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PLANT DENSITY AND GRAIN YIELD OF NIGERIAN SORGHUMS

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ABSTRACT

A series of experiments was conducted for three years (1968–70) at the Institute for Agricultural Research, Samaru, Nigeria to study the effect of stand density of long-season dwarf photosensitive varieties and hybrids on yield and to determine the optimum stand density for maximum yields. Good yields were obtained over a range of 50–90,000 plants per ha and the optimum harvest density is about 65,000 per ha. This is double the optimum population for best yields of tall long-season photosensitive varieties. The average yield of the dwarf variety in 1970 where stem-borers were controlled was 4.3 tonnes per ha.

Nigerian main food crop Sorghum (guineacorn) varieties are planted at the beginning of the rainy season, flower as the rains finish and ripen on residual soil moisture. Since the length of the rainy season increases from north to south in the country's sorghum areas, so in consequence does the life-span of the adapted local varieties, ranging from 4½ to 8 months or more.[1] Experiments have shown that 2,000–2,500 kg/ha are the best yields of which these varieties, such as Farafara or Kaura, are capable. This is because they are tall (4–5m) and the proportion of grain to stem and leaf is low, which gives a harvest index of 10% or less. While the stems do of course have uses, they cannot compare in value with the grain. Since they are tall, only small amounts of fertilizer can be used since otherwise lodging occurs before flowering. Also, increasing the plant population beyond 20,000–30,000 plants per ha does not result in further increases in grain yield. This may be compared with the performance of imported dwarf varieties and hybrids which, having a harvest index of up to 50%, give yields of 5,000 kg/ha. Unfortunately such imported varieties are not directly useful in most of Nigeria because of poor grain quality and lack of adaptation to prevalent pests and diseases.

It is apparent that while the local varieties are most efficient when grown in the traditional way they are not the right types of plants to exploit the increased inputs that are needed to increase yields per ha. For this, a plant type is required which can be grown at a high plant density and efficiently utilize fertilizer without lodging. However the use of higher plant densities requires careful consideration because of the risk of inducing moisture stress at the end of the season. The plant densities used by farmers, especially in crop mixtures, do not make a complete canopy at flowering time. Water use is related to plant arrangement and numbers, so the farmer, being familiar with his variety and soil, uses densities known by experience to minimise the risk of drought stress. Higher densities increase the risk because more of the limited reserve of water in the soil is needed to ripen the crop. In normal years this may be sufficient but in dry years the use of higher plant populations produces an unacceptable risk of crop failure.[2] The balance between density, maturity and moisture availability is therefore of crucial importance in considering ways of improving sorghum yields.

1. D.L. Curtis, 'The relation between yield and date of heading of Nigerian sorghums', *Experimental Agriculture*, 4, 1968, 93–101.
2. D.W. Norman, 'Inter-disciplinary research on rural development: the experience of the Rural Economy Research Unit in Northern Nigeria', Overseas Liaison Committee of American Council on Education Paper No. 6, Washington, 1974.

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The solution to this dilemma, that the increased densities essential for higher yields need more moisture, lies not in seeking water-efficient varieties (though drought-susceptible ones must be discarded[3]), but in finding varieties which avoid the period of stress. Sorghum is most susceptible to drought before or at head emergence. After flowering, water requirement declines sharply and the plant can endure progressively higher deficits.[4] Examination of the rainfall pattern shows that since the rains finish rather promptly each year,[5] an advance of only 7–10 days in the flowering date will greatly reduce the risk of drought and enable higher plant densities to be used for sorghum grown alone as well as in mixtures.

Grain quality is an important consideration and a clean attractive appearance is a prerequisite. The high quality of the Nigerian varieties is partly due to the late date of flowering, whereby the grain ripens in dry conditions. Excessively early flowering results in an increase in mould damage giving a poor appearance to the grain and may lead to loss in yield.[6] The use of very early varieties can also create a grain midge problem for later-flowering local varieties growing nearby. However 7–10 days advance in flowering is tolerable provided the varieties used have inherently good grain quality and some resistance to 'weathering'.[7]

In the sorghum breeding programme at Samaru, crosses were therefore made between Nigerian varieties, which were tall and late but with good grain quality, and high yielding exotic varieties which were dwarf and early but with at best mediocre grain quality. The resultant dwarf late varieties selected were found to be higher yielding, resistant to lodging and able to achieve harvest indices of up to 30%.[8] The experiments which are reported here were conducted to discover what plant densities should be used to give the best yields.

MATERIALS AND METHODS

The experiments were conducted over three consecutive years, 1968–1970, at the Institute for Agricultural Research, Samaru. In the first year three density levels (with similar rectangularity), three levels of nitrogen fertilizer and four genotypes (three varieties and a hybrid) were included in a split-split plot design with three replications. Net sub-plot size was 31.77m². The seeded densities were 35,880, 73,810 and 155,000 plants per ha, the last representing plants 25 cm apart in each direction. Nitrogen fertilizer treatments were 53, 132 and 211 kg N per ha, the last two being applied in split doses. Phosphate was not limiting, as 72 kg/ha P_2O_5 was applied before planting and the experiment was sited on a field where phosphate fertilizer had been continuously applied over several years. The experiment was sown on June 5th and harvested on November 24th.

One experiment and an observation were sown in 1969. One variety (2123) and a fixed distance between the rows were used (see discussion, below). The seeded densities of 26,900, 80,730, 134,550 and 190,000 were achieved by using distances between plants within the row of 61, 20, 12 and 8.6 cm, the distance between rows being 61 cm. Internal plot discards were used leaving a net plot size of 13.37 m². The experiment consisted of 6 replications of each of the 4 treatments, of which each plot consisted of 6 rows, the centre of the four inner rows being harvested. The adjacent observation had the same number of main plots, also the same

3. A. Blum, 'Genotypic responses of sorghum to drought stress: I. Response to soil water stress', *Crop Science,* 14, 1974, 361–64.

4. J. Kowal and D.J. Andrews, 'Pattern of water availability and water requirement for grain sorghum production at Samaru, Nigeria', *Tropical Agriculture* (Trinidad) 50, 1973, 89–100.

5. J. Kowal and D. Knabe, *An agroclimatological atlas of the northern states of Nigeria,* Ahmadu Bello University Press, Zaria, 1972.

6. D.L. Curtis, 'The relation between yield and date of heading of Nigerian sorghums' *Experimental Agriculture,* 4, 93–101.

7. 'Weathering' is the deterioration of the seed coat as a result of exposure to weather, especially rain.

8. D.J. Andrews, 'Breeding and testing dwarf sorghums in Nigeria', *Experimental Agriculture,* 6, 1970, 41–50.

size, but the consecutive rows within each plot were planted with the densities in order. Thus rows 1 (discard) and 2 were planted at 26,900 plants per ha., row 3 at 80,730, row 4 at 134,550 and rows 5 and 6 (discard) at 190,000. Whether the low density was on the left or right side of the plot was assigned at random, but since the treatments within each of the 24 main plots were not placed at random, the results cannot be conventionally analysed. Further, the yield of any one row (with this magnitude of difference between densities) must be somewhat influenced by the density of adjacent rows.[9] This observation was therefore planted next to and treated exactly the same way as the conventional experiment so that the results could be compared. Both were sown on May 25th and harvested on November 25th, and a standard rate of 40 kg/ha P_2O_5 and 71 kg/ha N (split dose) used throughout.

In 1970 the conventional design was repeated with two amendments, the row width was increased from 61 to 71 cm while maintaining the same distances between plants within the row, giving a net plot size of 15.56 m^2, and producing seeded densities of 23, 100, 69,200, 115,300 and 162,800 plants per ha respectively. Also the plants this year were protected against stemborer *(Busseola fusca,* Fuller) by two sprays of 0.5 kg/ha a.i. carbaryl. This experiment was fertilized at the same rates as the previous year, sown on May 31st and harvested on November 24th.

RESULTS

The principal result, as indicated by Figures 1 and 2, was that the best grain yields were achieved by the long season dwarf sorghums from plant densities which were approximately twice those required by local varieties. However similar yields were obtained over a wide range of about 50,000 to 90,000 plants per ha. Where it was possible to calculate regression optimum harvest densities were between 62,000 to 75,000 plants per ha.

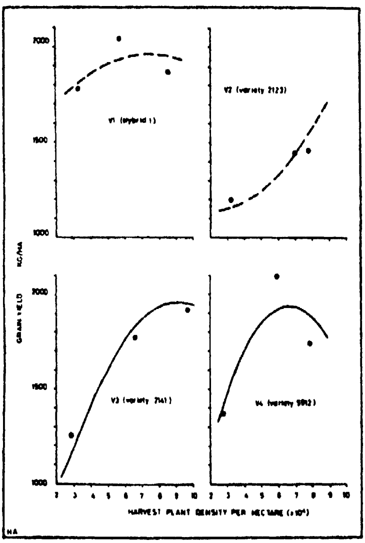

FIGURE 1. Variety x plant density trial, 1968. Mean grain yields from seeded density treatments (•) and regression curves for yield on harvest plant density (solid lines where significant at 5%).

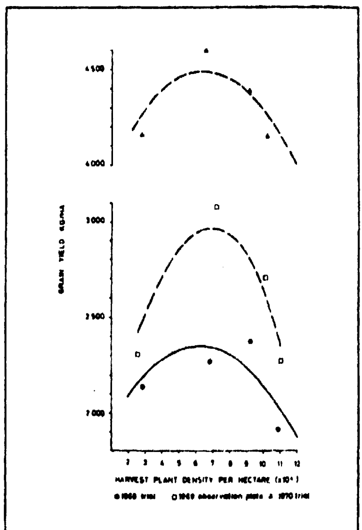

FIGURE 2. Plant density trials, 1969 and 1970. Mean grain yields from seeded density treatments and regression curves for yield on harvest plant density (solid lines where significant at 5%).

9. J.K.A. Bleasdale, 'Systematic designs for spacing experiments', *Experimental Agriculture,* 3, 1967, 73–85.

In the 1968 experiment there was no significant response to the nitrogen fertilizer. In all but variety 2123 the higher densities were better than the lowest. The hybrid gave significantly better yields than variety 2123 at all densities, but was only better than varieties 2141 and 5921 at the lowest density. The hybrid achieved this extra yield by means of heavier rather than more heads. Grain weight changed little or decreased slightly as plant density increased.

Substantially more plants failed to make heads as density increased (Tables 1 and 2), reaching 40–50% of the seeded density at the highest levels. The use of carbaryl in the 1970 experiment, where yields were double the previous year's level, reduced this failure rate though only 67% of the seeded population succeeded in producing heads at the highest density. The principal effect of carbaryl noted was a large increase in the survival of tillers at the lower densities and an increase in head weight.

TABLE 1. *Sorghum plant density trial, 1968. Plant and head densities per ha and 1,000 grain weight (gm) meaned over all fertilizer treatment.*

		Establishment density	Harvest density		Number of heads		Grain weight
			ha^{-1}	% of seeded	ha^{-1}	per plant	
V1 (Hybrid 1)	P_1	35,520	33,040	92.1	37,840	1.15	21.8
	P_2	72,570	57,700	78.2	57,700	1.00	21.5
	P_3	153,350	85,810	55.4	85,810	1.00	22.2
V2 (Variety 2123)	P_1	34,140	32,310	90.0	40,700	1.26	16.1
	P_2	71,190	69,760	94.5	69,760	1.00	15.6
	P_3	137,700	78,430	50.6	78,430	1.00	15.4
V3 (Variety 2141)	P_1	35,810	28,570	75.4	52,520	1.84	22.7
	P_2	72,230	66,580	90.2	66,580	1.00	21.0
	P_3	153,850	96,750	62.4	96,750	1.00	20.3
V4 (Variety 5912)	P_1	35,090	27,660	77.1	32,940	1.19	27.1
	P_2	71,810	58,810	79.7	58,810	1.00	26.7
	P_3	151,180	78,680	50.76	78,680	1.00	24.7

TABLE 2. *Sorghum plant density trials 1969 and 1970. Average plant and head densities per ha and 1,000 grain weight (gm)*

		Establishment density	Harvest density		Number of heads		Grain weight
			ha^{-1}	% of seeded	ha^{-1}	per plant	
1969	P_1	26,660	22,930	85.2	30,280	1.32	23.9
	P_2	79,030	67,790	84.0	68,280	1.01	22.3
	P_3	131,860	92,220	68.5	93,450	1.01	21.9
	P_4	185,820	109,160	57.4	113,880	1.04	21.9
1970	P_1	22,870	22,860	99.0	80,890	3.54	20.8
	P_2	68,090	65,460	94.6	102,750	1.57	21.8
	P_3	113,340	90,740	78.7	100,070	1.10	21.0
	P_4	158,400	101,990	62.6	106,710	1.05	20.5

DISCUSSION

Optimum plant densities for combine grain sorghums in the U.S.A. are in excess of 100,000 plants per ha;[10] but these normally take only 55-65 days to flower. While response to plant density may yet be improved by further breeding in the adapted Nigerian dwarf varieties, it is suggested that the long vegetative period of these genotypes provides enough plasticity by means of tiller establishment whereby low seeded densities may achieve the head population necessary for good yields. Comparison of the results of 1968 and 1969 with those of 1970 indicates that there may be a larger stemborer effect on the number of surviving tillers at low densities. Except for variety 2141, in 1968 and 1969, the lowest densities gave the lowest yields and produced at most 1.3 heads per plant, yet in 1970 when protected by insecticide, the plants at the lowest density averaged 3.5 and though this still meant fewer heads per ha, they yielded as well as the higher densities. If the amount of insecticide and labour needed is related to the tiller population (as it is when using a hand sprayer[11]), then the use of insecticide becomes more worthwhile at lower plant densities. This also has vital implications in the context of intercropping where, because of the lower plant number used an increase in the survival of tillers will mean an increase in yield.

The 1969 and 1970 trials concentrated on the effect of intrarow spacing only. In the first trial there was a lack of response to fertilizer though it now seems possible that this may have been suppressed by stemborer. Fixed interrow spacing was adopted because of the need for weeding. In the absence of herbicides, space is required in the crop for movement, either for mechanical or hand weeding; also the results with this plant arrangement are more appropriate to intercropping. Though moisture stress did not occur in the experiment other observations showed that variety 2141 was quite susceptible. Variety 2123 was chosen as the most suitable type to indicate population response as it was fully dwarf, capable of tillering and flowered about a week earlier than the other two varieties. The hybrid was not chosen as it proved susceptible to Striga (*Wuta-wuta*) damage.

In 1969 when the yields of the two intermediate densities were significantly better than the highest and lowest, the fitted regression showed the optimum density to be 62,000 plants per ha. The results from the observation also showed the extreme densities to be unsatisfactory and indicated an optimum population only slightly more than the conventional design. Despite its limitations, 5-10 plots of this design could be useful for new varieties in defining those population densities where more accurate experiments should be conducted. The 1969 and 1970 trials may be directly compared as the same variety, design and fertilizer levels were used. The 1970 trial however averaged twice as much yield and conclusively demonstrated that a dwarf variety (not a hybrid) could give over 4 tonnes of grain per ha without lodging which is over double that obtainable from the best tall varieties (where lodging and not stemborer is the first factor which limits yield). Additionally it showed that with the use of insecticide there need not be a great disparity between the seeded population needed to give the optimum harvest population, since previous experiments suggested that to obtain such a harvest population 10–15% more should be seeded.

10. F.C. Stickler, A.W. Pauli, H.H. Laude, H.D. Wilkins, and J.L. Mings, 'Row width and plant population studies with grain sorghum', *Crop Science*, **1**, 1961, 297–300; P.L. Brown and W.D. Shrader, 'Grain yields, evaporation and water use efficiency of grain sorghum under different cultural practices', *Agronomy Journal*, **51**, 1959, 339–343.

11. B.D. Barry and D.J. Andrews, 'A sprayer for the control of Busseola fusca in the whorl of sorghum', *Journal of Economic Entomology*, **67**, 1974, 310–311.

CONCLUSION

A series of trials using dwarf photosensitive sorghum varieties over 3 years showed that, over a range of yield levels, about 65,000 plants per ha at harvest gave the best yields. This is double the optimum population for the best yields using tall varieties. The average grain yield of the dwarf variety in the final trial where stemborers were controlled, was 4.3 tonnes per ha.

Acknowledgements

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