International Journal on Food, Agriculture, and Natural Resources
Volume 05, Issue 02, Page 111-117
ISSN: 2722-4066
http://www.fanres.org

Original Paper

Potassium, Zinc, and Boron Nutrients Effect on Sorghum (Sorghum bicolor L. Moench) Yield in Wag-Lasta, Northern, Ethiopia

Tilahun Esubalew[1], Workat Sebnie[1]*
1) Sekota Dryland Agricultural Research Center, P. O. Box 62 Sekota, Ethiopia
**) Corresponding Author: tilahun1215@gmail.com*

Received: 11 April 2024; Revised: 01 June 2024; Accepted: 24 June 2024
DOI: *https://doi.org/10.46676/ij-fanres.v5i2.323*

Abstract*— In Ethiopia using inorganic fertilizer started in the early 1970s. But it still depended solely on urea and DAP. Today, according to ATA and Ministry of Agriculture and Natural Resources K, Zn, B, S, and Cu are in deficit in Ethiopia and Amhara Region as well as in Wag-Lasta areas. But some studies conducted in Wag-Lasta and throughout the region in different crops indicate that these nutrients had no response on crop yields. So, this experiment was conducted in 2017 rain feed cropping season on five farmers' parcels per location to verify the response of sorghum to potassium, zinc, and boron nutrients. The treatments were: NPS, NPSK, NPSZnB, and NPSZnBK, with the recommended rate of 46 and 23 kg ha-1 N and P2O5, respectively for Sekota, 23 kg ha-1 N, and P2O5 for Lasta. Moreover, 150, 1.47, and 0.07 kg ha-1 KCl, Zn, and B, respectively used uniformly in both locations. The experiment was laid out in randomized complete block design (RCBD) with three replications. The collected data were analyzed by SAS software version 9.0. Analysis of variance revealed that the application of potassium, zinc, and boron had no significant effect ($P \leqslant 0.05$) on sorghum yield and yield components at all sites. The exchangeable potassium content in the soil of the study sites is above the critical value level. The result disagrees with the soil fertility map which showed more than 98% of potassium deficiency and more than 80% NPSZnB deficiency. Hence, the application of K, Zn, and B nutrients had no yield advantage over the recommended N and P nutrients in the Wag-Lasta areas. Therefore, currently to increase production and productivity of crops in Wag-Lasta areas using of recommended rate of nitrogen and phosphorous with organic fertilizer sources for each district is the best option rather than using K, Zn, and B nutrients.

***Keywords*— Boron, Grain yield, Potassium, Sorghum, Zinc**

I. INTRODUCTION

Agriculture is the main king of Ethiopia's economy, accounting for 34% of GDP and 85% of employment [1]. However, the sector is not effective due to low soil fertility and inappropriate nutrient management practice. Sorghum (Sorghum bicolor (L.) Moench) is a viable food grain for many of the World's most food-insecure people who live in marginal areas with poor and erratic rains and poor soils [2-3]. In Ethiopia, sorghum is a major staple food crop, ranking second after maize in total production. It ranks third after wheat and maize in productivity per hectare, and after teff and maize area cultivated. It is grown in almost all regions of Ethiopia, In Sekota and Lasta districts the crop is dominant. Sorghum production and productivity have been far below the potential. Currently, the average regional productivity is 2448 kg ha-1, but, in the Waghimera zone, it was 1520 kg ha-1 [4]. The reasons were poor soil fertility, moisture stress, and inappropriate inorganic fertilizer rate [5-6].

In Ethiopia, fertilizer use had been started since the early 1960s [7]. In the past three decades, Ethiopian agriculture depended solely on imported fertilizer products of urea and di-ammonium phosphate (DAP), sources of N and P. Today, according to [8] soil fertility inventory conducted in some woredas of the country and the region from 2012-13 not only N, and P but also K, S, B, Cu, and Zn nutrient deficiencies are widespread. The fertility map of Wag-Lasta indicates that nearly 80 % NPSZnB, 47% NPSB, and 98% K were deficit in the area. However, the result of diagnostic nutrient omission trial conducted in Dehana and Lasta districts on wheat and teff and the validation studies on new fertilizers across the region for different crops indicated that potassium,and zinc, and boron new fertilizers did not affect the yields of the studied crops [9-10]. Potassium, zinc, and boron nutrients are required and indispensable for crop optimum growth, development, and production [11]. However, in Wag-Lasta these nutrients had no significant effect on crop yield due to the areas' soil had a high amount of exchangeable potassium amount. But the extension agent widely distributes NPSB, Zn, NPSZnK, SPSZnBK fertilizers to the farmers, which expose users to extra cost. Therefore, the study was conducted to verify the response of sorghum to potassium, zinc, and boron fertilizers application and to validate the soil fertility map developed by the Ethiopian soil information system (EthioSIS).

II. MATERIALS AND METHODS

A. Description of the Study Area

The research was conducted in 2017 rain fed cropping season in Sekota and Lasta districts in 8 kebeles at 8 farmers' fields, located in Amhara National regional State, Ethiopia. The sites founed 12^{0}43’38’’N longitudinal and 39^{0}01’08’’E latitude with the altitude of 1915 meter, 12^{o} 43’ 52.82’’N longitude and 39^{o} 01’22.01’’E with an altitude of 1915 for Sekota district, 11^{o} 58’ 50.15’’ N longitude and 38^{o} 59’ 03.22’’E latitude with the altitude of 1966 meters above sea level, respectively. The district is semi-arid and the undulating land feature has a unimodal rainfall distribution system occurring in July, and August. The mean annual rainfall was 673.7 and 818.1 mm, with maximum and the minimum average temperature of 27.22^{0}c, 12.77 ^{0}c and 24.7 ^{0}c, 13.6 ^{0}c for Sekota and Lalibela, respectively.

In the Wag-Lasta areas, the crop-livestock mixed farming system has been dominantly practiced. The major grown crops are wheat (*Triticum aestivum L.),* sorghum (*Sorghum bicolor L.),* tef (*Eragrostis tef (Zucc) Trotter*), barley (*Hordeum vulgar L*), and faba bean (*Vicia faba L*.). The livestock productions are beekeeping, cattle, sheep, goat, donkey, and poultry. Soil types are: -Cambisols, Eutric Regosols, Nitosols, Vertisols, Leptosols and Orthic solonchaks. Among them Eutric Cambisols are the dominant for Sekota. In Lasta Eutric Cambisols, eutric Regosols, Leptosols and vertic Cambisols among them Eutric Cambisols and Vertic Cambisols cover most part of Lasta.

B. Experimental Design and Treatments

The treatments were NPS, NPSK, NPSZnB, and NPSZnBK. N and P fertilizers amount adjusted by the recommendation rate of 46 and 23 kg ha^{-1} N and P_2O_5 for Sekota respectively, and 23 kg ha^{-1} for both N and P_2O_5 for Lasta district, murite potash applied by blanket recommendation of 150 kg ha^{-1} KCl, Zn, and B uniformly applied 0.7 and 1.47 kg ha^{-1} for all trial sites respectively. NPS, NPSZnB, and murite potash fertilizer were added at planting time while urea was added in split application half at planting and the remains half after 30 - 45 days planting at knee height. The experiment was laid out in randomized complete block design (RCBD) with three replications. The plot size was $18.75m^2$ (3.75 m X 5 m) and consisted of 5 rows. 1m distance was left for both between plots and blocks. Spacing of 75 and 15 cm was used between rows and plants respectively. The tested variety was Misker. All recommended agronomic crop managements were done for all treatments uniformly as it needed.

C. Data collection and analysis

The average plant height taking representative ten samples from each plot randomly and measured by tape meter from ground to tip of the head, length of sorghum head, grain yield was collected from central rows, while excluding border rows from each plot separately. The data obtained from this research were subjected to analysis of variance using SAS software version 9.0 and treatment effects were compared using the Fisher’s Least Significant Differences test at a 0.05 significant level.

Representative composite soil samples were collected from the surface (0-20 cm depth) at planting time from the trial sites, for the analysis of pH, EC, SOC, TN, available P, exchangeable K, S, and textural class. Each composite sample was made up of ten sub-samples. Finally, the analyzed soil data were interpreted to illustrate the current soil fertility status of each trial site. The chemical properties of soils in the experimental fields were determined using different appropriate analytical procedures of Soil in Sekota Dryland Agricultural Research Center and Tigray soil laboratory. Soil reaction (pH) was measured from filtered suspension of 1:2.5 soil to water ratio using a glass electrode attached to a digital pH meter. Soil organic carbon was determined following the wet digestion method as described by [12]. Soil organic carbon was determined following the wet digestion method [12]. Then soil organic matter was determined by multiplying soil organic carbon value by 1.724. Total nitrogen was determined by the micro-Kjeldahl digestion, distillation, and titration method [13]. Available phosphorus was determined following the Olsen method [14]. Exchangeable potassium was extracted by ammonium acetate at pH 7 method [13]. Sulfur is also determined by the Turbidity method and soil texture was determined by the bouyoucos hydrometer method [15-16].

TABLE1. SOIL DATA BEFORE PLANTING TIME

Site	**pH**	**EC**	**%OC**	**%TN**	**Avi.P PPM**	**Exch.K cmolkg^{1}**	**S in PPM**	**Textural class**
Tiya	6	0.12	0.80	0.03	4.79	1.26	6.53	sandy loam
Q/Abeba	6.1	0.14	0.49	0.05	23.24	0.86	7.82	sandy loam
shumsha	5.8	0.14	0.49	0.04	15.68	1.35	5.34	sandy clay loam
Rubariya	5.8	0.12	0.45	0.04	7.43	0.85	5.02	sandy loam
Woleh	5.8	0.14	0.37	0.04	7.37	0.84	6.74	lomy sand

III. RESULTS AND DISCUSSION

A. *Soil analysis result at planting*

The soil analysis data was important to identify the level of nutrients in the soil and to determine suitable rates and types of fertilizer for the recommendation. The average soil pH of the trial sites was 5.92, according to [17] it was moderately acidic. Based on the results of soil analysis as shown above, in Table 1, the average total nitrogen (%TN) ranges from 0.02-0.05, based on [17] it was categorized under very low and low. Besides, the available phosphorus (Av. P) was ranged from 4.79-23.24 PPM, based on [18] grouped under very low, low, medium, and high class. Moreover, soil organic carbon (%OC) of the trial site was ranging from 0.37 - 0.8, as [17], it was very low and low, so improving soil organic amount needs immediate actions through applying organic fertilizers sources like organic manure, compost, crop residue retention, and crop rotation [19-20]. Soil textural class was also sandy loam, sandy clay loam, and loamy sand both of them were good for crop production activities but due to its high capacity of infiltration rate, it couldn't store water for a long time in dryland areas. The exchangeable potassium of the trial site ranged from 0.84-1.35, according to [21] it is very high and high.

TABLE II. EFFECT OF K, ZN, AND B NUTRIENTS ON PH AND HL OF SORGHUM IN SEKOTA DISTRICT

	Fikreselam		**Rubariya**		**Tiya**		**Woleh**	
Trts.	***PH.cm***	***HL.cm***	***PH.cm***	***HL.cm***	***PH.cm***	***HL.cm***	***PH.cm***	***HL.cm***
NPS	157.97	18.56	164.07	18.4	134.65	17.33	147.8	21.07
NPSK	152.17	17.88	160.07	18.46	142.05	16.81	155.48	19.87
NPSZnB	158.22	18.24	166.17	20.4	141.2	17.46	150.4	21
NPSZnBK	149.12	18.46	156.27	17.92	138.18	17.13	158.12	19.51
LSD 5%	NS	NS	NS	NS	NS	NS	NS	NS
CV	2.62	2.48	3.1	4.02	2.84	1.48	7.8	5.6

Where: Trts presents treatment, PH refers plant height, HL stands for head length, NS represents non significant.

TABLE III. EFFECT OF K, ZN, AND B NUTRIENTS ON GRAIN YIELD OF SORGHUM IN SEKOTA DISTRICT

	Fikreselam	**Rubriya**	**Tiya**	**Woleh**
Trts	***GY Kg ha^{-1}***	***GY Kg ha^{-1}***	***GY Kg ha^{-1}***	***GY Kg ha^{-1}***
NPS	1480	2670	1420	3230
NPSK	1370	2560	1570	3070
NPSZnB	1240	2610	1460	2910
NPSZnBK	1230	2400	1450	3100
LSD 5%	NS	NS	NS	Ns
CV	5.87	4.5	4.01	4.8

Where: GY refers to grain yield

TABLE IV. EFFECT OF K, ZN, AND B NUTRIENTS ON PH AND THE HL OF SORGHUM IN LASTA DISTRICT.

	GENET MARIAM		**QECHN ABEBA 1**		**QECHN ABEBA2**		**SHUMSHA**	
	PH.cm	***HL.cm***	***PH.cm***	***HL.cm***	***PH.cm***	***HL.cm***	***PH.cm***	***HL.cm***
NPS	159.39a	18.83	140.47	18.82	131.1	17.4	158.4	21.26
NPSK	146.27b	17.93	146.47	20.16	131.3	16.16	171.31	22.53
NPSZnB	146.47b	17.33	143.27	17.36	126.36	17.4	164.91	22.26
NPSZnBK	147.53b	17 43	145.87	18.9	132.84	17.2	149.96	18.58
LSD 5%	7.4	NS	NS	NS	NS	NS	16.05	NS
CV	6.9	3.68	2.6	4.4	2.31	2.82	2.75	9.1

TABLE V. EFFECT OF K, ZN, AND B NUTRIENTS ON GRAIN YIELD OF SORGHUM AT LASTA DISTRICT

Trts.	**Genet Mariyam**	**Qechn abeba1**	**Qechn abeba2**	**Shumsha**
	GY kg ha^{-1}	***GY kg ha^{-1}***	***GY kg ha^{-1}***	***GYkg ha^{-1}***
NPS	1710a	1080	1200	3300
NPSK	1040b	1240	860	4010
NPSZnB	940b	910	940	2860
NPSZnBK	1406a	1140	1090	3160
LSD 5%	0.3	NS	NS	NS
CV	8.4	11.75	14.16	8.43

B. Plant height and head length

Potassium, zinc, and boron nutrients had no significant effects, among and between treatments on plant height and head length of sorghum in Sekota and Lasta districts at ($p \leq 0.05$) Table 2 and 4. Thus the resulting matched with soil analysis results as mentioned in Table 1. When the available K in the soil was deficient or not supplied adequately, the growth would be stunted. But the amount of readily available (exchangeable) potassium in the soil to provide the crop was high. This result was in line with [10-11]. Furthermore, zinc and boron have a great role in plant growth and development. However, in the case of these experimental fields, it had no significant effect on plant height and head length. It might be due to the soil full filling the required amount of Zn, and B for sorghum. This result agreed with [10,22-24] who reported that K fertilizer application had no significant effect on crop growth parameters of sorghum, maize, wheat, potato and tef in northwestern, southern, and northeastern, Ethiopia. Though, it was contradicted with [25-27] who reported that K had a response on maize and wheat agronomic parameters. Similarly, it disagreed with [28-29] who reported that boron and potassium fertilizers had a significant effect on sorghum height.

C. Grain yield

The application of K, Zn, and B nutrients did not significantly affect grain yield in Sekota and Lasta districts (Tables 3 and 5). The highest grain yield was obtained from the application of NPS nutrient in most experimental fields. Whereas the lowest yield was recorded from K, Zn, and B combined with NPS. This might be due to the overdose applications of these nutrients. This finding positively correlated with soil analysis data of experimental fields as illustrated above in Table1. Although the overall yield except for Shumsha, Rubariya, and Woleh sites was low due to low soil fertility status and moisture deficit problems. But the yield was equal with [4,30] results. Shumsha and Rubariya sites yield similar to [6] who found 3822 and 2959 kg ha^{-1} by using 23 kg N ha^{-1} and P_2O_5 for Shumsha, and 46 and 23 kg N ha^{-1} and P_2O_5 for Rubaria. There were yield variations among sites due to soil fertility variation.

K, Zn, and B has a role in growth, development, yield increment, diseases resistance, formation of different enzymes for crops [31] but in the wag-Lasta areas it had no yield advantage on sorghum, rather than the recommended rate of nitrogen and phosphorous nutrients. This might be due to the soil having enough (high) amount of exchangeable potassium, the current result of this research was agreed to the diagnostic nutrient omission trial result of [10, 32]. Similarly, the current finding in line with Wag-Lasta areas results using 72 kg K_2O, ha^{-1} had no significant effect on teff and wheat yield. Also, this finding is in line with [33], who investigated potato tuber yield had no response for K fertilizer application in western Amhara Region, Ethiopia. Similarly, it was agreed with [24] who reported that the application of 150 kg KCl ha^{-1} had no yield increment advantage on sorghum, bread wheat, and food barley crops in the north Shewa zone of Amhara region, Ethiopia. Simultaneously, [22] reported that adding different rate levels of K fertilizer had no potato tuber yield increment in southern Ethiopia.

The finding of this research contradicted with soil fertility map of the Sekota and Lasta districts, developed by ATA and the ministry of Agriculture and Natural Resources. It showed more than 98% of potassium deficiency and more than 80% NPSZnB deficiency. But, this study proves that K Zn and B nutrients are not a deficit in Wag-Lasta districts, rather they are at adequate amount to provide for crop optimum growth, development, and yield in the areas as shown in Table 1. This study result was contrasting with [34] who reported that Zn is optimal and B below the critical level in Alicho-Woriro, woreda, Siltie zone, Southern Ethiopia. Simultaneously, it was disagreed with [26-27] who reported K nutrient had a yield advantage on wheat in southern, Ethiopia. However, this finding disagreed with [35-36], who reported that NPKSZn, NPK, and NPSZn had yield advantage by melkam variety of sorghum than NP fertilizer in Tigray Region, Ethiopia. Similarly, [37] who found using 120 kg ha^{-1} K_2O increased onion yield in Jimma, Southwestern Ethiopia. On the other hand [38-39] examined that Foliar application of 1% Zn and 0.5% B had to pronounce results on maize yield and boron 2 kg ha^{-1} recorded more grains spike^{-1}, higher grain weight, and increased grain yield of wheat.

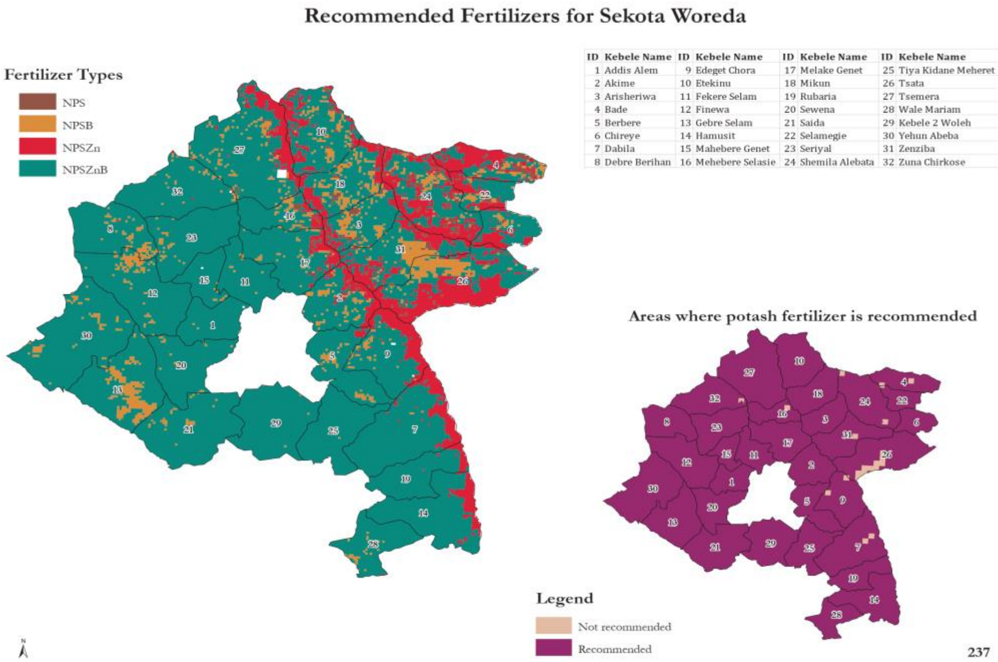

Fig. 1. Soil fertility map of Sekota district developed by Ethioian Agricultural Transformation Agency

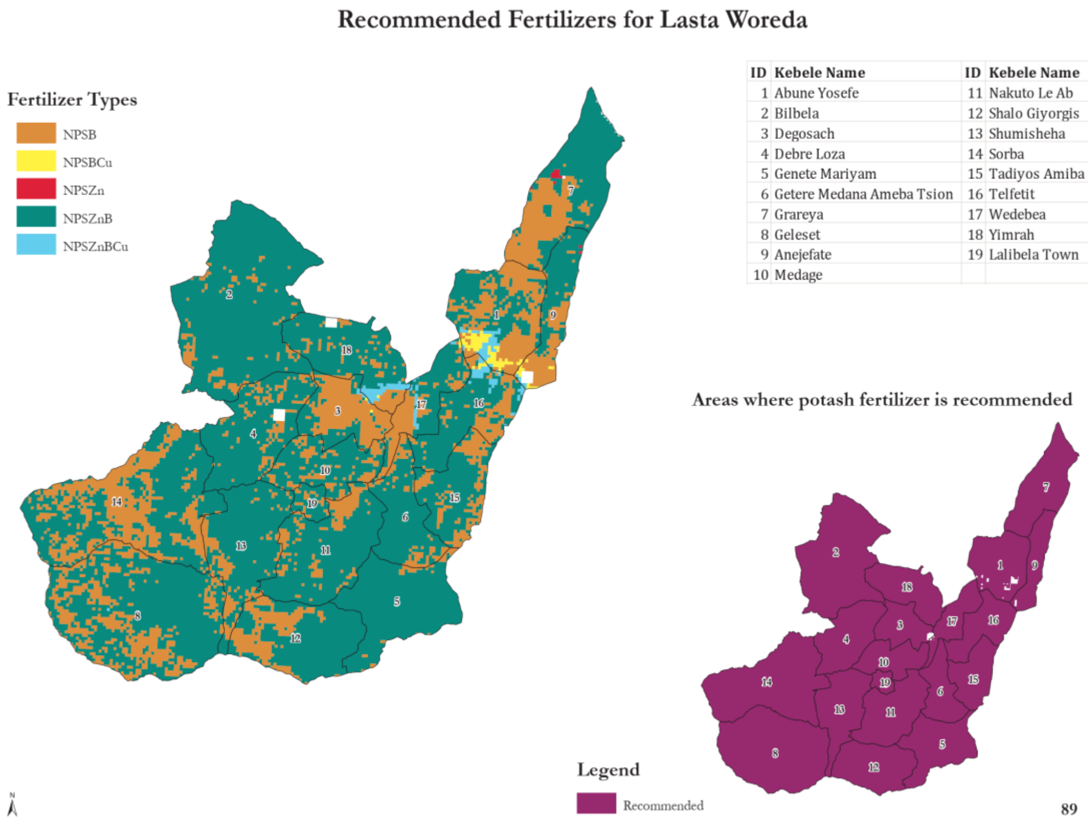

Fig. 2. Soil fertility map of Lasta district developed by Ethioian Agricultural Transformation Agency.

IV. Conclusions And Recommendations

Application of K Zn and B nutrients had an insignificant effect on plant height, head length, and grain yield of sorghum, in Sekota and Lasta districts. In most trial sites yields obtained from NPS nutrient containg fertilizer are better than NPSK NPSZnB and NPSZnBK, as a result, these nutrients had no yield advantage in the districts because the districts' soil has a sufficient amount of exchangeable potassium for optimum crop production. Soil fertility maps of Sekota and Lasta district are unrelated to the current soil status of potassium zinc and boron nutrient content. Currently to increase production and productivity of sorghum in Wag-Lasta areas using of recommended rate of nitrogen and phosphorous with organic nutrient sources for each district is the best option rather than using K Zn and B nutrients, and the effect of K Zn Cu B and other essential nutrients should be checked regularly as they will be expected deficit from the soil in the long run.

Acknowledgment

Researchers of this experiment express their deepest gratitude to the Amhara Agricultural Research Institute for funding the research work, and Sekota Dryland Agricultural Research Center for facilitating logistics during the research work.

References

[1] Baye TG. Poverty, peasantry and agriculture in Ethiopia. Annals of Agrarian Science. 2017 Sep 1;15(3):420-30.

[2] Muui CW, Muasya RM, Kirubi DT. Baseline survey on factors affecting sorghum production and use in eastern Kenya. African journal of food, agriculture, nutrition and development. 2013 Feb 8;13(1):7339-53.

[3] Okeyo SO, Ndirangu SN, Isaboke HN, Njeru LK. Determinants of sorghum productivity among small-scale farmers in Siaya County, Kenya. African Journal of Agricultural Research. 2020 May 31;16(5):722-31.

[4] Central Statistical Agency. Report on area and production of crops. Statistical Bulletin 578. Addis Ababa, Ethiopia. 2017.

[5] Amelework BA, Shimelis HA, Laing MD, Ayele DG, Tongoona P, Mengistu F. Sorghum production systems and constraints, and coping strategies under drought-prone agro-ecologies of Ethiopia. South African Journal of Plant and Soil. 2016 Jan 1;33(3):207-17.

[6] Sebnie W, Mengesha M. Response of nitrogen and phosphorus fertilizer rate for sorghum (Sorghum bicolor L. Moench) production in Wag-Lasta area of Ethiopia. Archives of Agriculture and Environmental Science. 2018.

[7] Murphy HF. A report on fertility status and other data on some soils of Ethiopia. Collage of Agriculture HSIU. Experimental Station Bulletin No. 44, College of Agriculture, Alemaya, Ethiopia: 1968, 551p

[8] Ministry of Agriculture and Natural Resources and Agricultural Transformation Agency of Ethiopia. Soil Fertility Status and Fertilizer Recommendation Atlas of Amhara National Regional State, Ethiopia: 2016, 297 pages

[9] Amare T, Feyisa T, G.selassie Y. Response of maize, malt barley, and tomato to potassium. In; Birru Yitaferu, Teshome Tessema, Zewdu Ayalew (eds.). Proceedings of the Third Annual Regional Conference on Completed Research activities on soil and water management, Forestry and Agricultural Mechanization 1-4 September 2008, Amhara regional agricultural research institute ARARI, Bahir Dar, Ethiopia, pp 67-75.

[10] Amare T, Bazie Z, Alemu E, Wubet A, Agumas B, Muche M, Feyisa T, Fentie D. Crops response to the balanced nutrient application in Northwestern Ethiopia. Amhara Agricultural Research Institute (Arari). 2018;17.

[11] Hasanuzzaman M, Bhuyan MH, Nahar K, Hossain M, Mahmud JA, Hossen M, Masud AA, Fujita M. Potassium: a vital regulator of plant responses and tolerance to abiotic stresses. Agronomy. 2018 Mar;8(3):31.

[12] Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil science. 1934 Jan 1;37(1):29-38.

[13] Sertsu S, Bekele T. Procedures for soil and plant analysis: Technical P. 74. National Soil Research Center, Addis Ababa Ethiopia, 2000.

[14] Watanabe FS, Olsen SR. Test of an ascorbic acid method for determining phosphorus in water and NaHCO3 extracts from soil. Soil Science Society of America Journal. 1965 Nov;29(6):677-8.

[15] Bouyoucos GJ. Hydrometer method improved for making particle size analyses of soils 1. Agronomy journal. 1962 Sep;54(5):464-5.

[16] Beverwijk A. Particle size analysis of soils by means of the hydrometer method. Sedimentary Geology. 1967 Jan 1;1:403-6.

[17] Tadesse T. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa, Ethiopia. 1991.

[18] Cottenie A. Soil and plant testing as a basis of fertilizer recommendations. FAO Soil Bulletin 38/2. Food and Agriculture Organization of the United Nations, Rome, Italy. 1980.

[19] Araya H. The effect of compost on soil fertility Enhancement and yield increment under smallholder farming, The case of Tahtai-Maichew district-Tigray region, Ethiopia, University of Hohenheim, Germany. Doctor, University of Hohenheim. (2010).

[20] Tulema B. Integrated plant nutrient management in crop production in the central Ethiopian highlands (Doctoral dissertation, Norwegian University of Life Sciences) 2015.

[21] FAO (Food and Agriculture Organization). Plant nutrition for food security: A guide for integrated nutrient management. FAO, Fertilizer, and Plant Nutrition Bulletin 16, Rome, Italy. 2006;16:368.

[22] Ayalew A, Beyene S. 2011. The influence of potassium fertilizer on the production of potato (Solanum tuberosum L.) at Kembata in southern Ethiopia. J Biol Agri Healthcare. 2011;1(1):1-3.

[23] G.selassie Y, Molla E, Muhabie D, Manaye F, Dessie D. (2020) Response of crops to fertilizer application in volcanic soils. Heliyon, 2020 Dec 1;6(12):e05629.

[24] Kassie K, Shewangizaw B, Lema G, Getaneh L, Tay G., Tigabie A. On-farm Verification of Potassium Fertilization for Major Cereal Crops under Balanced Fertilizers in North Shew Zone of Amhara Region, Ethiopia. Research Sequare. 2019. DOI: https://doi.org/10.21203/rs.2.16920/v1.

[25] Markos A, Haile W, Worku W. 2015. Response of maize (zea mays L.) to potassium fertilizer at Hadero, southern Ethiopia. 2015 Nov 24-26. DOI:10.13140/RG.2.1.2915.9443.

[26] Brhane H, Mamo T, Teka K. Potassium fertilization and its level on wheat (Triticum aestivum) yield in shallow depth soils of Northern Ethiopia. J Fertil Pestic. 2017;8(2):1000182.

[27] Tesfaye T, Laekemariam F, Habte A. Response of Bread Wheat (Triticum aestivum L.) to Potassium (K) and Blended NPS Fertilizer Rates in the Nitisols of Southern Ethiopia. Applied and Environmental Soil Science, 2021.

[28] Pholsen S, Sornsungnoen N. Effects of nitrogen and potassium rates and planting distances on growth, yield and fodder quality of a forage sorghum (Sorghum bicolor L. Moench). Pak. J. Biol. Sci. 2004;7(10):1793-800.

[29] Bayu W, Rethman NF, Hammes PS, Alemu G. Effects of farmyard manure and inorganic fertilizers on sorghum growth, yield, and nitrogen use in a semi-arid area of Ethiopia. Journal of plant nutrition. 2006 Feb 1;29(2):391-407.

[30] Assefa A, Bezabih A, Girmay G, Alemayehu T, Lakew A. 2020. Evaluation of sorghum (Sorghum bicolor (L.) Moench) variety performance in the lowlands area of wag lasta, north eastern Ethiopia. Cogent Food & Agriculture. 2020 Jan 1;6(1):1778603.

[31] Brady NC, Weil RR, Weil RR. The nature and properties of soils. Upper Saddle River, NJ: Prentice Hall; 2008.

[32] Amare T, Feyisa T, G.selassie Y. Response of maize, malt barley, and tomato to potassium. In; Birru Yitaferu, Teshome Tessema, Zewdu Ayalew (eds.). Proceedings of the Third Annual Regional Conference on

Completed Research activities on soil and water management, Forestry and Agricultural Mechanization 1-4 September 2008, Amhara regional agricultural research institute ARARI, Bahir Dar, Ethiopia, pp 67-75.

[33] G.selassie Y, Feyisa T, Amare T. Soil K status and K requirement of potato growing on different soils of western Amhara, Proceedings of the 2nd annual regional conference on completed natural resources management research activities (18-19 September 2007)

[34] Tilahun E, Kibret K, Mamo T, Shiferaw H. Assessment and mapping of some soil micronutrients status in agricultural land of Alicho-Woriro Woreda, Siltie Zone, Southern Ethiopia. American Journal of Plant Nutrition and Fertilization Technology. 2015;5(1):16-25.

[35] Gebrekorkos G, G.Egziabher Y, and Habtu S. Response of sorghum (Sorghum bicolor (L.) Moench) varieties to blended fertilizer on yield, yield component and nutritional content under irrigation in Raya valley, Northern Ethiopia. International Journal of Agriculture and Biosciences. 2017;6(3):153-62.

[36] Redai WG, Araya T, Egziabher YG. Effect of NPK and blended fertilizer application on Yield, Yield Component and its profitability of Sorghum (Sorghum bicolor (L.) Moench) varieties under rainfed condition in north western Tigray, Ethiopia. Int. J. of Life Sciences. 2018;6(1):60-8.

[37] Bekele M. Effects of different levels of potassium fertilization on yield, quality and storage life of onion (Allium cepa L.) at Jimma, Southwestern Ethiopia. J Food Sci Nutr. 2018; 1(2):32-9.

[38] Nadim MA, Awan IU, Baloch MS, Khan EA, Naveed K, Khan MA. Response of wheat (Triticum aestivum L.) to different micronutrients and their application methods. J. Anim. Plant Sci. 2012 Jan 1;22(1):113-9.

[39] Anjum SA, Saleem MF, Shahid M, Shakoor A, Safeer M, Khan I, Farooq A, Ali I, Nazir U. Dynamics of soil and foliar applied boron and zinc to improve maize productivity and profitability. Pakistan Journal of Agricultural Research. 2017 Sep 1;30(3).

[40]

[41] Sinsabaugh, R.L., Hill, B.H., and Shah, J.J.F.(2009). Eco enzymatic stoichiometry of microbial organic nutrient acquisition in soil and sediment. Nature 462, 795–798.doi: 10.1038/nature08632

[42] Allison SD, Vitousek PM (2005). Responses of extracellular enzymes to simple and complex nutrient inputs. Soil Biol Biochem 37:937–944

[43] Stone MM, Weiss MS, Goodale CL, Adams MB, Fernandez IJ, German DP et al (2012). Temperature sensitivity of soil enzyme kinetic sunder N-fertilization in two temperate forests. Global Change Biol 18:1173–1184

[44] Allison,S.D.(2005). Cheaters, diffusion and nutrients constrain decomposition by microbial enzymes in spatially structured environments. Ecol. Lett. 8, 626–635. doi:10.1111/j.1461-0248.2005.00756.x

[45] Blankinship, J. C., P. A. Niklaus, and B. A. Hungate. (2011). A meta-analysis of responses of soil biota to global change. Oecologia 165:553–565.

[46] Duan, B., Zhang, Y., Xu, G., Chen, J., Paquette, A., & Peng, S. (2015). Long-term responses of plant growth, soil microbial communities and soil enzyme activities to elevated CO2 and neighbouring plants. Agricultural and Forest Meteorology, 213, 91-101.

[47] Fierer N, Jackson RB (2006). The diversity and biogeography of soil bacterial communities. Proc Natl Acad Sci 103:626–631

[48] Wu Z, Dijkstra P, Koch GW, Pen˜uelas J, Hungate BA (2011). Responses of terrestrial ecosystems to temperature and precipitation change: a meta-analysis of experimental manipulation. Global Change Biol 17:927–942

[49] Andersen, R., Chapman, S. J., and Artz, R. R. E. (2013). Microbial communities in natural and disturbed peatlands: a review. Soil Biology and Biochemistry, 57, 979-994.

[50] De Vries, F. T., Griffiths, R. I., Bailey, M., Craig, H., Girlanda, M., Gweon, H. S., and Bardgett, R. D. (2018). Soil bacterial networks are less stable under drought than fungal networks. Nature communications, 9(1), 3033.

[51] Anderson JPE and Domsch KH (2010). A physiological method for the quantitative measurement of microbial biomass in soil. Soil Biol Biochem 2010:215–221

[52] Fierer N, Craine JM, McLauchlan K et al (2005). Litter quality and the temperature sensitivity of decomposition. Ecology 86:320–326

[53] Wang G, Post WM, Mayes MA (2013). Development of microbial-enzyme-mediated decomposition model parameters through steady-state and dynamic analyses. Ecol Appl 23:255–272

[54] Larionova A, Yevdokimov IV, Bykhovets SS (2007). Temperature response of soil respiration is dependent on concentration of readily decomposable C. Biogeosciences 4:1073–1081

[55] Joergensen RG (2010). Organic matter and micro-organisms in tropical soils. In: Dion P (ed) Soil biology and agriculture in the tropics. Springer, Berlin, pp 17–43

[56] Cardon ZG, Gage DJ (2006). Resource exchange in the rhizosphere: molecular tools and the microbial perspective. Ann Rev Ecol Evol Syst 37:459–488.

[57] Lauenroth WK, Bradford JB (2006). Ecohydrology and the partition- ing AET between transpiration and evaporation in a semiarid steppe. Ecosystems 9:756–767.

[58] Rey A and Jarvis P (2006). Modelling the effect of temperature on carbon mineralization rates across a network of European forest sites (FORCAST). Global Change Biol 12:1894–1908.