

Review of Potato Agronomic Research in Central highlands of Ethiopia: Achievements and Future Prospects

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Abstract
The suboptimal agronomic techniques practiced by potato growers in Ethiopia are undoubtedly one of the contributing factors to the existing low average national yield. Agronomic studies have been undertaken by different research centers and higher learning institutions to develop a package of optimum Agronomic management practices, together with improved potato varieties. Agronomic research at Holetta, Adet and Bako Agricultural Research Centers and various universities were carried out for more than two decades with the objectives to alleviate production constraints of potato in different parts of the country for various agro-ecologies for smallholder farmers and thereby increase the production and productivity of potato. Thus, experiments were carried out on agronomic research such as planting dates, planting depth and method of planting, inter and intra row spacing, planting depth and intra row spacing, seed tuber size & plant population density and number of hilling during the growing period. These experiments were carried out at different agro-ecological zones, via mid altitude and high altitude areas of the country. Moreover, fertilizer rate and time of applications, nitrogen fertilizer and planting density, and integrated use of organic and inorganic fertilizers application to see their effect on potato yield and quality for seed and ware potatoes productions comprise the major component of the agronomic/physiology research. In addition, agronomic practices such as intercropping, dates of dehaulming and vermicompost were carried out. Therefore, to boost the production and productivity of potato for food security and income generation in the country the appropriate use of recommended agronomic practices should be crucial.
Keywords: Potato, Agronomy, Nitrogen & Phosphorus, INM, Vermicompost, Ethiopia

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of mankind's most valuable food crops and mainstay in the diets of people in many parts of the world (Struik and Wiersema, 1999). Ethiopia is endowed with suitable climatic and endemic conditions for potato production. However, the national average yield is very low 10 t ha^{-1} as compared to the world's average production 17. 7 t ha^{-1} (FAO, 2010). Potato is the rich source of starch, vitamin C, B and minerals. It contains about 20.6 % carbohydrates, 2.1% protein, 0.3 % fat, 1.1 % crude fiber and 0.9 % ash. It also contains a good amount of essential amino acids like *leucine*, *tryptophane* and *isolucine* (Khurana and Naik, 2003). Likewise, it is a very important food and cash crop in the high and mid altitude areas of Ethiopia. It has a promising prospect in improving the quality of the basic diet in both rural and urban areas of the country.

Ethiopia is among the top potato producers in Africa, with 70% of its arable land in the high altitude areas above 1500 m being suitable for potato production (FAOSTAT, 2008). The major production problems that account for such low yield are unavailability and high cost of seed tubers, lack of well adapted cultivars, poor agronomic practices, diseases, insect pests, inadequate storage, transportation and marketing facilities (Tekalign, 2005). Low soil fertility is one of the most important constraints limiting potato production in Eastern Africa (Muriithi and Irungu, 2004) and also Tekalign *et al*. (2001) reported that, nitrogen and phosphorus are deficient in most Ethiopian soils and thus application of these nutrients could significantly increase crop yields. Moreover, inadequate application of proper agronomic management practices particularly time and rates of fertilizer application, inter & intera row spacing and manure used by potato growers determine the potato productivity (Girma, 2001; Daniel, 2006). It was reported that, the sub-optimal agronomic management practiced were the major contributing factors for low yield of potato cultivars (Gebremedhin *et al*., 2008). Declining soil fertility is one of the major problems causing yield reduction in Ethiopia. Farmers at major potato producing parts of the country apply both organic and inorganic fertilizers to overcome the problem and increase yield. However, application of manure is restricted only to homestead areas due to shortage of manure to cover the outfield and chemical fertilizers are costly to apply the recommended rate. Several Agronomic experiments were conducted to improve the production and productivity of potato.

Agronomic research work at Holetta, Adet and Bako Agricultural Research Centers and various higher learning institutions were carried out for more than two decades with the objectives to alleviate production constraints of potato in various regions and thereby increase the production and productivity of potato crop. Therefore, this paper reviews agronomic research results that have been recommended during the last two decades in major potato producing central highlands, Northwestern, and Eastern parts of Ethiopia.

Many diverse and complex biotic, abiotic, and human factors contribute to the existing low productivity of potato in Ethiopia. Some of these include shortages of good quality seed tubers of improved cultivars; disease and pests; and lack of appropriate agronomic practices, including optimum plant density, planting date, soil moisture, row planting, depth of planting, ridging, and soil fertility status (Berga *et al*., 1994b). Agronomic studies were carried out on different potato management practices at various agro-ecologies to mitigate factors limiting to potato production and productivity. In general, the poor crop management practices observed in most farmers' fields include the use of too low or too high plant density, inter and intra row spacing, absence of row planting, poor quality seed material, inappropriate land preparation, time of planting, depth of planting, ridging, harvesting techniques and crop rotation. Moreover, agronomic research such as fertilizer rate and time of applications, and number of hilling during the growing period and plant population density for seed and ware potato productions comprise the major component of the agronomic/physiology research undertaken by different research centre to improve production and productivity of potatoes in the country. Thus the results of various agronomic studies made in the past decade in the central highlands of Ethiopia were reviewed as follow.

Inter and intra row spacing on tuber yield of potato

The experiment was conducted in high altitude areas of Shambu and Arjo, located in western Oromia, Ethiopia; for three cropping seasons 2001-2003 to evaluate the influences of different inter and intra row spacing on yield, yield components and tuber quality of potato variety, Menagesha. The experiment was laid out in randomized complete block design with three replications. The treatments used were consisted of four inter row spacing (70, 80, 90 and 100 cm) and three intra row spacing (30, 40 and 50 cm) in a factorial arrangement. The over years combined analysis of variance for intra row spacing showed highly significant ($P< 0.01$) difference on tuber weight at Arjo and on total and marketable tuber yield at Shambu. Maximum marketable tuber yield of 27.86 and 18.85 t ha^{-1} was recorded for 30 cm intra row spacing at Shambu and Arjo, respectively (Table 1) (Berga *et al*., 1994b). Yield differences observed over the locations were due to the differences in the inherent soil macro and micronutrients and other agro-ecological conditions.

In contrast to intra row spacing, inter row spacing did not bring about any significant difference on all parameters measured except that significant ($P< 0.05$) difference recorded on total tuber yield at Shambu. The interaction effects of inter and intra row spacing resulted in non-significant ($P > 0.05$) difference for all parameters at both locations (Table 2). Based on the partitioning and interaction effects of inter and intra row spacing, 70 - 90 cm inter row spacing by 30 cm intra row spacing could be recommended for potato production in the western highlands of Shambu. This spacing range was in the nationally recommended spacing for potato production, which is 75 x 30 cm (Berga *et al*., 1994b).

Table 1. Influence of intra and inter row spacing on yield and yield-components of potato (2001 - 2003)

Spacing	Location							
Intra row (cm)	Arjo				Shambu			
	MTY (ton/ha)	TTY (ton/ha)	TN	TW (kg)	MTY (Ton/ha)	TTY (Ton/ha)	TN	TW (kg)
30	18.85	20.99	11.71	0.86	27.84	33.21	9.99	1.18
40	18.71	20.36	13.16	1.05	25.11	30. 13	10.42	1.25
50	17.60	18.88	13.01	1.15	21.76	26.11	11.05	1.33
CV (%)	2.35	2.00	23.96	26.66	3.23	2.60	19.73	29.09
LSD	NS	NS	NS	0.123**	2.75**	2.53**	NS	NS
Inter row (cm)								
70	18.48	20.38	11.54	0.92	27.31	33.24	10.65	1.18
80	19.12	20.61	12.42	1.02	23.77	27.89	9.73	1.22
90	18.18	20.35	13.36	1.07	25.59	29.99	10.99	1.37
100	17.77	18.96	12.77	1.07	22.86	23.89	10.58	1.24
CV (%)	2.35	2.00	23.96	26.66	3.2.3	2.60	19.73	29.09
LSD	NS	NS	NS	NS	NS	2.53*	NS	NS

MTY=Marketable tuber yield TTY= Total tuber yield TN= Tuber number TW= Tuber weight NS= Non significant ($P > 0.05$) *= 5% probability level ($P<0.05$) **= 1% probability level ($P< 0.01$)

Table 2. Interaction effect of inter and intra row spacing on yield and yield components of potato (2001 - 2003)

Inter X Intra row spacing (cm)	Arjo MTY (Ton/ha)	Arjo TTY (Ton/ha)	Arjo TN	Arjo TW (kg)	Shambu MTY (Ton/ha)	Shambu TTY (Ton/ha)	Shambu TN	Shambu TW (kg)
70 x 30	18.62	21.15	11.69	0.80	28.20	34.97	10.04	0.97
70 x 40	18.93	20.40	10.84	0.88	27.84	33.04	9.62	1.19
70 x 50	17.87	19.60	12.09	1.09	25.89	31.71	12.28	1.38
80 x 30	18.77	20.22	11.29	0.92	26.00	30.66	8.87	1.21
80 x 40	19.20	21.20	13.71	1.08	24.46	28.46	10.60	1.29
80 x 50	19.39	20.42	12.27	1.07	20.86	24.56	9.71	1.14
90 x 30	19.05	22.18	13.19	0.89	29.61	34.51	10.56	1.24
90 x 40	18.21	20.33	13.46	1.09	25.91	30.54	11.53	1.32
90 x 50	17.29	18.54	14.62	1.22	21.25	24.92	10.89	1.54
100 x 30	18.96	20.41	10.66	0.83	27.54	31.95	10.49	1.30
100 x 40	18.50	19.52	14.61	1.16	22.22	28.46	9.93	1.20
100 x 50	15.87	16.96	13.06	1.22	18.82	23.26	11.31	1.24
CV (%)	2.35	2.00	23.96	26.66	3.23	2.60	19.73	29.09
LSD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS

MTY=Marketable tuber yield TTY= Total tuber yield TN= Tuber number TW= Tuber weight
NS= Non significant (P > 0.05)

Similar experiment was conducted on a farmer's field in 2010/2011 under irrigation condition in southern zone of Tigray, Ofla Woreda at Hashenge kebele. There were 16 treatment combinations, consisting of four inter-rows spacing (65, 70, 75, and 80 cm) and four intra-rows spacing (20, 25, 30, and 35 cm). The experiment was laid out in 4 x 4 factorial arrangements using a randomized complete block design (RCBD) with three replications. The collected data on different growth stage was analyzed by using SAS Computer software version 9.0 (SAS Institute Inc., 2008).

The result reveled that, effect of inter- and intra-row spacing showed a very highly significant (p <.001) differences on total tuber yield per hectare (Table 1). The interaction effect was non-significant (p < 0.5). The highest yield (36.89 t/ha) was obtained from 65-cm inter-row spacing, whereas the lowest (31.87 t/ha) yield was recorded at 80-cm inter-row spacing. The present result agrees with the findings of Zabihi *et al*. (2011), who reported that plant density in potato affects some of the important plant traits such as total yield, tuber size distribution, and tuber quality. Increase in plant density led to decrease in mean tuber weight but not in number of tubers and yield per unit area. In contrast, Berga *et al*. (1994b) reported that wider row width by wider intra-row distance (80 x 40 cm) gave the highest yield (34 t/ha),whereas the narrower intra-row distance (60 x 20 cm) treatment gave the lowest (22.2 t/ha) yield.

Table 1: Means for the effect of inter- and intra-row spacing on total tuber yield and marketable tuber seed yield

Treatments	**Tuber seed yield (t/ha)**	**Marketable seed yield(t/ha)**
Intra-rows spacing (cm)		
20	37.54 ^{a}	35.89^{a}
25	35.75 ^{b}	34.49^{b}
30	35.61 ^{b}	34.66^{b}
35	29.38 ^{c}	28.65^{c}
Inter-rows spacing (cm)		
65	36.89 ^{a}	35.09^{a}
70	35.33^{b}	33.86^{b}
75	34.18^{b}	33.32^{b}
80	31.87 ^{c}	31.42^{c}
LSD (5%)	1.18	1.18
CV (%)	11.25	10.31

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

Based on the result of this study, yield per unit area was influenced by the different level of inter- and intra-rows spacing. One can conclude that the narrow spacing (20- and 65-cm intra- and inter-row spacing) produced higher seed tuber yield and marketable yield per hectare than other spacing's.

Time of planting

Planting time for potato varies from place to place and from variety to variety and also based on growing season. It influences tuber yield incidence of late blight and has significant impact of tuber yield and quality. To secure maximum yield potato should be planted during the time in which favorable conditions prevail for better growth and development of the crop. Planting from, Early June was recommended as optimum planting time for Emdiber (Gurage zone), Holetta (central Ethiopia) and other similar agro-ecological areas (Berga *et al.,* 1994a). Similarly, May first to mid May and from May first to June first are recommended as optimum planting dates for late blight susceptible and moderately tolerant/resistant potato cultivars around Adet and similar agro-ecologies. Abdulwahab and Semagn (2008) recommended that last week of May to mid June as an appropriate planting time for optimum potato production in the high lands of Ankober (North Shewa) and other similar agro-ecologies.

Depth of planting: Even though optimum planting depth varies with the areas of soil moisture content, soil temperature etc, under Holetta condition planting at 15cms depth followed by 10 and 20 cm performs best for high yield and protect from insect pest attack (Gebremedhin *et al*., 2008).

Planting depth and intra row spacing: are among the important agronomic management in potato production. However, most potato growing farmers in Ethiopia often use varies planting depth and intra row spacing which contributes to the low yield of the crop. Thus, the experiment consisted four levels planting depth (12, 15, 18 and 21cm) and intra row spacing (15cm, 20cm, 25cm and 30cm) which were combined in 4x4 factorial arrangements and laid out in randomized complete block design with three replications. Therefore, depth of 15cm-18cm and intra row of 15-20cm can be used as preliminary information for farther investigation of high marketable and better quality seed tuber yield production (kassaye *et al.*, 2016).

Planting Depth and Time of Earthing-up: The treatments consisted of 3 levels of planting depth (10, 12 and 14 cm) and four time of earthing-up (no earthing-up, at 15, 30 and 45 days after plant emergence) were applied to Jalenie potato variety. A 3x4 factorial experiment was laid out with 3 replications. Earthing-up at 15 days combined with planting depth of 10 and 12 cm recorded significantly ($P<0.01$) the highest total tuber number. Even though early earthing-up was superior when compared to very late earthing-up and no earthing-up with regard to different parameters, where as no earthing-up and shallow planting depth performed very poorly (Tadele *et al*., 2015).

Ridging/ earthing up

Ridging, which refers to the practice of hilling or earthing up the soil around the potato plant, is a normal practice in potato production. Riding is practiced to obtain sufficient earth or soil and form a well-shaped ridge that helps to loosen the subsoil for good aeration and/or to cover the tubers with sufficient layer of soil. On lighter soils ridging presents no difficulty, and it is very useful if the soil depth is shallow (Gebremedhin *et al*., 2008). However, on heavier soils, ridging may present a problem unless it is done under suitable conditions and good timing in relation to moisture content of the soil. Proper ridging increases tuber yield by creating favorable condition for tuber initiation and development. Poor ridging in potato may expose the tuber to sunlight, high temperature, disease and insect damage. Studies show that a yield loss as high as 8% is sacrificed due to poor ridging. The frequency and optimum of ridging may depend on variety, soil structure and workable soil depth (Gebremedhin, 2013). The highest yield was obtained from plots with the highest frequencies of four and three times ridging. Generally, increasing ridging frequency substantially reduced green tubers from 53.3% in no ridging to 29.5% at four times ridging. In a similar study conducted at Adet, ridging frequency had no significant effects on parameters like tuber size, marketable and total yields. The results under Holetta conditions showed that yield and tuber quality can be affected by ridging and at least twice ridging is very necessary. Light soil and heavy rainfall areas require more frequent ridging. Whereas, in light red soils care has to be taken to reduce insect damage and greening by modifying planting distance and increasing frequency of ridging. In ware potato production, good cover-up of soil does substantially reduce unmarketable tuber yield due to greening (Gebremedhin *et al*., 2008)

Intercropping

Intercropping of potato with maize is a common practice in northwest Amhara region. Consequently, an experiment was conducted at adet for two consecutive years (1997-1998) to identify economically feasible intercropping pattern. The result of the experiment was also statistically analyzed using total monetary value (TMV) of the system and economic yield of each component crop. Moreover, the land equivalent ratio (LER) of each intercropping system is calculated. From this work intercropping of potato with maize in 2:1 and 1:1 (potato: maize) row spatial arrangement are found superior in their order and recommended for potato production at Adetand its surrounding (Tesfaye *et al.,* 2008). In addition, intercropping study of potato and maize was mad at Bako for three cropping seasons. Maize and potato were arranged in 1:1 ratio alternating within a row (15 x 75cm) and between rows (37.5 x 30 cm) including sole planting (75 x 30 cm). The yield of potato in an intercropped field was as high as sole potato in one of the three study seasons. Intercropping was found economically advantageous than sole cropping as the maize grower could get potato yield as bonus in addition to maize yield (Gebremedhin *et al*., 2008).

Seed tuber size and plant population

Seed tuber size and population density are among the most determining factors of the production and productivity of potato. A potato tuber may at the end of dormancy grow one or more sprouts, and after planting variable proportion of these sprouts develop into main stem. A plant may contain a variable number of this stem as this again is dependant up on the tuber size and treatment of the parent tuber. This in turn affects the number of tubers set, the growth and longevity of the haulm and therefore the performance of the plant and yield (Gebremedhin *et al*., 2008). Closer intra-row spacing of 10 or 20cm in rows of 75cm apart would be beneficial for seed and larger seed tubers (45-55mm) do better than the smaller ones. Wider intra-row spacing of 30 or 40cm are better, again on rows 75cm apart, for ware. Similarly, considering the amount of seed tuber required type of output and synergism with other cultural practices, seed tuber size of 35- 45mm diameter, 60cm inter-row spacing and ridging once at 3- 4 weeks of crop emergence is recommended for seed potato production. However, 35- 45mm diameter seed tuber, 75cm inter-row spacing and ridging once at 3-4 weeks from crop emergence is found optimum and recommended for ware potato production at Adet and its surrounding (Tesfaye *et al.,* 2008). Therefore, use of 75 cm inter-row spacing is found suitable for ware potato production with tuber size of > 50 mm diameter. However, use of 60cm inter-row spacing is found ideal for seed tuber potato production.

Determination of optimum N and P fertilizer rate

In Ethiopia, some farmers use inorganic fertilizers for increasing potato yields. However, they use only nitrogen (as Urea) and phosphorus (as DAP) since these are the only fertilizers commercially available in the local market. In addition, application of these fertilizers to potato crop is based on blanket recommendations that were formulated for potato grown on soils of certain sites in the country decades ago that is, 165 kg Urea/ha (111 kg N/ha) and 195 kg DAP/ha (40 kg P/ha). These recommendations wholly disregard the specific physico-chemical characteristics of the varied soils on which the crop is grown as well as the dynamic nature of soil nutrient status (Simeret *et al*., 2013).

According to Beukema and Van der Zaag (1990), a potato crop of average yield may remove 50 to 80 kg N, 20 to 30 kg P_2O_5 and 80 to 100 K_2O per ha from the soil. Organic manure plays a significant role for removal of these nutrients. Potato, as a high yielding crop, consumes more nutrients from the soil at a given time. Many factors may affect the total nutrient consumption of the potato crop. Reports indicate that the effects of season, variety and rate and time of N, P and K fertilizer applications resulted in the removal of mineral nutrients in fresh tubers in the following ranges: N, 2.28–3.57; P, 0.40–0.62 and, K, 3.70–5.41 kg/t (Gunasena, 1969). However, the diversity of soil types, moisture and nutrient regimes, cropping sequences, fertilizer uses and climatic conditions as well as biotic factors such as weeds, pests and diseases all many affect the sate of soil nutrient flux and use by the growing crop. The extent of use of fertilizer may also be dictated by economic factors like market prices and the economic status of a farmer (Gebremedhin *et al*., 2008). Considering this problem area specific and economically feasible fertilizer rates were recommended by different research center for different potato growing areas across the country. According to (Tesfaye *et al.,* 2008) fertilizer rates of 108/69 and 81/69 kg/ha N/P_2O_5 are economically feasible in South Gondar and Gojam areas, respectively. Similarly, 110 kg/ha nitrogen and 70.5 kg/ha P_2O_5 kg/ha are recommended for optimum potato tuber yield in nitosol and light vertisol of the high land of North Shewa (Abdulwahab and Semagn, 2008). Berga *et al.* (1994b) also reported that 165/90 N/P_2O_5 recommended as feasible rate for the central shewa area and this recommendation is still in use in the central and southern part of the country as blanket recommendation. In the same fashion, 146/138 N/P_2O_5 were recommended for the highlands of Hararghe. These recommendations may not work for the current market, soil fertility status and other climatic variables.

Similar study was conducted at two locations; Arjo and Shambu for three cropping seasons 2001-2003 to evaluate the influences of different rates of nitrogen and phosphorous fertilizer on yield and yield components of potato variety, Menagesha. The experiment was laid out in randomized complete block design with three replications. The treatments used were consisted of five nitrogen levels (0, 41, 82, 123 and 164 kg/ha) and four phosphorous levels (0, 46, 92 and 138 kg/ha) in a factorial arrangement. Half the quantity of N was applied in band on the ridge and incorporated in to the soil at the time of planting while the remaining half N was side-dressed 5 cm around the root zone at one and half months after planting. The entire quantity of P was applied at the time of planting in band on the ridge and incorporated in to the soil. The over years combined analysis of variance for nitrogen showed highly significant difference ($P < 0.01$) on total and marketable tuber yield and tuber weight per plant at Arjo where as phosphorous resulted in significant difference ($0.05 > P > 0.01$) for total tuber yield and non-significant difference ($P > 0.05$) for marketable tuber yield and tuber weight per plant

(BARC, 2005). Non-significant difference was observed on tuber number per plant for both nitrogen and phosphorous (Table 3). At Arjo the maximum and minimum marketable tuber yield for nitrogen was 35.81 and 21.78 t/ha at 123 kg/ha and 0 level, respectively. However, for phosphorous this value varies from 42.63 to 36.16 t/ha at 138 kg/ha and 0 level, respectively (Table 3). On the other hand, both nitrogen and phosphorous have resulted in highly significant difference on total and marketable tuber yield and tuber weight per plant at Shambu. Phosphorous and nitrogen showed highly significant and non-significant difference on tuber number per plant, respectively. According to BARC (2005) report, at Shambu, the maximum and minimum marketable tuber yield for nitrogen was 30.36 and 24.74 t/ha at 82 kg/ha and 0 level, respectively where as for phosphorous it varies from 33.54 to 23.38 t/ha at 138 kg/ha and 0 level, respectively (Table 3). In spite of great difference between maximum and minimum marketable tuber yield (i.e. 37.22 / 19.33 t ha^{-1} at 164N x 92 P kg ha^{-1} / 0 x 0 level at Arjo and 40.66 / 19.72 t ha^{-1} at 123N x 138 P kg ha^{-1} / 123N x 0 P kg ha^{-1} at Shambu), the interaction of nitrogen and phosphorous has resulted in non-significant difference for marketable tuber yield and other parameters at both locations (BARC, 2005).

Table 3. Influence of nitrogen and phosphorous fertilizer rate on total and marketable tuber yield and yield components of potato (2001 - 2003)

Rate	Location							
Nitrogen	Arjo				Shambu			
(kg/ha)	TTY (Ton/ha)	MTY (Ton/ha)	TN	TW (kg)	TTY (Ton/ha)	MTY (Ton/ha)	TN	TW (kg)
0	28.85	21.78	9.43	0.84	29.05	24.74	8.73	0.79
41	38.13	28.39	10.63	1.08	35.25	29.38	9.35	0.92
82	42.35	29.84	10.16	1.13	37.30	30.36	9.47	0.98
123	46.71	35.81	11.07	1.23	35.76	30.00	9.44	1.01
164	43.13	32.40	10.56	1.21	36.88	28.13	9.62	1.00
CV (%)	2.55	3.51	25.29	24.34	1.91	2.55	19.87	25.07
LSD	4.74**	4.85**	NS	0.125**	3.11**	3.39**	NS	0.1125**
Phosphorous (kg/ha)								
0	36.16	27.07	9.97	1.02	28.81	23.38	8.52	0.76
46	39.45	28.87	9.92	1.08	32.82	26.82	8.90	0.90
92	41.10	31.42	10.74	1.15	36.78	30.34	9.69	1.00
138	42.63	31.23	10.84	1.15	40.98	33.54	10.12	1.11
CV (%)	2.55	3.51	25.29	24.34	1.91	2.55	19.87	25.07
LSD	4.24*	NS	NS	NS	2.78**	3.03**	0.7736**	0.1006**

MTY=Marketable tuber yield; TTY= Total tuber yield; TN= Tuber number per plant; TW= Tuber weight per plant; NS= Non significant ($P > 0.05$); *= 5% probability level ($P<0.05$); **= 1% probability level ($P< 0.01$)

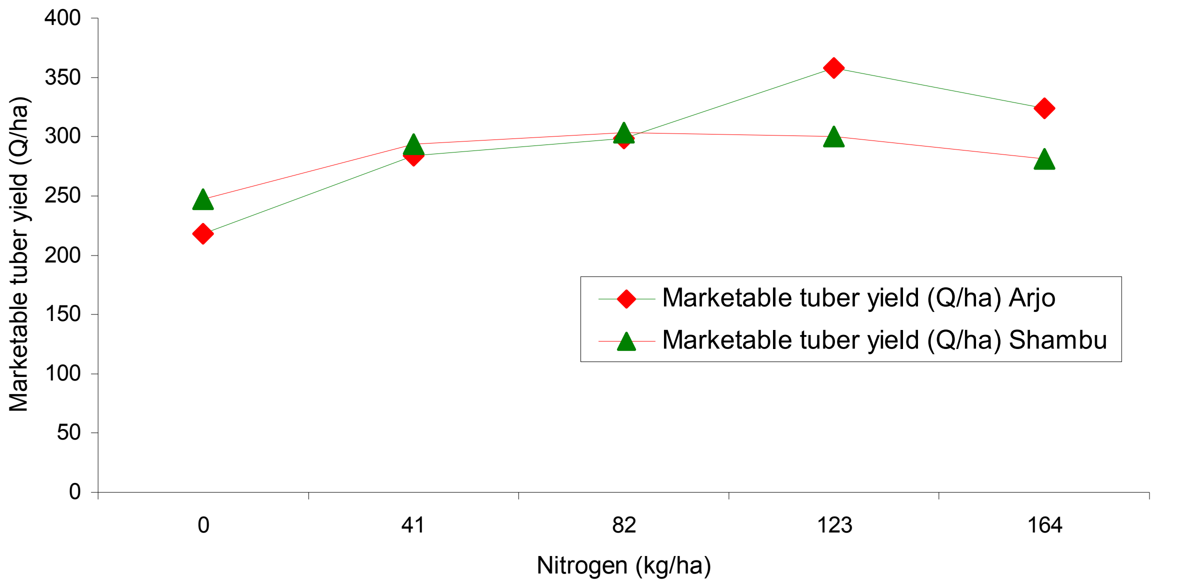

Figure 1. Marketable tuber yield of potato (Q/ha) as influenced by different levels of nitrogen (kg/ha) at Arjo and Shambu sites (2001/02 - 2003/04)

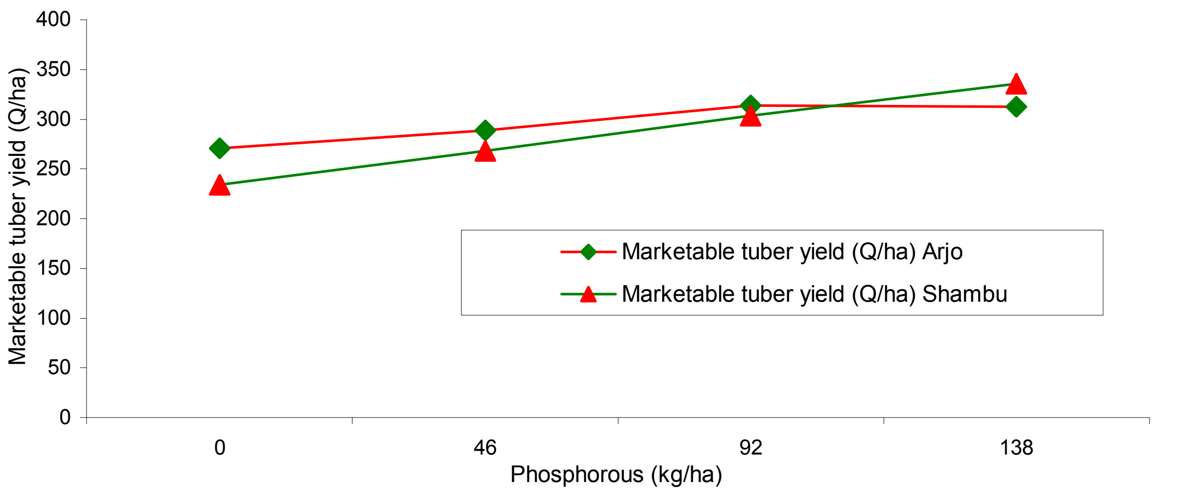

Figure 2. Marketable tuber yield of potato (Q/ha) as influenced by phosphorous (kg/ha) at Arjo and Shambu sites (2001/02 - 2003/04)

Based on the analysis made, N and P interaction resulted in non-significant difference for all parameters at both locations and location by nitrogen interaction (L x N) showed significant difference. Hence, it is possible to recommend nitrogen separately for both locations. Maximum biological yield obtained when 123 and 82 kg/ha N applied for Arjo and Shambu, respectively (Figure 1). For phosphorous, the yield increased with the increanment of P rate and therefore, additional rate should be tested at both locations (Figure 2). Therefore, considering the variability of the input-output market and soil fertility status, detail soil test based fertilizer rate studies should be carried out.

Integrated nutrient management (INM) on tuber yield of potato

The study was conducted at Bako in 2005 main cropping season to investigate the effect of integrated nutrient management on tuber yield of potato. A 3 X 4 factorial combinations of three levels of inorganic fertilizers (25%, 50% and 75% of recommended chemical fertilizer) and four levels of organic manure (4 t/ha vermicompost, 5 t/ha farmyard manure, 8 t/ha vermicompost and 10 t/ha farmyard manure) was evaluated along with four control treatments consisting of unfertilized plot (absolute control), 100% recommended rate of N and P, 10 t/ha farmyard manure and 8 t/ha vermicompost. The experiment was laid out in randomized complete block design with three replications. Well-sprouted potato tubers of 40-100 g were planted on prepared ridges in rows of four per plot at a spacing of 75 cm between rows and 30 cm between plants. The potato variety named 'Menagesha' was used for the experiment.

The result showed that significant difference among treatment both for integrated nutrient supply and different levels of organic and inorganic fertilizer on marketable and total tuber yield. The marketable and total tuber yield due to 75% recommended dose of fertilizer (26.19 and 27.75 t/ha) was significantly higher than application of 25 and 50 % recommended dose of fertilizer. The marketable yield increased significantly with increasing rates of farmyard manure from 5 to 10 t/ha (Daniel, 2006). The author found that, increasing vermicompost from 4 to 8 t/ha significantly increased total tuber yield without affecting marketable tuber yield. The results revealed that application of 10 t/ha farmyard manure in conjunction with 75% of recommended dose of fertilizer gave significantly higher marketable tuber yield (28.67 t/ha) over the rest of treatment combinations followed by 8 t/ha vermicompost plus 75% of recommended dose of fertilizer (26.81t/ha) and 5t/ha farmyard manure plus 75% of recommended dose of fertilizer (25.96 t/ha). Total tuber yield also followed similar trend and it was highest for those treatments, which had shown highest marketable yield. The result also showed that application of only farmyard manure and vermicompost did not significantly boost performance of potato; even it is comparable to unfertilized plot.

Application of 100% recommended dose of fertilizer alone and different recommended dose of inorganic fertilizers along with different levels of organic manures (farmyard manure and vermicompost) significantly increased marketable tuber yield and total tuber yield compared with plants receiving 8 t/ha vermicompost, 10 t/ha farmyard manure or no fertilization. The results generally indicated that there was some advantage in incorporating organic manure alone, also combining organic manure and mineral fertilizer in improving potato yield. Hence, it would be reasonable to conclude that integrated use of organic manure along with little inorganic fertilizer, significantly improved potato production and could save 25 to 50% inorganic fertilizer for sustainable potato production in potato growing areas (Daniel, 2006).

CONCLUSION

Agronomic practices in most of the potato growing areas of Ethiopia leave much to desire for improvement. The agro-ecologies where farmers thrive to grow potato are characterized by diverse conditions. They vary considerably in soil type, moisture and temperature regimes, fertility conditions, and in the on-set, intensity and duration of rain. Therefore, crop management operations have to take into account of these differences to ensure high yielding potential of cultivars. In general, several activities were conducted so far on various agronomic practices to improve the production and productivity of potato in different parts of the country. However, some of these research recommendations were obsolete and should be revised for enhancing the yield of the crop. Therefore, the research and development on agronomic practices of potato should be continued to improve the production and productivity of potato as a food security crop in the country.

References

Abdulwahab, A., and Semagn A. 2008. Research achievements in potato agronomy at Debre Birhan Agricultural Research Center. *In:* Proceeding of the 1st Amhara Regional workshop on potato research and development: achievements, transfer experiences and future directions. 20-21 Dec. 2007. Bahirdar. ARARI, Bahirdar.

BARC/OARI (Bako Agricultural Research Institute/Oromia Agricultural Research Institute). 2005. Five Years Achievement Report (2001-2005). OARI, Finfine, Ethiopia.

Beukema H.P, and D.E. Van der Zaag, 1990. Introduction to Potato Production. Pudoc Wageningen, Netherlands. pp 92-95

Berga, L., Gebremedhin, W.G., Teriessa, J., Bereke-Tsehai, T., and Yaynu, H. 1994a. Potato improvement research. *In:* Proceedings of the 2nd National Horticultural Workshop of Ethiopia. 1-3 Dec. 1992, Addis Ababa. EIAR, Addis Ababa.

Berga, L., Gebremedhin, W.G., Teriessa, J., and Bereke-Tsehai, T. 1994b. Potato agronomy research. In: Proceedings of the 2nd National Horticultural Workshop of Ethiopia.1-3 Dec. 1992. Addis Ababa. EIAR, Addis Ababa.

Daniel Mekonnen, 2006. Effects of integrated nutrient management on agronomic performance of potato (S*olanum tuberosum* L.) and fertility of Nitosol at Bako. An MSc thesis presented to School of Graduate Studies of Alemaya University. Pp 112.

FAO. 2011. World food and Agricultural Organization data of statistics. Rome, Italy. http://faostat.fao.org/site/567/. Accessed on June, 2012.

FAOSTAT, 2008. Potato world: Production and consumption. International year of the potato 2008.

Giller, K., Misiko, M. and Tittonell, P., 2006. "Managing Organic Resources for Soil Management", Magazine on Low External Input and Sustainable Agriculture (LEISA), Volume 22 no. 4.

Girma A, 2001. Influence of nitrogen and phosphorus on yield, yield components and tuber quality of two potatoes on Nitosols in Bako area. An MSc thesis presented to School of Graduate Studies of Alemaya University. pp 112

Gebremedhin, W., Endale, G., and Berga, L. 2008. Potato seed management. In Root and Tuber Crops: The Untapped Resources. (Eds.) Gebremedhin Woldegiorgis, Endale Gebre and Berga Lemaga. Ethiopian Institute of Agricultural Research (EIAR). ISBN: 978-99944- 53-19-1. Pp. 53-77.

Gebremedhin Woldegiorgis. 2013. Potato Variety Development Strategies and Methodologies in Ethiopia. Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination: Experiences, Challenges and Prospects. Gebremedhin Woldegiorgis, Steffen Schultz and Baye Berihun (eds.). 12-14 March 2012, Bahir Dar, Ethiopia. PP 91-100.

Girma Abera. 2001. Influence of Nitrogen and Prosperous on Yield, Yield Components and Tuber Quality of Two Potato Varieties (*Solanum Tubersum* L.) on Nitosols on Bako Area. MSc Thesis. Alemaya University, School of Graduate Studies, Alemaya, Ethiopia. 112p.

Gruhn, P., Goletti, F. and Yudelman, M., 2000. "Integrated Nutrient Management, Soil Fertility,and Sustainable Agriculture: Current Issues and Future Challenges", International Food Policy Research Institute, Washington, D.C. 2006 U.S.A.

Khurana, P. S. M. and Naik. P. S., 2003. The Potato: an overview. *In*: the Potato Production and Utilization in Sub-tropics (Edited by S. M. Paul Khurana, J. S. Minas and S. K. Pandy) Mehta Publication, New Delhi, 1-14.

Koenig, R. and Johnson, M., 1999. "Selecting and using Organic Fertilizers".

Menone, R.G., 1992. "Determining Fertility, Fertilizer Needs, and other constraints", International Fertilizer Development Centre (IFDC), U.S.A.

Muriithi, M.M. and Irungu, J.W. 2004. Effect of integrated use of inorganic fertilizer and organic manures on Bacterial Wilt Incidence (BWI) and tuber yield in potato production system on hill slopes of central Kenya. *J. Mountain Science. 1: 81-88.*

Simeret Burga, Nigussie Dechassa, and Tekalign Tsegaw. 2013. Influence of Inorganic Nitrogen and Potassium Fertilizers on Seed tuber Yield and Size Distribution of Potato. Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination: Experiences, Challenges and Prospects. Gebremedhin Woldegiorgis, Steffen Schultz and Baye Berihun (eds.). 12-14 March 2012, Bahir Dar, Ethiopia. PP 130-144.

Struik, P.C., Wiersema, S.G.1999. Seed potato technology. Wageningen Pers, Wageningen, the Netherlands, 383 P.

Tadele Fanos, Derbew Belew, Amsalu Nebiyu. 2015. Effect of Planting Depth and Time of Earthing-up on Potato (*Solanum Tuberosum* L.) Yield and Yield Components at Jimma University College of Agriculture and Veterinary Medicine, South West Ethiopia. International Journal of African and Asian Studies

Tadesse Yohannes and Abidissa Gemeda (1996), "Effect of Compost and NP fertilizers on growth and yield of maize and pepper", *In*: Teshome Yizengaw, Eyasu Mekonnen, and Mintestnot Behailu (eds.), Proceedings of the third conference of Ethiopian Society of Soil Science (ESSS),Addis Ababa, Ethiopia, 28-29 February 1996. Ethiopian Science and Technology Commission, Addis Ababa.

Tekalign Tsegaw. 2005. Response of potato to paclobutrazol and manipulation of reproductive growth under tropical conditions. PhD thesis. pp. 2-3.

Tekalign M, Teklu E, and Balesh T. 2001. Soil fertility and plant nutrition research on Teff in Ethiopia. Proceeding of the international workshop on Teff Genetics and Improvement, October 16-19, 2001, Debre Zeit, Ethiopia, pp: 191-200.

Tesfaye, A., Yigzaw, D., and Ermias, A. 2008. Crop management research and achievement on potato in Amhara Region with special reference to western Amhara parts. Proceeding of the 1stAmhara Region workshop on potato Research Development: achievements, transfer experiences and future directions. 20-21 Dec. 2007, Bahirdar.ARARI. Bahirdar.

Zabihi, R.M., Shahzad Jamaati-e-Somarin, Majid Khayatnezhad, and Roza Gholamin. 2011. Correlation of Tuber Yield Whit Yield Components of Potato Affected by Nitrogen Application Rate in Different Plant Density.*Advances in Environmental Biology*, 5(1) Islamic Azad University, Ardabil, Iran. Pp.131-135.