al*., 2011). Nutrient losses due to low rate of return of biomass to crop fields, inadequate fertilizer application (Gebrekidan, 2003; Zelleke *et al*., 2010), and escalating fertilizer prices (Morris *et al*., 2007; Bekunda *et al*., 2010; Walsh *et al*., 2012) are identified as major constraints to agricultural production and food security in the Ethiopian farming system (Amede and Takele, 2001). Thus, external supply of inorganic and organic fertilizer inputs is necessary to increase crop productivity of major food crops in Ethiopia (Wakene *et al*., 2005).

On the other hand, potatoes demand high levels of soil nutrients due to a relatively poorly developed, coarse, and shallow root system (Dechassa *et al*., 2003). The crop produces much more dry matter in a shorter cycle that results in large amounts of nutrients removed per unit time, which generally most of the soils are not able to supply (Islam *et al*., 2013). For example, it removes approximately 3-5 kg nitrogen (N), 0.4-0.8 kg phosphorus (P) and 4-6 kg potassium (K) t^{-1} of tubers (Perrenoud, 1983). Potatoes farmers apply DAP and urea at low rates as well as some amounts of manure at small and varied rates (Gildemacher *et al*., 2009; Haverkort, 2012). Therefore, nutrient deficiencies are a common cause of low yields of the crop.

Many farmers use inorganic fertilizers such as nitrogen and phosphorus because they have the highest concentration of nutrients and are easily transformed to available forms upon application (Alam *et al*., 2007). In the past four to five years, the cost of urea and Diammonium Phosphate (DAP) fertilizers increased three-fold and has escalated beyond the purchasing power of the majority of the farmers in Ethiopia (Garo *et al*., 2014). Among external fertilizers, cattle manure is a valuable source of nutrients and its yield increasing effect is well established (Silvia *et al*., 2006). Organic inputs which are often proposed as alternatives cannot meet crop nutrients demands for large scale production because of their relatively lower nutrient composition as compared to inorganic fertilizers, high application rates, high labor requirements, and limited availability (Palm *et al*., 1997). The use of cattle manure alone may not fully satisfy potato nutrient demand, especially in the year of application (Patel *et al.*, 2009). Soil fertility replenishment through the application of mineral and organic fertilizer is the only way to effectively address these problems (Palm *et al.*, 1997). Balemi (2012) had also suggested integrated nutrient management as an option to alleviate the problem and satisfy the crop's nutrient demand.

Ethiopian soils are very diverse in terms of inherent fertility. Thus, various researchers had recommended different rates and types of fertilizers across diverse agroecologies for soil fertility management and productive quality potato production. For instance, application of 150 kg N and 22 kg P_2O_5 ha^{-1} was suggested on red soil (Berga *et al.*, 1994), while 87 kg N and 46 kg P_2O_5 ha^{-1} was recommended for optimum potato production on clay soil at Alemaya (Getu, 1998). Like wise, combined application of 110 kg N and 90 kg P_2O_5 ha^{-1} for Holleta area (IAR, 2000) and combined application of 207 kg N and 60 kg P_2O_5 ha^{-1} for vertisols at Debre Berhan were recommended (Zelalem *et al.*, 2009). An experiment conducted by Balemi (2012) showed a positive interaction effect of integrated application of inorganic and organic fertilizers on potato. Erkossa *et al*. (2004) reported 94% tuber yield increase over the control due to integrated application of 2 t FYM ha^{-1} with 92 kg N ha^{-1} and 46 kg P ha^{-1}.

Cattle manure is a potential source of organic fertilizer in Ethiopia, as the country has the highest livestock number in Africa (Zinash, 2001). Farmers in the study area are aware of the response of potato to applied nutrients from inorganic fertilizers and cattle manure to raise crop yields. They do not, however, know the type and rate of fertilizers to be applied. As neither organic nor inorganic source of fertilizer is capable of supplying the required amount of plant nutrients, hence their integrated application is of paramount important to increase the production levels of potato, to improve food security, reduce poverty, and improve nutrition in the country (Daniel *et al.*, 2008). This study was, therefore, conducted with the objective of investigating the effect of combined application of inorganic nitrogen and phosphorus fertilizers and cattle manure on growth, yield, yield components and nutrient uptake of potato.

Materials and Methods

Description of the experimental site

The field experiment was conducted under irrigation in 2012 and 2013 at the experimental farm of Sirinka Agricultural Research Centre, Kobo district of north-eastern Ethiopia. It is situated at 12°8′21′′N latitude, 39°18′21′E longitude and on elevation of 1470 meters above sea level. The area has mean annual minimum and maximum temperatures of 16°C and 31°C, respectively with mean annual rainfall of 670 mm. Monthly mean minimum and maximum temperatures and monthly total rainfall of the research area during cropping seasons (February-May) are shown in Figure 1. Relative humidity ranged from 43 to 58% in 2012 and from 40 to 52% in 2013.

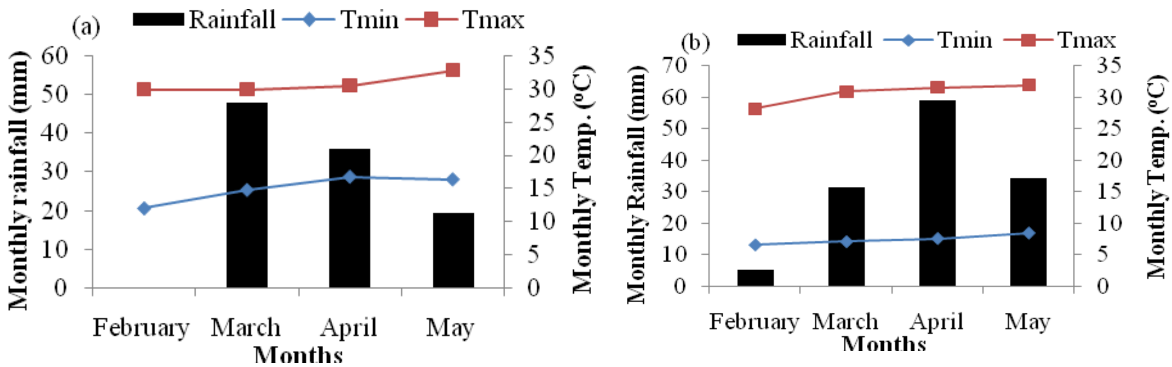

Figure 1. Monthly mean minimum (Tmin) and maximum (Tmax) temperatures (°C) and monthly total rainfall (mm) of the study site in 2012 (a) and 2013 (b) cropping seasons

Experimental materials

The potato variety '*Gera*' released by Sheno Agricultural Research Centre in 2003 (MoARD, 2009) was employed for this study. The variety is commonly grown in the study area, hence locally produced seed was used for the study. The fertilizer sources include nitrogen in the form of urea (46% N), phosphorus in the form of triple supper phosphate (45% P_2O_5) and well decomposed cattle manure (CM).

Treatments and experimental design

The treatments consisted of three rates each of nitrogen (0, 60, 120 kg N ha^{-1}), phosphorus (0, 46, 92 kg P_2O_5 ha^{-1}) and cattle manure, (0, 15, 30 t CM ha^{-1}), respectively. The experiment was laid out in randomized complete block design (RCBD) with 3x3x3 factorial arrangement of the treatments in three replications. The experiment was set on a plot of 3.75 m x 3.9 m, were the spacing was 30 cm between plants and 75 cm between rows. The spacing between adjacent plots and blocks were 1.0 m and 1.5 m, respectively. Each plot comprised five rows, while each row comprised 13 plants; accordingly the total number of plants per plot was 65.

Experimental procedure

One month prior to planting, cattle manure was spread in the plots and thoroughly incorporated into the soil. The triple superphosphate (45% P_2O_5) was drilled on the top of the ridge and then thoroughly mixed with soil. Nitrogen was side-dressed in three splits, i.e. 1/4 at plant emergence; 1/2 at the first earthling up and the remaining 1/4 at 40 days after planting. Pre-sprouted seed tubers of the potato variety named *'Gera'* were planted 6 February 2012 and 7 February 2013. All agronomic practices such as irrigation, weed control and earthling up were done regularly during the growing seasons. When the plants reached physiological maturity (when 70% of the haulms dried up), tubers were hand-harvested on 21 May 2012 and 22 May 2013, respectively.

Sampling and analysis

Soil sampling

Pre-plant soil samples were taken diagonally at 0-30 cm depth in three replications. Later the samples were bulked to make one composite sample for the determination of selected soil physicochemical properties. Sampled soils were air-dried, ground, and then sieved through a 2-mm sieve. These samples were analyzed for pH (1:2.5 soil: water ratio), electrical conductivity by conductivity meter (Jackson, 1973), organic carbon by rapid titration method (Walkley and Black, 1936), soil texture, available P by Olsen's method (Olsen *et al*., 1954), total N by Kjeldahl method (Jackson, 1958). Cation exchange capacity (CEC) and exchangeable bases (Na, K, Ca and Mg) were also analysed using standard procedures. Prior to application into soils selected chemical properties of cattle manure were analyzed using the same standard procedures.

Plant sampling

This was carried out at tuber initiation stage, i.e., 50 days after planting, 60 leaves (including petioles) of the 4th leaf from the top nodal insertion were sampled, washed with distilled water, and oven dried at 65^{o}C for 48 hours. The dried samples from each plot were milled and analyzed for nitrogen and phosphorus contents. The nitrogen (N) concentration in dried samples was analyzed using Kjeldahl method (Jackson, 1958); while the phosphorus (P) concentration was determined through the vanadomolybdate extraction method (Gericke and Kurmis, 1952). Plant nutrient uptake was then calculated as:

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{N or P concentration (\%)} \times \text{Dry weight (kg ha}^{-1}\text{)}}{100}$$

Data Collection and Measurement

Leaf area (LA) per hill was recorded from five randomly selected potato plants using a leaf area meter (Model-CI-202- Nebraska, U.S.A.) at 50 and 65 days after planting. Leaf area index (LAI) was then calculated as the average leaf area of the plant divided by the ground area covered by the plant.

Crop growth rate (CGR) was calculated as described by Gardner *et al*. (1985):

$$CGR = \left[\frac{W2 - W1}{T2 - T1}\right] \left[\frac{1}{SA}\right]$$

Where W1 and W2 are the first and second shoot dry weight, respectively; T1 and T2 are time of first and second harvest, respectively; and SA is the area covered by the plant.

At harvest, average tuber weight (g), weight of tuber per hill, marketable and total tuber yield per unit area were recorded from the net area (7.425 m^2) of each plot. Average tuber fresh weight was recorded by dividing total fresh weight of tubers per hill by the total number of fresh tubers per hill. For determination of harvest index, about 500 g sample tubers were taken from five plants in the central three rows and washed in running tap water to remove the soil and other particles adhering to it. The water adhering to the surface of tuber was removed by pressing a clean dry cloth over the tubers. The tubers were sliced into small pieces with a stainless sharp knife. The pieces were dried in a hot air oven at 70^{o}C to constant weight. The oven dried tuber weight was then reweighed using a digital balance. The dry weight of above ground part was determined using the same procedure. Thus, harvest index (HI) was estimated as the ratio of the average dry weight of tubers to the average dry weight of total (tuber and vegetative) biomass at harvest.

Economics

Net return (NR ha^{-1}) and benefit: cost ratio (B:C) was calculated by considering the sale prices of potato and cost of fertilizers and labour for all field activities done. Thus, the economic gains of the different treatments were calculated to estimate the net returns and the cost of cultivation, after considering the cost of fertilizer N, P, cattle manure and labour; and the income from marketable potato tubers for economic analysis. Hence, following the CIMMYT partial budget analysis methodology, total variable costs (TVC), gross benefits (GB) and net benefits (NB) were calculated (CIMMYT, 1988). For each pair of treatments, MRR (%) was calculated as the ratio of the difference in higher net benefit to lower benefit over the difference in higher total costs that vary to lower costs and expressed in percent. Thus, the treatment which was non-dominated and having a marginal rate of return (MRR) greater or equal to 50% with the highest net benefit was taken to be economically profitable.

Data analysis

Homogeneity of variances was performed using the F-test as illustrated by Gomez and Gomez (1984). The analysis of variance (ANOVA) was performed for a randomized complete block design using SAS (statistical analysis system) version 9.1 program. Differences among treatment means were delineated using the Duncan's Multiple Range Test (DMRT) at 5% level of significance.

Results

Soil characteristics

The pre-planting soil analysis indicated that the soil of the study site is clayey loam in texture and neutral pH. The nutrient contents (N, P, K, etc) and properties of the study soil range from low to medium (Table 1). Analysis of cattle manure before application indicated that it has a neutral pH and selected chemical properties are shown in Table 1.

Table 1. Soil physicochemical properties of the study site and chemical properties of cattle manure before planting

Physicochemical Properties	Parameters	
	Soil	Cattle manure
pH	7.32	7.01
Total N (%)	0.12	0.98
Available P (ppm)	8.33	1695
OM (%)	1.41	5.18
C:N ratio	6.83	3.07
CEC (cmol(+)/kg soil)	35.80	36.69
Ca^{2+} (cmol(+)/kg soil)	17.27	17.52
Mg^{2+} (cmol(+)/kg soil)	5.20	11.15
Na^{+} (cmol(+)/kg soil)	0.33	0.75
K^{+} (cmol(+)/kg soil)	0.52	1.03
EC (dS/m)	0.49	0.92
Clay (%)	35.00	-
Silt (%)	39.17	-
Sand (%)	25.83	-
Textural class	Clay loam	-

Growth parameters

The analysis of variance showed that the interaction of N, P and CM fertilizers had significant ($P < 0.001$) effect on leaf area index (LAI) at 50 and 65 days after planting (Table 2). Regardless of P and CM application, increasing the rate of N significantly increased LAI at both growth stages. At the nil rates of both N and P, LAI did not increase in response to increasing the rate of CM to 15 t ha^{-1}.

Leaf area index per plant increased significantly in response to increasing the combined application of the three fertilizers. Overall, LAI increased by 162 and 134% due to the combined application of 120 kg N ha^{-1}, 92 kg P_2O_5 ha^{-1} and 30 t CM ha^{-1} over the control treatment at 50 and 65 days after planting (DAP), respectively (Table 2).

There were significant ($P < 0.001$) differences in the crop growth rate (CGR) due to the interaction effects of N, P and CM (Table 2). Without N and P application, CGR was significantly increased in response to increasing CM rates. Similarly, without P and CM, CGR was increased all over the increment of N rates. A similar trend was observed with regard to P fertilizer (Table 2). The CGR recorded in response to the combined application of 120 kg N, 92 kg P_2O_5 and 15 t CM ha^{-1} exceeded the CGR recorded in response to unfertilized control by 1.86 g m^{-2} day^{-1} or 165% (Table 2).

Table 2. The effects of N, P and CM on leaf area index (LAI) and crop growth rate (CGR) of potato

Fertilizer rate (kg ha^{-1})		Growth parameters: Leaf area index at 50 DAP			Leaf area index at 65 DAP			Crop growth rate (g m^{-2} day^{-1})		
		Cattle manure rate (t ha^{-1})								
N	P_2O_5	0	15	30	0	15	30	0	15	30
0	0	2.20^{s}	2.21^{s}	2.56^{q}	2.48^{o}	2.77^{m}	3.26^{l}	1.13^{r}	1.82^{n}	1.76^{p}
	46	2.38^{r}	2.56^{q}	2.72^{p}	2.66^{n}	3.16^{l}	3.73^{i}	1.70^{q}	2.18^{h}	1.98^{l}
	92	2.66^{pq}	2.87^{o}	3.13^{n}	3.18^{l}	3.53^{j}	4.06^{fg}	2.02^{k}	2.21^{g}	2.30^{f}
60	0	3.04^{n}	3.26^{m}	3.44^{kl}	3.20^{l}	3.64^{ij}	4.08^{f}	1.70^{q}	1.78^{op}	2.2^{gh}
	46	3.40^{l}	3.52^{k}	3.74^{j}	3.40^{k}	3.68^{i}	4.14^{ef}	2.14^{i}	2.35^{e}	2.15^{i}
	92	3.64^{j}	3.86^{i}	4.06^{h}	3.56^{j}	3.96^{gh}	4.41^{d}	1.79^{o}	1.98^{l}	2.37^{e}
120	0	3.98^{h}	4.19^{g}	4.37^{f}	3.90^{h}	4.23^{e}	4.67^{c}	2.10^{j}	2.28^{f}	2.28^{f}
	46	4.30^{f}	4.62^{e}	4.95^{c}	3.91^{h}	4.56^{c}	5.22^{b}	2.40^{d}	1.91^{m}	2.56^{c}
	92	4.82^{d}	5.10^{b}	5.77^{a}	4.67^{c}	5.21^{b}	5.81^{a}	1.71^{q}	2.99^{a}	2.85^{b}
Significant level			***			***			***	
CV (%)			2.41			2.44			1.22	

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test (DMRT).

Yield components

The interaction of N and P, N and CM, and P and CM significantly ($P < 0.001$) influenced average tuber weight of potato. There observed increased trends of average tuber weight as the combined NP levels increased from the lowest to the highest levels (Table 3). However, the average tuber weight ranged from 59.0 to 68.9 g when interaction effect of NP is considered. Similarly, N and CM interaction resulted in average tuber weight of 60.6 to 69.2 g. When we disaggregate the effect of different fertilizer sources, application of N alone resulted in average tuber weight increase by 12.5%, while P alone by

10.4% and CM resulted in 4.6% (Table 3).

Considering the interaction effect of N and P, applying nitrogen at the rate of 60 kg N and phosphorus at 92 kg P_2O_5 ha^{-1} as well as nitrogen at 120 kg N ha^{-1} at all three rates of phosphorus resulted in the highest average tuber weight. The smallest tuber weight, on the other hand, was recorded from plots without any fertilizers application (Table 3). Similarly, in terms of the interaction effect of nitrogen and cattle manure, applying nitrogen at the rate of 60 kg N ha^{-1} and 15 and 30 t cattle manure ha^{-1} as well as at 120 kg N ha^{-1} and at each of the three rates of cattle manure resulted in the highest average tuber weight. However, application of nitrogen at nil rate combined with each of the three rates of cattle manure as well as at 60 kg N ha^{-1} and nil rate of cattle manure produced the smallest average tuber weight. On the other hand, applying phosphorus at 46 kg P_2O_5 ha^{-1} and cattle manure at 30 t ha^{-1} as well as phosphorus at 92 kg P_2O_5 ha^{-1} and cattle manure at each of the three rates resulted in the highest average tuber weight (Table 4). Without applying phosphorus and cattle manure at each of the three rates as well as phosphorus at 46 kg P_2O_5 ha^{-1} and cattle manure at nil and 15 t ha^{-1}, led to the smallest average tuber weight (Table 4).

The interaction effect of N and P significantly ($P < 0.01$) influenced tuber weight per hill. The highest tuber weight per hill was recorded from the combined application of 60 kg N and 92 kg P_2O_5 ha^{-1}. However, the lowest tuber weight per hill was obtained from plots without any fertilizer application. Thus, the tuber weight per hill obtained in response to the combined application of the highest rates of the two fertilizers exceeded the control plots by 186% (Table 5).

Table 3. Effects of N + P and N + CM on average tuber weight of potato

Nitrogen rate (kg N ha^{-1})	Average tuber weight (g $tuber^{-1}$)					
	Phosphorus rate (kg P_2O_5 ha^{-1})			Cattle manure rate (t ha^{-1})		
	0	46	92	0	15	30
0	59.03^{d}	63.20^{c}	65.18^{bc}	60.61^{d}	63.22^{cd}	63.38^{cd}
60	65.48^{bc}	65.46^{bc}	68.92^{a}	63.62^{bcd}	66.94^{ab}	67.98^{a}
120	66.40^{abc}	66.38^{abc}	68.15^{ab}	66.16^{abc}	67.14^{a}	69.15^{a}
Significant level		***			***	
CV (%)		7.91			7.91	

Means followed by the same letter are not significantly different according to DMRT.

Table 4. Interaction effect of P and CM on average tuber weight of potato

Phosphorus rate ($kg\ P_2O_5\ ha^{-1}$)	Average tuber weight ($g\ tuber^{-1}$) Cattle manure rate ($t\ ha^{-1}$)		
	0	15	30
0	61.77[d]	63.66[cd]	64.12[bcd]
46	64.70[bcd]	64.12[bcd]	65.76[abc]
92	65.31[abc]	68.24[a]	67.44[ab]
Significant level		**	
CV (%)		7.91	

Means followed by the same letter are not significantly different according to DMRT.

Table 5. Interaction effect of N and P fertilizers on tuber weight of potato per hill

Nitrogen rate ($kg\ N\ ha^{-1}$)	Tuber weight ($g\ hill^{-1}$) Phosphorus rate ($kg\ P_2O_5\ ha^{-1}$)		
	0	46	92
0	248.5[i]	335.3[h]	372.0[g]
60	409.9[f]	445.0[e]	524.7[d]
120	562.6[c]	612.9[b]	711.5[a]
Significant level		**	
CV (%)		8.53	

Means followed by different letter are significantly different according to DMRT.

The interaction effect of nitrogen, phosphorus and cattle manure significantly ($P < 0.001$) influenced harvest index (HI) of potato, which, however, remained inconsistent (Table 7). Applying nitrogen at 120 kg ha^{-1} and phosphorus at 46 kg P_2O_5 ha^{-1} combined with cattle manure at 15 t ha^{-1}, as well as nitrogen at 120 kg N ha^{-1}, phosphorus at 92 kg P_2O_5 ha^{-1} combined with nil and 30 t cattle manure ha^{-1} resulted in the highest harvest index (Table 7). On the other hand, the lowest harvest index was recorded for the application of cattle manure at 15 t ha^{-1} without both N and P fertilizers. Overall, the harvest index obtained in response to the combined application of the highest rates of the three fertilizers exceeded the harvest index obtained at nil rates of both nitrogen and phosphorus combined with 15 t cattle manure ha^{-1} by 40% (Table 7).

Tuber yield

Marketable tuber yield was significantly influenced by the two-factor interaction effect of N + P and P + CM fertilizers (Table 6). The highest marketable tuber yield (30.8 t ha^{-1}) was recorded at combined NP fertilizer application of (120 kg N and 92 kg P_2O_5 ha^{-1}). The combination of the highest rates of P and CM application also resulted in the highest marketable tuber yield production. In contrast, the lowest marketable tuber yield was produced without any fertilizer (control plots) application. Regardless of N and/or CM application marketable tuber yield was significantly ($P <0.05$) increased in response to increasing P rates. Thus, the marketable tuber yield per unit area in response to the combined application of phosphorus and nitrogen, as well as phosphorus and cattle manure exceeded the marketable tuber yield obtained at nil rates by 178% and 46%, respectively (Table 6). However, there were no significant differences due to the interaction effect of the three fertilizers on marketable tuber yield.

Table 6. Interaction effects P + N and P + CM on marketable tuber yield of potato

Phosphorus rate (kg P_2O_5 ha^{-1})	Marketable tuber yield (t ha^{-1})					
	Nitrogen rate (kg N ha^{-1})			Cattle manure rate (t ha^{-1})		
	0	60	120	0	15	30
0	11.08^{i}	18.06^{f}	24.66^{c}	17.26^{g}	18.04^{fg}	18.50^{ef}
46	14.68^{h}	19.27^{e}	26.69^{b}	19.62^{de}	20.24^{d}	20.78^{cd}
92	16.24^{g}	22.73^{d}	30.81^{a}	21.85^{bc}	22.71^{b}	25.22^{a}
Significant level		**			*	
CV (%)		8.76			8.76	

Means followed by the same letter are not significantly different according to the DMRT.

Total tuber yield of potato was significantly ($P < 0.05$) influenced by the interaction of N, P and CM fertilizers (Table 7). With the increase in the rate of N application, total tuber yield was significantly increased, regardless of CM and P. Thus, the highest total tuber yield was attained in response to the combined application of the three fertilizers at the highest rates (120 kg N ha^{-1} + 92 kg P_2O_5 ha^{-1} + 30 t CM ha^{-1}). The lowest total tuber yield was recorded on plots without any fertilizer application. Hence, the highest total tuber yield was about 3.6 fold higher than the lowest total tuber yield (Table 7).

Table 7. Interaction effects of N, P and CM on harvest index (HI) and total tuber yield of potato

Fertilizer rate (kg ha^{-1})		Harvest index (%)			Total tuber yield (t ha^{-1})		
		Cattle manure rate (t ha^{-1})					
N	P_2O_5	0	15	30	0	15	30
0	0	61.2^{hi}	52.3^{l}	54.5^{kl}	10.85^{q}	12.40^{q}	13.14^{pq}
	46	60.4^{ij}	54.6^{kl}	59.6^{ij}	15.06^{op}	16.12^{no}	16.91^{mno}
	92	59.6^{ij}	59.5^{ij}	56.7^{jk}	17.15^{mno}	17.74^{lmn}	18.69^{k-n}
60	0	66.5^{d-g}	64.9^{e-h}	63.3^{ghi}	19.17^{klm}	19.77^{jkl}	20.26^{jkl}
	46	64.8^{e-h}	61.3^{hi}	64.6^{fgh}	20.57^{jk}	20.86^{ijk}	21.82^{ij}
	92	69.3^{bcd}	68.5^{c-f}	66.9^{d-g}	23.25^{hi}	24.45^{gh}	25.92^{fg}
120	0	70.42^{bcd}	69.1^{b-e}	69.0^{b-f}	26.31^{efg}	27.07^{def}	28.38^{c-f}
	46	69.4^{bcd}	72.8^{abc}	69.3^{bcd}	28.82^{cde}	29.46^{bcd}	29.98^{bc}
	92	76.7^{a}	67.4^{d-g}	73.0^{ab}	30.54^{bc}	31.76^{b}	38.68^{a}
Significance			***			*	
CV (%)			5.09			9.03	

Means followed by the same letter are not significantly different according to the DMRT.

Nitrogen and phosphorus uptake

Application of inorganic N and P as well as CM on uptake of N and P by the potato plants was compared. The results show that combined application of these fertilizer sources significantly ($P < 0.001$) increased N uptake by the potato plants (Table 8). Even without application of any N fertilizer source, N uptake was significantly increased with application of P fertilizer. Generally, application of both N and P fertilizer sources had also significantly increased N uptake. Without applying N fertilizer source, application of CM significantly increased N uptake by the potato plants. However, N uptake obtained in response to the interaction effect of nitrogen at 60 kg N ha^{-1} and cattle manure at 30 t ha^{-1} without phosphorus did not significantly different from N uptake obtained due to the interaction of nitrogen at 60 kg N ha^{-1}, phosphorus at 46 kg P_2O_5 ha^{-1} and cattle manure at 30 t ha^{-1}. Overall, plant N uptake in response to the interaction of nitrogen, phosphorus and cattle manure at maximum rates exceeded N and P uptake obtained at control treatment by 2446% (Table 8).

Phosphorus uptake of potato was significantly ($P < 0.001$) influenced by the interaction of N, P and CM (Table 8). Phosphorus uptake was significantly increased due to increment of P and CM, in N omitted plots. Similarly phosphorus uptake was significantly increased with increasing nitrogen rates, regardless of P and CM application. However, P uptake obtained from the interaction of nitrogen at 60 kg N ha^{-1} and phosphorus at 92 kg P_2O_5 ha^{-1} without cattle manure did not significantly different from P uptake obtained due to the interaction of nitrogen at 120 kg N ha^{-1}, phosphorus at 92 kg P_2O_5 ha^{-1} without cattle manure (Table 8). Overall, plant P uptake in response to the interaction of nitrogen, phosphorus and cattle manure at maximum rates exceeded P uptake observed at the control treatment by 1186% (Table 8).

Table 8. Interaction effects of N, P and CM on nitrogen and phosphorus uptake of potato

Fertilizer rate (kg ha^{-1})		Nitrogen uptake (kg N ha^{-1})			Phosphorus uptake (kg P ha^{-1})		
		Cattle manure rate (t ha^{-1})					
N	P_2O_5	0	15	30	0	15	30
0	0	6.24^{y}	40.51^{v}	48.64^{t}	1.17^{x}	2.56^{u}	3.86^{r}
	46	9.21^{x}	48.74^{t}	54.26^{q}	3.45^{s}	5.71^{l}	8.07^{h}
	92	11.25^{w}	50.61^{s}	63.55^{n}	7.0^{i}	9.07^{f}	10.89^{e}
60	0	46.78^{u}	61.24^{o}	87.43^{j}	1.86^{w}	2.45^{v}	4.82^{p}
	46	59.69^{p}	80.75^{k}	87.29^{j}	4.39^{q}	6.17^{k}	9.04^{f}
	92	52.96^{r}	70.97^{m}	97.06^{g}	6.51^{j}	8.26^{g}	11.4^{d}
120	0	73.82^{l}	91.24^{h}	116.23^{d}	2.44^{v}	3.22^{t}	5.26^{n}
	46	100.49^{f}	102.23^{e}	139.51^{c}	5.11^{o}	5.38^{m}	11.6^{c}
	92	85.64^{i}	149.53^{b}	158.88^{a}	6.45^{j}	13.5^{b}	15.04^{a}
Significant level			***			***	
CV (%)			1.27			1.34	

Means followed by the same letter are not significantly different according to (DMRT).

Economic analysis

The results of the partial budget analyses showed maximum net benefit of 171,596 Birr ha^{-1} with an acceptable MRR of 190% from the integrated application of 120 kg N, 92 kg P_2O_5 and 30 t CM ha^{-1} (Table 9). This combination generated 117,704 Birr ha^{-1} compared to the control treatment; and 24,450 Birr ha^{-1} compared to 120-92 kg N-P_2O_5 ha^{-1} without manure. On the other hand, the interaction of 120 kg N and 92 kg P_2O_5 ha^{-1} generated 93,254 Birr ha^{-1} compared to control treatment (Table 9).

Table 9. Results of the economic analysis for integrated use of N, P and CM in potato

N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	CM (t ha^{-1})	TVC (Birr ha^{-1})*	NB (Birr ha^{-1})	MRR (%)
0	0	0	0	53892	-
0	46	0	790	73371	2466
60	0	0	931	93947	14573
60	46	0	1442	99682	1123
120	0	0	1862	127199	6543
120	46	0	2373	137091	1938
120	92	0	2884	147146	1969
120	92	30	15734	171596	190

*1 Birr=0.0526 USD (August, 2014)

Discussion

The pre-planting soil test results showed that the contents of total N, available P, and organic matter are low (Hazelton and Murphy, 2007). On the other hand, the exchangeable bases and the CEC contents are high (Landon, 1991; Roy *et al.*, 2006). Prior application CM test results showed that its content of total N, available P, and organic C are very high (Hazelton and Murphy, 2007), implying that this organic fertilizer can be a good source of essential nutrients. The CM's exchangeable bases and the CEC contents are high (Landon, 1991; Roy *et al.* (2006). Therefore, application of inorganic N and P fertilizers along with well decomposed cattle manure with very high nutrient content is justified to produce good yield of potato at the study site.

Effects of fertilizer application on growth parameters

The integrated application of organic (cattle manure) and inorganic (N and P) fertilizers enhanced leaf area index and plant growth rate. This could be ascribed to their synergistic effect in promoting cell division, cell growth, and proliferation of leaves and axillary branches as reported by Abou-Hossain *et al.* (2003). Application of cattle manure in combination with NP fertilizers provide balanced micro and macro nutrients, this would have helped in enhancing the metabolic activity in the early growth phase and in turn must have encouraged the overall growth (Najm *et al*., 2013). Furthermore, presence of nitrogen in manure could be sufficient in the beginning of growth season which might be caused the extension of leaf surface, the increase of photosynthesis capacity resulted in higher LAI and CGR, which in line with the report of Oliveira (2000).

Although not determined in the present study, the use of cattle manure could have probably improved the physical, chemical and biological characteristics of soil that resulted in the easily absorption of water and nutrient elements utilization for vital processes (Place *et al*., 2003). Accordingly, the haulm growth and leaves produced per plant may have contributed to the increment of LAI and plant growth rate. Similar results were also reported by Sincik *et al*. (2008) and Yourtchi *et al*. (2013). With this regard, Najm *et al*. (2013) found 89.74% more LAI due to the interaction of cattle manure at 20 t ha^{-1} and nitrogen at 150 kg ha^{-1} as compared to the interaction of cattle manure at 5 t $ha^{-1}$and nitrogen at 50 kg ha^{-1}.

Effects of fertilizer applications on yield components

The increment in yield components (average tuber weight and tuber weight per hill) of potato as result of CM application along with inorganic NP maybe attributed to their balanced nutrients supply released from the organic manure, in addition to N and P plant nutrients (Yourtchi *et al*. 2013). The presence of nutrients in manure and balanced supplement of nitrogen and phosphorus through inorganic fertilizers may have contributed to increased cell division, expansion of cell wall, meristematic activity, photosynthetic efficiency and regulation of water intake into the cells, resulting in the enhancement of yield parameters, which is in line with the report of Mohammad *et al*. (2013).

The integrated application of inorganic and organic fertilizers is reported to have a positive impact on potato crop growth, foliage and leaf area increase (Patricia and Bansal, 1999). This in turn resulted in increased radiation interception and higher supply of photosynthates products to the tuber which might have induced formation of bigger tubers and finally improved the average tuber weight (Ayoola and Adeniyan, 2006). Other study indicated that increasing levels of N and P fertilization is important in tuber initiation and duration of tuber bulking, which resulted in tuber enlargement (Kotsyuk, 1995). The improvement of yield components due to the interaction effects of inorganic fertilizers and organic manure could be ascribed to the fact that the addition of manure to soils enhances microbial activity and conserve soil moisture (Xiao *et al*., 2006). Consequently, supply of more nutrients may have delayed senescence and increased the life cycle of the potato plant, resulting in higher economic yield and harvest index (Mohammadi *et al*., 2013).

Effect of fertilizer application on tuber yields

The high total and marketable tuber yields obtained due to combined use of inorganic and organic fertilizers could be attributed to the synergetic effect of inorganic N, P and cattle manure, as manure could provide the favourable and meliorating environment for soil physical and chemical traits (Palm *et al*., 1997). The authors also indicated that macro and micro-nutrients available to the crop could be increased due to the presence of microorganisms in manure, which mediate its decomposition and mineralization process. This in turn, would have improved assimilation of nutrients, increased synthesis of carbohydrates and build up of new cells and thus yield as reported by Kaur *et al*. (2005), Kiani *et al*. (2005) and Powon *et al*. (2006). Consistent with this suggestion, Beukema and Vander (1990) suggested that the crop benefited from the application of FYM not only from the presence of other nutrients it contains but also from improved soil tilth and the moisture retaining properties of the soil. The result is also in accordance with Najm *et al*. (2013) who reported that combined use of inorganic nitrogen and cattle manure improved radiation absorption due to the increment of shoot growth and leaf area index, which might have the positive effect on the final tuber yield. Rees *et al*. (2014) also found 13 to 17% more annual total tuber yield due to poultry-manured treatment than unmanured control.

The improvement in tuber yields obtained in this study due to the combined application of inorganic fertilizers and cattle manure also agrees with the results of Balemi (2012) who found 35% more yield advantage due to the combined application of inorganic nitrogen and phosphorus and cattle manure than the application of inorganic nitrogen and phosphorus alone. Similarly, Nyiraneza and Snapp (2007) reported that the combined application of 179 kg N ha^{-1} and 5.6 t ha^{-1} poultry manure consistently increased tuber yield by 20% more than the use of inorganic N alone at 224 kg ha^{-1}. In our study, analysis of cattle manure for some selected chemical properties showed high amount of potassium (Hazelton and Murphy, 2007). This might be responsible for the increment of total tuber yield (Abd El-Latif *et al*., 2011). Moreover, the increased availability of P in addition to other plant nutrients released by the organic manures might have contributed in enhancing the tuber yields, which agrees with the report of Sharma *et al*. (2013).

On the other hand, lone application of cattle manure was not much helpful in increasing tuber yields. This could be due to slow release of plant nutrients in the soil through mineralization of cattle manure (Daniel *et al*., 2008).

Ayoola and Adeniyan (2006) reported that nutrients from mineral fertilizers enhance the production of potatoes, while those from mineralization of organic manure promoted yield when both fertilizers were combined. Therefore, the combined use of manure with inorganic nitrogen and phosphorus could be ascribed to the immediate availability of N and P from urea and TSP, respectively and their slow release from cattle manure achieving greater synchrony with crop demand and high yield as reported by N'Dayegamiye *et al*. (2013).

Nitrogen and phosphorus uptake in response to fertilizer application

The highest N and P uptake at the higher levels of combined application of NP and CM perhaps could be attributed to the complementary effect of the rapidly released nutrients from chemical fertilizers and slowly released nutrients from cattle manure. In addition, cattle manure serve as energy and carbon source for soil biota, besides improving soil chemical properties. Earlier study suggested that the increase in N and P uptake as a result of combined use of inorganic and organic fertilizers could be attributed to solubilisation of native nutrients, chelation of complex intermediate organic molecules produced during decomposition of added cattle manure (Kafkafi *et al*., 1988), mobilization and accumulation of different nutrients in different plant parts and the ability to release nutrients gradually throughout the growing season (Sharma *et al*., 2013).

The present result is also in agreement with the findings of Islam *et al*. (2013) who reported higher N uptake (210.3 kg ha^{-1}) in potato due to the combined application of poultry manure at 3 t ha^{-1} and NPKS at the rate of 135:20:135:10 kg ha^{-1} respectively. The increase in P uptake as a result of combined application of inorganic and organic fertilizers may be ascribed to the availability of nutrients partly in response to the presence of cattle manure (Jatav *et al*., 2011). In accordance with this result, Johnston and Steen (2000) reported that because much of the phosphorus ingested by animals' maybe excreted in faeces. Hence cattle manures, when properly used, are valuable sources of phosphorus and as a result P uptake by the plant may be enhanced. In addition, combined application of inorganic NP fertilizers may interfere with and delay normal P fixation, prolonging availability of fertilizer P (Greenwood *et al*., 2001), presence of cattle manure due to its buffering nature, which may increase part of unavailable native P might all be responsible for the enhancement of P uptake by the potato (Fernandes and Soratto, 2012).

Economic consideration

The profitability and feasibility of an integrated plant nutrient system is determined by its ultimate economic return per hectare. In the current study, net benefit due to marketable tuber yield was increased by 218%

due to the combined application of 120 kg N ha^{-1}, 92 kg P_2O_5 ha^{-1} and 30 t ha^{-1} cattle manure as compared to the control. In line with this result, N'Dayegamiye *et al*. (2013) reported that smallholder farmers should apply higher rates of CM together with inorganic fertilizers so as to improve cost of potato production. Roy *et al*. (2002) also reported that 25% of the crop's N requirement can be met through farmyard manure and legume green manuring, thereby reducing N fertilizer requirements by 25%.

Conclusion

The results of this study demonstrated that combined application of inorganic NP and CM increased growth, yield and nutrient uptake of the potato crop, perhaps through improving soil properties and synchronizing the nutrient release with the potato growth need for nutrients. The higher net benefits were obtained at the combined chemical and CM application rates. Integrated chemical and CM application also improved the agronomic efficiency of fertilizer use. Therefore, adopting the practices of combined application of inorganic NP fertilizers and CM should be encouraged in the study area for enhanced and sustainable production of the crop.

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