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AID IN CONFIDENCE

Tillage Trials in Vertisols in the South Kordofan Region of Sudan

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April 1982

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SUMMARY

This report covers the trials requested by the Nuba Mountains Agricultural Production Corporation (NMAPC) of four shallow tillage treatments applied to Vertisols in the South Kordofan region of Sudan during the 1981 growing season.

Observations on the four treatments are made and the results analysed for variation. No significant difference between the treatments can be found and the implications for minimising energy inputs are discussed.

One British made implement, known as the Bush and Bog Disc Harrow, appears to have some advantages over the commonly used Wide Level Disc Seeder and the NMAPC is advised to try them out over a longer period.

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1 Introduction

The 1982 tillage trials were carried out in conjunction with the Agricultural Mechanisation Project (AMP) at Kadugli. This project was first identified in 1974(1) and subsequent development has been well supported(2,3,4,5,6). Action to establish a shallow tillage trial was initiated in 1980(7), although improved cultivation techniques were in the terms of reference as a subject for study when the project was originally identified. The work of the Rural Planning Unit at Kadugli(8) provides comprehensive background information on agricultural practices and present developments in the area. Traditionally the soils are cultivated by hand, or more recently by the wide level disc seeder (WLD), both of which are essentially shallow cultivation techniques. The final decision to implement the 1981 trials came after a request form the Managing Director of the Nuba Mountains Agricultural Production Corporation (NMAPC) who was concerned that, although a great deal of work was being carried out on alternative cultivation techniques by other aid agencies at both high and low energy inputs, no work was being carried out to check the suitability of the present system.

The need for increased world food production necessitates the development of semi-arid farming systems, but because of the world energy crisis one must question the wisdom of high energy use in developing these systems. There is particular interest in the Sudan in developing semi-arid farming in light of the fact that Sudan's agreement to draw water from the White Nile ceases at the end of this century(9). The Nuba Mountains region is suited to semi-arid agriculture. The total area occupies some 5.8 million hectares of which 2.9 million hectares (50%), namely the predominately clay plains, is suitable for extensive mechanised crop production. However, only 10% of this available land is at present mechanised and cropped(8).

Rainfall, although sporadic, is sufficient to support a variety of crops. Records of mean precipitation and temperature are shown in figures 1 and 2 below. The temperatures do not appear to be limiting in that there is no cold period as experienced in some semi-arid regions. Similarly, from an analysis of the climate, using an Aridity Index(7) which considers rainfall and temperature, the environment is not limiting for crop production. However, crop water stress may occur during the months of October and May.

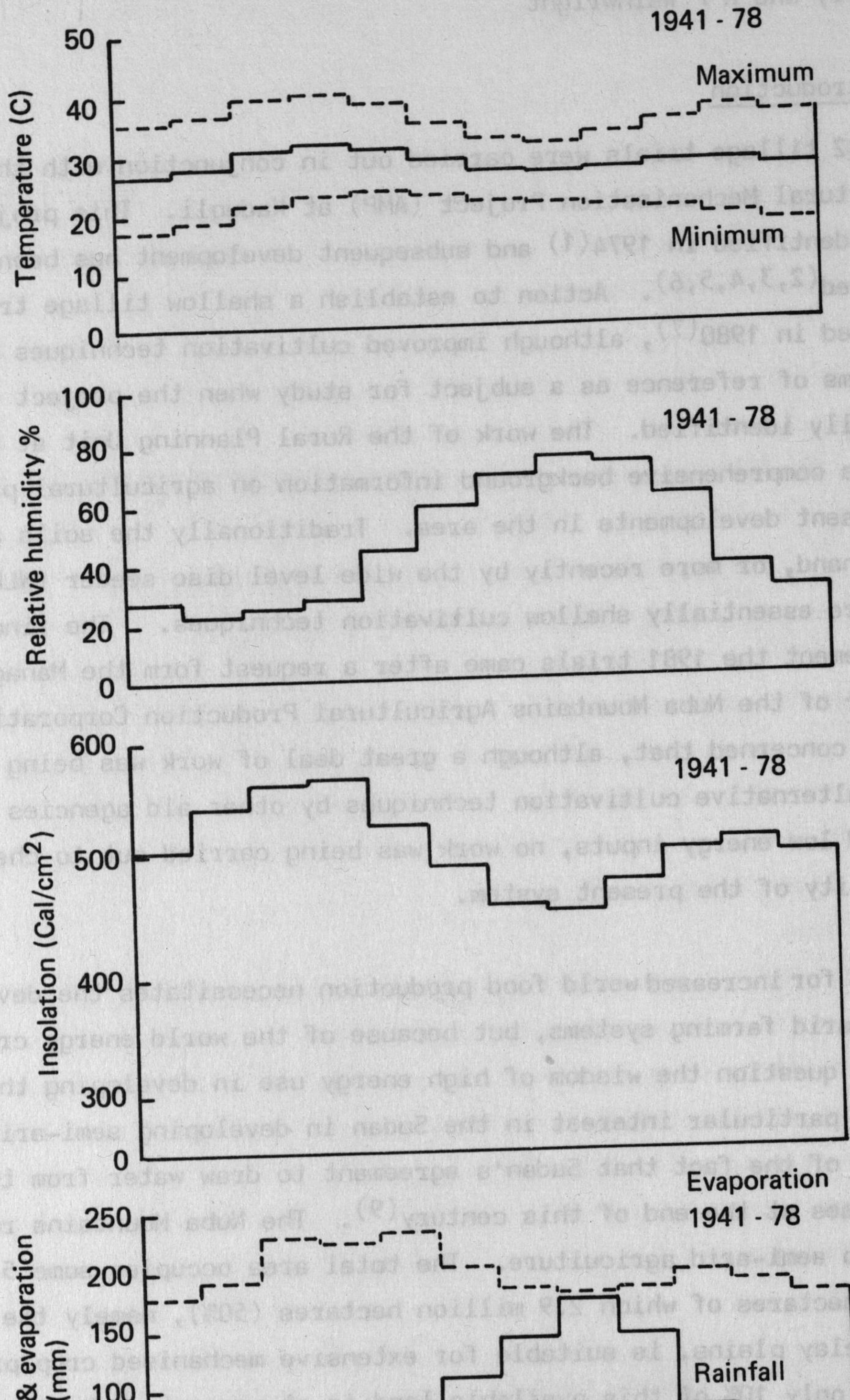

Figure 1 Climatic Norms for Kadugli (Source Huntings Technical Services)

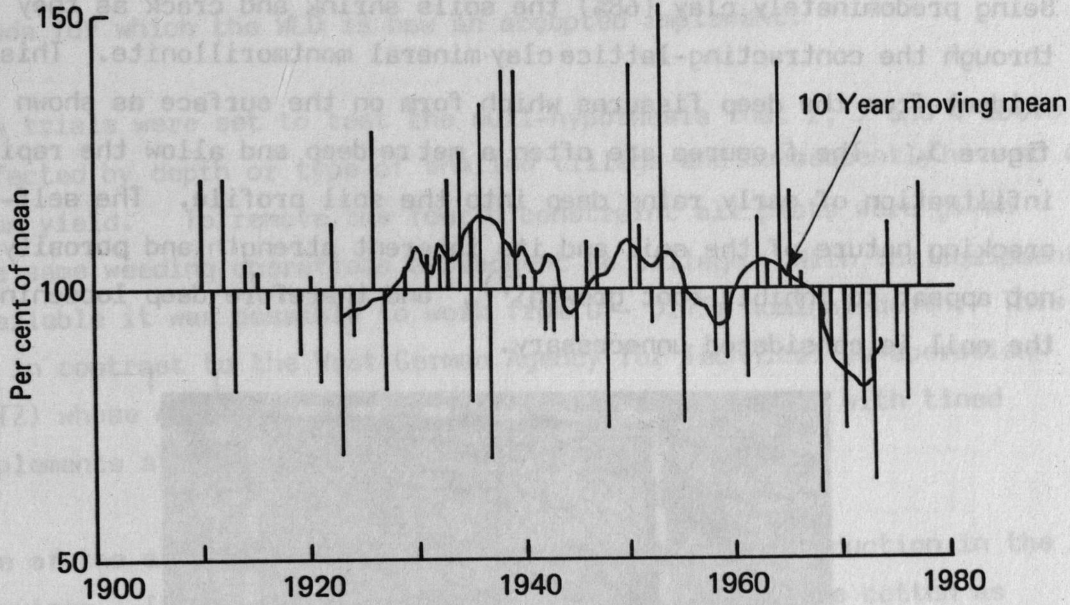

Figure 2 Fluctuations in Annual Rainfall at Kadugli
(Source: Huntings Technical Services, Rural Planning Unit, Kadguli, Sudan.)

2 Materials and Methods

2.1 Soils

The trials were carried out in the Nuba Mountains Region of the South Kordofan Province of Sudan, the capital town of which is Kadugli, approximate Latitude 28°50'E and 11°12'N. A map of the region appears at appendix 1. The trials were located just outside the village of Telo some 10km east of Kadugli on one of the NMAPC mechanisation schemes.

A flat (less than 2% slope) area (2ha) of ground was made available for this work by the NMAPC and the tenant farmer. The land had been cropped with sorghum for three years and was well cleared of bush and trees. The soil is classified as a dark cracking Vertisol with a mechanical analysis as follows in table 1:

Table 1 Mechanical Analysis of Telo Vertisol

Particle Size Analysis %					
Coarse sand (grms)	Fine Sand 0.05 - 2.00mm	Silt 0.002 - 0.05mm	Clay 0.002mm	Organic	Carbonate
10.8% (5.4g)	11.4%	26.6%	68%	0.02%	1.2%
Texture - Clay Plastic limit (MC & DB) 33.8%					

Source: NIAE Central Laboratory

Being predominately clay (68%) the soils shrink and crack as they dry out through the contracting-lattice clay mineral montmorillonite. This is evident from the deep fissures which form on the surface as shown in figure 3. The fissures are often a metre deep and allow the rapid infiltration of early rains deep into the soil profile. The self-cracking nature of the soil and its inherent strength and porosity do not appear to inhibit root growth(7), and therefore deep loosening of the soil is considered unnecessary.

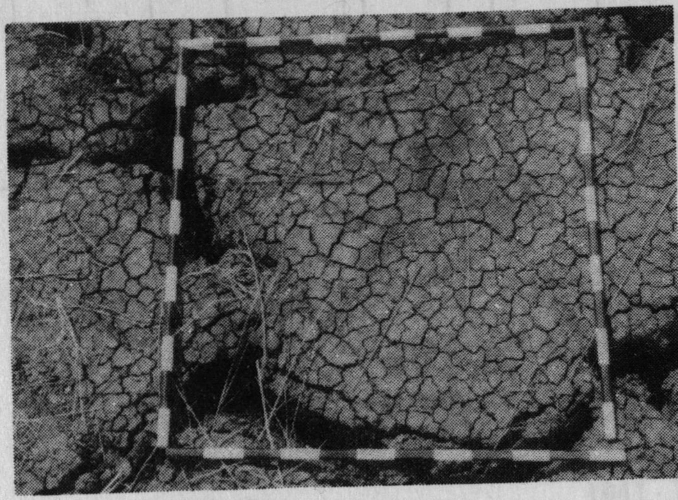

Figure 3 Vertisol at Telo in June 1981 (Poles graduated in decimetres)

Generally cultivations are carried out for one or more of the following reasons:

1 To control weeds.
2 To provide a suitable seed bed.
3 To obtain the optimum soil moisture conditions for germination.
4 To improve aeration deep in the soil profile and to break up any panning formed by previous field practices which could restrict plant root development.

With these Vertisols the top 30 - 50mm of soil becomes loose and friable when dry; consequently when rain falls an ideal seedbed layer is formed. The shrinkage and cracking through drying prevents the formation of any panning and it is the opinion of the authors that there is no improved moisture retention with cultivation irrespective of the depth of operation. Because of these characteristics it is not necessary to cultivate for reasons 2, 3 or 4 above and the main purpose in cultivation is to control weeds for which the WLD is now an accepted implement.

The trials were set to test the null-hypothesis that 2, 3 and 4 above are not effected by depth or type of shallow tillage and consequently have no effect upon yield. To remove the fourth constraint all plots were given the same weeding operations subsequent to tillage. With the equipment available it was possible to work from 0 - 0.15m nominal depth. This is in contrast to the West German Agency for Technical Co-operation (GTZ) whose objective is to till the soil consistently with tined implements at depths of 0.25 - 0.30m depth.

One of the aims of the NMAPC is to increase cotton production in the province. It was therefore considered expedient to use cotton as the trial crop as it was hoped that this would have some spin-off in showing the farmers that present levels of yield in the area (240kg/ha)[10] can be improved.

2.2 Design of tillage trials

The trial was designed as a randomised block with six replicates to evaluate four tillage treatments, definition of the treatments and coding is shown in Table 2 below.

Table 2 Tillage treatments and plot sizes

Treatment	Codes Treatment/Depth
No-till plus glyphosate herbicide (NoT)	0.0
Wide level disc at 0.05m nominal depth (control) (WLD)	1.1
Bush and Bog harrow at 0.10m nominal depth (BB)	2.2
Sweep tine cultivator at 0.05m nominal depth (SWE)	3.1

Plot dimensions were as follows:-

Field size (4 x 6 x 800m^2)	19200m^2 (1.92ha)
Plot size 100m x 8m	800m^2
Harvest plots (2 per plot) 20m x 5m	100m^2

A diagram of the field layout showing treatment allocations appears at figure 4.

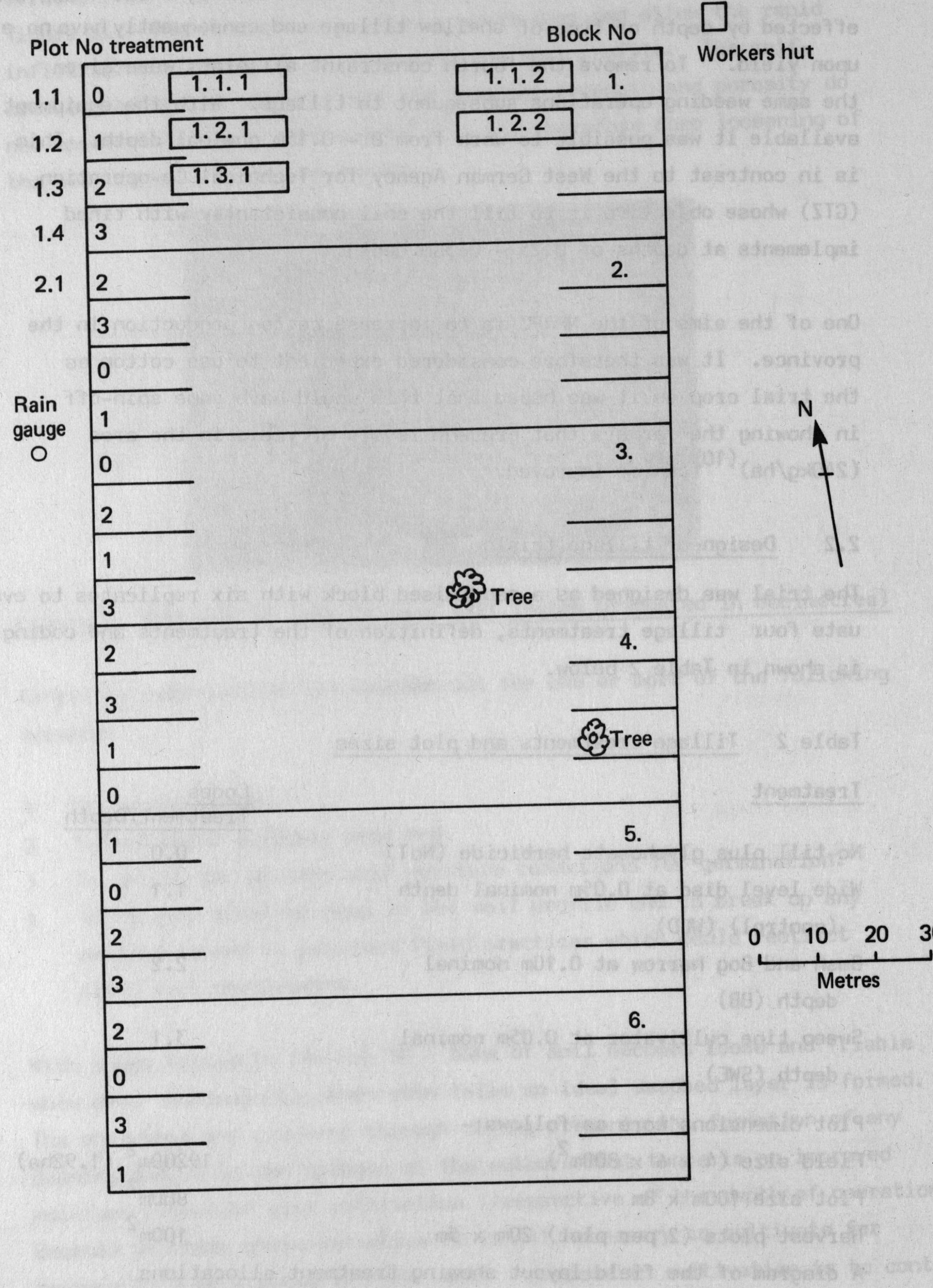

Figure 4 Diagram of Field Layout and Treatment Allocations

2.3 Description of Tillage Treatments

2.3.1 No-Till plus glyphosate herbicide (NoT) (0.0 depth)

This is an extreme treatment without tillage. Glyphosate herbicide, commonly sold under the trade name of 'Round-Up', was purchased from Shell Chemicals in Khartoum. For this trial it was applied at 4l/ha, (1.92 kg a.i.) 50% dilution, using a 'Herbi' sprayer from Micron Sprayers Ltd.

Figure 5 Hand held CDA sprayer - 'Herbi'

2.3.2 Wide level disc (WLD) (0.05 m depth)

This machine, commonly used in Australia, North America and Sudan, consists of one gang of 24 discs, 460 mm, diameter, above which is mounted a seeder unit. It has a nominal working width of 3.8 m and a working depth of 0.04 m - 0.10 m. Side thrust from the discs is taken up by two transport wheels.

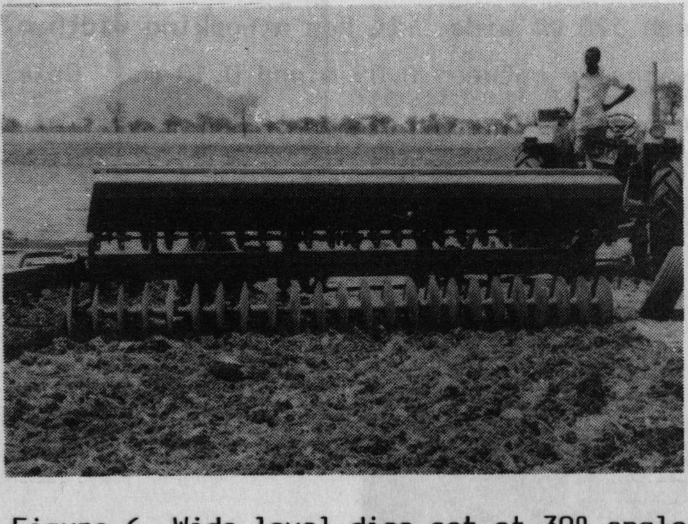

Figure 6 Wide level disc set at 30° angle of cut

2.3.3 Bush and Bog disc harrow (BB) (0.10 m depth)

This machine was adapted from an offset disc harrow, although it is of a type available in Britain and elsewhere. It consists of a frame mounted on the three-point linkage of the tractor from which are hung two opposing gangs of 10 discs, 560 mm diameter, spaced at 240 mm intervals. The angle of cut of each gang is adjustable from 90° (zero cut) to 65° (maximum cut) to the line of travel. A nominal setting of 68° was used for the trials. It has a working width of 4.9 m at this angle and can work up to 150 mm depth. The relative cost of this machine in Sudan is estimated as less than half that of the WLD.

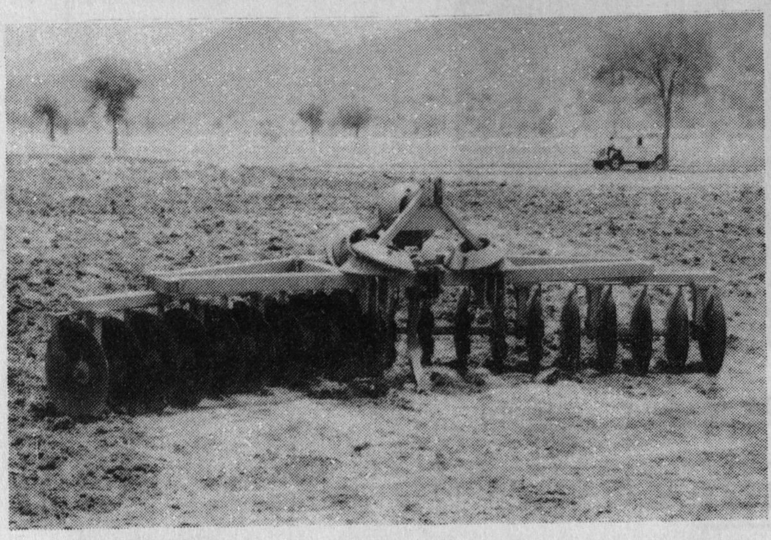

Figure 7 Bush and Bog disc harrow (22° angle of cut)

2.3.4 Sweep tine cultivator (SWE)

This machine comprises a Ransomes C79 cultivator frame, mounted on the three-point linkage of the tractor, on which are mounted five 'Texas style' sweep tine blades each 520 mm wide. It has a working width of 2.6 m. Depth of work is typically between 0.05 m and 0.10 m. Relative capital cost of the machine per metre width is about 25% of that of the WLD.

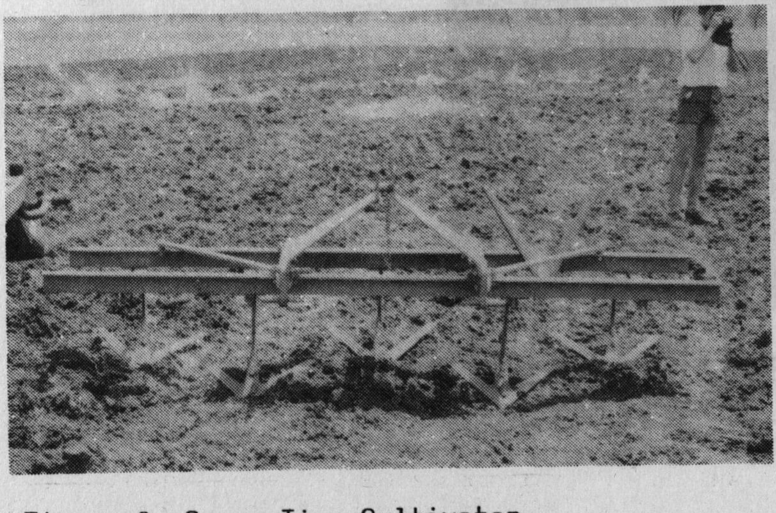

Figure 8 Sweep Tine Cultivator

3 Programme of Evaluation

A chronology of the evaluation programme appears in table 3 below.

Table 3 Chronology

Day No: Year 1981	Day No: Days from planting	Activity	Notes
179		Pre-tillage weed count	
180		Pre-tillage moisture content sampling	
180	-7	Tillage treatments	Meas. of draught
181			Rainstorm 7.5 mm
182		Post tillage moisture content sampling	
183			Rainstorm 30.0 mm (Delay planting)
187	0	Planting	10 man-days
191			Seedling emergence
201		Weed count	
202	+15	First weeding commenced	26 man-days
206		Weeding completed	
217	+30	Thinning commenced	12 man-days
218		Thinning completed	
220			Population count
247	+60	Second weeding commenced	16 man-days
251		Second weeding completed	
340		Harvest plot population count	
341		Harvest plot population count	
342	+155	Harvest commenced	30 man-days
344		Harvest completed	

The trial plots were all cultivated on day 180, seven days before planting. The work was carried out at the highest practical forward speed, namely 5.1 km/h, 4.8 km/h and 3.3 km/h for the WLD, BB and SWE respectively. Draught measurements were taken using a strain gauge link and Novatech indicator unit. For the WLD the link was fitted directly between the tractor and the drawbar of the implement. Ten to twenty readings were taken and the average draught used for subsequent calculations Forward speed was calculated to simultaneously record the time taken to cover either 10 or 20 m. The other two implements were mounted on the three point linkage of the tractor and for these a towing vehicle was used to pull the tractor with the implement in the ground. The draught forces were then measured by having the strain gauge link in the tow line. The tractor was also towed with the implement in the raised position to obtain rolling resistance and hence the net draught. Following each run the depth of work was recorded taking an average of three readings. With the WLD working width also recorded, as this was variable due to slight changes in speed or ground conditions. As the width of the other two implements remained constant it was only necessary to measure this once. Pre and post tillage samples were taken for soil moisture content analysis. The NoT plots were sprayed with the CDA sprayer as described in 2.3.1.

Prior to the cultivations and spraying a weed count was taken on each plot using three random samples of 1 m square. Results of this and a later weed count appear at Appendix 2. The complete area was weeded twice using the traditional short stick hoes.

The first effective rainstorm (30 mm) fell three days after cultivations. Planting had to be delayed a further three days while the soil surface dried out sufficiently. Cotton was hand planted in 0.7 m rows at approximately 0.6 m spacing as shown in figure 9. It was not possible to get accurate sowing rates because delinted seed was not available. Subsequent thinning was carried out to achieve the traditional stand of three plants per hole giving a population of 50,000 pl/ha.

Figure 9. Hand planting of cotton in 0.7 m rows at 0.6 m spacing

Rainfall was recorded throughout the growing period and later penetrometer work was also carried out with further soil samples taken for moisture content analysis. The crop was regularly examined during the growing period for insect infestation by staff of the NMAPC Crop Protection Department. In the event no chemical treatment was necessary.

There were two harvest plots per treatment and the layout is shown in figure 4. Some plots were repositioned to avoid any physical influences such as trees. Each plot was 20 m long and encompassed 6 rows giving a mean width of 4.9 m. The cotton was harvested into previously weighed and marked sacks by a team of 10 women. Field weights were obtained using a spring balance and records are at appendix 3.

4 Results and Discussion

4.1 Soil moisture content

Figures for the pre and post-tillage soil moisture content analysis appear at appendix 4. An analysis of the variation in the difference between pre and post-tillage soil moisture is summarised in table 4 below.

After tillage and 7.5 mm of rain the soil moisture content in the top 100 mm of the three tilled plots increased on average by 19%, whereas the increase in the no-till plot was 13%. The major difference in moisture content between no-till and tilled areas was in the 50 - 100 mm range and this was shown to be highly significant for that rainfall. It is believed that this is due to the uncovered fissures in the no-till plots which channel

Table 4 Analysis of Variation in the Difference between Pre and Post-Tillage Soil Moisture Content after 7.5 mm of Rainfall at Two Depths

Depth 0 - 50 mm

Source of Variation	DF	SS	MS	F
Blocks	5	26.252	5.250	1.690^{ns}
Treatment	3	37.945	12.648	4.070*
Residual	15	46.613	3.108	
TOTAL	23	110.809		

Depth 50 - 100 mm

Source of Variation	DF	SS	MS	F
Blocks	5	164.16	32.83	2.96^{ns}
Treatment	3	465.99	155.33	10.862**
Residual	15	214.50	14.30	
TOTAL	23	844.64		

ns Not significant
* Significant (@ 5% level)
** Highly significant (@ 0.1% level)

water quickly into the lower profile. No conclusions in respect to germination can be drawn from this because a 30 mm rainfall occurred three days after the above measurements and this ensured good germination conditions on all plots. This was followed be good periodic rainfall during the growing period, as can be seen in the rainfall data at appendix 5. In a year of poor periodicy of rainfall it is likely that seedlings in a NoT area could suffer moisture stress due to the poor moisture retention capacity of the seedbed.

The penetrometer results, as shown at appendix 6 , were used as a means of demonstrating the changes in the soil moisture profile.This indicated that with time and rainfall the soil moisture profile became uniform regardless of tillage treatment. This is illustrated in figure 10 which depicts the changes in soil moisture profile as indicated by penetrometer depth during the three weeks after tillage. However, from table 5 on page 14 it can be seen that this progression to uniformity may not hold true later in the season when the cracks have sealed up. From this penetrometer work and subsequent moisture content analysis it would appear that in a seaon of good rainfall the fissures play no major role in transferring moisture into the lower profile. However, in a season of poor rainfall or late drought this may not be the case. With limited rainfall the fissures could remain open for much longer in a season thereby allowing later rains to go deep into the soil profile and thus provide moisture to the plant later in the growing season.

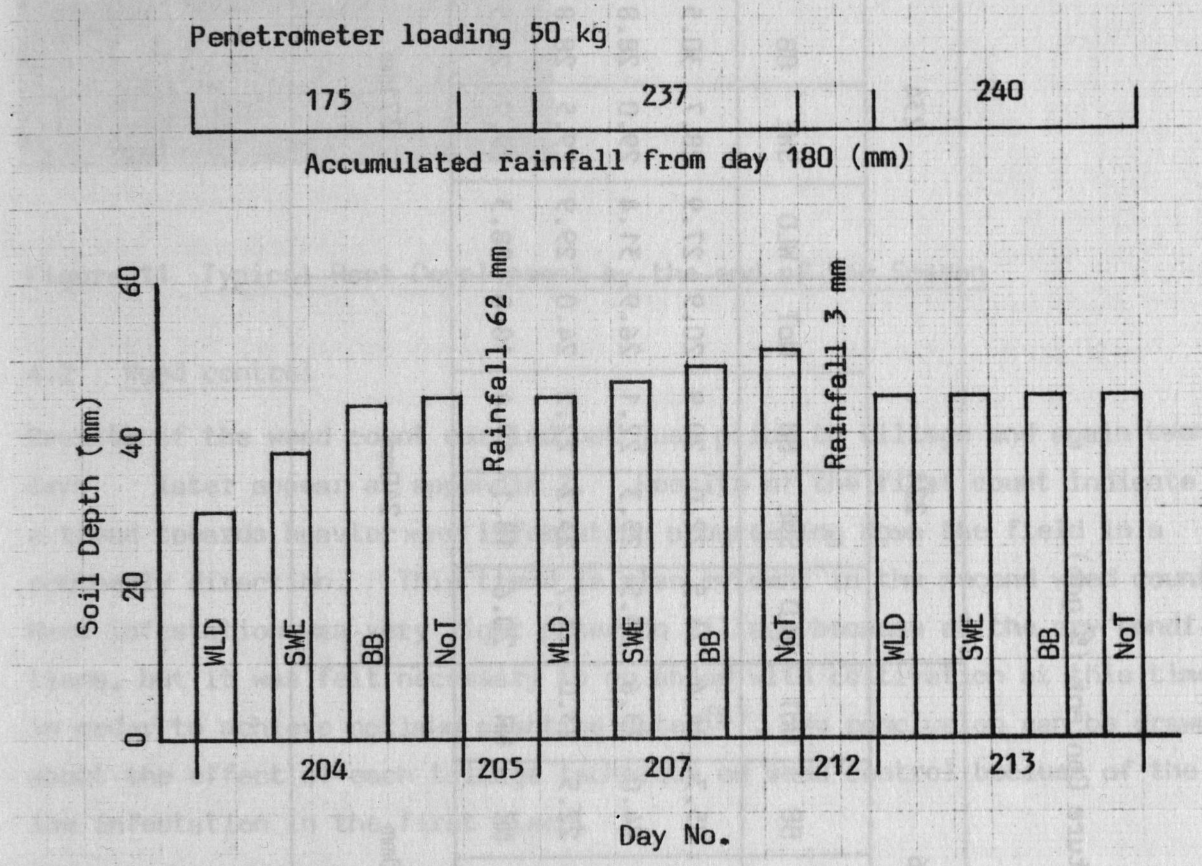

Figure 10 Showing Changes in Penetrometer Depth, at Constant Load, with Accumulated Rainfall

The penetrometer work has also shown significantly that there is no sub-surface panning in the soils, and therefore there is no inhibiting barrier to root growth, see figure 11.

Table 5 Soil Moisture Content (% gdb)

DAY No.	216				221				234				252			
Depth mm	WLD	SWE	BB	NoT	WLD	SWE	BB	NoT	WLD	SWE	BB	NoT	WLD	SWE	BB	NoT
0-150	25.2	25.3	25.3	24.4	24.5	22.0	20.9	20.9	27.9	28.7	30.5	26.9	26.7	26.8	27.9	26.8
150-300	25.8	25.4	24.0	23.6	23.5	23.3	22.1	26.9	31.4	29.0	28.8	26.0	28.2	25.0	28.4	26.5
300-450	25.4	25.7	22.5	23.0	21.7	23.2	22.2	24.0	29.9	29.5	28.8	25.7	27.0	25.3	29.0	23.7
450-600	NR	NR	NR	NR	20.6	18.1	19.4	18.8	28.3	29.9	26.5	20.1	24.0	23.1	25.7	18.7
Accumulated Rainfall	240mm				240mm				371mm				421mm			

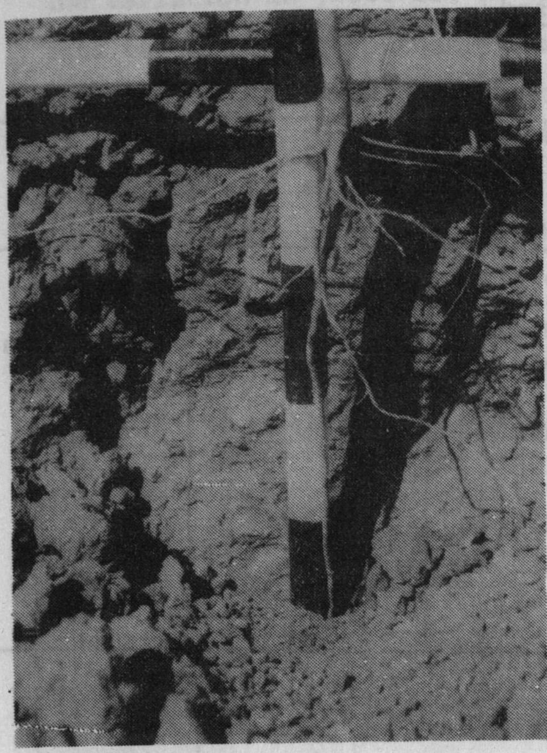

Figure 11 Typical Root Development by the end of the Season

4.2 Weed control

Results of the weed count carried out just prior to tillage and again twenty days later appear at appendix 2. Results of the first count indicate a trend towards heavier weed infestation progressing down the field in a southerly direction. This trend is also evident in the second weed count. Weed infestation was very light prior to tillage because of the dry conditions, but it was felt necessary to go ahead with cultivation at this time in order to achieve optimum planting dates(8). No conclusion can be drawn about the effect of each tillage technique on weed control because of the low infestation in the first place.

4.3 Harvest

4.3.1 Plant stand

Prior to harvest a plant count was made to check the conformity of plant stand in each harvest plot. Although there was some variation in the range, 378 - 521 plants per plot (equivalent an average of 45,000 pl/ha), there does not appear to be an correlation between plant stand and yield. This may be because it was observed that plots with fewer plants contained larger plants and hence higher boll numbers. The data for plant stand was analysed for variation and a summary appears in table 6 below. From this analysis it can be seen that the difference in plant stand across the field is not significant, 50,000 pl/ha is recommended by NMAPC for plant density.

Table 6 Analysis of Variation in Stand

Source of Variation	DF	SS	MS	F
Blocks	5	6,438	1,288	0.839
Treatment	3	568	189	0.126 ns
Block/ Treatment	15	21,471	1,431	0.993
Residual	24	36,814	1,534	
TOTAL	47	65,292		

ns Not significant

4.3.2 Yield

Figures for yield range between 440 - 830 kg/ha with an average of 580 kg/ha. This is about three times the local average which, for this year, is 215kg/ha and illustrates the importance of good weed control and early planting. The figures for yield were analysed for variation and the results are summarised in table 7 below.

Table 7 Analysis of Variation in Yield

Source of Variation	DF	SS	MS	F
Blocks	5	15.0533	3.0107	4.334
Treatment	3	2.3483	0.7828	1.647 ns
Block/ Treatment	15	16.0298	1.0687	2.248
Residual	24	11.4080	0.4753	
TOTAL	47	44.8394		

ns Not significant

The variation in yield due to treatment is not significant and this supports the hypothesis that the depth and type of shallow tillage have no effect upon yield. There is some significance in the block variation, although this does not effect the block/treatment effect unduly. Figures for the mean yield and stand appear in table 8 below, with the standard error and coefficient of variation. The two coefficients of variation are commendably low for this type of field experiment.

Table 8 Mean Yield, Stand, Standard Error and Coefficient of Variation

VARIATE		MEANS						SE	CV%
Yield	Block	1 6.97	2 5.42	3 5.76	4 5.76	5 5.22	6 5.62	0.6894	11.9
	Trt	NoT 5.77	WLD 5.60		BB 6.16		SWE 5.64		
Stand	Block	1 460	2 435	3 468	4 443	5 464	6 456	39.17	8.6
	Trt	NoT 460	WLD 451		BB 451		SWE 454		

4.4 Draught Measurements

A summary of the draught measurements averaged over the trial plots appears in table 9. The WLD and BB were operated at the desired depth, but the SWE had to be worked deeper to obtain sufficient depth control reaction from the tractor hydraulic system. From this table it can be seen that the WLD required a draught of 1.07 kN/m width against 1.71 kN and 1.82 kN for the BB and SWE respectively. These figures are reflected in the energy requirements relative to both the area covered, the volume of the soil disturbed and yields. The very shallow working depth of the WLD (0.04 m) results in a low energy input per unit area compared with the other implements. Spot rates of work also appear in table 9 and are calculated from forward speed and working width. In practice the actual rate of work, or field capacity, achieved by each implement will be considerably less since 'text book' levels for field efficiency would be about 80% for these tillage conditions and actual recorded levels could well be less.

Table 9 Results of Draught Measurements on Trial Plots

IMPLEMENT	Depth of Work	Width of Work	Speed		Spot rate of work (100% field effy.)	Draught			Net Energy		
						Force kN		Power	Relative to area	Relative to soil moved	Relative to yield
	m	m	m/s	km/h	ha/h	net	per metre width	kW (hp)	MJ/ha	kJ/m^3	MJ/t
Wide level disc (WLD)	0.04	3.87	1.41	5.09	1.97	4.15	1.07	5.9 (7.8)	10.7	26.8	18.1
Bush & bog harrow (BB)	0.08	4.9	1.34	4.82	2.36	8.38	1.71	11.2 (15.1)	17.1	21.4	28.9
Sweep tine (SWE)	0.09	2.60	0.91	3.27	0.85	4.89	1.82	4.5 (6.0)	18.8	20.9	31.8

Comparisons of implement work rates and draught power in appear in table 10 and are extended to include direct fuel use at an estimated rate of 0.5 l/kWh[11]. Figures for comparative capital costs of each machine at this time have also been included. The energy requirements of the WLD are the lowest relative to area cultivated and thus yield, but not relative to the volume of soil moved.

5 Observations on Implement Use

5.1 Wide level disc (WLD)

The hard soil accounted for the shallow working depth of the WLD and, although the planned working depth of 0.05 m was reached, farmers and NMPAC staff who observed the operation would have preferred it to have gone deeper. Where heavy grass cover is encountered two passes are traditionally necessary to obtain effective weed control. A field rate of work of 1.6 ha/h can be achieved with this machine with a very low power requirement. However, where two passes are required the rate of work per day must be reduced.

5.2 Bush and Bog disc harrow (BB)

Under these conditions the BB harrow consistently worked deeper than the WLD. Because of this it had a higher energy requirement per hectare but not in relation to the amount of soil moved. Under wetter conditions the WLD would undoubtedly have worked deeper and consequently this difference would decrease. The rate of work at nearly 2 ha/h was a 20% increase over the WLD which was largely due to the greater width (30% wider) and, being a heavier machine, was better able to cope with the grass covered areas in one pass.

From this it can be seen that the BB harrow is a strong contender to replace the WLD. It has a better performance, is less complicated and therefore less likely to breakdown, and, most importantly was well liked by farmers who saw it and by the NMAPC staff. The capital cost can be as little as one third of that of the WLD although a heavier duty version is likely to be around half the cost of a WLD. The performance and low cost factors of the machine clearly make it attractive to both the public and private sectors.

Table 10 Implement Performance and Predicted Fuel Use

IMPLEMENT	Width of work	Speed		Rate of work at 80% field efficiency		Fuel use at 0.5 l/kWh	
	m	m/s	km/h	ha/h	(acres/h)	l/h	l/ha
Wide level disc (Capital cost 100 units) WLD	3.87	1.41	5.09	1.58	(3.89)	3.0	1.9
Bush & Bog Harrow (Capital cost 30 units) BB	4.9	1.34	4.82	1.89	(4.67)	5.6	3.0
Sweep tine (Capital Cost 15 units) SWE	2.60	0.91	3.27	0.68	(1.68)	2.3	3.3

5.3 Sweep tine cultivator (SWE)

The SWE had a rate of work of less than half that of the WLD and almost one third of the BB. This could in theory be improved by widening the implement but, in view of implement flexing and the implications for durability, there is a practical limit of about 3 m unless it constructed with a heavy and expensive frame. In its present form at 2.6 m width it could be operated by a smaller tractor (33 kW) than those commonly used by NMAPC (48 kW). Problems of depth control precluded high speed operation and ideally to keep the implement at a nominal working depth of 0.05 m it would be essential to use depth control wheels. The energy requirement would then be reduced and the overall performance of a machine of comparable width would probably match the other two. However, it did not exhibit the ability to control weeds where the ground had previously been fallowed and where there was a heavy grass cover present.

5.4 Herbicide Spraying

Although the glyphosate herbicide as 'Round-Up' is available in Khartoum it is not generally available in other parts of Sudan. It is a most effective herbicide, but a large extension programme in the use of sprayers would have to be undertaken before it could be safely and effectively introduced. It would also be essential to consider the economics of chemical versus mechanical cultivation techniques. As it is a systemic herbicide 'Round-Up' must be applied to the actively growing weeds and consequently timeliness is particularly important. There remains however, much potential scope for the use of chemicals for inter-row weeding.

6 Conclusions

It is concluded from the results of these 1981 trials that there was no significant difference in yield which could be attributed to the type of tillage treatment. Whether or not this would hold true in a year with a different rainfall pattern is not known. What is important however is that there is no apparent need to cultivate the soil to any great depth in order to achieve good yields. Therefore the tillage energy requirement and fuel use can be kept low. The most important aspect of good crop management is weed control and this highlights the need for further work on row planting and techniques that enable improved weeding.

It is also worth noting the amount of time taken to harvest the cotton. At 30 man-days this is equivalent to some 66 man-days/ha and is likely to be a serious restraint in the production of this crop where labour is expensive or in short supply. Increased total production is unlikely to come from improved or more timely tillage techniques unless due consideration is also given to harvesting.

From observations during the trials the Bush and Bog disc harrow appears to have the following advantages:

1) Much lower capital cost than the WLD (probably 30-50% of the cost of WLD, depending on the quality of construction).
2) Work rate approximately 20% higher than WLD, due to greater width and better performance over grass-covered areas.
3) Probability of lower spares and repair costs due to simplicity of design.
4) Better performance than WLD in wet conditions due to larger diameter disc and consequently less clogging.
5) More easily transported than WLD as it is fully mounted on the tractor three point linkage, whereas the WLD's are towed but require transportation by lorry to some villages.

The only disadvantage in the BB would appear to be the marginally higher energy requirement, and hence fuel consumption, resulting from the greater depth of work. In addition it would be necessary to consider an operator retraining programme, as they are unfamiliar with mounted implements and particularly because problems could arise through three point linkage bounce during transport. Although farmers prefer slightly deeper cultivation the evidence from the trials suggests this is unnecessary. However the energy requirement remains very low compared with deep cultivation techniques and the increased total specific fuel consumption compared with the WLD is unlikely to be significant. Measurement of the performance of the Bush and Bog harrow over a greater area and period of time, particularly in relation to fallowed areas could well yield a lower total energy requirement and it is therefore in the interests of NMAPC to carry on using them over a longer trial period. The trials show that in a low weed infestation if you plant on the right day and it rains you can get a good yield with shallow tillage. The form of tillage being not important for yield, but some systems require less energy.

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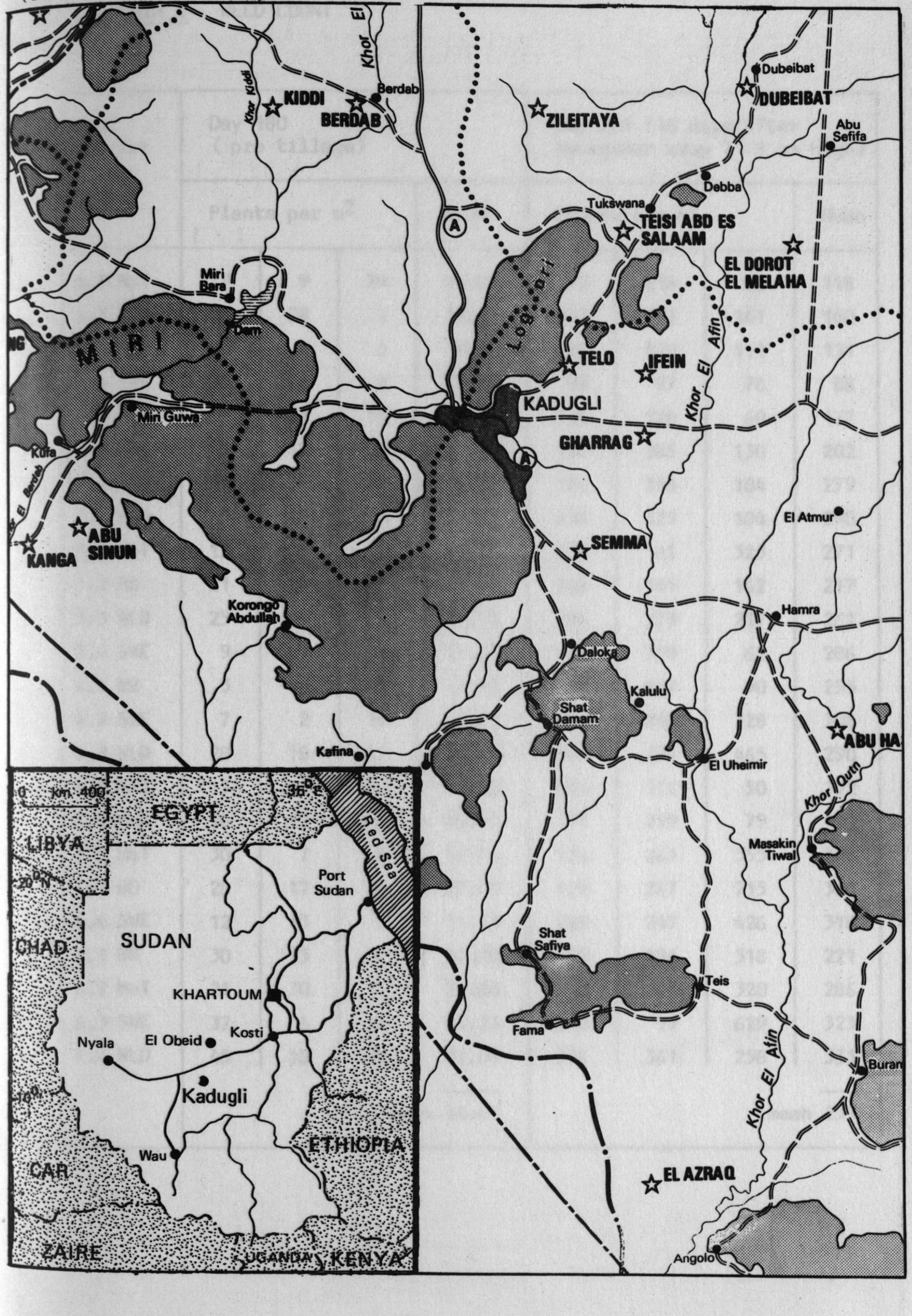
Appendix 1 MAP OF KADUGLI

(Source: Huntings Technical Services)



Appendix 2 WEED COUNT

Plot No./Trt	Day 180 (pre tillage)				Day 201 (10 days after emergence crop 7 - 8 cm high)			
	Plants per m^2			Mean	Plants per m^2			Mean
1.1 NoT	9	9	24	14.00	52	218	85	118
1.2 WLD	9	28	7	14.67	117	163	141	140
1.3 BB	15	4	5	8.00	92	189	111	131
1.4 SWE	31	4	4	13.00	90	97	78	88
2.1 BB	3	7	15	8.33	344	128	60	177
2.2 SWE	4	19	9	10.67	192	285	130	202
2.3 NoT	4	15	0	6.33	396	338	104	279
2.4 WLD	5	16	0	7.00	436	329	104	290
3.1 NoT	12	6	16	11.33	410	81	323	271
3.2 BB	21	9	26	18.67	348	141	162	217
3.3 WLD	25	19	2	15.33	294	273	217	261
3.4 SWE	9	17	9	11.67	479	318	62	286
4.1 BB	3	8	3	4.67	371	197	90	253
4.2 SWE	7	2	16	8.33	377	212	328	306
4.3 WLD	28	18	17	21.00	165	239	465	290
4.4 NoT	7	16	31	18.00	215	312	50	192
5.1 WLD	26	13	22	20.33	111	219	79	136
5.2 NoT	30	7	8	15.00	126	263	355	248
5.3 BB	28	17	24	23.00	122	267	715	368
5.4 SWE	12	13	9	11.33	280	247	426	318
6.1 BB	30	13	8	17.00	160	184	318	221
6.2 NoT	21	30	12	21.00	256	283	320	286
6.3 SWE	37	6	21	21.33	240	99	629	323
6.4 WLD	45	10	38	31.00	374	361	258	331
			mean	14.63			mean	239

Appendix 3 HARVEST YIELD AND PLANT STAND

Cultivation Plot No.	Treatment Code		Harvest Plot No.	Gross wt kg	Tare wt kg	Net wt kg		Plant Stand
1.1	NoT	0	1.1.1	9.24	1.21	8.03		465
1.1	"	"	1.1.2	9.30	1.16	8.14		481
1.2	WLD	1	1.2.1	6.93	1.6	5.77		423
1.2	"	"	1.2.2	8.42	1.42	7.00		374
1.3	B&B	2	1.3.1	7.56	1.20	6.36		452
1.3	"	"	1.3.2	7.98	1.20	6.78		487
1.4	SWE	3	1.4.1	8.60	1.30	7.30		472
1.4	"	"	1.4.2	7.65	1.29	6.36		523
2.1		2	2.1.1	7.23	1.20	6.03		410
2.1		"	2.1.2	6.42	1.20	5.22		460
2.2		3	2.2.1	7.52	1.30	6.22		468
2.2		"	2.2.2	6.40	1.27	5.13		378
2.3		0	2.3.1	6.07	1.18	4.89		437
2.3		"	2.3.2	5.96	1.28	4.68		492
2.4		1	2.41	7.07	1.42	5.65		453
2.4		"	2.4.2	6.82	1.26	5.56		382
3.1		0	3.1.1	7.64	1.25	6.39		511
3.1		"	3.1.2	6.10	1.44	4.66		438
3.2		2	3.2.1	8.25	1.24	7.01		421
3.2		"	3.2.2	6.19	1.15	5.04		472
3.3		1	3.3.1	7.43	1.48	5.95		444
3.3		"	3.3.2	6.66	1.40	5.26		521
3.4		3	3.4.1	7.62	1.32	6.30		474
3.4		"	3.4.2	6.77	1.32	5.45		463
4.1		2	4.1.1	9.70	1.40	8.30		459
4.1		"	4.1.2	8.64	1.34	7.30		399
4.2		3	4.2.1	7.00	1.32	5.68		429
4.2		"	4.2.3	5.56	1.14	4.42		432
4.3		1	4.3.1	7.12	1.14	5.98		517
4.3		"	4.3.2	6.08	1.08	5.00		433
4.4		0	4.4.1	5.94	1.12	4.82		478
4.4		"	4.4.2	5.96	1.24	4.72		397
5.1		1	5.1.1	5.99	1.10	4.89		457
5.1		"	5.1.2	5.84	1.15	4.69		441

Appendix 3 Cont.

Cultivation Plot No.	Treatment Code	Harvest Plot No.	Gross wt kg	Tare wt kg	Net wt kg	Plant Stand
5.2	0	5.2.1	7.04	1.23	5.81	473
5.2	"	5.2.2	5.76	1.08	4.68	482
5.3	2	5.3.1	7.46	1.24	6.22	502
5.3	"	5.3.2	6.30	1.20	5.10	448
5.4	3	5.4.1	6.88	1.24	5.64	427
5.4	"	5.4.2	5.94	1.24	4.70	479
6.1	2	6.1.1	7.20	1.21	5.99	468
6.1	"	6.1.2	5.84	1.27	4.57	437
6.2	0	6.2.1	8.12	1.46	6.66	388
6.2	"	6.2.2	6.98	1.20	5.78	474
6.3	3	6.3.1	6.72	1.14	5.58	462
6.3	"	6.3.2	6.24	1.31	4.93	446
6.4	1	6.4.1	7.08	1.46	5.62	511
6.4	"	6.4.2	7.02	1.21	5.81	459

Appendix 4 PRE AND POST TILLAGE SOIL MOISTURE CONTENT (% gdb) AT TWO DEPTHS

Trt.	Plot No/Depth		Day No			Means of differences		
			180	182	Diff.	0 - 5 mm	5 - 10 mm	0 - 10 mm
NoT	1.1	0-5	7.17	31.02	23.85			
		5-10	12.19	14.61	2.42			
NoT	2.3	0-5	7.69	30.97	23.28			
		5-10	11.01	16.23	5.22			
NoT	3.1	"	7.03	28.45	21.42			
			9.37	13.58	4.21	22.25	3.56	12.91
NoT	4.4		8.46	30.75	22.29			
			10.21	13.45	3.24			
NoT	5.2		7.53	26.39	18.84			
			10.00	13.63	3.63			
NoT	6.2		8.26	32.10	23.84			
			12.47	15.15	2.66			
WLD	1.2		6.44	32.14	25.70			
			8.52	22.36	13.84			
WLD	2.4		8.12	32.72	24.60			
			10.75	26.42	15.67			
WLD	3.3		7.91	32.07	24.16			
			9.28	20.76	11.48	24.11	12.51	18.31
WLD	4.3		8.37	31.60	23.24			
			10.49	19.73	9.25			
WLD	5.1		8.06	31.40	23.34			
			10.32	19.68	9.36			
WLD	6.4		10.27	33.89	23.63			
			10.79	26.26	15.46			
SWE	1.4		5.15	34.47	29.32			
			9.48	28.66	19.18			
SWE	2.2		7.56	33.22	25.69			
			10.49	23.63	13.14			
SWE	3.4		7.12	37.87	20.75			
			9.77	13.49	3.72	25.52	11.78	18.65
SWE	4.2		7.25	31.61	24.36			
			10.97	18.88	7.91			

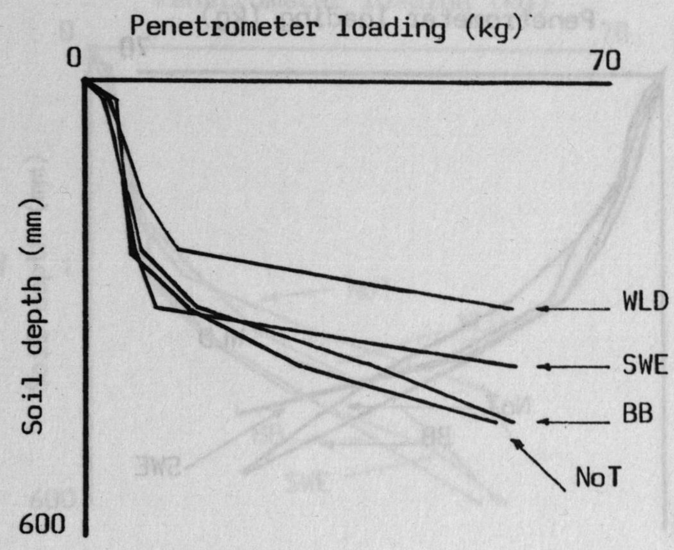
Appendix 4 Cont.

Trt.	Plot No/Depth	Day No 180	182	Diff.	Means of differences 0 - 5 mm	5 - 10 mm	0 - 10 mm
SWE	5.4	6.94	34.52	27.57			
		10.00	17.24	7.24			
SWE	6.3	8.62	34.03	25.41			
		10.51	30.02	19.51			
B&B	1.3	7.23	32.42	25.19			
		9.60	34.09	24.49			
B&B	2.1	9.02	34.12	25.10			
		10.93	21.85	10.92			
B&B	3.2	7.84	32.41	24.57			
		9.46	22.31	12.85	25.10	15.43	20.26
B&B	4.1	9.59	32.96	23.38			
		11.03	26.43	15.40			
B&B	5.3	7.92	35.02	27.10			
		9.75	22.92	13.17			
B&B	6.1	8.83	34.06	25.23			
		11.28	27.01	15.73			

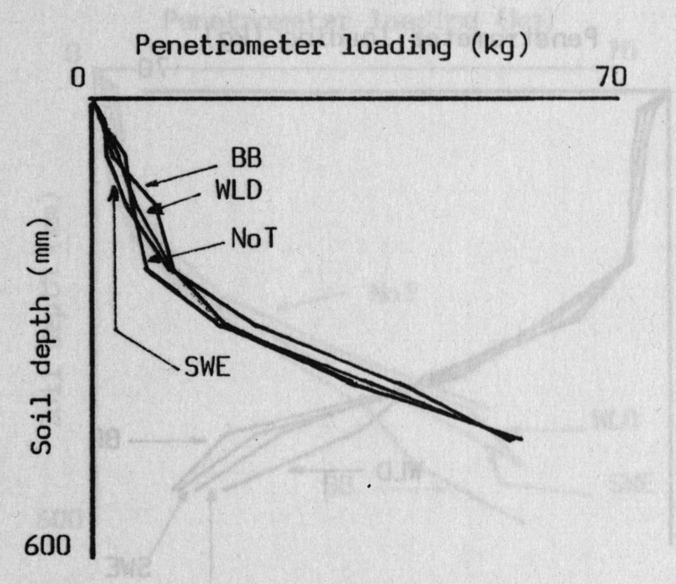
Appendix 5 RAINFALL TELO REGION 1981 (mm)

	May	June	July	August	September	October	November
1	0.2		30.0				
2			2.0		13.0		
3	0.1		5.0	0.3		4.2	
4		11.0			15.0		
5					20.0		
6		26.0	1.5				
7							
8			63.0		2.0		
9							
10						6.0	
11		15.5	25.0	0.5			
12			5.3	30.0	8.0		
13							
14				13.5		0.5	
15			8.5		54.5		
16	0.3	3.3					
17			12.5				
18			30.0	13.5		1.0	
19							
20		16.5					
21		5.8	12.0	73.0			
22		6.5			21.0		
23							
24			62.0				
25				2.5			
26							
27				8.5			
28			1.0		0.3		
29							
30		7.5					
31		-	2.5		-		-
TOTAL	0.6	92	260	142	134	12.0	

Appendix 6 PENETROMETER RESULTS

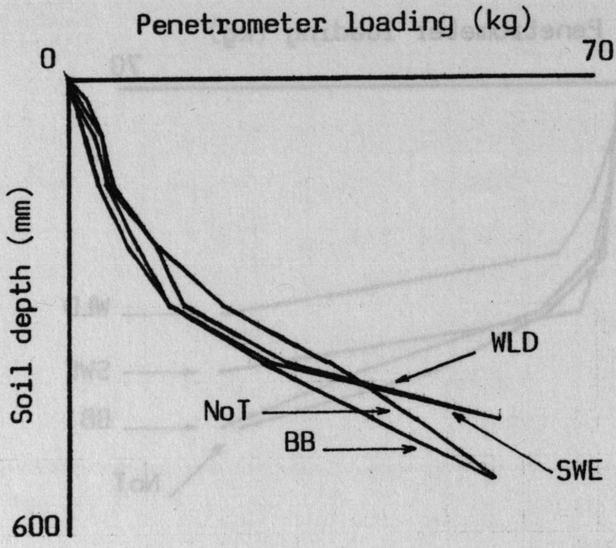


Day 204



Day 207

Appendix 6   Cont.



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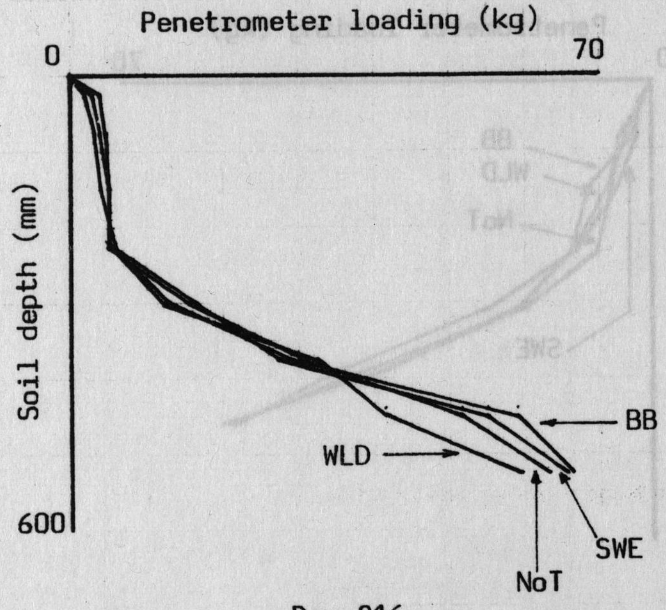

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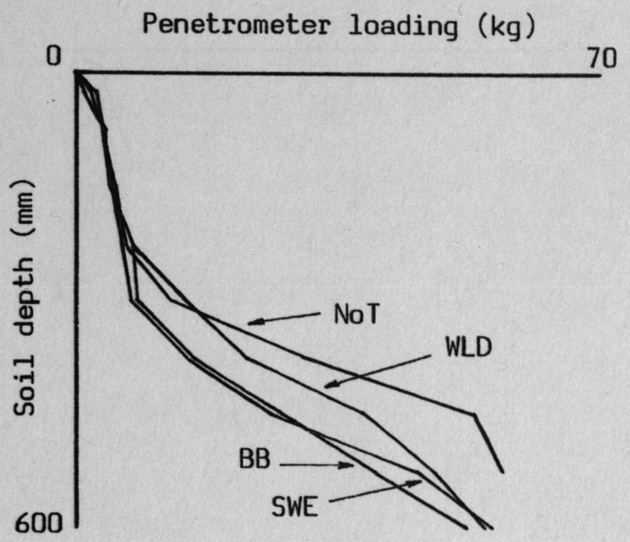

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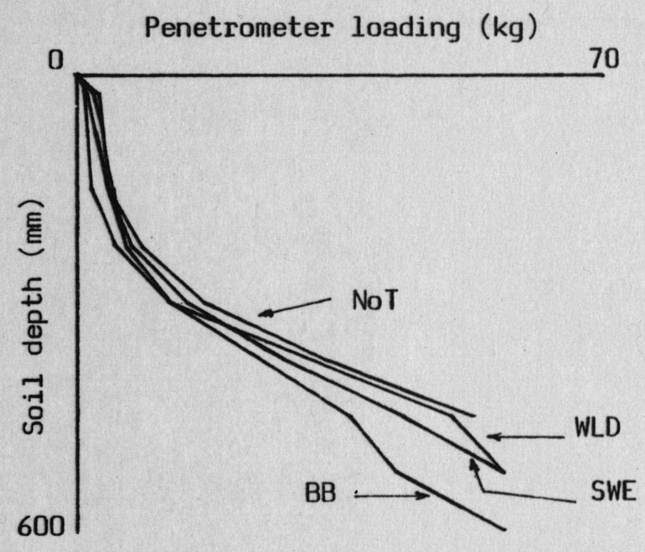

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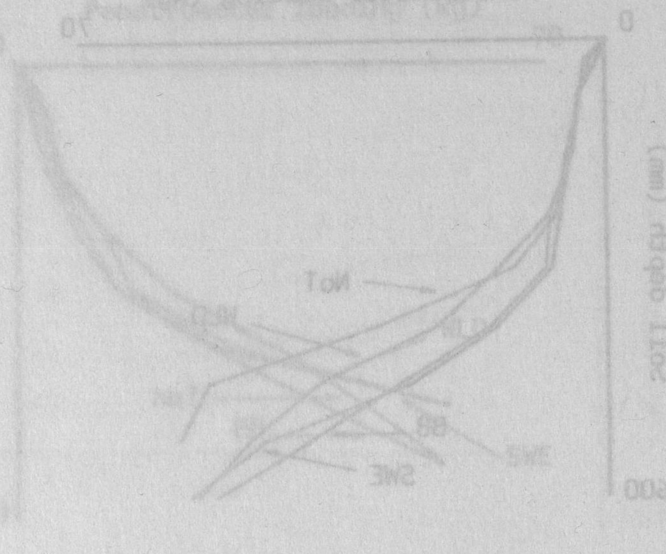

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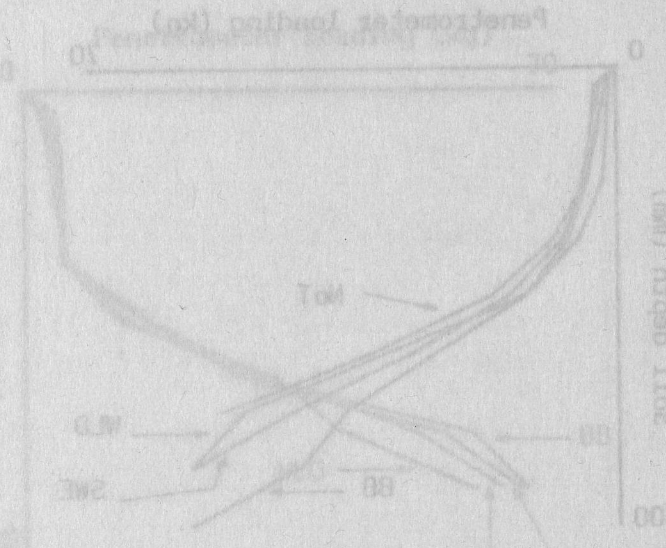

Day 232