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Influence of Combined Application of Inorganic N and P Fertilizers and Cattle Manure on Quality and Shelf-Life of Potato (*Solanum tuberosum* L.) Tubers

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Abstract

Potato tuber qualities, including dry matter content, specific gravity, total soluble solids, and crude protein content, are important parameters for human consumption. Tuber physiological weight loss, rotting, and sprouting during storage are important aspects that influence the keeping quality of the crop for profitable production. These tuber quality parameters can be affected by fertilizer management in the sense that inadequate or excess fertilizer application reduces tuber quality and shelf-life. Therefore, a study was conducted during two successive cropping seasons of 2012 and 2013 to determine the effect of combined application of nitrogen, phosphorus, and cattle manure on potato tuber quality and shelf-life during storage. The treatments consisted of three rates of nitrogen (0, 60 and120 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, 15 and 30 t ha^{-1}). The experiment was laid out as a randomized complete block design (RCBD) and replicated three times per treatment. Analysis of the results revealed that the main as well as the interaction effects of the three fertilizers significantly influenced tuber quality and shelf-life characteristics. The maximum tuber N (1.736%) and crude protein (10.85%) contents were obtained in response to the combined application of 120 kg N ha^{-1} and 30 t cattle manure ha^{-1}. The maximum tuber dry matter contents of 23.48%, 21.97% and 22.085 were obtained in response to the application of 120 kg N ha^{-1}, 92 kg P_2O_5 ha^{-1} and 30 t cattle manure ha^{-1}, respectively. The combined application of the highest rates of N, P and cattle manure resulted in the specific gravity (1.18) and total soluble solid (10.44%) after harvest. However, these combined rates of the three fertilizers led to the highest physiological weight loss (27.89%) and rotten tuber (29.43%) after 90 days of storage. In conclusion, the combined application of maximum rates of inorganic N, P and organic cattle manure exacerbated the deterioration and increased decay percentage compared with the other treatments. Therefore, appropriate management of integrated fertilizer application is required to increase yield without little compromise of tuber quality and the shelf-life of ware potatoes.

Keywords

Physiological weight loss
Sprout to tuber weight ratio
Tuber dry matter content
Tuber rotting
Tuber quality
Shelf-life

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INTRODUCTION

The quality, nutritive value and shelf-life of vegetables depend upon genetic, climatic, biotic, edaphic, chemical and other factors as well as combinations of these factors. Some cultural practices including fertilizer management have significant influence on the chemical and nutritional composition of plants as well as their anatomical and morphological structure (Salunkhe *et al.*, 1991).

The potato plant assimilates nutrients from both organic and inorganic fertilizers relatively intensively due to its long vegetative growth period (Harris, 1992). Makaraviciutte (2003) reported that types of fertilizer forms, rates and their combined application can increase or decrease dry matter, starch, protein and sugar contents in potato tubers. Several investigations have shown that the dry matter content, specific gravity, and crude protein content fall with an increase in the quantity of inorganic and organic fertilizers application (Hay and Walker, 1988). On the other hand, Daniel *et al*. (2009) found higher dry matter content, specific gravity and crude protein content due to combined application of organic and inorganic fertilizers relative to the unfertilized treatments.

The storage behavior of potato tubers involves many factors. The physiological age of the seed tuber, the cultivar, the soil type, climatic conditions during the growing period as well as agronomic factors like foliage killing before maturity and date of harvest influence weight losses and changes in the chemical composition of stored tubers (Firman and Allen, 2007). Early investigation showed that different fertilizer regimes caused a change in shelf-life. Subsequently, research has been done, especially to understand the effect of N fertilization on tuber weight loss and decay although the obtained results were often inconsistent (Kolbe, 1990).

Postharvest handling of potato is a challenge due its perishable nature and losses in tuber quality after harvest is a major problem that reduces farmers' income. Refrigerated storage is too expensive for smallholder farmers (Gebre *et al.*, 2008). Therefore, the farmers need to maintain the quality of the crop until sale or consumption under sub-optimal traditional storage condition. However, deterioration in tuber quality and post-harvest losses are rapid under this condition. Therefore, improved ventilation and other conditions that reduce deterioration in tuber quality should be maintained. In addition, pre-harvest agronomic practices such as fertilizer application should be optimized considering not only its effect on yield but also on tuber quality after harvest. This is because too low and too high fertilizer application reduces tuber quality and shelf-life (Kibar, 2012). Information on the effect of application of cattle manure and their optimum dose as well as their interaction effect with N and P fertilizers on the shelf-life and different quality attributes of potato is scanty in Ethiopia in general and in north-eastern parts of the country in particular. To increase productivity, improve quality and reduce postharvest loss of potato tubers, developing appropriate nutrient management practices is indispensable. Therefore, the present study was undertaken with the objective of evaluating the impact of combined application of inorganic NP and cattle manure on the post-harvest quality and shelf-life of potato tubers. This paper presents the results of the study.

MATERIALS AND METHODS

Experimental Site and Materials

The field experiment was conducted at the research field of Sirinka Agricultural Research Center (SARC), Kobo, north-eastern Ethiopia. Geographically, the area is situated at 12º8'21''N latitude, and 39º18'21'E longitude with an altitude of 1470 metres above sea level. The mean annual rainfall of the area is 637 mm per annum, while the mean minimum and maximum temperatures are 16°C and 31°C, respectively. The soil is clay-loam in texture and has a slightly neutral (pH 7.32) reaction. The soil has contents of 1.41% organic matter, 0.12% total N, and 8.33 ppm available P (Olsen). The CEC of the soil is 35.8 meq/100 g. The soil has exchangeable calcium of 17.27 meq/100g, exchangeable magnesium of 5.2 meq/100g, exchangeable sodium of 0.33 meq/100g, exchangeable potassium of 0.52 meq/100g, and an electrical conductivity (EC) of 0.49 dS/m. During two experimental seasons, the average maximum/minimum temperatures ranged between 29.9-32.8/12-16.4°C in 2012 (Figure 1a) and 28.9-31.9/13.1-16.8°C in 2013 (Figure 1b). The average rainfall varied from 0.0-47.7mm in 2012 (Figure 1a) and 5.2-58.9 mm in 2013 (Figure 1b). The relative humidity ranged between 43-58%/40-51.8% in 2012/2013 cropping seasons.

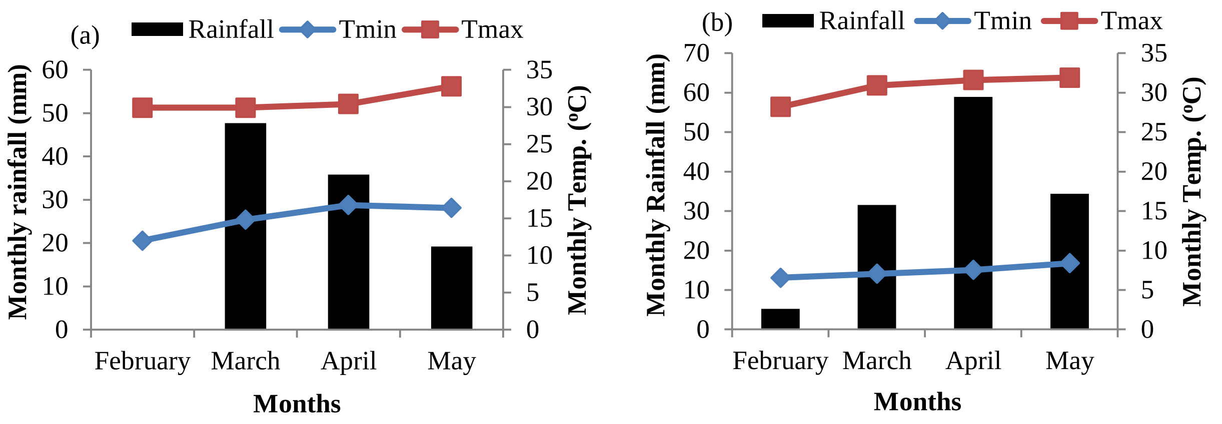

Figure 1. Monthly rainfall (mm), mean maximum (Tmax) and minimum (Tmin) temperature (°C) of the 2012 (a) and 2013 (b)

Treatments, Experimental Design and Management

The treatments consisted of three rates of nitrogen (0, 60 and 120 kg N ha^{-1}) in the form of urea (46% N); three rates phosphorus (0, 46 and 92 kg P_2O_5 ha^{-1}) in the form of triple super phosphate (45% P_2O_5) and three rates of cattle manure (CM) (0, 15 and 30 t ha^{-1}). Each treatment was laid out in a Randomized Completely Block Design (RCBD) with three replications. At planting, hills were created with distances of 70 cm between ridges and 30 cm within the ridges. The net and gross plot sizes were 7.425 and 14.63 m^2, respectively. The spacing between plots and replications were 1.0 and 1.5 m, respectively.

Full doses of P were applied as basal and N was side-dressed 5 cm away from the plants at three splits, i.e., 1/4 at plant emergence, 1/2 at the first earthing up and 1/4 at 40 days after planting. Cattle manure was spread and thoroughly pulverized with the soil one month before planting, as per the treatments. An improved potato variety *"Gera"* was used for the study, in both years due its good adaptation to the area. Planting was done on 6 February 2012 and 7 February 2013.

Data Collection for Tuber Quality

After harvesting, data on quality parameters *viz-a-viz*., tuber dry matter content, crude protein, total soluble solids (TSS) and specific gravity were collected. To determine dry matter content of tubers, five randomly selected tubers per plot were washed, sliced and 500 g sample was taken for each sample and minced into small cubes. The minced samples were weighed for fresh weight and oven dried at 70°C to constant weight. After drying, the samples were reweighed to determine the dry weight. The dry matter content was then calculated as the ratio of the dry weight to the fresh weight of sample, and expressed as a percentage according to procedures described by Biemond and Vos (1992). Tuber specific gravity was measured using the weight-in-air and weight-in-water method as described by Harris (1992). Starch content of tubers was determined according to Burton (1984):

Starch (%) = 17.546+199.07(SG - 1.0988)
where, SG: specific gravity of tubers

To determine total soluble solid (TSS), tubers were washed, sliced in small pieces and the juice from the sliced tubers was extracted with a juice extractor (6001, model No. 31JE35 6x.00777) and filtered using cheese cloth with two layers. Two drops of the clear juice were applied on a prism of a hand refractometer (AtagoAtc-1E, Japan), that has a range of 0 to 32°Brix, and a resolution of 0.2°Brix, as described by Cox and Pearson (1962). Between the intervals of sampling, the prism of the refractometer was washed with distilled water and dried before use. The refractometer was standardized against distilled water (0% TSS).

Nitrogen percentage in the potato tubers was determined at harvest using Kjeldhal procedure (Jackson, 1958). Crude protein estimation was carried out by multiplying the total nitrogen by a factor 6.25 using the Kjeldhal apparatus as described by Bolton (1962) method.

Evaluation of Storage Behavior

To evaluate tuber shelf-life, 1 kg (~10 tubers) were randomly taken from each plot. The samples were cured for 10-days after harvest in order to heal wounds. After curing, tubers were stored for 90 days. The storage room has two openings, one on the top north, and the other in the bottom south directions to facilitate air circulation. The doors were opened at night and closed during day time to balance cold and hot air within the storage. Physiological weight loss was determined by periodical weighing of potato tubers at 0, 15, 30, 45, 60, 75 and 90 days after storage during the 2012 and 2013 cropping seasons. The differential weight losses were calculated for each interval and converted into percentage by dividing the change with the initial weight recorded at each sampling interval. The cumulative physiological weight loss was expressed in percent with respect to different treatments. The difference between the initial weight and successive weights gave the rate of weight loss (as percentages) as described by Khurana and Singh (1984):

$$\mathrm{WL}(\%) = \frac{\mathrm{WI} - \mathrm{Wi}}{\mathrm{WI}} \times 100$$

where, WL: weight loss; WI: weight initial; Wi: weight at i^{th} days of storage.

At the end of the three-month storage period, the level of tuber rotting was evaluated by recording the numbers of tubers rotten. Rotten tuber (%) was determined using the following formula:

$$\mathrm{RT}\ (\%) = \frac{\mathrm{No.\,RT\ per\ treatment}}{\mathrm{T\ No.\,ST\ per\ treatment}} \times 100$$

where, RT: rotten tubers; No. RT: umber of rotten tubers; T No. ST: total number of stored tubers.

Similarly, additional 5 tubers were sampled to evaluate sprout to tuber weight ratio. After 90 days of storage, the sprouts were removed from the tubers and weighed separately. Sprout to tuber weight ratio was calculated as the weight of sprouts divided by the weight of sprouted tubers based on the method described by Krijthe (1962).

Data analysis

The data were subjected to analysis of variance (ANOVA) for each variable using SAS (Version 9.1, SAS Institute, 2002) software. Homogeneity of variance was tested using F-test as illustrated by Gomez and Gomez (1984) and the F-test has shown that there were no significant differences between results of the two cropping seasons. Consequently, combined analysis of the two-year data was carried out. Differences among treatment means were delineated using the Duncan's Multiple Range Test (DMRT) at 5% level of significance).

RESULTS

Tuber Quality

Dry matter content (%): The main effects of N, P and CM had significant influences on the dry matter contents of tubers (Figure 2). With increase in the rate of N tuber dry matter content increased significantly. Thus, the highest value (23.48%) was attained at 120 kg N ha^{-1}. Application of 46 and 92 kg P_2O_5 ha^{-1} did not result in any significant difference in tuber dry matter content. Moreover, no significant difference was observed between 0 and 15 t CM ha^{-1}. Therefore, the highest tuber dry matter contents (21.97% and 22.085) were obtained at 92 kg P_2O_5 ha^{-1} and 30 t CM ha^{-1}, respectively (Fig. 2)

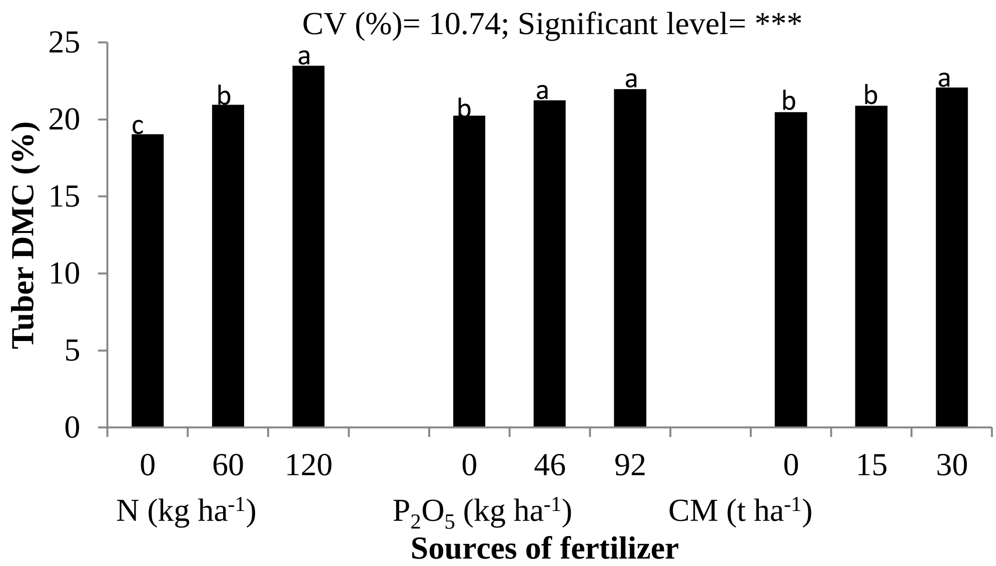

Figure 2. Main effects of N, P and CM on the dry matter content (DMC) of potato tubers (pooled data of 2-year).

Specific gravity: Combined application of N, P and CM significantly affected specific gravity of tubers (Table 1). At nil rate of P and CM, application of 120 kg N ha^{-1} significantly influenced the specific gravity; while no significant differences were observed when N was applied at 0 or 60 kg ha^{-1} (Table 1). Keeping the rate of N and P at nil, specific gravity increased significantly in response to increasing the rate of CM. The highest specific gravity (1.1817) of the potato tubers was recorded in response to the combined application of 120 kg N ha^{-1}, 46 kg P_2O_5 ha^{-1}and 30 t CM ha^{-1} (Table 1).

Starch (%): Application of N, P and CM had significant effect on starch content of tubers (Table 1). In response to increasing the rates of N without P and CM, starch content significantly increased. Similarly, it increased significantly all over the increment of CM at nil rate of both N and P; however, starch was insignificantly affected by P fertilizer without N and CM (Table 1). Even though the increments were inconsistent, starch content was increased with the increase in the rates of three fertilizers. Thus, the highest starch (34.0%) was attained in response to the combined application of 120 kg N ha^{-1}, 46 kg P_2O_5 ha^{-1} and 30 t CM ha^{-1} (Table 1).

Table 1. Interaction effects of N, P and CM on specific gravity, starch, and total soluble solids (TSS) of potato tuber (pooled data of 2-year)

N rate (kg ha^{-1})	P_2O_5 rate (kg ha^{-1})	CM (t ha^{-1}): Specific gravity 0	15	30	Starch (%) 0	15	30	TSS (°Brix) 0	15	30
0	0	1.062^{fgh}	1.125^{de}	1.154^{bc}	10.2^{gh}	22.8^{de}	28.5^{bc}	4.16^{p}	5.2^{no}	5.46^{m}
	46	1.047^{i}	1.070^{fgh}	1.058^{hi}	7.2^{h}	11.8^{fg}	9.5^{gh}	4.22^{p}	5.38^{mn}	5.47^{lm}
	92	1.072^{fgh}	1.058^{hi}	1.082^{f}	12.2^{fg}	9.5^{gh}	14.1^{f}	5.07^{o}	5.68^{k}	6.12^{j}
60	0	1.082^{f}	1.075^{fg}	1.115^{e}	14.1^{f}	12.8^{fg}	20.8^{e}	5.39^{mn}	6.35^{i}	6.56^{h}
	46	1.067^{fgh}	1.082^{f}	1.158^{b}	11.2^{fg}	14.1^{f}	29.4^{b}	5.43^{m}	6.15^{ij}	7.04^{g}
	92	1.073^{fgh}	1.118^{e}	1.153^{bc}	12.5^{fg}	21.4^{e}	28.4^{bc}	5.68^{kl}	5.80^{k}	7.08^{g}
120	0	1.138^{cd}	1.147^{bc}	1.177^{a}	25.4^{cd}	27.1^{a}	33.1^{bc}	6.28^{ij}	8.78^{e}	9.68^{c}
	46	1.115^{e}	1.155^{b}	1.182^{a}	20.8^{e}	28.7^{bc}	34.0^{a}	8.38^{f}	9.25^{d}	9.92^{b}
	92	1.122^{e}	1.178^{a}	1.180^{a}	22.1^{de}	33.8^{a}	33.7^{a}	8.36^{f}	9.43^{d}	10.44^{a}
Significance level			***			***			***	
CV (%)			1.31			14.35			2.67	

Means followed by the same letter are not significantly different at P < 0.05; *** significant at P < 0.001 level of probability according to the Duncan's Multiple Range Test (DMRT).

Table 2. Interaction effects of N and CM fertilizers on nitrogen and crude protein content of potato tubers (pooled data of 2-year)

Nitrogen (kg N ha^{-1})	CM (t ha^{-1}): Tuber nitrogen content (%) 0	15	30	CM (t ha^{-1}): Crude protein (%) 0	15	30
0	0.946^{i}	1.393^{f}	1.474^{d}	5.91^{i}	8.708^{f}	9.209^{d}
60	1.368^{h}	1.378^{g}	1.414^{e}	8.548^{h}	8.619^{g}	8.836^{e}
120	1.514^{c}	1.668^{b}	1.736^{a}	9.465^{c}	10.428^{b}	10.85^{a}
Significant level		***			***	
CV (%)		0.338			0.34	

Means followed by different letter(s) differ significantly at P < 0.05; *** significant at P < 0.001 level of probability according to the Duncan's Multiple Range Test (DMRT)

Total soluble solids (TSS): The combined application of N, P and CM fertilizers had significant effect on TSS of tuber (Table 1). The highest TSS (10.44 °Brix) was obtained due to the combined application of 120 kg N, 92 kg P_2O_5 and 30 t CM ha^{-1}; while that of the control was 4.16 °Brix. The TSS significantly increased with increasing the amount of N and CM without applying P. Without application of P and CM, the TSS increased in response to the increased application of N. without applying both N and CM, the TSS significantly increased with increasing the amount of P from 46 to 92 kg ha^{-1} and CM from 15 to 30 t ha^{-1} (Table 1)

Nitrogen content in tubers (%): Tuber N content was significantly affected by combined application of N and CM (Table 2). Keeping the rate of CM at 0 level, tuber N content was significantly increased over all three rates of nitrogen. Similarly, at nil rates of N, tuber N content was increased with increasing rates of CM. In response to increasing the rate of N, tuber N content was increased over all rates of CM. Hence, the highest tuber N content (1.736%) was recorded for the combined application of 120 kg N ha^{-1} and 30 t CM ha^{-1}; while the lowest N content (0.946%) was attained in the control treatment (Table 2).

Crude protein (%): Significant differences in tuber crude protein content were observed following a combined application of N and CM (Table 2). When the rate of N was kept at nil, crude protein increased over all the increment of CM. Similarly, it was increased with increasing the rates of nitrogen from 0 to 120 kg N ha^{-1}at nil rate of manure. Increasing the rates of N, crude protein significantly increased all over the three rates of CM. Thus, the highest crude protein (10.85%) content was therefore obtained from plots treated with 120 kg N ha^{-1} combined with 30 t CM ha^{-1} whereas the lowest value (5.91%) was recorded at unfertilized treatment (Table 2)

3.2. Shelf life of potato tuber

Physiological weight loss (%): When compared with the control treatment, significant loss in weight of potato tubers was observed in response to pre-harvest integrated application of N, P and CM at different storage periods (Table 3). At all (15, 30, 45) of the days compared after storage, physiological weight losses (PWL) of the stored tubers significantly increased with an increase in the amount of both N and P, whether the amount of applied CM was 0, 15 or 30 t ha^{-1}. Fifteen days after storage, in the absence of N and P, no significant differences in PWL were observed between tubers obtained from plots treated with either 15 or 30 t ha^{-1} of CM. Keeping the application rate of P and CM at zero level, PWL of tubers were significantly increased with increasing N application along with all storage periods. Similarly, significant increment in PWL of tubers was observed with increasing the rates of P from 0 to 92 kg ha^{-1} even without application of N and CM (Table 3).Generally, in most of the cases, at a specific amount of N and P applied together, increasing the amount of CM from 0 to 30 t ha^{-1} significantly increased PWL of the potato tubers (Table 3).

Tuber rotting (%): Pre-harvest integrated applications of N and P with CM had a significant influence on tuber rotting during storage (Table 4). At nil rates of N and P, increasing the amount of CM from 0 to 30 t ha^{-1} did not result in any significant difference in the percentage of rotted tubers. Similarly, at nil rates of N and CM, increasing the rates of P did not result in any significant difference in tuber rotting. The percentage of rotten tubers increased with increasing the combined applications of N, P and CM. Thus, the highest rotten tuber (29.43%) was attained at the combined application of 120 kg N, 92 kg P_2O_5 and 30 t CM ha^{-1} (Table 4).

Sprout to tuber weight ratio (%): As a result of combined application of N and P and N and CM sprout to tuber weight ratio significantly increased in potato tubers stored at ambient condition (Table 5). Increasing the combined application of N and P as well as N and CM significantly increased the sprout to tuber weight ratio. Hence, the highest values (8.80% and 8.66%) were recorded due to pre-harvest application of 120 kg N ha^{-1} combined with 92 kg P_2O_5 ha^{-1} as well as 120 kg N ha^{-1} combined with 30 t CM ha^{-1}, respectively. However, when the application rate of N was kept at 60 kg ha^{-1}, increasing the rates of CM from 15 to 30 t ha^{-1} did not result in any significant difference in sprout to tuber weight ratio (Table 5)

Table 3. Physiological weight loss of potato tuber subjected to the combined effect of pre-harvest inorganic-NP and organic-CM fertilizers during storage period of 90 days at ambient storage conditions (pooled data of 2-year)

N rate (kg ha^{-1})	P_2O_5 rate (kg ha^{-1})	CM rate (t ha^{-1})								
		0	15	30	0	15	30	0	15	30
		Weight loss (%)								
		15 days after storage			30 days after storage			45 days after storage		
0	0	1.88^{u}	2.45^{s}	2.56^{s}	2.87^{2a}	3.38^{z}	4.59^{x}	4.25^{r}	5.30^{q}	6.74^{op}
	46	2.05^{t}	3.20^{r}	3.75^{p}	3.58^{y}	5.88^{w}	6.97^{u}	5.75^{pq}	7.62^{no}	9.01^{m}
	92	3.36^{q}	4.06^{o}	4.37^{mn}	6.25^{v}	7.59^{t}	8.24^{r}	8.48^{mn}	10.14^{l}	10.44^{kl}
60	0	4.25^{n}	4.5^{m}	4.76^{l}	7.99^{s}	8.61^{q}	9.04^{o}	10.41^{kl}	10.81^{jkl}	11.68^{hij}
	46	4.65^{l}	5.16^{k}	5.31^{j}	8.79^{p}	9.79^{n}	10.10^{l}	11.49^{ijk}	11.94^{ghi}	12.75^{fgh}
	92	5.26^{jk}	6.02^{i}	6.46^{gh}	9.99^{m}	11.51^{k}	12.38^{i}	12.65^{gh}	13.78^{ef}	14.17^{e}
120	0	6.37^{h}	6.57^{fg}	6.84^{e}	12.21^{j}	12.51^{h}	13.16^{f}	13.94^{e}	14.28^{e}	15.41^{d}
	46	6.62^{f}	6.93^{e}	8.14^{c}	12.71^{g}	13.32^{e}	15.76^{c}	12.78^{fg}	15.80^{d}	18.24^{b}
	92	7.59^{d}	8.76^{b}	9.05^{a}	14.66^{d}	17.02^{b}	17.59^{a}	17.06^{c}	19.22^{ab}	19.89^{a}
Significant level		***			***			**		
CV (%)		1.02			0.37			7.88		

N rate (kg ha^{-1})	P_2O_5 rate (kg ha^{-1})	CM rate (t ha^{-1})								
		0	15	30	0	15	30	0	15	30
		Weight loss (%)								
		60 days after storage			75 days after storage			90 days after storage		
0	0	5.69^{y}	6.96^{x}	8.83^{v}	7.00^{y}	8.58^{x}	10.75^{v}	8.34^{2a}	10.25^{z}	12.48^{x}
	46	8.00^{w}	9.63^{u}	10.99^{s}	10.18^{w}	11.64^{u}	12.82^{s}	12.07^{y}	13.89^{w}	14.67^{u}
	92	10.58^{t}	12.18^{r}	12.64^{q}	12.56^{t}	14.10^{r}	14.8^{q}	14.21^{v}	15.78^{t}	17.12^{r}
60	0	12.49^{q}	13.25^{p}	13.95^{n}	14.3^{r}	15.44^{p}	16.23^{n}	16.38^{s}	17.67^{q}	18.58^{o}
	46	13.62^{o}	14.45^{m}	15.50^{k}	15.90^{o}	16.79^{m}	17.61^{l}	18.07^{p}	18.87^{n}	19.60^{l}
	92	15.04^{l}	16.05^{j}	16.32^{i}	17.50^{l}	18.00^{k}	18.56^{i}	19.35^{m}	20.19^{k}	21.19^{i}
120	0	16.15^{j}	16.63^{h}	17.91^{f}	18.32^{j}	19.18^{h}	20.65^{f}	20.83^{j}	21.99^{h}	23.47^{f}
	46	17.28^{g}	18.43^{e}	20.77^{c}	20.11^{g}	21.36^{e}	22.90^{c}	23.12^{g}	24.40^{e}	25.54^{c}
	92	19.40^{d}	21.59^{b}	22.35^{a}	22.33^{d}	23.88^{b}	25.10^{a}	25.04^{d}	26.36^{b}	27.89^{a}
Significant level		***			***			***		
CV (%)		1.02			1.11			1.02		

Means followed by different letter differ significantly at $P < 0.05$; ***significant at $P < 0.001$ level of probability according to the Duncan's Multiple Range Test (DMRT).

DISCUSSION

Tuber Quality

Some of the external and internal quality parameters that can be used to discriminate quality of potato tubers include tuber dry matter content, specific gravity, TSS, total nitrogen and crude protein(Vaezzadeh and Naderidarbaghshah, 2012).). At the farm-level, vegetable producers are faced with lack of modern input supply and high postharvest losses. It is expected that these potato tuber quality parameters can be influenced by either by the genetic composition of the variety in question or agronomic practices (Lin *et al*., 2004).

Dry matter content (%): Depending on the mineral fertilizer forms, rates and nutrient ratios, the contents of dry matter, may either increase or decrease .Too little N retards leaf growth, accelerates leaf senescence and therefore reduces the amount of incident solar radiation intercepted and consequently the dry matter content (Baniuniene and Zekaite, 2008). In the present study, the increase in tuber dry matter content by 23.38% over the control in response to the increased application of nitrogen demonstrates that more partitioning of dry matter to tubers as a result of nutrition in the treatment receiving N application. In accordance with this result, Kandil *et al*. (2011) reported that the highest average dry matter content after harvest was increased with rising nitrogen application. Similarly, Naz *et al.* (2011) found maximum dry matter content after harvest when the potato crop was grown at 140:140:210 NPK fertilizer proportion.

Table 4. Effect of pre-harvest integrated application of N, P and CM on the rotting of potato tubers after 90 days of storage (pooled data of 2-year)

Nitrogen ($kg\ N\ ha^{-1}$)	Phosphorous ($kg\ P_2O_5\ ha^{-1}$)	CM ($t\ ha^{-1}$) 0	15	30
		Rotten tuber number (%)		
0	0	17.18^{m}	17.20^{m}	17.25^{m}
	46	17.15^{m}	17.17^{m}	19.25^{l}
	92	17.20^{m}	17.48^{m}	22.29^{g}
60	0	17.33^{m}	17.45^{m}	23.78^{e}
	46	17.55^{m}	19.93^{jk}	21.53^{i}
	92	21.78^{hi}	22.05^{h}	23.58^{e}
120	0	19.30^{l}	20.08^{j}	23.01^{f}
	46	19.65^{kl}	25.57^{d}	26.45^{c}
	92	26.52^{c}	27.10^{b}	29.43^{a}
Significant level			***	
CV (%)			1.71	

Means followed by the same letter within columns and rows are not significantly different at $P < 0.05$; *** significant at $P < 0.001$ level of probability according to DMRT

Table 5. Pre-harvest application effects of N×P and N×CM fertilizers on sprout to tuber weight ratio of potato tubers after 90 days of storage (2 years pooled data)

Nitrogen ($kg\ N\ ha^{-1}$)	Phosphorous ($kg\ P_2O_5\ ha^{-1}$) 0	46	92	CM ($t\ ha^{-1}$) 0	15	30
	Sprout to tuber weight ratio (%)					
0	6.72^{i}	7.07^{h}	7.33^{g}	6.87^{h}	7.08^{g}	7.17^{f}
60	7.53^{f}	7.75^{e}	7.91^{d}	7.62^{e}	7.73^{d}	7.80^{d}
120	8.16^{c}	8.44^{b}	8.80^{a}	8.28^{c}	8.46^{b}	8.66^{a}
Significant level		***			***	
CV (%)		1.07			1.07	

Means followed by the same letter are not significantly different at $P < 0.05$; *** significant at $P < 0.001$ level of probability according to the Duncan's Multiple Range Test (DMRT)

In contrast to the results of this study, excessive nitrogen fertilization reduces dry matter content in tubers (Sincik *et al.*, 2008). This result from the fact that

nitrogen promotes growth of potato vines and by the time of harvesting, tubers may not have been able to mature completely and reach maximal dry matter content. Similar results are reported by Zelalem *et al*. (2009) and Öztürk *et al*. (2010) that increasing soil nitrogen content led to decrease in dry matter content of potato tubers. Sebastiani *et al*. (2007) indicated that excess N rates significantly reduced tuber dry matter content due to vigorous growth of the plants which produced more above ground vegetative parts competing for photosynthates necessary for tuber development. Zaag (1992) found that small applications of nitrogen increased the dry matter content of the tubers, whereas large applications tend to the opposite effect. Considering this result, there seems to be some difficulty in managing the nitrogen fertilization to maximize simultaneously the dry matter content and production (Rodrigues *et al*., 1998).

Phosphorus plays significant role in physiological and biochemical reactions such as photosynthesis, transfer characteristics, and convert sugar into starch in plant (Taheri *et al*., 2011). The increase in tuber dry matter content in

response to increasing the rate of P application signify that phosphorus is an important nutrient for enhancing production of photassimilate and starch storage in tubers. This suggestion is consistent with that of Kumar *et al*. (2013) who stated that P increases photosynthesis, and indicated that translocation of photosynthates from source to sink has occurred up to maturity as a result of increased nutrient absorption. On the other hand, Rosen and Bierman (2008) found no response of tuber dry matter content to increased P application. Similarly, non-significant differences in dry matter contents of the tubers in response to increased P application were reported by Sparrow *et al.* (1992).

The significant difference in dry matter content of tuber in response to increased application of cattle manure could be explained by the phenomenon that cattle manure is a source of macro and micro nutrients the uptake of which may have resulted in enhanced growth, photosynthesis, starch and dry matter accumulation in the tubers. Similar findings were reported by Raupp (1996) who reported a positive effect of organic fertilizer on dry matter contents of vegetables.

Specific gravity: Specific gravity, which is one of the most important quality traits of potatoes, provides a fast and easy measure of dry matter content (Hay and Walker, 1988). Optimum plant nutrient concentrations are essential for maintaining high vine and tuber growth rates over the entire growing season. In this study, the result showed that combined application of inorganic and organic fertilizers had positive effects on specific gravity. This could be due application of manure may provide macro and micro nutrients and promotes vegetative growth and plants have enough time to mature and accumulate starch to the tubers resulted in higher specific gravity. This suggestion is consistent with that of N'Dayegamiye *et al*. (2013) who reported that the specific gravity of tubers in plots amended with organic fertilizers ranged from 1.070 to 1.073, and was significantly increased by organic amendment and mineral fertilizer application. Helaly *et al.* (2009) found that specific gravity was increased with increasing rates of nitrogen. Abou-Hussein *et al*. (2003) found that application of cattle with chicken manures increased specific gravity. Soliman *et al*. (2008) showed that addition of 50% chicken manure combined with 50% mineral fertilizers (NPK) resulted in the highest values of tubers dry matter (%) and specific gravity at harvest. Conversely, Abo-Sedra and Shehata (1994) reported that specific gravity of potato tubers was not affected by application of nitrogen at the rate of 180 kg N ha^{-1}.

Starch (%): The integrated use of inorganic and organic fertilizers not only improved the yield but also benefited for quality i.e., starch content. Increase in starch content in response to increased application of N, P, and CM could be attributed to enhanced growth and photo-assimilation due to better nutrient uptake (Perrenoud, 1993). In this regard, Taheri *et al*. (2011) reported that Fertilizers and manure in the soil increased phosphorus uptake by plants; and hence, phosphorus plays significant role in physiological and biochemical reactions such as photosynthesis, transfer characteristics, and convert sugar into starch in plant. Similar result was reported by Susan *et al.* (2003) that balanced application of NPK at 100:50:100 kg ha^{-1} combined with FYM at 12.5 t ha^{-1} was beneficial in maintaining starch content of cassava tubers.

Total soluble solids (ºBrix): Total soluble solids in potato tuber is a function of the amount of pectin and the density of the finished product much of which is related to the ability to take up nutrients and convert sucrose to carbohydrate in the tuber (Kandil *et al*., 2011). In the current study, TSS responded positively to the combined use of inorganic NP and cattle manure. The positive results of TSS by the addition of manure might be due to availability of nutrients in addition to nitrogen and phosphorus fertilizers which improve the dry matter production of tubers through increasing the nutrients uptake by the plant. Increased TSS of tubers at the time of harvest due to combined application of inorganic and organic fertilizers was reported by Kandil *et al*. (2011). The results however contradicts the finding of Abou-Hussein *et al*. (2003) who reported that application of cattle with chicken manures reducing the content of TSS.

In the other studies, an increase in TSS with combined application of chemical fertilizers and poultry manure was not only observed in potato tubers (Islam *et al*., 2013), but it was also observed in tomato fruits (Chatterjee *et al*., 2008) and onion bulbs (Fatideh and Asil, 2012). Hailu *et al*. (2008) also reported that the pre-harvest combined orga and urea treatment at the rates of 309 kg ha^{-1} and 68.5 kg ha^{-1}, respectively, resulted in better accumulation of total soluble solids of carrot at the time of harvest.

Nitrogen content in tubers (%): The chemical composition of any plant is an important parameter to compare the performance of treatments applied (Kolbe *et al*., 1995; Abdel-Ati, 1998; Abazar *et al*., 2011). In this study, the N content in potato tubers was higher due to the combined application of N and CM. This might be due to the fact that the application of cattle manure increased microbial activity and nitrogen concentration; and has the synergistic effects of organic amendments with mineral N fertilizer on N uptake; and the N distribution to tubers could increased by the increased supply of N (Ghosh *et al*., 2000). These results show that additional mineral N fertilizer is necessary to satisfy crop N nutrition following organic amendments, as it is evident that applying nitrogen fertilizers increases tuber N concentration (White *et al*., 2009). In addition, this could be due to better availability of desired and required nutrients in the crop root zone resulting from its solubilization caused by the organic acids produced from the decomposed cattle manure and also the increased uptake by potato root due to their association with mycorrhizal filaments increasing the ascribing area of roots. Moreover, application of manure to the soil may provide K which may be attributed to the vital role in physiological processes inside the plant, enzyme activities, water absorption and transpiration that reflected on N-accumulation. These results are in accordance with those reported by (El-Sirafy *et al*., 2008). On the other hand, nitrogen was applied in split form, which could help to reduce N by leaching, volatilization and etc., and is important to keep the loss of this nutrient and crops can easily use and accumulated within their storage organs (Vos, 1999).

Crude protein (%): The effect of integrated nutrient management on potato tuber crude protein content is well documented (Honeycutt, 1998; Kandil *et al*., 2011). In the current study, differences in crude protein content among different doses of inorganic-N combined with cattle manure agreed on that finding. The high crude protein content might be due to higher nitrogen content in tubers of these treatments as cattle manure supplements additional nitrogen to the soil uptake of nitrogen improved as well. It is known that crude protein content is higher with mineral than with organic fertilization (Raupp, 1996). The positive effect of N fertilization on tuber crude protein content has already been reported by Bártová *et al*. (2008) and also confirmed by the current experiment. Similarly, Öztürk *et al*. (2010) reported that the crude protein contents of tubers significantly increased with increasing nitrogen dose. However, cattle manure and other organic fertilizers with high nitrogen availability can increase the crude protein content on a similar level as it is achieved by mineral fertilizers (Raupp, 1996). In this regard, Kandil *et al*. (2011) reported that due to combined application of mineral nitrogen fertilizer (238 Kg N ha^{-1}) and chicken manure (158 Kg N ha^{-1}), crude protein in tubers ranged from 15.21% to 17.29 %. Moreover, Matiwos and Shashidhar (2011) found the highest crude protein content in tuber (8.98%) with the application of 100:75:100 $N:P_2O_5:K_2O$ kg ha^{-1} fertilizer + 25 t FYM $ha^{-1.}$

Shelf Life and Storage Behavior of Tuber

Physiological weight loss (PWL): The significant increase in PWL during extended storage time could be caused because of loss of moisture from the tubers and depletion of carbohydrate reserves as a result of respiration (Kader and Rolle, 2004). In accordance with this result, Burton *et al.* (1992) indicated that PWL is mainly caused by respiration, sprouting, evaporation of water from the tubers, spread of disease, changes in chemical composition and physical properties of the tuber and damage by extreme temperatures. Schulz and Köpke (1996) described an increase in weight loss due to a more intense pre-harvest fertilization. Kolbe *et al*. (1995) reported that weight losses were enhanced after N and K fertilization and decreased by increasing P supply. Mehta and Singh (2002) concluded that the combined application of NPK and FYM resulted in higher storage losses compared with FYM alone. In another study, Mark *et al*. (2003) reported that excessive N fertilization resulted in increased PWL in sweet potato during storage. Hailu *et al*. (2008) reported that increasing inorganic-N fertilizer application combined with organic-P resulted in PWL of carrot stored under ambient conditions. Fatideh and Asil (2012) obtained the minimum physiological loss in weight for onion due to 100 kg N ha^{-1} as compared to 150 kg N ha^{-1}during 60 days of storage.

Tuber Rotting (%): In this study**,** the use of inorganic NP fertilizers and cattle manure in the production of potato resulted in decrease the storability of the crop. This could be due to the high nutrient doses which may have decreased some of the antioxidant content, probably due to rapid growth and development, and thus preferential allocation of resources directed to growth processes rather than secondary metabolism. In this regard, Toivonen and Hodges (2011) and Ghazavi and Houshmand (2010) reported that relatively high pre-harvest nutrient resulted in gradual chemical decomposition, involving the breakdown of starch, resulting in significant weight and decay percentage loss in storage. The favorable effects of P-fertilizer on tuber decay at the end of storage period could be explained through the great role of P element which is extremely important as a structural part of many compounds in plant, such as phosphoproteins, phospholipids, nucleotides and notable nuclic acids (El-Sayed *et al*., 2011). The results of this study also corroborate those found by Saif-EI-Deen (2005) who reported that decay was negatively correlated with P application rates.

Sprout to tuber weight ratio (%): Sprouting is the major problem during storage. Extension of storage life and a reduction in post storage loss by appropriate pre-harvest nutrient management would help to ensure a steadier supply and stabilize the prices of tubers. In the current study, tubers obtained from pre-harvest treatments of N, P and CM produced a high sprout to tuber weight ratio. This is because sprouting during storage depends on the pre-harvest integrated nutrient management during growth. In agreement with this result, Kumar *et al*. (2013) reported that potato crops grown with higher doses of nutrients tend to sprout earlier during storage. The same authors reported too low applications of nutrients, e.g., N fertilizer can adversely affect the crop, reducing growth and yield or delaying maturity and compromising storability. Kandil*et al*. (2011) mentioned that combined application of 20 t ha^{-1}cattle manure with 396 kg N ha^{-1} resulted in the highest value of sprout length (5.34 cm) after storage compared to sprout length (3.71 cm) obtained from the tubers grown with manure alone. In contrast, Ghorbani *et al*. (2008) reported that poultry manures showed a promising performance for improving storage life of tomato; and suggested that this improvement in storability is due to thicker skin and less acidic juice

CONCLUSION

The quality of potato tuber at harvest and storability during storage rely on the pre-harvest application of different fertilizer treatments. The dry matter content, specific gravity, nitrogen and crude protein content and total soluble solids of tubers at harvest were significantly affected by the combined application of organic and inorganic fertilizers. On the other hand, higher physiological weight losses, decay of tubers and the capacity to sprouting during storage were recorded in tubers produced from combined application of inorganic and organic fertilizers at higher rates. From the result of this 2-year study, it may be concluded that combined application of 120 kg N ha^{-1}, 92 kg P_2O_5 ha^{-1} and 30 t CM ha^{-1} gave higher total tuber yield and is a good compromise for storability of tubers under ambient storage conditions. Combined use of inorganic NP and cattle manure fertilizers along with storage management practices for optimum yield, quality and long shelf life of tubers requires further studies under different agro-climatic conditions and storage seasons.

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