IMPROVING THE QUALITY OF SOILS DERIVED FROM MIDDLE ECCA, DWYKA AND BEAUFORT SEDIMENTS

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Abstract

Poor cane growth often occurs on soils derived from Middle Ecca, Dwyka and Beaufort sediments. Low water intake rates, severe crusting, low total available moisture capacity, impeded drainage, the concentration of sodium, and susceptibility to compaction are the more important factors that limit rainfall efficiency in soils of the Longlands, Westleigh, Kroonstad, Valsrivier, and Katspruit forms. Current research is concerned with improving water intake rates and the movement of water through the soil profile, and the results of trials to test ridging-up, vertical mulching, and various ameliorants to minimise soil crusting, are reported. A management strategy for reducing the risk of moisture stress during dry years and waterlogging during wet years is considered for improving cane production on these soils.

Introduction

Poor cane growth often occurs on soils derived from Middle Ecca, Dwyka and Beaufort sediments, which collectively comprise about 20% of the area under sugarcane in South Africa. Factors which limit rainfall efficiency in soils of the Longlands, Westleigh, Kroonstad, Valsrivier, and Katspruit forms include: low water intake rates (less than 5 mm h^{-1}); low total available moisture capacity (less than 60 mm); surface crusting and high erodibility; slow internal drainage and poor aeration at depth; a strong tendency to compact, and a potential for saline and sodic conditions to develop when irrigation is practised.

The need for a better understanding of these soils was first suggested by Beater[1] following an examination of a large number of representative soil profiles. The soils were typically described as 'shallow pale grey fine sandy loams with a semi-bleached second horizon overlying a conspicuous layer of ironstone gravel on yellowish pot clay'. Unlike other soils in the industry, these soils are frequently associated with a hard surface crust, particularly when the land is fallow or when there is no trash mulch.

Continuing difficulties in the management of these soils led in 1979 to the initiation of the Middle Ecca and Dwyka soil project with a view to investigating practices that would

Table 1

Details of experiment sites, treatments, and designs of trials

Technique	Site no	Locality	Soil form	Physical analysis (0-300 mm) Clay (%)	Silt (%)	Fine sand (%)	Medium sand (%)	Coarse sand (%)	Trial start	Crops	Variety	Treatments	Trial design	No of replications
Ridging-up	1	La Mercy	Longlands	20	8	61	9	1	1985	P 1R	NCo376	Control (min tillage) Ridging-up 3 mths Ridge planting	Randomised block	8
	2	Nkwaleni	Katspruit	35	10	25	25	5	1986	P	NCo376	Control (conven plant) Ridging-up 3 mths Ridge planting	Randomised block	6
	3	Mtunzini	Longlands	26	14	38	20	2	1984	3R 4R 5R	NCo376 N7, N8 N11, N12 N13, N14	Tops scattered Ridging-up	Non-randomised	3
Vertical mulching	4	Mtunzini	Westleigh/ Longlands	9	7	46	30	8	1985	P	N12	Control (min tillage) VM* topsoil VM sand VM filtercake	Randomised block	3
Soil ameliorants	5	Mt Edgecombe	Longlands	9	8	43	32	8	1986	—	—	Control Gypsum, phosphogypsum Filtercake, PVA** Reverseal, molasses Trash	Randomised block	3
	6	La Mercy	Longlands	26	15	45	11	3	1987	1R	NCo376	Control Molasses meal Phosphogypsum Filtercake Trash PVA	Randomised block	3

* VM = vertical mulching
** PVA = polyvinyl alcohol

alleviate the problems being experienced. Early laboratory studies focused on the sensitivity of these soils to low concentrations of sodium and the need for amelioration with gypsum in order to prevent a reduction of soil permeability (Johnston[4]).

The effects on cane growth resulting from soil compaction caused by infield transport were studied in a trial on a Longlands form soil at La Mercy and various recommendations were made for minimising this problem (Swinford and Boevey[7]). The merits of mole drainage as a means of reducing waterlogging were also tested, in the presence and absence of gypsum, in two trials on Westleigh and Katspruit form soils at Mtunzini (Dewey, Meyer and George[2]).

Attempts to find practices that will reduce the risk of moisture stress during dry years and waterlogging during wet years have continued. The procedures reported in this paper include the following:

- improving surface drainage and increasing effective rooting depth by ridging-up
- improving intake and movement of water through the soil profile and increasing effective crop rooting depth by vertical mulching with filtercake or sand
- minimising crust formation and surface water runoff by using ameliorants such as phosphogypsum, polyvinyl alcohol, molasses meal, and filtercake. The effects of these treatments were compared with that due to a standard trash blanket.

Experimental procedure and results

The work reported covers 3 ridging-up trials, one vertical mulching trial, and a 3-phase soil amelioration study. Details of sites, treatments, and trial designs are summarised in Table 1.

Ridging-up trials

Middle Ecca and Dwyka-derived soils seldom contain sufficient clay at 500 mm depth to make them suitable for mole drains. It was thought that if sugarcane was grown on a ridge this practice could help to dispose of excess surface water and keep cane roots above any perched watertable, thus giving the roots an environment with better aeration in which to grow. The 3 trials in this investigation were established on poorly-drained shallow soils at La Mercy, Mtunzini, and Nkwaleni to compare ridging-up with conventional planting and ratoon practices.

La Mercy: this trial, established in March 1985 on a Longlands form soil under rainfed conditions, had 3 treatments: T1 minimum tillage (control) (C); T2 minimum tillage - ridging-up 3 months later (C + R), and T3 ridge planting (R).

Each treatment was replicated 8 times. The trial was planted with variety NCo376 and ridged plots were re-ridged mechanically following soil subsidence when the cane was 8 months old. Stalk populations did not increase due to ridging, but mean stalk heights in the ridged treatments increased on average by 120 mm when compared with the control treatment. The trial was harvested in June 1986 and a summary of the yield data is given in Table 2.

Although the plant crop indicated no response to ridging, the first ratoon crop showed a significant increase in cane yield of 17% when compared with the control treatment. It is likely that the response to ridging-up in the first ratoon was associated with the more effective removal of surface water during wetter conditions (1 092 mm rainfall, compared with 897 mm rainfall, plant crop).

Table 2

Yield data - La Mercy ridging-up trial

	Treatment	Plant March '85-June '86			1st ratoon June '86-July '87		
		tc ha^{-1}	ts ha^{-1}	t ers ha^{-1}	tc ha^{-1}	ts ha^{-1}	t ers ha^{-1}
T1	Min tillage (Control)	54	6,3	5,4	69	9,0	8,0
T2	Min till + ridging-up	56	6,9	6,0	75	9,3	8,2
T3	Ridge planting	53	6,2	5,4	82	10,8	9,7
	LSD 5%	4,8	1,0	1,0	6,8	1,1	1,0
	LSD 1%	6,7	1,4	1,4	9,5	1,6	1,5

Inspection of the ridges in a number of plots indicated that those in the T3 treatment were better shaped and of greater height than ridges in the T2 plots. In general, the best yielding ridged plots were associated with final ridge heights greater than 200 mm.

Nkwaleni: This trial was established in April 1986 on a Katspruit form soil under irrigated conditions and treatments were similar to those at La Mercy. Each treatment was replicated 6 times and the trial was planted with variety NCo376. The trial was harvested in June 1987 but variability was high and the responses to ridging-up and planting on the ridge were not statistically significant. Early subsidence of the ridges suggested that this practice was not likely to be successful under irrigation because such weakly aggregated soils break down easily, leading to surface crusting and reduced infiltration. Gypsum may be required to stabilise the soil surface prior to ridging-up.

Mtunzini: this trial on a Longlands form soil was superimposed on one originally designed to test mole drainage with and without various ameliorants. At the beginning of the 3rd ratoon (October 1984), half of the plots were ridged-up. On the remainder, burnt tops were scattered. The yield data for these two treatments are summarised in Table 3, and for the 7 cane varieties in Table 4, for the third, fourth and fifth ratoon crops.

Under relatively dry conditions during the third and fourth ratoon crops no significant benefit was obtained from ridging-up. However, during the fifth ratoon crop, rainfall was well above the long term mean and a highly significant yield increase of 29% was obtained from this treatment. The freely drained ridged plots probably offered a more suitable environment for crop growth than the plots with scattered tops, which under cool and wet soil conditions will tend to delay germination and slow early plant growth.

Table 3

Yield data - trial at Mtunzini comparing ridging-up with scattered tops

	Treatment	3rd ratoon Oct '84-Oct '85		4th ratoon Oct '85-Oct '86		5th ratoon Oct '86-Oct '87	
		tc ha^{-1} a^{-1}	ts ha^{-1} a^{-1}	tc ha^{-1} a^{-1}	ts ha^{-1} a^{-1}	tc ha^{-1} a^{-1}	ts ha^{-1} a^{-1}
T1	Tops scattered	56,3	7,2	64,0	8,5	51,6	6,7
T2	Ridged-up	50,5	6,2	68,0	9,0	66,5	8,6
	LSD P = 0,05	5,4	0,4	5,7	0,6	7,4	1,0
	LSD P = 0,01	7,4	0,8	7,9	0,9	10,3	1,4
	Rainfall (mm)	1 117		1 032		2 225	
	Long term mean (mm)	1 297					

Table 4

Response to ridging in relation to variety

Variety	tc ha⁻¹						Overall mean (tc ha⁻¹)	
	3rd ratoon		4th ratoon		5th ratoon			
	T1	T2	T1	T2	T1	T2	T1	T2
NCo376	55,2	57,0	56,7	57,8	42,0	60,8*	51,3	58,5
N7	51,7	51,5	57,8	65,0	48,0	61,4*	52,5	59,3
N8	51,5	49,6	67,3	67,3	67,6	70,5	62,1	62,6
N11	49,6	21,4	63,0	65,5	55,4	82,5**	56,0	56,5
N12	64,4	68,0	69,3	78,3	50,3	75,4**	61,3	73,9
N13	52,3	47,2	61,6	70,4	48,9	66,2*	54,3	61,3
N14	69,3	58,5	74,8	70,5	45,2	58,2	60,4	65,6

T1 - Tops only
T2 - No tops/ridged-up
* Significant at 5% level (14 tc ha^{-1})
** Significant at 1% level (19 tc ha^{-1})

A significant increase in yield in response to ridging-up was noted for all varieties except N8 and N14. NCo376, N11 and N12 showed the largest yield responses of 45, 49 and 50% respectively, while N13 showed a 35% increase. Inspection of ridges indicated that heights varied from 200 to 290 mm and, as in the La Mercy trial the largest responses to ridging-up were associated with the best-shaped and highest ridges.

Vertical mulching trials

It was shown by Gardner[3] that infiltration and the advance of the wetting front in a soil is more rapid where deep vertical channels are cut through the soil layers and filled with chopped organic material. This practice has been called 'vertical mulching'.

Mtunzini: a vertical mulching trial was established in April 1986, using an implement which allows surface applied materials to drop into the subsoil behind a tine to a depth of 500 mm (Figure 1).

FIGURE 1 The implement used for vertical mulching.

The trial which is situated on a Longlands/Westleigh form soil had 4 treatments: T1, a control hand-planted after minimum tillage; T2, vertical mulching with topsoil fed into the subsoil; T3, vertical mulching with coarse Umgeni sand at 150 t ha^{-1} fed into the subsoil, and T4, vertical mulching with filtercake at 100 t ha^{-1} fed into the subsoil.

Each treatment was replicated 3 times. Sand and filtercake treatments were initially banded in the old interrow and rotavated into the topsoil. Vertical mulching was then carried out, and cane setts of variety N12 were planted in the resulting furrow just above the top of the vertical mulch layer (Figure 1).

The trial was harvested in June 1987 when the plant crop was 14 months old. The mean yields obtained for the different mulching treatments are shown in Table 5. All vertical mulching treatments showed a significant (vertical mulching with topsoil) or highly significant response (vertical mulching with sand or filtercake) in terms of cane yield (11 to 16 tc ha^{-1}) when compared with that of the control treatment (no mulching). There was also a significant response to vertical mulching with either sand or filtercake of about 1,5 ts ha^{-1} when compared with the control.

Table 5

Yield data from the vertical mulching (VM) trial (plant crop - mean of 3 replicates)

Treatment		tc ha⁻¹	ts ha⁻¹	t ers ha⁻¹
T1	Control (no mulching)	67,9	7,5	6,4
T2	VM with topsoil	78,9	8,5	7,2
T3	VM with sand	82,0	9,0	7,7
T4	VM with filtercake	84,1	9,2	7,8
Mean		78,2	8,5	7,3
LSD (0,05)		7,9	1,4	1,3
(0,01)		12,0	2,1	2,0

The effect of the various treatments on root development was studied in two ways. In the first, root densities were measured by taking 3 undisturbed soil cores from each treatment at a depth of 250 mm adjacent to the cane row. The roots from each core were removed, washed and weighed after drying. Secondly, the root systems were exposed in selected plots from each treatment by root washing after which the roots were painted with limewash and a 200 mm^2 string grid was superimposed on them (Figures 2 and 3).

Both methods revealed large differences in root development due to vertical mulching. Soil core measurements showed that vertical mulching either with sand or filtercake increased root density by 58% compared with the control. Following root washing it was apparent that about 90% of the roots in the control treatment were present within the top 250 mm of the profile, whereas after vertical mulching either with sand or filtercake about 90% of the roots were distributed to a depth of 600 mm, and a considerable number were also present at a depth of 1 000 mm.

Soil ameliorants

Exploratory tray site experiment at Mount Edgecombe: preliminary soil permeability and clay dispersion studies conducted in the laboratory during 1985 indicated that soil aggregates could be stabilised with either phosphogypsum, molasses meal or polyvinyl alcohol. These results led to an experiment in which topsoil with a history of crusting problems was weighed into trays, saturated with water, and treated with ameliorants applied at rates equivalent to the following:

Gypsum	5 t ha^{-1}
Phosphogypsum	5 t ha^{-1}
Filtercake	50 t ha^{-1}
Polyvinyl alcohol	10 g m^{-2}
Reverseal 9/85	20 l ha^{-1} (diluted 50 times)
Molasses meal	25 t ha^{-1}
Trash blanket	10 t ha^{-1}

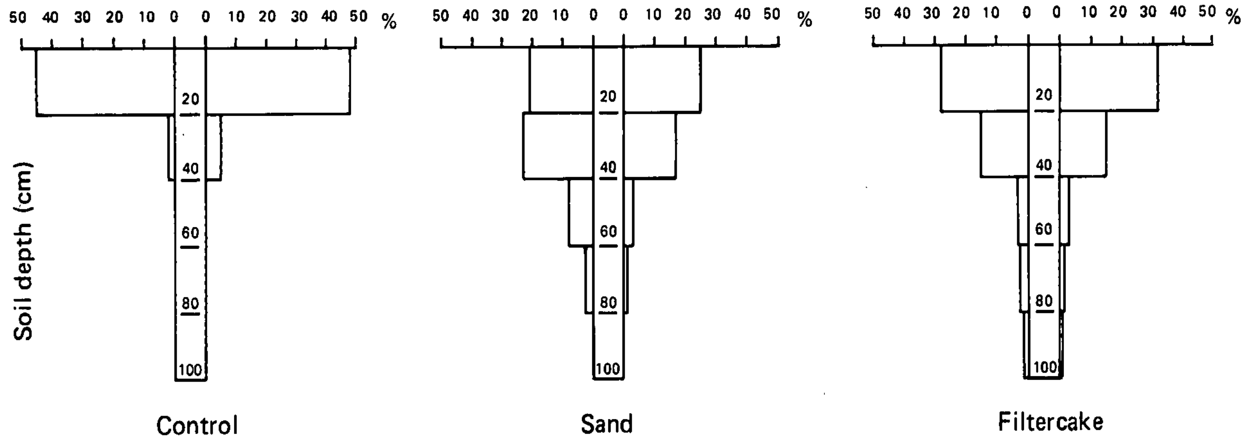

FIGURE 2 The effect of vertical mulching with sand and filtercake on cane root distribution.

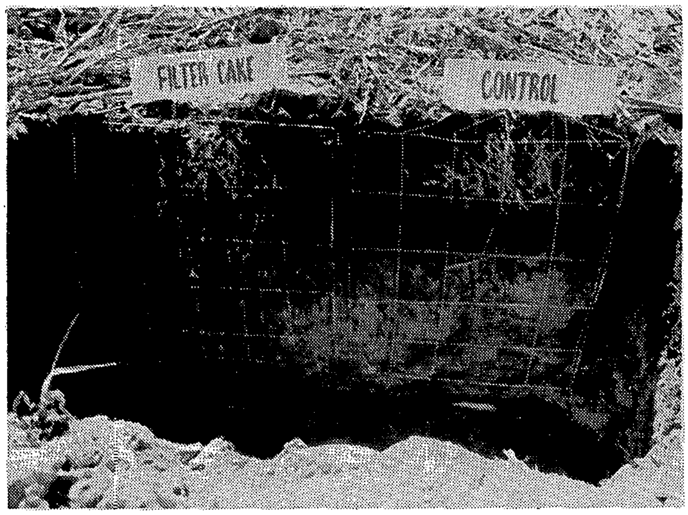

FIGURE 3 Cane root development under vertical mulching with filtercake compared with the control treatment.

Two control treatments were an 'undisturbed' soil and a disturbed soil, neither which received an ameliorant. Each treatment was replicated 3 times. The trays were left in the open for 6 months, then sampled to a depth of 10 mm, and the samples analysed for various physical properties.

The ameliorants which appeared to be most beneficial were polyvinyl alcohol and molasses meal. Both reduced dispersion within the crusting layer and improved intake rates. Although the results for phosphogypsum were somewhat disappointing, the availability and relatively low cost of this ameliorant led to its use in a pilot field study with the rainfall simulator described by Platford.[6]

Rainfall simulator trials

Pilot field study at La Mercy: a joint experiment with the Farm Planning Department was conducted at the Experiment Station's farm at La Mercy on a Longlands form soil prone to crusting and severe erosion. The effects of phosphogypsum (surface applied at 5 t ha^{-1} two months previously) in reducing crusting and soil loss were assessed with a rainfall simulator. Two 63 mm ha^{-1} storms were simulated on two consecutive days (ie one storm to a dry profile, one storm to a saturated profile). Four treatments were established, two using minimum tillage with and without phosphogypsum applied at 5 t ha^{-1}, and the other two treatments with conventional planting also with and without phosphogypsum. The results are given in Table 6.

Table 6

Soil loss and runoff from phosphogypsum treatment at La Mercy

Treatment	Storm 1		Storm 2	
	Soil loss (t ha^{-1})	Runoff (%)	Soil loss (t ha^{-1})	Runoff (%)
Min tillage + phosphogypsum (5 t ha^{-1})	0,28	27,1	0,77	67,1
Min tillage : no phosphogypsum	1,38	45,0	3,43	69,4
Conventional + phosphogypsum (5 t ha^{-1})	2,52	56,5	4,38	88,6
Conventional : no phosphogypsum	3,33	51,5	8,61	87,9
Mean minimum tillage	0,83	36,0	2,10	68,2
Mean conventional	2,92	54,0	6,49	88,2
Mean : phosphogypsum	1,60	41,8	2,57	77,8
Mean : no phosphogypsum	2,35	48,2	6,02	78,6

Soil and water losses were reduced under minimum tillage for both storms, and were further reduced by the application of phosphogypsum. Phosphogypsum, by causing reduced crusting, appeared to improve intake rates. Following these promising results, a wider range of ameliorants was considered for a large-scale replicated trial in which crust development prior to and during simulated rainfall conditions could be compared.

Large-scale field trial: the following treatments, replicated 3 times, were applied on a Longlands form soil to a ratoon crop of N12: T1, control - no amelioration; T2, phosphogypsum at 5 t ha^{-1}; T3, filtercake at 50 t ha^{-1}; T4, molasses meal at 25 t ha^{-1}; T5, polyvinyl alcohol at 100 kg ha^{-1}, and T6, trash blanket at 10 t ha^{-1}.

Treatments 2, 3 and 4 were lightly incorporated into the soil surface of the interrow. The remaining treatments were applied after light cultivation. This was to destroy any crust which had developed under normal rainfall before the trial was established. The treatments were then left undisturbed for 6 months.

Just prior to the application of simulated rainfall the trash blanket was removed and penetrometer measurements were taken on all treatments to determine the strength and depth of crusting. The results are shown in Table 7.

The crusting index is the ratio of the pressure required to break the crust to the depth of the crust. The ratio was highest for the control plot (crust most well-developed), followed by the filtercake treatment, and much lower for the phosphogypsum and polyvinyl alcohol treatments. The trash blanket resulted in the weakest crust formation, presumably because it had protected the soil surface from the impact of raindrops during the preceding 6 months.

Table 7

Penetrometer measurements to determine crust strength

	Treatment	Crusting peak Depth (mm)	Pressure ($N\ cm^{-2}$)	Pressure depth ratio
T1	Control	35	278	7,9
T2	Phosphogypsum	47	230	4,9
T3	Filtercake	42	285	6,8
T4	Molasses meal	50	270	5,4
T5	Polyvinyl alcohol	52	242	4,7
T6	Trash blanket	45	205	4,6

The trial received 2 × 63 mm ha^{-1} simulated storms 24 hours apart (ie on a dry and saturated profile as previously). Of the various ameliorants, polyvinyl alcohol, phosphogypsum and trash showed the greatest effects in reducing runoff.

The largest differences in both soil and water losses were measured between the control plots and those that had been trashed. Soil loss from the control treatment was immediate (Figure 4), commencing within 5 min of storm initiation, while in the plots that had been trashed runoff commenced only after 20 min rainfall. Soil loss from the control plots was more than 100 kg ha^{-1} min^{-1}, and from the previously trashed plots it was 10 kg ha^{-1} min^{-1}, showing how the trash had reduced crusting and improved water intake rate.

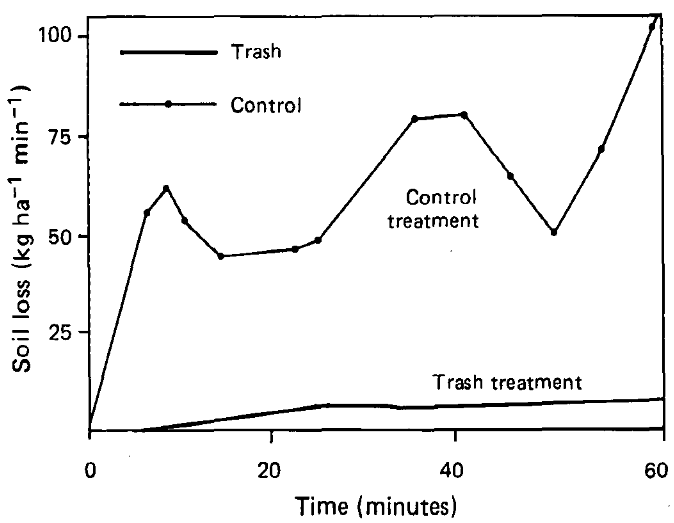

FIGURE 4 Soil loss during Storm 1.

Figure 5 shows a comparison of the mean soil loss per hour for all treatments. The efficacy of the various treatments in reducing soil loss declined in the following order: trash : molasses meal : phosphogypsum = polyvinyl alcohol : filtercake : control.

In comparison with the control, polyvinyl alcohol, molasses meal, and phosphogypsum all reduced crusting and soil and water losses. Molasses meal, due to its sticky nature, was very effective in reducing crust formation. However, at rates of 25 t ha^{-1}, this treatment appeared to retard germination and cane growth. The most important effects of these three treatments was the reduction in crust formation and increased infiltration.

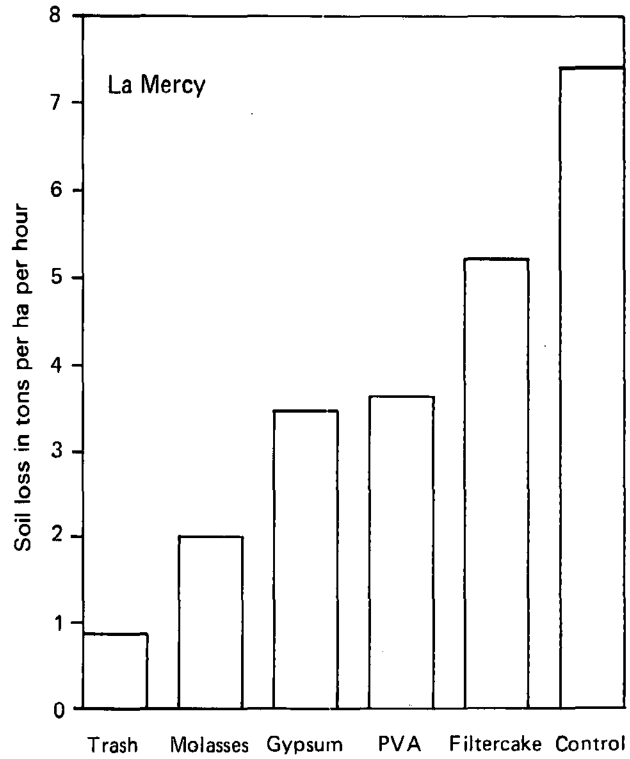

FIGURE 5 Soil loss per treatment.

Discussion

Ridging-up

The main advantages of ridging-up are considered to be improved drainage due to the more effective removal of surface water, better cane germination, more vigorous early growth on the ridge due to higher soil temperature, and an increase in effective rooting depth. In a ridging trial under irrigated conditions at the Experiment Station's farm at Pongola, lodging of cane was prevented by ridging-up later in the season. While there are advantages to ridging-up, particularly in soils that are not suitable for mole drainage, the ridges create considerable practical difficulties in the field. Ridges prevent infield transport from crossing cane rows thus limiting wheeled traffic to the interrow. Cambered beds may have to be considered as an alternative under such conditions. However, ridges have been used successfully in Swaziland and the Eastern Transvaal, especially on soils which are subject to compaction.

Vertical mulching

Improved water intake, greater hydraulic flow, and increased available moisture capacity, appear to be the main reasons for the better performance of cane growing where vertical mulching is practised. Evidence from root washing, showing an apparently large increase in effective rooting depth, indicates that vertical mulching had a substantial effect on the total available moisture capacity of a soil.

The advantage of improved hydraulic flow is particularly significant in soils with sandy 'E' horizons or soft plinthite 'B' horizons. It has been demonstrated by Gardner[3] that such subsurface layers act as a barrier to water flow because capillaries in sand are larger than those in the overlying loam topsoil. Only when the topsoil is nearly saturated does the water move rapidly through the impeding subsurface horizon. Vertical mulching is currently being tested under irrigated conditions on similar soils in Swaziland, and it is possible that this practice will improve irrigation efficiency in soils with low intake rates.

Soil ameliorants

The use of phosphogypsum as an ameliorant appears to be very promising for improving water intake rate and reducing soil loss, particularly in areas where trashing is not recommended. This includes areas prone to waterlogging, and high altitude areas where trashing of autumn and winter-cut cane is not carried out because of low soil temperatures. Phosphogypsum is readily available, economical, and fairly easily applied..

Laboratory work is also required to reassess the critical sodium adsorption ratio (SAR) values for soils prone to crusting. Work in Israel has demonstrated the effectiveness of industrial gypsum in reducing surface runoff even in soils with low exchangeable sodium percentage (ESP) values (Keren *et al.*[5]). It appears that the ESP or SAR values may provide useful diagnostic guides to determine the need for gypsum and the amount required to minimise the dispersive effects of sodium.

Conclusions

It will always be difficult to minimise moisture stress on these poor quality soils in dry years, and to avoid waterlogging in wet years, unless expensive irrigation and drainage systems are used. However, the results reported in this paper suggest that vertical mulching, the use of phosphogypsum, or ridging-up can lead to significant gains in rainfall efficiency and improved crop growth.

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