

Performance Comparison of Sorghum Varieties Treated with NP and NPSZn Fertilizers in the Raya Valley, Northern Ethiopia

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ABSTRACT

The productivity of sorghum, an important staple food crop in Ethiopia, has been constrained by environmental stresses and declining soil fertility, and addressing these constraints improves the productivity of sorghum. A field experiment was conducted in Raya Valley to evaluate the responses of eight sorghum varieties to NPSZn and NP fertilizers and to select the varieties that combine desirable traits. The field experiment was laid out in RCBD in three replications. The varieties showed significant ($p < 0.001$) variations for phenological, agronomic, and physiological traits. Meko and Melkam were the early maturing varieties with different yielding potential. Melkam was the second highest (4808 kg ha⁻¹) yielding variety after Dagnev. Melkam has combined desirable traits, earliness, and high yield, for production in semi-arid drought-prone areas like the Raya valley. The local sorghum varieties outperformed Meko in most traits, which shows their potential use in breeding and production systems. NPSZn and NP fertilizers did not affect the studied traits differently but differed significantly from the zero treatment. The variety × fertilizer interaction effect was significant on most traits except PW, TGW, and GY. NPSZn treatment has increased biomass yield by 18.4% and 8.6% over NP in Gombilu and Dagnev, respectively. High LA and LAI were recorded from the high-yielding varieties, Dagnev and Melkam, and vice versa for low-yielding varieties. It can be concluded that working for varietal selection could be more rewarding than switching the application of NP to NPSZn fertilizer type in the Raya Valley to enhance sorghum production and productivity. The 100 kg ha⁻¹ NPSZn blend recommendation, however, makes a 50% fertilizer price discount. Hence, Melkam from improved and Dagnev from the local varieties had better performance and can be preferably cultivated by farming communities.

Keywords: Blend fertilizer; Leaf area index; Phenology; Physiology; Sorghum varieties; Terminal drought.

1. INTRODUCTION

Sorghum (*Sorghum bicolor* (L) Moench) is among the major staple cereals in the Arid and semiarid environments. It is the fifth major cereal crop in the world in terms of production after maize, wheat, rice, and barley (FAO, 2012). In Ethiopia, it is the third important crop after tef and maize in terms of total area coverage and the fourth after maize, wheat and tef in

Momona Ethiopian Journal of Science (MEJS), V16(1):76-94, 2024 © CNCS, Mekelle University, ISSN:2220-184X

Submitted on: 2nd May 2023

Revised and Accepted on: 7th February 2024

terms of production (CSA, 2015). However, it is second to tef for making several local food stuffs such as *Injera*, *Kitta*, *Nifro*, *Pourage*, processed infant food and local beverages such as *Tella* and *Areke* (MoA, 2010). Besides using its grain for human consumption, the straw can serve as animal feed while its stalk is used as construction material and firewood. The grain analysis showed that it has good nutritional content for essential nutrition types: 69.3-75.99% carbohydrate, 8.2-13.7% protein, 2.48-4.59% fat, 2.61-7.84% fiber, and 1.1-2.29% ash (Masresha and Belay, 2020) and preferred over other cereals. Protein in sorghum is gluten free and thus, it is a specialty food for people who suffer from celiac disease, including diabetic patients and is a good substitute for cereal grains such as wheat, barley, and rye (Dial, 2012).

In Ethiopia, sorghum is grown in almost all regions covering an estimated total arable land area of 1.83 million ha with national average productivity of 2369 kg/ha (CSA, 2015), with a share of 16.1% total cereal crops production. The major sorghum production regions of the country are Oromia (38.5%), Amhara (32.9%), Tigray (14.1%), and Southern Nations, Nationalities and People (S.N.N.P.) region (7.6%) (CSA, 2015). In Tigray, it is mainly produced in southern, central, and western zones (Yemane et al., 2009). In the Raya valley, southern Tigray, it covers an estimated total cultivable area of 40,302 ha with an average productivity of 1930 kg ha⁻¹, which is much less than the national average productivity (CSA, 2015). Sorghum is considered as a rescue crop and is widely produced more than any other crop in moisture deficit areas (MoA, 2010; Asfaw, 2007), which implies that moisture stress is among several factors constraining sorghum production and productivity. In the Raya valley, poor soil fertility, erratic rainfall and lack of improved varieties are the major factors that significantly influence the production and productivity of sorghum. Moisture deficit is the major constraint of rainfed agriculture which coincides with the most sensitive development stages (flowering and grain filling) of the crop and resulting in poor crop performance and low yield (EIAR and TARI, 2011).

Even though sorghum is an important crop in the Raya valley, farmers are forced to depend on few late maturing sorghum varieties (Berhane et al., 2010), probably because the varietal replacement by the national breeding system is low and most of the local farmers' varieties are gradually disappearing. As a result, the farmers in the area have been vulnerable to the recurrent terminal drought occurring in the area. On the other hand, the decline in soil fertility due to cereal based cropping is another factor challenging crop production (Corral-Núñez et al., 2014). Soil fertility has been managed by applying NP fertilizer in the form of UREA and Diammonium Phosphate (DAP) for the last two decades. In most part of Ethiopia,

NP has been applied at a rate of 64 kg ha⁻¹ N and 20.24 kg ha⁻¹ P or 100 kg ha⁻¹ UREA and 100 kg ha⁻¹ of DAP in blanket regardless of the soil type and crop nutrient requirement. Such unbalanced application of plant nutrients may aggravate the depletion of other important nutrient elements such as micronutrients in soils (Fayera et al., 2014). Fertilizer recommendation by Agricultural Transformation Agency (ATA) and Ministry of Agriculture (MoA) based on soil analysis indicated that the soil of Raya Valley is deficient in micronutrients like zinc and iron besides the macronutrients nitrogen, phosphorus, and sulfur (ATA and MoA, 2014). Afterward, the application of blended fertilizers containing either one or two of Sulfur, Zinc, Boron, and Iron became common in Ethiopia. However, the response of crops to the new recommended blend fertilizers and its comparative advantage to application of the accustomed NP, applied as UREA and Diammonium sulphate (DAP), fertilization has not been well studied. This study aimed at i) evaluating the genotypic variation in sorghum varieties under NP and blended NPSZn fertilizers treatment and ii) compare the gain in trait performance in sorghum varieties because of NPSZn fertilizer application over the accustomed NP fertilizer.

2. MATERIALS AND METHODS

2.1. Climatic and Edaphic Characteristics of the Study Area

This field experiment was conducted at Mehoni Agricultural Research center (MhARC) research station during 2016/2017 cropping season (Fig 1). The research station is situated at latitude of 12.70°N and longitude of 39.70°E at an elevation of 1578 meter above sea level (m.a.s.l) in the Raya valley. The area lies in the lowland agroecology classification with semi-arid climate which is almost hot and dry throughout the year. Tef and sorghum are dominantly cultivated because of their adaptation potential.

The annual rainfall in the area ranges from 450 mm to 600 mm which is characterized by uneven erratic distribution, with most of the rain falling in April, July, August, and September (Fig 2; Mehari and Hailu, 2019). The intra – and inter - annual rainfall variability in terms of amount and distribution significantly affects the agricultural sector. For instance, the amount of rainfall received during the crop growing period of 2016 cropping season was only 350 mm and the temperature during the same period ranges from 12.2°C to 23.6°C (Fig 2). The pre-trial soil sample analysis indicated that the soil of experimental site is clay with near neutral (6.89) pH and high (36%) CEC (Hazelton and Murphy, 2007), low nitrogen content (Tekalign, 1991) and low to medium available phosphorus (London, 1991; Olsen et al., 1954). The organic matter content of the soil is 1.92%.

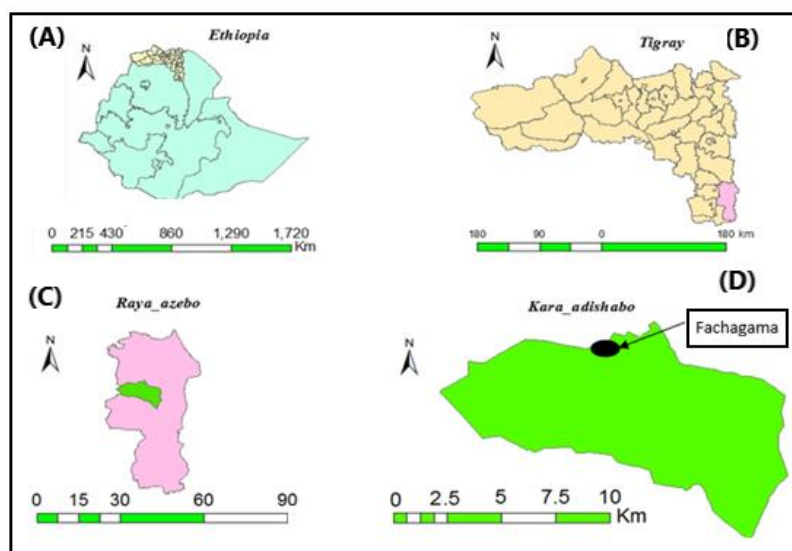


Figure 1. Map of the study area Raya-azebo and the study site Kara-adishabo.

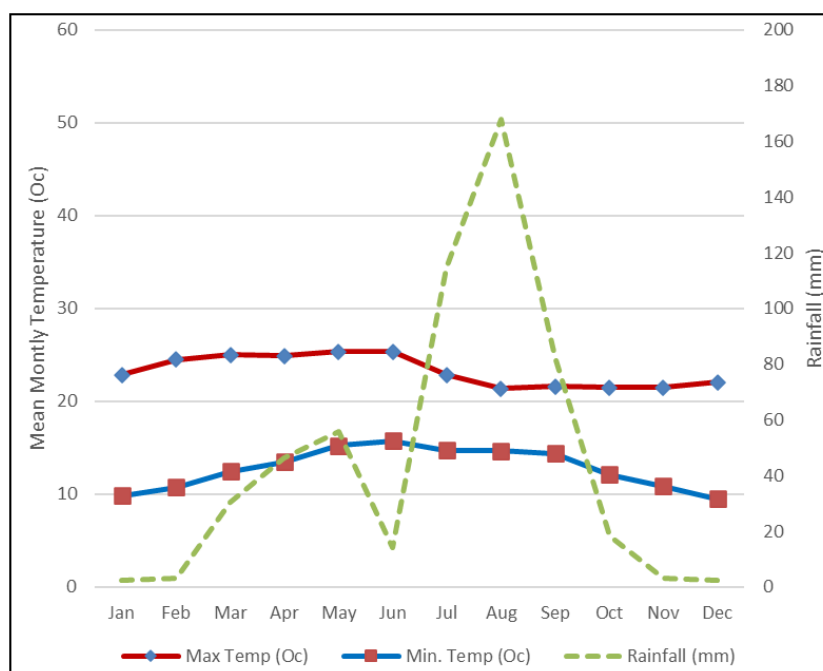


Figure 2. Graph of climate long-term data (1980-2015), Mekoni area, Raya Valley.

2.2. Description of the Sorghum Varieties

Eight sorghum varieties, six local landraces (*America, Dagneu, Gombilu, Kodom, Mereawi, and Woitozera*) and two improved varieties (*Meko and Melkam*) were grown during 2016 cropping season under field conditions. The varieties were selected for variation in their phenology and agronomic characteristics (Table 1). It was supposed that the varieties differently respond to the applied fertilizers [unfertilized (F1), 100 kg/ha of DAP and Urea which is equivalent to 64 kg ha⁻¹N and 20.24 kg ha⁻¹P (NP) (F2) and 100 kg ha⁻¹ of blended

fertilizer NPSZn (17.7N+35.3 P₂O₅ +6.5S +2.5 Zn) (F3)]. *Meko* and *Melkam* were obtained from Melkassa agricultural research center, whereas the local varieties were collected from farmers field in southern and central Tigray during 2015/2016 cropping seasons.

2.3. Treatments and Experimental Design

The eight sorghum varieties, described above, were grown under two fertilizer types of application: the conventional NP at a rate of 64 kg ha⁻¹ N and 20.24 kg ha⁻¹ P each and the new blend NPSZn fertilizer at a rate of 100 kg ha⁻¹ with elemental composition of 17.7 kg ha⁻¹ N, 35.3 kg ha⁻¹ P₂O₅, 6.5 kg ha⁻¹ S and 2.5 kg ha⁻¹ Zn. For comparison purpose, non-fertilized was also included.

Table 1. Characteristics of the tested sorghum varieties (present study).

<i>SN</i>	<i>Name</i>	<i>Release/ collection year</i>	<i>Breeder/ collection wereda/</i>	<i>Status</i>	<i>Maturity group</i>	<i>Days to flowering</i>	<i>Plant height group</i>	<i>Seed color</i>
1	Meko	1997	MARC	Improved	Early	65	short	white
2	Melkam	2009	MARC	Improved	Early	78	short	white
3	America	2016	Alamata	Local	Medium	87	tall	reddish brown
4	Woitozera	2016	Mereb-Leke	Local	Medium	68	tall	dark brown
5	Gombilu	2016	Alamata	Local	Medium	87	Tall	deep yellow
6	Kodom	2016	Mehoni	Local	Medium	92	Tall	light yellow
7	Mereawi	2016	Tankua Abergele	Local	Medium	92	Short	white
8	Dagnew	2016	Abergele	Local	Medium	85	Tall	white+scattered red

Note: MARC = Melkassa Agricultural Research Center; Maturity group: early<120 days; medium: 121 – 150 days; late: >151 days (local area classification); Height group: <150cm = short; 151 – 200cm = medium; >201cm = tall (local area classification).

Varieties and fertilizers were arranged in factorial randomized complete block design (fRCBD) whereby each treatment was replicated thrice. The trial was laid out on 810 m² plot size, where the size of individual plot was 11.25 m² (3.75 m x 3 m) with inter- and intra-row spacing of 0.75 m and 0.20 m, respectively (Adugna et al., 2005; Wilson and Myers, 1954). Blocks and plots were separated by gang way of 1.5 m and 1 m, respectively. The three central rows were used for all agronomic data recording.

2.4. Field Management

Seedbed preparation was done following standard procedures from June until planting time in July using tractor traction. The trial was manually planted on 25th July 2016 in rows whereby the seeds were placed at 5 cm depth by drilling hole at a rate of 2 seeds per hole (Adugna et al., 2005). After emergence, the number of seedlings per hole was reduced to one by hand thinning to avoid unnecessary competition among plants and to adjust the number of plants per plot. Fertilizer treatments were applied at planting with full dose of the blend fertilizer

and DAP and half dose of UREA. The remaining half dose of UREA was top dressed when the crop reached at knee height. Weeds were maintained at bay throughout the trial period using manual weeding. Stalk borer was controlled by applying soluble Karate Insecticide (Lambda Cyhalothrin 5% EC), which was applied twice uniformly to all plots at a rate of 300 ml/ha, as per the manufacturer guideline. The Raya Valley is severely moisture stressed area which is affected by terminal drought frequently (Fig 2). Hence, the rainfall of the area could not fully provide the water required to support the complete sorghum growth life span. Supplementary irrigation was, therefore, applied twice at ten days interval to all varieties to alleviate soil water shortage at critical developmental stages of the crop up to maturity after the rainfall completely stopped.

2.5. Data Collection

The phenology traits such as days to 50% flowering (DF), days to heading (DH) and days to maturity (DM) were recorded on plot basis after 50% of the plant population reached the respective phenology. DM was recorded after the plants completed their physiological maturity at growth stage 9, confirmed by inspection of the black layer formed on the kernel. The other traits such as plant height (PH), panicle length (PL) and leaf area index (LAI) were collected from five randomly sampled and tagged plants. Plant height was measured in cm from the ground soil surface to the tip of the panicle and panicle length was also measured from the lower panicle branch to the tip of the panicle as described in Boukrouh et al. (2023). The LAI was calculated as the ratio of unit leaf area to unit ground area covered, as described by Watson (1958), at heading stages.

The panicles of the five randomly selected and tagged plants per plot were bulk harvested to determine head grain weight per plant (g plant^{-1}). Head grain weight per plant was measured at adjusted moisture content to 12.5% using Digital Grain Moisture Meter (Satake, UK). After recording the head grain weight, 1000 kernels were manually counted and weighed on electronic sensitive balance (Sartorius, Germany). Grain yield (GY) in kilogram per hectare (kg ha^{-1}) was measured by harvesting the central two rows per plot. GY was weighed using the same electronic sensitive balance used to weigh TGW and then converted to kg ha^{-1} . Similarly, the above ground biomass (BY), in kg ha^{-1} , was recorded from the two central rows by harvesting all the plants from the ground and sun dried for equal days to remove the water content.

2.6. Data Analysis

The raw data, after checking for normality and homogeneity, was analyzed for variance using GenStat statistical software version 14 (Payne et al., 2011), following factorial

randomized complete block design procedure. This analysis allowed us to examine the main effects and the interaction effects between genotypes and applied fertilizer types. For significant effects, means were compared using least significance difference (LSD) at 5% significance level. While main effects results were presented in tabular form, the interaction effects results were presented graphically to make its visualization easier. The mean value of each variety by fertilizer combination was used to construct the bar graphs using excel graphing features with standard deviation used to assign error levels on each bar.

3. RESULTS

3.1. Genotypic Variation for Agronomic, Phenological and Physiological Traits

The tested sorghum varieties showed highly significant ($p < 0.001$) variations for all measured agronomic, phenological and physiological traits (Table 2). The magnitude of variation in the measured traits helps to select varieties that combined desired traits for Raya valley areas, which is affected by frequent terminal drought. The flowering time was ranged from 65.33 days (for variety Meko) to 92.22 days (for variety Mereawi) (Table 3), with a difference of 27 days between the two varieties. Meko was the earliest maturing variety with 101.44 days followed by Melkam (~113 days). On the other hand, Kodom took longer time (141 days) to mature and was late by 40 and 28 days compared to Meko and Melkam, respectively. This showed that there has been genetic diversity in the tested sorghum varieties for phenological traits variations.

Table 2. Mean square values from analysis of variance for phenological‡, agronomic§ and physiological§ traits due to variety, fertilizer rates and their interaction effects.

Source of variation	d.f	DH	DF	DM	PH	PL	PW	BY	GY	TGW	LA	LAI
Rep	2	2	50.42	10.94	1551.7	10.48	288.50	8679726	1061543	18.78	4729945	2.11
Variety(V)	7	905 ^c	964.21 ^c	1742.78 ^c	22640.2 ^c	133.55 ^c	496.45 ^c	74062390 ^c	5208059 ^c	251.90 ^c	15879923 ^c	7.10 ^c
Fertilizer rate (FR)	2	11 ^a	3.55 ^a	18.62 ^c	3125.2 ^c	22.51 ^c	902.22 ^c	36795045 ^c	4356665 ^c	55.46 ^c	1051513 ^b	0.47 ^b
V×FR	14	7 ^b	8.47 ^c	4.77 ^c	649.8 ^c	7.38 ^b	56.36 ^{ns}	3982365 ^b	262689 ^{ns}	3.34 ^{ns}	323147 ^a	0.15 ^a
Error	44	3	1.04	1.255	103.8	2.88	60.77	1470032	196797	2.70	148721	0.07

Note: ^a = significant at 5% significance level, ^b = significant at 1% level of significance, ^c = significant at 0.1% level of significance, ^{ns} = non-significant.

‡ DH= Days to heading; DF = Days to flowering, DM=Days to 90% physiological maturity, § PH= Plant height, PL = panicle length, PW = panicle weight, BY = Biomass yield, GY= Grain yield, TGW = 1000 grain weight, § LA= leaf area, and LAI= leaf area index.

Table 3. Best linear unbiased predicted means of phenological, agronomic and physiological traits of sorghum because of varieties and fertilizer types.

Factor	Entry	DH	DF	DM	PH (cm)	PL (cm)	PW (g)	BY (Kg ha^{-1})	GY (Kg ha^{-1})	TGW (g)	LA (cm 2)	LAI
Varieties	America	77.61	86.73	135.11	256.7	23.07	85.56	17111	4593	48.56	5622	3.75
	Dagnew	78.41	85.45	135.72	218.6	29.18	81.20	13777	5878	48.86	4773	3.18
	Gombilu	79.36	87.06	133.83	221.1	25.16	88.42	16719	4793	47.78	4592	3.06
	Kodom	83.29	91.83	140.89	279.9	29.74	91.36	15852	4504	51.67	7270	4.85
	Meko	58.67	65.33	101.44	158.5	24.29	83.07	9108	3930	37.71	3831	2.55
	Melkam	71.56	77.56	112.72	152.2	30.84	99.53	10703	4808	37.67	6231	4.15
	Mereawi	83.75	92.22	137.61	143.1	25.60	75.20	12407	3226	44.66	4801	3.20
	Woitozera	59.16	68.15	124.11	216.0	19.37	81.47	12926	4696	48.61	3082	2.05
LSD (5%)		1.57	0.99	1.07	9.76	0.61	7.30	1154.3	421.5	1.57	366.9	0.24
Fertilizer	Control	73.40	81.42	126.67	192.6	24.79	78.76	12150	4067	44.04	4790	3.19
	NP	74.72	82.19	128.25	213.3	26.44	88.12	14194	4730	45.99	5096	3.40
	NPSZn	73.81	81.77	128.13	211.3	26.49	90.30	14382	4863	47.03	5190	3.46
LSD (5%)		0.96	0.60	0.66	5.98	0.99	4.53	706.8	258.1	0.96	224.7	0.15

Note: DH= Days to heading, DF= Days to flowering, DM= days to 90 % physiological maturity, PH = Plant height PL = panicle length, PW = panicle weight, BY = Biomass yield (kg ha $^{-1}$), GY = Grain yield and TGW = 1000 grain weight, LA = leaf area, LAI = leaf area index.

The difference in the tested sorghum varieties for other traits such as PH, PL, PW, BY and GY, was highly significant ($p < 0.001$). The mean difference in PH ranges from about 2.6m for variety America to 1.43m for variety Mereawi. Consequently, the highest BY was recorded from the tallest variety, America while the other shorter variety, Meko, gave the lowest BY which implies that BY linearly associates with plant height (Table 3). The extent of variation among the varieties for PL and PW was large where the longest (31cm) and most compact (99.5cm) panicle was recorded from the variety Melkam while the shortest (18.37 cm) and lighter (75.2 gram) panicle was recorded from Dagnew and Mereawi respectively (Table 3). It is well accepted that yield components such as PL and PW are indicators for varietal yield performance.

The result showed that the highest (5878 kg ha $^{-1}$) GY was obtained from Dagnew and the second highest (4808) GY was obtained from Melkam variety, which is early maturing next to Meko and having long and dense panicle (Table 3). On the other hand, the lowest (3930 kg ha $^{-1}$) GY was obtained from Meko, the earliest maturing variety. The early maturing varieties, Meko and Melkam, have produced lighter seeds compared to the other varieties. The late maturing variety, Kodom, has produced the heaviest (51.67) grains compared to the other varieties, which might imply that this variety benefited the most from the supplementary irrigation in extending its grain filling period. The knowledge of varieties performance for LA and LAI in the drylands is very important to select resource use efficient varieties.

This study showed that the LA and LAI of the tested sorghum varieties ranged from 7270 (Kodom) to 3083 (Woitozera) and 4.85 (Kodom) to 2.05 (Woitozera), respectively (Table 3). Grain yields of field crops are dependent on their rates of growth and on the efficiency with which they partition dry matter to the different plant organs. Low yielding varieties, Meko and Dagneu, had lower LA and LAI while the high yielding varieties Dagneu and Melkam varieties had high LA and LAI values (Table 3). Leaf area (LA) and leaf area index (LAI) are important indicators of radiation and precipitation interception, energy conversion and water balance.

3.2. Effect of Fertilizer Types on Phenological, Agronomic and Physiological Traits

The effect of fertilizer ranged from significant ($p < 0.05$) on DH and DF to highly significant ($p < 0.001$) on the remaining traits implying that the difference in response to applied fertilizers inflicted during grain filling stages (Table 2). Both NP and the new NPSZn have affected the performance of sorghum varieties over the control (Table 3). NP fertilizer significantly affected phenological traits (DB, DF, and DM) when compared with the control, while NPSZn did not affect these traits significantly compared to the control. NP and NPSZn fertilizers have improved the performance of agronomic and physiological traits over the check but it didn't show statistically significant effect due to the two fertilizers on most of the traits except on PH and LAI. Averaged over genotypes the tallest (213.3 cm) plant was recorded from plots treated with blanket NP application. On the other hand, the highest LAI (3.46) was recorded from NPSZn treated plants.

The applied fertilizer types improved the yield and yield components of the sorghum varieties over the unfertilized plots. The mean PL and PW due to the application of NPSZn increased by 2 cm and 11.54 grams, respectively over the unfertilized performance. Averaged over genotypes, the mean BY, which is important for livestock feed and fencing in some cases, has increased by 18.4% and 16.8% due to application of NPSZn and NP fertilizers, respectively. Similarly, an increase of 19.6% and 16.3% for GY was obtained from application of NPSZn and NP, respectively over the control (Table 3). The current study found that application of both types of fertilizers had significant effect on GY, BY and other related traits.

3.3. Genotype (G) × Fertilizer (E) Interaction Effect on Sorghum Traits

The analysis of variance showed that the important traits such as PW, GY and TGW were not significantly affected by the interaction effect of genotypes (G) and applied fertilizers (E). (Table 2). However, DH, DF, DM, LA, LAI, PH, PL and BY were significantly affected by G×E effects. The varieties Meko, Melkam and Woitozera reached each of the phenological

traits earlier than the rest varieties under both fertilizer types (Fig 3). They head, flower, and mature earlier than the other varieties.

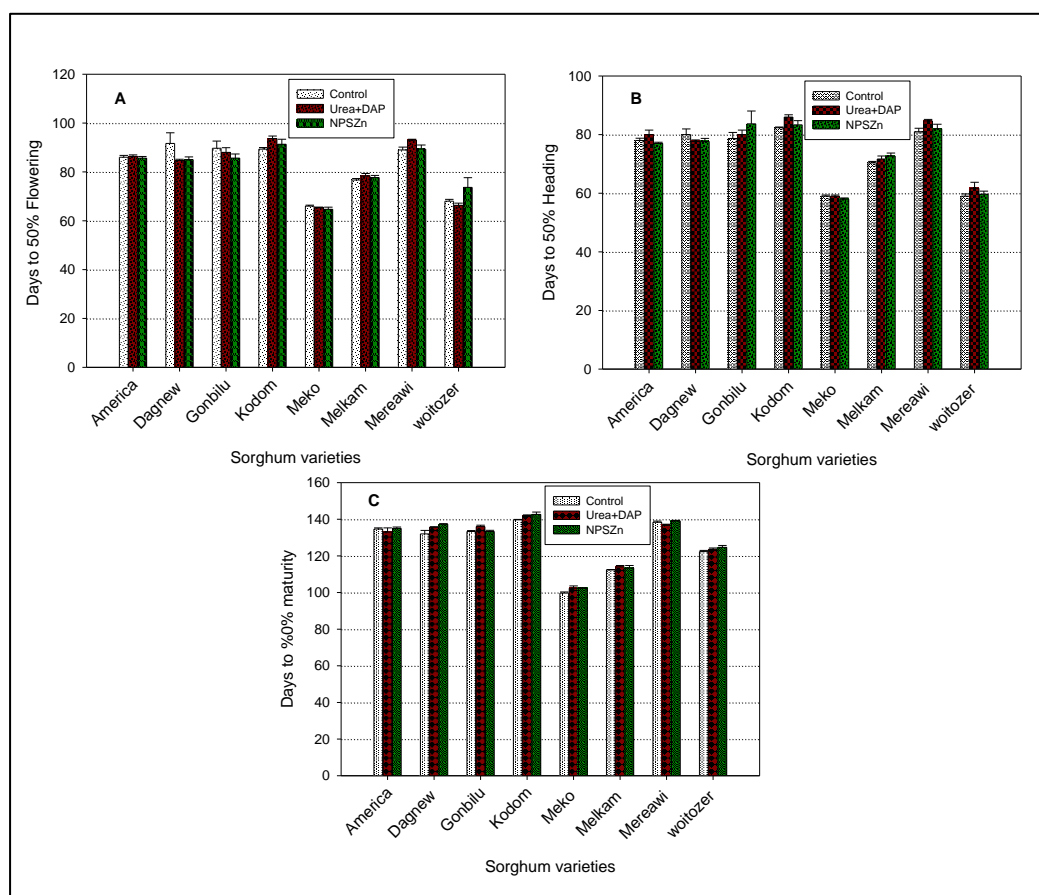


Figure 3. Sorghum Genotypes interaction with applied fertilizers effect on sorghum phenological traits DF (A), DH (B) and DM (C) under unfertilized (control), 100 Kg ha^{-1} NP combinations and NPSZn blend (17.7 Kg ha^{-1} N, 35.3Kg ha^{-1} P $_2$ O $_5$, 6.5 kg ha^{-1} S and 2.5Kg ha^{-1} Zn).

The effect of the applied fertilizer seems similar across varieties except for variety *Gombilu* for which the DH, DF and DM showed decrease under NPSZn fertilizer treatment (Fig 3). Variety *America*, *Kodom*, *Mereawi* and *Dagnaw* matured late under all fertilizer treatment and might not be suitable for moisture stressed areas like Raya valley. The variety *Meko* is super - early maturing followed by variety *Melkam* under all the three fertilizer treatments which might imply that their earliness could be genetically determined.

Four of the eight varieties showed a significant varietal difference for the variety by fertilizer interaction (G×E) effect on PL trait in their response to the applied fertilizer (Fig 4). The PL of varieties *America*, *Woitozera*, *Mereawi* and *Dagnaw* responded positively to the applied NP and NPSZn fertilizers (Fig 4). The shortest PL was recorded from the unfertilized plants. However, there was no clear effect observed on PL due to interaction between some

varieties, such as Gombilu, Kodom, Meko and Melkam, and the applied fertilizers. Similarly, the change in PH and BY due to applied fertilizers showed great variation across tested varieties. The tallest plants were recorded for varieties America and Gombilu treated with NPSZn fertilizer than under the treatment of NP or zero control for the same varieties (Fig 4). However, for Dagnev variety the tallest PH was recorded from NP treatment. The remaining varieties did not show significant difference in their PH due to fertilizer variety interaction effects.

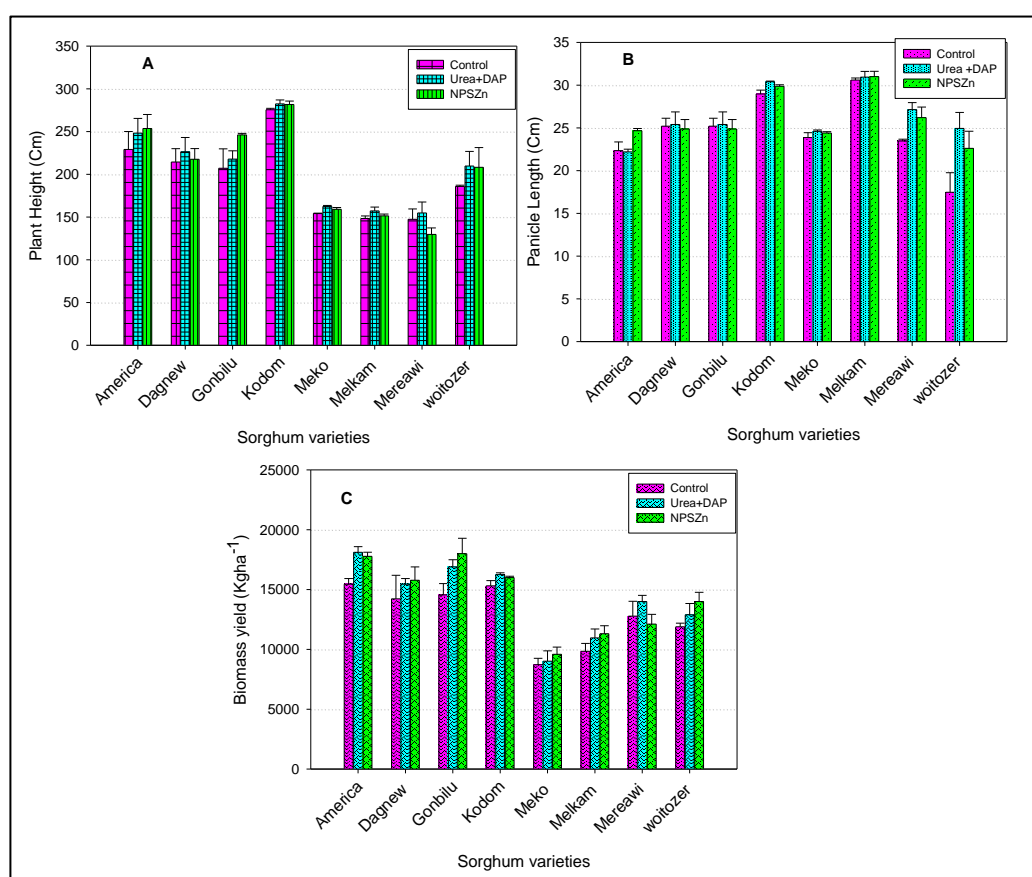


Figure 4. Sorghum Genotypes interaction with applied fertilizers effect on sorghum PH (A), PL (B) and BY (C) traits under unfertilized (control), 100 Kg/ha⁻¹ NP combinations and NPSZn blend (17.7 Kg/ha⁻¹N, 35.3Kg/ha⁻¹ P₂O₅, 6.5 kg/ha⁻¹ S and 2.5Kg/ha⁻¹ Zn).

The BY of sorghum varieties was significantly affected by the applied fertilizer types (Table 2; Fig 4). The degree of its increment due to the applied fertilizers greatly differed from variety to variety. In Gombilu and Woitozera the application of NPSZn increased the BY by 18.4% and 8.6%, respectively over NP treated plants. Compared to the unfertilized plants, BY increment of 50.6% and 17.8% was obtained in these varieties due to NPSZn application. On the other hand, some varieties such as Dagnev and Mereawi responded well

to NP fertilization (Fig 4). The results showed that there is genetic difference among the sorghum varieties in their response to the applied fertilizer types. Yet, the magnitude of the interaction effect between varieties and fertilizer types on PW, TGW and GY was not statistically significant despite larger numerical differences recorded (*data not shown*).

Similarly, the interaction between varieties and fertilizer types imposed significant ($p < 0.01$) effects on physiological traits: LA and LAI (Table 2). The result from the V×E effects on LA and LAI was presented in figure 5. The highest LA and LAI under all fertilizer treatments were obtained from Kodom while the lowest values were recorded from Woitozera. Varieties like America, Meko, Melkam and Mereawi responded differently to the different fertilizers (Fig 5). The highest mean LA and LAI were obtained from NPSZn treated plants for America, Meko and Melkam while NP treated plants recorded the highest LA and LAI values for Mereawi variety. In Woitozera variety it seems that application of both NP and NPSZn reduced the LA and LAI, which is unexpected result.

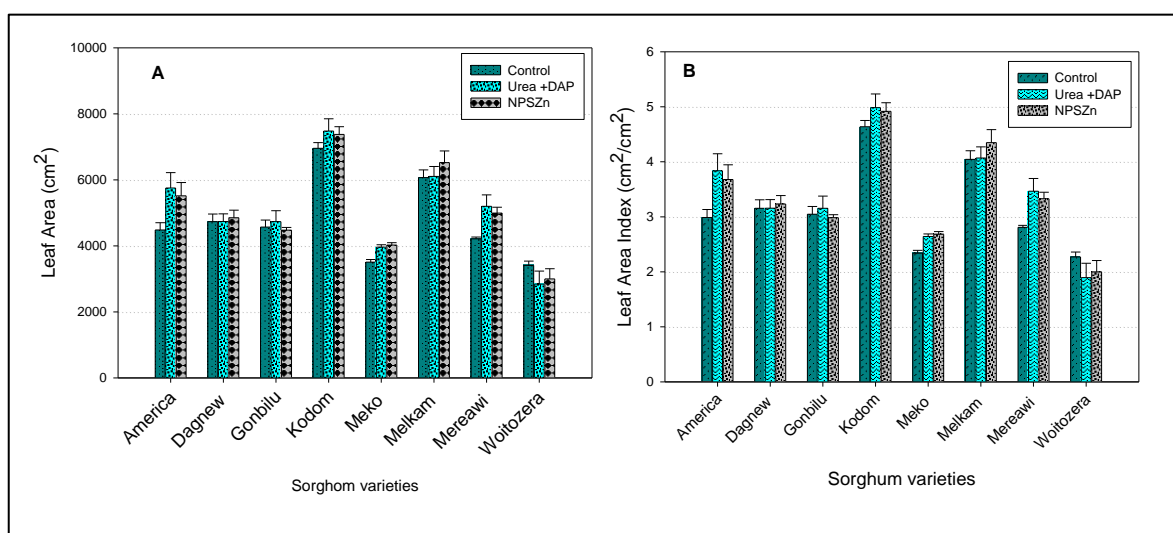


Figure 5. Effect of sorghum genotypes and fertilizers interaction on sorghum physiological traits (A=LA and B=LAI). Control= unfertilized, 100 kg ha⁻¹ NP combinations and NPSZn blend fertilizer (17.7 kg ha⁻¹ N, 35.3 kg ha⁻¹ P₂O₅, 6.5 kg ha⁻¹ S and 2.5 kg ha⁻¹ Zn).

4. DISCUSSION

The eight sorghum varieties are genetically different for the studied phenological, agronomic and physiological traits; this is in par with the work of Boyles et al. (2019). Variability for phenological traits especially maturity time is very important trait in dryland farming systems where terminal drought is a major production constraint. This genetic variability can be exploited by growers and breeders to respond to the impact of climate change on crop production. In Raya valley, identification of early maturing varieties for any crop is

rewarding as the crop growth period is shorter than 100 days (NAM 2017). The maturity time of sorghum varieties currently tested ranged from 101.4 days for Meko to 140.9 days for Kodom variety with a maturity time difference of 39 days. Meko and Melkam varieties matured in less than four months. Previous studies conducted in the drought prone parts of eastern Hararghe and Wag-Lasta reported that Meko and Melkam were the earliest maturing and high yielding varieties respectively among the tested varieties (Abdusalam et al., 2018; Assefa et al., 2020).

This implies that the earliness of Meko and yielding potential of Melkam could be repeatable over environments and can be concluded that earliness in Meko and high yielding of Melkam could be genetically controlled. Our result showed that the local varieties were late maturing compared to the two improved varieties. Melkam was the second early maturing and second high yielding variety (Table 3). The tallest PL and densest PW was recorded for Melkam variety while the shortest PL and lighter PW were recorded for Woitozera and Mereawi varieties, respectively. The result presented in Table 3 showed that the genetic variation for GY ranged from 3930 kg ha⁻¹ for Meko, an improved variety, to 5878 kg ha⁻¹ for Dagneu, a local sorghum variety. The second-high yielding (4808 kg ha⁻¹) was Melkam which was also the second early maturing variety. The combination of earliness and high yielding capacity makes Melkam the most preferred variety in dryland environments. The current result agreed with other scholars finding who reported the superiority of Melkam variety for GY in moisture stressed areas (Assefa et al. 2020; Abdusalam et al., 2018).

The genotypic variation for BY ranged from 9108 kg ha⁻¹ for Meko variety to 17111 kg ha⁻¹ for America variety (Table 3). It was observed that the improved varieties had lower BY compared to the local varieties presumably due to their shorter height. Variation in sorghum varieties for BY was reported by other scholars as well (Assefa et al., 2020; Fantaye and Hintsa, 2017). The genotypic variation for TGW ranged from 37.67 g to 51.67 g for Melkam and Kodom varieties, respectively, which imply that the local sorghum varieties produced heavier seeds than the two improved varieties (Table 3). The variations observed in yield and yield related traits could be due to variation in growth parameters like LA and LAI. The varieties showed significant variation for LA and LAI whereby the highest LA (7270 cm²) and LAI (4.85) were recorded from Kodom variety while the lowest LA (3082 m²) and LAI (2.05) were recorded from Woitozera variety. Variety Melkam had the second highest LA (6231 cm²) and LAI (4.15). Such genetic variations in sorghum varieties for LAI is important as LAI influences photon capture, photosynthesis, assimilate partitioning as well as

growth and yield formation in crops (Tsialtas and Maslaris, 2008; Rosenthal and Vaderlip, 2004). Genotypic difference in sorghum varieties for LAI was also reported by Olugbemi and Ababyomi (2016).

The effect of applied fertilizer types was apparent on all studied traits (Tables 2 & 3). Although traits from fertilized plants did significantly differ from respective mean values over the unfertilized control, no significant difference existed between plants treated with NPSZn and NP fertilizer. There was slight delay in reaching heading, flowering and maturity time due to application of both types of fertilizers over the control. Similarly, higher mean values for each agronomic and physiological trait were obtained from fertilized plants (Table 3), which shows that the sorghum varieties positively responded to the applied fertilizer regardless of its type. Despite absence of statistical significance numerical advance in mean values of most agronomic and physiological traits was obtained from NPSZn treatment. Previous study conducted on few sorghum varieties involving rates of blended fertilizers and NP reported the absence of significant difference between NPSZn and NP rates on most phenological, agronomic and physiological traits (Gebrekokos et al., 2017). The result shows that sorghum varieties responded well to NP and NPSZn fertilizers even though the response to the two fertilizer types was not substantially separated probably due lack of sufficient rates for NPSZn.

The significant variety \times fertilizers interaction effect was observed for most traits but was not significant on PW, TGW and GY (Table 2; Figs 3-5). The non-significance of variety \times fertilizer interaction effects on PW, TGW and GY does not necessarily indicate the absence of the effect rather it implies the magnitude of variation expressed by $G \times E$ could be small and not sufficiently detected (Saltz et al., 2018). Gombilu and Melkam varieties treated with NPSZn fertilizer matured earlier than under the zero and NP treatments. Woitozera, Meko and Dagnaw varieties have delayed the maturity time under both NP and NPSZn treatments. The results imply that the varieties differently interacted with the applied fertilizers. Among agronomic traits, PL, PH and BY differentially affected by applied NP and NPSZn fertilizers across varieties. In varieties America and Dagnaw, the tallest PL was recorded from plants treated with NPSZN while Kodom and Melkam NP fertilization yielded tallest mean PL (Fig 4). The result showed that the local sorghum varieties tend to interact more with fertilizers than the improved varieties, Meko and Melkam, in contrast to the expectation. Significant difference was observed in PH for America, Gombilu, Mereawi and Dagnaw varieties under NP and NPSZn treatments. NPSZn application has increased PH in America and Gombilu

over the control and NP while NP application surpass the effect of others in Mereawi and Dagneu.

The BY of all varieties was positively affected by the application of NP and NPSZn fertilizers over the unfertilized control. Slightly higher BY was harvested from NPSZn treated plants for Woitozera, Gombilu, Meko and Melkam varieties. On the other hand, the BY of Mereawi and Dagneu was higher under NP treatment. This clearly showed that there could be genetic variations in responses of the varieties to applied fertilizers. These differences in BY due to the fertilizer types might be related to the differential nutrient uptake and translocation under the different fertilizers' treatment (Redai et al., 2018; Kurmar et al., 2010). Gebrekorkos et al. (2017) also reported that some sorghum varieties responded differently to NPSZn and NP fertilizers. In other crops such as Maize, application of blended fertilizers reported to increase productivity (Chimdessa, 2016).

The variety \times fertilizer type interaction effect on physiological traits (LA and LAI) was significant (Table 2; Fig 5). The LA of America and Meko varieties were higher under NPSZn treatment while no clear difference observed for other varieties under NPSZn and NP treatment (Fig 5). The LAI of America, Kodom, Meko, Melkam and Mereawi were affected by NPSZn and NP fertilizations. However, there were no clear effects observed for Gombilu and Dagneu varieties due to fertilizer application over non-fertilization. The result showed that there is a clear genetic effect in determining sorghum varieties response to applied fertilizer. The differential effect of NPSZn and NP fertilizers on LA and LAI of sorghum varieties was also reported by other scholars (Gebrekorkos et al., 2017; Addai and Alimiyawo, 2015).

5. CONCLUSION

There was vast genetic variation among the tested sorghum varieties for phenological, agronomic and physiological traits. The improved varieties, Meko and Melkam, matured earlier than the local varieties. Melkam can be considered as best variety for Raya valley area, prone to terminal drought, for combining earliness and high yielding. Application of NPSZn and NP fertilizers could bring different degree of performance improvement in sorghum varieties. Averaged over varieties, application of NPSZn and NP fertilizers has produced a yield advantage of 19.6% and 16.3% over the unfertilized control, which implies that fertilizer application is an important management practice in sorghum production. The non-significant effect of variety \times fertilizer interaction on some traits such as PW, TGW and

GY does not necessarily indicate the absence of the interaction effect rather it implies the magnitude of variation expressed by G×E could be small and not sufficiently detected.

However, the other traits such as DH, DF, DM, PL, PH, BY, LA and LAI exhibited significant genotypes × fertilizer interaction showing that the variation explained by the interaction effect was substantial. That means genotypes differ in their trait value more under one form of fertilizer treatment than under the other treatment indicating that genotypic variation in response of applied fertilizer is plastic. The local variety Dagnev and the improved variety Melkam are the most preferred for GY but Melkam could be the favorite variety as it combined earliness, high GY and exhibited leaf growth nature and Dagnev from the local had better performance. The blend NPSB is also preferred due to the 50% discount in price because only a 100kg ha⁻¹ is recommended. The widely adopted improved variety Meko was inferior to all local varieties for most agronomic and physiological traits. The result indicates that use of the diverse local sorghum varieties in breeding programs or directly for production through quick participatory varietal selection is important to address the shortage of adaptable sorghum varieties in marginal environments like Raya valley.

6. ACKNOWLEDGEMENTS

The authors duly acknowledge Mekelle University for financially supporting the study. Our sincere thanks to the technical staff of Mehoni Agricultural research center for their assistance in trial follow up and data collection.

7. CONFLICT OF INTEREST

The authors declared no competing interest.

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