I.J.S.N., VOL.7 (4) 2016: 702-706 ISSN 2229 – 6441

INTERNATIONAL JOURNAL OF SCIENCE AND NATURE

www.scienceandnature.org

Review Article

PLANT DENSITY AND NITROGEN IN SORGHUM

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ABSTRACT
In the recent past Sorghum is emerging as a potential alternate feed, fodder and bio-energy crop, Further its tolerance to high temperature and drought makes it suitable for any climatic condition. Optimum plant density is the pre-requisite for obtaining maximum yield. Similarly, optimum rate of N at right time is considered to be the single most significant factor in improving crop productivity. Plant density is important from the point of intercepting sunlight for photosynthesis, besides efficient use of plant nutrients and soil moisture. Therefore, matching optimum plant density with nitrogen schedule is essential to achieve the targeted yields. It is an established fact that higher grain yield depends on optimum plant density and adequate amount of nitrogenous fertilizer. An attempt has been made to review the research on plant densities and nitrogen levels on the growth and yield of sorghum.

KEYWORDS: alternate feed, Sorghum, climatic condition, improving crop, density, nitrogen schedule.

IMPORTANCE OF SORGHUM AND ZERO-TILL SORGHUM

Sorghum (*Sorghum bicolor* L. Moench) traditionally grown for food in semi-arid tropics of India, occupies an area of 6.32 m ha with a productivity of 1,004 kg ha^{-1} and a total production of 6.03 m t (ASG, 2011). The area under grain sorghum in India declined considerably. With the increase in human and animal population and due to a fragile balance between food supply and demand, sorghum production must be increased to meet the current and future fodder and food needs. Sorghum cultivation in rice-fallows under zero tillage is an area of interest. Though rice-fallow pulses was a dominant cropping sequence of Krishna zone, the area under these crops has declined due to late planting of rice, owing to late onset of monsoon and delayed release of water in the canals besides severe attack of viral diseases and parasitic weed *Cuscuta* (Mishra, 2013). In this changed scenario, farmers are now growing maize (in assured irrigated area) and sorghum (in less irrigated areas) in rice-fallows as an alternate crop to pulses.

RESPONSE OF SORGHUM TO DIFFERENT PLANTING DENSITIES

The number of plants required per unit area is one of the prime considerations, which depends upon the nature of crop and its environment. This number can neither be too small so that all the production potential will not be utilized, nor can it be too large to impose excessive plant competition, which reduces the overall efficiency of the crop. Row spacing is one of the important factors in adjusting optimum levels of plant population so that plant makes efficient use of the resources. Closer spacing in sorghum crop reduces the panicle size, but the total grain yield ha^{-1} will be higher under increased plant population as the reduction in grain yield plant^{-1} due to reduced panicle size will be usually compensated by higher number of panicles ha^{-1}.

Donald's theory (1963) on "relationship of plant population with yield" explained about the peak of the grain curve (seed yield) occurred approximately at the density at which the biological yield levelled off. At this plant density, any gain in total yield ha^{-1} due to addition of extra plants is offset by the decrease in weight plant^{-1}. As the plant density increases, most components of yield of the individual plant, in general are reduced. At lower plant density there is little competition between plants at the early stages of crop growth and a large number of primordia are initiated in early plant growth. As growth proceeds, inter-plant competition increases progressively. The load of inflorescence reduces the number of seeds per inflorescence and reduces seed weight, compared with somewhat denser stands. In very dense stands, both inter-plant and intra-plant competition are sufficiently severe to reduce all components of yield.

GROWTH PARAMETERS

The results of the experiments conducted in India and other parts of the world have indicated that plant height is significantly increased with increase in plant density. Ali El-Toum Hassan (2002) from an experiment conducted on clay soils at Lagawa Research Site of West Kordofan and reported that the highest plant height (129 cm) in sorghum was obtained at a plant population of 1,25,000 plants ha^{-1} over remaining planting densities of 50,000 plants ha^{-1}, 75,000 plants ha^{-1} and 1,00,000 plants ha^{-1}. Kaushik and Shaktawat (2005) observed that growth attributes *viz.*, plant height (184 cm) and drymatter yield (53.9 g plant^{-1}) in sorghum were significantly higher with row spacing of 40 cm over 60 cm and 80 cm. In sandy loam soils the highest plant height (1.15m) and less number of days to 50% flowering (72) was obtained at a spacing of 75 cm x 10 cm (1,33,333 plants ha^{-1}), which was significantly superior to the remaining spacings of 75 cm x 15 cm (88,888 plants ha^{-1}), 75 cm x 20 cm (66,666 plants ha $^{-1}$) and 75 cm x 25 cm (53,333 plants ha^{-1}) [Buah and Mwinkaara (2009)]. Emile *et al.* (2009) conducted an experiment at the Lusignan Research Center, France and observed that in sorghum crop, the growth attributes *viz*., plant height, plant number m^{-2} and plant drymatter yield were significantly higher with narrow row spacing of 20 cm over 75 cm row spacing. According to Yakadri and Murali (2009), the highest plant height (187 cm) was obtained with planting pattern of ridge and furrow with a spacing of 60 cm which was significantly superior to uniform sowing of 40 cm and ridge and furrow sowing of 50 cm in sorghum on sandy loam soils of Rajendranagar, Hyderabad. Mosavi *et al.* (2009) conducted a field experiment on sorghum and concluded that the maximum plant height (148.3 cm) and total dry weight (5830 kg ha^{-1}) were recorded at a plant population of 5 lakh plants ha^{-1} over remaining planting densities of 2 lakh plants ha^{-1}, 3 lakh plants ha^{-1} and 4 lakh plants ha^{-1}, on sandy loam soils of Agricultural Research Station of Islamic Azad University, Birjand. Ali Soleymani *et al.* (2013) reported that the plant height was decreased significantly with increase in plant population from 1 lakh plants ha^{-1} to 6 lakh plants ha^{-1} in sorghum on clay loam soils at the Isfahan University Research Station, Isfahan, Iran. Taleshi *et al.* (2013) conducted a field experiment during summer 2012 at Zanjan province, Iran and concluded that the highest grain yield and stem drymatter of sorghum was obtained with the plant density of 40 cm x 30 cm over 60 cm x 20 cm and 50 cm x 20 cm on silty clay loam soils under no-till conditions. The results revealed that the plant height was significantly affected by plant densities, however; numerically taller plants were produced at a plant density of 1.66 lakh plants ha^{-1} than that of 2.22 lakh plants ha^{-1} and 3.33 lakh plants ha^{-1} at all stages of growth period (30, 60, 90 DAS and at harvest). [(Arunakumari *et al.* (2015)].

Yield Parameters and Yield

Hegde *et al.* (1976) reported that though maximum number of panicles m^{-2} (61.9) was observed in grain sorghum at 3.4 lakh plants ha^{-1}, grain yield (3009 kg ha^{-1}) was maximum under 1.7 lakh plants ha^{-1} over 0.87 lakh plants ha^{-1} , 2.6 lakh plants ha^{-1} and 3.4 lakh plants ha^{-1} on silty clay loam soils of Alberta, Canada. A plant population of 2.25 lakh plants ha^{-1} with 38 cm row spacing gave the highest grain yield (6250 kg ha^{-1}) compared to 78 cm row spacing, over 0.75 lakh plants ha^{-1}, 1.25 lakh plants ha^{-1} and 1.75 lakh plants ha^{-1} in grain sorghum reported by Schatz *et al.* (1986) on clay loam soils at Carrington in North Dakota. Raghuwanshi *et al*. (1990) conducted a field experiment at JNKVV, College of Agriculture, Indore (M.P) on medium black soils and reported that increased grain yield (2320 kg ha^{-1}) in sorghum was obtained with a spacing of 45 cm × 24 cm over 45 cm × 12 cm. Mali *et al.* (2000) conducted a field experiment on sorghum at Instructional Farm, Rajasthan College of Agriculture, Udaipur on clay loam soils and reported that higher grain yield (2495 kg ha^{-1}) was obtained at a plant population of 1.5 lakh plants ha^{-1} than 3.3 lakh plants ha $^{-1}$ (2034 kg ha^{-1}). Ali El-Toum Hassan (2002) conducted an experiment on clay soils at Lagawa Research Site of West Kordofan and reported that the plant population (1,25,000 plants ha^{-1}) in sorghum gave higher yield (2286 kg ha^{-1}) and number of earheads m^{-2} (13) over remaining plant densities of 50,000 plants ha^{-1}, 75,000 plants ha^{-1} and 1,00,000 plantsha^{-1}. Bishnoi *et al.* (2002) from an experiment conducted on silty clay loam soils of Alabama A & M University, USA, reported that grain sorghum planted after clover and wheat under no-till produced higher yields than conventional tillage at a spacing of 45 cm x 20 cm over 60 cm x 20 cm and 90 cm x 20 cm. Kaushik and Shaktawat (2005) from an experiment conducted at Rajasthan, College of Agriculture, Udaipur and reported that the highest grain yield (2432 kg ha^{-1}), test weight (22.25 g) in sorghum were obtained at a row spacing of 60 cm than that of 20 cm and 80 cm row spacing. A field experiment conducted in grain sorghum by Shawn *et al.* (2005) on silty loam soils of Missouri revealed that the higher grain yield (8375 kg ha^{-1}) and test weight (59.7 g) were obtained under plant density of 3 lakh plants ha^{-1} over remaining planting densities of 0.75 lakh plants ha^{-1}, 1.5 lakh plants ha^{-1} and 2.25 lakh plants ha^{-1}. An experiment conducted by Buah and Mwinkaara (2009) revealed that the maximum grain yield (2058 kg ha^{-1}) in sorghum was obtained at a spacing of 75 cm x 10 cm (1.3 lakh plants ha^{-1}), which was significantly superior to remaining spacings of 75 cm x 15 cm (88,888 plants ha^{-1}), 75 cm x 20 cm (66,666 plants ha^{-1}) and 75 cm x 25 cm (53,333 plants ha^{-1}) on sandy loam soils in Guinea Savanna of Ghana. Emile *et al.* (2009) from a field experiment conducted on sorghum crop at the Lusignan Research Center, France, and reported that the highest harvest index (45.7%) was recorded at a row spacing of 75 cm than that of 20 cm row spacing . Yakadri and Murali (2009) stated that the highest grain and stover yield (2650 and 5780 kg ha^{-1}) were obtained in sorghum at planting pattern of ridge and furrow with a spacing of 50 cm which was significantly superior to uniform sowing of 40 cm and ridge and furrow sowing of 60 cm on sandy loam soils of Rajendranagar, Hyderabad. Abunyewa *et al.* (2010) from an experiment conducted in Nebraska under no-till conditions and reported that the maximum grain yield (8 kg ha^{-1}) in sorghum was recorded at a plant density of 1.0 lakh plants ha^{-1} with alternate rows planted as skip configuration on silty loam soils than 50000 plants ha^{-1} (6 kg ha^{-1}). Fernandez *et al.* (2012) reported that higher grain yield (4666 kg ha^{-1}) in sorghum was obtained at a plant population of 2.0 lakh plants ha^{-1} with a row spacing of 76 cm over 38 cm row spacing at 2.4 lakh plants ha^{-1} and 1.7 lakh plants ha^{-1} on clay soil in Coastal region of Texas. Fromme *et al.* (2012) reviewed the results obtained in a three year field study in Texas and concluded that the highest yield response (3775 kg ha^{-1}) in sorghum was noticed at a plant population of 1.4 lakh plants ha^{-1} with a row spacing of 102 cm over remaining planting densities of 1.8 lakh plants ha^{-1} and 2.2 lakh plants ha^{-1} at 51 cm row spacing on sandy loam soil in Upper Texas Gulf Coast. Ali Soleymani *et al.* (2013) reported that the tiller number hill^{-1} was decreased with increase in plant population from l lakh plants ha^{-1} to 6 lakh plants ha^{-1} in an experiment on sorghum conducted at the Isfahan University Research Station, Isfahan, Iran on clay loam soil.

Taleshi *et al.* (2013) conducted a field experiment in summer 2012 at Zanjan province, Iran and reported that the highest yield of grain sorghum was recorded with the plant spacing of 40 cm x 30 cm over 60 cm x 20 cm and 50 cm x 20 cm on silty clay loam soils under no-till conditions. Zand *et al.* (2014) concluded that the maximum grain yield (7503 kg ha^{-1}) in sorghum was obtained at a plant population of 2 lakh plants ha^{-1} when compared to 0.8 lakh plants ha^{-1} and 1.4 lakh plants ha^{-1} in a field experiment conducted at the Research Farm of the Faculty of Agriculture, University of Tabriz, Iran. According to Arunakumari *et al.* (2015) grain yield of rice fallow sorghum recorded at planting density of 2.22 lakh plants ha^{-1} was found significantly higher (5758 kg ha^{-1}) than that of 3.33 lakh plants ha^{-1} (4911 kg ha^{-1}) and 1.66 lakh plants ha^{-1} (4379 kg ha^{-1}).

RESPONSE OF SORGHUM TO DIFFERENT NITROGEN LEVELS

Growth Parameters

Nitrogen is one of the most important nutrient which influences the growth and yield of sorghum. Most of the sorghum growing soils in India are deficient in nitrogen and varied response has been obtained when this nutrient was supplied to sorghum either alone or in combination with major nutrients. Balanced nutrition plays an important role in crop production. Increasing levels of nitrogen application will increase crop yield upto a certain level. Particularly in cereals, plant height is often related to the fertilizer response, moisture level and susceptibility to crop lodging. Nitrogen is one of the most important nutrients which influence the growth of the sorghum. Patel *et al.* (1990) conducted a field experiment at the Gujarath Agricultural University, Junagadh and reported that nitrogen applied @ 150 kg ha^{-1} recorded significantly higher plant height (144 cm), number of productive tillers plant^{-1} (1.9) and straw weight plant $^{-1}$ (86.0 g) in sorghum. on clay soils during *rabi* over other N levels (50 kg ha^{-1} and 100 kg ha^{-1}).

Singh *et al.* (1996) carried out a field experiment at Livestock Research Center, Pantnagar, on silty clay loam soils and reported that in grain sorghum the higher plant height (218.4 cm) and total dry weight plant^{-1} (112.1 g) were recorded at 100 kg N ha^{-1} when compared to other levels (20 kg N ha^{-1}, 40 kg N ha^{-1}, 60 kg N ha^{-1} and 80 kg N ha^{-1}). From an experiment carried out on dual purpose sorghum at Kenya Agricultural Research Institute, Nakuru, Kenya, revealed that maximum plant height (167 cm) was noticed with application of 40 kg N ha^{-1} over other levels of N (0 kg ha^{-1}, 20 kg ha^{-1}, 30 kg ha^{-1} and 50 kg ha^{-1}) on deep sandy loam soils by Ashiono *et al.* (2005). Kaushik and Shaktauat (2005) from an experiment conducted at Rajasthan, College of Agriculture, Udaipur and stated that nitrogen applied @ 120 kg ha^{-1} recorded significantly higher plant height (196.7 cm) & drymatter plant^{-1} (61.4 g) in sorghum on clay loam soils during rainy season over other N levels (0 kg ha^{-1}, 40 kg ha^{-1}, and 80 kg ha^{-1}). A study carried out by Miko and Manga (2008) at rainy seasons in the Teaching and Research Farm of the Institute for Agricultural Research, Ahamadu Bello University, Zaria showed that the maximum plant height (78.25 cm) and drymatter accumulation plant^{-1} (29.82 g) in sorghum were noticed with the application of 90 kg N ha^{-1} over other levels of N (0 kg N ha^{-1}, 30 kg N ha^{-1}and 60 kg N ha^{-1}). Yakadri and Murali (2009) conducted a field experiment at the student's farm, college of Agriculture, Rajendranagar, Hyderabad and reported that nitrogen applied @ 100 kg ha^{-1} recorded significantly higher plant height (187.9 cm) and dry matter (69.3 g plant^{-1}) in sorghum on sandy loam soils during late *kharif* over other N levels (40 kg ha^{-1}, 60 kg ha^{-1} and 80 kg ha^{-1}).

A field experiment conducted by Pushpendra Singh *et al.* (2012) on clay loam soils at Rajasthan College of Agriculture, Udaipur and reported that the highest plant height (260.1 cm) and drymatter accumulation (180.5 g plant^{-1}) in sorghum were recorded with the application of 80 kg N ha^{-1} than that of 40 kg N ha^{-1} and 120 kg N ha^{-1}. A study carried out by Mishra *et al.* (2013) showed that maximum plant height (188 cm) in sorghum was obtained by application of 225 kg N ha^{-1} but the response was significant upto 125 kg N ha^{-1} during *rabi* at farmer's field in Kondura village, Tenali, in Guntur district of coastal AP on clay loam soils. Results showed that application of 150 kg N ha^{-1} produced significantly higher amount of drymatter than rest of the nitrogen levels at 30, 60 and 90 DAS. But at harvesting stage higher drymatter was produced at 150 kg N ha^{-1} than rest of the nitrogen levels, which was however on a par with 100 kg N ha^{-1}, but significantly superior to other N levels (0 kg N ha^{-1} and 50 kg N ha^{-1})[Arunakumari *et al.* (2015)].

Yield Parameters and Yield

Patel *et al.* (1990) conducted a field experiment during *rabi* at the Gujarath Agricultural University, Junagadh on clayey soils and stated that nitrogen application @ 150 kg ha^{-1} recorded significantly higher grain yield (3600 kg ha^{-1}) and stover (8340 kg ha^{-1}) in sorghum over other levels of nitrogen 50 kg ha^{-1} and 100 kg ha^{-1}. Application of 100 kg N + 60 kg P_2O_5 + 40 kg K_2O ha^{-1} produced significantly higher grain yield (2470 kg ha^{-1}) of sorghum over 50 kg N + 30 kg P_2O_5 + 20 kg K_2O ha^{-1} (18.4 kg ha^{-1}) in sorghum – wheat sequence a field experiment conducted at JNKVV, College of Agriculture, Indore (M.P) during *kharif* and *rabi* season for two consecutive years on medium black soils. (Raghuwanshi *et al*., 1990). Singh *et al.* (1993) conducted a field trial at Sumerpur, Rajasthan, on sandy loam soil and found that the highest seed yield (1318 kg ha^{-1}) in sorghum was recorded with the application of 80 kg N ha^{-1} which was significantly superior to remaining levels (0 kg N ha^{-1} and 40 kg N ha^{-1}). Results showed that optimum plant density for obtaining good yields ranged between 83,000-10,600 plants ha^{-1} as reported by Ismail (1996) in sorghum on calcareous sandy clay loam soils in the Field Crop's Experimental Station at Rodat Horma.

Singh *et al.* (1996) carried out a field experiment at Livestock Research Center, Pantnagar, on silty clay loam soils and reported that the highest number of grains panicle^{-1} (1473) and 1000 grain weight (28.76 g) in grain sorghum were noticed with the application of 80 kg N ha^{-1} than other levels of nitrogen 20 kg ha^{-1}, 40 kg ha^{-1}, 60 kg ha^{-1} and 100 kg ha^{-1}. Sorghum responded upto 100 kg N ha^{-1} on medium loam soils at University of Agriculture, Faisalabad, by producing the highest drymatter yield (1568 kg ha^{-1}) than without nitrogen and 50 kg N ha^{-1} (Ayub *et al.,* 1999). The maximum grain yield (1655 kg ha^{-1}), straw yield (2011 kg ha^{-1}) and harvest index (0.45 %) were recorded with the application of 50 kg N ha^{-1} compared to lower levels (0 kg N ha^{-1}& 25 kg N ha^{-1}) in an experiment conducted at Regional Research Station, University of Agricultural Sciences, Bijapur (Karnataka) on clay loam soils and the highest number of grains $earhead^{-1}$ (1,101) and 1000 grain weight (29.90 g) in *rabi* sorghum were noticed with the application of 50 kg N ha^{-1} than 0 kg N ha^{-1} and 25 kg N ha^{-1} (Patil and Sheelavantar, 2000). Ashiono *et al.* (2005) carried out an experiment at Kenya Agricultural Research Institute, Nakuru, Kenya and found that 1000-seed weight (22.5g) in dual purpose sorghum was higher with the application of 50 kg N ha^{-1} on deep sandy loam soils than other nitrogen levels (0 kg N ha^{-1}, 20 kg N ha^{-1}, 30 kg N ha^{-1} and 40 kg N ha^{-1}). Kaushik and Shaktawat (2005) showed that the maximum grain yield (2670 kg ha^{-1}) and stover yield (6580 kg ha^{-1}) in sorghum were obtained with the application of 120 kg N ha^{-1} on clay loam soils which was on a par with 80 kg N ha^{-1} and superior to 0 kg N ha^{-1} and 40 kg N ha^{-1} at Rajasthan, College of Agriculture, Udaipur.

A study carried out by Miko and Manga (2008) conducted in rainy seasons at the Teaching and Research Farm of the Institute for Agricultural Research, Ahamadu Bello University, Zaria showed that the maximum panicle length (25.20 cm) in sorghum was noticed with the application of 30 kg N ha^{-1} over other levels of N (0 kg N ha^{-1}, 30 kg N ha^{-1} and 60 kg N ha^{-1}) and the highest grain yield (1864 kg ha^{-1}) was obtained at 60 kg N ha^{-1} than the other levels of N (0 kg N ha^{-1}, 30 kg N ha^{-1} and 90 kg N ha^{-1}). In sorghum a field experiment was conducted by Yakadri and Murali (2009) and noticed that the highest grain yield (2700 kg ha^{-1}) and stover yield (5840 kg ha^{-1}) obtained with fertilizer added @ 100 kg N ha^{-1} over other levels of 40 kg ha^{-1}, 60 kg ha^{-1} and 80 kg ha^{-1} at the student's farm, college of Agriculture, Rajendranagar, Hyderabad. Maximum grain yield (3915 kg ha^{-1}), straw yield (12,922 kg ha^{-1}) and biological yield (16,837 kg ha^{-1}) of sorghum were recorded with the application of 120 kg N ha^{-1} compared to lower levels (40 kg N ha^{-1} and 80 kg N ha^{-1}) but HI (23.47%) was recorded maximum at 80 kg N ha^{-1} in an experiment conducted at Rajasthan College of Agriculture, Udaipur on clay loam soils (Pushpendra Singh *et al.,* 2012). The experiment was carried out at the Student Farm of CCS HAU, Hisar for two consecutive *kharif* seasons in sorghum by Namoobe *et al.* (2014) and reported that the significant increase in yield attributes, *viz.,* panicle length (25.70 cm), grains $panicle^{-1}$ (1556), test weight (21.49 g) and grain yield (1961.5 kg ha^{-1}) with the application of 100 kg N ha^{-1} over remaining N levels (0 kg N ha^{-1}, 40 kg N ha^{-1}, 60 kg N ha^{-1} and 80 kg N ha^{-1}). In sorghum, significant increase in yield attributes, *viz.,* panicle length (29.10 cm), grains $panicle^{-1}$ (2391) and grain weight $panicle^{-1}$ (65.81 g) was recorded at 175 kg N ha^{-1} but the increase in 1000 grain weight (29.6 g) was significantly higher at 225 kg N ha^{-1} as compared to 175 kg N ha^{-1} (27.8 g), application of 225 kg N ha^{-1} produced the highest grain yield (8040 kg ha^{-1}) which was 2.8 %, 8.9 % , 36.3 % and 67.2 % higher than that of 175 kg N ha^{-1}, 125 kg N ha^{-1}, 75 kg N ha^{-1} and 25 kg N ha^{-1}, respectively. Grain yield obtained with 225 kg N ha^{-1} (8040 kg ha^{-1}) was on a par with that of 175 N kg ha^{-1} (7820 kg ha^{-1}) and 125 kg N ha^{-1} (5960 kg ha^{-1}) conducted during *rabi*, in Kondura village, Tenali, in Guntur district of coastal AP on clay loam soils (Mishra *et al*., 2013). Application of 150 kg N ha^{-1} significantly improved the grain yield (5771 kg ha^{-1}) of rice fallow sorghum over 0 kg N ha^{-1} (4113 kg ha^{-1}), 50 kg N ha^{-1} (4846 kg ha^{-1}) and 100 kg N ha^{-1} (5334 kg ha^{-1}) [Arunakumari *et al.* (2015)].

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