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# ESTABLISHMENT OF OPTIMUM PLANT DENSITIES FOR DRY SEASON SORGHUM GROWN ON *VERTISOLS* IN THE SEMI-ARID ZONE OF CAMEROON

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## ABSTRACT

Dry season transplanted sorghum is grown on *Vertisols* in the Lake Chad Basin at approximately 10,000 plants ha$^{-1}$. Increasing plant density was hypothesised to be one way of increasing yields in this cropping system. To test this hypothesis, a trial was conducted in four environments near Maroua in northern Cameroon (one year at Yoldeo and three years at Salak) examining densities ranging from 10,000 to 50,000 plants ha$^{-1}$. Grain yields were not significantly increased by increasing planting density in any of the environments because of reduced panicle size. For example, as planting density was doubled from 10,000 to 20,000 ha$^{-1}$, the mean density of panicles harvested was increased by 85% but mean grain weight per panicle was decreased by 45%. Thus, in all environments, mean grain yields increased by 100 kg ha$^{-1}$ (9%) at the transplant density of 20,000 ha$^{-1}$ and 150 kg ha$^{-1}$ at 26,667 plants ha$^{-1}$. A comparison of results from three years at Salak suggests that the fraction of plants bearing panicles is influenced by the annual rainfall and, especially, the amount of rain during August and September. However, even after a season of adequate rainfall, panicle grain weight decreased with increasing panicle density, suggesting that there is little scope for increasing dry season sorghum transplant density without supplemental irrigation. Considering increases in labour input for nursery establishment, transplanting and harvest, the increased revenue from increasing planting density does not compensate for increased costs. The economic optimum is around 10,000 ha$^{-1}$, which is similar to the current farmers' practice.

*Key words*: Economic optimum, environment, irrigation, partial budget analysis, *Sorghum bicolor*

## RÉSUMÉ

La densité de plantation pour des sorghos repiqués en saison sèche sur les *Vertisols* dans le basin du lac Tchad environne 10000 plantes ha$^{-1}$. L'augmentation de la densité semble être un moyen d'augmenter son rendement dans ce systeme agricole. Pour tester cette hypothèse, un essai comportant cinq densité variant entre 10000 et 50000 plantes ha$^{-1}$ a été conduit pendant trois ans à Salak et un an à Yoldeo dans le nord du Cameroun près de Maroura. Le rendement en grains n'a pas significativement augmenté avec la densité des plantes à cause de la réduction de dimensions de la panicule. Par exemple, en doublant la densité de 10000 plantes ha$^{-1}$, la densité moyenne de penicules récoltées a augmenté de 85%, mais le poids moyen de grains par penicule a dimunué de 45%. Pour différents environnements, le rendement en grains a été augmenté de 100 kg dans le traitement de 20000 plantes ha$^{-1}$ et 150 kg dans le traitement de 26666 plantes ha$^{-1}$. Les résultats suggèrent que à Salak la fraction de plantes avec penicules est influencée par la pluviométrie des mois d'Août et Septembre. Toutefois, malgré un regime pluviométrique adéquate, le poids de grains des penicules a diminué avec l'augmentation de la densité de penicules faisant transparaitre moins d'espoir d'augmenter la densité de repiquage du sorgho sans irrigation, pendant la saison sèche. Considérant le coût du travail pour l'installation des pépinières, le repiquage et la récolte, le revenue généré ne couvre pas les dépenses engagées. L'optimum économique est autour des 10000 plantes ha-1 actuellement utilisé par les agriculteurs.

*Mots Clés*: Optimum économique, environnement, analyse du budget partiel, *Sorghum bicolor*

## INTRODUCTION

Dry season transplanted sorghum (*Sorghum bicolor* (L.) Moench, durra or caudatum races) is an important crop in the Lake Chad basin (northern Cameroon, northeastern Nigeria, and western Chad). In Cameroon, dry season sorghum accounts for almost 40% of sorghum grain production (USDA, 1978; MINAGRI, 1991). The area of soils having a very high potential for dry season sorghum cropping in northern Cameroon covers 800,000 ha (USDA, 1978). The estimate for northeastern Nigeria is 400,000 ha (Kolawole *et al.*, 1996). The major constraint to increased production is soil moisture availability (Carsky *et al.*, 1995; Kolawole *et al.*, 1996).

Farmers generally transplant dry season sorghum (called *Muskwari* in Cameroon and *Masakwa* in Nigeria) at a density of about 10,000 plants $ha^{-1}$ (Njomaha and Kamuanga, 1991; Kolawole *et al.*, 1996). There may be some potential to increase yields by increasing plant density, especially in "wet years" and possibly in sites with high soil moisture holding capacity.

Survival of transplanted sorghum requires placement of seedlings deep enough to access soil moisture. Substantial labour is required to make holes 10 to 30 cm deep with a heavy, pointed tool besides watering since, each planting hole receives 0.3 l of water at planting (Njomaha and Kamuanga, 1991). The increase in labour input must be taken into account in judging the economic viability of increased planting density. Thus, the purpose of this paper is to report not only on the agronomic performance, but also on the economic viability of increasing plant density with regard to increased labour requirements.

## MATERIALS AND METHODS

**Trial sites and operations.** The trial was conducted at Salak in 1986-87, 1987-88, and 1988-89, and at Yoldéo in 1986-87 on *Vertisols* with approximately 40% clay content. Both sites are within 30 km of Maroua (10°36'N; 14°20'E; 550 m above sea level).

Variable plant densities were accomplished by changing the distance between plants within rows, while spacing between rows was maintained at 1 m. There were 2 plants per hole for all treatments. Intra-row spacing of 2, 1, 0.75, 0.5, and 0.4 m gave theoretical densities of 10,000, 20,000, 26,667, 40,000, and 50,000 $ha^{-1}$. Plots were 6 rows wide and 8 m long and were laid out in a randomised complete block design with four replicates.

Trial management closely reflected farmers' practices (Table 1). Sorghum nursery plots were established from mid-August to mid-September at 10-day intervals to ensure availability of seedlings of appropriate age. When the rains stopped, native grass was cut and burnt *in situ* as practiced by farmers. Transplanting of 4 to 5 week old seedlings was done generally in early to mid-October and harvested in early February. There were some cases of plant mortality caused by brief episodes of localised flooding caused by late rains. In these cases, the stands were replanted with seedlings left over from the nursery. The crop was weeded once in November.

TABLE 1. Summary of major trial management factors in Muskwari transplant density trial in sites near Maroua, Cameroon, 1986-89

| Environment | Transplanting date | Sorghum variety | Harvest date |
|---|---|---|---|
| Salak '86-87 | 09/10/86 | SAF-7 | 12/02/87 |
| Yoldéo '86-87 | 15/10/86 | Bourgouri-28 | 07/02/87 |
| Salak '87-88 | 28/09/87 | SAF-40 | 26/01/88 |
| Salak '87-88 | 18/10/88 | SAF-40 | 13/02/89 |

Number of panicles and grain yield after threshing and drying were determined in the four central rows at physiological maturity. Panicle grain weight was calculated as the yield of grain divided by the number of panicles harvested. Stover yield was determined once at Yoldeo and once at Salak. Analysis of variance (ANOVA) was conducted for yield and yield components for each environment separately because a combined analysis showed a significant effect of environment and environment by planting density interaction for panicle density and panicle weight.

**Partial budget analysis.** A partial budget was estimated following CIMMYT (1988) approach. Net benefit was calculated as gross field benefits minus total costs that vary (TCV). These costs (TCV) included labour costs, seed and water for transplanting. Only operations for which labour input would be affected by a change in planting density were considered, namely seedling preparation (in nursery), transplanting, panicle harvest and stover harvest. Field preparation labour and weeding labour were considered to be independent of density. Labour input estimates used in our analysis are 28 h ha$^{-1}$ for seedling preparation, 135 h ha$^{-1}$ for transplanting, 78 h ha$^{-1}$ for panicle harvesting, 60 h ha$^{-1}$ for stover harvesting as reported previously by Njomaha and Kamuanga (1991). Labour costs were 550 FCFA per 7-hour day (Njomaha and Kamuanga, 1991). We assumed a labour increase of 60% for each additional 10,000 plants in the nursery and each additional 5,000 holes per hectare for transplanting. Likewise, labour input for transplanting 10,000 additional plants was assumed to be 60% of the 135 h estimated by (Njomaha and Kamuanga, 1991) for the first 10,000 plants, rather than a proportional increase. Panicle harvest labour input was multiplied by half of the ratio of actual panicle number to panicle number for the 10,000 ha$^{-1}$ treatment. Labour input for stover harvest was assumed to increase proportionally with increasing weight of harvest. Cost of seed was calculated as the product of the target density, the weight per seed (45 g per 1000 seeds), and the seed price (100 FCFA kg$^{-1}$) and adjusted upward by 20% to obtain enough seed in the nursery. The cost of water for transplanting was estimated from the field value of 0.3 l per planting hole (1,875 FCFA ha$^{-1}$ for 5,000 holes).

The average grain price estimate recorded by Njomaha and Kamuanga (1991) for five villages in the area (70 FCFA kg$^{-1}$) was reduced to 60 FCFA kg$^{-1}$ to take into account the costs of threshing and transporting the grain (CIMMYT, 1988). Stover price was estimated at 40 to 60 FCFA kg$^{-1}$ by Njomaha and Kamuanga (1991), but was reduced to 20 FCFA kg$^{-1}$ because of transport and marketing costs.

Partial budget analysis was followed by dominance analysis to eliminate dominated options and then calculation of marginal rates of return for the remaining options (CIMMYT, 1988).

## RESULTS AND DISCUSSION

**Agronomic performance.** Panicle density increased significantly with increasing transplanting density at both sites in 1986-87 (Table 2). Panicle density was increased by 73% at Salak and 81% at Yoldeo by doubling transplanting density. Grain yield increase was not significant ($P<0.05$). The increase in grain yields from doubling transplanting density was less than 50 kg ha$^{-1}$ at the two sites. Transplanting density of 26,667 ha$^{-1}$ gave 250 kg ha$^{-1}$ of additional grain over the control at Salak and 90 kg ha$^{-1}$ at Yoldeo.

At Salak in 1987-88 there was a high proportion of barren sorghum plants as 4,000 panicles with grain were produced by the control treatment (Table 3). Grain yield was lowest in this environment with 730 kg ha$^{-1}$ for the control. As transplanting density increased, the number of panicles increased significantly ($P<0.05$) but grain yield did not. The yield increase was 50 kg ha$^{-1}$ from 20,000 plants ha$^{-1}$ and 100 kg ha$^{-1}$ from 26,667 plants ha$^{-1}$. In 1988-89, panicle densities were high with approximately 100% of plants forming panicles at the lower densities and 80% at the higher densities (Table 3). Grain yield was not increased significantly by increasing transplant density, although 260 kg ha$^{-1}$ of additional grain was produced by the 20,000 plants ha$^{-1}$ treatment.

The fraction of stands that beared panicles ranged from 40 to 100% in the four environments and five treatments. The fraction tended to be higher at low planting densities than at higher densities in each environment (Fig.1). This is expected as more plants compete for a fixed amount of soil moisture. Other results reported by Barrault *et al.* (1972) and Carsky *et al.* (1995) suggest that moisture is much more limiting than nutrients in dry season sorghum. The results in Figure 1 suggest that an important determinant of the fraction of plants producing panicles is the amount of rainfall during the previous rainy season. In 1987-88, following a dry year, only about 80% of plants survived and 60% of surviving plants produced panicles. In 1988-89, following a season of "normal rainfall", approximately 100% of plants survived and produced panicles at the lower densities. The situation at Salak in 1986-87 was intermediate in terms of rainfall and panicle density.

In addition to an increase in the number of barren plants as shown above, the lack of a response of sorghum grain yield to increasing transplanting density is due to smaller panicles. For example, at the transplanting density of 10,000 plants ha$^{-1}$, mean panicle density was 8,360 ha$^{-1}$ and mean grain weight per panicle was 148g. At the transplanting density of 20,000 ha$^{-1}$, the mean panicle density was 15,500 ha$^{-1}$ and mean grain weight per panicle was 81 g. Thus, 85% increase in the number of panicles was offset by a 45% decrease in grain weight per panicle. The relationship between panicle grain weight and density was very consistent at three environments (Fig. 2). Higher panicle grain weights were produced in the 1986-87 and 1988-89 trials following rainfall of 600 to 800 mm. Low panicle grain weight was produced in the 1987-88 trial following less than 500 mm rainfall. The curves have the same shape showing progressively smaller decreases in grain weight per panicle as panicle density increases. The shape of the curves indicates that yield (density multiplied by weight)

TABLE 2. Effect of transplant density on yield and yield components of dry season sorghum at Salak and Yoldéo, 1986 - 1987

| | Salak | | Yoldeo | | |
|---|---|---|---|---|---|
| Planting density (ha$^{-1}$) | Panicle density (ha$^{-1}$) | Grain yield (kg ha$^{-1}$) | Panicle density (ha$^{-1}$) | Grain yield (kg ha$^{-1}$) | Stover yield (kg ha$^{-1}$) |
| 10,000 | 8,190 | 1,350 | 10,070 | 1,390 | 1,720 |
| 20,000 | 14,170 | 1,380 | 18,190 | 1,430 | 1,720 |
| 26,667 | 16,250 | 1,580 | 23,120 | 1,480 | 2,090 |
| 40,000 | 22,010 | 1,560 | 37,640 | 1,440 | 1,640 |
| 50,000 | 29,170 | 1,340 | 49,375 | 1,470 | 1,850 |
| SE | 1,537 | 100 | 849 | 70 | 90 |

TABLE 3. Effect of transplant density on yield and yield components of dry season sorghum at Salak 1987 - 88 and 1988-89

| | 1987-1988 | | 1988-1989 | | |
|---|---|---|---|---|---|
| Planting density (ha$^{-1}$) | Panicle density (ha$^{-1}$) | Grain yield (kg ha$^{-1}$) | Panicle density (ha$^{-1}$) | Grain yield (kg ha$^{-1}$) | Stover yield (kg ha$^{-1}$) |
| 10,000 | 3,990 | 730 | 11,190 | 1,170 | 2,190 |
| 20,000 | 9,600 | 780 | 20,060 | 1,430 | 2,780 |
| 26,667 | 14,610 | 830 | 22,060 | 1,360 | 3,313 |
| 40,000 | 21,960 | 640 | 32,250 | 1,290 | 3,530 |
| 50,000 | 18,360 | 580 | 40,250 | 1,290 | 3,280 |
| SE | 2,462 | 105 | 1,594 | 130 | 225 |

is relatively constant and increasing density cannot be expected to increase yield substantially in this system. Doubling transplanting density from 10,000 to 20,000 ha$^{-1}$ resulted in an average grain yield increase of 100 kg ha$^{-1}$ or 9%. The next density increment was associated with a yield increase of 50 kg ha$^{-1}$.

Salak in 1987-88 had the highest plant mortality and proportion of barren plants but lowest grain yields. Even the relationship between panicle density and panicle grain weight was not maintained as in the other environments (Fig. 2). Panicle density was lowest at each transplanting density and total annual rainfall was lowest (Fig. 1), suggesting that lower moisture availability was responsible for this. Further synthesis of the data (Table 4) shows that the rainfall during the two months immediately preceding the dry season

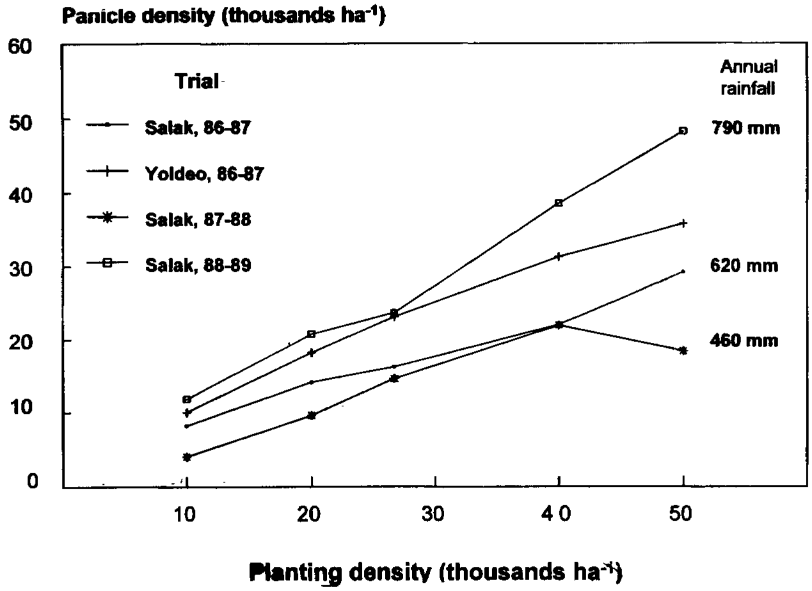


Figure 1. Effect of dry season sorghum planting density and total annual rainfall on panicle density at harvest on *Vertisols* in northern Cameroon.

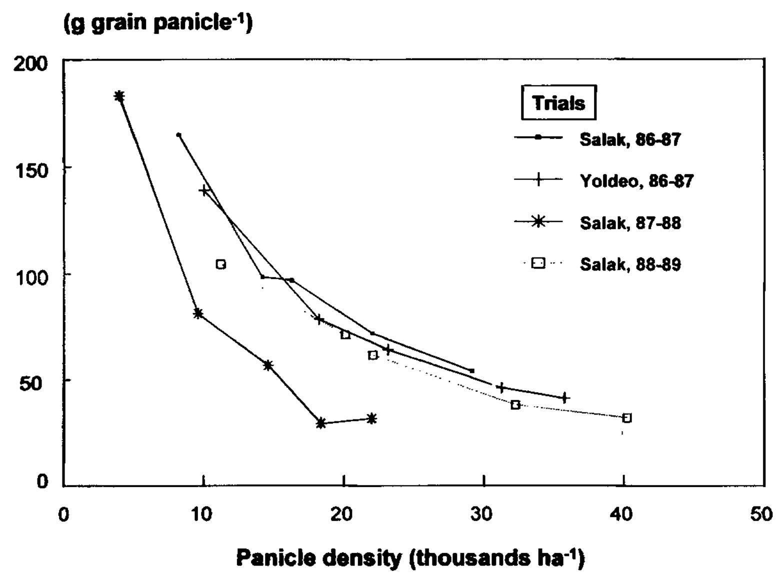


Figure 2. Effect of sorghum panicle density on grain weight of panicles in dry season sorghum transplanted into four *Vertisol* environments in northern Cameroon.

totaled 150 mm. During the 1986-87 season with the highest control yield, 280 mm of rainfall fell during the same period.

A dry season sorghum crop has access to an amount of available soil moisture which is defined by the soil profile depth, the potential available moisture retention of each soil layer, and the degree to which each layer is filled (Barrault *et al.*, 1972). The maximum moisture capacity was estimated at 213 mm by Barrault *et al.* (1972) for sites similar to those in our study. In a dry year, lower layers may not be filled. In most years, upper layers are depleted as substantial evaporation occurs before transplanting. The upper-most soil layer (5 to 15 cm) is usually very dry at planting.

From comparison of the results of three years at Salak, it appears that an adequate annual rainfall for dry season sorghum production is approximately 600 mm with August-September rainfall of 250 mm (Table 4). The low rainfall of 1987 (465 mm) may have been insufficient to fill the soil profile to capacity and the relatively high rainfall of 1988 probably did not increase soil profile moisture above its fixed capacity. Therefore, it appears that *Muskwari* yield is determined by the amount of available soil moisture at planting. Competition between neighboring plants occurs as the soil profile moisture reserve is depleted. Biomass accumulation and grain dry matter per plant are reduced. Increasing planting density results in competition at an earlier stage of growth, which consequently, decreases yield per plant. Figure 2 shows that increasing transplant density results in substantial reductions of panicle grain weight for *Muskwari* crop, irrespective of a normal or a dry rainy season. In the face of this difficulty, farmers rationally apportion labour. Farmers have no doubt experimented with planting density to find the density which suits their soil type, the previous seasons' rainfall, and available labour. *Muskwari* plant density on 72 farmers' fields ranged from approximately 8,000 to 18,000 ha$^{-1}$ when surveyed by De Steenhuijsen Piters (1995). In this study, there was no significant relationship between yield and density above 12,000 ha$^{-1}$. Rather than increase planting density, farmers' labour would be better used to extend the surface cultivated or to store water for irrigation. One or two applications of supplemental water can effect large yield increases in this production system (Carsky *et al.*, 1995).

The varieties used for these trials were not uniform from year to year. It is likely that varietal differences played a minor part in the differences observed, with the major factor being soil moisture. Indeed, the same variety (SAF-40) was used in 1987 and 1988 when large differences in previous rainfall, panicle density and grain yield were observed.

**Partial Budget Analysis.** The total variable costs ranged from approximately 25,600 FCFA ha$^{-1}$ at the 10,000 ha$^{-1}$ transplant density to 75,000 FCFA ha$^{-1}$ at a density of 50,000 ha$^{-1}$ (Table 5). Gross revenue from grain and stover ranged from 108,700 to 132,700 FCFA ha$^{-1}$ (Table 6), with the highest revenue coming from the 26,667 ha$^{-1}$ planting density. Dominance analysis (CIMMYT, 1988) shows that all higher densities except the 26,667 ha$^{-1}$ treatment are dominated because their net benefits are lower than that of the control and TCV are higher. Net benefit was highest with the 26,667 ha$^{-1}$ planting density but only 2,300 FCFA ha$^{-1}$ higher than the 10,000 ha$^{-1}$ treatment. The marginal rate of return for that treatment is only 11%, which is not sufficiently high for farmers to consider (CIMMYT, 1988). This is in spite of the assumptions that were made to favor increasing planting density. Specifically, labour input for

TABLE 4. Relationship between yearly rainfall and yield and yield components of the 10,000 plants ha$^{-1}$ treatment at Salak

| Year | Annual rainfall (mm) | Aug + Sept rainfall (mm) | Panicle density (ha$^{-1}$) | Grain per panicle | Grain yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|
| 1986-87 | 620 | 280 | 8,190 | 165 | 1,350 |
| 1987-88 | 460 | 150 | 3,990 | 183 | 730 |
| 1988-89 | 790 | 500 | 11,190 | 104 | 1,170 |

nursery preparation and transplanting was not increased in proportion to the increasing transplanting density but by 60%.

The economic analyses are sensitive to labour estimates, which are difficult to obtain. Estimates from a different study of one village in which farmers were given watches and notebooks to record labour input were 51 h $ha^{-1}$ for seedling preparation, 225 h $ha^{-1}$ for transplanting, and 52 h $ha^{-1}$ for harvest (De Steenhuijsen Piters, Agricultural University of Wageningen, personal communication, 1993). Using these values gives net benefits even less favourable for all increases in transplant density. Another area of sensitivity of the partial budget is the price of sorghum products. We used a sorghum grain price that was 15% less than the village market price recorded by Njomaha and Kamuanga (1991) to take threshing and transport into account. The stover price used in our analysis was much lower than the price estimated by Njomaha and Kamuanga (1991). Doubling the price of sorghum stover (to 40 FCFA $kg^{-1}$) gave marginal rates of return that are favourable for the 20,000 and 26,667 $ha^{-1}$ transplanting densities. However, it must be noted that we only have two environments for the stover yield estimates so we would hesitate to make recommendations based on this.

## CONCLUSIONS

Increasing dry season sorghum transplanting density reduces panicle size because the volume of available water, the limiting production factor, is fixed. Thus, the possibility to increase yield is limited unless the moisture constraint is first alleviated. Actual farmers' transplanting densities are in the economically optimal range of approximately 10,000 $ha^{-1}$. Instead of using available labour to increase plant density, farmers may extend the area of dry season sorghum cultivation or invest in supplemental irrigation.

TABLE 5. Estimates of costs that vary (FCFA $ha^{-1}$) from increasing transplant density of dry season sorghum on Vertisols in northern Cameroon

| Planting density | Seed and water | Labour | | | | Total costs that vary |
|---|---|---|---|---|---|---|
| | | Nursery prep. | Transplanting | Grain | Stover harvest | |
| 10,000 | 1,930 | 2,200 | 10,610 | 6,130 | 4,710 | 25,600 |
| 20,000 | 3,860 | 3,520 | 16,970 | 8,750 | 5,430 | 38,500 |
| 26,667 | 5,140 | 4,400 | 21,210 | 10,030 | 6,510 | 47,300 |
| 40,000 | 7,720 | 6,160 | 29,700 | 13,500 | 6,230 | 63,300 |
| 50,000 | 9,640 | 7,480 | 36,060 | 15,630 | 6,180 | 75,000 |

TABLE 6. Estimates of gross and net benefit (in 1992 FCFA ha-1) from increasing transplanting density of dry season sorghum

| Planting ($ha^{-1}$) | Grain [a] (kg $ha^{-1}$) | Stover [b] (kg $ha^{-1}$) | Gross field benefits | | | Net benefit |
|---|---|---|---|---|---|---|
| | | | Grain [c] | Stover [d] | Total | |
| 10,000 | 1,160 | 1,950 | 69,600 | 39,100 | 108,700 | 83,100 |
| 20,000 | 1,250 | 2,250 | 75,300 | 45,000 | 120,300 | 81,800 |
| 26,667 | 1,310 | 2,700 | 78,750 | 54,000 | 132,700 | 85,400 |
| 40,000 | 1,230 | 2,580 | 73,950 | 51,700 | 125,600 | 62,300 |
| 50,000 | 1,170 | 2,560 | 70,200 | 51,300 | 121,500 | 46,500 |

[a] Means from Salak 86-87, 87-88, and 89-89 and Yoldéo 86-87; [b] Means from Salak 88-89 and Yoldéo 86-87; [c] Grain price = 70 FCFA $kg^{-1}$ at village market adjusted to 60 FCFA $kg^{-1}$ for threshing and transport; [d] Stover price = 20 FCFA $kg^{-1}$

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