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Nitrogen Fertilization Effect on Grain Sorghum (*Sorghum bicolor* L. Moench) Yield, Yield Components and Witchweed (*Striga hermonthica* (Del.) Benth) Infestation in Northern Ethiopia

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ABSTRACT

Sorghum (*Sorghum bicolor* L. Moench) is an important food crop in Ethiopian. The plant's capacity to produce respectable yields under unfavorable growing situations has made it a well-liked crop for many growers. However, the crop's production is constrained by many biotic and abiotic factors amongst *Striga hermonthica* (Del.) Benth is the most tenacious, prolific and destructive pests of sorghum. *Striga* is most abundant and damaging on soils of low fertility and nitrogen is an essential element for reversing this effect. A study was conducted during 2008 (2000/01 E.C.) main crop growing season in Northern Ethiopia to study the productivity response of sorghum to rates of nitrogen application under natural Striga infestation. The experiment was arranged in randomized complete block design with three replications. The experiment consisted of four nitrogen fertilizer levels (0, 50, 100 and 150 kg ha^{-1}). Data on sorghum growth parameters and yield components as well as some *Striga* growth parameters were recorded at their respective growth stages. Results showed that application of N-fertilizer significantly increased plant height, leaf area index, panicle length, yield per panicle, 1000 grain weight, grain yield, stover yield and harvest index over the control. Highest responses of these parameters were obtained with application of 150 kg N ha^{-1}. *Striga* plant height, number of branches per plant and *Striga* plant count/plot were also reduced significantly ($p<0.05$) with 150 kg N ha^{-1} application over the control by 9.54, 35.76 and 36.95%, respectively.

Key words: *Sorghum bicolor*, *Striga hermonthica*, nitrogen fertilizer, Northern Ethiopia

INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench), is an important cereal crop in Tigray region (Northern Ethiopia) covering 0.17 million ha of land with an average yield of 15.89 qt ha^{-1} (CSA., 2008). It is extremely drought tolerant crop and has an ability to survive and yield grain during continuous or intermittent drought stress (Hulse *et al*., 1980). As a result, the crop has been and is still an important staple in the Semi-Arid Tropics (SAT) of Asia and Africa (Jambunathan *et al*., 1984). In Ethiopia, sorghum has wider geographical adaptation than any other cereal growing from lowlands to highlands (Tesso *et al*., 2007).

Sorghum productivity in the world in general and in Ethiopia in particular is by far below its potential. In areas where sorghum is commonly grown yields of more than 3000 to 4000 kg ha^{-1} are obtained under better conditions dropping down to 300 to 1000 kg ha^{-1} as moisture, soil fertility and other biotic and abiotic factors become limiting (ICRISAT., 1995). In Northern Ethiopia, the average yield of sorghum is even below the national yield average (CSA., 2008). The major factors that account for this low yield are moisture stress, low soil fertility and pest damages. Among the pests, the root parasitic weed *Striga* has long been recognized as the greatest biological constraint to sorghum production in the region.

Striga spp. are root hemi-parasitic weeds of tropical cereal and legume crops including maize, sorghum, millet, rice, sugarcane and cowpea causing significant losses to food crops in Africa and Asia. These parasitic weeds threaten around 45 million hectare of African arable land (Sauerborn, 1991). In infested areas, yield losses related with *Striga* damage are often significant, varying from 40-100% (Hess *et al.*, 1996). Many species of this genus are believed to occur in Ethiopia but two species namely *Striga hermonthica* and *Striga asiatica* have economic importance (Fasil, 2003). *Striga hermonthica* is the most widely distributed and devastating species in Northern Ethiopia severely affecting sorghum yield, the second most important crop in the region. The *Striga* found in Northern Ethiopia shows greatest diversity in morphology and behavior attacking exceptionally wide range of crops as compared to the *Striga* spp. found in any other sub-Sahara African countries (Fasil, 2003).

Controlling *Striga* spp. grows to be a massive assignment considering the seed production rate of 10,000-100,000 seeds/plant which remains viable in the soil for many years (Parker and Riches, 1993), their intimate physiological interaction with their host plants (Elzein and Kroschel, 2003) and the damage the weed cause to crop before emergence and its ability to thrive best in poor soil fertility (Kanampiu, 2008). However, several control methods have been tried and developed for the control of this parasitic weed in other part of the world but not in the northern Ethiopia. The control measures include; crop rotation, catch cropping, hand-pulling, nitrogen fertilization, intercropping, solarization, chemical (herbicides and or artificial seed germination stimulants, e.g., ethylene, strigol analogue), use of resistant varieties and biological control.

Sorghum hermonthica infestation is a result of declining soil fertility which weakens the host plant to *Striga* attack. Poor soil fertility, mainly soils low in nitrogen and organic matter which is a typical characteristics of most soils in the Northern part of Ethiopia, not only give poor crop yields but also contribute to increased *Striga* germination, increased flowering and seed production and prolonged *Striga* seed viability in the soil (Shank, 1996). Kudi and Abdulsalam (2008) reported *Striga* spreads rapidly in areas of low soil fertility and decreasing plant diversity, conditions often experienced by poor farmers in dry land zones. Adequate application of nitrogen fertilizer increases plant vigor and dry matter weight (shoot and root) and according to Showemimo (2007) good plant vigor and high dry matter weight are important criteria for selecting sorghum that are resistant/tolerant to *Striga* threat. Levels of nitrogen fertilizer from 110-170 kg N ha^{-1} were reported to control *Striga hermonthica* in sorghum (Showemimo, 2007). Mumera (1983) recorded a 64% reduction in *S. hermonthica* emergence in maize using 39 kg N ha^{-1}. Moreover, nitrogenous fertilizer may enhance the degree of resistance shown by resistant sorghum cultivars (Ramaiah and Parker, 1982). Therefore, there can be no doubt that steadily increasing the fertility of the land which includes providing a good level of nitrogen in the fertilizer used is an essential component of any *Striga* control system. However, there exists no clear-cut recommendation for the control of *Striga* by nitrogen application and hence the experiment was initiated with the objective of evaluating the effect of nitrogen fertilization and amount on yield and yield component of sorghum grown in *Striga* sick soil.

MATERIALS AND METHODS

Study area: The study was conducted in Northern Ethiopia, Humera Agricultural Research Center (HARC) Sheraro research sub-site, from July up to October during 2008 main growing season. Geographical location of the experimental site is 14° 24' 0" North latitudes and 37° 56' 0" East longitudes. The agro-ecology of the area is hot to warm semi arid low land plains with an altitude of 970 m above sea level. The Southwesterly monsoon winds bring rainfall to the area during the summer mainly from June to October. The area has a unimodal rainfall pattern more than 80-85% of the rain falling in the summer (between June and October) season. The average annual rainfall of the area is about 1000 mm with good distribution, whereas, average annual temperature vary with the ranges from 27-30°C.

Experimental design and treatments: The experiment consisted of four levels of nitrogen fertilizers viz. N_0 (no nitrogen), N_1 (50 kg N ha^{-1}), N_2 (100 kg N ha^{-1}), N_3 (150 kg N ha^{-1}) laid out in a randomized complete block design with three replications. One meter and 1.5 m distances were maintained among plots within replication and between replications, respectively. The crop was drilled in naturally *Striga* infested soils maintaining 75 and 20 cm spacing between rows and plants, respectively, in 3.75 by 4 m (15 m^2) plot area. The field was ploughed twice using traditional oxen drawn plough before planting and seedbeds were prepared using human labor. The nitrogen fertilizer rates were applied to corresponding experimental plot divided in to two halves. One-half of the fertilizer was applied during planting time and the remaining half was top dressed when the crop reached at knee height stage. Due to the need to monitor *Striga* emergence without obstruction and quantify the effect of *Striga* only, plots were kept free of weeds by repeated hoe and hand weeding at all growth stages. All the experimental units where receiving all the other management practices equally and properly.

Data collection: At harvest, random sample of ten plants were taken from each experimental units and plant height, leaf area index (cm), panicle length, yield per panicle and thousand seed weight were determined. Grain yield was recorded from the harvest of three central rows in each plot and was converted into kg ha^{-1} accordingly. Sorghum leaf area index was calculated using the formula developed by Krishnamurthy *et al.* (1974):

Leaf area (cm^2) = Maximum leaf width (cm)×Maximum leaf length (cm)×0.747

Leaf area index (LAI) = Was calculated using the following equation:

$$\text{Leaf area index (LAI)} = \frac{\text{Leaf Area (cm}^2)}{\text{Ground area (cm}^2)}$$

Data on *Striga* days to first emergence, branch per plant, plant height and *Striga* count per plot were recorded. A combined soil sample was taken from the experimental site using auger for soil physical and chemical properties analysis. Moreover, straw and grain samples were collected from each plot of central rows at harvest for nitrogen analysis following kjeldahl method. These were used to estimate Agronomic Nitrogen Use Efficiency (ANUE), Physiological Nitrogen Use Efficiency (PNUE), Apparent Nutrient Recovery Efficiency (ANRE) and total nitrogen uptake of sorghum using the following equation:

$$\text{ANUE} = \frac{\text{(Grain yield of sorghum at N rate)} - \text{(Grain yield of sorghum with out N application)}}{\text{Fertilizer N applied to the sorghum}}$$

$$\text{N uptake} = \frac{\text{Biomass yield (kg ha}^{-1}) \times (\%) \text{ Total N}}{100}$$

Statistical analysis: All data collected was subjected to the analysis of variance for using "JMP" statistical software package Version five. Whenever treatment effects were significant (p<0.05), mean comparison between and/or among treatment means were computed using "LSMeans Tuky's HSD" method.

RESULT AND DISCUSSION

Table 1 portrays the result of pre planting soil analysis. The soil type of the area is Euthric Vertisol. Pre planting soil analysis illustrates that the textural class of the soil is clay (52.36%) with soil pH of 7.4. The organic matter of the area is very low (1.0%). The result also indicated that the soil had Cation Exchange Capacity (CEC) of 30.8 meq/100 g, 1.06 ppm available phosphorus, 224.5 ppm available potassium and 0.043% total nitrogen.

Plant height and leaf area index: Nitrogen levels showed significant effect on sorghum plant height (Table 2). Nitrogen application at a rate of 150 kg ha^{-1} recorded the highest plant height (137.04 cm). On the other hand, the lowest plant height (120.83 cm) was obtained from plots

Table 1: Characteristics of soil sample of experiment site at 30 cm depth

Parameters	Values
pH	7.35
EC (ds m^{-1})	0.16
Total %N	0.043
CEC (meq/100 g)	30.8
Available P (ppm)	1.06
Available K (ppm)	224.5
OM (%)	1.0
Texture (%)	
Sand	24.36
Silt	23.28
Clay	52.36
Class	Clay

EC: Exchange capacity, CEC: Cationic exchange capacity, OM: Organic matter, P: Phosphorus, K: Potassium

Table 2: Effect of N levels on plant height and leaf area index

Nitrogen rate (kg ha^{-1})	Plant height	Leaf area index
0	120.83^{b}	1.90^{b}
50	124.16^{b}	2.00^{b}
100	132.33^{a}	2.10^{ab}
150	137.04^{a}	2.40^{a}
SEM (±)	3.50	0.41
Prop>F	<0.0001	0.035
CV	18.87	11.32

NB: Levels not connected by same letter within the same column are significantly different

Table 3: Effect of N levels and varieties on panicle length and yield per panicle thousand seed weight

Nitrogen levels	Panicle length (cm)	Yield per panicle (g)	Thousand seed weight (g)
0	17.03[b]	54.97[b]	24.1[b]
50	18.46[b]	58.63[b]	24.3[b]
100	20.93[a]	75.47[a]	25.3[a]
150	21.25[a]	75.87[a]	26.7[a]
SEM (±)	0.43	2.05	0.41
Prop>F	<0.0001	<0.0001	0.035
CV (%)	15.44	21.43	11.32

NB: Levels not connected by same letter within the same column are significantly different

without nitrogen application though remained in par with 50 kg N ha^{-1} application. Increase in plant height with increased nitrogen rates is not unexpected and might be more possibly due to the direct effect of nitrogen for vegetative growth and its indirect effect by reducing *Striga* infestation which was reported to have significant negative effect on plant height (Olupot *et al.*, 2003). Bilal *et al.* (2000) also reported that plant height increased progressively up to harvest over control with the application of nitrogen fertilizers. Mustafa and Abdelmagid (1982) has also shown that application of nitrogen fertilizer increased plant height in sorghum. In general the positive effect of high dose of nitrogen on plant height could be due to the utilization of more nitrogen as nitrogen is an essential nutrient for growth.

Results of analysis of variance on leaf area index revealed that nitrogen levels showed significant difference ($p<0.05$). It is evident from table below that nitrogen fertilization had increased the leaf area index compared to control plots. Leaf area index increases were 5.0, 9.5 and 20.8% over the control at 50, 100 and 150 kg ha^{-1} nitrogen fertilizations, respectively.

Panicle length and yield per panicle and thousand seed weight: Application of nitrogen fertilizer in various rates influenced panicle length and yield per panicle of sorghum significantly ($p<0.05$) (Table 3). *Sorghum* panicle lengths increased with increased levels of nitrogen application. Maximum panicle length was recorded in plot receiving 150 kg ha^{-1} nitrogen application (21.25 cm) which was statistically similar with 100 N kg ha^{-1} applications which produced 20.93 cm panicle length. The lowest value for panicle length was obtained from the untreated plot (17.03 cm) which was also significantly at par with 50 kg N ha^{-1} application. The increased panicle length at high level of nitrogen application might be due to high nitrogen uptake under these treatments.

As depicted in Table 3, response of yield per panicle to nitrogen rates was significant ($p<0.05$). Yield per panicle increased with increasing of nitrogen levels. The highest value of the mentioned trait was registered at fertilizer rate of 150 and 100 kg N ha^{-1}. The lowest yield per panicle was recorded from nitrogen untreated plots which was statistically comparable with 50 kg N ha^{-1} application. This increase in yield per panicle may be attributed to the increase in panicle length with the highest nitrogen application.

Analysis of variance revealed significant ($p<0.05$) effect of nitrogen application at various levels on thousand grain weight of grain sorghum. Nitrogen level of 150 kg ha^{-1} gave the highest thousand seed weight (26.7 g) which was comparable with nitrogen application at 100 kg ha^{-1}. On the other hand, the lowest 1000 grain weight was recorded from the control and plots receiving 50 kg N ha^{-1}. Increase in grain weight at higher nitrogen rates might be primarily due to increase in photosynthetic rate which ultimately produce sufficient photosynthates available during grain development.

Table 4: Effect of N levels on grain yield, Stover yield and harvest index

Nitrogen levels	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index
0	1629.63^{b}	3787.04^{b}	0.30^{b}
50	1722.22^{b}	4027.78^{b}	0.30^{b}
100	2083.33^{a}	4129.63^{b}	0.34^{a}
150	2231.48^{a}	4851.85^{a}	0.32^{ab}
SEM (±)	51.38	123.25	0.007
Prop>F	<0.0001	0.0006	0.02
CV (%)	18.7	20.33	16.67

NB: Levels not connected by same letter within the same column are significantly different

Grain yield, stover yield and harvest index (HI): Result of data analysis presented in Table 4 indicated that nitrogen application at different rates significantly ($p<0.05$) increased grain yield over control. The grain yield improved with increased levels of nitrogen fertilizer application. The highest grain yield was obtained with 150 kg N ha^{-1} (2231.48 kg yield ha^{-1}) application which was comparable with 100 kg N ha^{-1} (2083.33 kg ha^{-1} grain yield) application. The enhance in grain yield with increase in N levels application might be due to the increase up of yield attributing characters and nutrient uptake of the crop under these levels as well as reduced *Striga* infestation at high application levels. This result is in line with the findings of Poornima *et al.* (2008) and Akdeniz *et al.* (2006) who reported higher grain yield with increased levels of N in sweet *Sorghum* and grain *Sorghum*, respectively. Fasil (2003) also reported very high and two season consistent response of *Sorghum* to inorganic fertilizers mainly nitrogen in Sheraro (the area where this study was conducted).

There was a significant ($p<0.05$) effect of nitrogen levels on stover yield (Table 4). Among all nitrogen levels, 150 kg N ha^{-1} application rate gave the highest stover yield (4851.85 kg ha^{-1}) while the lowest stover yield (3787.04 kg ha^{-1}) was obtained in the control treatments, though it was statistically not different with the other two N rates. This variation in stover yield might be due to the variation in plant height as well as leaf area.

The physiological efficiency and ability of a crop for converting the total dry matter into economic yield is known as Harvest Index (HI). Nitrogen rates showed significant differences on harvest index. The highest harvest index (0.34) was obtained with 100 kg N ha^{-1} application which was statistically not different from 150 kg ha^{-1} nitrogen application rate. Lowest harvest index was obtained in the control and with 50 kg N ha^{-1} application. However, the result showed that the effect of nitrogen on harvest index is not directly proportional with increase in nitrogen levels. The results were consistent with the findings of Akdeniz *et al.* (2006) as in the presented study, reported a positive effect of nitrogen fertilizer application on the harvest index on grain sorghum.

Agronomic Nitrogen Use Efficiency (ANUE): The data in the Fig. 1 indicates that, Agronomic Nitrogen Use Efficiency (ANUE) of sorghum was affected by nitrogen levels. Increased application of nitrogen results incoherent augmentation of ANUE (Fig. 1). Increasing nitrogen application from 50-100 and 150 kg N ha^{-1} increased ANUE by 59.2 and 53.8%, respectively. However, though it was comparable statistically, ANUE tended to decline by 11.6% with increment of nitrogen application level from 100-150 kg N ha^{-1}. Effect of nitrogen levels on *Sorghum* nitrogen use efficiency was also reported by Amiri *et al.* (2014).

Nitrogen uptake: The ANOVA results for mean nitrogen uptake revealed significant difference ($p<0.05$) of nitrogen levels. There was significant gradual increase in nitrogen uptake as the level of N fertilizer increases (Fig. 2). Increasing nitrogen application from 0 to 50, 100 and 150 kg N ha^{-1} increased total nitrogen uptake by the whole plant by 15.4, 28 and 35.8%, respectively. The least total nitrogen uptake (46 kg N ha^{-1}) was at the control and the highest (75 kg N ha^{-1}) was at 150 kg N ha^{-1}. The significant increase in total nitrogen uptake at high N levels application could be attributed probably to increased availability of nitrogen and good root growth. This observation collaborates with that of Regassa (2005) who found increasing the levels of applied inorganic nitrogen fertilizer from 0 to 30.75 N ha^{-1} increased N uptakes by the whole plant from 171.2 to 245.3 kg N ha^{-1}. Ashebir (2005) also reported increasing levels of N from 0-69 kg N ha^{-1} resulted in a consistent increase in uptake of N by rice plants at the mid-flowering stage.

Effect of nitrogen on *Striga* emergence: The result in Table 5 clearly indicates variation in nitrogen rates had no effect on *Striga* emergence ($p>0.05$). This means application of nitrogen did not affect the speed of *Striga* germination at all levels. This result disagrees with previous findings. Cechin and Press (1993) reported that application of nitrogenous fertilizer like ammonium nitrate

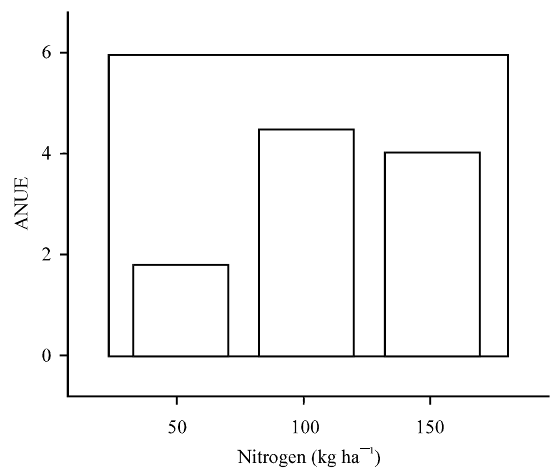

Fig. 1: Effect of nitrogen levels on Agronomic Nitrogen Use Efficiency (ANUE)

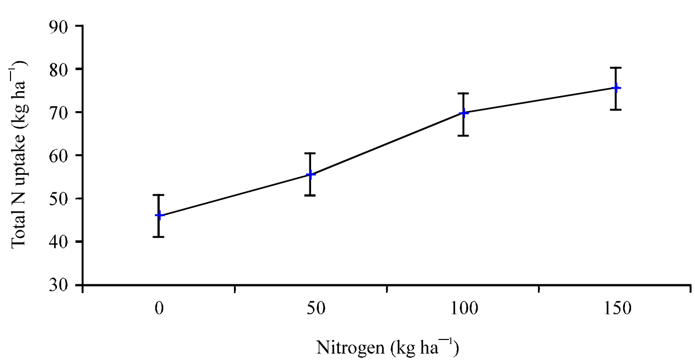

Fig. 2: Main effect of nitrogen on N-uptake (kg N ha^{-1})

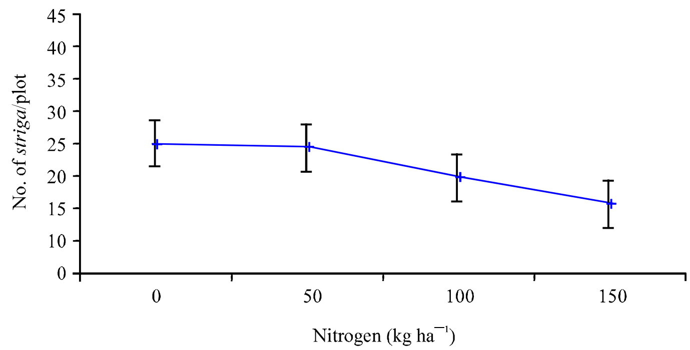

Fig. 3: Effect of N levels on *Striga* count/plot

Table 5: Effect of N levels on days to first *Striga* emergence, No. of branch/plant and *Striga* count/plot

Nitrogen rates (kg ha^{-1})	Days to first *Striga* emergence	No. of branch/plant	Striga plant height
0	33.08	8.78^{a}	35.2^{b}
50	31.00	7.43^{ab}	34.2^{b}
100	30.08	6.78^{bc}	31.5^{a}
150	28.83	5.64^{c}	32.0^{a}
SEM (±)	1.16	0.28	1.2
Prob>F	0.48	<0.0001	<0.0001
CV (%)	26.07	27.53	12.5

NB: Levels not connected by same letter within the same column are significantly different

affect *Striga* emergence either by reducing production of stimulatory compounds or their specific leakage from host roots and Kabambe *et al*. (2008) reported fertilizer application promoted *Striga* emergence.

Effect of nitrogen on *Striga* plant height, branching and count per plot: As depicted in the Table 5 and Fig. 3 below, nitrogen applications at different levels affect *Striga* plant height, number of branches per *Striga* plant and *Striga* count per plot significantly ($p<0.05$). Decrease in *Striga* plant height was observed with increased nitrogen level application. Significantly, highest *Striga* plant heights were recorded from the control and the lowest nitrogen rate (50 kg ha^{-1}) (35.2 and 34.2 cm, respectively). Lowest *Striga* plant height (31.5 cm) was recorded with 100 kg N ha^{-1} application, though it was non-significant with 150 kg N ha^{-1} application rate. In agreement with the present finding Sinebo and Drennan (2003), reported reduced height and weight of the parasite weed *S. hermonthica* with nitrogen application. Nitrogen application also affected number of *Striga* branches per plant significantly ($p<0.05$) (Table 5). Nitrogen application at a rate of 150 kg N ha^{-1} gave the lowest numbers of *Striga* branches per plant (5.6). Table 5 also shows that *Striga* plants grown in plots amended with 50 kg N ha^{-1} and the control gave significantly more branches per plants than high dose of nitrogen application (150 kg N ha^{-1}).

High dose of nitrogen fertilizer application also affected *Striga* count per plot significantly (Table 5 and Fig. 3). Numbers of *Striga* germinated per plot were lower in plots treated with nitrogen at a dose of 150 kg ha^{-1} (15.9) while highest numbers of *Striga* per plot were obtained in none treated plots with nitrogen (25.2). This finding confirms the results reported by Showemimo (2007) which stated nitrogen fertilizer application from 110-170 kg of N ha^{-1} control *S. hermonthica* in sorghum. Similarly, Agbobli (1991) reported application rates greater than 60 kg N ha^{-1} reduced number of emerged *Striga asiatica* in maize crop.

Different authors also reported the negative effect of nitrogen on *Striga* growth and development. Nitrogen suppresses some development stages of *Striga* such as stimulant production or activity (Cechin and Press, 1993). The present finding could be in concurrence with Ogborn (1987) which realized reduction in the number of flowering *S. hermonthica* with application of 155 kg N ha^{-1} in sorghum crop.

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