

OPEN ACCESS



# Journal of Horticulture and Forestry

March 2019  
ISSN 2006-9782  
DOI: 10.5897/JHF  
[www.academicjournals.org](http://www.academicjournals.org)



**ACADEMIC  
JOURNALS**  
expand your knowledge

# ABOUT JHF

The **Journal of Horticulture and Forestry (JHF)** is published monthly (one volume per year) by Academic Journals.

**Journal of Horticulture and Forestry (JHF)** is an open access journal that provides rapid publication (monthly) of articles in all areas of the subject such as Arboriculture, Plant growth by hydroponic methods on straw bales, Postharvest physiology of crops, Permaculture etc.

The Journal welcomes the submission of manuscripts that meet the general criteria of significance and scientific excellence. Papers will be published shortly after acceptance. All articles published in JHF are peer-reviewed.

## Contact Us

**Editorial Office:** [jhf@academicjournals.org](mailto:jhf@academicjournals.org)

**Help Desk:** [helpdesk@academicjournals.org](mailto:helpdesk@academicjournals.org)

**Website:** <http://www.academicjournals.org/journal/JHF>

**Submit manuscript online** <http://ms.academicjournals.me/>

## Editors

**Dr. Amanullah Khan**

Khyber Pakhtunkhwa Agricultural University,  
Department of Agronomy, Faculty of Crop  
Production Sciences, Peshawar-25130, Pakistan.

**Prof. Paul K. Baiyeri**

Department of Crop Science,  
Faculty of Agriculture,  
University of Nigeria, Nsukka,  
Nigeria

**Dr. Fahrettin Tilki**

Artvin Coruh University  
Faculty of Forestry  
08000-Artvin,  
Turkey

**Dr. Peter Fredenburg**

Freewheel Media  
2D Samtoh Building  
386 Queens Road West  
Sai Ying Pun,  
Hong Kong

**Dr. Deepu Mathew**

Kerala Agricultural University  
Tavanur - 679 573,  
India

**Dr. Süleyman Korkut**

~~Prof. Festus K. Akinnifesi~~  
Strategic Objective 2 - Sustainable Agricultural  
Production Systems (SO2)  
Food and Agriculture Organization of the United  
Nations (FAO)  
Viale delle Terme di Caracalla,  
Rome,  
Italy.

**Dr. Süleyman Korkut**

*Düzce University, Faculty of Forestry*  
Department of Forest Industrial Engineering  
81620 Beciyorukler Campus, Duzce  
Turkey

**Dr. Geoff Sellers**

Research Fellow Agronomy Institute  
UHI Orkney College Kirkwall  
Orkney KW15 1LX

**Dr. Xianmin Chang**

Agronomy Institute, Orkney College  
University of Highlands and Islands  
East Road, Kirkwall, Orkney  
UK

**Dr. Alireza Iranbakhsh**

Islamic Azad Univeristy,  
Aliabad Katoul Branch, Aliabad Katoul,  
Golestan  
Iran

## Editorial Board

**Dr. Gecele Matos Paggi**

Federal University of Mato Grosso do Sul  
Brazil

**Dr. Mekou Youssoufa Bele**

Center for International Forestry Research (CIFOR)  
Central Africa Regional Office (CARO)  
P.O.Box 2008, Messa.  
Yaounde - CAMEROON

**Dr Ugur Cakilcioglu**

Firat University,  
Faculty of Science and Arts,  
Department of Biology  
TURKEY

**Dr Hare Krishna**

Central Institute of Temperate Horticulture-Regional  
Station,  
Mukteshwar-263 138, District- Nainital, Uttarakhand,  
India

**Dr. Zhonglian('Julie') Huang**

Donald Danforth Plant Science Center  
975 North Warson Road  
St.Louis, MO 63132  
USA

**Dr. Gholamreza Sharifisirchi**

Reza Sharifi-Sirchi  
Biotechnology Department, Agriculture college,  
Shahid Bahonar University-Kerman  
Iran

**Dr Ashwani Tapwal**

Scientist  
Rain Forest Research Institute (RFRI),  
Ministry of Environment & Forests (GOI)  
P.O. Box -136, Deovan, Jorhat-785 001,  
Assam, Tanzania

**Dr. Karim Hosni**

School of Agriculture, Mograne,  
Department of Agricultural Production, 1121, Zaghouan,  
Tunisia

**Dr. Jasper Abowei**

Department of Biological Sciences,  
Faculty of Science,  
Niger Delta University, Wilberforce Island,  
Bayelsa State  
Nigeria

**Dr. Hasan Turkez**

Faculty of Science, Molecular Biology and Genetics  
Department,  
Erzurum Technical University,  
Erzurum, Turkey

**Dr. Ricardo Aroca**

Department of Soil Microbiology  
Zaidin Experimental Station (CSIC)  
Professor Albareda 1  
18008 Granada  
Spain

**Dr. Maarit Kallio**

Finnish Forest Research Institute  
Vantaa Unit,  
POB 18,  
FI-01301 VANTAA  
Finland

**Dr. Iulian Costache**

University of Craiova  
Faculty of Agriculture and Horticulture  
Department of Biology and Environmental Engineering  
13 A. I. Cuza Street, 200583 Craiova,  
Romania

**Dr. Rajesh Kumar**

Scientist C  
Forest Protection Division  
Rain Forest Research Institute (RFRI),  
P.O. Box -136, Deovan, Jorhat-785 001,  
Assam, India

**Bharat Sharma Acharya**

Ratnanagar 01, Chitwan, Nepal  
Nepali

**Dr. Subhasis Panda**

Taxonomy & Biosystematics Laboratory  
Post-Graduate Department of Botany  
Darjeeling Govt. College  
Darjeeling-734101  
India

**Dr. Kadiriye URUÇ PARLAK**

Agri Ibrahim Cecen University  
Science and Arts Faculty  
Department of Biology  
04100 Agri/TURKEY

# Journal of Horticulture and Forestry

Table of Contents: Volume 11 Number 3 March 2019

## ARTICLES

- The role of *Faidherbia albida* tree species in parkland agroforestry and its management in Ethiopia** 42  
Tsegu Ereso
- Evaluation of potato (*Solanum tuberosum* L.) varieties for yield and yield components** 48  
Solomon Fantaw, Asrat Ayalew, Daniel Tadesse, Zenebe G/Medhin and Eshetu Agegnehu
- Effect of blended chemical fertilizer (sulfur, nitrogen and phosphorus) on yield and yield components of potato (*Solanum tuberosum* L.) in the rainy season** 54  
Solomon Fantaw\*, Derajew Asres and Aleminew Tagele

*Full Length Research Paper*

## **Evaluation of potato (*Solanum tuberosum* L.) varieties for yield and yield components**

**Solomon Fantaw\*, Asrat Ayalew, Daniel Tadesse, Zenebe G/Medhin and Eshetu Agegnehu**

College of Agriculture and Rural Transformation, University of Gondar, Gondar, Ethiopia.

Received 16 December, 2016; Accepted 3 January 2018

**Lack of well adapted potato (*Solanum tuberosum* L.) varieties is a production problem accounting for low yield. Farmers grow local landraces. A field experiment was conducted to investigate the performance of potato varieties for yield and yield components from 2013 to 2015 under rain fed condition using improved varieties and a local landrace. There were differences among varieties for all traits. Year had little effect on most traits except for days to emergence, days to flowering and days to maturity. Only days to emergence and average number of stems per plant were affected by the variety by year interaction. The improved varieties outperformed than the local landrace for the majority of traits studied except that the local landrace emerges, flowers and matures earlier than the others. The varieties Belete and Guassa were superior for tuber weight, tuber yield and average number of stems per plant. 'Belete' and 'Guassa' had tuber yields that were 155 and 136.6% greater than the local landrace. Moreover, these two varieties have larger tuber size which may be good means to get market value better return for the farmer and are comparably good in all other studied traits. Hence, they are recommended for the area and similar agro-ecologies.**

**Key words:** *Solanum tuberosum*, correlation, Ethiopia, traits, varieties.

### **INTRODUCTION**

Potato (*Solanum tuberosum* L.) has potential for adaptation to diverse growing conditions of the tropics. The shorter growing period makes it possible for a small-scale farmer to fit this crop into intensive cropping systems and have more than one crop on the same land in a year (Gebremedhin et al., 2008). The crop has great yield potential per unit area which is a key for attaining food security especially for developing countries.

Potato produces more energy and protein per unit area and unit of time than most other major food crops, and it

is fat-free (Lutaladio and Castaldi, 2009). Potato is also rich in several micronutrients and vitamin C (FAO, 2008), is a source of iron, vitamins B<sub>1</sub>, B<sub>3</sub> and B<sub>6</sub> and minerals. It is a source of dietary antioxidants, which may play a part in preventing diseases related to ageing, and a source of dietary fiber (Mulatu et al., 2005).

Potato average yield is low (7.2 Mt·ha<sup>-1</sup>), far below the crop potential. Lack of well adapted varieties, inappropriate rate and application of fertilizer, unavailability and high cost of seed tubers, improper planting

\*Corresponding author. E-mail: fantawsol1@gmail.com.

**Table 1.** Characteristics of varieties used.

S/N	Genotype name	Year of release	Released by	Favorable environment		Time to maturity	Yield performance (t/ha)	
				Altitude (m)	Rainfall (mm)		Farmer field	Research site
1	Guasa (CIP-384321.9)	2002	ADARC	2000-2800	1000-1500	110-115	22-25	24.4-33
2	Belete (CIP-393371.58)	2009	HARC	1600-2800	750-1000	110-120	28-33.8	47
3	Jalenie (CIP-37792-5)	2002	HARC	1600-2800	750-1000	100-110	29.1	40.3
4	Gera (KP-90134.2)	2003	ShARC	2200-3200	800-950	120-157	27.2	31.2
5	Gudenie (CIP-386423.13)	2006	HARC	1600-2800	750-1000	120	21	29.2
6	Local	-	-	1600-3100	980-1398	-	-	-

ADARC = Adet Agricultural Research Center, HARC = Holetta Agricultural Research Center, and ShARC = Sheno Agricultural Research Center. Source: Anonymous (2010, 2012).

density, diseases, insect, inadequate storage, transportation and marketing facilities are major problems in potato production (Gebremedhin et al., 2008; Adane et al., 2010).

None of the currently used varieties or cultivars has potential for production in all environments and for all uses (Bradshaw, 2007), since agro-ecologies vary with respect to soil type, moisture and temperature regimes, fertility condition and the onset, intensity and duration of rain as well as availability of irrigation facilities (Gebremedhin et al., 2008). Farmers grow local landraces in traditional production systems, even though improved varieties have been released. This is due to lack of awareness of farmers of improved varieties and lack of research to select well adaptive potato varieties. The objective of the study was to evaluate varieties for yield and yield components.

## MATERIALS AND METHODS

The study was conducted on farmers' field in Dara Kebele, Dabat district of North Gondar Zone, Ethiopia, from 2013 to 2015. The area is located at 12°59'3"N and 37°45'54"E, 814 km from Addis Ababa. The altitude ranges from 1500

to 3200 m.a.s.l. Mean annual rainfall ranges from 800 to 1100 mm with the main rainy season extending from June to October. Average annual maximum and minimum temperatures are 19.9 and 8.58°C, respectively (Tafere, 2012). The major soil types are clay, sandy loam and clay loam.

Five improved varieties of potato (Table 1) and one local landrace were arranged in a randomized complete block design with 3 replications. The soil was tilled 3 times and compost from the university site was applied a month before planting with a rate of 15 Mt·ha<sup>-1</sup> (13.5 kg/plot) to provide nutrients (Edwards et al., 2007). Medium sized potato tubers (35-45 mm diameter) were planted by hand in rows with 75 cm between rows and 30 cm between plants within rows and each experimental plot was 9 m<sup>2</sup> in size. Blocks were separated by 1.5 and 1 m between blocks and within a block, respectively. There were 4 rows/plot for each treatment. Data were collected from the middle two rows; the 2 outermost rows and terminal plants were considered as guards. Other cultural practices like earthening up and weeding were carried out 3 times each during the growing period.

## Data collected

Data on days to emergence, plant heights (cm), days to 50% flowering, days to maturity, average number of stem per plant, average number of tuber per plant, weight of tuber per plant (g/plant) and tuber yield (t/plant) were recorded from the middle two rows. On each middle two

rows, the two outer most rows and terminal plants were considered as guard rows and plants, respectively.

## Data analysis

Analysis of variance and correlation of traits were performed using Statistical Analysis Software (SAS, ver. 9.2, SAS, Cary, NC). Least Significant Difference (LSD) test at 5% probability level was used for mean comparison when the ANOVA showed significant difference. Before performing ANOVA, normality and constant of variance test was performed using Minitab (ver. 16 Minitab Inc., State college, PA).

## RESULTS AND DISCUSSION

Variety affected all measured traits (Table 2), indicating there was sufficient variability for selection of varieties (Habtamu et al., 2016). Year affected plant height, tuber weight, number of stems/plant and yield indicating annual environmental fluctuation mediated responses. The interaction of variety and year was significant for days to emergence and number of stems/plant indicating that genetic makeup could be affected by environmental conditions.

**Table 2.** Mean square values of yield and yield components of potato varieties for combined analysis of variance over three years (2013 to 2015).

Source of variation	df	DEM	DFL	PH	DTM	ANSt	ATWt	ANTu	AL
Variety (V)	5	15.84**	201.75**	89.18*	216.31**	21.67**	1419.35**	14.79*	268.23**
Year (Y)	2	0.13ns	6.12ns	345.91**	20.06ns	8.09*	816.49**	88.73**	582.37**
V×Y	10	4.57*	5.06ns	48.34ns	7.63ns	3.46*	82.38ns	10.47ns	22.17ns
Error	34	1.68	4.82	29.40	14.40	1.68	58.96	5.26	11.05

ns, \*\*, \* not significant or significant at 0.01% and 0.05%, respectively. df = Degrees of freedom, DEM = Days to emergence, DFL = Days to flowering, PH = Plant height, DTM = Days to maturity, ANSt = Average numbers of stems, ATWt = Average tuber weight, ANTu = Average numbers of tubers, AL = Average yield.

**Table 3.** Means of variety over yield and yield characters of potato varieties combined over years (2013 to 2015).

Variety	DEM	DFL	PH	DTM	ANSt	ATWt	ANTu	YIL
Gudene	15.44 <sup>c</sup>	54.89 <sup>c</sup>	57.06 <sup>a</sup>	108.45 <sup>c</sup>	5.93 <sup>bc</sup>	33.13 <sup>c</sup>	13.71 <sup>a</sup>	20.02 <sup>c</sup>
Belete	16.77 <sup>b</sup>	63.55 <sup>ab</sup>	51.84 <sup>b</sup>	121.67 <sup>a</sup>	8.37 <sup>a</sup>	52.05 <sup>a</sup>	11.29 <sup>b</sup>	25.93 <sup>a</sup>
Jalene	16.77 <sup>b</sup>	65.22 <sup>a</sup>	50.93 <sup>b</sup>	116.44 <sup>b</sup>	6.93 <sup>b</sup>	34.26 <sup>bc</sup>	13.75 <sup>a</sup>	21.01 <sup>bc</sup>
Gera	17.22 <sup>b</sup>	55.22 <sup>c</sup>	57.51 <sup>a</sup>	113.78 <sup>b</sup>	6.37 <sup>b</sup>	41.54 <sup>b</sup>	11.24 <sup>b</sup>	20.13 <sup>c</sup>
Guassa	17.77 <sup>b</sup>	62 <sup>b</sup>	53.2 <sup>ab</sup>	115.89 <sup>b</sup>	8.88 <sup>a</sup>	50.75 <sup>a</sup>	11.09 <sup>b</sup>	24.04 <sup>ab</sup>
Local	19.44 <sup>a</sup>	65 <sup>a</sup>	50.13 <sup>b</sup>	121.11 <sup>a</sup>	4.73 <sup>c</sup>	18.53 <sup>d</sup>	13.02 <sup>ab</sup>	10.16 <sup>d</sup>
R <sup>2</sup>	69.82	86.76	62.44	71.12	73.53	83.21	67.23	87.98
CV	7.5	3.6	10.15	3.26	18.89	20	18.57	16.43
Gm	17.24	60.98	53.44	116.22	6.87	38.38	12.35	20.21
LSD	1.24	2.1	5.19	3.63	1.24	7.35	2.19	3.18
P value	<.0001	<.0001	0.0228	<.0001	<.0001	<.0001	0.0314	<.0001

DEM = Days to emergence, DFL = Days to flowering, PH = plant height (cm), DTM = Days to Maturity, ANSt = Average numbers of stems, ATWt = Average tuber weight (g), ANTu = Average numbers of tubers, AL = Average yield (Mt·ha<sup>-1</sup>), Gm = Grand mean; LSD = Least significant difference. Means in columns followed by the same letters are not significantly different, p <0.05.

Numbers of days to emergence, flowering and maturity are important for potato producers because they enable growers to forecast and develop a suitable production scheme and marketing plan (Khalafalla, 2001). In this study, variety affected number of days to 50% emergence, flowering and maturity (Table 3). 'Gudene' emerged earlier than the others and the local landrace emerged late. It is possible to select early, or late, emerging varieties based on duration of rainfall, temperature, labor availability and maturation period based on the number of days for maturation. The variety Jalene exhibited late flowering while 'Gudene' and 'Gera' flowered earlier than other varieties. Early flowering of these varieties may indicate the beginning of tuberization at an early stage (Carrie et al., 2014). Differences in emergence and flowering between varieties may be due to genetic differences (Bradshaw, 2007).

Variety also affected numbers of days to maturity. 'Gudene' matured early while 'Belete' and the local landrace was late (Table 3). Varieties Gera, Guassa and Gudene matured in fewer days than the grand mean which allow farmers to increase land vs. time use

efficiency, that is, possible to intensify production on unit of land. The difference between varieties in length of growing period might be due to differences in genetic makeup (Girma, 2012), since flowering and maturity are heritable traits (Getachew et al., 2016).

Variety affected plant height (Table 3). The variety Jalene produced shorter stems; 'Gera' produced longer stems. 'Gudene', 'Gera' and 'Guassa' were the tallest and different from 'Belete', 'Jalene', and the local landrace. Many authors in different part of the world have observed that potato germplasm had different response of plant height (Regassa and Basavaraj, 2005; Getachew et al., 2016).

Variety affected the number of stems/plant. The number of stems relate to numbers of branches and numbers of leaves which contributes to photosynthesis potential. An increase in absorption of solar radiation can ensure a higher photosynthesis potential and promote synthesis and accumulation of reserve carbohydrates in the potato tuber which has a positive effect on the final tuber yield (White et al., 2007). More stems/plant were obtained from varieties Guassa and Belete (Table 3)



**Table 4.** Correlation matrix of the measured traits.

Correlation	DTF	Ph	DTM	ANSt	ATWt	ANTPt	Yield
DEM	0.41079 0.0020	-0.12016 0.3868	0.31477 0.0204	0.00413 0.9764	-0.21296 0.1221	0.01064 0.9391	-0.25486 0.0629
DTF		-0.40029 0.0027	0.66197 <0.0001	0.13023 0.3479	-0.04709 0.7353	0.04006 0.7737	-0.03073 0.8254
Ph			-0.50106 0.0001	0.15496 0.2632	0.28358 0.0377	0.12184 0.3801	0.41997 0.0016
DTM				-0.02910 0.8345	-0.12457 0.3695	0.01013 0.9420	-0.13424 0.3332
ANSt					0.70793 <0.0001	-0.14955 0.2804	0.59254 <0.0001
ATWt						-0.39769 0.0029	0.72767 <0.0001
ANTPt							0.29652 0.0295

DEM = Days to emergence, DFL = days to flowering, Ph = plant height (cm), DTM = days to maturity, ANSt = average number of stems, ATWt = average tuber weight (g), ANTPt = average number of tubers, Yield = average yield (Mt·ha<sup>-1</sup>).

while fewer stems were produced on the local landrace. According to Paul (2007) the number of initially available (first order) stems have a role in increase in leaf number and position on the plant which is important for rate of leaf area increase. Stem density, which is influenced by genetic makeup, increase tuber yield as stem density increases numbers of tubers, or size of tubers, or both (Tsegaw, 2005; Zelalem et al., 2009).

Variety affected average tuber weight (Table 2). Average tuber weight is an important yield component of potato contributing to total tuber yield (Morena et al., 1994). Higher tuber weights were produced by 'Belete' and 'Guassa' and the lowest tuber weight was for the local landrace (Table 3). According to Kirkman (2007), number and size of potato tubers are an economically important characteristic in processing, marketing demand, human consumption, and for seed for planting. Gray and Hughes (1978) stated that tuber size required by consumers depends upon ease of handling for household purposes and upon acceptable level of peeling loss. Varieties Belete and Guassa were better in tuber size and weight.

Variety affected number of tubers/plant (Table 3). The highest number of tubers was from 'Jalene' followed by 'Gudene'. Fewer tubers were produced on 'Guassa', 'Belete' and 'Gera'. The variety with more tubers had lower average tuber weight. Getachew et al. (2016) reported significant differences among 24 potato

genotypes in their number of tubers per plant due to genetic variation.

Variety affected tuber yield (Table 3). The highest tuber yield was from 'Belete' followed by 'Guassa', and the lowest yield was from the local landrace. 'Belete' and 'Guassa' produced yields that were 155 and 136% over the local landrace, respectively. Improving traditional production and management practices will increase yield even for the local variety from 7.2 Mt·ha<sup>-1</sup> of national production to 10.16 Mt·ha<sup>-1</sup> as in Table 3.

'Belete' and 'Guassa' had an intermediate number of days to emergence and flowering but late maturity as compared to other varieties. The two highest yielding varieties had the most stems and longest stems which could result in high photo-assimilate production. Even though 'Belete' and 'Guassa' had fewer tubers/plant they produced larger/heavier tubers which increased yield (Table 4). This result agrees with Ahmed et al. (2000), Endale and Woldegiorgis (2001), Girma (2012), and Getachew et al. (2016) which were done in different locations and with different germplasm.

There was a significant, positive, correlation with average tuber weight, average number of stems, and plant height with average number of tubers (Table 4). Tuber yield may be increased by using varieties which have higher average tuber size/weight, taller plants, and which produce more stems and tubers. According to Girma (2012) increased number of stem/plant leads to

increased plant height due to light availability and its effect on increased length and number of node. The traits having positive correlation with yield can be used to improve yield by making simultaneous improvement of those traits (Solomon et al., 2014). Khayatnezhad et al. (2011) indicated strong positive correlations between tuber yield and stems/plant, tuber weight and plant height. Similarly, Girma (2012) reported that tuber yield was significantly, and positively, correlated with average tuber weight, plant height, and total tuber number. Increasing numbers of stems and plant height allowed more light interception and likely an increase of production, and accumulation of, more carbon assimilation resulting in increased individual tuber size, weight and total tuber yield.

Days to emergence was positively, and significantly, correlated with days to maturity and with days to flowering (Table 4). Delaying tuber initiation prolongs the growth period and days to flowering. The period of tuber initiation and emergence is a determinant factor in length of time to maturity. The result disagrees with Gebeyehu (2011) who reported that a day to emergence was significantly, and positively, correlated with days to flowering and days to maturity.

Generally, "Belete" and "Guassa" varieties offered better performance over the other varieties regarding their tuber yield. Also they have tuber size which has direct relationship with market acceptance for consumption purpose and are comparably good in all other studied traits. In order to boost productivity of potato in the study and similar agro-ecological area, it is better to consider the characters of the best variety having high yield and market advantage. Therefore, these two varieties are recommended for future use in the study area and similar environments. The local landrace is out performed by all the improved varieties tested for the traits studied.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

## ACKNOWLEDGEMENTS

The authors are grateful to the Kossoye Development Programme for providing funds to conduct the research. The authors thank the University of Gondar for use of the facilities and the participating farmers and extension officials of Dabat district for their cooperation in the project.

## REFERENCES

Adane H, Miranda PMM, Agajie T, Willemien JML, Alfons OL, AdmasuT, Paul CS (2010). Analysis of Seed Potato Systems in Ethiopia. *American Journal of Potato Research* 87(6):537-552.

- Ahmed I, Hussain SA, Abdur R, Nawab A (2000). Yield Dynamic in Potato in Relation to Variety and Row Spacing, *Pakistan Journal of Biological Sciences* 3(18):1247-1249.
- Bradshaw JE (2007). Potato-Breeding Strategy. In: *Potato Biology and Biotechnology: Advances and Perspectives*, (eds). Vreugdenhil D, Bradshaw J, Gebhardt C, Govers F, Mackerron DKL, Taylor MA and Ross HA. Elsevier Ltd., Amsterdam, Netherlands pp. 157-178.
- Carrie H, Wohleb N, Richard K, Mark JP (2014). Plant growth and development. In: R. Navarre, and J. P. Mark (eds.), pp. 64-82. *The Potato: Botany, production and uses*. CABI International, Wallingford, UK.
- Edwards S, Asmelash A, Araya H, Gebre-Egziabher TB (2007). Impact of compost use on crop production in Tigary, Ethiopia. *Natural Resources Management and Environment Department, Food and Agriculture Organization of the United Nations, Rome, Italy*. <http://www.fao.org/3/a-ai434e.pdf>.
- Endale G, Woldegiorgis G (2001). Effect of spatial arrangement on tuber yield of some potato cultivars. *EARO, Holetta Agricultural Research Centre, African Crop Science Journal* 9(1):67-76.
- Food and Agricultural Organization (FAO) (2008). Highlighting the role of potato in fighting against hunger and poverty. *Food and Agricultural Organization of the United Nation, Rome, Italy*. [www.fao.org/newsroom/en/news/2008/1000799/index.html](http://www.fao.org/newsroom/en/news/2008/1000799/index.html).
- Gebeyehu W (2011). Influence of intra row spacing on yield and yield components of potato (*Solanum tuberosum* L.) varieties at highlands of Guragie zone, southern Ethiopia, An: M.Sc. thesis presented to school of graduates of Jimma University of agriculture and veterinary medicine, Jimma, Ethiopia pp. 21-30.
- Gebremedhin W, Endale G, Lemaga B (2008). Potato variety development. In *Root and tuber crops: The untapped resources*, ed. W. Gebremedhin, G. Endale, and B. Lemaga, 15-32. Addis Ababa: Ethiopian Institute of Agricultural Research. <http://publication.eiar.gov.et:8080/xmlui/handle/123456789/1496>
- Getachew A, Wassu M, Tesfaye A (2016). Genetic Variability Studies in Potato (*Solanum tuberosum* L.) Genotypes in Bale Highlands, South Eastern Ethiopia. *Journal of Biology, Agriculture and Healthcare* 6(3):117-119.
- Girma T (2012). Effect of variety and earthing up frequency on growth, yield and quality of potato (*Solanum tuberosum* L.) at Bure, north western Ethiopia. An: M.Sc. thesis presented to school of graduates of Jimma University of agriculture and veterinary medicine, Jimma, Ethiopia pp. 24-45.
- Gray D, Hughes JC (1978). Tuber Quality. In Harris PM (ed.), *The potato crop: The scientific basis for improvement*, 2<sup>nd</sup> edition. Chapman and hall, London P 504.
- Habtamu G, Wahassu M, Beneberu S (2016). Evaluation of Potato (*Solanum tuberosum* L.) Varieties for Yield and Yield Components in Eastern Ethiopia. *Journal of Biology, Agriculture and Healthcare* 6(5):146-145.
- Khalafalla AM (2001). Effect of Plant Density and Seed Size on Growth and Yield of Solanum Potato in Khartoum State, Sudan. *African Crop Science Journal* 9(1):77-82.
- Khayatnezhad M, Reza Shahriari, Roza Gholamin, Shahzad Jamaati-e-Somarin and Roghayeh Zabihi-e-Mahmoodabad (2011). Correlation and Path Analysis Between Yield and Yield Components in Potato (*Solanum tuberosum* L.). *Middle-East Journal of Scientific Research* 7(1):17-21.
- Kirkman MA (2007). Global Markets for Processed Potato Products. In: *Potato Biology and Biotechnology: Advances and Perspectives*, (eds). Vreugdenhil D, Bradshaw J, Gebhardt C, Govers F, Mackerron DKL, Taylor MA and Ross HA. Elsevier Ltd., Amsterdam, Netherlands pp. 27-43.
- Lutaladio N, Castaldi L (2009). Potato: The hidden treasure. *Journal of Food Composition and Analysis* 22(6):491-493.
- Morena I, Guillen A, Moral LFG (1994). Yield development in potatoes as influenced by cultivar and the timing and level of nitrogen fertilization. *American Journal of Potato Research* 71(3):165-173.
- Mulatu E, Ibrahim O, Bekele E (2005). Improving Potato Seed Tuber Quality and Producers Livelihoods in Hararghe, Eastern Ethiopia. *Journal of New Seeds* 7(3):31-56.
- Paul CS (2007). Above-Ground and Below-Ground Plant Development. In: *Potato Biology and Biotechnology: Advances and Perspectives*,

- (eds). Vreugdenhil D, Bradshaw J, Gebhardt C, Govers F, Mackerron DKL, Taylor MA and Ross HA. Elsevier Ltd, Amsterdam, Netherlands pp. 219-236.
- Regassa D, Basavaraj N (2005). Genetic Variability Studies in Potato (*Solanum tuberosum* L.). Karnataka Journal of Agricultural Sciences: 18(1):87-90.
- Solomon F, Amsalu N, Tewodros (2014). Correlation And Path Coefficient Studies of Yield and Yield Related Characters in Tannia (*Xanthosoma sagittifolium* (L.) Schott) Genotypes. International Journal of Plant Breeding and Genetics 8:241-254.
- Tafere M (2012). The Role of Participatory Varietal Selection for seed production in Case, Dabat District, North Western Ethiopia. Global Advanced Research Journal of Agricultural Science 1(9):257-260.
- Tsegaw T (2005). Response of potato to paclobutrazol and manipulation of reproductive growth under tropical conditions (Doctoral dissertation, University of Pretoria).
- White PJ, Wheatley RE, Hammond JP, Zhang K (2007). Minerals, soils and roots. In: Potato Biology and Biotechnology: Advances and Perspectives, (eds). Vreugdenhil D, Bradshaw J, Gebhardt C, Govers F, Mackerron DKL, Taylor MA and Ross HA. Elsevier Ltd., Amsterdam, Netherlands pp. 739-751.
- Zelalem A, Tekalign T, Nigussie D (2009). Response of potato (*Solanum tuberosum* L.) to different rates of nitrogen and phosphorus fertilization on vertisols at DebreBerhan, in the central highlands of Ethiopia. African Journal of Plant Science 3(2):16-24.

*Review*

# The role of *Faidherbia albida* tree species in parkland agroforestry and its management in Ethiopia

Tsegu Ereso

Department of Natural Resource Management College of Agricultural Science, Bule Hora University. P. O. Box, 144 West Guji Zone, Oromia, Ethiopia.

Received 19 November, 2018; Accepted 28 December 2018

**Agroforestry has been defined as a dynamic ecologically based natural resources management system that through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels. This paper highlighted the role of *Faidherbia albida* tree species in Parkland Agroforestry and its management. Large part of the Ethiopian agricultural landscape is mostly dominant by Parkland Agroforestry practice. These practices are characterized by well grown scattered trees on cultivated land. *F. albida* is a multipurpose tree grown in addition to its gum production, used in soil fertility improvement as well as fuel and fodder production in rural communities. These trees have been promoted in agroforestry as its characteristic reverse phenology allows satisfactory production of crops under a full stand of the species. Several trials have shown the positive effect of *F. albida* on crops. In areas where there is too little crop rotation, severe cases of *Striga* infestation are more noticeable, often resulting in total crop failure. One of the cheapest means of improving his soil fertility, which could effectively reduce or eliminate *Striga* infestation, is the use of the *F. albida* tree in an agroforestry practice on his farm. Socio- economically, *F. albida* have served as a fodder for livestock and the source of nectar for honey.**

**Key words:** Agroforestry, *Faidherbia albida*, Parkland, management.

## INTRODUCTION

Agroforestry is defined as “a dynamic, ecologically based natural resources management system that, through the integration of trees in farmland and rangeland, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels” (Leakey, 1996). A major reason for practicing agroforestry land use systems is domestication of soil-improving trees for enhancing soil productivity through a combination of selected trees and food crops on the same farm field (ICRAF, 2000). Scattered trees grown in farmlands

characterize a large part of the Ethiopian agricultural landscape and it is the most dominant Agroforestry practice in the semi-arid and sub humid zones of the country (Kindeya 2004), while tree species differ depending on their agro-ecological suitability such as rainfall, altitude, and soil and natural distribution patterns. In central Ethiopia, for example, *Faidherbia albida* trees are dominant in tef-wheat zones of central and eastern highlands. The objective of this paper was to highlight the importance of *F. albida* in Parkland Agroforestry and its

E-mail: haresa2@gmail.com.

Author(s) agree that this article remain permanently open access under the terms of the [Creative Commons Attribution License 4.0 International License](https://creativecommons.org/licenses/by/4.0/)

management.

### Parkland agroforestry systems

Parklands Agroforestry are characterized by well grown scattered trees on cultivated and recently fallowed land (CTA, 2003). This system is also known as scattered tree. These parklands develop when crop cultivation on a piece of land becomes more permanent. The trees are scattered far apart so that they do not compete with their neighbors. Parkland trees have the following characteristics: They are deep rooting, preferably reaching ground water table (Van Noordwijk et al., 2000). They have capacity to fix nitrogen Produce litter that decomposes well and add as much as possible to soil organic matter. *F. albida* trees fulfill these criteria.

### ETHNO BOTANY OF *Faidherbia albida*

*F. albida* (Delile) A. Chev belongs to a large and economically significant family of flowering plants, Fabaceae (Leguminosae), commonly known as the legume or bean family. Based on the classification by the (Santiago and Lambert, 2010). The genus *Faidherbia* belongs to the Mimosoideae subfamily and is monotypic with *F. albida* as its only member in the tribe Ingeae and subtribe Acacieae. *F. albida* was formerly assigned to the genus *Acacia* as *Acacia albida* Del. *F. albida* grows in a wide range of ecological conditions either scattered or gregarious, in closed canopy woodlands or open savanna (Mokgolodi et al., 2011). It grows on the banks of seasonal and perennial rivers and streams on sandy alluvial soils or on flat land where Vertisols predominate. It thrives in climates characterized by long summers, or a dry season with long days. It tolerates seasonal waterlogging and salinity but cannot withstand heavy clayey soils (Orwa et al., 2009). The tree has strong and fast growing tap roots that can reach aquifers of up to 80 m below the surface to secure permanent water availability (Le Houérou et al., 1988). Access to groundwater allows *F. albida* to flourish in an otherwise desert or water scarce environment. It grows in areas with mean annual rainfall of 250-1200 mm, mean annual temperature of 18-30°C and altitude of 270-2700 m (Reubens et al., 2011). It is also associated with low rainfall areas. In South-West Africa, it can thrive under desert conditions where the mean annual rainfall is only 20 mm and the mean annual daily temperature 16.8°C (Yirgu and Tsega, 2015).

### MORPHOLGY OF *Faidherbia albida*

*F. albida* is one of the largest thorn trees, reaching 30 m in height, with spreading branches and a rounded crown. Mature *F. albida* has spreading branches and a rough, dark brown or greenish-grey bark that is often light grey

and smooth when young (Oluwakanyinsola et al., 2010). The bark of the tree is characteristically dull brown to whitish grey, smooth when young, more fissured and flaky and more cork-like in older specimens. The slash is fibrous, pink to light brown. In contrast to all other native "acacias", *F. albida* has a peculiar inverse phenology an unusual habit of retaining its leaves during the dry season and dropping them during the rains. However, this phenology does not occur in seedlings until their tap roots are well into the water table (Fagg, 1995).

In addition to reverse phenology, *F. albida* is also distinguished by its whitish twigs and paired straight thorns. These reddish-brown with white tip thorns are found at the base of the leaves and are about 3 cm long and thickened at their base (Palgrave, 2002). Thorns occur in pairs at the base of the leaves and are modified, spiny stipules. They are straight and robust, thickened at the base and often (particularly when juvenile) orange or brown at the tip and are 0.2-3.2 cm long. They may be distinguished from those of *Acacia* species with long thorns, such as *Acacia tortilis*, *Acacia nilotica*, or *Acacia seyal*, by their basal thickening. The leaves are bipinnate, blue-green with 3 to 12 pairs of pinnae, carrying 6 to 23 pairs of leaflets that are up to 12 mm long and 5 mm wide and partly overlapping (Oluwakanyinsola et al., 2010).

### *Faidherbia albida* USE IN AGROFORESTRY

*F. albida* has been promoted in agroforestry as its characteristic reverse phenology allows satisfactory production of crops under a full stand of the species (Ibrahim and Tibin, 2003). Its importance is underscored by a peculiar inverted (reverse) phenology, a phenomenon whereby the tree undergoes a physiological dormancy and sheds its nitrogen rich leaves during the early rainy season – when seeds are being planted and need the nutrients and then regrow its leaves when the dry season begins and the crops are dormant. This makes it highly compatible with food crops since it does not compete with them for nutrients and light (ICRAF, 1989). The leaves are shed at the onset of the rainy season which significantly reduces the shade cast beneath the trees and reduces competition for water, light and nutrients with associated crops grown during the rainy season. Shedding leaves during the rainy season at the time of higher microbial activity in the soil improves the soil structure, permeability while retaining leaves in the dry season provides shade and mulch reducing evaporation thus conserving the available soil moisture (Dangasuk et al., 2006).

### ROLE OF *Faidherbia albida* ON SOIL FERTILITY

*F. albida* is a multipurpose tree grown in addition to its gum production, used in soil fertility improvement as well

**Table 1.** Soil properties at different distance from *Faidherbia albida* trunk.

Property	Radial distance from the truck (m)				ANOVA
	1	3	5	12	
OC (%)	2.74±0.08 <sup>a</sup>	2.62±0.07 <sup>ab</sup>	2.44±0.09 <sup>b</sup>	2.35±0.04 <sup>b</sup>	*
OM	4.7±0.14 <sup>a</sup>	4.5±0.18 <sup>ab</sup>	4.21±0.15 <sup>b</sup>	4.04±0.08 <sup>b</sup>	**
TN (%)	0.21±0.02 <sup>a</sup>	0.19±0.01 <sup>ab</sup>	0.18±0.00 <sup>b</sup>	0.17±0.00 <sup>b</sup>	**
P(PPM)	17.1±2.02 <sup>a</sup>	16.1±0.66 <sup>a</sup>	14.81±0.88 <sup>a</sup>	15.16±0.11 <sup>a</sup>	ns
C/N	13.49±0.83	13.72±0.4 <sup>b</sup>	13.95±0.4 <sup>b</sup>	14.23±0.24 <sup>b</sup>	ns
PH	6.18±0.06 <sup>a</sup>	6.15±0.09 <sup>a</sup>	6.11±0.07 <sup>a</sup>	6.12±0.07 <sup>a</sup>	ns
MC (%)	29.53±1.01 <sup>a</sup>	28.75±1.13 <sup>a</sup>	28.35±1.45 <sup>a</sup>	28.32±1.49 <sup>a</sup>	ns
BD(g/cm)	1.12±0.04 <sup>b</sup>	1.13±0.03 <sup>b</sup>	1.14±0.06 <sup>b</sup>	1.15±0.02 <sup>b</sup>	ns

Values followed by the same letters in a row are not significantly different at  $P < 0.05$ .

as fuel and fodder production in rural communities. Conservation Agriculture promoters contend that integrating *F. albida* trees into Conservation Agriculture systems based on the three principles of minimum tillage, diversified crop rotations and permanent soil surface cover enhances the soil improving benefits of Conservation Agriculture as not only does *F. albida* fix nitrogen, it also returns other nutrients to the soil and increases Soil Organic Matter content through the shedding of its nutrient-rich leaves and the subsequent decomposition of its leaf litter at the onset of rains. The increased soil organic matter improves soil structure, enhances soil microfauna populations and minimizes excessive evapo-transpiration and soil temperatures (Umar et al., 2012). Soil organic matter improves water holding capacity, increases plant nutrient and moisture availability and reduces soil erosion.

Studies have shown that *F. albida* significantly changes the soil beneath the canopy and that the overall effect of these changes is increased soil fertility (Barnes and Fagg, 2003). The tree cover increases water infiltration and also has a beneficial effect on bulk density, structural stability and chemical and biochemical properties. It is a crucial nutrient source and also helps in cycling of nutrients. *F. albida* has been shown to improve some physical and chemical properties of soils under its canopy; it has been shown to values of total nitrogen and organic carbon while having no effect on soil texture, pH and available phosphorus (Zomer et al., 2009). The trees extensive root systems mine the surface layers of the soil beyond the reaches of its crown and in so doing redistribute the nutrients in the litter that then falls beneath its canopy. In a study of *F. albida* and its effects on Ethiopian Highland Vertisols (Kamara and Haque, 1992) found a significant inverse relationship between SOM, N, P, K concentration and distance from the tree. The *F. albida* did not seem to influence soil reaction (pH) and the exchangeable cations Na, Ca and Mg. The build-up of SOM, N, P and K under the tree canopies was attributed to the litter fall accumulation. They found N and

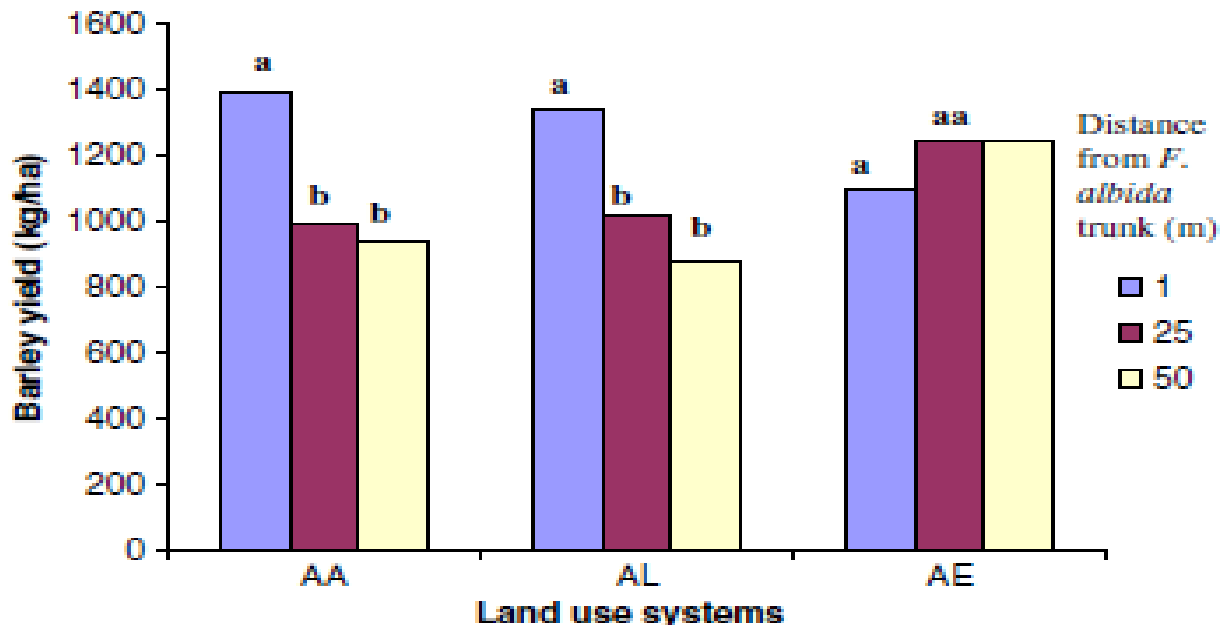
P contents in the fresh leaves and twigs to be 3.85% N and 0.3% P for the leaves and 1.27% N and 0.2% P for twigs (Table 1) (Getahun et al., 2014).

Mature *F. albida* trees supplied significant amounts of nitrogen, organic carbon and K to the soils under their canopies resulted in a clear fertility gradient for these nutrients. The N, OC and K levels were 42, 31 and 25% respectively higher under the canopies than outside (Umar et al., 2012). The benefit of *F. albida* is its nitrogen-fixing quality, which is the result of protein-rich foliage (pods) that fall from the tree in large quantities during dormancy in the early rainy season and enrich the soil with nitrogen, phosphorus, and exchangeable calcium. It sheds its leaves when ploughing begins and hardly competes for light and water during the growing season of the crop.

## THE ROLE OF *Faidherbia albida* ON CROP YIELDS

Several trials have shown the positive effect of *F. albida* on crops. The species has a potential to improve the yield of intercropped plants for instance barley yield was significantly affected by distance from the center of *F. albida* trunk and by the interaction of distance and land use systems. As shown in Figure 1 below significantly higher barley yields ( $p < 0.05$ ) were found at 1 m distance from the tree compared to yields at 25 and 50 m for land use systems *F. albida* only, and *F. albida* and livestock. In contrast, in the *F. albida* and *Eucalyptus camaldulensis* land use systems barley yields did not change significantly with distance from the tree although average yields were lowest under the tree. *F. albida* is renowned for the so-called 'albida effect', that is crops growing under *F. albida* trees have higher yields than crops growing away from the tree canopy.

This yield increase may result from: (1) light shading early in the cropping season, which results in a decrease in soil surface temperatures (2) nutrient cycling, where nitrogen (N) fixed by the tree and nutrients assimilated



**Figure 1.** Mean ( $\pm$ SE) barley yield (kg/ha) at increasing distance from the centre of an *F. albida* trunk and for three land use system (*F. albida* only, *F. albida* and livestock, and *F. albida* and Eucalyptus) for 77 field locations sampled in 2005 in Tigray, Northern Ethiopia.

through the roots are returned to the soil surface through litter fall; and (3) feces and urine deposition by cattle seeking shade and fodder during the dry season (Figure 1) (Hadgu et al., 2009).

### ***Faidherbia albida* FOR CONTROL OF WEEDS**

The food production potential of the semi-arid region of West Africa, especially cereals, for example sorghum (*Sorghum bicolor* (L.) Moench), millet (*Pennisetum glaucum* (L.) R. Br. and maize (*Zea mays* L.) (Kassa et al., 2010) has seriously been reduced due to the parasitic weed *Striga hermonthica*. Pearl millet is a major food crop grown in the semi-arid region of West Africa.

In areas where there is too little crop rotation, severe cases of *Striga* infestation are more noticeable, often resulting in total crop failure. Great yield losses can occur in cereal crops due to *Striga* infestation; for example, grain yield losses in sorghum may reach up to 70% as a result of *Striga* infestation (Gworgwor et al., 2001). According to (Sauerborn, 1991), the cultivated areas actually infested by *Striga* in Africa are estimated at 21 million hectares. The overall loss in grain production amounts to 4.1 million tons. The loss of revenue from sorghum, pearl millet and maize due to the parasite infection could total 2.9 billion \$ US.

One of the most successful and promising control measures is the adequate application of mineral nitrogenous fertilizers. One of the cheapest means of improving his soil fertility, which could effectively reduce

or eliminate *Striga* infestation, is the use of the *F. albida* tree in an agroforestry practice on his farm. *F. albida* is well spread all over the dried region of West Africa, and East and South Africa where there is a long dry season (Giffard, 1964), which equally favors *Striga* survival.

### **SOCIO ECONOMIC USE *Faidherbia albida***

The functions of *F. albida* differ widely from one region to another within its vast natural distribution area, which covers the whole of semi-arid Africa, north and south of the equator. There was positive relationship between *F. albida* tree density and bee hives per farm household. Because of its reverse phenology in keeping its leaves and flowers during the long dry season and shedding them during short wet season (Hadgu et al., 2009), bees in the study areas were dependent on *F. albida* flowers as their main source of forage as most of other plants are dry during the long dry season. Therefore for beekeepers, it has the advantage of producing flowers at the end of the rains while most of the sahelian species flower just before or during the rains. It therefore becomes the main source of pollen and nectar at this time. In other respects, the seeds, gum, bark, and wood are utilized for many purposes; food, traditional medicine, construction, furniture, canoes, and other domestic uses making *F. albida* the "miracle" tree of the Sahel (Figure 2) (Kessler, 1990). The interest in tree species as a food source for domestic animals lies in the fact that they offer green fodder rich in protein in a period when animal feed is

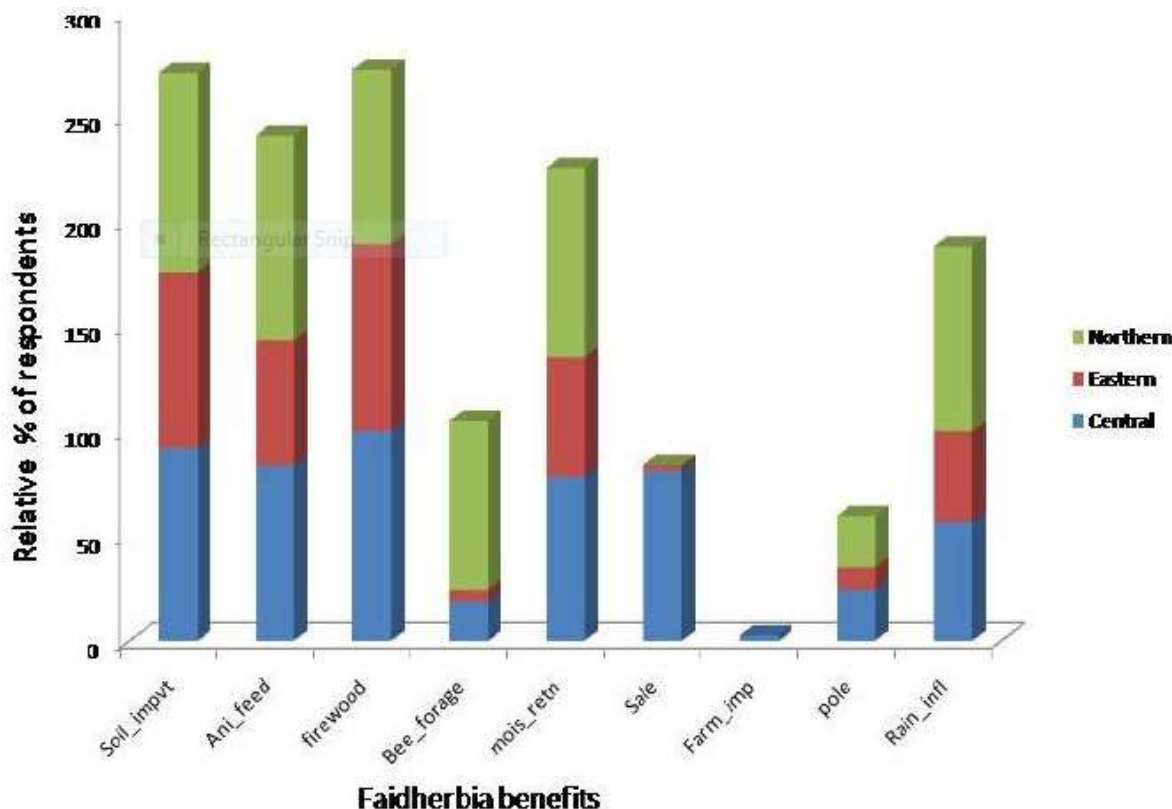


Figure 2. Benefits of *F. albida* according to the respondent farmers in 2010 in Ethiopia.

scarce; (Hadgu et al., 2009).

### ***Faidherbia albida* PROPAGATION AND TREE MANAGEMENT**

The hard coated *F. albida* seeds store well under dry conditions and are usually extracted by pounding the pods in a mortar. Pretreatment is often needed for rapid uniform germination. Various methods used include; mechanical scarification, dipping in concentrated sulphuric acid for 5-15 min and dipping in boiling water. Early seed collection is recommended to avoid heavy infestation by bruchid beetles. Seed storage behavior is orthodox; there is no loss after one year in hermetic storage at 4°C; viability maintained for several years in hermitic storage at 10°C with 6-10% mc. When treated with insecticides and kept in simple closed containers, seed can be stored for several years.

Seedlings and direct sowing at site may be used for propagation of *F. albida*. Pruning in the second year to about half the tree height may be needed to control low branching. Repeated pruning during periods of average biomass production stimulates leaf production. It can be pruned twice a year. Resulting re-growth is especially vigorous in the first year but decreases as exploitation

continues; trees show stress at the end of the sixth year. Regular lopping (once every 3 - 4 years) removing 0.4 - 0.5 m<sup>3</sup> of foliage (or 35% of the total volume) at the start of the growing season is recommended (Maundu and Tengnas, 2005). However, care should be taken as improper methods of lopping have been observed to cause wounds, predisposing the tree to attack by pathogens. This tree responds well to coppicing.

Natural stands of *F. albida* in Ethiopia are generally managed in two ways, depending on the type of farming system and area where it grows. In the coffee growing region of Hararghe (eastern Ethiopia), particularly in the Gelemso area, farmers usually maintain and protect *F. albida* in their coffee plantations for shade. Pods of the trees are collected and fed to livestock. On the other hand, mature trees found in cereal-based farming systems (southeastern Shewa region and the Fedis area of Hararghe) are regularly pollarded at intervals of 3-4 years. Whole canopies are cut right back to the trunk, leaving the trees completely bare. Farmers use the branches for fuelwood and for fencing their compounds and barns.

### **CONCLUSION**

*F. albida* can simultaneously store significant quantities of



carbon in aboveground biomass and increase crop yields. The unusual phenology and the ability to fix nitrogen makes it excellent in agroforestry systems. The mulch created by falling leaf litter and the canopy shade at planting time favors crop production beneath its canopy. It has positive effect on crops yield. Litter drop combined with high microbiological activity in the soil (especially during the rainy season) apparently constitute its main soil improving effect. The deep-rooting capabilities of the trees play a particularly important role in enriching surface soil horizons by drawing up mineral elements from lower horizons. Its reverse phenology of contributes much to crop fertilization, since its litter fall occurs in the rainy season. Other beneficial effects of *F. albida*, such as nodulation and the attraction it holds for cattle resulting in manuring of the site are important as well.

*F. albida* is considered as keystone species by local farmers as they derive benefits such as livestock fodder, bee forage, fuel wood and income through sale of wood products which contributes to the improvement of their livelihood. Besides, it is used as a vegetative soil cover during the long dry season, and serves as shade for livestock. This agroforestry tree species are not only an effective tool for smallholders to increase cereal yields and short-term food security, the long-term soil fertility and available soil moisture increases hold promise for making cropping systems more resilient under increasing climate variability. In addition, these species provide multiple benefits, developing carbon stocks that may be converted into offsets, providing on-farm fuelwood, as well as fodder, food and medicinal products.

## CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

## REFERENCES

- Barnes RD, Fagg CW (2003). *Faidherbia albida* monograph and annotated bibliography. CTA (2003). Agroforestry. Arbruset Agricultures MultietageesD' Afrique. CTA, Wageningen, the Netherlands P. 280.
- Dangasuk GO (2006). Geographical characterization of African provenances of *Faidherbia albida*. *African Crop Science*, 14(4):263-273.
- Getahun HF, Mulugeta L (2014). Status of soil properties of scattered *Faidherbia albida* (DEL) in agricultural landscapes in central highlands of Ethiopia. *African Journal of Agricultural Research* 9(46):3379-3387.
- Giffard PL (1964). Les possibilités de reboisement en *Acacia albida*, au Sénégal. *BOIS and FORETS DES TROPIQUES*, 95(95):21-33.
- Gworgwor NA, Ndahi WB, Weber HC (2001). Parasitic weeds of North-eastern region of Nigeria: a new potential threat to crop production. In *The BCPC Conference: Weeds, 2001, Volume 1 and Volume 2*. Proceedings of an international conference held at the Brighton Hilton Metropole Hotel, Brighton, UK, 12-15 November 2001 British Crop Protection Council pp. 181-186.
- Hadgu KM, Kooistra L, Rossing WA, van Bruggen AH (2009). Assessing the effect of *Faidherbia albida* based land use systems on barley yield at field and regional scale in the highlands of Tigray, Northern Ethiopia. *Food Security* 1(3):337-350.
- International Centre for Research in Agroforestry (ICRAF) (1989). The apple ring. *Agroforestry today* 1:11-12.
- International Centre for Research in Agroforestry (ICRAF) (2000). *Tree-Soil-Crop Interaction*. In Asian Regional Research Programme. P 2.
- Kamara CS, Haque I (1992). *Faidherbia albida* and its effects on Ethiopian highland vertisols. *Agroforestry Systems* 18:17-29.
- Kessler JJ (1990). Agroforestry in the Sahel and Sudan zones of West Africa. *Bosnews letter* No.29, 9(1):27-33.
- Kindeya G (2004). The development of Agroforestry in the dry lands of Ethiopia. *Kenya Journal of Forestry* 6(11):202-299.
- Kassa H, Gebrehiwet, K, Yamoah C (2010). *Balanites aegyptiaca*, a potential tree for parkland agroforestry systems with sorghum in Northern Ethiopia. *Journal of Soil Science and Environmental Management* 1(6):107-114.
- Le Houérou HN, Bingham RL, Skerbek W (1988). Relationship between the variability of primary production and the variability of annual precipitation in world arid lands. *Journal of arid Environments* 15(1):1-18.
- Leakey RRB (1996). Definition of agroforestry revisited. *Agroforestry today* 8:5-7.
- Maundu P, Tengnäs B (2005). Useful trees and shrubs for Kenya. ICRAF Technical handbook series.
- Mokgolodi NC, Setshogo MP, Shi LL, Liu YJ, Ma C (2011). Achieving food and nutritional security through agroforestry: a case of *Faidherbia albida* in sub-Saharan Africa. *Forestry Studies in China* 13(2):123-131.
- Oluwakanyinsola SA, Adeniyi TJA, Oga E (2010). Acute and subacute toxicity study of ethanolic extract of the stem bark of *Faidherbia albida* (Del.) A. chev (Mimosoidae) in rats. *African Journal of Biotechnology* 9:1218-1224.
- Orwa C, Mutua A, Kindt R, Jamnadass R, Anthony S (2009). *Agroforestry Database: a tree reference and selection guide version 4.0* (<http://www.worldagroforestry.org/sites/treedb/treedatabases.asp>)
- Palgrave CK (2002). *Trees of Southern Africa* (3rd edition). Cape Town, South Africa: Struik.
- Reubens B, Moeremans C, Poesen J, Nyssen J, Tewoldeberhan S, Franzel S, Deckers J, Orwa C, Muys B (2011). Tree species selection for land rehabilitation in Ethiopia: from fragmented knowledge to an integrated multi-criteria decision approach. *Agroforestry Systems* 82(3):303-330.
- Santiago BJA, Lambert JB (2010). Legumes and their exudates. *Bulletin of The Desert Legume Program of The BoyceThompson Southwestern Arboretum and The University of Arizona* 22(1).
- Sauerborn J (1991). *Parasitic flowering plants: ecology and management*. Verlag Josef Margraf.
- Umar BB, Aune JB, Lungu O (2012). Effects of *Faidherbia albida* on the fertility of soil in smallholder conservation agriculture systems in eastern and southern Zambia. Aas, Norway.
- Van Noordwijk M, Lusiana B, Khasanah N, Mulia R (2000). *WaNuL CAS Version 2.0: Background on a Model of Water, Nutrient and Light Capture in Agroforestry Systems*. ICRAF.
- Yirgu A, Tsega M (2015). Pre-dispersal seed predation of *Faidherbia albida* in the Central Rift Valley of Ethiopia. *Agroforestry systems* 89(4):759-763.
- Zommer RJ, Trabucco A, Coe R, Place F (2009). *Trees on farm: Analysis of Global Extent and Geographical Patterns of Agroforestry* ICRAF Working Paper No. 69. World Agroforestry Center, Nairobi, Kenya.

*Full Length Research Paper*

# **Effect of blended chemical fertilizer (sulfur, nitrogen and phosphorus) on yield and yield components of potato (*Solanum tuberosum* L.) in the rainy season**

**Solomon Fantaw\*, Derajew Asres and Aleminew Tagele**

College of Agriculture and Environmental Sciences, University of Gondar, Gondar, Ethiopia.

Received 16 January, 2019; Accepted 20 February 2019

Potato is the fourth most important crop and consumed all around the world and is one of the main favorite vegetable in Ethiopia. However, the national productivity is very low as compared to the potential of the crop. One of the main reason for low productivity is low soil fertility. Hence, a field experiment was conducted from 2016-2018 with 9 combination of nitrogen, phosphorous and sulfur fertilizers arranged in randomized complete block design with three replications to assess response of potato to these rates. The application 110-19.74-50.8 kg-ha<sup>-1</sup> N<sub>2</sub>/S<sub>2</sub> /P<sub>2</sub>O<sub>5</sub> fertilizer delayed days to flowering and maturity by 8 and 11 days at Darark and 10 and 14 days at Dabat. However, it increased plant height and number of stems per plant, which may positively contribute to increased photosynthetic area. The application of these fertilizers advanced marketable tuber yield by 153% and the total tuber yield by 86.6% relative to unfertilized plants. Furthermore, the partial budget analysis data showed that the highest net benefit and marginal rate of return (4453.6%) was obtained from 110-19.74-50.8 kg ha<sup>-1</sup>. Therefore, the current study results is indicative that potato can grow well and provide better yield at Dabat, Dabark and similar agro ecology by using 110-19.74-50.8 kg ha<sup>-1</sup> N<sub>2</sub>/S<sub>2</sub> /P<sub>2</sub>O<sub>5</sub>, respectively.

**Key words:** Fertilizer, marginal rate of return, marketable tuber, yield.

## **INTRODUCTION**

Potato (*Solanum tuberosum* L.) is the fourth most economically important crop globally and the first among root and tuber crops (FAO, 2016). It is among high yielder crops in short duration of time (mostly < 120 days) and nutritionally; it is source of energy, minerals, vitamins and dietary fiber (Mulatu et al., 2005; Litaladio and Castaldi, 2009). Potato was introduced to Ethiopia in 1859 by the German botanist Schimper (Gebremedhin et al., 2008). Its production has increased considerably

through time and has contributed greatly for millions of Ethiopians. Hence, it is among the major crops of Ethiopia. North Gondar is one of the major potato production zones in north-western part of Ethiopia (Gebremedhin et al., 2001; Adane et al., 2010).

Though Ethiopia has a favorable climate for potato production, national productivity (13.45 t/ha) is very low (CSA, 2016). Among the limiting factor, low soil fertility is a detriment to sustained agricultural production and

\*Corresponding author. Email: fantawsol1@gmail.com.

**Table 1.** The treatment combinations.

Treatment number	Rate (kg/ha) and type of fertilizer (N <sub>2</sub> , S <sub>2</sub> , P <sub>2</sub> O <sub>5</sub> )	Treatment number	Rate (kg/ha) and type of fertilizer (N <sub>2</sub> , S <sub>2</sub> , P <sub>2</sub> O <sub>5</sub> )	Treatment number	Rate (kg/ha) and type of fertilizer (N <sub>2</sub> , S <sub>2</sub> , P <sub>2</sub> O <sub>5</sub> )
1	Unfertilized (0-0-0)	4	110-0-0	7	110-19.74-50.8
2	0-0-90	5	55-0-45	8	110-0-45
3	55-9.87-25.4	6	55-0-90	9	110-0-90

productivity in Ethiopia (Tamir, 1989). The average nutrient depletion in highlands of Ethiopia, like the present research area, much more than the lowlands (Henao and Baanante, 1999). This is due to the reasons that the area receives high rainfall, creates high runoff and high soil erosion, fixation of phosphorus and leaching in respect of nitrogen and potassium. Also poor culture of the farmer for nutrient replacement through application of micro and macro nutrient, absence of nutrient recommendation specifically for those areas considering the soil and the agroecology are another challenge.

Potato has shallow and inefficient rooting system (Munoz et al., 2005) and crops absorb huge amount of nutrients from soil per season (Trehan et al., 2005). Fertility status of soil, type, amount and time of fertilizer application has great influence on yield and quality of potato production (Westermann, 2005). Nitrogen, phosphorus, potassium and sulfur are among the elements that are essential for potato production.

Nitrogen is an integral component of many compounds such as chlorophyll, nucleotides, alkaloids, enzymes, hormones and vitamins and these are essential for plant growth processes (Brady and Weil, 2008). Nitrogen is a valuable nutrient for plants and plays an important role in tuber size development but overdose of nitrogen lowers the tuber dry matter (Zelalem et al., 2009). Adequate amount of nitrogen has a positive impact on quality and yield of potatoes. Likewise phosphorus influences plant metabolism through its role in cellular energy transfer, respiration and photosynthesis (Grant et al., 2001). The application of appropriate rate of phosphorus fertilizer increases the tuber yield of potato, however the response will be negative if applied beyond the optimum rate (Sharma and Arora, 1987).

Sulfur is one of 16 essential nutrient elements and fourth major nutrient after NPK, required by plants for proper growth and yield as it is known to take part in many reactions in all living cells (Sud and Sharma, 2002). According to Klikocka (2004), the content of sulfur in potato tubers is on average between 0.7-2.0 g kg<sup>-1</sup> and its uptake ranges from 18 to 40 kg ha<sup>-1</sup>. Sulfur enhances starch synthesis in tubers and it is a component of proteins and many enzymes (Lalitha et al., 2002). It increases the resistance of this cultivar of potato to environmental stress and plays an important role in protecting the plants from pests and diseases (Klikocka,

2005). Sulfur deficient plants had poor utilization of nitrogen, phosphorus and potash (Nasreen et al., 2003).

In the study area, farmers utilized inorganic fertilizers for increasing potato yields like Urea as a source of nitrogen and Di-ammonium phosphate (DAP) as a source of phosphorus since these are the only fertilizers commercially available in the local market. Currently, the Ethiopian government introduces blended fertilizer for the study and similar agro ecology which has sulfur, nitrogen and phosphorus. However, there was no appropriate fertilizer rate recommendation for potato crop in the study area. Therefore, the study was undertaken to assess responses of potato to Nitrogen, Phosphorus and sulfur fertilizers combination and identify economically feasible fertilizer rate for potato production in the rainy season.

## MATERIALS AND METHODS

This study was conducted at Dabat and Dabark District of North Gondar Administrative Zone during 2016-2018 main cropping seasons. Belete (CIP-393371.58) potato variety, obtained from Holeta Agricultural Research Center, Holeta, Ethiopia, with a medium tuber diameter of 40-45 mm were planted on flat land at the beginning of the main rainy season (June). The study area has a clay loam soil which was plowed 3 times using Oxen.

A total of nine treatment combinations of nitrogen sulfur and phosphorus (Table 1) were arranged in randomized complete block design with three replications. Prior to planting, representative soil samples were taken using an auger from the top 0-30 cm and combined into a composite sample. Samples were analyzed in the laboratory using the standard procedure for each of soil pH, organic carbon, total N, available phosphorus, cation exchange capacity (CEC) (Table 2).

Sprouted tubers in the diffused light store (DLS) were planted by hand in rows 75 cm apart and with 30 cm between plants within rows, each experimental plot was 9 m<sup>2</sup> in size. Blocks were separated by 1.5 m. All of the phosphorus and sulfur, half the nitrogen was applied at planting and the remaining nitrogen applied at 45 days after planting. Urea (46%N), blended fertilizer (39%N<sub>2</sub>, 18% P<sub>2</sub>O<sub>5</sub>, 7% S<sub>2</sub>) and triple super phosphate TSP (46% P<sub>2</sub>O<sub>5</sub>) fertilizers were used as sources of nitrogen, sulfur and phosphorus. There were 4 rows/plot for each treatment. Data were collected from the middle 2 rows; the outermost rows and terminal plants were borders. Earthening up and weeding were each carried out 3 times by hand during the growing period.

Data were collected on phenological and growth parameters such as days to 50% flowering and maturity, plant heights, number of stem per plant and yield parameters like total tuber number, marketable and unmarketable tuber number, marketable, unmarketable and total tuber yields (t ha<sup>-1</sup>) and average total tuber

**Table 2.** Chemical properties of the soil of experimental sites taken before planting.

Parameter	Value at Dabat	Value at Dabark
pH	5.65	5.91
Total nitrogen (%)	0.239	0.192
Available phosphorus (ppm)	10.65	26.91
Organic matter (%)	5.57	4.47
EC (mS·cm <sup>-1</sup> )	0.14	0.17
Cation Exchange Capacity (Cmol <sub>c</sub> ·kg <sup>-1</sup> )	43.87	40.44

weight. Data were checked for constant variance and normality and over year combined data were subjected to analysis of variance using SAS Version 9.2 statistical software (SAS, 2008). Treatment means were compared using LSD value at 5% significant level.

Partial budget analysis was employed for economic analysis of fertilizer application using a technique described by CIMMYT (1988). It was carried out for combined tuber yield data. The marketable tuber yield data was adjusted by bringing down 10% to minimize plot management effect by the research or to reflect the actual farm level performance. To estimate the total costs, mean market prices of Urea and NPS, DAP, Cost of fertilizer transportation and labor for application of fertilizer were taken from market assessment at the time of planting and market price of potato tubers was taken after harvest.

## RESULTS AND DISCUSSION

### Phenological and growth parameters

The results of analysis of variance (ANOVA) showed that NSP fertilizers influenced the days to 50% flowering and maturity. The application of 110-19.74-50.8N<sub>2</sub>/S<sub>2</sub>/P<sub>2</sub>O<sub>5</sub> kg/ha at Dabark site delayed days to flowering and maturity by 8 and 11 day, respectively as compared to unfertilized treatment (Table 3). A similar fertilizer rate when used at Dabat, delayed flowering and maturity by 10 and 14 days respectively. Over all combined result of both location and year revealed that application of the same treatment prolonged the flowering and maturity period by 9 and 12 days respectively as compared to none treated one followed by application of 110kg/ha N<sub>2</sub> with 90 P<sub>2</sub>O<sub>5</sub> kg/ha. This is due to the fact that, increased concentration of nitrogen fertilizer can increase the nitrogen uptake and this increase contributes to have excessive haulm development for staying longer duration (Mulubrhan, 2004). Such research findings were reported previously by Zelalem et al. (2009) where the application of phosphorous and nitrogen fertilizer significantly delayed days to 50% flowering and maturity. Similarly, Israel et al. (2012) and Melkamu and Minwyelet (2018) reported that application of nitrogen, phosphorous and sulfur fertilizer showed significant effect on prolonging of time of flowering and maturity.

Plant height was significantly influenced by the application of fertilizers (Table 3). The two years combined analysis of the experiment in Dabark and Dabat areas showed that application of 110 kg N<sub>2</sub> with 90

kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> fertilizer gave the maximum plant height, 70.16 and 64.2 cm while the shortest (47.83 and 42.73 cm) was found from untreated plant, respectively. Here, the fertilizer application resulted in a difference of 22.3 and 21.4cm height respectively as compared to the untreated potato (Table 3). It is true also for the overall combined result that revealed 48.3% height increment as compared to untreated plants. The probable reason for increment in plant height might be due to more uptake of N<sub>2</sub> during growth period resulting in increase in cell size, elongation and enhancement of cell division which ultimately increase the plant growth. The result goes in line with those of Zelalem et al. (2009) who had reported significant height difference (10.5 to 24 cm) and resulted from application of NITROGEN and phosphorous fertilizer. Results of the present experiment are in agreement with the finding of Sharma et al. (2014) who had reported that plant height increased with increasing fertilizer levels of nitrogen and phosphorus. Also, Mojtaba et al. (2013) reported a significant and 23.82% plant height increment due to increasing the level of nitrogen rate 0 to 150 kg·ha<sup>-1</sup>.

The number of stem per plant was significantly affected by the application of fertilizers (Table 3). The highest number of stems were recorded from application of 110-19.74-50.8 N<sub>2</sub>/S<sub>2</sub>/P<sub>2</sub>O<sub>5</sub> kg ha<sup>-1</sup> and 110 kg N<sub>2</sub>/ha with 90 kg/ha P<sub>2</sub>O<sub>5</sub> at Dabark and Dabat, respectively whereas the lowest number of stems were from untreated plants. The result of overall combined data showed that an application of 110 kg N<sub>2</sub> with 90 kg/ha P<sub>2</sub>O<sub>5</sub> resulted in the maximum number of stems followed by 110-19.74-50.8 N<sub>2</sub>/S<sub>2</sub>/P<sub>2</sub>O<sub>5</sub> kg ha<sup>-1</sup>. This might be due to the fact that fertilization application encouraged more number of independent stems. According to Jamaati-e-Somarin et al. (2009) increasing nitrogen level up to 110 kg/ha increased the stem number; however further increases nitrogen fertilizer level did not affect it any more. Singh et al. (2016) and Melkamu and Minwyelet (2018) reported that nitrogen with sulfur fertilizer resulted in a significant and maximum number of stem per plant.

### NPS effects on yield components

Number of marketable, unmarketable tubers and total number of tubers were influenced significantly by the

**Table 3.** The effect of nitrogen/sulfur/phosphorous on phenological and growth parameter.

N <sub>2</sub> , S <sub>2</sub> , P <sub>2</sub> O <sub>5</sub> kg/ha respectively	Dabark ( combined, 2016-2017)				Dabat ( combined, 2016-2017)				over all combined result (over location-over year)			
	DTF	DM	Pht	Nstm	DTF	DM	Pht	Nstm	DTF	DTM	Pht	Nstm
0-0-0	58d	117.16 <sup>d</sup>	47.83 <sup>f</sup>	3.41 <sup>e</sup>	56.33 <sup>d</sup>	115.83 <sup>f</sup>	42.73 <sup>e</sup>	3.4 <sup>c</sup>	57.16 <sup>d</sup>	116.5 <sup>e</sup>	45.28 <sup>e</sup>	3.4 <sup>e</sup>
0-0- 90	63.16 <sup>bc</sup>	123.66 <sup>b</sup>	61.7 <sup>c</sup>	4.23 <sup>d</sup>	63.5 <sup>b</sup>	119.33 <sup>e</sup>	53.26 <sup>cd</sup>	4.23 <sup>b</sup>	63.5 <sup>b</sup>	120.58 <sup>d</sup>	54.81 <sup>d</sup>	4.23 <sup>d</sup>
55-9.87-25.4	63.83 <sup>abc</sup>	123.83 <sup>b</sup>	62.8 <sup>c</sup>	5.1 <sup>abc</sup>	62.16 <sup>bc</sup>	124.16 <sup>c</sup>	51.26 <sup>d</sup>	4.68 <sup>b</sup>	62.66 <sup>bc</sup>	123.91 <sup>c</sup>	56.48 <sup>d</sup>	4.87 <sup>bc</sup>
110-0-0	63.66 <sup>abc</sup>	124.16 <sup>b</sup>	61.11 <sup>c</sup>	5.0 <sup>bc</sup>	66.66 <sup>b</sup>	122.67 <sup>dc</sup>	60.23 <sup>ab</sup>	4.8 <sup>b</sup>	63.75 <sup>b</sup>	123.25 <sup>c</sup>	61.51 <sup>bc</sup>	4.9b <sup>c</sup>
55-0-45	61.5 <sup>c</sup>	120.83 <sup>c</sup>	58.43 <sup>de</sup>	4.73 <sup>cd</sup>	61 <sup>c</sup>	120.66 <sup>de</sup>	58.26 <sup>bc</sup>	4.8 <sup>b</sup>	61.25 <sup>c</sup>	120.75 <sup>d</sup>	58.35 <sup>cd</sup>	4.76 <sup>c</sup>
55-0-90	63.5 <sup>bc</sup>	124.16 <sup>b</sup>	59.9 <sup>cd</sup>	4.6b <sup>cd</sup>	63.66 <sup>b</sup>	124 <sup>c</sup>	60.26 <sup>ab</sup>	4.33 <sup>b</sup>	63.66 <sup>b</sup>	120.08 <sup>c</sup>	61.19 <sup>bcd</sup>	4.46 <sup>cd</sup>
110-19.74-50.8	66.67 <sup>a</sup>	128 <sup>a</sup>	66.18 <sup>b</sup>	5.65 <sup>a</sup>	66.66 <sup>a</sup>	130.16 <sup>a</sup>	59.36 <sup>ab</sup>	5 <sup>b</sup>	66.66 <sup>a</sup>	129.08 <sup>a</sup>	62.77 <sup>b</sup>	5.32 <sup>b</sup>
110- 0- 45	63.5 <sup>bc</sup>	121.83 <sup>bc</sup>	56.36 <sup>e</sup>	4.93 <sup>c</sup>	61.83 <sup>bc</sup>	124.66 <sup>c</sup>	62.86 <sup>ab</sup>	4.33 <sup>b</sup>	62.66 <sup>bc</sup>	124.41 <sup>c</sup>	61.38 <sup>bcd</sup>	4.63 <sup>cd</sup>
110-0-90	66.16 <sup>ab</sup>	127a	70.16 <sup>a</sup>	5.6 <sup>ab</sup>	66 <sup>a</sup>	127.33 <sup>b</sup>	64.2 <sup>a</sup>	6.1 <sup>a</sup>	66.08 <sup>a</sup>	127.16 <sup>b</sup>	67.18 <sup>a</sup>	5.95 <sup>a</sup>
CV	4.21	1.66	4.59	11.33	2.62	1.61	8.15	14.9	3.47	1.62	6.78	13.45
Mean	63.33	123.4	60.6	4.8	62.75	123.2	56.94	4.63	63.04	123.3	58.77	4.79
LSD	3.1	2.4	3.26	0.63	1.92	2.32	5.44	0.8	1.78	1.62	3.24	0.51

DTF = days to flowering; DEM = days to maturity; Pht = plant height (cm); Nstm= number of Stem per plant.

\*Significant, \*\* highly significant, LSD =least significant difference, means followed by the same letter(s) are not significantly different.

application of different level and type of fertilizer (Table 4). The two years combined analysis of the experiment at both location and the overall combined result revealed that the maximum number of unmarketable tuber was recorded from unfertilized treatment followed by application of 55 kg ha<sup>-1</sup> N<sub>2</sub> with 45 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> whereas the minimum number of unmarketable tuber was recorded from 90 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> for Dabark and 110 kg ha<sup>-1</sup> N<sub>2</sub> for Dabat.

On the other hand, the maximum number of marketable tuber for overall combined result and Dabat area were recorded from application of 110- 90 kg/ha N<sub>2</sub>/P<sub>2</sub>O<sub>5</sub> while 110-19.74-50.8 kg/ha N<sub>2</sub>/S<sub>2</sub>/P<sub>2</sub>O<sub>5</sub> for Dabark area. The raise in the application of N<sub>2</sub> 0 to 110 kg/ha with 90 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> increased the number of marketable tuber by 122% at Dabat (Table 4). Increasing the rate 0 to 110-19.74-50.8 kg ha<sup>-1</sup> N<sub>2</sub>/S<sub>2</sub>/P<sub>2</sub>O<sub>5</sub> at Dabark

increased the number of marketable tuber by 127%. The maximum total number of tubers/plant were recorded from untreated plants for all cases but the minimum number of total tuber at Dabark was from application of 110-45 kg ha<sup>-1</sup> N<sub>2</sub>/P<sub>2</sub>O<sub>5</sub> while 90 kg/ha P<sub>2</sub>O<sub>5</sub> for Dabat.

It is clear that the increase in number of marketable tuber with increase in applied nitrogen, sulfur and phosphorous was associated with decrease in the number of the small size tubers and increase in the weight of individual tubers. This could be probably due to the fact that marketable tuber number increases at higher nitrogen rate because nitrogen can trigger the vegetative growth for more photo-assimilate production while phosphorous enhanced the development of roots for nutrient uptake. According to Israel et al. (2012), application of nitrogen from 0 -165 kg N ha<sup>-1</sup> and phosphorus

from 0 - 60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> increases marketable tuber number by 56.36 and 19.2% respectively as compared to control. Similarly, Singh et al. (2016) reported that application of 180 kg N<sub>2</sub> along with 50 kg S<sub>2</sub> increase the number of tuber by 43%. Rosen and Bierman (2008) reported that application of phosphorus fertilizer had significant contribution to increase total tuber yield and total number of tubers per plant as compared to unfertilized.

#### NPS effect on potato tuber yield

The application of different type and rate of fertilizer significantly influenced the marketable, unmarketable and total tuber yield (Table 5). The result of the two years combined analysis of the experiment in Dabark areas showed that a

**Table 4.** The effect of nitrogen/sulfur/phosphorous on number of tubers/plant.

N <sub>2</sub> , S <sub>2</sub> , P <sub>2</sub> O <sub>5</sub> kg/ha respectively	Dabark ( combined, 2016-2017)			Dabat ( combined, 2016-2017)			Combined result (over location-over year)		
	UMTN	MTN	TTN	UMTN	MTN	TTN	UMTN	MTN	TTN
0-0-0	13.58 <sup>a</sup>	3.63 <sup>f</sup>	17.21 <sup>a</sup>	13.86 <sup>a</sup>	3.81 <sup>f</sup>	17.68 <sup>a</sup>	13.72 <sup>a</sup>	3.72 <sup>e</sup>	17.45 <sup>a</sup>
0-0- 90	6.23 <sup>dc</sup>	5.68 <sup>de</sup>	11.91 <sup>de</sup>	4.53 <sup>def</sup>	6.2 <sup>cdr</sup>	10.73 <sup>c</sup>	5.38 <sup>cde</sup>	5.94 <sup>c</sup>	11.32 <sup>e</sup>
55-9.87-25.4	4.85 <sup>d</sup>	6.91 <sup>bc</sup>	11.7 <sup>6e</sup>	5.4 <sup>d</sup>	5.63 <sup>e</sup>	11.03 <sup>c</sup>	5.12 <sup>cde</sup>	6.27 <sup>bc</sup>	11.47 <sup>de</sup>
110-0-0	6.2 <sup>cd</sup>	7.63 <sup>ab</sup>	13.83 <sup>bc</sup>	3.71 <sup>f</sup>	7.51 <sup>ab</sup>	11.23 <sup>c</sup>	4.95 <sup>de</sup>	7.57 <sup>a</sup>	11.53 <sup>cd</sup>
55- 0-45	9.86 <sup>b</sup>	5.21 <sup>e</sup>	15.08 <sup>b</sup>	8.95 <sup>b</sup>	4.23 <sup>f</sup>	13.18 <sup>b</sup>	9.4 <sup>b</sup>	4.72 <sup>d</sup>	14.13 <sup>b</sup>
55-0- 90	6.8 <sup>c</sup>	6.83 <sup>bc</sup>	13.68 <sup>bcd</sup>	5.26 <sup>de</sup>	6.71 <sup>bcd</sup>	11.98 <sup>bc</sup>	6.05 <sup>cd</sup>	6.77 <sup>b</sup>	12.83 <sup>c</sup>
110-19.74-50.8	5.38 <sup>cd</sup>	8.25 <sup>a</sup>	13.63 <sup>bcd</sup>	4.88 <sup>d<sup>ef</sup></sup>	7.13 <sup>bc</sup>	12.01 <sup>bc</sup>	5.13 <sup>dce</sup>	7.69 <sup>a</sup>	12.82 <sup>c</sup>
110- 0-45	5.13 <sup>cd</sup>	6.48 <sup>cd</sup>	11.61 <sup>e</sup>	7.2 <sup>c</sup>	6 <sup>de</sup>	13.2 <sup>b</sup>	6.16 <sup>c</sup>	6.24 <sup>bc</sup>	13.40 <sup>cde</sup>
110-0-90	5.06 <sup>d</sup>	7.73 <sup>ab</sup>	12.8 <sup>cde</sup>	3.85 <sup>ef</sup>	8.46 <sup>a</sup>	12.31 <sup>b<sup>c</sup></sup>	4.45 <sup>e</sup>	8.10 <sup>a</sup>	12.55 <sup>cd</sup>
CV	21.44	14.64	11.6	20.24	13.38	10.91	19.58	14.04	11.35
Mean	7.01	6.48	13.5	6.4	6.19	12.59	7.45	6.33	13.05
LSD	1.76	1.11	1.84	1.61	0.97	1.61	1.13	0.72	1.2

UMTN = number of unmarketable tuber; MTN= number of marketable tuber; TTN= total tuber number.

\*Significant, \*\*highly significant, LSD =least significant difference, means followed by the same letter(s) are not significantly different.

**Table 5.** The effect of nitrogen/sulfur/phosphorous on yield.

N <sub>2</sub> , S <sub>2</sub> , P <sub>2</sub> O <sub>5</sub> kg/ha respectively	Dabark ( combined, 2016-2017)				Dabat ( combined, 2016-2017)				Combined result (over location-over year)			
	UMTY	MTY	TTY	AWtT	UMTY	MTY	TTY	AWtT	UMTY	MTY	TTY	AWtT
0-0-0	6.65 <sup>a</sup>	12.4 <sup>e</sup>	19.05 <sup>d</sup>	26.48 <sup>f</sup>	7.13 <sup>a</sup>	11.96 <sup>d</sup>	19.05 <sup>d</sup>	26.24 <sup>f</sup>	6.89 <sup>a</sup>	12.15 <sup>f</sup>	19.05 <sup>e</sup>	26.36 <sup>e</sup>
0- 0- 90	5.58 <sup>ab</sup>	19.75 <sup>cd</sup>	25.33 <sup>c</sup>	48.03 <sup>cde</sup>	4.11 <sup>f</sup>	21.88 <sup>b</sup>	26 <sup>b<sup>c</sup></sup>	54.73 <sup>bcd</sup>	4.85 <sup>bc</sup>	20.81 <sup>d</sup>	25.66 <sup>c</sup>	51.38 <sup>bc</sup>
55-9.87-25.4	3.5 <sup>e</sup>	22.53 <sup>bc</sup>	26.03 <sup>c</sup>	49.47 <sup>bcd</sup>	5.55 <sup>bcd</sup>	21.95 <sup>b</sup>	27.5 <sup>bc</sup>	56.38 <sup>b<sup>c</sup></sup>	4.52 <sup>c</sup>	22.24 <sup>cd</sup>	26.76 <sup>c</sup>	52.92 <sup>b</sup>
110-0- 0	4.21 <sup>cde</sup>	23.35 <sup>b</sup>	27.56 <sup>c</sup>	45.15 <sup>de</sup>	4.16 <sup>ef</sup>	22.86 <sup>b</sup>	27.03 <sup>bc</sup>	54.51 <sup>bcd</sup>	4.19 <sup>c</sup>	23.1 <sup>c</sup>	27.3 <sup>c</sup>	49.83 <sup>bc</sup>
55-0- 45	4.73 <sup>bcd</sup>	16.65 <sup>d</sup>	21.38 <sup>d</sup>	31.69 <sup>f</sup>	6.45 <sup>ab</sup>	18.18 <sup>c</sup>	24.7 <sup>c</sup>	41.93 <sup>e</sup>	5.59 <sup>b</sup>	17.41 <sup>e</sup>	23.0 <sup>d</sup>	36.81 <sup>d</sup>
55- 0-90	5.18 <sup>bc</sup>	20.08 <sup>c</sup>	25.26 <sup>c</sup>	41.66 <sup>e</sup>	5.96 <sup>bc</sup>	21.73 <sup>c</sup>	27.7 <sup>b</sup>	52.28 <sup>cd</sup>	5.57 <sup>b</sup>	20.9 <sup>d</sup>	26.48 <sup>c</sup>	46.97 <sup>c</sup>
110-19.74-50.8	5.15 <sup>bc</sup>	30.26 <sup>a</sup>	35.41 <sup>a</sup>	58.99 <sup>a</sup>	4.46 <sup>def</sup>	31.37 <sup>a</sup>	35.5 <sup>a</sup>	67.59 <sup>a</sup>	4.8b <sup>c</sup>	30.74 <sup>a</sup>	35.55 <sup>a</sup>	63.29 <sup>a</sup>
110 0-45	3.7d <sup>e</sup>	23.73 <sup>b</sup>	27.43 <sup>c</sup>	53.1a <sup>bc</sup>	5.28 <sup>cde</sup>	22.18 <sup>c</sup>	27.46 <sup>bc</sup>	47.62 <sup>de</sup>	4.49 <sup>c</sup>	22.95 <sup>cd</sup>	27.45 <sup>c</sup>	50.36 <sup>bc</sup>
110-0-90	3.61 <sup>de</sup>	27.95 <sup>a</sup>	31.56 <sup>b</sup>	55.64 <sup>ab</sup>	4.73 <sup>def</sup>	28.32 <sup>a</sup>	33.01 <sup>a</sup>	61.07 <sup>ab</sup>	4.17 <sup>c</sup>	28.11 <sup>b</sup>	32.29 <sup>b</sup>	58.35 <sup>a</sup>
CV	21.5	12.27	9.79	12.43	18.3	11.6	9.23	12.34	20.58	12.07	9.44	12.68
Mean	4.7	21.85	26.56	45.59	5.31	22.24	27.34	51.3	5.01	22.05	27.04	48.44
LSD	1.19	3.14	3.05	6.64	1.14	3.02	2.98	7.44	0.86	2.16	2.08	5

UMTY = yield of unmarketable tuber; MTY= Yield of marketable tuber; TTY= total tuber yield;AWtT= Average weigh of total tuber. \*Significant, \*\* highly significant, LSD =least significant difference, means followed by the same letter(s) are not significantly different.

a minimum unmarketable tuber yield was recorded from application of 55-9.87-25.4 kg/ha  $N_2/S_2/P_2O_5$ , while the maximum unmarketable yield was measured from unfertilized treatment (Table 5). On the contrary, the lowest marketable tuber yield ( $12.4 \text{ t ha}^{-1}$ ) was recorded from untreated and the maximum marketable tuber yield ( $30.26 \text{ t ha}^{-1}$ ) was from application of 110-19.74-50.8 kg  $ha^{-1}N_2/S_2 /P_2O_5$ . Similarly, at Dabat site a maximum unmarketable yield ( $7.13 \text{ t ha}^{-1}$ ) and a minimum marketable tuber yield ( $11.96 \text{ t ha}^{-1}$ ) were recorded from untreated plant, while the maximum marketable tuber ( $31.37 \text{ t ha}^{-1}$ ) was from 110-19.74-50.8kg  $ha^{-1}N_2/S_2 /P_2O_5$ . This indicated that as the rate of fertilizer increased the size of the tuber increased which might be due to initiation of more vegetative growth that resulted production of more photo-assimilate to be translocated to the tubers and decreased the number and yield of unmarketable tubers (Grant et al., 2001; Nasreen et al., 2003; Brady and Weil, 2008).

The overall combined data showed that increased level of nitrogen and phosphorous fertilizer from 0 to 110  $N_2$  with 90 kg  $ha^{-1} P_2O_5$  increased the marketable yield by 131% (Table 5). Moreover, addition of 20 kg sulfur over this (110-90  $N_2 /P_2O_5$ ) raised the marketable yield by 153%. Similarly, the overall combined result revealed that 86.6% total yield increment was due to increase in the application of 0 to 110-19.74-50.8 kg  $ha^{-1}N_2/S_2 /P_2O_5$  followed by 69.5% from application of 110 kg  $N_2$  with 90 kg  $P_2O_5 ha^{-1}$ . Even application of 9.87 kg  $ha^{-1}S_2$  with 55-25.5 kg  $ha^{-1}N_2 P_2O_5$  increased the total yield by 40.47%. The probable reason for increased in tuber yield with increasing sulfur levels might be attributed to its role in better partitioning of the photo-assimilates in the shoot and tubers (Sud and Sharma, 2002). Another probable reason might be due to addition of phosphorus which enhances development of roots particularly lateral and fibrous rootlets which in turn contributed in nutrient absorption, photosynthesis and general physiological processes. According to the report of Mahmoodabad et al. (2010) and Sharma and Arora (1987), increment of nitrogen fertilizer rate resulted in more tuber yield but excessive rate of nitrogen ( $250 \text{ kg ha}^{-1}$ ) and decreased the total number of tubers per unit area and yield, since high amount of nitrogen encourage vegetative growth more than tuber growth.

The present investigation is in line with those of Singh et al. (2016) that reported application of nitrogen and sulfur fertilizer resulted a significant increment on marketable and total tuber yield. Similarly, Sharma et al. (2011) reported that application of sulfur fertilizer resulted significant differences on yield and raising the level 0 to 45kg/ha increased total tuber yield per plant by 32.55%. Also, Zelalem et al. (2009) reported similar response of potato with application of nitrogen and phosphorous fertilizers.

In the present study, the type and rate of fertilizer significantly affected average weight of a tuber. The

minimum average weight of tuber at both locations was obtained from unfertilized treatment. The overall combined result reveal that application of 110-19.74-50.8 kg/ha  $N_2/S_2 /P_2O_5$  provided the maximum average tuber weight (63.29 gm/tuber) followed by 110-90 kg  $ha^{-1}N_2/P_2O_5$ . Moreover, application of 9.87 kg  $ha^{-1} S_2$  with 55-25.4kg  $ha^{-1}N_2/P_2O_5$  doubled the size of average tuber weight as compared with unfertilized plant. The current result is in conformity with the work of Israel et al. (2012) who reported an increase in nitrogen and phosphorous fertilizer revealed significant contribution to increase in total tuber yield and advanced to get larger average tuber weight. Similarly, Barczak et al. (2013) reported that sulfur fertilizer contributed for a significant increment of potato tuber yield through enlarging tuber weight during a three-year research.

### Partial budget analysis

As indicated in Table 6, except treatments combinations of 0-0-0, 55-9.87-25.4, 110-0-0 and 110-19.74-50.8 N-S-P Kg  $ha^{-1}$ , all the other treatments were dominated. This means the net benefit that was obtained from these treatments was lower than the net benefit obtained from the treatments with lower variable cost and there was no proportional increment in the net benefit with increase in variable cost.

The partial budget analysis revealed that application of nitrogen, sulfur and phosphorous fertilizer gave the high gross profit, net return and marginal rate of return compared to the control. The highest net benefit (134,500 birr/ha) and marginal rate of return (4453.6%) were obtained from the combination of the tree nutrient application at the rate of 110-19.74-50.8N-S-P Kg  $ha^{-1}$  followed by 55- 9.87- 25.4 N-S-P Kg  $ha^{-1}$  which had 2264.8% marginal rate of return. The results showed that the rate of 110 Kg  $ha^{-1}$  with 90 Kg  $ha^{-1}$  were dominated (D) by 110-19.74-50.8N-S-P Kg  $ha^{-1}$  indicating that the former level and composition of treatment was less profitable than the later. The fertilizer rates of 110-19.74-50.8 N-S-P Kg  $ha^{-1}$  was proved to be the superior and economically viable for potato production that can be recommended for farmers in the area.

### Conclusion

The two-year and two location research showed that the application of nitrogen, sulfur and phosphorous significantly increased the potato tuber yield as compared to the control. Application of 110-19.74-50.8 kg/ha  $N_2/S_2 /P_2O_5$  fertilizer delayed days to flowering and days to maturity by 8 and 11 days at Darark and 10 and 14 days at Dabat, respectively. However, it had positive and significant effect to increase plant height and number of stem per plant, which may have positive contribution to

**Table 6.** Partial budget analysis data for the combined fertilizer rate.

Treatment combination (Nitrogen-sulfur-phosphorous)	Average Yield (Kg/ha)	Adjusted yield (Kg/ha)	Gross field benefit	cost of Fertilizer	Cost Fertilizer application (Labor)	Cost for fertilizer transport	Total variable cost	Net Benefit	Marginal net benefit	Marginal variable cost	Marginal rate of return
0-0-0	12150	10935	54675	0	0	0	0	54675			
55-9.87-25.4	22240	20016	100080	1650	180	90	1920	98160	43485	1920	2264.8
55- 0- 45	17710	15939	79695	2248	240	110	2598	77097 <sup>d</sup>			
0-0- 90	20810	18729	93645	2300	240	120	2660	90985 <sup>d</sup>			
110-0- 0	23100	20790	103950	2625	300	150	3075	100875	2715	1155	235.06
55-0- 90	20900	18810	94050	2849	300	150	3299	90751 <sup>d</sup>			
110-19.74-50.8	30740	27666	138330	3300	360	170	3830	134500	33625	755	4453.6
110- 0- 45	22950	20655	103275	3346	360	180	3886	99389 <sup>d</sup>			
110-0- 90	28110	25299	126495	3398	330	170	3898	122597 <sup>d</sup>			

Price of UREA=1050 birr qt<sup>-1</sup>; NPS =1100 birr qt<sup>-1</sup>; DAP= 1150 birr qt<sup>-1</sup>; Field price of Potato = 500 qt<sup>-1</sup>; d=dominated.

increase size of photosynthetic area. Moreover, overall combined result revealed 153% increment of marketable tuber yield and the total tuber yield by 86.6% as compared to unfertilized. In addition, this rate and type of fertilizer increased the number of marketable tuber by 106.7% and provided lesser yield and number of unmarketable tuber, which has direct economic value for the benefit of the farmers as well as the consumer. On the other hand, the highest marginal rate of return (4453.6 %) was found from this fertilizer combination and rate. Therefore, the current result use of 110-19.74-50.8 kg/ha N<sub>2</sub>/S<sub>2</sub>/P<sub>2</sub>O<sub>5</sub> provided better yield and can be used at Dabat, Dabark and similar agro ecologies.

## ACKNOWLEDGEMENTS

The authors are grateful for the contributions of the University of Gondar of funds and facilities to conduct the research. The authors thank Dabat and Dabark district Agriculture office, the experts

and the participating farmers for their cooperation in the project.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

## REFERENCES

- Adane H, Miranda PMM, Agajie T, Willemien JML, Alfons OL, Admasu T, Paul CS (2010). Analysis of Seed Potato Systems in Ethiopia. *American Journal of Potato Research* 87(6):537-552.
- Barczak B, Nowak K, Knapowski T (2013). Potato yield is affected by sulphur form and rate. *Agrochimica* 57(4):363-372.
- Brady NC, Weil RR (2008). The nature and properties of soils. 14th ed. Pearson Prentice Hall, NJ.
- CIMMYT (1998). From Agronomic Data to Farmer Recommendations: An Economics Training Manual. Completely revised edition. D.F.Maxico.
- Central Statistical Agency (CSA) (2016). Agricultural sample survey on crop and livestock product utilization. Statistical Agency, The Federal Democratic Republic of Ethiopia

Central, Addis Ababa, Ethiopia. <http://www.csa.gov.et/survey-report/category/347-eth-agss-2016>

- Food and Agriculture Organization (FAO) (2016). statistical databases FAOSTAT <http://faostat3.fao.org/>.
- Gebremedhin W, Endale G, Kiflu B, Lemaga B (2001). Country profile on Potato production and utilization: Ethiopia. Ethiopian Agricultural Research Organization, Holeta Agricultural Research Centre, Holeta, Ethiopia.
- Gebremedhin W, Endale G, Lemaga B (2008). Potato variety development. In *Root and tuber crops: The untapped resources*, ed. W. Gebremedhin, G. Endale, and B. Lemaga, 15-32. Addis Ababa: Ethiopian Institute of Agricultural Research.
- Grant CA, Flaten DN, Tomasiwicz DJ, Sheppard SC (2001). The importance of early season phosphorus nutrition. *Canadian Journal of Plant Science* 81:211-224.
- Henao J, Baanante C (1999). Estimating rates of nutrient depletion in soils of agricultural lands of Africa. International Fertilizer Development Center, Muscle Shoals, AL.
- Israel Z, Ali M, Solomon T (2012). Effect of different rates of nitrogen and phosphorus on yield and yield components of Potato (*Solanum tuberosum* L.) at Masha District, southwestern Ethiopia. *International Journal of Soil Science* 7:146-156.
- Jamaati-e-Somarin S, Hokmalipour S, Shiri-e-Janagrad M, Abbasi A (2009). Vegetative growth of potato (*Solanum tuberosum* L.) cultivars under the effects of different level of nitrogen fertilizer. *Journal of Biological Science* 4(7):807-



- 814.
- Klikocka H (2004). Sulphur fertilization of potato. *Fragmenta Agronomica* 21(3):80-94. (in Polish).
- Klikocka H (2005). The influence of sulphur fertilization on the yield value and infection rate of potato tubers by *Streptomyces scabies* and *Rhizoctonia solani*. *Fragmenta Agronomica* 4:38-50. (in Polish).
- Lalitha BS, Nagaraj KH, Anand TN (2002). Effect of source propagation, level of potassium and sulphur on potato (*Solanum tuberosum* L.). *Mysore Journal of Agricultural Sciences* 36:148-153.
- Lutaladio N, Castaldi L (2009). Potato: The hidden treasure. *Journal of Food Composition and Analysis* 22(6):491-493.
- Mahmoodabad R, Jamaati S, Khayatnezhad M, Gholamin R (2010). Quantitative and qualitative yield of Potato tuber by use of nitrogen fertilizer and plant density. *American-Eurasian Journal of Agriculture and Environmental Sciences* 9(3):310-318.
- Melkamu A, Minwelet J (2018). Optimum rates of NPS fertilizer application for economically profitable production of potato varieties at Koga Irrigation Scheme, Northwestern, Ethiopia. *Cogent Food and Agriculture Cogent Food and Agriculture* 4(1): (doi: 10.1080/23311932.2018.1439663).
- Mojtaba SY, Mohammadreza HS, Mohammad TD (2013). Effect of nitrogen fertilizer and vermicompost on vegetative growth, yield and NPK uptake by tuber of potato (Agria cv.) *International Journal of Agriculture and Crop Sciences* 5(18):2033-2040.
- Mulatu E, Ibrahim O, Bekele E (2005). Improving Potato seed tuber quality and producers livelihoods in Hararghe, Eastern Ethiopia. *Journal of New Seeds* 7(3):31-56.
- Mulubrhan H (2004). The effects of nitrogen, phosphorus and potassium fertilization on the yield and yield components of potato (*Solanum tuberosum* L.), grown on vertisols of Mekelle area Ethiopia. School of Graduate Study, Alemaya University, Ethiopia, MS Thesis.
- Munoz F, Mylavarapu RS, Hutchinson CM (2005). Environmentally responsible potato production systems. *Journal of Plant Nutrition* 28:1287-1309.
- Nasreen S, Haq SMI, Hossain MA (2003). Sulphur effects on growth responses and yield of onion. *Asian Journal of Plant Sciences* 2:897-902.
- Rosen CJ, Bierman PM (2008). Potato yield and tuber set as affected by phosphorus fertilization. *American Journal of Potato Research* 85(2):110-120.
- SAS (2008). SAS/STAT. 9.2 computer software. Cary, NC: SAS Institute Inc., USA. [https://www.sas.com/en\\_us/software/stat.html](https://www.sas.com/en_us/software/stat.html)
- Sharma DK, Kushwah SS, Nema PK, Rathore SS (2011). Effect of sulphur on yield and quality of Potato (*Solanum tuberosum* L.). *International Journal of Agricultural Research* 6(2):143-148.
- Sharma SP, Sandhu AS, Bhutani RD, Khurana SC (2014). Effects of planting date and fertilizer dose on plant growth attributes and nutrient uptake of potato (*Solanum tuberosum* L.). *International Journal of Agricultural Sciences* 4(5):196-202.
- Sharma VC, Arora BR (1987). Effects of nitrogen, phosphorus, and potassium application on the yield of potato (*Solanum tuberosum* L.) tubers. *Journal of Agricultural Sciences* 108:321-329.
- Singh H, Madhu S, Aakash G, Monika B (2016). Effect of Nitrogen and Sulphur on Growth and Yield Attributes of Potato (*Solanum tuberosum* L.). *International Journal of Plant and Soil Science* 9(5):1-8.
- Sud KC, Sharma RC (2002). Sulphur needs of potato under rainfed conditions in Shimla hills, In: Paul SM, Khurana G, Shekhawat S, Pandey SK, Singh BS (eds.). *Potato global research and development*, Indian Potato Association, Shimla, India pp. 889-899.
- Tamirie H (1989). Increasing agricultural production in Ethiopia through improved soil. *Water and crop management practices* pp. 243-275. In: Belshaw, D.G.R. (ed.). *Towards a food and nutrition strategy for Ethiopia*. Proceedings National Workshop on Food Strategies for Ethiopia. Addis Ababa, Ethiopia.
- Trehan SP, Dessougi HEL, Claassen N (2005). Potassium efficiency of 10 potato cultivars as related to their capability to use nonexchangeable soil potassium by chemical mobilization. *Communications in Soil Science and Plant Analysis* 36:1809-1822.
- Westermann DT (2005). Nutritional requirements of potatoes. *American Journal of Potato Research* 82:301-307.
- Zelalem A, Takalign T, Nigussie D (2009). Response of potato (*Solanum tuberosum* L.) to different rate of nitrogen and phosphorus fertilization on vertisols at Debre Birhan, in the central highlands of Ethiopia. *African Journal of Plant Science* 3:16-24.

## Related Journals:

