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Effects of Nitrogen Fertilizer Application Timing and Inter-Row Spacing on Growth and Tuber Yield of Potato (*Solanum tuberosum* L.) in Wolaita Zone, Southern Ethiopia

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Abstract

Field experiment was undertaken to evaluate the effects of nitrogen fertilizer application timing and inter-row spacing on potato growth, yield and quality in Sodo Zuriya District, Southern Ethiopia, during main potato cropping season (February to June) of 2018. The experiment was laid out in split plot design with three replications. As main plot factor three N timing levels along with the control (once, twice, thrice and no) and as sub plot factor row spacing with three levels (60 cm, 75 cm and 90 cm) were used. The analyses of variances indicated that most of the growth, yield component and yield parameters as well as nitrogen use efficiency of potato crop were significantly influenced by the main effects of N timing and row spacing. In addition, partial budget analysis showed that maximum net benefits and greater marginal rate of returns were obtained from investing in potato production with nitrogen application in three splits than others. Similarly, maximum net benefits and acceptable marginal rate of returns were obtained from investing in potato production using 60 cm row spacing. In general, in this study, applying nitrogen fertilizer in three splits and using 60 cm inter-row spacing performed better than other treatments in the specific study area.

Keywords: Nitrogen; Inter-Row Spacing; Potato Tuber.

Introduction

On a global scale, potato (*Solanum tuberosum* L.) is the fourth most cultivated food crop after maize, rice and wheat. And among root and tuber crops, potato ranks first in volume produced and consumed, followed by cassava, sweet potato and yam in the world. In Ethiopia in the year 2015/16 using the total area of 70,131 hectares about 943,233 tons of potato tubers was with average national yield pe r hectare of 13.45 tha^{-1}. This indicates that its productivity is still far less than that of other countries in the world [1-6].

One of the challenges of potato production as with any crop is the efficient management of Nitrogen (N) fertilizer. Excessive N fertilizer applied at or before tuberization can extend the vegetative growth period and delay tuber development resulting in a lower tuber yield. However, too much N applied later in the season can delay maturity of the tubers reducing yield and adversely affecting tuber quality and skin set. Conversely, under application of N at any point in the season can result in lower tuber yields and reduced profits. Environmental considerations must also be taken into account in N fertilizer management. Since, nitrogen is a mobile nutrient in the soil and any excess N has the potential to move off-site *via* leaching or surface runoff. Effective N management is critical to profitable production of potatoes. Nitrogen fertilizer application timing is one of the most important management techniques that potato growers can use to increase nitrogen use efficiency, and to improve tuber yield and quality. For efficient nitrogen utilization nitrogen fertilizer application has to be synchronized with times of higher nitrogen demand by the potato crop. Nitrogen is highly mobile hence its use and demand is continuously increasing as it is subjected to high loss from the soil plant system [7-10].

In Ethiopia, generally, lack of area specific improved agronomic techniques such as nitrogen application timing and plant spacing is known to be one of the major contributing factors to the existing low potato tuber yield per unit area. Except the blanket recommendations, site-specific research findings are lacking particularly on effects of N fertilizer application timing and row spacing on potato productivity in the study area. Hence, the objective of this study was to investigate the effects of nitrogen fertilizer application timing and inter-row spacing on potato crop productivity in Sodo Zuriya district, Wolaita Zone, Southern Ethiopia [11-16].

Materials and Methods

Description of study area

The study was carried out in Wolaita zone, Sodo Zuriya district, within main growing season (February to June) in 2018. Wolaitazone is located between 06°30′–07°12′N 037°14′–038°7′E. It covers an altitude range of 700–2900 m above sea level, having a bimodal

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rainfall. Mean annual rainfall of the study area is 1001 mm with the lowest and highest record in January and August, respectively. The mean monthly maximum and minimum temperature is 27°C and 14°C, respectively. Soils of the zone are varying due to its diverse topography. The dominant soils of the zone are reported to be Nitisols. It is derived from a multistory ignimbrite substratum, deep and has a good general porosity, a high capacity to absorb rainfall water and a high infiltration speed. An improved potato variety named Gudanie, which was widely adopted in the study area was used as a test crop. Urea (46% N) and Triple Super Phosphate (TSP, 46% P2O5) fertilizers were used as the sources of nitrogen and phosphorus per as recommended rates, respectively. The experiment was laid out as a split plot design with nitrogen timings (no, once, twice and thrice) as main plot factor and inter-row spacings (60 cm, 75 cm and 90 cm) as sub plot factor, replicated three times. All other field activities were carried out following the recommended production practices for potato crop in the country [17-25].

Data collection and analysis

Crop performance was evaluated on the basis of many parameters considered as its components. Data on crop phenology, growth, yield components and yield aspects as well as agronomic N use efficiency were collected and subjected to Analysis of Variance (ANOVA) using the SAS software by the command PROC GLM version 9.2 (SAS Institute, 2009). Least Significant Difference (LSD) test at 5% probability was used to separate means when the F test was significant. The partial budget and marginal analysis of this study was carried out according to the manual of CIMMYT (1988).

Results and Discussion

Effects of N Timing and Inter-Row Spacing on Potato Phenology

Days to flowering: Analysis of Variance showed that the main effect of inter-row spacing was highly significant on days to flowering of potato crop. Whereas, the main effect of N timing and the interaction effect were not significant. The longest days to reach flowering were recorded with the widest row spacing of 90 cm while decreasing row spacing from 90 cm to 60 cm decreased the number of days required to reach the growth stage of flowering (Table 1). This could be due to less competition occurred for sun light, water and nutrient as a result of planting with the widest row spacing, hence low physiological stresses to induce flowering. Similarly, Harnet et al. recently reported that a crop with narrow spacing could flower faster than a crop with wider spacing [26-28].

Days to maturity: The main effects of nitrogen application timing and inter-row spacing highly significantly influenced attaining days to physiological maturity in potato crop in the study site while their interaction did not. Applications of N in three splits (at planting, vegetative growth stage and tuber initiation stage) had required lesser days for maturity than applying total N once at vegetative growth stage (Table 1). This could be associated with excess N availability that ensured maintenance of photosynthetic active leaves for longer duration. This result is in line with the findings of Vos who reported that the total growth period of plants is prolonged by high amount of N supply. Maximum number of days for physiological maturity was required to plants grown at wider row spacing of 90 cm, whereas the minimum number of days was required to the plants grown at the narrower row spacing of 60 cm. This could be attributable to plant populations grown per unit area, higher in the case of 60 cm row spacing than that of 90 cm row spacing. This result is in accordance with Beukema and Vander who stated that a high planting density stimulates early tuber growth and maturity in potatoes [29].

Main effects	Days to flowering	Days to maturity
NTiming		
Once	52	104.00^{a}
Twice	55.11	102.00^{b}
Thrice	56.22	100.67^{c}
LSD (0.05)	ns	0.873
CV (%)	6.1	0.65
Row spacing		
60 cm	52.67^{c}	100.67^{c}
75 cm	54.89^{b}	102.22^{b}
90 cm	55.78^{a}	103.78^{a}
LSD (0.05)	0.559	0.685
CV (%)	0.99	0.65

Table 1: Effects of nitrogen timing and inter-row spacing on days to flowering and maturity of potato crop at Kokate, Southern Ethiopia, 2018.

Effects of N timing and inter-row spacing on potato crop growth

Plant Height (cm): Potato plant height was highly significantly influenced by the main effects of both nitrogen application timing and row spacing. The interaction effect was not significant. The longest plant height was recorded when N was applied in three splits while the shortest height was recorded when N was applied once after the plant establishment (Table 2). These differences could be due to the fact that an application of judicious amount of nitrogen fertilizer in three splits starting from early growth stage until tuber initiation could have induced the plant to be competent to take more nutrient and photosynthetic active radiation. Chowdhury et al. explained that better availability of nitrogen, by increasing cell division and cell elongation, could increase plant height [30].

Regarding row spacing, the longest plant height was recorded with row spacing of 60 cm, the intermediate height was recorded with the row spacing of 75 cm and the shortest height with row spacing of 90 cm (Table 2). This could be attributed to higher plant populations per unit area that resulted in mutual shading. This situation might have induced the plants to increase their height as a response for shade avoidance, mediated by plant hormones such as auxins and gibberellins. The result of this study agrees with Vander et al. who reported that closer spacing increased the potato plant height.

Number of main stems per square meters: The main effects of nitrogen application timing and inter-row spacing highly significantly influenced number of main stems per square meters; however, they did not interact to influence this trait of potato. Even though, applying N in three and two splits did show statistical difference, however, the practical importance of the difference is very low, which is less than a stem (Table 2). This little effect of timing of N on stem numbers could be attributed to the fact that the character of number of main stems per plant mainly depends on the cultivar, seed size, sprout numbers and the physiological age of the seed tuber rather than the fertility of the soil. Lungaho et al. also argued that stem number is basically determined by the number of eyes present on the tubers and the physiological age of the tuber during the storage period rather than by manipulating the supply of plant nutrients.

In contrast, inter-row spacing of 60 cm, 75 cm and 90 cm resulted in very different number of main stems per meter square. The possible reason for this could be due to the presence of more number of plants per unit area at narrower spacing which resulted in more number of main stems per unit area. This result is consistent with the findings of Fernando et al. who reported that decreasing plant spacing resulted in more number of stems per square meters and vice versa.

Number of leaves: Except their interaction, the main effects of nitrogen application timing and inter-row spacing highly significantly influenced leaf numbers per square meters (Table 2). This could be due to the fact that the split applications of nitrogen starting from planting time might have improved the soil as well as plant nitrogen status at early growth stage, in which the basic plant organs including leaves were fully formed at this stage. More stem with long stem height also led to more leaf numbers per square meters. In contrast, applying total N once after the plant already established might have led to low soil N availability during the critical early canopy development stage and thereby restrict number of leaves. Lower number of stems with short height might have resulted in lower numbers of leaf per square meters. In the other words, even though N was made available lately after leaves formation, the determinate type of potato variety like the one used in this study, did not tend to produce many successive canopy orders unlike those of indeterminate types. The current study agree with the findings of Hopkins et al. who demonstrated that potatoes require a modest amount of N early in the season for adequate canopy development. Concerning row spacing, the maximum leaf number per square meters was recorded at the narrowest row spacing of 60 cm (high plant density) while the minimum number of leaf was recorded at the widest row spacing of 90 cm (low plant density) (Table 2). This could be attributed to more main stems with longest stem length were grown per unit of area in the case of narrow spacing.

Main effects	Plant height (cm)	Stem number/m^2	Leaf number/m^2
N Timing			
Once	74.13^c	26.12^b	479.47^b
Twice	76.96^b	26.76^a	595.06^a
Thrice	82.56^a	26.94^a	606.63^a
LSD (0.05)	1.314	0.332	14.843
CV (%)	1.29	0.95	2.41
Row spacing			
60 cm	80.73^a	31.85^a	642.4^a
75 cm	76.98^b	26.07^b	556.15^b
90 cm	75.93^c	21.89^c	482.62^c
LSD (0.05)	0.918	0.265	13.861
CV (%)	1.15	0.97	2.02

Table 2: Plant height, number of main stems and leaves of potato as influenced by nitrogen fertilizer timing and inter-row spacing.

Effects of N timing and inter-row spacing on potato yield components

Mean weight (g) of tubers per hill: The main effects of N application timing and row spacing highly significantly influenced average weight (g) of tubers per hill. The interaction effect of N timing and row spacing on mean weight of tubers was not statistically significant. The heaviest tubers per hill were obtained with N application in three splits whereas the lighter tubers were obtained with N applied once at mid vegetative growth stage (Table 3). It could be the result of N applied in three judicious splits that created a continuous supply of nitrogen during tuber initiation and growth. Consistent with these result, Chowdhury, et al. reported that the improvement in weight of tubers per hill could be due to better growth and development of plant and larger tuber formation that were resulted due to better availability and efficient use of nitrogen by plant.

Similarly, the heaviest tubers were produced at the widest spacing of 90 cm whereas the lightest tubers were produced at the narrowest spacing of 60 cm. This result indicates that as row spacing widens, average tuber mass per hill also increases (Table 3). This may be attributed to less competition among tubers for assimilates. This result corroborates the findings of Tesfa, et al. who reported that as planting density decreased there is a trend of increased average tuber weight per hill.

Number of tubers per hill: The main effect of N application timing highly significantly influenced average tubers number per hill. However, this trait was not significantly affected by the main effect of row spacing and interaction effect of N timing and row spacing. The highest number of tubers per hill was obtained with N application in three splits. Whereas N applied once gave the lowest number of tubers, which were statistically at par with that obtained with two time N applications (Table 3). The reason for this phenomenon could be due to the effect of inadequate N during stolon formation that might have led in turn to formation of less number of tubers. In agreement with this result, Lang et al. also emphasized the need to avoid excess nitrogen availability during growth stages I and II as a way of enhancing a balanced proportion of roots and shoots, resulting in enhanced tuber set.

Individual tuber mean weight (g): Potato individual tuber mean weight was highly significantly affected by main effect of inter-row spacing whereas main effect of N timing and interaction did not. The heaviest tuber was produced at the widest spacing of 90 cm row spacing while the lightest tuber was produced at the narrowest spacing of 60 cm. This result indicated that as spacing widened, average individual tuber weight also increased (Table 3). The increase in average individual tuber weight in response to widening plant spacing could be attributed to less competition among tubers for assimilates. Similarly, Karafyllidis et al. reported that increase in plant density may increase the competition between the plants and hence, lead to decrease in availability of nutrients for each plant thereby declines mean individual tuber weight. Moreover, the finding of this study agrees with Tesfa et al. Fayera and Arega et al. who reported that when planting density decreased, there was a trend of increased average tuber weight.

Main effects	Tubers weight (g) /hill	Tubers number/hill	Tuber mean weight (g)
N timing			
Once	737.46^{b}	11.51^{b}	64.1
Twice	766.29^{b}	11.64^{b}	65.83
Thrice	853.59^{a}	12.78^{a}	66.8
LSD(0.05)	43.22	0.58	ns
CV (%)	4.2	6.1	6.6
Row spacing			
60 cm	712.73^{c}	11.73	60.76^{c}
75 cm	768.47^{b}	11.89	64.63^{b}
90 cm	876.15^{a}	12.31	71.20^{a}
LSD(0.05)	24.87	ns	3.49
CV (%)	3.1	4.2	5.2

Table 3: Effect of nitrogen timing and inter-row spacing on mean weight of tubers per hill, number of tubers per hill and mean individual tuber weight of potato.

Effects of N timing and inter-row spacing on potato fresh tuber yield

Unmarketable tuber yield (Tons Ha^{-1}): The main effects of N timing and row spacing highly significantly influenced unmarketable tuber yield, however, their interaction did not. Applying N in three splits at planting, vegetative growth stage and tuber initiation stage reduced the production of unmarketable tubers yield by 29.7% compared to applying it once after plant establishment (Table 4). This could be associated with the increment of yield of marketable sized tubers as a result of the adequate N nutrition starting from planting until tuber bulking stages. In addition to this, higher unmarketable tuber yields were obtained in response to planting at row spacing of 60 cm than planting at 75 cm and 90 cm spacing (Table 4). This could be due to strong competition at closer spacing for nutrients and radiation for photosynthesis which led to production of more numbers of undersized tubers which are unmarketable. In agreement Tesfa also reported that high unmarketable tuber yield was observed at narrower spacing.

Marketable tuber yield (Tons Ha^{-1}): Nitrogen application timing and row spacing highly significantly affected marketable tuber yield, however, their interaction did not. Applying N in three splits yielded significantly more marketable yield than applying total N once at vegetative growth stage only or twice at planting and tuber initiation stage (Table 4). This could be due to better growth and development of plant as well as an increase in number and yield of marketable sized tubers' formation as a result of a better synchrony between nitrogen supply and plant demand. This result is in agreement with Lei et al. who suggested that in order to get an ideal yield, the plant should be kept green during tuber bulking stage to produce carbohydrates, but it should senescence near harvest to promote redistribution of carbohydrates to tubers.

Furthermore, statistically different marketable tuber yields were obtained in response to planting the tubers at the inter spacing of 60 cm, 75 cm and 90 cm. The row spacing of 60 cm produced the highest marketable tuber yield per hectare (Table 4). In agreement to this Beukema and Vander reported that increased plant population increased yield due to more tubers being harvested per unit area of land. Similarly, Zebenay reported that 60 cm spacing produced highest marketable tuber yield of potato.

Total tuber yield (Tons Ha^{-1}): Main effects of N timing and inter-row spacing highly significantly influenced total tuber yield per hectare. Applying N in three splits at planting, vegetative growth stage and tuber initiation stage yielded significantly more total tuber yield than the other treatments (Table 4). This could be due to the fact that it received the best averaged portion of fertilizer per respective growth stages of the potato crop. In addition, split applications reduced fertilizer leaching losses by matching fertilizer applications with crop nutrient uptake and synchronize nutrient availability with crop demand. This is in line with Gathungu et al., Jaamati et al. and Sun who observed that application of N starting from early and followed by some split applications in season showed the greatest total tuber yield concerning row spacing, the highest total tuber yields were obtained in response to using the row spacing of 60 cm (Table 4). This could be due to more tubers were produced as results of high main stem numbers found per unit area in the case of narrower row spacing. In agreement with this result Beukema and Vander also reported that increased plant population increased yield due to more tubers being harvested per unit area of land.

Main effects	Unmarketable yield (tons ha^{-1})	Marketable yield (tons ha^{-1})	Total (tons ha^{-1})
N Timing			
Once	1.92^{a}	31.44^{b}	33.37^{b}
Twice	1.50^{b}	33.03^{b}	34.53^{b}
Thrice	1.35^{b}	37.08^{a}	38.44^{a}
LSD (0.05)	0.2267	1.9985	2.008
CV (%)	15.99	4.51	4.33
Row Spacing			
60 cm	2.31^{a}	37.28^{a}	39.60^{a}
75 cm	1.53^{b}	32.75^{b}	34.28^{b}
90 cm	0.93^{c}	31.52^{c}	32.45^{c}
LSD (0.05)	0.2614	1.0722	1.051
CV (%)	11	3.08	2.89

Table 4: Unmarketable, marketable and total yields as influenced by N timing and row spacing.

Effects of N timing and inter-row spacing on ANUE of potato crop

Agronomic Nitrogen Use Efficiency (ANUE) was highly significantly affected by the main effects of nitrogen application timings as well as inter-row spacing. Applying N in three splits increased ANUE by 36.8% compared to applying it once only at vegetative growth stage (Figure 1). This result agrees with Peter et al. reported that nitrogen applications which are split between pre-plant and in-season provide opportunities to increase nitrogen use efficiency and minimize leaching by preventing excess availability.

Concerning to effects of inter-row spacing on agronomic nitrogen use efficiency, widening the row spacing from 60 cm to 90 cm decreased agronomic nitrogen use efficiency by 50.5% in the study area (Figure 1). This implies that using dense plant population might increase nitrogen nutrient uptake by crops, and thereby, reduce nitrogen losses from the crop growing area of the soil. This explanation agrees with Bationo et al. who stated that management practices must aim at maximizing the amount of nutrients that are taken up by the crop and minimizing the amount of nutrients that are lost from the soil.

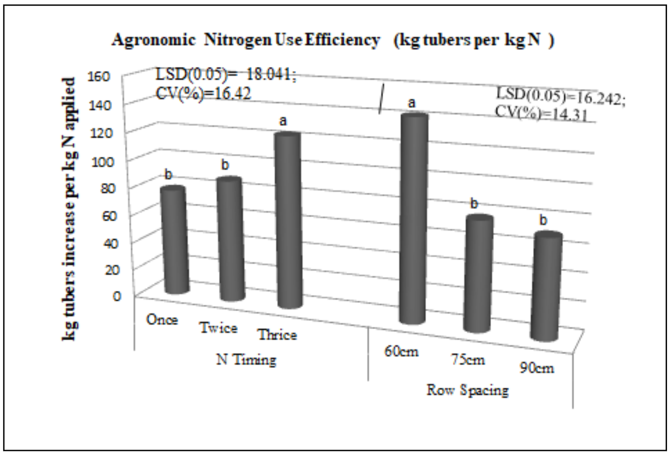

Figure 1: Effects of N timing (Graph A at left) and row spacing (Graph B at right) on agronomic N use efficiency of potato.

Partial budget and marginal analysis

Partial budget analysis showed that applying recommended N in three splits resulted in the highest net benefit per hectare compared to other N timings. Similarly, using inter-row spacing of 60 cm resulted in the highest net benefit per hectare compared to other inter-row spacing (Table 5). For the recommendation domain where this experiment was carried out, 100% minimum rate of return acceptable to farmers was used. Hence, in this experiment, N applications in three splits has the highest marginal rate of returns (4320%) which is very greater than the 100% minimum compared to other N timings. Row spacing of 60 cm also has the highest marginal rate of returns (251%) well above the 100% minimum, compared to other row distances. The greater the increase in net income and the higher rate of return, the more economically attractive an alternative technology is. Farmers should be willing to change from one treatment to another if the marginal rate of return of that change is greater than the minimum rate of return (CIMMYT, 1988).

Main Effects	Adj. yield* (tons/ ha)	GFB (Birr/ha)**	TVC (Birr/ha)	NB (Birr/ha)	MRR%
N timing					
Once	28.3	1,37,235.60	23,475.13	1,13,760.47	1,635
Twice	29.73	1,44,175.95	23,875.13	1,20,300.82	4,320
Thrice	33.37	1,61,854.20	24,275.13	1,37,579.07	
Row spacing					
90 cm	28.36	1,37,546.00	19,505.20	1,18,040.80	45
75 cm	29.48	1,42,953.75	23,242.20	1,19,711.55	251
60 cm	33.55	1,62,727.20	28,878.00	1,33,849.20	

*Adj. -Adjusted Marketable Yield by 10%; GFB: Gross Field Benefit; TVC: Total Variable Costs; NB: Net Benefit; MRR: Marginal Rate of Returns;**Field price of 1 kg tubers at harvest time was 4.85ETB

Table 5: Partial budget and marginal rate of returns of potato crop production as influenced by main effects of N timing and row spacing in the study area.

Conclusion

The results of the experiment revealed that most of the growth, yield components, tuber yield and quality as well as nitrogen use efficiency parameters of potato crop weresignificantly influenced by main effects of N timing and inter row spacing. Therefore, based on their optimum agronomic performances observed and also inferring to their economic returns estimated, it is possible to conclude that applying the recommended N in three splits at planting, vegetative growth stage and tuber initiation stage as well as using inter-row spacing of 60 cm could be considered as the best management options for potato production, particularly for the varieties having similar growth habits like the one tested in the specific study area.

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Competing interests

The authors declare that they have no competing interests.

References

1. Arega A, Tekalign A, Solomon T, Tekile B (2018) Effect of Inter and Intra Row Spacing on Tuber Yield and Yield Components of Potato (*Solanum tuberosum* L.) in Guji zone, Southern Ethiopia. JAPS 1:102
2. Bationo A, Fairhurst T, Giller K, Kelly V, Lunduka R (2012) Handbook for Integrated Soil Fertility Management. Africa Soil Health Consortium Fairhurst, CAB International.
3. Beukema HP, Vander Zaag DE (1990) Introduction to Potato Production. PudocWageningen, the Netherlands.
4. CSA (Central Statistical Agency) of Ethiopia). (2016) Agricultural sample survey: Report on area and production of crops, Addis Abeba, Ethiopia, 121.

5. Chowdhury MRI, Sarwar AKMG, Farooque AM (2002) Effect of nitrogen and its methods of application on growth and yield in potato. Sci J Biol Sci 2: 616-619.
6. CIMMYT (1988) From agronomic data to farmer demonstrations. An economic manual, completely revised edition. DF. Maxico. 79.
7. Eyasu E, Scoons I (1999) Perspective on Soil Fertility Change: A case study from Southern Ethiopia. Land Degradadtion and Development. 10: 195-206.
8. Fanuel L, Kibebew K, Tekalign M, Heluf G (2016) Soil-plant nutrient status and their relations in maize-growing fields of Wolaita Zone, Southern Ethiopia. Soil Sci Plant Analysis 47:1343–1356.
9. Wakjira F (2017) Yield and yield components of potato (*Solanum tuberosum* L.) as influenced by planting density andnrate of nitrogen application at Holeta, West Oromiaregion of Ethiopia. Afr J Agric Res 12:2242-2254.
10. FAO (Food and Agriculture Organization). (2015) FAO statistical Pocketbook. Rome, Italy 236.
11. Gathungu GK, Shibairo SI, Githiri SM, Mburu MWK, Ojiambo PS (2000) Effect of source, time and methods of nitrogen application on growth and yield components of potato in Kenya. African Crop Sci J 8: 387-402.
12. Gildemacher P, Kaguongo W, Ortiz O, Tesfaye A, Woldegiorgis G (2009) Improving Potato Production in Kenya, Uganda and Ethiopia:A System Diagnosis. Am Potato J 173-205.
13. Gebru H, Mohammed A, Dechassa N, Belew D (2017) Assessment of production practices of smallholder potato (*Solanum tuberosum* L.) farmers in Wolaita zone, southern Ethiopia. Agric Food Security 6:31.
14. Abrha A, Belew D, Woldegiorgis G (2014) Effect of Inter and Intra-Row Spacing on Seed Tuber Yield and Yield Components of Potato at Ofla Woreda. Bahirdar Ethiopia.
15. Hopkins BG, Rosen CJ, Shiffler AK, Taysom TW (2008) Enhanced efficiency Horticulture Science, 34: 629-633.
16. Jaamaati S, Samarin EO, Hashemimajd K (2010) Effects of nitrogen fertilizer and plant density on N P K uptake by potato tuber. Indian J Hortic 67:12-14.
17. Karafyllidis DI, Georgakis DN, Stavropoulos NI, Nianiou EX, Vezyroglou IA (1997) Effect of planting density and size of potato seed-mini tubers on their yielding capacity. Acta Horticulturae 462:943-950.
18. Lang NS, Stevens RG, Thornton RE, Pan WL, Victory S (1999) Potato nutrient management for central Washington. Wash State Univ Pullman Coop Ext Bul 1871.
19. Liulian S, Xianlong G, Liu P, Li X, Yan X (2012) Effects of nitrogen fertilizer application time on dry matter accumulation and yield of chinese potato variety KX 13. Potato Res 55:303-313.
20. Aho L, Lemaga CB, Nyongesa M, Gildermacher P, Kinyale P, et al. (2007) Commercial seed potato production in eastern and central Africa. Kenya Agricultural Institute 140.
21. MoARD (Ministry of Agriculture and Natural Resources Development). (2016) Crop Variety Register Book. Addis Ababa, Ethiopia.
22. Peter M, Katsaruware RD, Ezekia S (2015) Effect of split nitrogen application and fertilizer rate on yield of Irish potatoes (*Solanum tuberosum*) in a smallholder farming sector of Zimbabwe. Int J Innov Sci Eng Technol 2: 112-123
23. Cary NC (2009) SAS Institute Inc SAS Statistical Analysi Software (SAS)., USA.
24. Sun L, Liulian G, Xianlong P, Liu Y, Li X (2012) Effects of nitrogen fertilizer application time on dry matter accumulation and yield of chinese potato variety KX 13. Potato Res 55:303-313.
25. Binalfew T, Dechassa N, Tana T (2015) Influence of Plant Spacing on Seed and Ware Tuber Production of Potato Sci Technol Arts Res J 4: 11-17.
26. Tesfaye Beshah (2003) Understanding Farmers: Explaining soil and water conservation in Konso,Wolaita and Wello, Ethiopia. PhD. Dissertation Wegeningen University. The Nethrelands.
27. Vander Zaag P, Demagante AL, Ewing EE (1990) Influence of plant spacing on potato (*Solanum tuberosum* L.)morphology, growth and yield two contrasting environments. Potato Res 33:313-23.
28. Vos J (2009) Nitrogen responses and nitrogen management in potato. Potato Res 52:305-317.
29. Wolaita Meteorological Station (WMS) (2018) Meteorological data. National Meteorological Agency, Woliata Branch, Ethiopia.
30. Dagne Z (2015) Influence of seed tuber size and plant spacing on yield and quality of potato (*solanum tuberosum* L.) in Holetta, M.Sc. thesis, Central Ethiopia.