Integrated Use of Farmyard Manure and NPS Influenced Soil Chemical Properties, Yield and Yield Attributes of Sorghum (*Sorghum bicolor* L.) in Assosa District, Western Ethiopia

Tefera Teshome[1]*, Yibekal Alemayehu[2], and Alemayehu Regasa[3]

[1]College of Agriculture and Natural Resources, Assosa University, P.O. Box 18, Assosa, Ethiopia
[2]School of Plant Sciences, Haramaya University, P.O. Box 138, Dire Dawa, Ethiopia
[3]Department of Natural Resource Management, Jimma University, P.O. Box 307, Jimma, Ethiopia

Abstract

Background: Sorghum is the staple food crop in Assosa area and most important cereal crop next to teff and maize in Ethiopia. However, sorghum productivity is constrained by lack of improved agronomic practices, low soil fertility and associated low soil nutrient availability especially Nitrogen and Phosphorous deficiency and lack of integrated use of nutrient management practices.

Objective: The objective of this study was to increase sorghum production and productivity by optimizing integrated use of blended NPS +N and FYM fertilizers in Assosa district, Western Ethiopia.

Materials and Methods: The treatments consisted of four rates of FYM (0, 5, 10, and 15 t ha^{-1}) and four rates of NPS (having 19N:38P:7S nutrient ratios) applied at the levels of 0, 50, 100 and 150% ha^{-1} along with N 46 kg ha^{-1}. The experiment was laid out as a completely randomized block design in a factorial arrangement and replicated three times. The experiment was conducted for a period of two years, from 2020 to 2022. Data were collected on soil chemical properties and crop yield and yield attributes.

Results: The results showed that the main effect of FYM and NPS significantly ($P < 0.01$) affected leaf area index, thousand seed weight and grain yield of sorghum. The integrated use of FYM and NPS significantly ($P < 0.05$) affected leaf area index, thousand seed weight, grain, and biomass and harvest index of sorghum. The soil pH (5.52 to 5.63), organic carbon (1.57 to 1.93%) and CEC (25 to 31.08 cmol(+) kg^{-1}) were improved in response to the application of 15 t FYM ha^{-1}, whereas some improvement of total nitrogen (0.15 to 0.18%) and available phosphorous (3.32 to 9.64 mg P kg^{-1}) in response to the application of 150% NPS ha^{-1} + 46 kg N ha^{-1}. The integrated use of 15 t FYM ha^{-1} and 150% NPS ha^{-1}+ N 46 kg ha^{-1} resulted in the best improvement of soil organic carbon (0.85% to 2.95%, total nitrogen (0.15 % to 0.20%), available P (3.26 to 10.03 mg P kg^{-1}) and CEC (18.2 to 36.92 cmol(+) kg^{-1}). However, the highest soil pH (5.88) value was recorded in response to the integrated use of 10 t FYM ha^{-1}and 150% NPS ha^{-1}+ N 46 kg ha^{-1}. The highest grain yield (3.98 t ha^{-1}) was obtained from the integrated use of 10 t FYM ha^{-1} and 150% NPS ha^{-1} + N 46 kg ha^{-1}. The highest biological yield (5.09 t ha^{-1}) obtained from the integrated use of 15 t FYM ha^{-1}and 150% NPS ha^{-1} + N 46 kg ha^{-1}. However, the lowest grain yield (0.63 t ha^{-1}) and biological yield (1.07 t ha^{-1}) recorded from the non-treated plots respectively. This implies that the grain yield was increased over by 84.2% and biological yield by 78.9% respectively when compared to the control. Economic analysis also indicated that the application of 10 t farmyard manure ha^{-1}and 150% NPS ha^{-1} + N 46 kg ha^{-1} was provided the highest gross and net benefit.

Conclusion: It is concluded that the application of 10 t FYM ha^{-1}and 150% NPS ha^{-1} + N 46 kg ha^{-1} resulted in the most economical yield and improved soil chemical properties, particularly soil organic carbon and available phosphorous. The highest mean net benefit (24, 640.14 ETB ha^{-1}) was obtained from the application of 10 t FYM ha^{-1} and 150% NPS ha^{-1} + N 46 kg ha^{-1}. This implies that combined applying of farmyard manure and mineral fertilizers at the above mentioned rates enhances the grain yield of sorghum accompanied enhanced contents of soil organic carbon and total nitrogen for sustainable production of the crop.

Keywords: Available P; Grain yield; Mineral fertilizer; Organic fertilizer; Soil organic carbon; Total N.

1. Introduction

Globally, sorghum [*Sorghum bicolor* L. Moench] is regarded as the fifth most significant cereal after wheat, corn, and rice and barely in case of its role for human consumption, the crops stands fourth after wheat, corn, and rice (FAO, 2022). With a 12% contribution to annual output, Ethiopia ranks third in Africa behind

*Corresponding Author: teshometefera36@yahoo.com

ISSN 1993-8195 (Online), ISSN 1992-0407(Print)

Sudan and Nigeria as a producer of sorghum. After teff and maize, it is the third-most significant crop in Ethiopia in terms of production area and total productivity (CSA, 2020). Being native to Africa, sorghum is still a basic staple grain for many rural cultures, especially in lower mid-continental sub-humid and semiarid regions (Robe Elmawako and Sisay Negash, 2021). In Ethiopia, sorghum is cultivated in all regions between 400 m and 2500 m altitude, mostly at lower altitudes where its productivity has been significantly lower than the region's potential yields (4 to 6 t ha^{-1}) in research stations and farm verification experiments (Bodena Guddisa *et al*., 2021).

According to Gebremeskel Gebrekorkos *et al.* (2017), the maximum grain yield (5.11 t ha^{-1}) was recorded from the blended fertilizer NPSZn application amended with N and P in eastern Ethiopia. However, according to Getahun Dereje *et al.* (2016) report, the highest grain yield (4.64 t ha^{-1}) was obtained from the integrated application of compost, farmyard manure and NP fertilizer in western Ethiopia. This could show that the yield recorded from different countries and regions were variable due to various yield limiting factors and cultural practices. For instance, Nebyou Masebo and Muluneh Menamo (2016) reported that the increasing rates of NP fertilizers from 0/0 to 92/30 kg ha^{-1} has increased the yield of sorghum from 0.81 to 3.89 t ha^{-1} at Derashe district. In contrast, Kinfe Hailegebriel and Tesfaye Adane (2018) reported that global sorghum average yield during 2016 was 3.2 t ha^{-1} and national productivity in Ethiopia was only 2.1 t ha^{-1}. Recent study indicated that yield differences were observed on different sites. For example the yield gap between farmers' (4.18, 2.69 and 1.97 t ha^{-1}) and released cultivars potential yield were (6.11, 3.69 and 3.29 t ha^{-1}) for maize, sorghum, and oats respectively recoded in 2021. In this study the average cereal yield level is very low (2.1 t ha^{-1}) at farmers field as compared to that of the estimated average potential (3.2 t ha^{-1}) in Ethiopia for the studied crops (Daniel Hailu and Rozina Gidey, 2022). This implies that, inorganic nitrogenous and phosphate fertilizers are generally used to improve nitrogen and P deficiencies but their high cost makes smallholder farmers unaffordable to purchase. In other condition, the reason why farmers have stayed with the traditional cultivation of long-cycle sorghum was the fact that people use the plant not only as a food source but use the stems as animal feed, construction material for house roofs and as cooking fuel and not practicing the integrated nutrient managements. Under such circumstances and continuous decreases in organic matter and nutrient content of the soils, the importance of integrated use of organic and inorganic nutrient sources has been imperative (Sher *et al*., 2022). Other study reported that low soil fertility and shortage of moisture is the major constraints in the reduction of growth and productivity of sorghum (Gebreyesus Berhane, 2012).

Generally soils of the study area was not benefited from the integrated use of organic matter, notably FYM and inorganic fertilizers, which increases crop yield, soil pH, organic carbon content, and the amount of accessible nitrogen and phosphorous (field observation).In accordance with (EthioSIS, 2014), the status of total nitrogen and available phosphors were found to be very low and organic carbon was also found to be low in western Ethiopia. In the western Ethiopia particularly in Assosa zone, not sufficient research has been done to investigate the effect of blended NPS and farmyard manure. As a result, there is no documented information on responses of yield and yield components of sorghum to integrated uses of blended NPS and farmyard manure rates. However, information on production practices to increase the sorghum grain yield and soil chemical improvement through applying the appropriate rates of NPS and farmyard manure was very important. Therefore; the general objective of this study was to increase sorghum production and productivity by optimizing integrated use of blended NPS and FYM fertilizers in Assosa district, Western Ethiopia.

2. Materials and Methods

2.1. Description of Experimental Site

The study was conducted for two consecutive years during the 2020 and 2022 main cropping seasons on farmers' field at Assosa woreda, Benishagul Gumuz region, Western Ethiopia. The study site was selected purposively based on its high sorghum production potential. The experimental site is located at "09°58'41.7 N latitude and 034°38'09.5 E longitude, and an altitude of 1580 meters above sea level, with the minimum and maximum temperature of 16.5 °C to 27.5 °C, respectively. The mean annual rainfall at Assosa was 1275 mm to 1316 mm with mono-modal pattern lasts from April to October, and the hottest months observed in March and May. The dominant soil type in the study area is Nitosols (Ethio SIS, 2014). Major crops produced in the area includes; maize, sorghum, soybean, sesame, finger millet, ground nut etc. Livestock productions like cattle's, goat, sheep, hen, and donkey were part of society's livelihood and different willed animals also found in larger natural forest and grasses.

2.2. Experimental Materials

A Sorghum variety named Assosa1, which was released in 2015 by Assosa Agricultural Research Center in Ethiopia was used as the test crop and selected as best performing variety in experimental area. It needs 1200 mm of rainfall for high yield and grows at an altitude of 1550 meters above sea level. The average grain yield of the variety at Assosa research center ranges from 3.8 t ha^{-1} under station and 3.45 t ha^{-1} under farmer's field respectively. The variety needs 180 days to reach physiological maturity (AARC, 2017). In addition inorganic fertilizers (NPS + Urea) and farmyard manure were used as basic experimental materials.

2.3. Soil and Farmyard Manure Sampling and Analysis

Composite soil samples were taken prior from the whole experimental site and after harvest from main plots at the depth of 0 to 20 cm in a zigzag pattern by soil auger. Soil samples was air-dried, ground and sieved to pass through a 2 mm sieve. Determination of soil chemical properties like, soil pH, OC%, total N, and available P and cation exchange capacity (CEC), was analyzed under Assosa soil laboratory. Soil pH was measured using soil to water ratio of 1:2.5 by pH meter (potentiometric analysis) (Jackson, 2003). The percent organic carbon content (% OC) was measured by using wet potassium dichromate oxidation method (Walkley, 2003). Total N was measured using Kjeldahl digestion method (Jackson, 2003). Available P was measured by Olsen extraction method and cation exchange capacity (CEC) was determined using 1N ammonium acetate extraction at pH 7 and titration with ammonium counter ion (Amma, 2003). Before the application of farmyard manure to the experimental plots, samples of 1 kg were collected from the source and stored in plastic bags. Then, it was air dried and ground to pass through a 2 mm sieve and packaged for laboratory analyses. Then after, pH, total N, available P, organic carbon, and available sulfur were determined according to methods described in (Okalebo, 2002).

2.4. Treatments and Experimental Design

The treatment consisted four rates of farmyard manure (0, 5, 10, and 15 t ha^{-1}) and four rates of blended NPS + N (0, 50, 100, and 150% ha^{-1} of the recommended rates of NPS) with a total of 16 treatments. The experiment was laid out in randomized complete block design with three replications. The net plot size was 3 m x 2 m (6 m^2) for all experimental plots, with four rows at spacing of 75 cm between rows and 20 cm between plants. The gross size of experimental plot or replication was 3 m x 40 m (120 m^2) in which the two outer most rows of both ends were considered as border effects.

2.5. Experimental Procedures

The land was prepared in accordance with the standard of local practice at a depth of 20 to 30 cm with oxen. Plots were leveled and rows prepared using hand tools to provide a medium fine soil for the growth of the crop. The cattle manure was applied two weeks before sowing and incorporated into the soil at a depth 20 cm. The whole NPS blended and half of the urea fertilizers were applied at planting while half of the urea was applied after 45 days of sowing. The experiment was done under rain-fed condition and all agronomic practices were kept uniform for all treatments as recommended and adopted for the location.

2.6. Data Collection

Data of the yield attributes were recorded after harvesting except for the stand count, which was recorded after thinning and the number of panicles during physiological maturity. Heading occurs when the panicle becomes visible as it emerges from the flag leaf sheath. Thousand seed weight (TSW) was recorded from the composite samples of kernels of each plot; then counted and weighed with digital balance after dried under optimum temperature. Leaf area index (LAI) was calculated as the ratio of total LA of the ten selected plants (cm^2) to the area of land (cm^2) occupied by those plants (Valentinuz and Tollenaar, 2006). Biological and the grain yield (t ha^{-1}) were measured 30 days after harvesting of sorghum to facilitate drying until the dry biomass yield attains approximately constant moisture content. The biological yield was measured by harvesting the whole above ground plant part of each plot. Then the kernels were threshed and weighed for the total grain yield from each plot. The grain moisture content was tested with seed moisture test and adjusted to 12% and the yield per plot was converted in to hectare in order to determine average yield of sorghum. The harvest index (%) was calculated as the percentage of the grain yield to above ground dry biomass yield per plot.

2.7. Data Analysis

Data was subjected to analysis of variance using the General Linear Model (GLM) procedure of SAS 9.4 (SAS Institute, 2016). A combined analysis of the two-year data was performed after testing homogeneity of variances using F-test (Fisher, 1935). Since the F-test results of most agronomic parameters of the two-season data depicted homogeneity of variances, a combined analysis was done. Whenever the ANOVA detected significant differences between treatments, mean separation was conducted using Tukey's mean separation test at 5% level of significance.

2.8. Economic Feasibility Analysis

Partial budget and economic analysis were performed to investigate the economic feasibility of the treatments using agronomic manual of (CIMMYT, 1988). The economic yield or the actual grain yield was converted into adjusted yield after harvesting and then used to calculate total revenue. Production of sorghum was determined by considering the various variable costs, such as the cost of purchasing materials and inputs, site preparation, labor for all cultivation and site guard was calculated. Generally, costs of all agronomic practices were properly calculated and the cost benefit ratio was determined for each treatment.

3. Results and Discussion

3.1. Soil and Farmyard Manure Analysis before Sowing

The initial average soil pH of the study area was 5.52, which is in a low range for crop production and 6.8 for fresh cow dung, which is an optimum rage. The percentage of organic carbon in the soil and farmyard manure was 1.57 and 4.2, respectively. The organic carbon content in both sources was low to moderate range for crop production. However, total nitrogen content of the soil (0.15%) is lower than that found in the FYM (1.83%). Available phosphorous and sulfur contents in the soil and FYM were 3.32 mg kg^{-1} and 3.81mg kg^{-1}, 0.42 mg kg^{-1} and 0.05 mg kg^{-1}, respectively. Cation exchange capacity of the initial soil was 25 cmol (+) kg^{-1} and not tested in farmyard manure (Table 1 and 2). Generally, the experimental soil apparently contains low to very high levels of soil quality parameters initially to support plant growth (Table 1). This is in agreement with standardizations of Hazelton and Murphy (2007) who categorized a soil with pH (5.41) as strongly acidic. About 3.05% organic carbon and 0.34% nitrogen were considered as high in standards. Based on the values recorded, the pH of farmyard manure was moderately alkaline. In addition, the recorded values of total nitrogen, available phosphorus, organic carbon, and the available sulfur of farmyard manure were very high and best option for crop growth and yield when integrated with inorganic fertilizers (Table 2).

3.2. Soil Chemical Properties

3.2.1. Soil pH

The soil pH varied significantly ($P < 0.05$) in response to the main and interaction effects of year, farmyard manure, and inorganic fertilizer (Table 3). The pH of the soil in different treatments was ranged from 5.07 for main effect to 5.88 for interaction effect in surface soil (0 to 20 cm). The highest pH was recorded from the integrated use of 150% NPS + N 46 kg ha^{-1} and 10 ton FYM ha^{-1}. Similarly, the integrated application of 100% NPS + N 46 kg ha^{-1}and 5 ton FYM ha^{-1}, as well as whereas, 100% NPS + N 46 kg ha^{-1} and 10 t FYM ha^{-1} were produced the highest pH of the soil. The lowest pH of the soil was recorded from the integrated application of 150% NPS + N 46 kg ha^{-1}and 15 t FYM ha^{-1} (Table 4).

Table 1. Initial soil chemical properties of the experimental site before sorghum planting.

Chemical properties	Soil	Rating	References
pH(H_2O)	5.52	Strongly acidic	Jones (2003)
Organic carbon (%)	1.57	Low	Tekalign (1991)
Total Nitrogen (%)	0.15	Low	Murphy (1968)
Available Phosphorous (mg kg^{-1})	3.32	Very high	Cottenie (1980)
Available Sulfur (mg kg^{-1})	3.81	Below critical	Havlin *et al.* (1999)
Cation exchange capacity (cmol (+) kg^{-1})	25.0	Critical	Booker (1991)

Table 2 Chemical composition of farmyard manure (FYM) before sorghum planting.

Chemical properties	FYM	Rating
pH(H_2O)	6.8	Alkaline
Organic carbon (%)	4.2	Very high
Total Nitrogen (%)	1.83	Very high
Available Phosphorous (mg kg^{-1})	0.42	Very high
Available Sulfur (mg kg^{-1})	0.05	Low
Cation exchange capacity (cmol (+) kg^{-1})	18.0	Very high

Note: *Rating was made according to Hazelton and Murphy (2007).*

The integrated application of 150% NPS + N 46 kg ha^{-1} and 10 t FYM ha^{-1} was improved pH of the soil nearly by 13.8% over the highest combined fertilizer application of 150% NPS + N 46 kg ha^{-1} and 15 t FYM ha^{-1}. The result is in line with the findings of Kisinyo *et al.* (2019) reported that soil pH increased due to application of organic materials and decrease due to sole application of inorganic fertilizer. The decrease in the soil pH from increased level of inorganic fertilized treatment might be due to nitrification of ammonium (NH^{4+}) to nitrate (NO^{3-}) and release of phosphoric acid by P_2O_5 during its dissolution into the soil solution. The result is in agreement with Roobroeck *et al.* (2015), who reported soil pH was increased due to the application of organic materials and decrease due to inorganic fertilizer application.

3.2.2. Soil organic carbon

Soil organic carbon was significantly ($P < 0.01$) influenced by the main and interaction effect of year, farmyard manure, and inorganic fertilizer (Table 3). Application of FYM either alone or with inorganic fertilizer resulted in considerable changes on SOC in the surface (0 to 20 cm) of soil layer than control. The highest SOC was recorded from the integrated use of 15 t FYM ha^{-1} and 150% NPS + N 46 kg ha^{-1}, followed by the integrated application of 15 t FYM ha^{-1} and 50% NPS + 46 N ha^{-1}, as well as the sole application of 15 t FYM ha^{-1}. The minimum soil organic carbon was produced from control and sole application of 15 t FYM ha^{-1} (Table 4). The result is in consistent with the findings of Shiferaw Nesgea *et al.* (2012) who reported that the combined application of FYM with inorganic NP has increased the soil carbon content after harvest by 65% as compared to the application of 100% recommended NP alone (N 46 kg ha^{-1} and 65 kg P ha^{-1}). Likewise, Hui *et al.* (2017) reported that annual application of compost at rate of 20 t ha^{-1} significantly improved the residual organic matter of the soil compared to the control.

Table 3. Mean squares of ANOVA for effects of year, farmyard manure and inorganic fertilizer on selected soil chemical properties in Assosa district during 2022 and 2022.

Source of variation	df	Mean squares					
		Soil pH	SOC	TN	Av. P	Av. S	CEC
Year(Y)	1	6.31**	0.66**	0.08**	28.06*	15.83**	1372.84**
Farm yard manure(FYM)	3	0.15*	0.05*	0.02*	30.12*	1.68*	58.42*
Inorganic fertilizer (IF)	3	0.32*	0.04ns	0.003*	26.46*	1.26*	8.42ns
Y x FYM	3	0.37*	0.54**	0.006*	16.08*	1.82*	18.44*
Y x IF	3	0.42*	0.03ns	0.03*	63.40ns	1.39*	10.62ns
FYM x IF	9	0.48*	0.25*	0.003*	18.42*	0.89**	0.42*
Y x FYM x IF	9	0.14*	0.08*	0.009*	1.18**	1.11**	4.61*
Error	18	0.62	0.07	0.006	2.73	0.09	3.87
CV (%)		5.43	8.49	31.23	10.12	38.26	24.16

Note: *pH = Power of hydrogen, OC = Organic carbon of the soil, TN = Total nitrogen, Av. P = Available phosphorous, Av. S = Available sulfur, and CEC = Cation exchange capacity. ns = non-significant difference, and *, ** and *** refer significant difference at probability level of 5, 1, and 0.1%, respectively. df = Degree of freedom.*

The integrated application of 150% NPS + N ha^{-1} and 15 t FYM ha^{-1} was increased soil organic carbon nearly by 71.2% over the control. The presence of moderate organic carbon might be due to the synergetic effect of combined resources which improves the soil structure and proliferation of soil microorganisms that could also improve the clay organic carbon bond and increase the net soil organic carbon. On the other hand the low soil carbon level was observed due to inadequate use of organic inputs in soil fertility management as reported by (Cui *et al.*, 2022). As others stated that when a soil organic matter has increased, the acidity of the soil decreases, because the carboxyl groups on the humus develop negative charge and suppress the positively charged hydrogen (H^+) that reacts with the hydroxyl (OH^-) to form water (Tellen and Yerima, 2018).

3.2.3. Total nitrogen

Mean square of ANOVA showed that the total nitrogen of the soil was highly significantly ($P < 0.01$) influenced by the main and interaction effect of year, farmyard manure, and inorganic fertilizer (Table 3). Total nitrogen of the soil was improved more due the main effect of inorganic fertilizers than farmyard manure (Table 3). The integrated use of 150% NPS + N 46 kg ha^{-1} and 10 t FYM ha^{-1} was produced the highest total nitrogen, as well as 150 kg NPS fertilizer ha^{-1} with all the farmyard manure rates, as well as 50 kg NPS fertilizer ha^{-1} with 15 t FYM ha^{-1} rates produced the highest total nitrogen. The integrated application of 150% NPS + N 46 kg ha^{-1} and 10 t FYM ha^{-1} was improved soil total nitrogen nearly by 6% over the sole application of 50 and 100 kg NPS ha^{-1} (Table 4). The result is in line with Weldegebriel Redai *et al.* (2018) reported significant amount of total nitrogen, $NH4^+$ nitrogen and $NO3^-$ nitrogen increased when fresh cow dung was applied to the soil. The application of FYM and inorganic fertilizers might be resulted in interactive enhancement of soil microbial activity, which increases the soil organic matter and in turn increase total N of the soil. In support to this result, Zerssa *et al.* (2021) reported, the existence of interaction between P and N in the soil as well as in plant tissues such that treatment of P in N fertilized soils increased the total N of the soil. In contrast, maximum application of fertilizers were negatively influenced soil chemical properties like the decline of TN (0.16%) due to the interaction effect of 150% NPS + 46 N ha^{-1} and 15 t FYM ha^{-1} (Table 4). The possible reason for total nitrogen reduction from the application of higher rate of inorganic fertilizer might be due to high loss of nitrogen through leaching by high rainfall, excess and inadequate application to replenish the removed nitrogen through crop harvests and high rate of organic matter decomposition.

3.2.4. Available phosphorous

Mean square of ANOVA showed that the available phosphorous of the soil was highly significantly ($P < 0.01$) influenced by the main and interaction effect of year, farmyard manure, and inorganic fertilizer (Table 3). The maximum soil available P was recorded from the integrated use of 150% NPS + N 46 kg ha^{-1} and 15 t FYM ha^{-1}. Similarly, the integrated application of 150% NPS +46% N ha^{-1} with all farmyard manure rates were produced the highest available P of the soil. The lowest available P was recorded from control and sole application of 5 t and 10 t FYM ha^{-1} (Table 4). The increase in soil N and P after FYM application might be due to the direct addition of N and P through decomposition of the FYM added to the soil and/or residual effect of inorganic fertilizers. The result is in agreement with the findings of Tunya *et al.* (2014) who reported significant increase in residual available P_2O_5 as a result of combined application of manure (5 t ha^{-1}), lime (3 t ha^{-1}) and P_2O_5 (60 kg ha^{-1}).

Table 4. Interaction effects of inorganic fertilizer and farmyard manure on available P, available S and soil CEC after crop harvesting.

Treatments		pH(H_2O)	%OC	Total	Av. P	Av. S	CEC
IF (% ha^{-1})	FYM (t ha^{-1})			N%	(mg kg^{-1})	(mg kg^{-1})	
0	0	5.52^{f}	0.85^{g}	0.15^{cd}	3.26^{f}	19.94^{g}	18.2^{h}
	5	5.53^{ef}	0.88^{g}	0.15^{cd}	3.25^{f}	19.95^{g}	18.48^{gh}
	10	5.53^{ef}	1.06^{fg}	0.15^{cd}	3.26^{f}	19.87^{g}	18.96^{gh}
	15	5.56^{e}	2.62c	0.16^{c}	4.75^{ef}	20.02^{fg}	19.75^{g}
50	0	5.68^{c}	2.84^{b}	0.14^{d}	4.82^{ef}	23.54^{de}	23.85^{fg}
	5	5.54^{de}	0.98^{fg}	0.15^{c}	4.94^{ef}	22.86^{ef}	24.32^{fg}
	10	5.63^{cd}	1.24f	0.16^{c}	5.03^{e}	23.47^{de}	24.86^{f}
	15	5.59^{d}	2.04^{d}	0.17^{bc}	6.05^{d}	23.85^{d}	26.67^{ef}
100	0	5.48^{ef}	1.54^{ef}	0.14^{d}	5.89^{de}	24.28^{cd}	28.43^{e}
	5	5.55^{de}	1.86^{de}	0.15^{cd}	5.78^{de}	22.98^{e}	29.45^{de}
	10	5.76^{cb}	1.96^{ed}	0.16^{c}	6.25^{cd}	25.08^{c}	28.74^{e}
	15	5.78^{b}	2.46^{cd}	0.16^{c}	6.74^{cd}	21.45^{f}	34.02^{c}
150	0	5.25^{fg}	1.65^{e}	0.17^{bc}	9.64^{b}	24.35^{cd}	34.65^{cb}
	5	5.64^{cd}	1.78^{de}	0.18^{b}	7.82^{c}	24.56^{cd}	30.52^{d}
	10	5.88^{a}	2.03^{d}	0.20^{a}	9.42^{cb}	29.38^{b}	35.09^{b}
	15	5.07^{g}	2.95^{a}	0.16^{c}	10.03^{a}	32.02^{a}	36.92^{a}
CV (%)		7.03	10.86	13.32	18.74	8.06	10.63

Note: *Means in columns followed by different letters are significantly different at P < 0.05 probability level.*

In fact, none of the treatments had available P levels greater than the critical 10.03 mg kg^{-1} that is considered as adequate for most cereals in the region. The result is in contrary with Kisinyo *et al.* (2019), in that the increase in soil P_2O_5 due to the applications of organic materials and inorganic fertilizers on acid phosphorous deficient soils. Almost all the P_2O_5 in NPS is soluble and readily available while some of the P_2O_5 in the FYM is in organic forms and must first be mineralized before it becomes available. Soils were sampled after harvest, by which time most of the P_2O_5 could also have been fixed in these high P-fixing soils (Roobroeck *et al.*, 2015). Above all, P application in combination with organic manures may not only improve fertility status but are also potential for restoring and maintaining productivity of a soil which could otherwise be impossible even with balanced application of inorganic fertilizers alone. Similarly, Tilahun Tadesse *et al.* (2013) reported phosphorus deficiency is likely in such an acidic soil due to its fixation by aluminum and iron ions, which is compounded by parent materials with low phosphorous and inadequate phosphorus fertilizer replenishment by users.

3.2.5. Available sulfur

The available sulfur (S) was significantly (P < 0.05) influenced by main and interaction effect of year, farmyard manure and inorganic fertilizers (Table 3). The highest value of available soil sulfur was recorded from the integrated use of 15 t FYM ha^{-1} and 150% NPS + N 46 kg ha^{-1}, as well as the integrated use of 10 t FYM ha^{-1} and 150% NPS + N 46 kg ha^{-1} was produced the maximum available sulfur. The lowest available sulfur was recorded from control and sole application of farmyard manure (Table 4). The result is in line with the findings of Deekshitha *et al.* (2017) reported that application of P_2O_5 fertilizer results in increased anion adsorption sites, which releases sulfate ions in to the solution. However, its deficiency might be higher in savanna area than in the forest zone due to very long period of plant burning during which sulfur in the grass and other plant goes up in smoke as sulfur dioxide. Several studies reported both synergistic and antagonistic relationship between P_2O_5 and sulfur depending on their rate of application and crop species (Muhammad *et al.*, 2015). This is might be the capacity of applied sulfur to reduce soil pH and increase availability of other nutrients to plant has enhanced the synergy between phosphorous and sulfur.

3.2.6. Cation exchange capacity

Mean square of analysis showed that CEC was highly significantly influenced by the main effect of year, significantly influenced by the main effect of FYM, interaction effect of (Y x FYM, IF x FYM and Y x FYM x IF); whilst it did not significantly influenced by the main effect of IF and interaction effect of Y x IF (Table 3). The highest CEC (36.92 cmol (+) kg^{-1}) was observed from the integrated use of 15 t FYM ha^{-1} and 150% NPS + N 46 kg ha^{-1} and the lowest 18.2 cmol (+) kg^{-1} for control (Table 4). The CEC of the soil was increased by 49.29% (18.2-36.92cmol (+) kg^{-1}) with increase in rate of farmyard manure and inorganic fertilizer. The reason for high CEC might be due to the residual effects of farmyard manure and initial CEC in experimental site. In conformity with this result Kumar *et al.* (2019) reported that CEC significantly increased with increased organic manure (15 t FYM ha^{-1}) in conjunction with inorganic fertilizer than the application of only inorganic NPK fertilizers. Cation exchange capacity (CEC) is an imperative soil property influencing structure stability of soil, nutrient accessibility, soil pH and soil's reaction to fertilizers and other ameliorants (Hazelton *et al.*, 1991). The lowest CEC values observed in the control plots and sole application of 50% IF and 15 t FYM ha^{-1} might be attributed to the leaching of bases from the soil due to the high rainfall which were not replenished since there was less fertilizer provided or late decomposition of manure to these plots.

3.3. Yield Attributes of Sorghum

3.3.1. Number of tillers

Sorghum number tillers (NT) were significantly ($P < 0.05$) influced by the main effect of year, inorganic fertilizers (IF), interaction effect of Y x IF, FYM IF and Y IF FYM. However, it was not significantly ($P > 0.05$) influnced by the main effect of FYM and the interaction effect of Y x FYM (Table 5). The maximum number of tillers (47) per plot were recorded from the integrated use of 150% NPS + N 46 kg ha^{-1} and 10 t FYM ha^{-1}; whereas, the lowest (30) was observed for control (Table 6). The result is in agreement with the findings of Shamme *et al.* (2016), reported that stimulation of tillers with high application rate of nitrogen might be due to its positive effect on cytokinin synthesis. The reason for the tiller increment might be noted due to the application of optimum rate of fertilizer which improves the survival of plants at emergence. The result is in contrast with Nikus *et al.* (2004) findings, who reported residual effect of farmyard manure can change soil environment and fertility status to germinate all number of seeds planted, initiate tillers and yields. This might be resulted based on the term used for cultivation, farmyard manure requires long time to decompose and easly available for plant growth and yield than commercial fertilizers. The result is also consisted with the findings of Onyari *et al.* (2015) showed that increase in rate of N (60 to 105 kg N ha^{-1}) significantly improved the stand count of maize at the optimum rate of N (90 kg N ha^{-1}), while the higher and lower rate of N decreased the stand count.

Table 5. Mean squares of ANOVA for effect of year, FYM and IF on yield attributes and yields of sorghum.

Source of variation	df	Mean squares						
		NT	NH	LAI	TSW	GY	BY	HI
Year	1	13.13*	76.33*	2.13**	164.22**	75.84*	354.76ns	0.2ns
Farmyard manure	3	17.51ns	191.19*	1.4*	35.53**	1266.34**	1184.28*	0.3*
Inorganic fertilizer	3	13.56*	257.25*	10.13**	105.54**	14159.39**	12501.62*	1.49*
Y x IF	3	64.56*	68.83*	0.15**	3.49*	26.39*	77.2ns	0.12ns
Y x FYM	3	5.96ns	5.31*	0.45*	2.23*	8.57**	138.75*	0.16*
FYM x IF	9	0.56*	5.31*	0.45**	2.23*	0.13***	0.39**	0.09**
Y x FYM x IF	9	3.97*	27.47*	0.22*	55.33**	335.23***	420.52**	0.05**
Error	18	3.13	7.3	0.21	4.9	17.2	15.2	0.08
CV(%)		16.04	17.24	21.91	9.48	8.1	19.93	12

Note: *NT = Number of tillage, NH = Number of heads, LAI = Leaf area index, TSW = Thousand seed weight; GY = Grain yield, BY = Biological yield, and HI = Harvest index. ns = non-significant difference, and *, ** and *** refer to significant difference at probability level of 5, 1, and 0.1%, respectively. df = Degree of freedom.*

3.3.2. Number of heads

The number of heads (NH) of sorghum per plot significantly ($P < 0.05$) influenced by all sources of variations (Table 5). Number of heads per plant is an important yield attributes of sorghum that contributes to grain yield. Crops with higher number of heads/panicle number could have higher grain yield. The maximum number of heads (48) was recorded from the integrated use of 150% NPS + N 46 kg ha^{-1} and 10 t FYM ha^{-1}, whereas the lowest (34) was recorded for non-treated plots (Table 6). The result is in line with the findings of Shuaibu *et al.* (2018), who found that the grain sorghum yield and yield attributes positively responds to organic and inorganic fertilizer combination. The lowest and highest level of integrated nutrient application was reduced the number of heads as compared to number of tillers observed in the field (Table 6). This is might be indicated that all the emerged tillers did not attain the matured heads due to nutrient deficiency or excess nutrient. The significant difference observed was also indicated that number of heads might more influenced by inorganic fertilizer than farmyard manure.

3.3.3. Leaf area index

The Leaf area index of sorghum was highly significantly ($P < 0.01$) influenced by main and interaction effects of all sources of variations (Table 5). The highest LAI was recorded from the integrated use of 150% NPS + N 46 kg ha^{-1} and 10 t FYM ha^{-1}. Similarly, the combination of 150% NPS + N 46 kg ha^{-1} with all farmyard manure rates were produced the highest leaf area index of sorghum. However, the lowest LAI was recorded from control (Table 6). The highest LAI produced was might be happen due to more light interception and enhanced photosynthetic rate, which ultimately resulted in higher dry matter production. The result is in accordance with the findings of Elamin and Madhavi (2015), reported the highest leaf area index (4.8) was recorded for 100% inorganic fertilizer and 2.5 t vermicompost per hectare. Similarly, Shamme *et al.* (2016) reported that the highest LAI for *Lalo* sorghum (3.28) was recorded with the application of 138 kg N ha^{-1}, while the lowest (2.15) was recorded from variety *Chemada* with no nitrogen application. Therefore, the increase in LAI was possibly due to the improved leaf expansion in plants through application of optimum nitrogenous fertilizers.

3.3.4. Thousand seed weight (TSW)

Mean square of ANOVA showed that thousand seed weight was highly significantly ($P < 0.01$) influenced by the main and interaction effect of year, farmyard manure, and inorganic fertilizer (Table 5). The highest thousand seed weight was recorded from the integrated application of 10 t FYM ha^{-1} and 150% NPS + N 46 kg ha^{-1}, followed by interaction effect of 15 t FYM ha^{-1} and 50% NPS + N 46 kg ha^{-1}, and 5 t FYM ha^{-1} with 150% NPS + N 46 kg ha^{-1}. Similarly, the integrated use of 100% NPS + N 46 kg ha^{-1} and all farmyard manure rates were produced the maximum thousand seed weight of sorghum. The lowest TSW was recorded from the highest interaction level of inorganic and farmyard manure (150% NPS + N 46 kg ha^{-1} and 15 t FYM ha^{-1}) and sole application of 5 t, 10 t and 15 t FYM ha^{-1} (Table 6). The lowest thousand seed weight recorded from the integrated use of 150% NPS + N 46 kg ha^{-1} and 15 t FYM ha^{-1} was 53.4% less than the highest thousand seed weight. This could be due to the presence of good monthly rainfall distribution throughout the cropping season that may extend the grain-filling period and optimum nutrient supplied for plant growth and yield. The result is in line with the findings of Biya Muhidin (2018), who reported that the highest thousand grain weight (2.49 g) produced from (0 N kg ha^{-1}), while the minimum was (2.25 g) recorded from the highest nitrogen rate (69 kg N ha^{-1}). The result is in contrary to the finding of Yalemtesfa Firew and Asfaw Adugna (2017), reported that no significant effect of the application of different rates of nitrogen fertilizer on 1000 kernel weight of bread wheat.

3.4. Yields of Sorghum

3.4.1. Biological yield

Mean square of ANOVA showed that biological yield was highly significantly ($P < 0.01$) influenced by the main and interaction effect of year, farmyard manure, and inorganic fertilizer (Table 5). The maximum biological yield was recorded from the integrated use of 150% NPS + N 46 kg ha^{-1} and 15 t FYM ha^{-1}, which was followed by the interaction effect of 150% NPS + N 46 kg ha^{-1} and 10 t FYM ha^{-1}. The sole application of 150% NPS + N 46 kg ha^{-1}, integrated use of 100% NPS + N 46 kg ha^{-1} and 10 t FYM ha^{-1} and 100% NPS + 46% N ha^{-1} and 15 t FYM ha^{-1} were produced the highest biological yield consecutively. However, the minimum weight of biological yield was obtained from plots treated without fertilizers (Table 6). Increasing in biological yield might be from the application of inorganic fertilizer in combination with farmyard manure that increased the growth rate of sorghum, which ultimately produced more biological yield. The result is in line with the findings of Weldegebriel Redai *et al.* (2018), ascertained the increasing application of fertilizer nutrients such as N P and K increases the grain yield and biomass weight of sorghum significantly. Biological yield is a function of photosynthetic rate and proportion of the assimilatory surface area. As observed from field experiment, sorghum biological yield produced from integrated nutrients were relatively greater by 79% over sole application of treatments (Table 6). Related to this finding, Gebremeskel Gebrekorkos *et al.* (2017) had reported the highest biomass yield (12672 kg ha^{-1}) from the application of blended fertilizer amended with N and P. The increase in biological yield with increase in rate of fertilizers might be due to better crop growth rate, LAI and accumulation of photo assimilate, which ultimately produced more biological yield. Similarly, Berhane Shibabaw *et al.* (2015) found that application of high N level results in high amount of biomass yield in sorghum.

Table 6. Interaction effects of inorganic fertilizer and farmyard manure on yield attributes and yields of sorghum at Assosa district in 2020 and 2022.

Treatments		Yield attributes				Yields		
IF (%)	FYM (t ha^{-1})	NT	NH	LAI	TSW (g)	GY (t ha^{-1})	BY (t ha^{-1})	HI (%)
0	0	33.67^{igh}	34^{h}	0.77^{g}	27.99^{g}	0.63^{j}	1.07^{g}	46.28^{d}
	5	32.67^{i}	34.33^{h}	1.24^{gfe}	21.19^{j}	0.79^{i}	1.21^{hg}	65.84^{bc}
	10	33.67^{igh}	34.33^{h}	1.45^{gdf}	21.80^{j}	0.83^{i}	1.26^{hg}	66.19^{bc}
	15	33^{ih}	35.33^{hg}	1.79^{dfc}	22.32^{ji}	0.87^{i}	1.25^{hg}	69.55^{bc}
50	0	35.33^{feg}	35.67^{hgf}	1.18^{gf}	23.65^{i}	0.74^{j}	1.16^{hg}	63.74^{dc}
	5	34.67^{fig}	35.67^{hgf}	1.67^{gdf}	25.87^{h}	0.83^{i}	1.20^{hg}	69.72^{bc}
	10	36.67^{fec}	37.67^{edf}	1.52^{gdf}	28^{g}	0.95^{ih}	1.29^{hgf}	74.1^{bac}
	15	36f^{eg}	37^{egf}	1.67^{gdf}	36.14^{b}	1.15^{gh}	1.54^{gf}	74.93^{bac}
100	0	38^{bcd}	39.67^{bdc}	1.89^{dfc}	29.01^{fg}	1.37^{gf}	1.76^{egf}	77.52^{bac}
	5	38^{bcd}	39.33^{bdc}	2.09^{dfc}	29.33^{fg}	1.47^{f}	1.92^{edf}	76.89^{bac}
	10	39^{bc}	40^{bac}	2.20^{dce}	30.39^{fe}	1.80^{e}	2.23^{ed}	80.74^{bac}
	15	39.33^{ba}	40^{bc}	2.26^{dc}	31.17^{de}	1.83^{e}	2.22^{ed}	82.53^{ba}
150	0	37.67^{bec}	38.33^{edc}	2.49^{bc}	32.74^{dc}	2.12^{d}	2.54^{cb}	83.36^{ba}
	5	39.67^{ba}	42.7^{ba}	3.35^{ba}	34.21^{c}	2.97^{c}	3.34^{c}	88.74^{a}
	10	46.67^{a}	48^{a}	4.08^{a}	44.64^{a}	3.98^{a}	4.49^{b}	89.53^{a}
	15	40^{ba}	40.7^{bc}	3.50^{a}	20.79^{j}	3.43^{b}	5.09^{a}	89.71^{a}
LSD		4.8	4.56	0.38	1.87	1.53	1.93	1.63
CV (%)		13.27	10.96	28.45	16.8	23.28	22.68	14.11

Note: *Means in columns followed by different letters are significantly different at P ≤ 0.05 probability level.*

3.4.2. Grain yield

The grain yield highly significantly ($P < 0.001$) influenced by the two factor interaction of farmyard manure x inorganic fertilizer and the three factor interaction of year x farmyard manure and inorganic fertilizers. The main effect of year, farmyard manure, inorganic fertilizer and their interaction effect of year x inorganic fertilizer significantly ($P < 0.01$) influenced the grain yield of sorghum. Whereas, grain yield significantly ($P < 0.05$) influenced by the main effect of year and the interaction effect of year x inorganic fertilizer (Table 5).

The maximum grain yield was gained from the integrated use of 150% NPS + N 46 kg ha^{-1} and 10 t FYM ha^{-1}, which is followed by the integrated use of 150% NPS + N 46 kg ha^{-1} and 15 t FYM ha N 46 kg ha^{-1}. The integrated use of 150% NPS + N 46 kg ha^{-1} and 5 t FYM ha^{-1} and the sole application of 150% NPS + N 46 kg ha^{-1} also gave the highest grain yield of sorghum. However, the sole application 5 t FYM ha^{-1}, 50% NPS + N 46 kg ha^{-1} and control were produced the lowest grain yield of sorghum (Table 6). This might be due to optimum contents in inorganic fertilizers and high nutrient contents in farmyard manure released and available for plants then contributed to yield and yield attributes of sorghum. This result is in line with Tilahun Tadesse *et al.* (2013), reported as the highest grain yield of 4535 kg ha^{-1}was obtained from the plots received the highest fertility level (15 t FYM ha^{-1} plus 100% of the recommended inorganic fertilizer rate) and the lowest yield of 3340 kg ha^{-1} was obtained from the control plots. Similarly, Dagne Chimdessa (2016) reported that the application of blended fertilizers and NP fertilizers significantly increased grain yield of sorghum as compared to N fertilizers and the control.

The enhanced in grain yield with increase in nitrogen levels application might be also due to the increase up of yield attributing characters and nutrient uptake of the crop under these levels, while the reduced yield might be due to yield limiting factors at low and maximum application levels. The highest integrated use of 150% NPS + N 46 kg ha^{-1} and 10 t FYM ha^{-1} was increased the yield by 84.2% over control (Table 6). The result is again in line with Shuaibu *et al.* (2018), they reported the application of 45 kg ha^{-1} NPK + 2 tons of cow dung per hectare produced the best result in both growth and yield of sorghum. The results of the present study substantiates that lack of adequate nutrient supply and poor soil structure are the principal constraints to crop production under low input agriculture systems(Azrag and Dagash, 2015).

3.4.3. Harvest index

Harvest index of sorghum was significantly ($P < 0.01$) influenced by the two factor interaction effect of FYM x inorganic fertilizer (IF) and the three factors interaction of Y x IF x FYM; whilst, significantly ($P < 0.05$) influenced by all sources of variation; however, it did not significantly ($P > 0.05$) influenced by main effect of year and interaction effect of Y x IF (Table 5). The highest HI was recorded from the integrated use of 150% NPS + N 46 kg ha^{-1} and all rates of farmyard manure. The integrated use of 150% NPS + N 46 kg ha^{-1} and all rates of farmyard manure also produced the highest percentage of harvest index. However, the lowest harvest index was obtained from control (Table 6). The variation found for HI dynamics might be largely explained by difference in assimilation during grain filling and remobilization of pre-heading assimilates and this variation could be due to genetic variation for the trait has been reported by Weldegebriel Redai *et al.* (2018), thus, the harvest index increased significantly up to 92 kg N ha^{-1}. The result was in agreement with the findings of Shamme *et al.* (2016), who reported that, harvest index in maize increases when nitrogen rates increased.

3.5. Partial Budget Analysis

The adjusted grain yield and biological yield of sorghum were used to calculate the gross field benefits (total revenue) for the partial budget analysis (economic analysis). Therefore, farmyard manure (10 t ha^{-1}) and 150% NPS + N 46 kg ha^{-1} produced the highest net benefit (24,640.14 ETB), followed by farmyard manure (15 t ha^{-1}) applied with 50% of NPS + N 46 (12,993.73 ETB), while fresh cow dung applied at 5 t ha^{-1} and inorganic fertilizers at 50% produced the net benefit of 6,056.99 ETB (Table 7). These three treatments maintained for the least cost, as farmers prefer high net benefit with the least cost than high benefit with high cost (CIMMYT, 1988). The value of economic efficiency indicated that sorghum production has an index of 3.18. This means that for every birr 1.00 spent in the production of sorghum integrated fertilizers, birr 3.18 was realized as a net revenue. Therefore, the combined effect of farmyard manure (10 t ha^{-1}) and inorganic fertilizer (150% NPS + N 46 kg ha^{-1}) recommended for the farmers, as this treatment were with high net benefit and lower cost of production.

Table 7. Partial budget analysis of sorghum by the effect of farmyard manure and inorganic fertilizers in Assosa district during 2020 and 2022.

Treatments	UGY (t ha^{-1})	AGY (t ha^{-1}) (12%)	ADBY (t ha^{-1}) (12%)	TR (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	Economic Efficiency
IF_0FYM_0	0.63	0.60	1.07	3012.09	1796.15	1215.94	1.68
IF_1FYM_1	0.81	0.77	1.20	9658.5	3601.51	6056.99	2.68
IF_2FYM_3	1.79	1.65	2.14	20184.2	7190.44	12993.73	2.81
IF_4FYM_3	3.98	3.80	4.28	35962.7	11322.5	24640.14	3.18
IF_4FYM_4	3.43	3.41	3.84	23685.5	12973.2	10712.3	1.82
CV (%)		32.74					
LSD		0.82**					

Note: *UGY= Unadjusted grain yield; AGY = Adjusted grain yield; ADBY = Adjusted dry biomass yield; TR = Total revenue; TVC = Total variable costs; NB = Net benefit; ETB ha^{-1} = Ethiopian Birr per hectare.*

4. Conclusion

The results of this study have showed that the integrated use of 150 % NPS +46% N ha^{-1} with 10 t FYM ha^{-1} produced the highest grain yield. The highest net benefit (24,640.14 Birr) was obtained from the same treatment interaction during two cropping seasons. In addition, application of 15 t FYM ha^{-1} and 50% of NPS + N 46 kg ha^{-1} was produced the next highest (12,993.73 ETB) net benefit, which is also economically feasible. Therefore, it is concluded that applying 150 % NPS + N 46 kg ha^{-1} with 10 t FYM ha^{-1} to Assosa1 sorghum variety is the optimum fertilizer rate to get economical grain yield in the study area and other similar agro-ecology in both years. The results imply that the productivity of sorghum is determined by the availability of sufficient N, P, S in the soil supplied as fertilizer in the study area. The results also indicate that the availability of OC, N, P, S and CEC in the soil during the growing period is also a vital prerequisite for enhanced production of the crop. Thus, the integration of organic and inorganic fertilizer is the best for producing the crop in the study area with the aforementioned rates of the fertilizers. Farmers in the study area should, therefore, be advised to use Assosa1 sorghum variety and the aforementioned fertilizer rates to produce the best yield. Further research should be conducted to investigate long term effects of integrated fertilizers on sorghum productivity across various locations and growing years.

5. Acknowledgements

The authors thank Ministry of Science and Higher Education for financing the research, Assosa University and Assosa soil laboratory technical assistants for providing support during field management, data collection and laboratory analysis.

6. References

Amma, M. 2003. Plant and soil analysis. Pp. 125-129. *In*: Jasiwal, P. (ed.), Soil plant and water analysis. Kalyani Publishing, New Delhi.

Assosa Agricultural Research Center (AARC). 2017. Annual report. Assosa Agricultural Research Center, Assosa, Ethiopia.

Azrag, A. and Dagash, Y. 2015. Effect of sowing date and nitrogen rate on growth, yield components of sorghum (*Sorghum bicolor* L .) and nitrogen use efficiency. *Journal of Progressive Research in Biology*, 2(2): 78–87.

Biya Muhidin. 2018. Determination of nitrogen and phosherous fertilizer requirement for sorghum (*Sorghum bicolor* L .) production in Kersa-Jimma Zone of Ethiopia. *East Africa.Journal of Biology, Agriculture and Health Care*, 8(7): 14–22.

Bodena Guddisa, Kebeda Desalegn, Chemeda Birhanu, Gudeta Bedada and Girma Chemeda. 2021. Effect of NPS and nitrogen fertilizer rate on yield and yield components of sorghum in Western Oromia, Ethiopia. *International Journal of Agriculture, Forestry and Fisheries*, 9(2): 12–16.

Berhane Shibabaw, Ketema Belete and Taye Tegegn, 2015. Effect of cowpea density and nitrogen fertilizer on a sorghum-cowpea intercropping system in Kobo, Northern Ethiopia. *International Journal of Agriculture and Forest*, 5: 305–317.

CSA (Central Statistical Agency). 2020. Agricultural sample survey report on area and production of major crops (Private peasant holdings 'meher' season): Statistical Bulletin 585. Addis Ababa, Ethiopia.

CIMMYT (International Maize and Wheat Improvement Center). 1988. From agronomic data to farmer recommendations: An economic work book. CIMMYT, Mexico.

Cui, S., Zhu, X. and Cao, G. 2022. Effects of tillage on soil nitrogen and its components from rice-wheat fields in subtropical regions of China. *International Journal of Agriculture and Biological Engineering*, 15(3): 146–152.

Dagne Chimdesa. 2016. Blended fertilizers effects on maize yield and yield components of Western Oromia, Ethiopia. *Agriculture and Forest Fish*, 5: 151–162.

Daniel Hailu and Rozina Gidey. 2022. Yield trends and yield gap analysis of cereal crops in Ethiopia: Implications for research and policy. *International Journal of Agricultural Economics,* 7(5): 222–226.

Deekshitha, D.K.D., Babu, P.R. and Madhuvani, P. 2017. Effect of fertilizer levels and sulphur on soil properties in clay loam soil. *Plant Archives*, 17(2): 846–850.

Elamin, A.Y. and Madhavi, K. 2015. Influence of integrated nutrient management on growth and yield parameters of kharif sorghum *(Sorghum bicolor* L. Moench*). American Journal Scientific and Industrial Research*, 6: 90–96.

EthioSIS (Ethiopian Soil Information System). 2014. Soil fertility status and fertilizer recommendation atlas for Tigray regional state, Ethiopia. Addis Ababa, Ethiopia.

FAO (Food and Agricultural Organization). 2022. *World Food and Agricultural - Statistical Yearbook 2022*. Rome, Italy. Available at https:doi.org/10.4060/cc2211en.

Fisher, A.R. 1935. The design of experiments. Oliver and Boyd, Edinburgh. Pp. 256.

Gebremeskel Gebrekorkos, Yemane G. Egziabher and Solomon Habtu. 2017. Response of sorghum varieties to blended fertilizer on yield, yield component and nutritional content under irrigation in Raya Valley, Northern Ethiopia. *International Journal of Agriculture and Bioloscience,* 6(3): 153–162.

Gebreyesus Brhane. 2012. Effect of tillage and fertilizer practices on sorghum production in Abergelle Area, Northern Ethiopia. *Journal of Science*, 4(2): 52–69.

Getahun Dereje, Tesfa Bogale, Cherukuri,V., Bogale Walelegn and Arvind, B. 2016. On-farm productivity response of rainfed grain sorghum (*Sorghum bicolor* L.) to integrated nutrient supply system in Assosa Zone, Western Ethiopia, East Africa. *International Journal of Life Sciences*, 4(2): 169–175.

Hazelton, P. and Murphy, B. 2007. Interpreting soil test results (What do all the numbers mean?). CSIRO Publishing, Australia.

Hazelton, P. and Murphy, B. 1991. Classifications, Ratings, and critical and toxicity levels of some soil constituent: Collected from différent sources.

Hui, L.I., Wen-ting, F., Xin-hua, H.E., Ping, Z.H.U. and Hong-Jun, G.A.O. 2017. Chemical fertilizers could be completely replaced by manure to maintain high maize yield and soil organic carbon in Northeast China Plain. *Journal of Integrative Agriculture*, 16(4): 937–946.

Jackson, M.L. 2003. Soil chemical analysis. Pp. 106–120. *In*: Jasiwal, P. (ed.), Soil, plant and water analysis. Kalyani Publishers, New Delhi.

Kinfe Hailegebrial and Tesfaye Adane. 2018. Yield Performance and adoption of released sorghum varieties in Ethiopia. *Edelweiss Applied Science and Technology*, 2(1): 46–55.

Kisinyo, P.O., Gudu, S.O. and Opala, P.A. 2019. Response of sorghum (*Sorghum bicolor* L.) and chemical characteristics of soil to organic and inorganic fertilizers on Kenyan lower midlands acid soil. *International Journal of Plant & Soil Science*, 28(1): 1–8.

Kumar, B.M., Labanya, R. and Joshi, H.C. 2019. Influence of long-term chemical fertilizers and organic manures on soil fertility. A Review. *Universal Journal of Agricultural Research*, 7(5): 177–188.

Muhammad, I., Muhammad, J.K., Amjad, A., Amanullah, J. and Sajida, P. 2015. Effect of phosphorus and sulfur on the yield and nutrient uptake of maize. *International Journal of Farming and Allied Sciences*, 4(3): 244–252.

Nebyou Masebo and Muluneh Menamo. 2016. The effect of application of different rate of N-P fertilizers rate on yield and yield components of sorghum (*Sorghum bicolor*). *Journal of Natural Sciences Research*, 6(5): 88–94.

Nikus, O., Turk, M.A. and Al-Tawaha, A.M. 2004. Yield response of sorghum (*Sorghum bicolor L.*) to manure supplemented with phosphate fertilizer under semi-arid Mediterranean conditions. *International Journal of Agriculture and Biology*, 6(5): 889–893.

Okalebo, J.R., Gathua, K.W. and Woomer, P. L. 2002. *Laboratory Methods of Plant and Soil Analysis: A Working Manual.* 2nd edition. TSBFUNESCO, Nairobi, Kenya.

Onyari, C., Kibe, A. and Mwonga, S. 2015. Growth parameters of DK8031 maize variety as affected by varying irrigation and nitrogen fertilizer rates in embu county, Kenya. *Journal of Environmental Science and Engineering*, 4(1): 432–444.

Robe Elemawako and Sisay Negash. 2021. Evaluation of different blended fertilizer type on yield and yield components of sorghum crop at Fadis District of East Hararghe Zone.*International Journal of Current Research and Academic Review,* 9(4): 30–38.

Roobroeck, D., Van Asten, P., Jama, B., Harawa, R. and Vanlauwe, B. 2015. Integrated soil fertility management: Contributions of framework and practices to climate-smart agriculture. Copenhagen, Denmark.

SAS (Statistical Analysis of Software). 2016. Institute, "SAS Version 9. 4 ©2002-2003," SAS Institute, Inc., Cary.

Shamme, S.K., Raghavaiah, C.V., Tesfaye Balemi and Hamza, I. 2016. Sorghum (*Sorghum bicolor* L .) growth , productivity , nitrogen removal , N-use efficiencies and economics in relation to genotypes and nitrogen nutrition in Kellem Wollega Zone of Ethiopia, East Africa. *Advances in Crop Science and Technology*, 4(3): 3–10.

Sher, A., Adnan, M., Sattar, A., Ul-Allah, S. and Ijaz, M. 2022. Combined application of organic and inorganic amendments improved the yield and nutritional quality of forage sorghum. *Agronomy*. https:// doi.org/10.3390/agronomy12040896.

Shiferaw Nesgea, Heluf Gebrekidan, Sharma, J.J. and Tareke Berhe. 2012. Effects of nitrogen and phosphorus fertilizer application on yield attributes, grain yield and quality of rain fed rice (NERICA-3) in Gambella, Southwestern Ethiopia. *East African Journal of Sciences,* 6(2): 91–104.

Shuaibu, Y.M., Bala, R.A., Kawure, S. and Shuaibu, Z. 2018. Effect of organic and inorganic fertilizer on the growth and yield of sorghum (*Sorghum bicolor* L. Moench) in Bauchi state, Nigeria. *GSC Biological and Pharmaceutical Sciences*, 2(1): 025–031.

Tekalign Mamo and Haque, I. 1991. Phosphorus status of some Ethiopian soils. III. Evaluation of soil test methods for available phosphorus. *Tropical Agriculture* (Trinidad), 68: 51–56.

Tellen, V.A. and Yerima, B.P.K. 2018. Effects of land use change on soil physicochemical properties in selected areas in the North West region of Cameroon. *Environmental Systems Research*, 7(1): 1–29.

Tilahun Tadesse, Nigussie Dechassa, Wondimu Bayu and Setegn Gebeyehu. 2013. Effects of farmyard manure and inorganic fertilizer application on soil physico-chemical properties and nutrient balance in rain-fed lowland rice ecosystem. *American Journal of Plant Sciences*, 4(1): 309–316.

Tunya, B.A., Lelei, J.J., Ouma, J.P. and Onwonga, R.N. 2014. Changes in soil chemical properties in response to application of phosphorus sources in legume sorghum cropping systems. *Journal of Agriculture and Environmental Sciences,* 3(4): 151–168.

Valentinuz, O.R. and Tollenaar, M. 2006. Effect of genotype, nitrogen, plant density, and row spacing on the area-per-leaf profile in maize. *Agronomy Journal*, 98(1): 94–99.

Walkley, A. 2003. Critical examination of rapid method for determining organic carbon in soils: Effect of variation in digestion conditions and of organic soil constituents. Pp. 72–82. *In*: Jaiswal, P. (ed.). Soil, plant and water analysis.

Weldegebriel Redai, Araya Tesfay and Gebre Egziabher Yemane. 2018. Effect of NPK and blended fertilizer application on yield, yield component and its profitability of sorghum varieties under rainfed condition in north western Tigray. *Life Sciences*, 6(1): 60–68.

Yalemtesfa Firew and Asfaw Adugna. 2017. Participatory varietal selection of intermediate altitude sorghum (*Sorghum bicolor* L. Moench) genotypes in Western part of Ethiopia. *African Journal of Plant Science*, 11(3): 48–53.

Zerssa, G.W., Kim, D.G., Koal, P. and Eichler-Löbermann, B. 2021. Combination of compost and mineral fertilizers as an option for enhancing maize yields and mitigating greenhouse gas emissions from a Nitisol in Ethiopia. *Agronomy*, 11: 11–20.