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Response of Potato (Solanum tuberosum L.) to Nitrogen Fertilizer Application at Angecha, Southern Ethiopia

Girma Workineh[1] Gobeze Loha[2] Legese Hidoto[3]
1.Areka Agricultural Research Center, Areka, Ethiopia
2.Wolaita Sodo University, Department of Plant Sciences, Sodo, Ethiopia
3.Hawassa Agricultural Research Center, Hawassa, Ethiopia

Abstract
Nitrogen is one of the most limiting essential nutrients for plant growth and development. Its fertilizations play an important role in the balance between vegetative and reproductive growth of potato. In this context, field experiment was conducted during 2015/16 cropping season at Angacha testing site of Areka Agricultural Research Center to determine the optimum N fertilizer rate for potato production. Treatments consisted of two potato varieties: Gudane (CIP-386423.13) and Belete (CIP393371.58) with seven N levels (0, 23, 46, 69, 92, 115 and 138 kg ha^{-1} N) were combined in factorial and laid out in a randomized complete block design (RCBD) with four replications. Analysis of variance revealed that N rates had significant effect on days to flowering and physiological maturity where both parameters were prolonged with increasing N rates**.** Significant differences were detected due to effect of varieties by N rates interactions on days to flowering and maturity where for both varieties days to flowering and physiological maturity delayed with increasing N rates. Regarding variety by N rate interactions, the highest plant height was observed for Gudane at N rate of 138 kg ha^{-1} and the lowest plant height was recorded for Belete from non N application plots. Varieties by N rates interactions resulted in significant differences on marketable tuber yield with the highest marketable tuber yield was observed for Belete at N rate of 69 kg ha^{-1}. In line with this, varieties significantly differed for total tuber yield where variety Belete gave higher total tuber yield than that of variety Gudane. This result revealed that both varieties gave better yield that N rate of 69 kg/ha with superior performance of variety Belete. Based on this finding, application of 69kg N ha^{-1} for both cultivars could be recommended for production at Angecha and similar agro-ecologies.
Keywords: Varieties, Nitrogen fertilizer, Tuber yield, Tuber number, Economic feasibility

1. Introduction

Potato (*Solanum tuberosum* L.) is one of the most important crops globally (Tekalign, 2005; FAO, 2008) and ranking fourth being the most cultivated food crops after wheat, rice and maize (FAO, 1995; FAOSTAT, 2012). It is followed by cassava, sweet potato and yam (FAO, 2010). In Ethiopia, among root and tuber crops potato ranks first in volume produced and consumed followed by sweet potato, enset, yam and taro (Olango, 2008). Major potato growing areas in Ethiopia include central, eastern, north-western and southern part comprising approximately 83% of the potato producing farmers (Hirpa *et al*., 2010). Potato is an important nutrient source in human nutrition. It produces approximately twice as many calories per hectare as rice or wheat and is highly nutritious due to its high concentrations of vitamin C and other essential amino acids for balanced human nutrition. Increasing potato yield is necessary to meet the demands of an increasing human population.

The yield and quality of potato are affected by variety, environmental conditions and cultural practices where fertilizer application has prominent effects on the quality and tuber yield of potato (Westermann, 2005). Potato absorbs large quantities of plant nutrients, especially nitrogen (N) from the soil during the growing period (White *et al*., 2007). Thus, nitrogen (N) has been identified as being the most often limiting nutrient in plant growth and development. It is found to be an essential constituent of metabolically active compounds such as amino acids, proteins, enzymes, co-enzymes and some non-proteinous compound. Plants with adequate amount of nitrogen fertilizer stimulates rapid growth, root growth, tiller production which leads to high grain yield and leaf area; thereby increases photosynthetic activity and growth (Evans, 1997). Therefore, availability and uptake of sufficient N during rapid growth period helps to prevent decreased N content in leaves with corresponding reduction in the rates of photosynthesis. On the other hand, the quantity of nutrients required to optimize crop production depends on the inherent capacity of the soil to supply adequate level of the nutrients to the growing plant, the yield potential of the crops, variety grown and the availability and cost of fertilizers (Tilahun, 1994). Excess N supply causes higher photosynthetic activity and more vegetative growth which is accompanied by weak stem, long internodes, droopy leaf and increased susceptibility to lodging (Temesgen, 2001).

Among the production problems, low soil fertility especially nitrogen fertilizer is one the major ones because most Ethiopian soils are deficit in major nutrients, especially nitrogen and phosphorus (Tekalign *et al*., 2001). Fertilizer application has significantly improved growth and yields of potato (Mwangi, 1995; Girma and Hailu, 2007). On the other hand, potato is highly responsive to N fertilization and N is usually the most limiting essential nutrient for plant growth and developments particularly on sandy soils (Errebhi *et al***.,** 1998). Nitrogen fertilizations play an important role in the balance between vegetative and reproductive growth of potato (Alva

2004; White *et al*., 2007). According to Kara (2002), Bélanger *et al*. (2003), Zebarth *et al*. (2004) and Zelalem *et al*. (2009) N applications increased dry matter accumulation and protein content of potato tubers, total and/or marketable tuber yield. On the other hand, soil fertility is a great challenge in crop production in densely populated areas like Angecha. In line with this, potato yield is very low (below 10 t ha^{-1}) as compared to the yield in developed countries (30 to 40 t ha^{-1}) which still needs to increase the productivity of the crop (FAO, 2000). Moreover, the information regarding optimum nitrogen fertilizer requirement with respect to locations for newly released potato varieties is scanty. Hence, this study was designed with the objective to determine the optimum N fertilizer rate for potato production.

2. Materials and methods

2.1. Experimental site

Field experiment was conducted during 2015/16 cropping season at Angacha testing site of Areka Agricultural Research Center, Southern Ethiopia. An approximate geographical coordinates of the site is 7^o 0' N latitude and 38^o 29' E longitude having an altitude of 2381 meters above sea level. The experimental area is characterized with a bimodal pattern of rainfall that extends from February to September. Its mean annual rainfall is 1656 mm. The peak rainy months are April, July, August and September. The mean annual maximum and minimum temperatures are 24 and 14 ^oC, respectively. The coldest months are June and August, whereas February is the hottest month. Some physical and chemical properties of the soils of experimental site is summarized in Table 1.

2.2. Treatments and experimental design

Treatments consisted in two potato varieties: Gudane (CIP-386423.13) and Belete (CIP393371.58) which are well adapted to altitudes of 1600-2800 masl and require annual rainfall 750-1000 mm. The varieties are of determinate in growth habit with white flower colour having maturity period of 110-120 days after planting. The N rates used were 0, 23, 46, 69, 92, 115 and 138 kg/ha N. Urea was used as a source of N and applied in split where the first half applied at planting and the remaining second half applied near flowering. The treatments were combined in factorial and laid out in a randomized complete block design (RCBD) with four replications. The plot size was 4.5 m wide and 3.6 m long having growth area of 16.2 m^2. The inter and intra row spacing were 75 and 30 cm, respectively. The recommended P fertilizer in form of triple super phosphate was applied uniformly to all plots at planting. All crop managements practices such as cultivation, weeding etc., carried out as desired. Diseases and insect damage were visually monitored during the crop growing season.

Table 1. Some physical and chemical properties of soils of experimental site

Parameter	Value
Particle size distribution (%)	
Sand	26
Silt	40
Clay	34
pH	5.9
Organic carbon (%)	1.83
Organic matter	3.14
Total N (%)	0.15
Available P (mg kg^{-1})	4.96
CEC (cmol kg^{-1})	20.22
Exchangeable acidity	0.88
Exchangeable aluminum	0.16

2.3. Data collection and measurements

Plant parameters recorded were days to flowering, days to physiological maturity, plant height, number of stems per plant, marketable tuber yield, unmarketable tuber yield and total tuber yield.

Days to flowering was recorded when 50% of plants per plot extrude flowering whereas days to physiological maturity was recorded when 90% of the plants per plot ready for harvest as indicated by the senescence of the haulms. *Plant height and number of stems per hill were determined f*or five randomly selected plants per plot at flowering. *Marketable tuber yield was determined by weighing tubers harvested from central rows avoiding border effects and separating into marketable and unmarketable by farmers near trial site based on local market criteria.* Unmarketable tuber yield was determined by weighing tubers that rejected by farmers with respect to local market criteria. T*otal tubers yield was estimated as summation of* marketable and unmarketable tuber yield from net plot area. *Dry matter content was estimated f*rom sample tubers that were oven dried at temperature of 60 $^\circ C$ for 15 using the formula (Williams, 1968) as:

$$\text{Dry matter (\%)} = \frac{Weight\ of\ dried\ sample\ (g)}{Initial\ weight\ of\ sample\ \ (g)} x\ 100$$

Harvest index (HI) which is the ratio of dry weight of the tubers to the dry weight of the total biomass and estimated as:

$$\text{HI} = \frac{Dry\ weight\ of\ tubers}{Dry\ weight\ of\ total\ biomass}$$

Economic analysis was done by using the mean grain yields of the treatments in partial budget analysis as described by CIMMYT (1998). The field price of 1 kg of potato at the time of harvesting in August 2015 was taken as 6 Ethiopian Birr based on the market price of potato at Angecha near the experimental site. Net return was calculated by subtracting total variable cost from the gross benefit. In order to use the marginal rate of return (MRR) as a basis for fertilizer recommendation, the minimum acceptable rate of return was set at 100% (CIMMYT, 1998). Thus, MRR calculated was the marginal net benefit (i.e., the change in net benefits) divided by the marginal cost (i.e., the change in costs), expressed as a percentage. Treatments that have higher costs that vary but lower net benefit than treatments of lower cost with higher net benefit were considered dominated and were not included in the partial analysis. All the measured parameters were subjected to analysis of variance using the General Linear Model (GLM) of GenStat15th edition (GenStat, 2012) and treatments with significant mean differences were compared using the Least Significant Differences (LSD) test at 5% probability level.

3. Results and discussion

3.1. Days to flowering and maturity

The data for days to flowering and maturity as affected by varieties and N rates are depicted in Table 2. Varieties were significantly differed for days to flowering where variety Belete took relatively longer days to flowering as compared to Gudane. In contrast, no significant differences were seen between varieties for days to physiological maturity. On the other hand, main effect of N rates had significant effect on days to flowering and physiological maturity (Table 2). Both parameters were prolonged with increasing N rates. The differences of 7.13 days for flowering and 12 days for physiological maturity were existed between the highest N rate and non N application plots. The longest days to flowering (59.38) and physiological maturity (105.10) were receded at N rate of 138 kg/ha followed by N rate of 115 kg/ha with mean days to flowering and physiological maturity of 57.75 and 102.50, respectively. The shortest days to flowering (51.25) and physiological maturity (93.00) were observed at non N application plots. This result clearly indicated that increasing N rates prolonged days to flowering and physiological maturity probably due to extended vegetative growth period with excess availability of N in the soil for uptakes by plants. Similar findings were reported by Daniel *et al*. (2008) that higher N rates promoted excessive vegetative growth leading to delayed flowering and physiological maturity. Moreover, earlier results of Brady and Weil (2002) showed that adequate nitrogen application enhances many aspects of physiological processes like photosynthesis, flowering, seed formation and maturation with extension of phonological processes like flowering.

Significant differences were detected due to effect of varieties by N rates interactions on days to flowering and maturity (Table 2). For both varieties days to flowering and physiological maturity delayed with increasing N rates within rows. The longest days to flowering (59.75) was observed for variety Gudane at N rate of 138 kg ha^{-1} followed by the same variety with mean days to flowering of 58.75. The shortest days to flowering (50.00) was obtained from variety Belete at N rate of 0 kg ha^{-1}. In line with this, the longest days to physiological maturity (105.20) was recorded for variety Gudane at N rate of 138 kg ha^{-1} followed by variety Belete at N rate of 115 kg/ha with mean days to physiological maturity of 103.80. The shortest days to physiological maturity (94.20) was seen for variety Gudane at N rate of 0 kg/ha. This result is in conformity with finding of Zelalem *et al*. (2009) reported that increasing N rates extended days to flowering and physiological maturity.

Table 2. Days to flowering and maturity as affected by variety and N rates

Variety	N rates (kg ha^{-1})	Days to flowering	Days to maturity
Belete	0	50.00f	96.00f
	23	53.00ef	97.20ef
	46	55.25cde	97.50def
	69	56.50bcd	101.20bcd
	92	56.75bcd	103.20abc
	115	57.25abc	103.80abc
	138	57.75abc	105.00ab
Gudane	0	52.00f	94.20f
	23	53.25ef	96.00f
	46	54.00def	97.00ef
	69	57.25abc	100.20cde
	92	58.25ab	101.80abc
	115	58.75ab	103.2abc
	138	59.75a	105.20a
	LSD	2.76	3.84
	Belete	57.39a	100.57
Variety mean	Gudane	55.29b	99.68
	LSD	0.51	NS
	0	51.25c	93.0d
	23	54.25b	96.50c
N mean	46	55.25b	95.80c
	69	54.62b	96.80c
	92	54.88b	100.80b
	115	57.75a	102.50ab
	138	59.38a	105.10a
	LS	1.95	2.72
	CV (%)	3.4	2.7

Means followed by different letters within a column are significantly different at 5% probability level, NS= not significant

3.2. Plant height and number of stems per plant

Analysis of variance indicated that varieties, N rates and their interactions resulted in significant differences on plant height (Table 3). Variety Gudane exhibited relatively higher plant height as compared to Belete which is an indication of their inherent varietal difference. Plant heights tended to increase with increasing N rates thus increasing N rate from 0 to 138 kg ha^{-1} increased plant height from 62.05 to 77. 51 cm. The highest plant height (77.51 cm), averaged over variety, was obtained from N rate of 138 kg ha^{-1} followed by N rate of 115 kg ha^{-1} with mean plant height of 74.00 cm. The shortest plant height (62.05 cm) was recorded at N rate of 0 kg ha^{-1}. Regarding variety by N rate interactions, the highest plant height (85.40 cm) was observed for Gudane at N rate of 138 kg ha^{-1} followed by the same variety at N rate of 115 kg ha^{-1} with mean plant height of 81.00 cm. The lowest plant height (58.10 cm) was recorded from non N application plots. This result is in line with findings of Yohannes (1994) and Biruk (2015) increasing N rates resulted in proportional increment in plant height of potato.

Significant differences were detected due to main effect of N rates on number of stems per plant (Table 3). Increasing N rates tended to increase number of stems per hill up to 69 kg ha^{-1} and declined with rates above that optimum. The highest number of stems per hill (2.48) were achieved from N rate of 69 kg ha^{-1} followed by N rate of 92 kg/ha with mean number stems per hill of 2.20. The least number of stems per hill (1.50) was observed at control (N rate of 0 kg ha^{-1}). This result indicated that at 69 kg ha^{-1} N rate the number of number stems per hill increased by 65.3% and 46.7% at N rate of 92 kg ha^{-1} over the control. Similarly, varieties by N rates interactions had significant effect on number stems per hill (Table 3). Number stems per hill increased with N rates for both varieties up to N rate of 69 kg/ha and tended to decline with N rates above it. Both varieties produced the highest number of stems per hill at N rate of 69 kg ha^{-1} followed by N rate of 92 kg ha^{-1}. The lowest number of stems per hill was seen for both varieties at non application plots. Conversely, main effect of varieties did not show significant differences on number of stems per hill.

Table 3. Plant height and stems per hill as affected by varieties and N rates

Variety	N rates (kg ha^{-1})	Plant height (cm)	Stem number/hill
Belete	0	58.10g	1.65bc
	23	58.80g	1.75bc
	46	63.00fg	1.95abc
	69	64.75fg	2.75a
	92	66.20f	2.00abc
	115	67.00ef	1.55bc
	138	69.62def	1.50bc
Gudane	0	66.00f	1.35c
	23	68.55ef	1.50bc
	46	73.00cde	1.75bc
	69	76.15bcd	2.40ab
	92	79.00abc	2.20abc
	115	81.00ab	2.05abc
	138	85.40a	1.55bc
	LSD	6.76	1.3
	Belete	63.93b	1.88
Variety mean	Gudane	75.59a	1.83
	LSD	2.55	NS
	0	62.05e	1.50c
	23	63.68de	1.63bc
N mean	46	68.00cd	1.85abc
	69	70.45bc	2.48a
	92	72.60bc	2.20ab
	115	74.00ab	1.80abc
	138	77.51a	1.53bc
	LS	4.78	0.68
	CV (%)	6.8	36.7

Means followed by different letters within a column are significantly different at 5% probability level, NS= not significant

3.3. Tubers per plant, marketable, unmarketable and total tuber yield

The data for number of tubers per plant, marketable, unmarketable and total tuber yield as affected by varieties and N rates are depicted in Table 4. Varieties did not show significant differences on number tubers per plant. However, N fertilizer rates resulted in significant differences on number of tubers per plant. The greatest number of tubers per plant (14.4) was obtained from N rate of 115 kg ha^{-1} followed by 92 kg ha^{-1} with mean number of tuber per plant of 13.4. The least number of tubers per plant (8.9) was observed at control. In the same way variety by N rates interactions resulted in significant differences on number of tubers per plant. Number of tubers per hill showed tendency increasing as N rates increased for both varieties up to 115 kg ha^{-1} and then decreased for immediate N rate above it. Both varieties yielded the highest number of tubers per plant at N rate of 115 kg ha^{-1} followed by N rate of 92 kg ha^{-1}. The lowest number of tubers per plant were recorded at control. The present finding is in agreement with earlier findings of Sparrow *et al.* (1992) and Lynch and Rowberry (1997) reported a significant tuber number per plant increment in response to increasing N rates. However, contradictory results were reported by (Sharma and Arora (1987) and De La Morena *et al. (*1994) that there was absence of strong relationship between N rates and number of tubers per plant.

Significant differences were detected due to main effects varieties and N rates on marketable tuber yield (Table 4). Variety Belete gave significantly higher yield as compared to Gudeane. This probably indicates variety Belete has relatively better adaptability to the environment than Gudane. In line with this, marketable tuber yield as affected by N main effect ranged from 16.10 to 31.6 tons ha^{-1}. Generally all fertilized plots out yielded over the control. The highest tuber yield (31.6 tons ha^{-1}) was recorded at N rate of 92 kg ha^{-1} followed by N rate of 69 kg ha^{-1} with mean tuber yield of 31.5 tons ha^{-1}. The lowest tuber yield (16.1 tons ha^{-1}) was observed at control. At highest tuber yield, a yield gain of 94.3% was attained over the control. Moreover, the relationship between main effects of N rates and tuber yield is shown in Figure 1. Tuber yield of potato, averaged over varieties, in response to main effect of N rates exhibited a nearly a curvilinear relationships. Thus, the yield increased with increasing N rates from control to 46 kg ha^{-1} indicating proportional correspondence of tuber yield with N fertilization rates (Figure 1a). This probably suggests that plant uptake of available N in the soils was active. With increasing N rates from 69–92 kg ha^{-1} the yield nearly reached plateau with insignificant increment in tuber yield (Figure 1b). At N rate 92 kg/ha and above the tuber yield relatively tended to decline indicating that N rates above it has no positive impact on tuber yield (Figure 1c). Thus, after this level excess N in the soil is subjected to different losses and cannot be consumed by plants. Hence, N application optimization is of prime important for proper exploitation of genetic potential of a crop including potato.

Varieties by N rates interactions resulted in significant differences on marketable tuber yield (Table 4). Marketable tuber yield increased for both varieties with increasing N rates up to 69 kg ha^{-1} and then declined with further increase above it. The highest marketable tuber yield (32.4 tons ha^{-1}) was observed for Belete at N rate of 69 kg ha^{-1} followed by the same variety at N rate 92 kg ha^{-1} with marketable tuber yield of 32.00 tons ha^{-1}. In line with this, varieties significantly differed for total tuber yield where variety Belete gave the higher total tuber yield than that of variety Gudane. However, varieties did not show significant differences for unmarketable tuber yield. In contrast, N rates had significant differences on unmarketable and total tuber yield. Both parameters were highest at N rate of 92 kg ha^{-1} and lowest at control. In the same way, varieties by N rates interaction caused significant differences on unmarketable and total tuber yield. The highest unmarketable tuber yield was recorded for both varieties at control indicating that shortage of N fertilization had great impact on tuber formation and its size increment.

Table 4. Tubers per plant, marketable, unmarketable and total tuber yield as affected by varieties and N rates

Variety	N rates (kg ha^{-1})	Tubers/plant	Marketable tuber yield (ton ha^{-1})	Unmarketable tuber yield (ton ha^{-1})	Total tuber yield (ton ha^{-1})
Belete	0	8.0d	18.6d	2.2ab	20.4g
	23	9.3cd	21.6c	1.7abc	23.4ef
	46	11.0bc	25.8b	1.8abc	27.6d
	69	11.0bc	32.4a	2.1abc	34.3a
	92	14.0a	32.0a	2.1abc	34.1ab
	115	15.0a	30.2a	1.8abc	32.5abc
	138	13.0ab	29.6a	1.4c	30.9c
Gudane	0	9.5cd	17.6d	2.2a	19.9g
	23	9.8cd	18.6d	1.9abc	20.6fg
	46	12.8ab	24.3bc	1.5bc	25.9de
	69	13.0ab	31.2a	1.7abc	32.2abc
	92	13.3ab	30.7a	1.9abc	32.9abc
	115	13.8a	30.4a	1.6abc	32.0abc
	138	12.8ab	29.8a	1.6abc	31.4bc
	LSD	2.7	2.8	0.6	2.8
	Belete	12.0	27.2a	1.8	29.0a
Variety mean	Gudane	12.1	26.1b	1.8	27.8b
	LSD	NS	1.0	NS	1.1
	0	8.9c	16.1d	1.9a	20.1d
	23	9.4c	20.1c	1.8ab	21.9d
N mean	46	12.0b	25.1b	1.7ab	26.7c
	69	13.3ab	31.5a	1.7ab	33.3a
	92	13.4ab	31.6a	2.0a	33.5a
	115	14.4a	30.3a	1.9ab	32.2ab
	138	13.1ab	29.7a	1.5b	31.2b
	LSD	1.9	1.9	0.4	1.9
	CV (%)	15.8	7.4	25.0	6.9

Means followed by different letters within a column are significantly different at 5% probability level, NS= not significant

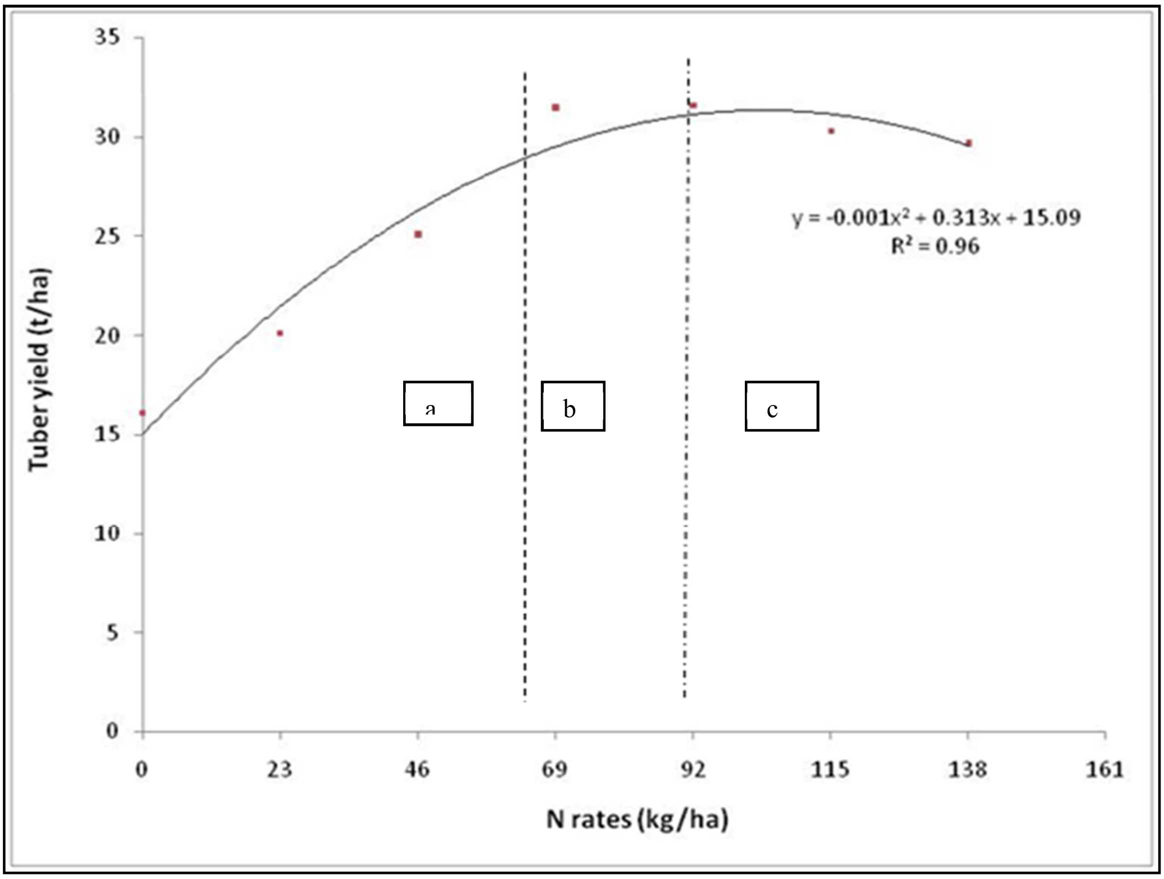

Figure 1. Relationship between N rates and total tuber yield

3.4. Biomass, dry matter content and harvest index

The data for dry biomass, dry matter content and HI as affected by varieties and N rates are presented in Table 5. Varieties did not show significant differences on biomass yield. However, analysis of variance revealed that main effects N rates resulted in significant differences on biomass yield. Generally biomass yield showed tendency of increasing as N rates increased. The highest biomass yield (56.74 ton ha^{-1}) was recorded at N rate of 138 kg ha^{-1} followed by N rate of 115 kg ha^{-1} with mean biomass yield of 56.74 ton ha^{-1}. The lowest biomass yield (37.18 ton ha^{-1}) was achieved from non N application plots. In line with this, varieties by N rates interactions resulted in significant differences on biomass yield. Biomass yield tended to increase for both varieties with increasing N rates. The greatest biomass yield (56.85 ton ha^{-1}) was observed for variety Gudane at N rate of 138 kg ha^{-1} followed by Belete at the same N rate with mean biomass yield of 56.65 ton ha^{-1}. The lowest biomass yield (37.65 ton ha^{-1}) was recorded for variety Belete at control. This finding is in line with results of Millard and Marshall (1986) and Saluzzo *et al.* (1999) that increasing N fertilization led to significant increment of biomass yield.

Significant differences were detected due to effect main effects of N rates on dry matter content percentage (Table 5). Dry matter content increased with increasing N rates up N rate of 69 kg/ha and declined with N rate above that optimum. The highest dry matter content (24.5%) was recorded at N rate of 69 kg ha^{-1} followed by N rate 92 kg ha^{-1} with mean dry matter content of 23.2%. The lowest dry matter (13.7%) was observed at N rate of 0 kg/ha. Similarly, varieties by N rates interactions resulted in significant difference on dry matter content. Dry matter content showed the tendency of increasing for both varieties as N rates increased up to 69 kg ha^{-1} and then tended to decline above that rate. The highest dry matter content (24.7%) was obtained from variety Gudane at N rate of 69 kg ha^{-1} followed by Belete at the same N rate with mean dry matter content of 24.3%. The lowest dry matter content (13.8%) was seen for variety Belete at N rate of 0 kg ha^{-1}. Dry matter content in potato tubers depends on the environmental condition. However, the highest possible amount of dry matter is limited by genetic characteristics of the potato variety (Harris, 1992; Tesfaye *et al*., 2012). It is also influenced by a wide range of factors that affect the growth and development of the crop including most importantly, environmental factors such as intercepted solar radiation, soil temperature, available soil moisture and cultural treatments (Storey and Davies, 1992). Beukema and Van der Zaag (1990) indicated that excessive nitrogen may cause low dry matter content of potato. The present result is in general agreement with the findings of Westermann *et al.* (1994) and Kanzikwera *et al.* (2001) that excessive N fertilization led to reduction in percent dry matter content of potato. This could probably be attributed to higher N rates stimulate more top growth than tuber growth thereby delaying tuber formation and maturity. In contrast, varieties, N rates and their interactions did not have significant effect on HI (Table 5). Moreover, economic analysis (Table 6) revealed that the highest net benefit of 222270 birr/ha with MRR of 500% was obtained from variety Belete at N rate of 69 kg ha^{-1}. An increase in output will always raise profit as long as the marginal rate of return is higher than the minimum rate of return *i.e.* 50 to 100% (CIMMYT, 1998). The marginal rate of return at the nitrogen rate 69 kg ha^{-1} was greater than 100% showed an economically feasible rate since it is greater than 50% marginal rate of return. Based on this finding, both cultivars could be used for production using N rate of 69 kg ha^{-1} at Angecha and similar agro-ecologies.

Table 5. Biomass, dry matter and HI as affected by variety and N rates

Variety	N rates (kg ha^{-1})	Biomass (ton ha^{-1})	Dry matter (%)	HI
Belete	0	37.65e	13.8g	0.54
	23	41.90de	15.2f	0.56
	46	47.85cd	22.4cd	0.58
	69	54.55c	24.3ab	0.63
	92	55.05c	23.0cd	0.62
	115	56.00b	22.1d	0.58
	138	56.65a	20.9e	0.55
Gudane	0	36.71e	13.6g	0.54
	23	38.08e	15.4f	0.54
	46	45.96c	22.6cd	0.56
	69	51.95cd	24.7a	0.62
	92	52.93cd	23.4bc	0.62
	115	55.50b	22.6cd	0.58
	138	56.83a	20.5e	0.55
	LSD	2.33	1.1	NS
	Belete	49.95	20.2	0.60
Variety mean	Gudane	48.27	20.4	0.55
	LSD	NS	NS	NS
	0	37.18d	13.7e	0.60
	23	39.98d	15.3d	0.59
N mean	46	46.91c	22.5b	0.59
	69	53.25c	24.5a	0.59
	92	53.99c	23.2b	0.56
	115	55.75b	22.4b	0.56
	138	56.74a	20.7c	0.56
	LSD	1.32	0.8	NS
	CV (%)	6.3	4.1	4.1

Means followed by different letters within a column are significantly different at 5% probability level, NS= not significant

Table 6. Profitability as affected by varieties and N fertilizer rates

Varieties	N rates (kg ha^{-1})	Total revenue	Profit	MRR (%)
	0	178060	148100	-
	23	203400	151640	24
Belete	46	241360	179150	430
	69	300090	222270	500
	92	290350	222000	190
	115	283000	207690	690
	138	271060	197800	770
	0	173850	144830	190
	23	180080	134110	-100
Gudane	46	226190	167770	440
	69	281980	208690	450
	92	288670	212800	260
	115	280030	205430	950
	138	274000	200680	2040

4. CONCLUSION

The results of present study investigated that both varieties gave better tuber yield and economic benefit at the N fertilization rate of 69 kg ha^{-1}. Based on this finding, application of 69kg N ha^{-1} for both cultivars recommended for production at Angecha and similar agro-ecologies.

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