International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 21, No. 5, p. 172-183, 2022

INNSPUB

RESEARCH PAPER OPEN ACCESS

Agronomic Response of Sorghum [*Sorghum bicolor* (L) Moench] Variety to Density, Nitrogen and Blended Fertilizer Rates for Yield Components and Seed Quality in Southern Ethiopia

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Key words: Density, Kernel, Production, Seedling, Tiller, Vigour index.

http://dx.doi.org/10.12692/ijb/21.5.172-183 Article published on November 15, 2022

Abstract

Low soil fertility and density are the major yields and seed quality limiting constraints. Therefore, the field experiment was conducted to elucidate the effect of density, nitrogen and NPS rates on yield components and seed quality of sorghum. The treatments consisted of a factorial combination of 4 density, 3 nitrogen and NPS rates laid out in a Randomized Complete Block Design with three replications. The results revealed that days to flowering, maturity, plant height, leaf area, productive tillers, grain yield, 1000 kernel weight, normal seedlings, and vigour index i and ii were significantly affected by the main and interaction effects of nitrogen and NPS fertilizers. The main effects of density influenced days to flowering, leaf area index, grain yield, productive tillers and 1000 kernel weight. Therefore, it could be concluded that the application of 46 kg N, 100 kg NPS ha^{-1} density, of 66 666 plants was economically profitable in the study area.

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Introduction

Sorghum [*Sorghum bicolor* L. Moench] is one of the most important crops in the world. It is considered the fourth cereal crop after maize, wheat and rice (Kumara *et al.*, 2011). In Ethiopia, sorghum is used in various ways. The grain is used for human food in different forms in different parts of the country. It is used as porridge, "*Injera*", "*Kitta*", "*Nefro*", infant food, syrup, and local beverages known as "*Tella*" and "*Areke*" and traditional dishes where it is mixed with legumes. Also the leave, stover and stalk are used for animal feed and further the stalk is also used for the construction of houses and fence, and as fuel. Industrially, the grain is used to manufacture wax, starch, syrup, alcohol, dextrose agar, edible oils and gluten feed (Mamoudou *et al.,* 2006). The productivity of sorghum varies across different parts of the world. The world average yield is 1314 kg ha^{-1}; the yield from developed countries is 3056 kg ha^{-1} and from developing countries is 1127 kg ha^{-1}. The national estimated average grain yield of sorghum in Ethiopia is 2137 kg ha^{-1}. Even though sorghum adapts to wide ecological conditions, the yield remains low under the traditional farming practice (CSA, 2013).

Low soil fertility is one of the bottlenecks to sustaining agricultural production and productivity in Ethiopia. The low productivity of sorghum in developing countries including Ethiopia can be attributed to many factors (CSA, 2005). Among those, chemical fertilizers and plant density are the two important factors that greatly affect the grain yield of sorghum. To maintain high crop production levels and seed quality, the plant population and the nutrient status of the soil have to be maintained through the application of appropriate rates of fertilizer rates Weltz *et al.*, 1998). In most cereal-growing regions of the world, the soils are deficient in essential nutrients, especially nitrogen and phosphorus. Soil moisture without soil fertility and fertilizer without soil moisture are less effective for crop production increment in semi-arid areas (Gebreyesus, 2012). Soil nutrients become depleted due to the leaching of nitrogen, fixation of phosphorus, soil erosion and removal by crops. The low level of chemical fertilizer use, the decline in soil organic matter, and contribute the most to the loss of soil fertility in Sub-Saharan Africa. However, an unbalanced, excess nitrogen supply for sorghum may result in greater weed competition and pest attacks, with substantial losses of production. In addition, the nitrogen not taken up by the crop is likely to be lost to the environment. NPS is deficient in most natural or agricultural soils or where fixation limits its availability. Phosphorus deficiency is invariably a common crop growth and yield limiting factor in unfertilized soils. Imbalanced fertilizer use, especially in terms of phosphate compared with nitrogen, may affect overall agricultural productivity and the economy (Holmgren and Scheffer, 2001).

Nutrient inputs from chemical fertilizers are needed to replace nutrients that are exported and lost during cropping, to maintain a positive nutrient balance (Mafongoya *et al.*, 2006). Of all nutrients; nitrogen, phosphorus and sulfur are the most crop growth and yield-limiting factors in the country (Kidane *et al.*, 2001). Nitrogen with NPS fertilizers is a major input in sorghum production, affecting both yield and quality by influencing those components which have a great contribution in increasing the grain yield of sorghum. Blended fertilizer supplies the required nutrients in a readily available form for immediate plant use (Wondimu, 2004). The use of little or no fertilizer on crops may negatively affect the seed quality of the crop (Tekrony and Egli, 1991). Farmers use nitrogen and NPS fertilizers as a blanket recommendation, which is the same rate of fertilizer application without considering the soil moisture condition and the fertility status of the soil of an area even though soil moisture content and soil fertility status vary from place to place (MoARD, 2003).

Plant population is a variable that can have a significant impact on the net returns of sorghum producers. It can impact the crop yield potential. Weed-sorghum competition is intensified by open canopy structures, while narrow row planting gives sorghum a competitive advantage over weeds and reduces light transmittance to the soil (Fernandez *et* *al.,* 2012). The optimum plant population for higher yield varies according to the growing conditions. The grain yield of sorghum was affected by plant population Ould Ahmed *et al.,* 2007). Sub-standard plant density result in high weeds infestation, poor radiation use efficiency and low yield, while dense plant population on the other hand cause lodging, poor light penetration in the canopy, reduce photosynthesis production due to shading of lower leaves and drastically reduce the yield (Lemerle *et al.,* 2004). Plant population can also affect sorghum water use by altering canopy development. Optimizing plant population based on the potential supply of water minimizes the opportunity for plant water stress that could be caused by high water demand (Yared *et al.,* 2010). The plant population should be high enough to enable plants to extract as much water as possible from the soil profile, but not too high to exhaust it before the grain filling (Tabo *et al.,* 2002).

The nationally recommended spacing for sorghum in Ethiopia is 75 cm by 20 cm between rows and plants, respectively (MoARD, 2003). This row spacing is based on the study of tall and late-maturing sorghum varieties. But, farmers in the semi-arid area of eastern Ethiopia also practice this spacing for both late and early-maturing sorghum varieties without considering nutrient status. This indicates that further study is needed to determine the response of short and early-maturing sorghum varieties in terms of high plant population densities and nitrogen and NPS fertilizer rates. Therefore, the objective of this study was to elucidate the effect of plant population densities, nitrogen and NPS fertilizer rates on grain yield and yield components and seed quality of grain sorghum.

Materials and methods

Description of the experimental sites

The field experiment was conducted in Lemo district, Southern Ethiopia, during the main cropping season of 2019. The site is located at 9° 06' 38" to 9° 14' 24" N latitude and 42° 14' 40" to 42° 19' 18" E longitude with an altitude of 1500 meters above sea level. In the study area, the mean annual maximum and minimum temperature was 28.2°C and 11.9°C, respectively, and the mean annual rainfall of 950 mm (Lemo Woreda Agricultural Office, 2000). The laboratory experiment was conducted at Wachemo University laboratories as per International Seed Testing Association rules and procedure (ISTA, 2008).

Description of the experimental materials

Short and early maturing sorghum variety, namely *"Teshalle"* which was released by Melkassa Agricultural Research Centers in 2002 for the drought-prone area was used as a test crop.

Treatments and experimental design

An experiment with treatments of a factorial combination of four densities (66 666, 76 923, 90 909 and 102 564 plants ha^{-1}), three nitrogen levels (0, 23, and 46 kg N ha^{-1}) in the form of urea and three NPS (0, 50 and 100 kg fertilizer rates. It was conducted using a Randomized Complete Block Design in 4 × 3 × 3 factorial arrangement for the field and a completely randomized design for the laboratory with three replications.

Experimental procedure and field management

Before planting, soil samples were taken from the experimental site according to the appropriate sampling technique and subjected to soil analysis to determine the chemical and physical properties of the soil. The samples were taken from 0 to 30 cm depth of the experimental sites using an auger. While taking the sample, the zigzag method of soil sampling was implemented. A composite sample of 1 kg was prepared from the primary samples through the quartering method.

After passing through the proper drying and grinding processes, a composite sample was sieved with a 2 mm sieve and submitted to the soil laboratory of Wachemo University for the analysis of physical and chemical properties. Total nitrogen, available phosphorus, exchangeable potassium, organic matter, soil pH and soil textures were determined in the laboratory.

The land was prepared by a tractor thoroughly, leveled and made suitable and available for planting. Seeds were drilled in rows at depth of 3-4 cm and thinned at 21 days after sowing to achieve the required population densities. Accordingly, the treatments were assigned randomly. The full dose of NPS and half of the nitrogen fertilizer as Urea for each experimental unit were applied during planting at about 5 cm under the seed in the row and the remaining half of nitrogen fertilizer was applied 45 days after planting (plant reached a knee-height) as side dressing at a distance of 5 cm away from the plant to avoid direct contacts with the plant. Cultivation, weed, disease and pest management practices were carried out for all treatments accordingly as recommended for sorghum.

Each plot size in the experiment was 15 m^2 (4 x 75 m), 13 m^2 (4 x 3.25 m) and 11 m^2 (4 x 2.75 m) for 75, 65 and 55 cm row spacing, respectively. The net harvestable plot size was 8.1 m^2 (2.25 x 3.6 m), 7.02 m^2 (1.95 x 3.6 m), 5.94 m^2 (1.65 x 3.6 m) and 7.215 m^2 (1.95 x 3.7 m) for 75 x 20 cm, 65 x 20 cm, 55 x 20 cm and 65 x 15 cm row spacing, respectively. One border row from each side of the plot and one plant at each end of the harvestable rows were not harvested to avoid the border effects. Distance between blocks was 1.5 m and between plots was 1m in each replication.

Data collection and measurement

Days to 50% flowering: It was recorded as the number of days from sowing until the date on which 50% of the panicles flowered per plot.

Days to 90% physiological maturity: It was taken when 90% of the plants in the plot formed black layer on the sorghum head.

Plant height (cm): It was recorded on five random plants at maturity by measuring the height from the ground to the tip of the panicle.

Number of leaves per plant: It was counted and the average value of 5 randomly taken plants was determined and taken as the number of leaves per plant.

Leaf area: To determine the leaf area per plant, sample leaves were taken from the lower, middle and upper part of the sampled plants and determined by using the method developed by (Sticker *et al.*, 1961).as: LA = L x W x 0.75

Where: LA = Leaf Area; L = Leaf Length; W = Maximum Width of the leaf; 0.75 = Constant or correction factor for sorghum.

Leaf Area Index: The leaf area index was also calculated as the ratio of the leaf area to the respective area of land occupied by the plant.

Panicle length (cm): It was measured from the base to the tip of the panicle at the time of maturity and was determined by taking a sample of 5 plants from the net plot area.

Number of productive tillers: It was taken by counting those tillers which had grains.

Grain yield (kg): It was measured at harvest from the net plot. Grain yield was then recorded on 12.5% moisture basis after converting plot results to yield in kg ha^{-1}.

Thousand kernel weights (g): It was determined from composite samples taken from each net plot of the harvested grain yield. The kernel was counted using an electronic seed counter and the weight was determined by an electronic sensitive balance and adjusted to 12.5% moisture content after measuring the actual moisture content of the seed.

Germination test: The working samples, consisted of 300 pure kernels in three replicates of 100 kernels each germinated in double moist filter paper. The kernels were placed in each of the Petri dishes at a temperature of 25oC under optimum relative humidity for 10 days. The kernels were checked every day and the papers were moistened with distilled water. At the end of the germination period, the seedlings were recorded as normal seedlings; abnormal seedlings; dead kernels and fresh kernels following the protocol described in (ISTA, 2008). The normal seedlings were considered those possessing well-developed and vigorous shoot and root systems. Kernels that germinated but did not fall to the normal seedlings were categorized as abnormal seedlings. Fresh kernels remain firm, apparently viable and un-germinated after the prescribed period. Kernels at the end of the test period are neither hard nor fresh and have not produced seedlings as classified as dead kernels. The percent germination was determined by considering only the proportion of normal seedlings as follows:

$$Germination\ (\%) = \frac{Number\ of\ normal\ seedlings}{Total\ number\ of\ kernels\ sown} \times 100$$

Seedlings shoot and root length (cm): Kernels from the different treatments were germinated as per the standard germination test. At the end of the germination period, shoot and root length of five normal seedlings were measured. Shoot length was measured from the point of attachment to the kernel to the tip of the seedling, and the average shoot length was calculated by dividing the total shoot length by the number of normal seedlings measured. Similarly, the root length was measured from the point of attachment to the kernel to the tip of the root, and the average root length was computed by dividing the total root length by the total number of normal seedlings.

Seedling vigor index i: To determine the seedling vigor index I, seedling lengths (shoot and root length) were measured at the day of final count and determined by: Seed vigor index i = GP x SL; Where: GP = Germination Percentage; SL = Seedling Length.

Seedling vigor index ii: To determine the seed vigor index II, seedling dry weight was taken after the final count in grams using a sensitive balance and determined by: Seed vigor index ii = GP x SDW; Where: GP = Germination Percentage; SDW = Seedling Dry Weight. Seedling dry weight (g): The weight of five normal seedlings randomly taken from normal germination percentage excluding the cotyledons were oven dried at 80^{o}C for 24 hours and then the seedlings were transferred from the oven to desiccators with active silica jel and left for 30 minutes.

The seedling dry weight was determined after the final count in grams using a sensitive balance as per the (ISTA, 2008) procedure and the average seedling dry weight was calculated.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using Gen Stat 15th edition statistical software package. All treatment means were compared using the least significant difference (LSD) test at 5% level of significance

Results and discussion

Soil analysis

(Hazelton and Murphy, 2007) classified soil organic carbon percentages of <1.0, 1.0 – 1.71, 1.72 – 3.0, 3.1 – 4.29, and > 4.3 as very low, low, medium, high, and very high, respectively. Similarly, the authors classified soil total nitrogen percentages of < 0.05, 0.05 – 0.15, 0.15 – 0.25, 0.25 – 0.5, and > 0.5 as very low, low, medium, high, and very high, respectively.

The authors also classified available phosphorus contents of < 5, 5 – 10, 10 – 17, 17 – 25, and > 25 mg/kg soil as very low, low, medium, high, and very high, respectively. Similarly, they classified exchangeable potassium contents of < 0.2, 0.2 – 0.3, 0.3 – 0.7, 0.7 – 2.0, and > 2.0 as very low, low, medium, high, and very high, respectively (Table 1).

Field experiment

Days to 50% flowering: The main effects of plant population, nitrogen and NPS fertilizer rates and interaction of nitrogen and NPS were significant on the number of days required for 50% flowering. The highest and the lowest plant populations enhanced and delayed days to 50% flowering, respectively (Table 2). Densely populated plants might exploit the major growth resources faster by exerting intraspecific competitions which resulted in sorghum plants flowering earlier while sparsely populated plants might have experienced luxurious vegetative growth due to ample growth resources which resulted in delayed flowering. This is in agreement with that of (Buah and Mwinkaara 2009) who reported that sorghum planted at the highest plant density flowered earlier than those planted at the lower densities.

Table 1. Physico-chemical properties of the topsoil (0 to 30 cm) of the experimental fields.

Properties	Values	Rating
Soil pH	6.9	Slightly acidic
Organic carbon (%)	0.797	Very low
Organic matter (%)	1.375	Low
Total nitrogen (%)	0.069	Low
Available phosphorus (ppm)	7.670	Low
Exchangeable potassium (ppm)	3.053	Very high
Particle size proportion (%)		
Sand	83	High
Clay	14	Medium
Silt	3	Low
Soil texture	Sandy loam	

Days to 50% flowering was also influenced by the interaction effects of nitrogen and NPS fertilizer rates. The treatments without nitrogen and NPS fertilizers significantly delayed days to 50% flowering than the others (Table 3). This might be due to the insufficient amount of essential elements for plant growth. On the other hand, all combinations except control treatments enhanced days to 50% flowering. It might be due to nitrogen and NPS fertilizer contributing to the availability of soil nutrients which increases their uptake by plants. This is in agreement with that of (Buah and Mwinkaara, 2009) who reported that fertilized sorghum plants flowered five days earlier than those that were not fertilized.

Table 2. Days to 50% flowering, leaf area index, panicle length (cm), number of productive tillers, thousand kernels weight (g) and grain yield (kg ha^{-1}) of sorghum as affected by the main effects of plant population

Plant population (plants ha^{-1})	Days to flowering	Leaf area index	Panicle length	No of productive tillers	Thousand kernels weight	Grain yield
66,666	71.4^{b}	1.039^{a}	18.44^{b}	7.407^{c}	25.43^{c}	2239^{a}
76,923	71.3^{b}	1.183^{ab}	18.05^{ab}	7.000^{b}	24.90^{b}	2358^{ab}
90,909	71.1^{b}	1.296^{b}	17.51^{a}	6.593^{a}	24.37^{a}	2434^{bc}
102,564	70.4^{a}	1.486^{c}	17.47^{a}	6.370^{a}	24.19^{a}	2538^{c}

Means followed by the same letter in each column are not significantly different at the 0.05 level of significance.

Days to 90% physiological maturity: The main effects of nitrogen and NPS fertilizers and their interactions were significant. The control treatments delayed maturity, while 46 kg N ha^{-1} with all rate of NPS, 23 kg N with 50 and 100 kg NPS ha^{-1} and 0 kg N with 100 kg NPS ha^{-1} enhanced maturity (Table 3). This might be due to plants treated with nitrogen and phosphorus fertilizer obtaining available plant nutrition from both essential elements. However, the delay of physiological maturity may be due to an insufficient amount of essential elements under unfertilized treatment conditions. Plant height: The main effects of nitrogen and NPS fertilizer rates and their interaction were significant. The result of the interaction (Table 3) revealed the tallest plant (166.1 cm) was obtained in response to 46 kg N and 100 kg

NPS ha-1. On the other hand, the shortest plant was obtained in control treatments. This may be because both nutrients are involved in vital plant functions and contribute to enhanced growth in the height of the plant. This result agrees with the observations of (Dwivedi *et al.*, 1997) who reported an increase in height of the plant with an increase in phosphorus fertilizer rates.

Table 3. Days to 50% flowering, days to 90% physiological maturity and plant height as affected by nitrogen and NPS fertilizer interaction.

Nitrogen (kg ha-1)	NPS (kg ha-1)								
	Days to maturity			Days to 50% flowering			Plant height		
	0	50	100	0	50	100	0	50	100
0	113.3^{d}	111.5^{c}	109.8^{b}	73.67^{d}	71.58^{bc}	71.67^{c}	142.0^{a}	144.8^{a}	148.8^{a}
23	111.8^{c}	108.6^{a}	109.0^{ab}	70.58^{a}	70.67^{ab}	70.00^{a}	143.5^{a}	158.6^{b}	161.7^{bc}
46	109.1^{ab}	109.1^{ab}	109.0^{ab}	70.25^{a}	70.92^{abc}	70.17^{a}	144.9^{a}	165.0^{bc}	166.1^{c}

Means followed by the same letter in each column are not significantly different at the 0.05 level of significance.

Number of leaves per plant: The main effects of NPS and nitrogen fertilizer rates were significant. A more number of leaves were observed due to the application of 46 kg N and 100 kg NPS ha-1 fertilizer rates as compared to control treatments (Table 4). Leaf area: The main effects of NPS and nitrogen fertilizer rates were significant. The increase in leaf area was consistent across the increasing nitrogen and NPS fertilizer rates from control to different nitrogen and NPS fertilizer rates. The highest leaf area was observed due to the application of 46 kg N and 100 kg NPS ha-1 as compared to control treatments (Table 4). Mean values of nitrogen and NPS showed that leaf area was highest in plants applied with nitrogen and NPS rates than in control treatments. The value obtained due to 0 kg N ha-1 was statistically significant compared to 23 and 46 kg N ha-1. Also, significant differences were observed among the applied nitrogen fertilizer rates of 23 and 46 kg N ha-1. The increase in leaf area due to the application of nitrogen and NPS fertilizer may be due to the addition of nitrogen, phosphorus and sulfur fertilizer which might contribute to the availability of soil nutrients to plant growth.

Table 4. Number of leaves, leaf area and leaf area index of sorghum as affected by the main effect of nitrogen and NPS fertilizers rates.

Nitrogen (kg N ha-1)	Number of leaves	Leaf area	Leaf area index
0	7.6^{a}	1232^{a}	1.038^{a}
23	8.1^{b}	1523^{b}	1.274^{b}
46	8.3^{b}	1674^{c}	1.440^{c}
NPS (kg ha-1)			
0	7.6^{a}	1284^{a}	1.080^{a}
50	8.0^{b}	1538^{b}	1.282^{b}
100	8.3^{c}	1607^{b}	1.390^{b}

Means followed by the same letter in each column are not significantly different at the 0.05 level of significance.

Leaf area index: Leaf area index was significantly affected by the main effects of plant population, nitrogen and NPS fertilizer rates. The lowest value was observed on control treatments for both fertilizers and the highest value was observed on 46 kg N and 100 kg NPS ha-1 (Table 4). There was a significant difference among the different levels of nitrogen fertilizer (0, 23 and 46 kg N ha-1) and only between the control and the two rate of NPS (50 and 100 kg ha-1) while, there was no significant difference between 23 and 46 kg N ha^{-1}. This might be due to nitrogen effects on leaf area index mainly that have resulted from a higher number of tillers and to a lesser extent from an increase in leaf area per tiller. This study is in agreement with the findings of (Buah *et al.*, 2012). Who reported that sorghum fertilized with nitrogen fertilizer produced a higher leaf area index than those that were not fertilized?

Leaf area index was also significantly affected by the main effects of plant population. At experimental sites, increasing plant population increased leaf area index. The highest and lowest leaf area index was recorded from the highest and lowest plant population respectively (Table 2). The highest value of leaf area index in the highest plant population may be due to the presence of a large number of plants per unit area as compared to the lowest plant population.

An increase in leaf area index with increasing plant population is associated with an effective light interception and may thus allow high plant populations to attain greater photosynthetic output per unit area. The results were consistent with the findings of (Buah and Mwinkaara, 2009). Who reported that an increase in plant population per hectare increased leaf area index significantly from the lowest plant population to the highest.

Table 5. Thousand kernels weight (g) and grain yield (kg ha^{-1}) of sorghum as affected by the interaction of nitrogen and NPS fertilizer rates.

Nitrogen (kg ha^{-1})	NPS(kg ha^{-1})					
	Thousand kernels weight			Grain yield		
	0	50	100	0	50	100
0	22.79^{a}	24.71^{bc}	24.31^{b}	1934^{a}	2261^{b}	2193^{b}
23	24.65^{bc}	24.50^{bc}	24.91^{bc}	2166^{b}	2560^{c}	2549^{c}
46	25.23^{c}	26.81^{d}	24.60^{bc}	2722^{cd}	2298^{b}	2848^{d}

Means followed by the same letter in each column are not significantly different at the 0.05 level of significance.

Panicle length: Panicle length was significantly affected by the main effects of plant population and nitrogen fertilizer. The tallest and shortest panicle lengths were recorded from plots of the lowest and the highest plant population, respectively (Table 2). This may be due to high competition for growth resources. Under lower plant populations, they have enough amounts of growth resources whereby panicle length increased. The results were consistent with the findings of (Miko and Manga, 2008) who reported that an increase in plant population decreased panicle length.

Number of productive tillers: The main effect of plant population was significant. The plant population increased number of productive tillers decreased. The highest and the lowest number of productive tillers were recorded from 66,666 and 102,564 plants ha^{-1}, respectively (Table 2). High tillering in low plant populations might result from more space and low interplant competition for growth resources. The decrease in number of productive tillers with increasing plant population per unit area may be due to the shortage of growth resources to develop productive tillers rather than mother plants. This result agrees with that of (Miko and Manga, 2008) who reported a decrease in the number of productive tillers with an increasing plant population per unit area.

Thousand kernels weight: The main effects of plant population, nitrogen and phosphorus fertilizer were significant. In general, the thousand kernels' weight decreased as the plant population increased. Thousand kernels weight at the lowest plant population (66,666 plants ha^{-1}) was significantly higher than at the highest (102,564 plants ha^{-1}) (Table 2). The increase in thousand kernels weight at low densities might be due to the availability of more resources for a comparatively less number of plants that they utilized efficiently. This result was in agreement with the results reported by Dwivedi *et al.*, 1997) who reported that the thousand kernels weight at the lowest plant population was higher than at the highest plant population.

Thousand kernel weights were the highest at 46 kg N and 50 kg NPS ha^{-1} and the lowest was due to control treatments (Table 5). This might be due to the application of nitrogen and NPS that provided more appropriate nutritional conditions for grains during the grain filling period by providing suitable conditions for plant biomass and the increase in assimilates whereby it increases 1000-kernel weight. The results are consistent with the results of (Coulter, 2009) who reported that the increase in fertilization rate increased thousand kernel weights. Grain yield: The main effects of plant population, nitrogen and NPS and interactions of nitrogen and NPS were significant. The highest grain yield was recorded from the highest plant population while the lowest grain yield was recorded from the lowest plant population (Table 2). In general, with an increase in plant population, grain yield increases. The trend of increase was consistent across the increasing plant population from 66,666 to 102,564 plants ha^{-1}. Increases in grain yield resulting from higher plant populations might be due to increased light interception by the crop canopy during grain-filling. These results agree with that of Ashiono *et al.*, 2005) who reported increases in grain yield resulting from higher plant populations.

Table 6. Percentage of normal seedlings (%), dead kernels (%) and seedling length affected by the interaction of nitrogen and NPS fertilizers.

Nitrogen (kg ha^{-1})	NPS (kg ha^{-1})								
	of normal seedlings			% of dead kernels			Seedling length		
	0	50	100	0	50	100	0	50	100
0	86.75^{a}	88.92^{b}	88.67^{b}	5.583^{b}	4.417^{a}	4.500^{a}	19.58^{a}	21.10^{bc}	20.75^{bc}
23	88.83^{b}	89.00^{b}	89.00^{b}	4.167^{a}	4.333^{a}	4.333^{a}	21.20^{bc}	20.96^{bc}	20.49^{b}
46	88.58^{b}	90.83^{c}	89.00^{b}	4.083^{a}	3.750^{a}	4.417^{a}	21.03^{bc}	22.30^{d}	21.34^{c}

Means followed by the same letter in each column are not significantly different at the 0.05 level of significance.

The significant interaction effect on grain yield indicates that grain yield was influenced by different nitrogen and NPS fertilizer rates. The highest grain yield of 2848 kg ha^{-1} was obtained from the application of 46 kg N and 100 kg NPS ha^{-1} (Table 5). This existence of significant nitrogen and NPS fertilizer interaction indicates the need for nutrients to achieve a maximum grain yield.

Laboratory experiment

Germination percentage: The main effects of nitrogen and NPS fertilizer rates and their interactions were significant on normal seedlings and dead kernels. The highest normal seedlings were observed in kernel samples treated with 46 kg N and 50 kg NPS ha^{-1} rates while the lowest normal seedlings were observed in control treatments (Table 6). Kernels produced under fertilized conditions exhibited relatively better normal germination than those obtained from control treatments. However, the germination percentage of kernels fulfilled the national seed standard set (85%) for sorghum kernels in Ethiopia. Sorghum plants treated with nitrogen and NPS fertilizers provided more appropriate nutritional conditions for grain development during the grain filling period and the increase in kernel weight. This may be due to kernels containing high quality and larger food reserves (endosperm), which enabled them to nourish the embryo properly during the germination period. The results are consistent with the results of (Coulter, 2009) who reported that the germination of seeds supplied with phosphorus fertilizer was higher than that of seeds not supplied with fertilizer.

Kernels produced under control treatment conditions gave the highest number of dead kernels than others (Table 6). This may be due to the control treatments, metabolic processes of germination were retarded and the percentage of dead kernels increased due to the shortage of stored food during the germination period. The results are consistent with the results of (Ashiono *et al.*, 2005) who reported that seeds that have not been supplied with phosphorus fertilizer and therefore stressed.

Seedling length and vigour index i: The main effects of nitrogen and NPS and their interactions were significant on the seedling length and seedling vigour index i. The tallest and shortest seedling length was observed from 46 kg N, 50 kg NPS ha^{-1} and control treatments, respectively (Table 6). This may be due to kernels treated with nitrogen and NPS fertilizer containing high quality and larger food reserves, which enable them to nourish the embryo properly during the germination period and develop good seedling length.

Table 7. Seedling vigour index i, seedling vigour index ii and seedling dry weight (g) of sorghum as affected by the interaction of nitrogen and NPS fertilizer.

Nitrogen (kg ha^{-1})	NPS (kg ha^{-1})								
	Seedling vigour index i			Seedling vigour index ii			Seedling dry weight		
	0	50	100	0	50	100	0	50	100
0	16.99^{a}	18.76^{b}	18.40^{b}	0.0075^{a}	0.0087^{b}	0.0090^{bc}	0.0087^{a}	0.0098^{b}	0.0102^{b}
23	18.84^{b}	18.65^{b}	18.24^{b}	0.0087^{b}	0.0089^{bc}	0.0086^{b}	0.0098^{b}	0.0100^{b}	0.0097^{b}
46	18.63^{b}	20.26^{c}	18.99^{b}	0.0086^{b}	0.0094^{c}	0.0086^{b}	0.0097^{b}	0.0103^{b}	0.0097^{b}

Means followed by the same letter in each column are not significantly different at the 0.05 level of significance.

The highest and lowest seedling vigour index i was recorded for samples collected from 46 kg N with 50 kg NPS ha^{-1} and control treatments, respectively (Table 7). This may be due to kernels treated with N and NPS fertilizer containing high quality and larger food reserves, which enable them to nourish the embryo properly during the germination period and develop good seedling length thereby increasing seedling vigour index i. This result agrees with that of (Ashiono *et al.*, 2005) who reported that the vigour of seeds supplied with phosphorus fertilizer was higher than that of seeds not supplied with fertilizer.

Seedling dry weight and vigour index ii: The main effects of NPS on seedling dry weight, nitrogen and NPS on vigour index ii and their interaction on both were significant. The highest and lowest seedling dry weights and vigour index ii were obtained from 46 kg N with 50 kg NPS ha^{-1} and control treatments, respectively (Table 7). This might be due to kernels treated with fertilizers had got a sufficient amount of nutrients, which play an important role in the metabolic process during germination and seedling growth whereby increasing seedling dry weight and vigour index ii.

Conclusions

The results of yield components and seed quality investigations showed that days to 50% flowering, days to 90% maturity, plant height, leaf area, productive tillers, grain yield, 1000 kernel weight, normal seedlings, seedling vigour index i and ii were significantly affected by the main and interaction effects of nitrogen and NPS fertilizer and plant population was influence days to 50% flowering, leaf area index, panicle length, productive tillers, grain yield and 1000 kernel weight. Therefore, population densities of 66 666 plants ha^{-1}, application of 46 kg N and 100 kg NPS ha^{-1} fertilizer rates in the production of Teshalle variety was economically beneficial and recommended around the experimental area.

Conflicts of Interest

None.

Funding Statement

This study was funded by the Authors.

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