STOOL POPULATIONS AND YIELD OF SUGARCANE UNDER IRRIGATED CONDITIONS AT PONGOLA

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Abstract

Yield per unit area increased rapidly to a maximum as the number of stools increased, and either remained relatively constant or declined slightly with higher stool densities, depending upon the particular component of yield. The results imply that under favourable growing conditions, maximum yield per unit area can be achieved with relatively low stool populations. There is considerable potential for reducing seedcane requirements and the number of harvestable stalks in irrigated fields. It may also be economically feasible to transplant nursery-grown seedlings into irrigated commercial fields. Comparisons of the yields of isolated stools of different varieties could be misleading because the relative performance of the same varieties can be different at high stool densities.

Introduction

The results of row and sett spacing experiments have been described by Thompson and du Toit[10] and Boyce[3]. Whilst the relationship between row or sett spacing and crop yield was studied, no attempt was made to specify the number of stools initially established. The number of buds which germinate and form primary shoots may be as few as 50 per cent of the number planted. It was decided therefore to determine the number of stools required to achieve the maximum yield per unit area. An experiment was designed to define the relationship between complete stands of stool populations planted "on the square" and crop yield over a very wide range of treatments. Similar studies for vegetative yields of other crops (Holliday[5], Bleasdale[2], Jarvis[7]) have indicated that above a relatively low density, the yield response is likely to be negligible.

The experiment was located at Pongola on the South African Sugar Association Field Station. The soil is a deep sandy clay of the Makatini series, the characteristics of which were described by Thompson and Boyce[9]. The plant and first ratoon crops were grown over 9- and 12-month periods respectively between 26 October, 1967, and 4 August, 1969.

Treatments

The treatments consisted of seven stool densities established "on the square" and two varieties. These treatments were established with pre-germinated single-bud setts. An extraneous row spacing treatment (S8; N:Co.376) was allotted to two vacant plots on the site. The rows were 144.5 cm apart and were planted with pre-germinated three-bud setts of variety N:Co.376. The purpose of this S8 treatment was to provide some indication of the relationship between the square spacing treatments and current commercial practice. The treatments were as follows:

(i) *Stool populations per hectare*

Treatment Code	Stools per hectare	Square spacing cm
S1	746	366
S2	1,912	229
S3	4,787	144
S4	12,034	91
S5	30,480	57
S6	75,770	36
S7	192,131	23
S8; N : Co.376	75,770	144 cm rows

(ii) *Varieties*

V1 : N:Co.376
V2 : C.B.36/14

The population treatments were spaced on a log scale. Successive populations were increased by a factor of 2.5. The upper limit of 192,131 stools per hectare was intended to give a final stalk population consisting mainly of the original primary stalks. The lower limit of 746 stools per hectare was chosen to give minimal inter-stool competition. The two varieties were included to identify population × variety interactions. These particular varieties were chosen because of their different morphological characteristics.

Design and Analysis

The experiment consisted of three replications of a split-plot design with the varieties as whole-plot factors and the seven stool population treatments as sub-plot factors. No particular attention was given to the differences between individual treatment means; what was of interest was the form of the trend of each characteristic with increasing stool density, and not the significance of treatment differences. Since competition was minimal with the S1 treatment, no particular population could be safely associated with the yield data for this treatment. For the purpose of describing the form of the trends with increasing density, the data for treatment S1 were excluded. Since the variance of the data for treatment S1 was similar to that of the other treatments, these data were included in the analyses of variance.

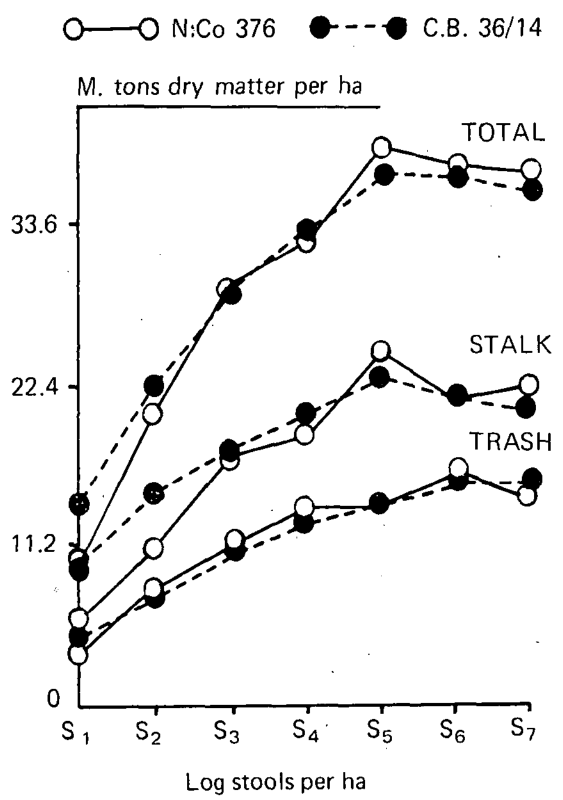
Field Operations

Adequate supplies of water and nutrients were available to the crop. Basal fertilizer applications and top-dressings were broadcast over the entire site. Healthy seedcane was cut into uniform single-bud setts which were treated with insecticide and fungicide before being pre-germinated under wet sacks.

Uniformly pre-germinated setts were planted "on the square" and covered evenly with soil which was then compacted. Irrigation was controlled by means of a profit and loss account system. Weeds were eliminated by means of a herbicide and by hand cultivation when necessary. Complete stands of stools were established by filling gaps with transplants from a separate nursery supply, before competition began.

At harvesting, the dead leaf, green foliage and millable stalk components of the above-ground yield were weighed for the plant crop, but for the first ratoon crop, only the fresh weight of millable stalk was obtained. The moisture contents of sub-samples of the dead leaves, green foliage and millable stalk of the plant crop were determined, so that the results could be expressed on a dry-weight basis. Sub-samples of the millable cane were taken for quality analyses. The stalks were counted and a sub-sample of the stalks in each plot was measured for lengths and diameters at the bottom, middle and top of each stalk. After harvesting the plant crop, the crop residues were spread over the site and burnt.

FIGURE 1: Production of dry matter in the plant crop.



Results

Dry Matter Production

The results for production of dry matter in the plant crop are plotted graphically in Fig. 1, whilst Table I shows the levels of significance and signs of the trends with increasing stool density.

TABLE I
Dry matter (D.M.) production in the plant crop
Levels of significance and signs for trends of characteristics with increasing stool populations per hectare.

Sub-division of S.S. for treatments S2 to S7	Effects	Total D.M. per hectare		Stalk D.M. per hectare		Trash D.M. per hectare	
Population S.S.	Linear	***	+	***	+	***	+
	Quadratic	***		***		***	
Population x Variety S.S.	Linear	NS	+	*	+	NS	−
	Quadratic	NS		NS		NS	

*** : $P < 0.001$
** : $P < 0.01$
* : $P < 0.05$

As shown in Fig. 1, the dry matter in stalks and trash, and the total above-ground dry matter increased linearly at first and then at a decreasing rate with increasing density, both linear and quadratic effects being very high significant ($P<0.001$). For stalk dry matter, the population × variety interaction was significant ($P<0.05$).

Yield and Quality of Cane

The results and summarised statistical analyses for yield and quality of cane for both plant and first ratoon crops are given in Tables II and III.

In the plant crop, metric (m) tons cane per hectare increased at a decreasing rate with increasing stool density and declined at very high stool densities ($P<0.001$), but in the ratoon crop the effect of stool density on the yield of cane was non-significant. In spite of the obvious limitations of the data for the row spacing treatment S8; N:Co.376, the results for this treatment were not very different from the best results achieved with square planting treatments. The population × variety interaction was highly significant for m tons cane per hectare in the plant crop for both linear ($P<0.01$) and quadratic ($P<0.05$) effects. This interaction was due to the higher yield of C.B.36/14 than N:Co.376 at low stool densities and the reversal of this situation at higher stool densities. There was no significant interaction in the ratoon crop.

Sucrose per cent cane increased linearly ($P<0.001$) with increasing density in the plant crop but in the first ratoon crop this effect was less

TABLE II
Yield and Quality of Cane

Treatments	M.tons cane/hectare			Sucrose % cane			M.tons Sucrose/hectare		
	376	36/14	Mean	376	36/14	Mean	376	36/14	Mean
PLANT CROP									
S1 : 746	34.7	50.6	42.8	9.2	10.2	9.6	3.2	5.2	4.2
S2 : 1,912	68.5	86.2	77.3	8.9	9.9	9.4	6.1	8.5	7.3
S3 : 4,787	111.1	104.6	107.7	9.0	10.2	9.6	10.0	10.7	10.3
S4 : 12,034	125.7	112.4	118.9	9.0	10.6	9.8	11.3	12.0	11.6
S5 : 30,480	145.4	125.7	135.5	9.7	11.3	10.5	14.1	14.2	14.2
S6 : 75,770	117.6	107.5	112.4	9.9	11.6	10.7	11.6	12.5	12.0
S7 : 192,131	124.3	106.0	115.1	9.8	11.3	10.6	12.2	12.0	12.1
S8 : 75,770	142.0	—	—	9.4	—	—	13.4	—	—
S.E. popn.means	4.9	4.9	3.4	0.2	0.2	0.1	0.5	0.5	0.3
C.V. for sub-plots	—	—	8.2%	—	—	3.2%	—	—	8.2%
FIRST RATOON									
S1 : 746	71.0	75.7	73.5	12.1	12.0	12.0	8.6	9.1	8.8
S2 : 1,912	134.2	115.6	125.0	11.2	11.3	11.3	15.1	13.1	14.1
S3 : 4,787	159.9	111.1	135.5	10.7	10.9	10.8	17.2	13.4	15.3
S4 : 12,034	133.7	110.0	121.9	10.0	11.4	10.7	13.3	12.6	12.9
S5 : 30,480	138.2	119.2	128.6	11.1	11.3	11.2	15.5	13.5	14.5
S6 : 75,770	164.6	109.1	136.9	11.2	11.7	11.4	18.3	12.8	15.5
S7 : 192,131	140.4	109.5	125.0	11.5	11.7	11.6	17.1	12.9	15.0
S8 : 75,770	160.2	—	—	11.7	—	—	18.7	—	—
S.E. popn.means	7.4	7.4	5.1	0.3	0.3	0.2	1.1	1.1	0.8
C.V. for sub-plots	—	—	10.5%	—	—	4.9%	—	—	13.6%

TABLE III
Yield and quality of cane
Levels of significance and signs for trends of characteristics with increasing stool populations per hectare.

Sub-division of S.S. for treatments S2 to S7	Effects	M. tons cane per hectare	Sucrose percent cane	M. tons Sucrose per hectare
PLANT CROP Population S.S.	Linear	*** +	*** +	*** +
	Quadratic	***	NS	***
Population x Variety S.S.	Linear	** +	NS −	* +
	Quadratic	*	NS	NS
RATOON CROP Population S.S.	Linear	NS +	* +	NS +
	Quadratic	NS	*	NS
Population x Variety S.S.	Linear	NS +	NS −	NS +
	Quadratic	NS	NS	NS

marked ($P<0.05$) and the response curves showed significant curvature ($P<0.05$). Sucrose per cent cane was much higher at low stool populations in the ratoon crop. The differences between the plant and ratoon crops in the trends of sucrose per cent cane with increasing density were apparently related to seasonal and crop age effects.

In the plant crop, m tons sucrose per hectare increased at a diminishing rate with increasing stool density and declined at very high stool densities. The population × variety interaction for m tons sucrose per hectare was significant at the 5% level. In the ratoon crop, the effect of stool density on m tons sucrose per hectare was non-significant.

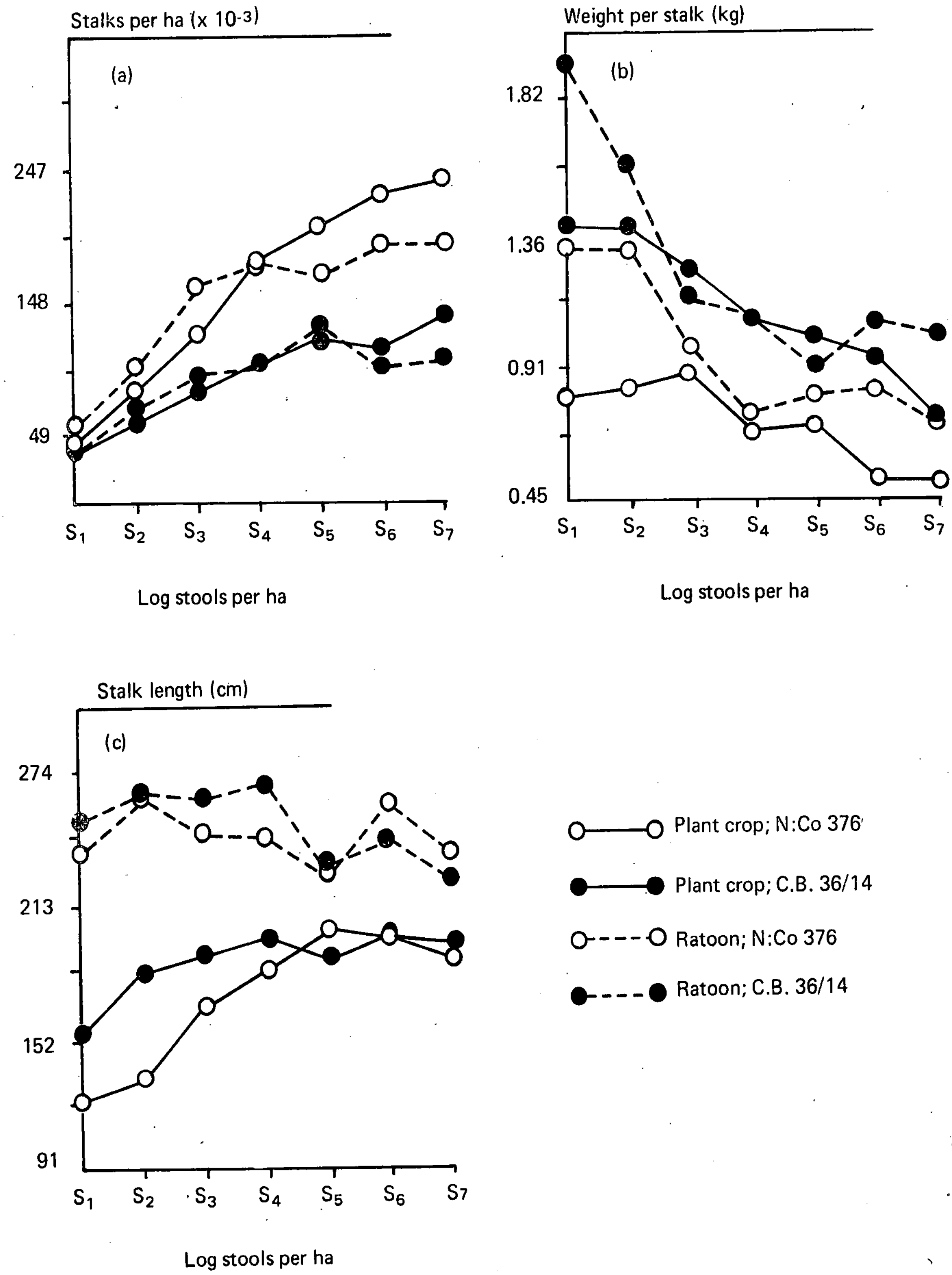
Harvested Crop Characteristics

Statistical analyses for harvested crop characteristics in both crops are summarised in Table IV while the effects of treatments on stalks per hectare, stalk weight and stalk length are depicted graphically in Fig. 2.

TABLE IV
Harvested crop characteristics
Levels of significance and signs for trends of characteristics with increasing stool populations per hectare

Sub-division of S.S. for treatments S2 to S7	Effects	Stalks per hectare	Stalk weight	Stalk length
PLANT CROP Population S.S.	Linear	*** +	*** −	*** +
	Quadratic	**	NS	***
Population x Variety S.S.	Linear	*** +	* +	*** +
	Quadratic	NS	NS	***
RATOON CROP Population S.S.	Linear	*** +	*** −	** −
	Quadratic	***	***	NS
Population x Variety S.S.	Linear	** +	NS +	NS
	Quadratic	NS	NS	NS

FIGURE 2: Harvested crop characteristics for both crops.



In the plant crop, the number of harvestable stalks per hectare increased at a diminishing rate with increasing stool density. Both the linear ($P<0.001$) and quadratic ($P<0.01$) effects were significant. The population × variety interaction for this characteristic was very highly significant ($P<0.001$). Stalk populations of the varieties were similar at very low densities but the difference increased linearly with increasing densities.

In the first ratoon crop, harvestable stalk populations again increased at a decreasing rate as stool density increased ($P<0.001$) and the interaction was highly significant ($P<0.01$). Stalk populations in the ratoon crop were higher at lower densities and lower at higher densities than in the plant crop. Increased stalk populations at lower densities were associated with higher yields in the ratoon compared with the plant crop.

Stalk weights declined linearly ($P<0.001$) with increasing density in the plant crop and the population × variety interaction was significant ($P<0.05$). In the ratoon crop, both linear and quadratic effects were very highly significant ($P<0.001$), indicating that weight per stalk declined at a diminishing rate as density increased.

Marked effects of density on stalk length were evident. In the plant crop, stalk length increased at a diminishing rate with increasing density ($P<0.001$). The population × variety interaction was very highly significant ($P<0.001$), the difference between the two varieties decreasing as density increased.

In the ratoon crop stalk length declined significantly ($P<0.01$) as density increased, but there was no significant population x variety interaction. The much greater stalk lengths at low densities in the first ratoon crop compared with the plant crop were associated with higher yields at low densities. The stalk lengths for the two varieties were surprisingly similar.

Discussion

The results showed that the yield per unit area of land from stools planted "on the square" increased rapidly to a maximum as density increased and then the yield either remained relatively constant or declined slightly. Thus the indications were that there was little to be gained in terms of cane and sucrose production, from increasing stool populations above a relatively low number per hectare when conditions were favourable for rapid growth. Statistically fitted curves describing the relationship between stool populations and yield are shown in Fig. 3 (Bleasdale[1, 2]; Farazdaghi and Harris[4]). The yield/density relationships were very similar for total dry matter, stalk dry matter, and millable cane in the plant and first ratoon crops. The yield response to stool populations exceeding 30,480 per hectare in the plant crop and 1,912 per hectare in the ratoon crop, was either very small or slightly negative. The number of buds planted per hectare in current commercial practice probably ranges from 50,000 to 75,000.

The large discrepancy between the number of stools required to exploit an environment and the number of buds planted in commercial fields, can be attributed mainly to the need to compensate for poor germination and poor distribution of those primary shoots which do survive. The factors causing poor germination and mortality of young shoots are many and diverse, including moisture, temperature and various other soil conditions, quality and treatment of seedcane, disease and insect damage, weed competition, and several cultural practices (Humbert[6]). With current field practices, the planting of excessive seedcane to ensure that maximum yields are achieved is probably justified under most conditions in the sugar industry. The current recommendation is that there should be a gradual change towards narrower row spacings to a minimum of 0.90 metre wherever soil moisture is not a severe limiting factor, and that setts should be laid continuously in the furrow, and evenly overlapped where conditions for establishment of a crop are adverse.

Whilst the results of the experiment described here refer to square-planted stool populations grown at very high fertility levels, which tend to accentuate lodging, it can' be predicted that similar results would be achieved if stools were grown in rows approximately one metre apart. It follows that it may be necessary, in the case of fully irrigated crops, to adhere to the current recommendation that setts should almost invariably be laid continuously in rows. However, the results may not be applicable with widely spaced rows where rectangularity of plant arrangement is extreme ("rectangularity" refers to the ratio of the between - row to the within - row distance).

Furthermore, if as few as 10,000 to 25,000 stools per hectare can produce the maximum yield, then the feasibility of growing seedlings in a nursery and transplanting to the field can be contemplated. Humbert[6] referred to "spaced planting" experiments in Hawaii which showed that within 3½ months of planting, the leaf canopy of stools spaced five feet apart was as complete as that obtained with continuous-sett planting in rows five feet apart. Humbert[6] questioned the necessity for growing large numbers of small stools, but stressed that complete stands are essential for "spaced planting". Nickell[8] stated that "properly grown transplants, properly spaced, can out-produce areas planted and raised by current practices—and can drastically reduce 'seed' requirements". Wilson[11] considered that effective chemical weed control could eliminate the arguments in favour of the traditional method of planting sugarcane as a row crop, and that engineers would probably experience no major problems designing machines for planting and harvesting the new type of crop. An experiment designed specifically to provide appropriate data is already in progress at Pongola.

The significant population x variety interactions for m tons cane and sucrose per hectare in the plant crop were due to the higher yield of C.B.36/14 at low stool densities than N:Co.376 and the reversal of this position at higher stool densities. The mean weights of millable cane per stool at three stool densities were as follows:—

Stools/hectare	*N:Co.376*	*C.B.36/14*
746	46.5 kg	68.0 kg
1,912	35.9 kg	45.1 kg
30,480	10.5 kg	9.3 kg

The greater yield of the C.B.36/14 stools at low stool densities was attributed to the more recumbent growth habit and broader leaves of this variety compared with N:Co.376. These morphological features promoted greater light interception at low densities, but were of no apparent advantage at higher densities.

The implication of this population × variety interaction is that comparisons of the yields of isolated stools or low stool densities of different varieties could be misleading. It follows that selection procedures in plant breeding programmes should not be based on the assumption that stools which produce the highest yields when grown in the absence of competition will also produce the highest yields in commercial crop production. It is equally important, however, to guard against the assumption in selection programmes that ability to compete against other varieties is associated with ability to produce maximum yields in commercial fields of a single variety.

Inspection of Fig. 3a shows that competition did not reduce the number of stalks at high densities to the stalk populations which were capable of producing the maximum yields of cane per unit area. This illustrates the capacity of plants to exploit an environment on the one hand, and their ability to survive under conditions of acute competitive stress on the other. However, the increase in harvested stalk numbers with increasing density, did become more gradual at high populations, particularly with variety C.B.36/14 and with the ratoon crop of N:Co.376. In practical terms, the survival of excessive stalk populations with little or no increase in yield, simply increases handling costs.

The increase in stalk length with increasing density was associated with increasing yield but was also due to the fact that the stools were planted "on the square" rather than in rows. With cane planted in rows, inter-stool competition commences within rows at the same time regardless of the row spacing, whereas with square-planted crops, competition begins later at lower stool densities. During the growth of the plant crop, there were marked differences in stalk height due to population treatments. The onset of rapid stalk elongation corresponded with the commencement of inter-stool competition.

The highly significant population × variety interaction for stalk length in the plant crop arose because the varieties had similar stalk lengths at high stool densities. Even in the ratoon crop, the stalk lengths for the varieties were surprisingly similar over a wide range of stool densities. When grown in rows at high densities, C.B.36/14 is normally much taller than N:Co.376, possibly because competition is more intense within rows than between stools arranged "on the square".

Future research in this field should be aimed towards decreasing the amount of seedcane planted and the number of stalks harvested. This conclusion is consistent with the finding that, under irrigated conditions, the potential for reducing seedcane requirements and the number of harvestable stalks is considerable. Knowledge of the number of stools required to exploit an environment is the first step towards the ideal; that is, to establish a complete stand of the optimum number of stools, whilst maintaining maximum economic returns.

Acknowledgements

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The results discussed in this paper are being used for post-graduate work in the Department of Crop Science at the University of Natal.

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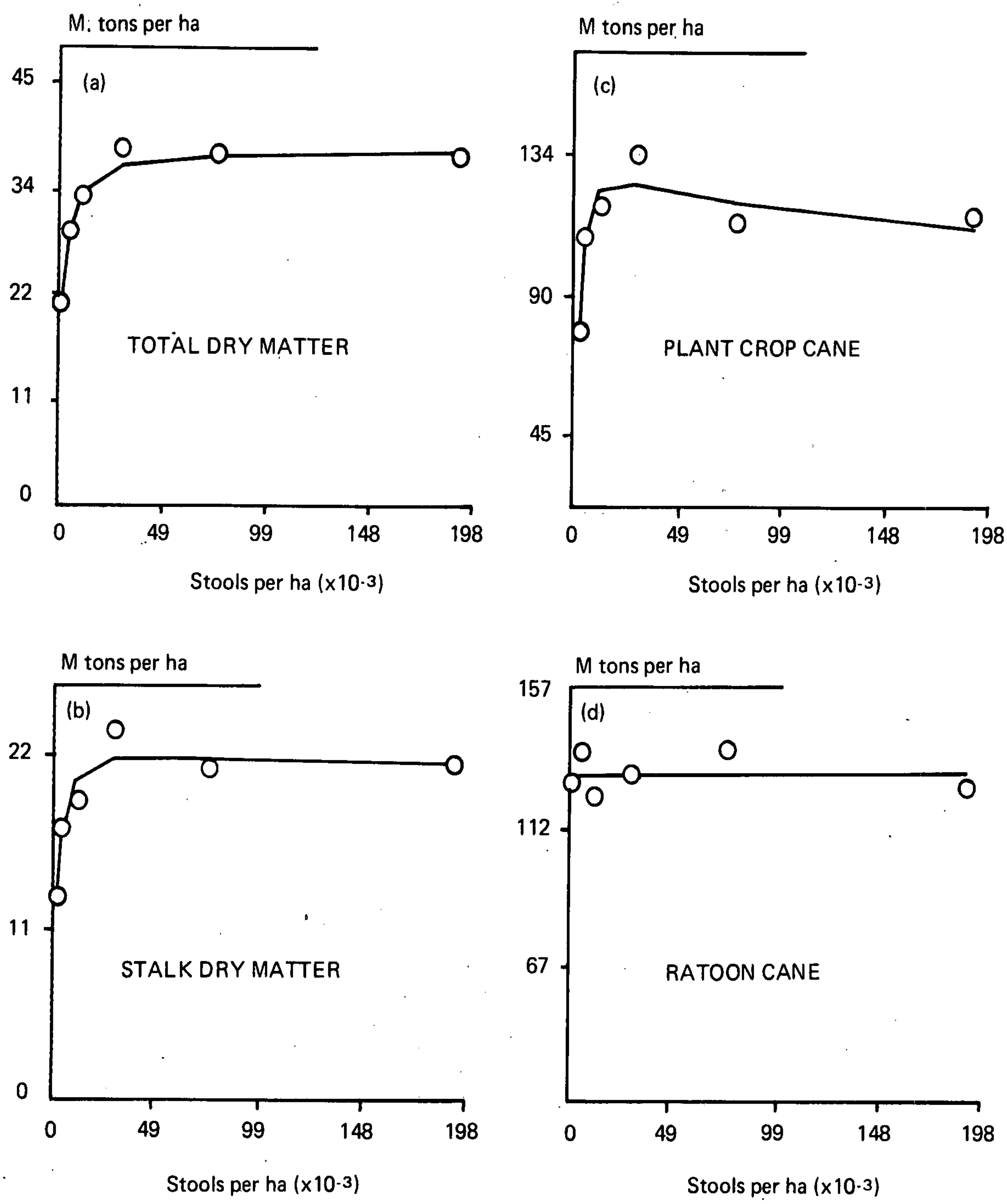
FIGURE 3: The relationship of stool populations to crop yield. Solid lines represent yield/density curves fitted statistically to the experimental data.



Discussion

Dr. Shuker (in the chair): With the increased width of spacing between your stools there was presumably some variation in frequency of weeding. Did you have a record of this?

Mr. Boyce: We used a herbicide to eliminate weeds completely at the beginning and all plots were maintained weed-free throughout in this experiment.

Mr. Odendaal: What is the difference between pregerminated setts and seedlings?

Mr. Boyce: The seedling were grown in a nursery and then transplanted in the field. The single-bud setts were planted directly into the field as shown in the slide.

Mr. Wise: Would these same conclusions apply to dry land conditions, where competition for moisture would be greater than for irrigated conditions?

Mr. Boyce: It would depend on how dry conditions were. I have limited my remarks to irrigated conditions because the relationship between stool population and yield is based on the ability of individual stools at low population to "catch up" and they must have a sufficiently long period of growth to do so.

Mr. Pearson: In our experiments under dry land conditions water was the important factor. With wide spacing we grew the same tonnage as we did with continuous rows.

Mr. Bartlett: I think the results of these experiments will have an effect on mechanising, or rather on minimising mechanising.

Regarding mechanisation, some hold that there should be as many stools as possible per acre and that a machine would first flatten the cane and then cut it and lift it onto a chopper type harvester. But today most consideration is being given to a harvesting on a row crop, with the object of reducing the work load.

On certain of our steep lands we will never use machines. At present we plant in 3′ 9″ to 4′ row spacing in continuous rows. One object is to obtain canopy as soon as possible. Could not the spacing be 2′ but not with a continuous row, so as to get a quicker canopy?

Mr. Boyce: In an experiment at Pongola, we have closer rows and different sett spacings within the row. Stool distribution is improved by reducing the row spacing and increasing the distance between setts within the row.

However, it is essential to achieve an adequate population of stools by taking into account the risk of poor germination when planting with normal setts.

Dr. Thompson: By increasing sett spacing, you will increase the weed problem within the rows, so I think it is important to achieve an adequate row population.