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Effects of inorganic fertilizer on growth, yield and quality of Irish potato (*Solanum tuberosum* L.) grown in synthetic plastic bags

Masimba Rumhungwe, Wisdom Kurangwa, Edmore Masama* and Lovejoy Tembo

Department of Agricultural Management, Harare Region, Zimbabwe Open University, P. O. Box MP 1119, Mount Pleasant, Harare, Zimbabwe.

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A field experiment was carried out with the Irish potato (*Solanum tuberosum L.*) variety BP1 to determine the effect of inorganic fertilizer (Compound C) on the growth rate, yield and quality of potatoes grown in bags. The experiment was laid out in a randomized complete block design (RCBD) with five treatments replicated four times, giving a total of 20 plots. In each plot, 5 plants were planted to give a total plant population of 100. The treatments comprised of Compound C fertilizer applied as a basal fertilizer at (1) 1800 kg/ha (2) 1400 kg/ha (3) 1000 kg/ha, (4) 600 kg/ha, and (5) control in which no fertilizer was applied. In addition, a top dress of ammonium nitrate was applied at 3 weeks after emergence (WAE) at a rate of 200 kg/ha in all treatments except the control. Parameters evaluated included average plant height at 2 WAE up to maturity, number of stems per plant, number of tubers per plant, yield per hectare, tuber sizes and percentage of marketable tubers. The results showed that there was a significant difference (P<0.05) in all the parameters measured. Treatment 2 (1400 kg/ha) recorded the highest yield of potato tubers per hectare (19.2 t/ha), while the control treatment (0 kg/ha) had the lowest yield (4.0 t/ha). Treatment 2 had the highest number of marketable tubers (87%), while the control (0 kg/ha) had the lowest (54%). From the results of the study, it can be concluded that basal dress of Compound C at a rate of 1400 kg/ha plus a top dressing rate of 200kg/ha of ammonium nitrate can be used in bag potato production. Further research should be conducted to investigate the appropriate type of fertilizer that can be used in bag potato production.

Key words: Inorganic fertilizer, Irish potatoes, growth rate, quality, yield.

INTRODUCTION

Irish potatoes (*Solanum tuberosum*) belong to the order Solanales in the Solanaceae or nightshade family of flowering plants (Ross, 1979; Grun, 1990). It originated in the South American Andes but its heartland of wild genetic diversity stretches from Venezuela, Columbia, Ecuador, Peru, Bolivia, Argentina to Chile (Grun, 1990;

*Corresponding author. E-mail: edmasama@yahoo.com. Tel: +263772125947.

Hawkes, 1990). It was first cultivated 6000 years ago by Incas in Peru (Ugent et al., 1982; Quinn, 2011).

S. tuberosum is widely grown and ranks fourth among the world's food crops after wheat, rice and maize and is staple food of almost half of the world's population (Van der Zaag, 1984; Hamm and Baron, 1999; FAOSTAT, 2012). According to Tamm (2007), 100 g of the potato tuber can give the following nutrients: 79.9 g water, 78.0 kcal Energy, 16.8 g carbohydrates, 2.4 g protein, 36.0mg calcium, 49.0 mg phosphorus, 31.0 mg ascorbic acid, 2.2 mg niacin, 1.1 mg iron, 0.12 mg thiamine and 0.06mg riboflavin. Irish potatoes simply boiled, baked or roasted, are an inexpensive and nutritious source of carbohydrate calories and good quality protein (Woolfe and Poates, 1987). Potato protein like that of legumes is high in lysine and low in sulphur-containing amino acids, making them a good nutritional staple food for adults (Bouis and Scott, 1996). Potato skins are an excellent source of vitamin C which prevents scurvy in children (Woolfe and Poates, 1987). Potato tubers can also be used in the manufacture of starch, spirits and industrial alcohol (Mujaya and Mereki, 2010).

Irish potato is a seasonal crop grown in temperate zones all over the world but primarily in the northern hemisphere (FAOSTAT, 2012). Potatoes generally require a high altitude of about 1200 m above sea level, cool temperatures ranging between 15 and 20°C and high rainfall ranging between 1000 and 1500 mm per year (Gusha, 2014). This explains why in Zimbabwe potato farming is very successful in the Eastern Highlands particularly in Nyanga and Mutasa districts (Gusha, 2014; Mujaya and Mereki, 2010).

Growing potatoes in bags or sacks was a method adopted from Israel and the United States of America where it helped in the use of discarded bags, less use of pesticides in diseases control, controlled use of fertilizer, preservation of moisture, and use of limited space in urban areas (Gusha, 2014). It improves food security especially of urban population that has limited land for crop production (Hamm and Baron, 1999; Quin, 2011; Didur and Volunteers, 2014). Economically, it creates a better local economy that produces its own food reducing importation of agricultural food products (Mubvami, 2011). Environmentally, it increases the amount of food grown and bought locally, decreasing carbon footprint (Hamm and Baron, 1999).

Didur and Volunteers, (2014) suggested that although 3 kg per plant has been recorded to be the optimum, yields of 1 kg per plant and below have been recorded when potatoes were grown in bags in the United States of America. In Africa, it is believed most initiatives in line with bag potato gardens are being done in Nairobi, Kenya. In Kenya bag potato yields recorded in 2010 averaged 1 kg per plant and these low yields have been blamed on failure to use clean seeds, fertilizers, fungicides and irrigation (Quin, 2011).

Bag potato production is a relatively new phenomenon in Zimbabwe and the majority of people embraced the method in November and December 2013 (Gusha, 2014). A number of Harare urban dwellers with small backyard gardens measuring an average of less than 50 m^2 in area (Kurangwa et al., 2014) turned to bag potato production to argument their meagre incomes (Gusha, 2014). However, the problem is that most farmers who have used this method got poor yields of less than 2 kg per plant characterized by very small stem tubers (Gusha and Mupangi, 2013). These poor yields may have been attributed to lack of knowledge and scarce referenced information on appropriate Compound C fertilizer rates in bag potato production. Therefore, this study sought to evaluate the effects of Compound C fertilizer rates on the growth, yield and quality of potatoes grown in synthetic plastic bags.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at Kuwadzana 2 High School in Harare. The latitude is 17° 51` 50S, 31° 1` 47E / 17,86389° S, 31,02972° E; whilst altitude is 1483 m above sea level. The area is in the natural ecological region II which has a subtropical highland climate. The average annual temperature is 17.95°C, low for the tropics, and this is due to its high altitude position and the prevalence of a cool south-easterly airflow (Surveyor General, 1995; Nyamapfene, 1991). There are three main seasons: a warm, wet season from November to March/April; a cool dry season from May to August, and a hot, dry season in September/October. The average annual rainfall is about 825 mm in the southwest, rising to 855 mm on the higher land of the northeast that is from around Borrowdale to Glen Lorne (Surveyor General, 1995). Very little rain falls during the period May to September, although sporadic showers occur most years. Rainfall varies from year to year and it follows cycles of wet and dry periods from 7 to 10 years long. According to Nyamapfene (1991), the soils in Harare are predominantly paraferrallitic soils under the kaolinitic order with a course grained sand fraction, derived from granite. The kaolinitic soils are moderately to strongly leached soils; clay fractions mainly inert together with appreciable amounts of free sesquioxides of iron and aluminium (Hussein, 1981).

Experimental design and treatments

The experiment was laid out in a randomized complete block design (RCBD) with five treatments replicated four times. The experimental plots were 20 in total and each block had 5 experimental plots. Each plot had 5 bags (with one tuber) giving a total of 100 planted tubers. The treatments comprised of different inorganic Compound C fertilizer (6% nitrogen; 17% phosphorus; 15% potassium) application rates: Treatment 1- 1800 kg ha^{-1}, Treatment 2- 1400 kg ha^{-1}, Treatment 3- 1000 kg ha^{-1}, Treatment 4- 600 kg ha^{-1} and Treatment 5 (control) with no fertilizer. All treatments were top dressed with ammonium nitrate (34.5% N) applied at a rate of 200 kg per hectare except the control. The amount of fertilizer applied in each bag was determined by dividing the amount of fertilizer per hectare per each treatment by the plant population of potatoes grown on the ground. For example: The plant population for Irish potatoes grown on ground = 37000/ha (Mujaya and Mereki, 2010). Therefore, the fertilizer rate for treatment 1 is 1800 kg/37000 plants = 48.65 g/bag.

For ammonium nitrate the rate for treatments 1 to 4 is 200 kg/37000 plants = 5.4 g/bag.

Trial establishment

Media preparation

The bottoms of the bags were filled with compost to conserve moisture (Gusha, 2014) and 15 kg of fertile red clay soil was put in each bag. Compound C was incorporated as a basal dress according to treatments and mixed thoroughly with the soil.

Planting

Planting was done on the 3rd of December 2014. One tuber was planted in each bag with 5 bags per plot. Porous polythene bags 45 cm in diameter and 65 cm high were used. The bags were placed next to each other with no spacing in the rows such that when the tubers germinate in the bags the space from one plant to another was 45 cm in row and the distance between rows was 90 cm giving a total plant population of 24666 plants per hectare. One seed tuber was planted per bag. More soil was gradually added as potato plants increased in height (McCraw, 2010).

Management

Watering

Fifteen (15) litres of water was applied per bag to ensure that the soil is saturated to field capacity at planting. Since the temperatures were expected to be high at the time of planting, watering was done at two day intervals after the initial watering for the first two weeks because potato roots grow to en effective water extraction depth of 60 cm and obtain 70% of the plants' seasonal water from the upper 30 cm depth (Hawkes, 1990). Watering cans with fine roses were used. After the first two weeks, the rains started and irrigation was only done once; there were five consecutive days without rain.

Weeding and earthing up

Weeds were removed as soon as they were appeared, before they reached a height of 5 cm. The weeds were removed physically using garden trowels. Initial earthing up was done by adding more soil into the bags once the shoots of the plants reached an average of 20 cm in height using enough soil so that just 5 cm of stem were left visible above the mound. Thereafter, more soil was added every time the plant reaches 15 cm of new growth above the soil and the process was repeated three times before harvesting.

Disease and pest control

Fungal diseases, particularly late blight (*Phytophtora infestans*) were treated using protective sprays, specifically Mancozeb (Dithane –M-45) an alkylenebisdithiocarbamate containing manganese and zinc; and copper oxychloride. A foliar spray containing copper and chlorine was sprayed at weekly intervals starting from the first week after emergence (Agrios, 1988). Alternate spraying of dimethoate and carbaryl as pesticides was done at two week intervals starting from the first week after emergence. Dimethoate is an organophosphate under the group of phosphorothiolates and carbaryl, a systemic insecticide in the sub class of phenyl carbamates and these are effective against insect pests such as potato beetles (*Leptinotarsa decemlineata*), aphids (*Myzus persicae*), leaf miners (*Lirimyza sativa*), leafhoppers (*Empoasca stevensi*) and tuberworms (*Phthorimaea operculella*) (Metcalf and Luckmann, 1994).

Top dressing

Top dressing with ammonium nitrate (AN) which was 34.5% nitrogen was applied at flowering stage (3 weeks after planting) at a rate of 200 kg per hectare.

Data collection

Plant height was recorded every 2 weeks starting from the second week after emergence. The average number of stems per plant was recorded at 10 weeks after emergence and it was also a parameter used to measure the growth rate. Average number of tubers and average weight (yield) of tubers per plant was calculated at harvesting. The quality of the potatoes was determined by the sizes of the potato tubers per plant after measuring the diameter of tubers and classifying them into small (20-35 mm), medium (35-45 mm), large (45-55 mm) and very large (>55 mm). Quality was also measured considering number of marketable and unmarketable tubers per plant. For the yield and quality, all the parameters were measured at harvesting which was carried out 110 days after planting and measurements were taken from all the plants in every plot on each treatment.

Statistical analysis

The data collected were subjected to analysis of variance (ANOVA) using Genstat 14th edition statistical package. Prior to analysis, data was transformed where necessary. Treatment means and standard errors were compared using the Tukey studentized range (HSD) test procedure in order to determine any significant differences between the treatments.

RESULTS

Average plant height of potatoes

The results show that 2 weeks after emergence (WAE), plants did not show any significant difference ($P>0.05$) in terms of plant height. At 8 WAE, significant differences were observed in plant height among the different treatments with the control recording lowest height of 44.82 cm as compared to other treatments (Table 1).

Average number of stems per plant

A significant difference ($p<0.05$) was observed among treatments with respect to number of stems per plant in treatments 2, 3 and 4 (Figure 1).

Average number of tubers per plant

The results show that there are some significant differences ($P<0.05$) among different treatments with respect to the number of tubers produced per plant.

Table 1. Effect of different fertilizer rates on the growth rate/height (cm) of potato plants at various times after emergence.

Treatment	Height at 2 WAE	Height at 4 WAE	Height at 6 WAE	Height at 8 WAE	Height at 10 WAE	Height at 12 WAE
1	9.33^{a}	38.18^{a}	46.2^{a}	59^{c}	68.25^{cde}	68.75^{cd}
2	9.23^{a}	34.13^{a}	38.2^{a}	53.1^{b}	64.5^{cd}	68.25^{cd}
3	9.45^{a}	33.8^{a}	40.4^{a}	51.95^{b}	62.5^{c}	67.7^{bc}
4	8.18^{a}	30.35^{a}	35.1^{a}	47.8^{a}	56.25^{b}	62.4^{b}
5 (control)	10.68^{a}	33.23^{a}	42.12^{a}	44.82^{a}	44.83^{a}	44.83^{a}
Grand mean	9.37	33.94	40.41	51.33	59.27	62.39
P- Value	0.204	0.068	0.015	<0.001	<0.001	<0.001
L.S.D	2.072	5.07	5.849	4.973	5.257	5.429

Means within a column are significantly different if they do not share a common superscript (P<0.05).

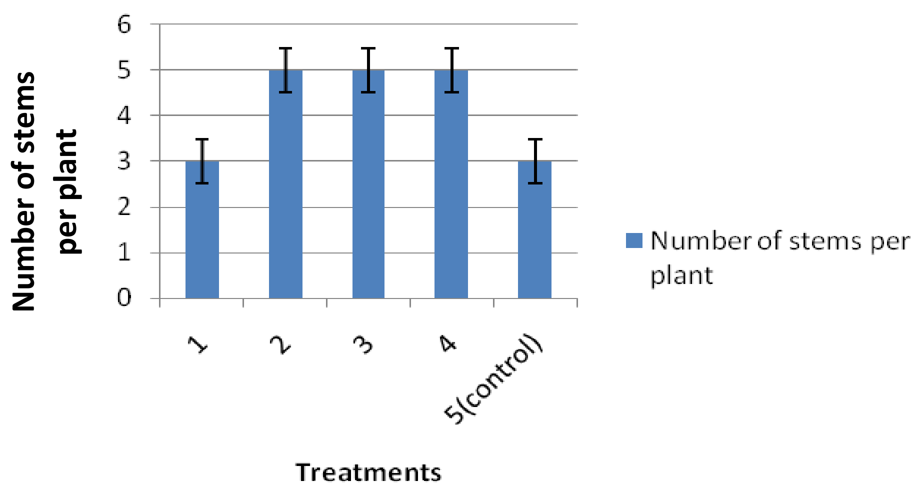

Figure 1. Average number of stems produced per plant in relation to treatment used at 10 weeks after emergence (WAE).

Table 2. Effect of different fertilizer rates on the number of tubers produced per plant at 110 days after planting.

Treatments (fertilizer in g/bag)	Number of tubers per plant
1	12^{b}
2	14^{bc}
3	13^{bc}
4	12^{b}
5 (control)	8^{a}
Grand mean	11.7
P- Value	0.004
L.S.D	2.802

Means within a column are significantly different if they do not share common superscript (P<0.05).

Treatment 2 has the highest number of tubers per plant while the control had the least number (Table 2).

Average yields of tubers per plant

A significant difference (P<0.05) is noted on the average yields obtained per plant among different treatments. Treatment 2 had the highest yield (0.777 kg/plant) while the control treatment had the least yield (0.163 kg/plant) (Figure 2).

Tuber sizes

There are significant differences (P<0.05) in all the tuber sizes produced in different treatments. Treatment 1 had the highest number of very large tubers, while treatment 2 produced the highest number of large and small tubers (Table 3).

Tuber marketability

A significant difference (P<0.05) was also observed in the

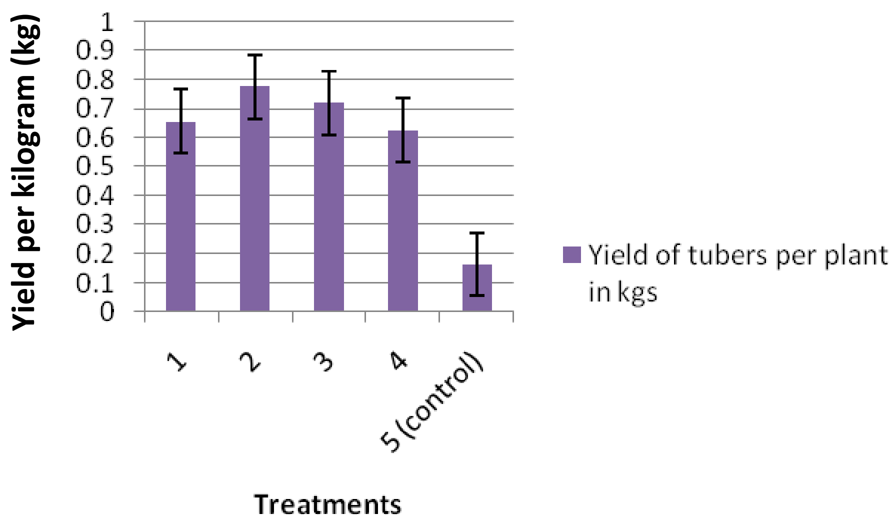

Figure 2. Average yields of tubers per plant in relation to treatment at 110 days after planting.

Table 3. Effect of different fertilizer rates on tuber sizes at 110 days after planting (mm).

Treatment	Small (20-35 mm)	Medium (20-35 mm)	Large (45-55 mm)	Very large (>55 mm)
1	31.1^{b}	14.8^{b}	8^{b}	6^{cd}
2	36^{bc}	16.2^{cd}	12.25^{cd}	5.5^{c}
3	31^{b}	18.8^{cd}	9^{bc}	5.5^{c}
4	23.8^{a}	15.5^{bc}	9.75^{bc}	4.75^{b}
5(control)	16.8^{a}	5.2^{a}	1^{a}	0^{a}
Grand mean	27.8	14.1	8	4.35
P- Value	0.007	0.024	<0.001	0.011
L.S.D	9.44	7.81	4.054	3.334

Means within a column are significantly different if they do not share a common superscript (P<0.05).

percentage of marketable tubers. Treatments 2 and 4 recorded the highest marketable yield (87%) while the control recorded the least percentage of marketable tuber (54%) (Figure 3).

DISCUSSION

There was no significant difference with respect to average plant height for up to 4 weeks after planting largely due to utilization of reserve material and metabolites in the mother tuber (Wurr et al., 1993; Love and Thompson-Johns, 1999; Kabir et al., 2004). However, the significant differences which were observed in plant height from week 6 to week 12 may be due to root establishment and utilization of nutrients supplied by Compound C fertilizer and ammonium nitrate (Perrenoud, 1993). Similarly, Arafa (1999) and Awad (2005) found that the vegetative growth parameters such as plant height on Irish potatoes were gradually and significantly influenced by increasing levels of N, P and K supplied by inorganic fertilizers 4 WAE. Applied ammonium nitrate resulted in significant changes in the growth of potato plants. Davis et al. (2014) further acknowledged that vegetative growth of Irish potato plant is influenced by high nitrogen supplies but excessive amounts produce too much vegetative growth at the expense of tuber formation. In contrast, plant height was poor in the control experiment up to 12 weeks and this is also supported by Alva (2004) and White et al. (2007), who acknowledged the influence of nitrogen on the balance between vegetative and reproductive growth for potato.

A significant difference was observed among treatments with respect to number of stems per plant at the end of the growing period. There was no variation in number of stems in treatments during the growing period because numbers of stems is mainly dependent on tuber size and shoot number per plant (Wurr et al., 1993). Similarly, Barry et al. (1990) and Gulluoglu and Arioglu (2009) found that seed tubers of the same size produce

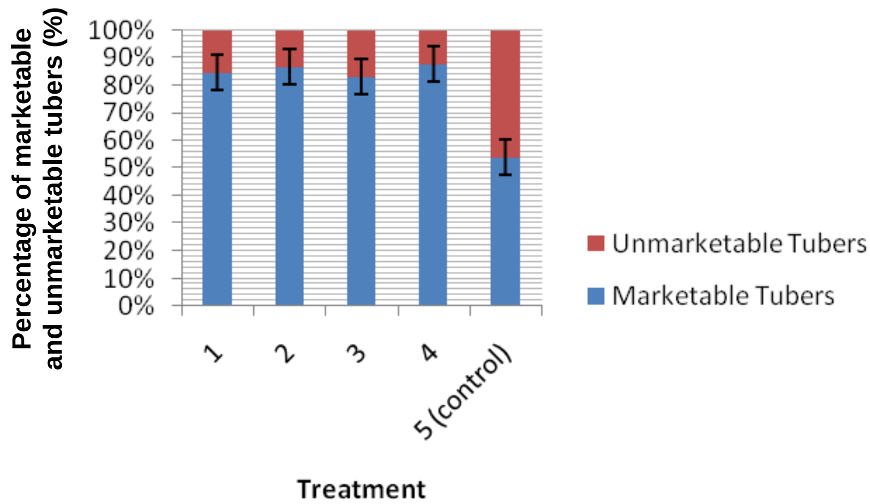

Figure 3. Percentage of marketable and unmarketable tubers in relation to treatment at 110days after planting.

the same number of sprouts and correspondingly the same number of stems per plant. Treatment 1 had an initial vigorous production of main and secondary stems. However, the lifespan of the plants in this treatment was short and the plants started browning much early before they produced more stems as compared to plants in other treatments. This concurs with studies by Firman and Allen (1988) which showed that the field potato crops provided with a higher N application had shorter life spans than comparable ones from N deficient crops. In the control treatment, the plants lacked nitrogen responsible for vegetative growth and stem production and this is in agreement with those obtained by Ayoola and Makinde (2007) and Al-Balikh (2008), where plants grown without any fertilizer (inorganic or organic) produced the least number of stems per plant.

A significant difference was noted on the average number of tubers produced per plant with the highest number of tubers recorded at 1400 kg/ha of Compound C, while the bags with no fertilizer had the lowest mean number of tubers per plant. These results indicated that Compound C fertilizer provides plants with necessary nutrients such as N, P and K that lead to an increase in the size of tubers (Ayoola and Makinde, 2007). Studies carried out by various authors showed positive influence of N, P and K on Irish potato production. For example, Fedotova et al. (2002) findings showed that application of Compound fertilizer coupled with N application at flowering resulted in an increased number of tubers per plant. Davis et al. (2014) also acknowledged the importance of phosphorous availability at tuber initiation, maximum tuber set and number of tubers per plant. Studies by Grewal et al. (1991) also showed the positive influence of potassium on number of tubers produced per plant. Similarly, Al-Balikh (2008) showed that plants provided with compound fertilizers of N, P, K produced more tubers as compared to those with a deficit of these. The number of tubers produced per plant is also directly related to the number of stems produced per plant (Barry et al., 1990; Gulluoglu and Arioglu, 2009).

Fertilizer rate at 1400 kg/ha of Compound C fertilizer had the highest yield of 0.777 kg per bag. Similarly, other studies carried out by Mujaya and Mereki (2010) and Shayanowako et al. (2014) obtained average potato yields which ranged between 24-28 tonnes/ha or 0.648-0.756 kg per plant station which is comparable to the 0.777 kg per bag obtained in this study. Potato yield in bags was attributed to availability of phosphorus, potassium and mineral nitrogen in the soil (Vos, 1999; Shield et al., 1997). Also, other studies concur with this finding that fertilizer N applications can increase dry matter content, protein content of potato tubers, total and/or marketable tuber yield (Bélanger et al., 2002; Kara, 2002; Zebarth et al., 2004; Zelalem et al., 2009; Ruiz et al., 1999). The results are also in line with those reported by Al-Balikh (2008), which indicated that inorganic fertilizers give plants exposure to nutrients resulting in an increase in the total tuber yield/ha. Further, Mujaya and Mereki (2010) indicated the importance of phosphorous in potato production and lack of it during growth drastically reduced yield. Potassium in Compound C fertilizer is considered as one of the most important factors affecting the growth and yield of potato because it influences the physiological tuberization process in potato plants. This is in agreement with those obtained by El Gamal (1985) and Humadi (1986) who recorded an increase in yield and quality of Irish potato tubers due to increased levels of potassium (K) fertilization. However, treatment 1 with highest fertilizer rate of 1800 kg/ha plus high vegetative growth recorded less yield than treatment

2 with 1400 kg/ha. This was the result of high vegetative growth at the expense of tuber formation. This concurs with Davis et al. (2014). Excessive nitrogen fertilization also reduces starch, dry matter and sugar contents in tubers and reduced shelf life (Vos, 1999).

Very large tubers were obtained at 1800 kg/ha of Compound C and top dressing of 200 kg/ha but with fewer number of tubers than those obtained at 1400 kg/ha with same top dressing rate of ammonium nitrate. Tuber growth is enhanced by K and increases the proportion of large tubers relative to small ones (Martin-Prevel, 1989) by increasing water accumulation in tubers resulting in a lowering of dry matter content and specific gravity (Perrenoud, 1993). This simply means that plants supplied with more Compound fertilizer rich in K can produce larger tubers relative to those with less of this fertilizer (El-Gamal, 1985).

A higher percentage of marketable tubers was obtained at 1400 kg/ha of Compound C and lowest marketable tubers at 0 kg/ha. Kara (2002) also found that poorly developed tubers were consistent with lack of nutrients. Nutrients enhance the quality of tubers and make them more marketable. Other studies have shown that fertilizer N applications can increase dry matter content, protein content of potato tubers, total and/or marketable tuber yield (Bélanger et al., 2002; Kara, 2002; Zebarth et al., 2004; Zelalem et al., 2009; Ruiz et al., 1999).

CONCLUSION AND RECOMMENDATION

This study showed that the final yield of bag potatoes was determined by nutrient availability and the fertilizer application rate. In this study, the highest yields were obtained at a fertilizer rate of 1400 kg/ha but the biggest tubers were achieved at 1800 kg/ha. It can be concluded that the best rate of fertilizer application is 1400 kg/ha for the most marketable potatoes which can give economic returns to the farmer. We therefore recommend farmers with small areas of land, particularly urban dwellers, to adopt bag potato production for food security and income generation.

Conflict of Interests

The authors have not declared any conflict of interests.

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