IMPROVED CANE YIELDS FROM VERTICAL MULCHING UNDER RAINFED AND IRRIGATED CANE CONDITIONS

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Abstract

The performance of cane established under vertical mulching (VM) tillage was compared with that grown under normal cultivation in two rainfed and two irrigated trials. Materials used for vertical mulching carriers included topsoil, river sand and filtercake and gypsum was also tested in one of the irrigated trials. Vertical mulching with filtercake or sand were the most effective treatments in the plant cane crop, giving significant responses ranging from 1,1 to 5,9 tons sucrose per hectare. However, VM with filtercake was the most successful treatment overall as the residual effects lasted longer than those of sand. The cumulative response to VM with filtercake averaged seven tons sucrose per hectare over three crops for the two irrigated trials, compared with an average of three tons sucrose per hectare in the two rainfed trials. Monitoring of soil properties, root development and moisture distribution indicated that the main benefits of VM were improved water intake rate and an increase in effective rooting depth. The economics of vertical mulching are considered as are guidelines for further research.

Introduction

Low water intake rates due to surface crusting and sealing of soils is recognised as a severe problem in many agricultural areas of the world, because of its effects in reducing rainfall and irrigation efficiency. In the South African sugar industry poor cane growth and low yields with frequent need for crop re-establishment, are a feature of the duplex soils derived from Middle Ecca (Vryheid sediments), Dwyka Tillite and Beaufort sediments which collectively comprise about 20 per cent of the rainfed cane areas of South Africa. Factors which limit rainfall efficiency in soils of the Kroonstad, Westleigh, Valsrivier, Longlands and Katspruit forms include low water intake rates (less than 5 mm/ha); 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.

In the Swaziland sugar industry, low intake rates due to surface sealing and the high swelling potential of 2:1 lattice clays, coupled with slow internal drainage and accumulation of salts are important factors that limit irrigation efficiency in heavy K set soils (Rensburg and Arcadia forms) as well as in some of the V and C set soils (Bonheim form). Collectively these soils comprise about 30 per cent of the area under cane.

In the South African sugar industry, attempts to improve the intake rate of difficult soils by various methods have been only partially successful (Meyer *et al.*, 1988). There has been increasing interest in the USA (Howell and Phene, 1983) and Australia (Jayawardane and Blackwell, 1986) regarding the use of vertical mulching to increase intake rate and improve hydraulic flow through soils. Vertical mulching is a modification of subsoiling, in which organic or other materials such as sand and gypsum are inserted in the slot created by the subsoiler. The idea was originally developed in 1956 at Purdue University, and tested subsequently by other workers (Curley, 1958, Hauser and Taylor, 1964, Gardner, 1968). Most studies showed two-to-fourfold increases in water intake rate from the vertical mulching treatment, and in a study conducted in California, cotton yields were also increased by 25% (Howell and Phene, 1983). These promising findings stimulated a co-ordinated programme of research by the Experiment Station and the Swaziland Sugar Association into the applicability of this technique for improving sugarcane productivity on duplex and vertisol soils.

Experimental procedure

Description of trial sites

Four field trials were conducted to study the yield response of sugarcane to vertical mulching and to determine the relative efficiency of materials such as topsoil, sand and filtercake used as a mulch in grey hydromorphic soils and heavy black cracking clays. Selected characteristics of the soils from the four sites, and the various treatments used are summarised in Table 1.

Rainfed trials

The first trial, located at Mtunzini was established in April 1986 on a site with a history of poor and uneven cane growth, comprising soils of the Longlands and Westleigh forms. The depth of the heavier impermeable subsoil layer varied between 350 and 500 mm. The second trial was established in February 1987 at Mount Elias in the Natal midlands, also on a Longlands form soil but which had a greater effective rooting depth (500-700 mm) and a higher clay percentage than the soil at Mtunzini. Both trials were of similar design and had the following treatments which were replicated three times at Mtunzini and four times at Mt. Elias:

- Control - hand planting after minimum tillage
- Vertical mulching (VM) with topsoil fed down the soil profile
- VM with coarse river sand at 150 t/ha fed down the profile
- VM with filtercake at 100 t/ha fed down the profile.

The sand and filtercake treatments were initially banded in the old interrow and rotavated into the topsoil. Vertical mulching was then carried out with an alubuster, which is a rigid tine implement with wings attached, allowing surface material to drop into the subsoil to a depth of about 450 mm behind the tine. Cane setts of variety N12 were planted in the resulting furrow just above the top of the vertically mulched layer.

Irrigated trials

Unlike the grey duplex soils which contained a fairly sandy topsoil prone to crusting, the soils used in the irrigated trials conducted in Swaziland, were strongly structured black clays dominated by shrinking and swelling 2:1 lattice clay minerals. The first trial was established in June 1988 at Simunye Sugar Estate on an Arcadia form soil, varying in depth from

600 to 1 000 mm. In accordance with estate practice, planting ridges were made before the application of the following treatments which were replicated six times:

- Control - normal planting on the ridge
- VM with only topsoil fed down the profile
- VM with 150 t/ha of river sand fed down the profile
- VM with 150 t/ha of filtercake fed down the profile.

The sand and filtercake were evenly spread by hand into the furrow on top of the ridge in the appropriate plots, and lightly incorporated with a rotary hoe before drawing the alubuster. The VM with topsoil plots were also rotavated but the control plots were left undisturbed.

Two months later the second trial was established at Ubombo Ranches on a heavy Rensburg form soil prone to waterlogging. As management were particularly interested in the potential drainage benefit of sand-filled vertically mulched channels, half the trial comprising 24 plots in all, was left undrained and the other half was connected to sand-filled slotted PVC drains. Gypsum was included as a carrier in the vertical mulching treatments as the subsoil showed a history of sodicity. The vertical mulching treatments that were tested without and with subsurface drainage each replicated three times were:

- Control - no mulching
- VM with only topsoil fed down the profile
- VM with 150 t/ha river sand fed down the profile
- VM with 150 t/ha filtercake fed down the profile
- VM with 10 t/ha gypsum fed down the profile.

The first trial was planted to variety NCo376 and variety N14 was used in the second trial. Both trials were under sprinkler irrigation.

Root studies

Root development was studied at the Mtunzini, Mt. Elias and Simunye sites by opening pits across the cane rows of selected plots, exposing the roots by washing with water and painting them with lime wash. A 200 x 200 mm string grid was superimposed over the painted roots and the numbers of roots in each grid block were counted to estimate root density. Root densities were also measured in the two rainfed trials, by taking three 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.

Soil measurements

Various field and laboratory measurements were carried out. These included:

- Moisture characteristics, by taking undisturbed cores to a depth of 300 mm in selected rows of the vertically mulched plots to determine treatment effects on moisture release
- Infiltration rate, using the double ring infiltrometer to measure the relative effect of the various vertical mulching treatments on intake rate
- Physical and chemical composition, by sampling to a depth of 600 mm in the cane row to determine the residual effects of VM treatments on various soil properties.

Crop water use

Gypsum soil moisture blocks were installed at both the rainfed trial sites to a depth of 600 mm to monitor water use by the crop under the various treatments.

Table 1

Details of experiment sites, treatments and trial design

Site No	Locality	Soil form	Topsoil characteristics					Trial start	Crops	Variety	Treatments	Trial design	No of replications	Water regime
			Clay %	Silt %	Sand %	pH	OM %							
1	Zululand (Mtunzini)	Longlands/ Westleigh	10	8	82	5,8	1,30	1986	5	N12	Control (conventional plant) VM with topsoil VM with sand (150 t/ha) VM with filtercake (100 t/ha)	Randomised block	3	Rainfed
2	Midlands (Mt Elias)	Longlands	17	6	77	4,8	1,90	1987	3	N12	Control (conventional plant) VM with topsoil VM with sand (150 t/ha) VM with filtercake (100 t/ha)	Randomised block	4	Rainfed
3	Swaziland North (Simunye)	Arcadia (K set)	55	13	31	6,1	2,90	1988	3	NC0376	Control (planting on ridge) VM with topsoil VM with sand (150 t/ha) VM with filtercake (150 t/ha)	Randomised block	6	Irrigated
4	Swaziland South (Ubombo Ranches)	Rensburg (V set)	66	15	18	7,25	2,50	1988	3	N14	Control (planting on ridge)* VM with topsoil* VM with river sand (150 t/ha)* VM with filtercake (150 t/ha)* VM with gypsum (10 t/ha)*	Randomised block	3	Irrigated

* Half the trial connected to subsurface drains

Leaf analysis

Third leaf samples were taken for analysis from every crop in all trials to determine whether any of the VM treatments were having a beneficial or detrimental effect on nutrient uptake.

Results and discussion

Effect of vertical mulching treatment on yield

Rainfed trials:

The mean yields obtained at both sites for the different vertical mulching (VM) treatments are summarised in Table 2. In the plant crop at Mtunzini all VM treatments showed a significant (VM with topsoil) or highly significant response (VM with sand or filtercake) in terms of cane yield (11-16 tc/ha) when compared with the control treatment (no mulching). In the following crop no significant residual responses were recorded, possibly because VM treatments were not designed to cope with excessive quantities of water such as those received from cyclone Demoina in September 1987. Although no significant responses were recorded in the second ratoon, the best residual response was obtained from the VM with filtercake treatment. In the third and fourth ratoon crops, significant residual cane and sucrose yield responses were obtained only from the VM with filtercake treatment. The unusually large residual response of 18 tc/ha/an and 2,7 ts/ha/an from the VM with filtercake treatment in the fourth ratoon, was unexpected and the reasons are considered to be both physical and chemical in nature as discussed later. The cumulative response to VM with filtercake over five crops amounted to 64 tc/ha or 7,5 ts/ha. VM with filtercake was the only treatment to produce a significant mean response calculated from all crops at site 1.

In general, VM proved to be less effective at the Mt. Elias site. In the plant crop, slightly improved cane and sucrose yields were produced by the VM with topsoil and sand treatments. In the first ratoon a significant cane yield response was obtained to the VM with topsoil only. The order of residual responses changed in the second ratoon crop, with the VM with sand treatment producing a significant effect both in terms of tc/ha and ts/ha. Overall, this treatment also produced the best cumulative response of 27 tc/ha or 3,2 ts/ha over three crops.

Irrigated trials

Table 3 shows that at both trials marked cane yield responses were obtained to the various vertical mulching treatments. At Simunye significant sucrose yield increases were obtained to both filtercake and river sand. Although residual effects from these treatments were apparent in the first ratoon crop the responses were not significant and were even less obvious in the second ratoon crop. Cumulative responses to VM over the three harvests declined in the order filtercake (+ 5,2 ts/ha), river sand (+ 3,8 ts/ha) and topsoil (- 1 ts/ha). Despite the large quantity of filtercake used, cane quality was only slightly decreased by this treatment.

At Ubombo, VM with filtercake consistently improved sucrose yields significantly, especially in the presence of subsurface drainage. The response to this treatment combined with drainage was highly significant in the plant crop (3,9 ts/ha) and significant residual effects were also obtained in the two subsequent ratoon crops. After three crops, vertical mulching with filtercake gave a cumulative response of 9,1 ts/ha when compared with the control treatment. VM with river sand also proved quite effective, particularly in the absence of drainage, giving a cumulative response of 4,6 ts/ha compared with 3,1 ts/ha with drainage. The larger cumulative response to VM with sand was considered to be due to the drainage benefit of a concentrated slot of sand contained in a soil with an extremely low hydraulic conductivity. Both VM with topsoil and gypsum produced no benefits in the plant and first ratoon crops, but significant residual responses to these treatments were obtained where drainage was present in the second ratoon crop.

Effect of vertical mulching on root development

In general, the root washing studies showed that VM with filtercake produced a better root distribution pattern to depth compared with control and other VM treatments. This was particularly evident at the Mt. Elias (see Figure 1) and Simunye trials where, in the control treatments, more than 90% of roots were found within 400 mm of the soil surface, whereas with filtercake the same amount of roots were distributed to a depth of 600 mm, and a considerable number of roots were also present at a depth of 1 000 mm. Similar results were reported by Meyer *et al.*, 1988. Soil core meas-

Table 2

Response to vertical mulching under rainfed conditions

Treatment	Mtunzini (Site 1)												Mount Elias (Site 2)						Cumulative response	
	Plant Apr 86–Jun 87		1st ratoon Jun 87–Jun 88		2nd ratoon Jun 88–Jul 89		3rd ratoon Jul 98–Aug 90		4th ratoon Aug 90–Aug 91		Cumulative response		Plant Feb 87–Oct 88		1st ratoon Oct 88–May 90		2nd ratoon May 90–Nov 91			
	tc/ha	ts/ha	tc/ha	ts/ha	tc/ha	ts/ha	tc/ha	ts/ha	tc/ha	ts/ha	tc/ha	ts/ha	tc/ha	ts/ha	tc/ha	ts/ha	tc/ha	ts/ha	tc/ha	ts/ha
Control	68	7,5	47	6,0	57	7,9	57	8,9	50	5,8	–	–	103	14,5	79	9,6	74	8,4	–	–
VM with topsoil	79*	8,5	49	6,4	50	7,1	58	9,1	53	6,5	10	1,5	108	14,9	88*	10,6	81	9,4	21	2,4
VM with sand (150 t/ha)	82**	9,0*	48	6,0	58	7,7	64	10,3	55	6,9	28	3,8	114	15,6	84	10,2	86*	9,9*	27	3,2
VM with filtercake (100 t/ha)	84**	9,2*	51	6,5	65	8,4	71*	11,0	68*	8,5**	64*	7,5*	106	13,9	87	10,4	79	9,1	16	0,9
LSD (0,05)	8	1,3	11	1,5	11	1,3	12	2,1	14	1,6			13	1,3	8	1,7	9	1,1		
Rainfall (mm)	1134		2559+		1113		1477+		1482+				1715+		1437		1106			
Long term mean (mm)	1329 (12 months)												1325 (18 months)							

* significant at P = 0,05
** significant at P = 0,01
\+ rainfall above long term mean

urements from site 1 showed that vertical mulching with sand or filtercake increased root density by 58% compared with control.

Crop water use

The monitoring of relative crop water use with gypsum blocks to two depths showed no major differences. However, it is evident from results of at least two rainfed crops that vertical mulching with filtercake tended to show the greatest profile moisture depletion, particularly at Mt. Elias, which received less and more poorly distributed rainfall than Mtunzini. Figure 2 shows the effect of vertical mulching on crop moisture use at depths of 300 and 600 mm at Mt. Elias. Each curve represents the mean of six gypsum block readings. During the relatively dry summer months of 1988/89 moisture depletion was most rapid in the filtercake treatment, particularly in the subsoil. During the winter period water content in the subsoil declined to as little as 5%. This implied that roots were actively taking up water beyond a depth of 600 mm. The pattern of greater moisture depletion by VM with filtercake was again evident between February and May 1990. In general the moisture use patterns at both sites were reasonably consistent with observed root distribution patterns.

Infiltration rates

Infiltration rates were studied annually at both rainfed sites with the aid of double ring infiltrometers. Results were similar, with the highest infiltration rates occurring in the VM with filtercake treatments followed in decreasing order by VM with sand, control and VM with topsoil treatments. On each occasion these measurements were made, the infiltration rate from VM with filtercake was about double that of the control. Mean infiltration rates recorded at Mtunzini were 7,2, 3,9, 1,5 and 1,0 mm/h for VM with filtercake, VM with sand, control and VM with topsoil treatments respectively. Cumulative infiltration measured over a period of three hours showed that VM with filtercake resulted in the profile being wetted to a depth of 70 mm compared with 34, 28 and 15 mm for the VM with sand, control and topsoil treatments (see Figure 3).

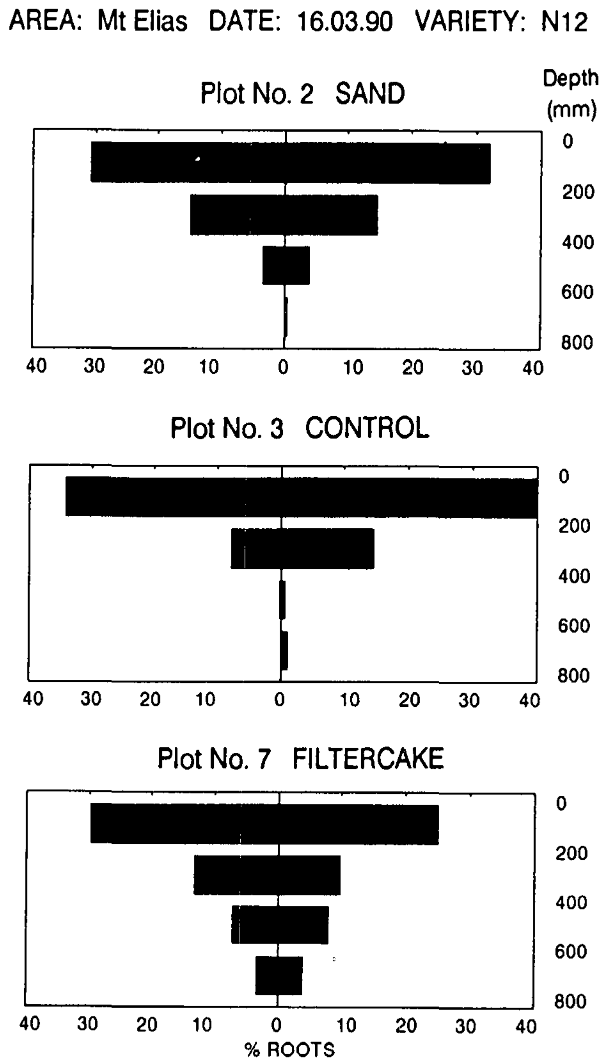

FIGURE 1 Root distribution with depth for plots 2,3 and 7 at Mt Elias.

Table 3

Response to vertical mulching under irrigation

Treatments	Simunye (Site 3)				Ubombo (Site 4)							
	Plant Jun 88– May 89	1st ratoon May 89– Apr 90	2nd ratoon Apr 90– Jun 91	Cumulative response	Plant Aug 88– Nov 89		1st ratoon Nov 89– Nov 90		2nd ratoon Nov 90– Nov 91		Cumulative response	
	ts/ha			ts/ha	ts/ha						ts/ha	
					DO	DI	DO	DI	DO	DI	DO	DI
Control	12,1	13,8	16,4	-	21,4	20,6	15,0	15,0	12,5	11,0	-	-
VM + topsoil	13,6	13,7	14,0	-1	20,1	18,6	14,8	15,4	12,6	16,6*	- 0,5	4,0
VM + sand (150 t/ha)	14,7*	14,9	16,5	3,8	20,8	19,3	16,6	16,3	16,1*	14,1*	4,6	3,1
VM + filtercake (150 t/ha)	15,1*	15,0	17,4	5,2	22,1	24,5*	16,0	17,8*	13,0	13,4*	2,2	9,1
VM + gypsum (10 t/ha)	-	-	-	-	18,1	19,9	15,1	14,5	12,5	13,5*	- 3,2	1,3
LSD (0,05)	2,3	2,4	2,2	-	2,4		1,6		2,1		-	-
Rain (mm)	711	423	1248		513		259		282			
Rain + irrigation	1279	1172	1996		1554		1031		901			

DO - no subsurface drainage
DI - subsurface drainage

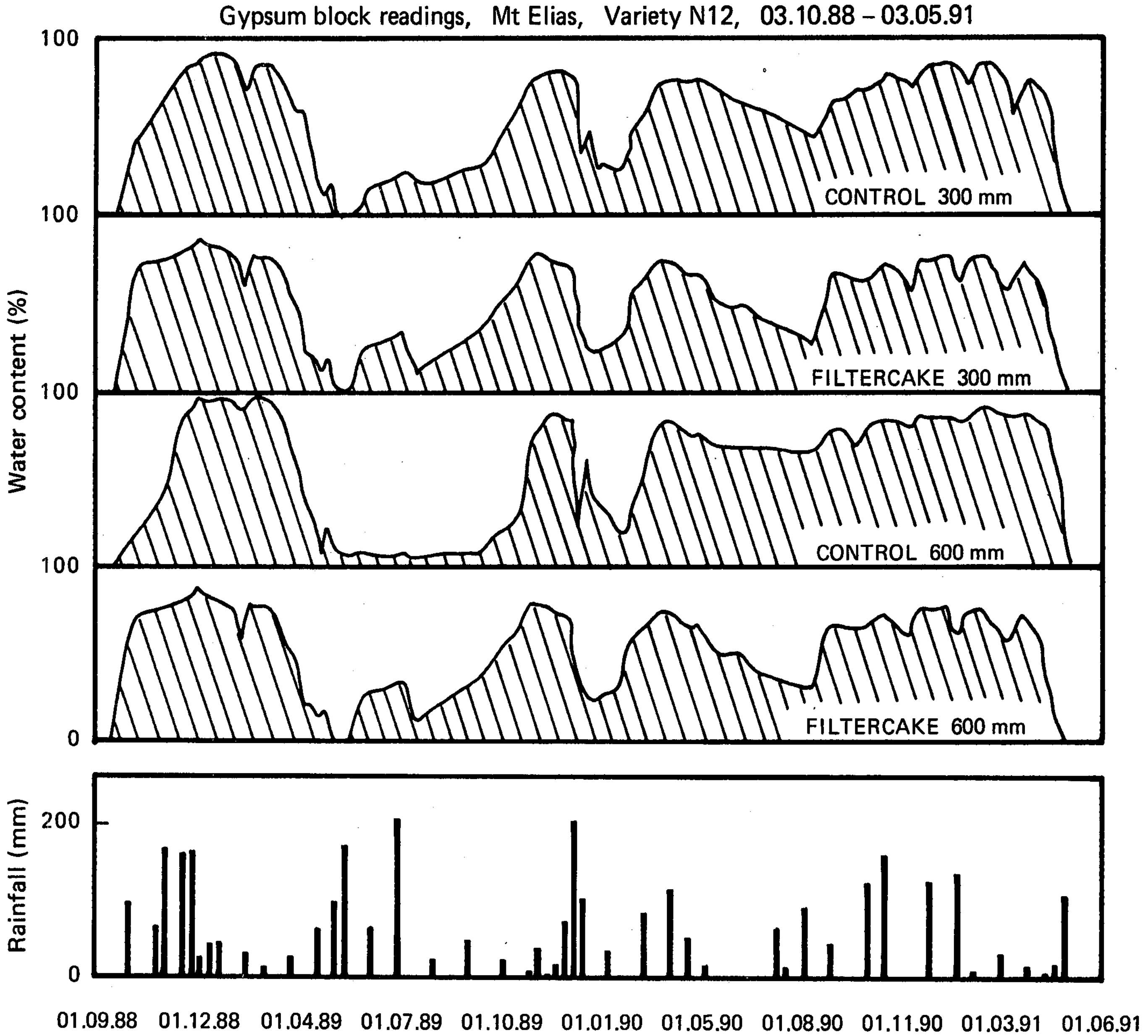

FIGURE 2 Effect of vertical mulching with filtercake compared with conventional tillage on water use of cane to a depth of 600 mm (shaded areas indicate relative percentage crop available water).

In the irrigated trial at Simunye, infiltration was also measured in the cane rows of selected VM filtercake treated and control plots about 24 hours after irrigation, when soil moisture conditions were close to field moisture capacity. Measurements were made every hour for nine hours and a comparison of average infiltration rates showed that filtercake (11,6 mm/h) was more effective than the control treatment (5,3 mm/h). Filtercake contains substantial amounts of calcium, which will have the effect of reducing dispersion of clay colloids by sodium ions and increasing hydraulic conductivity.

Soil moisture release

Results from undisturbed cores taken from the rainfed trial at Mt. Elias indicated that available moisture capacity (AMC, mm/m) increased by about 50% in the VM with filtercake treatment (82 mm/m) when compared with control (57 mm/m) and had decreased by about 20% for the VM with sand treatment (48 mm/m). This implies that perhaps more water was available to the plant during the dry winter months under the VM with filtercake treatment, thus reducing the period of moisture stress. The results at Simunye also indicated that the AMC of the vertic topsoil (0-200 mm) was increased by about 20% in the VM with filtercake treatment (181 mm/m) when compared with that of the control treatment (150 mm/m).

Soil fertility changes

Detailed monitoring of the effects of the various VM treatments on selected physical and chemical properties at sites 1, 2 and 3 revealed the following:

VM with filtercake compared with control

- Small but consistent increases in the organic matter content of the topsoil (0-200 mm), ranging from 0,3 to 1,3% and from 0,1 to 0,4% in the subsoil (200 mm)
- A substantial increase in the plant available phosphorus and calcium content of the top and subsoil
- A generally higher cation exchange capacity in both the top and subsoil horizons.

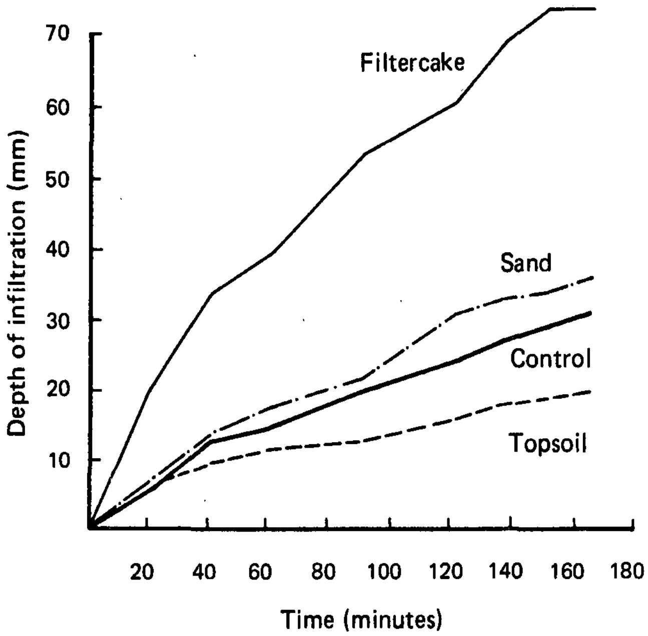

FIGURE 3 Cumulative infiltration rates in relation to vertical mulching treatments.

VM with sand compared with control

- A small but consistent increase in the coarse sand fraction. At Mt. Elias VM with sand increased the coarse sand fraction on average from 27% to 34% and from 23% to 28% in the 0-150 mm and 150-300 mm soil depths respectively
- A moderate reduction in salinity level at depth. At the Mtunzini trial the electrical conductivity level in the vertically mulched subsoil layer was 137 mS/m compared with 259 mS/m in the control treatment. This reduction in salt content may be associated with improved internal drainage.

Leaf analysis

At first it was thought that the improved residual response from filtercake treatment could have been due to the N and P content of filtercake. While leaf analysis did tend to indicate enhanced N and P uptake in all the trials, it was observed that VM with sand also improved uptake of these nutrients when compared with control. As sand is inert and contains no N or P, it was inferred that improved physical conditions at depth, and not nutritional effects were more likely to be responsible for the residual effects from VM with filtercake and sand. Leaf nutrient contents in all treatments, including the control were also consistently above the FAS threshold values, further suggesting that nutritional effects were unlikely to be limiting cane growth. Provision has been made for application of additional N and P fertilizer as a blanket application to all treatments in the Mtunzini trial to minimise any confounding effects of N and P in the filtercake treatment.

Conclusions

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, which showed 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 (1968) that such subsurface layers act as a barrier to water flow because capillaries in sand are larger than those in the overlying fine textured topsoil layer. Only when the topsoil is nearly saturated does the water move rapidly through the impeding subsurface horizon. Studies in Australia have also shown that vertically mulched slots maintained higher air-filled porosity values between irrigation, due to faster moisture redistribution providing pathways for oxygen flow to roots at lower depths (Jayawardane and Blackwell, 1986).

The economics of vertical mulching will depend on the ready availability of either river sand on the farm or distance from the mill in the case of filtercake. For a grower within 15 km of the mill the cost of applying filtercake as a vertical mulch at a rate of 100 t/ha is unlikely to exceed R500, which is roughly equal to the value of a ton of sucrose. In terms of the large cumulative responses obtained to VM with filtercake in three out of the four trials, it may be concluded that this practice would be economical. As grey hydromorphic soils comprise about 20% and vertisols about 10% of the South African sugar industry there appears to be considerable scope for improving cane yields on such soils. Trials are in progress to test VM in combination with ridging. Ridge tillage is an inexpensive technique, which has been shown to be successful in improving surface water management on grey hydromorphic soils (van Antwerpen, *et al.*, 1991). It is possible that a strategy of combined VM and ridge tillage will greatly help to minimise moisture stress in dry years, and avoid waterlogging in wet years for rainfed cane grown on hydromorphic soils.

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