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Research Paper

Response of Irish potato to NPK fertilizer application and its economic return when grown on an Ultisol of Morogoro, Tanzania

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Abstract. A field experiment was conducted to determine the effects of different rates of NPK fertilizer on performance of Irish potato (*Solanum tuberosum* L.). This experiment employed use of 150 and 300 kg ha^{-1} of NPK (23:10:5) fertilizer and a local cultivar *Alika* of Irish potato as a response crop. Results indicated that the significantly ($p < 0.05$) highest average marketable number of tubers per plant (3.5) and tuber yield (18.74 t ha^{-1}) was recorded at an application of 300 kg NPK ha^{-1}. The lowest average number of tubers per plant (2.2) was recorded in the absolute control while the lowest tuber yield (14.99 t ha^{-1}) was recorded at 150 kg NPK ha^{-1} compared with the absolute control (15.97 t ha^{-1}). The coefficients of determination (R^2) from the linear regression model showed that the variation in tuber yield was 50.7% with NPK fertilizer, 21.4% with number of tubers per plant and 23.6% with tubers per plot. Partial budget analysis indicated that the net benefit was in the decreasing order of 300 kg NPK ha^{-1} (5,335,500 Tshs/ha) > absolute control (4,135,000 Tshs/ha) >150 kg NPK ha^{-1} (3,552,000 Tshs/ha). The benefit cost ratios obtained for the absolute control, 150 and 300 kg NPK ha^{-1} were 2.1, 1.9 and 2.3, respectively, while the marginal rate of return for the two rates of fertilizer were -0.45 and 1.27, respectively. Based on the total variable costs and net benefit, NPK applied at 150 kg ha^{-1} was dominated (D) by the absolute control.

Keywords: Partial budget, Irish potato *cv. Alika*, tuber yield.

INTRODUCTION

Irish potato is the most efficient tuberous crop in terms of time it takes to attain maturity. Potential tubers in potato can be harvested in 60 to 120 days after planting. Potato is the fourth most important food crop in the world on the basis of production after maize, rice, and wheat, with annual production approaching 300 million tons (Naz et al., 2011), produced from about 20 million hectares of arable land (Jasim et al., 2013). However, according to Haile and Boke (2011), the world dedicated 18.6 million hectares in 2010 for Irish potato cultivation and the average world farm yield was 17.4 t ha^{-1}.

Potato is among the major food crops grown in more than 100 countries in the world (Nyunza and Mwakaje, 2012), Tanzania inclusive. Irish potatoes production in Tanzania is more concentrated in Njombe, Iringa regions and mostly Mbeya rural district but production is as low as 5 t ha^{-1} (Namwata et al., 2010). Studies conducted by Kanyeka et al. (2007) and Al-Dalain (2009) revealed that the potential average potato tuber yield in Tanzania is 25 t ha^{-1} under optimal agronomic practices. The low level of potato production in Tanzania is associated with low soil fertility and absence of deliberately replenishment of the nutrients to the agricultural soils in the cropping cycle after crop harvest.

Tanzanian population is generally food insecure (Kanyeka et al., 2007). Some of the reasons for this are the diverse and complex nutrients transformations and declining soil fertility and soil degradation (Kisetu and

Mtakimwa, 2013). It has been traditionally a practice where some farmers use only fertilizers containing nitrogen (N) and phosphorus (P) because they have been identified as being the most deficient nutrients in almost all Tanzanian soils. As a result, application of fertilizers containing N and P (urea and diammonium phosphate-DAP) and now Minjingu Mazao, producing dramatic increases in the yields of several crops. Consequently, the use of urea and DAP have been by far the most widely adopted inputs by farmers excepting smallholder farmers, causing a steady year-on-year increase in the consumption of these fertilizers (Haile and Mamo, 2013). However, there are unregulated increases in fertilizer costs in Tanzania which hamper the decision of farmers to apply fertilizers in their cropping fields (Kisetu and Mtakimwa, 2013).

The efforts of using N and P containing fertilizers do not satisfy crop nutrient requirements because K deficiency in highly weathered Tanzanian soils is also reported to be very low (Kisetu et al., 2013). This is attributed to high soil erosion, crop nutrient removal, and continuous cropping, and inadequate and imbalanced use of organic and inorganic fertilizers (Haile and Mamo, 2013). This calls for the need to supplement all essential nutrient elements to these soils for plant use, the quantities which are yet to be determined and recommended accordingly. According to Jasim et al. (2013), tuber yield and quality of potato are affected by cultivar, environmental conditions, and agronomic practices.

One of the contributing factors to low potato yields in most parts of the world is low soil fertility. This is attributed to continuous cultivation without adequate replenishment of the mined nutrients (Kaguongo et al., 2008; Muthoni and Kabira, 2011). Naz et al. (2011) depicted that NPK fertilizers improve yield and quality of potato tubers. Potato requires high amounts of NPK but more K fertilizer for optimum growth, production and tuber quality (Al-Moshileh and Errebi, 2004), but the ability of this crop to recover P and K is very low. According to Naz et al. (2011), response of potato to NPK fertilizers varies depending upon the variety, soil characteristics and geographical escarpment. There is no documentation available for deliberately use of NPK fertilizer in soils of Morogoro region aiming at increasing performance and hence yield of Irish potato. In addition, the existing documentations do not comprehend production costs and net return obtained from Irish potato production. Therefore, this study was intended to answer several debatable but scientific queries pertaining to Irish potato improvement in poor fertility soils of Tanzania. Results of this study would be worthwhile to improve food security-base by the use of suitable combinations of NPK fertilizer. The specific objectives of this study were to: (i) study the effects of different rates of NPK fertilizer on tuber yield and yield components of Irish potato, (ii) determine the strength of the relationship between NPK fertilizer, yield components and tuber yield by correlation coefficient and regression analysis, and (iii) determine economic performance of Irish potato under NPK fertilizer rates by partial budget analysis.

MATERIALS AND METHODS

Description of the study area

The study area is located at the Sokoine University of Agriculture (SUA) Farm, section of the Department of Soil Science located in Morogoro urban, Tanzania. The area is located at 06° 51′ 15.0" S and 37° 38′ 33.1" E and at an altitude of 540 m above mean sea level. The soil of the field where this study was conducted is kaolinitic clay with low pH (<7.0), deficient in most of the essential plant nutrients, and with bimodal rainfall pattern which its distribution is often unreliable (Kisetu et al., 2013).

Experimental layout, design and experimentation

The experiment was laid out in randomized complete block design (RCBD) in three replications. There was only one factor applied to the experimental unit. The treatments consisted of 0, 150 and 300 kg ha^{-1} of NPK (23:10:5) fertilizer. The rate of 150 kg NPK ha^{-1} was equivalent to 34.5, 6.5 and 6 kg of N, P and K per ha, respectively. This means that these rates of elemental forms of N, P and K where equally double at 300 kg NPK ha^{-1}. The experimental unit or rather the test crop was the local cultivar (whole seed tuber) *Alika* of Irish potato. The land was cleared, harrowed and made into 75 cm row ridges and then 3 blocks of 2m × 18 m dimensions demarcated. Each block was separated from the other by 2 unplanted ridges. A whole seed tuber (35 to 50 g) containing at least one eye was planted per planting hill spaced 30 cm apart within the row and 50 cm between rows accounting to 183 planting holes per block. The fertilizer application was done in two equal splits by band placement that is at planting and at 21 days after planting.

Data collection

Data collection was from four plants in each sub-plot obtained based on three quadrants in a diagonal design each with 0.5 m × 0.5m size. The data included: (i) Growth parameters: plant height (cm) starting at 10 days after planting at an interval of 10 days until constant height, number of leaves per plant and number of haulms per hill; (ii) Yield and yield components: number of tubers per plot, number of tubers plant, and weight of unmarketable and marketable tubers. The latter was corrected to tuber yield per ha and subjected to partial budget analysis.

Table 1. Effect of NPK fertilizer on potato growth parameters at 21 days after planting.

Treatment	Response variables			
Equivalent NPK (kgha^{-1})	Plants/plot	Plant height (cm)	Haulm/hill	Leaves/plant
0	8.3^{b}	20.5	4.52	109.0^{a}
150	5.0^{a}	24.6	4.57	117.3^{a}
300	5.2^{a}	20.8	4.74	154.1^{b}
LSD (0.05)	1.2***	5.0	1.20	35.14*
CV (%)	19.1	23.3	26.7	28.4
F pr.	<.001	0.19	0.92	0.033

Different letter(s) in a column for the response of NPK rates indicate(s) significant difference at p = 0.05.

Statistical data analysis

The data collected was analyzed for the effects of treatments on the experimental unit using GenStat software. The significant treatment means were compared by least significance difference (LSD) of ascending approach at 5% level of statistic. The same means were subjected to Pearson matrix correlation analysis technique to determine the relationship between tuber yield and different phenological crop growth parameters and under different rates of NPK fertilizer. Step-wise regression analysis was then used to select the critical factors and yield components influencing tuber yield of Irish potato.

Partial budget analysis of the rates of NPK fertilizer used

The mean yield of the marketable tuber data over the growing season in each NPK rate was adjusted down by 10% to minimize plot management effect by the research or to reflect the actual farm level performance as described by Haile and Boke (2011) and Akinpelu et al. (2011). The gross benefit (GB) was calculated as average of adjusted tuber yield (kg/ha) × field price that farmers receive for the sale of the crop per kg. Total variable cost (TVC) was calculated as the sum of all production costs incurred in the farm. Net benefit (NB) or marginal return (MR) was calculated by subtracting total variable costs from the GB. Marginal rate of return (MRR) was calculated as the ratio of differences between net benefits of successive treatments (rates of NPK) to the difference between total variable costs of successive treatments. Treatments with high variable cost and with lower net benefit than the previous treatment were indicated as dominated (D).

RESULTS

Effects of NPK fertilizer on growth of Irish potato

The results of the effects of different levels of NPK fertilizer on the growth parameters of the studied Irish potato namely number of plants, number of haulm, number of leaves and plant height are as presented in Table 1.

Results indicated that the number of plants did not differ significantly under different rates of NPK fertilizer applied and the mean ranged between 5.0 and 5.2. However, the absolute control where no NPK fertilizer was applied recorded significantly ($p < 0.001$) large number of plants (8.3). In addition, results indicated that plant height was not significantly affected by the rates of NPK fertilizer applied.

Results also indicated that the number of haulm formed per hill was not significantly affected by NPK fertilizer application. Generally, results indicated that the number of leaves per plant concomitantly followed the same trend of the number of haulm per hill. The significantly ($p = 0.033$) largest mean number of leaves (154.1) was recorded at an application of 300 kg NPK ha^{-1}, which differed from the mean number (117.3) recorded at 150 kg NPK ha^{-1} which was statistically at par with the absolute control (109).

Effects of NPK fertilizer on tuber yield and yield components of Irish potato

The results of the effects of NPK levels on tuber yield and yield components of the studied Irish potato are presented in Table 2.

The number of tubers per plot differed significantly ($p = 0.002$) with the rates of NPK fertilizer applied. Results showed that mean for the number of tubers was 16.8 in the absolute control and18.7 at an application of NPK fertilizer. The latter was the highest mean number recorded at 150 kg NPK ha^{-1} fertilizer application. In addition, application of 300 kg NPK ha^{-1} recorded relatively larger mean number of tubers (17.2) than the absolute control.

The number of tubers per plant also differed significantly ($p = 0.002$) with NPK fertilizer application. Results indicated that the largest mean number of tubers per plant (3.5) was recorded at an application of 300 kg NPK ha^{-1} followed by 3.3 which were recorded at 150 kg

Table 2. Effects of different rates of NPK fertilizer on tuber yield of Irish potato.

Treatment	Response variables			
NPK (kgha^{-1})	Tubers per plot	Tubers per plant	Weight of tubers per plot (kg)	Tuber yield (t ha^{-1})
0	16.8^{a}	2.2^{a}	6.39^{b}	15.97^{b}
150	18.7^{c}	3.3^{b}	5.99^{a}	14.99^{a}
300	17.2^{b}	3.5^{c}	7.5^{c}	18.74^{c}
LSD(0.05)	0.29**	0.18**	0.26**	0.43**
CV (%)	0.4	1.3	0.9	0.6
Fpr.	0.002	0.002	0.003	0.001

Similar letter(s) in each column for the response to NPK rates indicate(s) significant difference at p = 0.05.

Table 3. Pearson matrix correlation of the response variables of Irish potato.

Variables	1	2	3	4	5	6	7
1. Tuber yield	1						
2. Plants/plot	0.01	1					
3. Haulm/hill	0.76	-0.64	1				
4. Tubers/plant	0.24	-0.97	0.82	1			
5. Tubers/plot	-0.7	-0.72	-0.06	0.53	1		
6. Leaves/plot	0.8	-0.6	0.99*	0.78	-0.13	1	
7. Plant height	-0.81	-0.6	-0.232	0.38	0.99	-0.29	1

* Significant at p < 0.05.

NPK ha^{-1}. The latter was however, larger than those recorded in the absolute control (2.2). Similar trend of significant (p = 0.003) effect of NPK application was observed in the mean weight of tubers per plot and the final tuber yield. Results indicated that the highest tuber weight per plot and then significant (p = 0.001) tuber yield (7.5 kg/plot and 18.74 t ha^{-1}, respectively) was recorded at 300 kg NPK ha^{-1} and in absolute control (6.39 kg/plot and 15.97 t ha^{-1}, respectively). The application of 150 kg NPK recorded the smallest tuber weight and yield (5.99 kg/plot and 14.99 t ha^{-1}, respectively).

Relationship between yield components and tuber yield of Irish potato

Pearson matrix correlation

The relationship between yield components and tuber yield of the studied Irish potato is presented in Table 3.

The results showed that there was strong and positive correlation between the number of leaves per plot and the number of haulm in the same plot. The number of leaves had the strongest relationship with those of haulm per hill in a plot (r = 0.99*; p = 0.0193).

Linear regression analysis of the variables

Results of the linear regression analysis among the studied variables with tuber yield are shown in Figures 1, 2 and 3. The linear regression models presented the factors determining tuber yield particularly the yield components and its predictor variables. The dependent variable was the tuber yield and the independent (predictors) variables were the rates of NPK fertilizer application, number of tubers per plant and weight of individual tubers per plant. Results indicated that with no NPK fertilizer application and with application to rates not exceeding 150 kg NPK ha^{-1}, the average tuber yield remained almost below 15.18 t ha^{-1}. However, an application beyond that to 300 kg NPK ha^{-1} gave tuber yield which stood at an average of 18.74 t ha^{-1}.

Economic performance of Irish potato under NPK fertilizer rates

Results of the economic performance of the studied Irish potato produced under different rates of NPK fertilizer are presented in Table 4. Results indicated that the highest total cost (4,034,500 Tshs/ha) was obtained where 300 kg NPK ha^{-1} was applied. On the other hand, the lowest total cost (3,850,000 Tshs/ha) was obtained in the plot where there was no NPK fertilizer applied. The highest gross benefit (9,370,000 Tshs/ha) was also obtained at 300 kg NPK ha^{-1} and the lowest (7,495,000 Tshs/ha) at 150 kg NPK ha^{-1}. The latter was however, outperformed by the gross benefit (7,985,000 Tshs/ha) obtained in the absolute control.

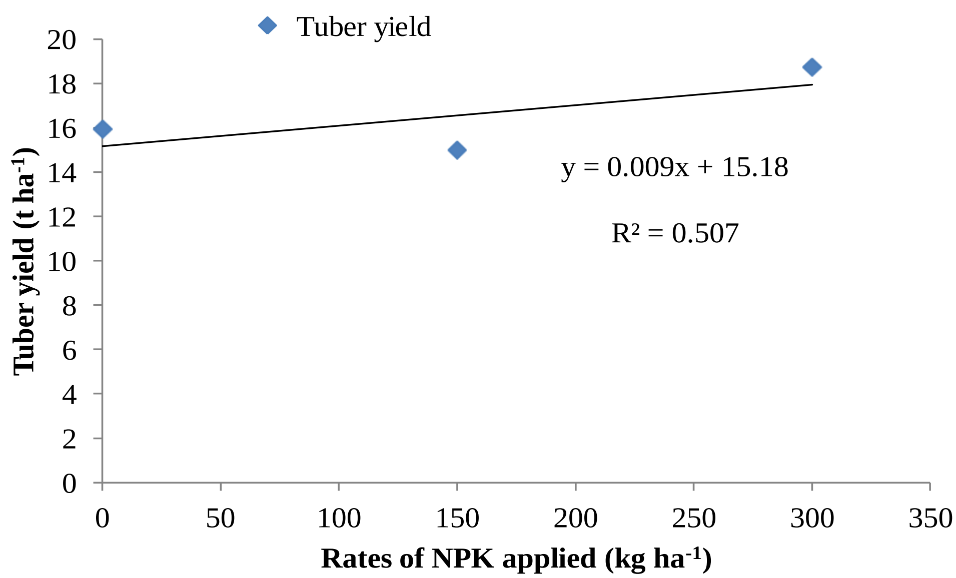

Figure 1. Relationship between tuber yield and rates of NPK applied.

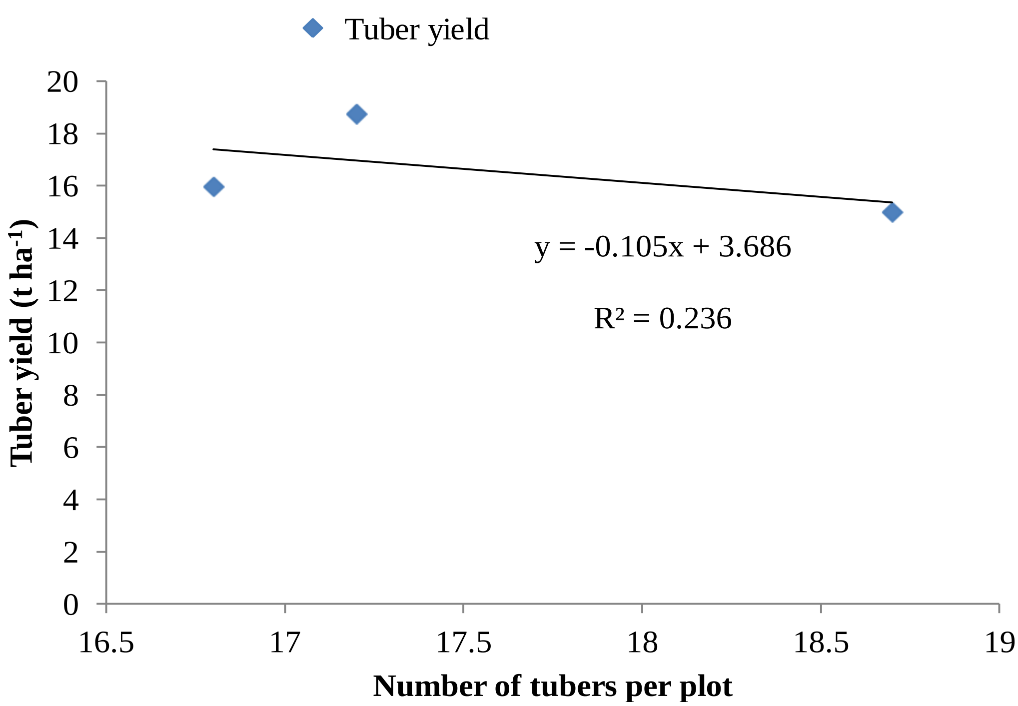

Figure 2. Relationship between tuber yield and the number of tubers per plot.

Results also revealed that the highest marginal return (5,335,500 Tshs/ha) and benefit cost ratio (2.3) were recorded at 300 kgNPK ha^{-1}applied. In addition, the next high marginal return (4,135,000 Tshs/ha) and benefit cost ratio (2.1) were recorded in the absolute control which outweighed the marginal return (3,552,000 Tshs/ha) and the benefit cost ratio (1.9) recorded at 150 kg NPK ha^{-1} application. The highest marginal rate of return (1.27) was recorded at an application of 300 kg NPK ha^{-1} and the lowest (-0.45) was recorded at 150 kg NPK ha^{-1}.

DISCUSSION

Plant height and other growth parameters

The vegetative growth parameters of the studied Irish potato which included number of plants per plot, plant

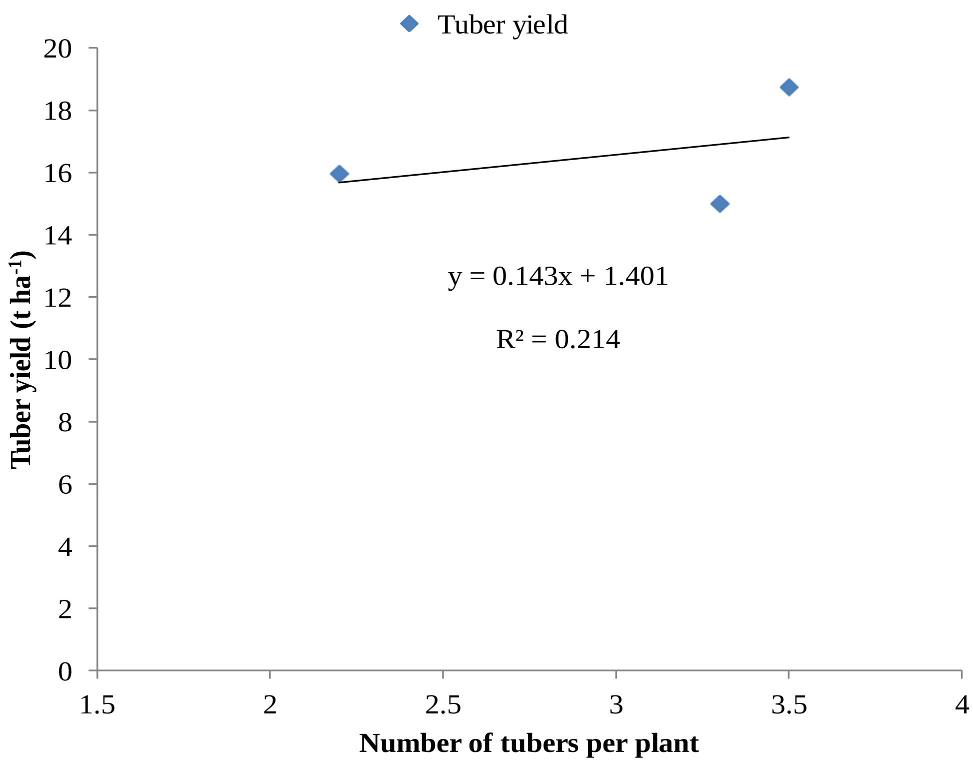

Figure 3. Relationship between tuber yield and the number of tubers per plant.

Table 4. Partial budget analysis of the economic performance of Irish potato under NPK fertilizer.

Production costs	At absolute control	At 150 kg NPK ha^{-1}	At 300 kg NPK ha^{-1}
1. Variable Costs	(Tshs/ha)	(Tshs/ha)	(Tshs/ha)
Land preparation	1,000,000/-	1,000,000/-	1,000,000/-
Labour	1,000,000/-	1,000,000/-	1,000,000/-
Weeding	1,000,000/-	1,000,000/-	1,000,000/-
Pesticide application	500,000/-	500,000/-	500,000/-
Seeds	350,000/-	350,000/-	350,000/-
Total fertilizer (185 kg NPK) @ 1,500/-	Nil	62 kg × 1500/- = 93,000/-	123 kg × 1500/- = 1,84,500/-
Total Variable Cost (*TVC*)	3,850,000/-	3,943,000/-	4,034,500/-
2. Gross benefit (GB)	15970 kg @ 500/- = 7,985,000/-	14990 kg@ 500/- = 7,495,000/-	18740 kg @ 500/- = 9,370,000/-
3. Marginal Return (MR) = GB – TVC	4,135,000/-	3,552,000/-	5,335,500/-
4. Benefit cost ratio $(BCR) = \frac{GB}{TVC}$	2.1	1.9	2.3
5. Marginal Rate of Return (MRR)			
$\mathrm{MRR} = \frac{GB\ with\ fertilizer - GB\ without\ fertilizer}{TVC\ with\ fertilizer - TVC\ without\ fertilizer}$		-0.45 and D	1.27

Note: The exchange rate was Tshs. 1,600/- per 1 $ based on Bank of Tanzania (BOT) rates of July 2, 2014.

height, number of haulm per hill, and number of leaves per plant varied inconsistently with NPK fertilizer application. Of these variables, the number of plants and that of leaves differed significantly among the treatments because of the high variation during seedling emergence and plant establishment. Plants were also highly affected by the underground bacterial wilts which hindered intended plant population in the experimental plots. Further to that, the same observation was expressed on the number of leaves formed per plant. The number of plants per plot and that of haulm per hill probably had combined effect on the number of leaves formed because of the dependencies of leaves on the plant stands. Similar previous study conducted by Kamau (2005) indicated that many round potato farmers in Kenya were unable to control bacterial wilt and other related diseases such as potato tuber and late blight. Consequently, these diseases reduced round potato population and their productivity per unit land area.

The significant number of leaves per plant and many types of haulm per hill obtained at 300 kg NPK ha^{-1} probably increased vegetative growth and therefore more assimilate production by the green leaves that were translated into high tuber yield. Harris (1992) reported that N is a component of protein which in turn is an integral part of chlorophyll molecule and of nucleic acids that make up the chromosome and thus, very essential and important for growth and development. Babaji et al. (2007) reported that P is responsible for energy transfer necessary for metabolic processes within the plant. Harris (1992) insisted that P is also a part of the nucleic acid which is very important for seed and fruit formation, and root growth. Phosphorus also is responsible in increasing the number of leaves in the early stages of plant growth, which in turn hastens the senescence of leaves thus depressing the leaves toward the end of the growing period (Waddell et al., 1999).

Potassium is important in carbohydrate formation and in the transformation and movement of starch from potato leaves to tubers (Babaji et al., 2009). Harris (1992) and Khiari et al. (2001) also reported that K has profoundly an important role in controlling stomatal opening and closing and regulates water status of the plant and delayed senescence of the plant leaves. A study conducted by Zamil et al. (2010) also reported that application of nitrogen levels significantly influenced plant height, foliage coverage, number of main stem per hill, fresh weight of haulm per hill, number of tubers per hill, weight of tubers per hill, yield of tubers and seed tubers per hectare.

Tuber yield

The highest average tuber yield obtained at 300 kg NPK ha^{-1} application as opposed to the lowest tuber yield obtained at 150 kg NPK ha^{-1} indicates the high demand of Irish potato to these essential nutrients. However, the higher tuber yield obtained in the absolute control than at 150 kg NPK ha^{-1} application could be attributed to the ability of the plants to adjust and acclimatize themselves to the nutrient deficient soils thereby benefiting from the residual nutrients in the soil. The declining trends of tuber yield observed in Figure 1 between absolute control and at 150 kg NPK ha^{-1} towards 300 kg NPK ha^{-1} applications suggest that an application of 150 kg NPK ha^{-1} to the studied Irish potato is not quantitatively viable. However, the increased rate of NPK beyond 150 kg ha^{-1} improved tuber yield, which suggests that the studied Irish potato needs more than 150 kg NPK ha^{-1} (23:10:5) for its optimum tuber yield.

Abdissa et al. (2012) also reported similar findings that with increase in the amount of farmyard manure and phosphorus, root diameter also increased progressively and attributed this to the enhanced availability of micronutrients as well as organic carbon as food for soil biota. They also stretched that enhanced release of nutrients from the soil promoted root growth and nutrient uptake, hence better root growth and tuber yield. These findings concur also with those of Ano and Orkwor (2006) and Islam et al. (2002) who reported the highest tuber yield with the application of NPK 15:15:15 fertilizer.

Pearson matrix correlation among variables of Irish potato

The strong and positive relationship between number of leaves and number of haulm per hill observed in this study stressed the importance of these parameters in the growth and the development of the crop as well as the degree of interdependence that exists between them. This relationship could be associated with the elevation of the amount of the fertilizer applied from 150 to 300 kg NPK ha^{-1} signifying the importance of nutrients N, P and K for plant growth and development. According to Babaji et al. (2009), nutrients N, P and K have a major role in the increase in dry matter composition in plant and hence in leaf area. The weaker relationship among tuber yield and leaves per plot, haulm per hill, plants per plot, and plant height could be attributed to increased rainfall during growing period (Kisetu et al., 2014), which transformed some of the tubers back into vegetative state thereby forming new haulms in a hill. A similar study conducted by Zamil et al. (2010) found that the tuber yield per hectare was significantly and positively correlated with plant height, foliage coverage, and number of stems per hill, fresh weight of haulm per hill, number of tubers per hill and weight of tubers per hill.

Regression analysis of tuber yield and its affiliated variables

Through its coefficients of determination (R^2) the linear regression model showed inconsistent variation in the tuber yield with its affiliated variables. The R^2 value obtained with NPK fertilizer indicates that 50.7% of the variation in tuber yield was due to fertilizer application as a predictor and the remained 49.3% was caused by other predictors not included in the fertilizer related model. In addition, the linear regression model indicated that tuber yield was positively related with the number of tubers per individual plant. The R^2 value indicated 21.4% variation in tuber yield which was caused by the number of tubers per plant but the model also predicts that at an average of 2 potato plants, the tuber yield increased by 0.143 t ha^{-1}. On the contrary, the regression model showed that the tuber yield is not favoured by number of tubers in a given piece of land. The R^2 value showed that the variation in tuber yield caused by the number of tubers per plot was 23.6% and for every unit increase in the number of tubers per plot there was a decrease in tuber yield by 0.105 t ha^{-1}. The variation in tuber yield caused by the number of tubers per plot suggests that most of the factors that are likely to affect tuber yield are the nutrients in the soil and the number of tubers in an individual plant. Further to that, the number of tubers per plot is mostly determined by the plant population and the number of haulm in a hill. This argument suggests that the population of Irish potato plants is a very important factor to consider when a farmer is anxiously driven toward optimum yield.

Inferring to the linear regression model, every unit (kg) increase in the amount of fertilizer application beyond 150 kg NPK ha^{-1}also resulted to an increase in the tuber yield. This signifies the importance of these three primary macronutrients in plant growth and development and their possible synergistic relationships. The coefficient of determination was also positive and strong in describing the validity of this argument. Similar findings are also reported by Babaji et al. (2007) that potato like other most crops shows high response to N and P nutrient elements. Previous studies which involved linear regression analysis of different yield and yield attributes have also reported similar findings. For example, Zamil et al. (2010) reported a linear relationship between yield of tubers per hectare and the different levels of nitrogen, hence reported the increase in tuber yield with the application of higher levels of nitrogen.

Partial budget analysis of NPK fertilizer

The highest marginal return and benefit cost ratio obtained in the absolute control over 150 kg NPK ha^{-1} application was expected because the costs of fertilizer requirements and application were not included in the total cost of production in the absolute control. Asogwa et al. (2006) reported similar situations that if these cases exist, it might be an incentive to most smallholder farmers who cannot invest heavily on their cropping systems. Similar findings are also reported by Akinpelu et al. (2011) that the highest gross return and benefit cost ratio implies that it is profitable to cultivate potato with the application of NPK 15:15:15 fertilizer at the rate of 200 kg ha^{-1}. Further to that, the lowest and negative marginal rate of return obtained when 150 kg NPK ha^{-1} was applied was attributed to the very low gross benefit obtained when this rate of NPK fertilizer was applied compared with the gross benefit obtained in the absolute control. Zamil et al. (2010) with economic analysis of fertilizer also had similar findings that application of 254.0 kg N ha^{-1} in potato at the closest spacing of 60 cm × 15 cm gave the maximum economic and net return of 72,317.01 Tk/ha with a benefit-cost ratio of 2.01.

The gross benefit obtained in the absolute control outweighed that obtained at an application of 150 kg NPK ha^{-1} by 490,000 Tshs/ha. This justifies economic losses when this rate of NPK fertilizer is applied to the studied Irish potato cultivar under the same climatic conditions. These findings also suggest that it is not worthwhile to use 150 kg NPK ha^{-1} for Irish potato production in the study area if the rates larger than that cannot be met by the farmer. Furthermore, the findings of this study suggest that Irish potato could be produced in the study area profitably when fertilizer is scarce or sold at high prices in the fertilizer market. However, inferring to the marginal returns, benefit cost ratio and the marginal rate of returns of the present study, it is obvious that an application of 300 kg NPK ha^{-1} would be economically viable in the study area of Morogoro region. These findings can also be extrapolated in other areas of the country with similar agro-ecological conditions. This is because of the nature and findings of this study following stagnantly unanswered queries in the agricultural communities in Tanzania. Mwanukuzi (2010), for instance, reported that lack or inadequate of extension services and credits to rural farmers were the major impediments to most farmers in rural Tanzania.

The findings of this study which compared the economic production values of absolute control with 150 and 300 kg NPK ha^{-1} indicated that an application of 150 kg NPK ha^{-1} was dominated(D) when compared with the absolute control. This was attributed to its larger total variable cost (3,943,000 Tshs/ha) than that of the absolute control (3,850,000 Tshs/ha). In addition, this depiction is supported by the lower net benefit or marginal return (3,552,000 Tshs/ha) obtained at 150 kg NPK ha^{-1} as opposed to that obtained in the absolute control (4,135,000 Tshs/ha). These comparisons were not feasible between the two NPK fertilizer rates of 150 and 300 kg ha^{-1} in that ascending order because the latter rate was superior to the former in terms of net benefit obtained.

The dominance of one treatment by the other in terms of economic potentials has also been reported by other authors using different treatments and response crops. The findings of this study are in line with those of Haile and Boke (2011) who used different rates of K applied as muriate of potash (KCl) for partial budget or economic analysis of K levels to determine and recommend K level that gives biologically and economically feasible yield of Irish potato. The rates of K used in their trial were the absolute control, 30, 60, 90, 120, 150, and 180 kg K ha^{-}

^{1}and the findings showed that K at 180 kg ha^{-1} was dominated in comparison with K at 150 kg ha^{-1}. They also found that at 180 kg K ha^{-1}, the total variable cost was 1,084.5 birr/ha and the net benefit was 79,195.5 birr/ha. The former rate of K was then justifiably dominated over K at 150 kg ha^{-1} which had a total variable cost of 903.75 birr/ha and the net benefit of 93,776.25 birr/ha.

Literature has indicated an evidence of crop productivity being retracted by poor farmers' awareness on farming systems and access to appropriate farm inputs (Namwata et al., 2010). For example, Nyunza and Mwakaje (2012) reported that farmers who cultivate Irish potato in Tanzania earned only 8% of the total marginal return or gross margin compared to 30.9% for the wholesalers. They also stretched that selling volumes and selling price had significant ($p < 0.01$) impact on the crop profitability. Furthermore, they highlighted that although farming knowledge and land size was not significant in yield potentials, but they had positive relationship with the marginal return. Namwata (2010) reported that farmers' marginal return could be enhanced through improved awareness on agricultural potentials, productivity, bargaining power and access to market information.

CONCLUSION

Fertilizers containing nutrients N, P, K should be used to replenish these nutrients lost in the soil but at rates between 150 and 300 kg ha^{-1}. Similar studies which accommodate structured questionnaires for stakeholders in the same field of crop production are invited in this field to capture crop production needs, challenges, and market information and its acquisition to farmers who are mostly the smallholder farmers.

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