Soil Moisture Conservation in Dryland Viticulture as affected by Conventional and Minimum Tillage Practices*

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The effect of conventional clean cultivation, a straw mulch, chemical weed control and a grass sward on the soil moisture regime in a dryland vineyard was investigated. The results demonstrate that both a straw mulch and chemical weed control were very effective in conserving winter-stored soil moisture until mid- or even late summer to support the vines during the almost rainless growing season. Further, it appeared that a mere loosening of the soil surface periodically by way of clean cultivation cannot conserve soil moisture effectively; it may, on the contrary, promote evaporation in the top-soil layers, especially when done after rain. On the other hand, an undisturbed soil surface, as in the case of chemical weed control, acts as a mulch in itself after the surface layer has dried out, thus reducing evaporation. Even under conditions of frequent rainfall, as during the first part of 1976/77 season, the straw mulch cover treatment was still superior to all other treatments in conserving soil moisture.

In many cases tillage operations are performed mainly out of mere tradition (Greenland, 1978). Unfortunately, it is not generally known that frequent tillage may cause damage to the soil rather than improving it as a medium for root growth (Barnes, Taylor, Throckmorton, Van den Bergh & Carleton, 1971; Greenland, 1977). Even if done infrequently with the sole intention of keeping the soil surface free from moisture consuming weeds, a slow but incessant breakdown of soil structure may result. These practices may, in the long run, lead to the formation of a subsoil tillage pan and the accompanying pulverization of the surface layer (Van Huyssteen & Weber, 1980a) with an undesirable effect on water storage in the subsoil layers.

Many researchers concluded that clean cultivation cannot conserve soil moisture (Möhr, 1970; Baeumer & Bakermans, 1973; Unger & Phillips, 1973; Greenland, 1977). On the contrary, plant residues left as a mulch cover on the untilled soil surface, will conserve soil moisture much more effectively. For the Great Plains of the USA, Greb, Smika & Black (1970) reported that precipitation storage in the soil increased from 16%, without any mulch, to 37% with 6,72 ton/ha harvest residues left as a mulch. At Bushland, Texas, USA, precipitation storage during eleven months of fallow after irrigated wheat, was 52% with chemical fallow treatment, and 26% with a mechanical (disc tillage) treatment (Unger & Phillips, 1973). In another experiment under irrigation conditions, precipitation storage during fallow was 39% with a herbicide treatment, as compared to an average of 20% for three tillage treatments, viz. tandem disc, tandem disc plus sweep, and sweep (Unger, Allen & Wiese, 1971). According to McCalla & Army (1961), harvest residues left on the soil surface lowered soil temperatures because of their insulating effect, increased reflection of radiant energy and, consequently, reduced surface evaporation.

The rainfall distribution pattern in the wine growing areas of the Western Cape is unfavourable for summer crops, and summer droughts often occur. This region has a long-term mean annual rainfall of about 600 mm, ranging from 465 mm/a in the drier areas to 693 mm/a in the wetter areas.* Only 30% of the mean rainfall occurs during the growing season, viz. September to March inclusive. Compared to conditions in wine producing regions in the Northern Hemisphere, e.g. France (growth season March to September), the Western Cape area thus receive at most 180 mm as against the 375 mm of Montpellier and 439 mm of Bordeaux (Saayman & Van Zyl, 1976).

By using long term statistics* a mean seasonal crop factor of 0,25 for vines was determined (Van Zyl, 1975), so that the mean seasonal (September to March) Class-A-pan evaporation (Eo) of 1 552 mm represents a consumptive water use (Et) of 388 mm. This implies a theoretical soil moisture deficit of 208 mm in the vineyards of this area during this period. Moreover, light summer showers of less than 20 mm, contribute very little towards replenishing the soil moisture store because of the prevailing high temperatures, continuous south-easterly winds and high atmospheric water vapour saturation deficits (Van Eeden, 1970). A considerable amount of the 180 mm seasonal rainfall usually consists of such light showers.

Under dryland conditions, all available winter rainfall should be stored in the soil for as long as possible to bridge the dry seasons. This task is a major concern of soil management in vineyards. Tillage practices should be applied which would minimize unproductive evaporation directly from the soil surface, and increase productive transpiration through the plant.

Seen against the background of dwindling water and land resources in the arid and semi-arid regions of the world, much more skill than was necessary previously would be needed in future to integrate soil, climatic and other factors into a management system which would prove to be practical for a given situation (Hanks, 1978). However, this author pointed out that measures which effectively decrease soil evaporation have unfortunately proved to be uneconomical. Further research is needed to find management methods, such as "minimum tillage" or even "no-tillage" practices, that would modify the soil climate in the way desired (Allmaras, Hallauer, Nelson & Evans, 1977).

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The effect of several tillage practices on the physical properties and on the water conservation capabilities of a vineyard soil under dryland conditions was, therefore, studied. Van Huyssteen & Weber (1980a) have already reported on the changes in the physical conditions of the soil brought about by such tillage practices, and this paper reports the effect on soil moisture.

MATERIALS AND METHODS

The characteristics of the experimental site, soil and design, as well as particulars of the treatments applied have been described by Van Huyssteen and Weber (1980a). Infiltration rate measurements were carried out using a Double Ring Infiltrometer.

The following meteorological data were registered since the commencement of this study.

(i) Air temperature and relative humidity by means of a thermohygrograph in a Stevenson screen.
(ii) Evaporation from an American Weather Bureau Standard Class-A-pan.
(iii) Rainfall.

Moisture retention curves were constructed from moisture content/tension data as obtained on undisturbed soil samples. These were taken at different depths of the profile using a soil core sampler which holds two brass cylinders of 66,6 cm^3 internal volume each. A filter paper disc to keep the soil core in place was glued to the bottom of each cylinder. After initial water saturation of these cores, stepwise air pressures starting at 2,5 kPa and ending with 1 500 kPa (which was regarded as permanent wilting point) were applied by means of pressure plate and pressure membrane extractors. After attaining equilibrium at each pressure stage the mass of each soil core with its enclosing cylinder was determined. Finally, the soil cores were oven-dried, and the water contents at each pressure interval calculated as mass and volume percentages.

In winter field water capacities were determined repeatedly on the different plots. A rectangular earth basin having a surface area of 3 m × 3 m was constructed, kept filled with sufficient water in order to wet the profile down to 900 mm, and subsequently covered with layers of straw and plastic sheets to prevent evaporation. A set of five mercury tensiometers of different lengths was inserted in the middle of each basin. Gravimetric soil moisture determinations on soil samples taken in triplicate from the top layer were carried out at six-hourly intervals until a constant water content was reached. In the case of the deeper strata, soil samples were taken daily around the tensiometers down to 900 mm depth, using a Veihmeyer tube, until a constant water content at the depth of the respective tensiometer cup was reached. Tensiometer readings were taken simultaneously.

Soil moisture depletion curves against time were constructed by measuring the moisture content gravimetrically every three weeks on all replications of each treatment during the 1974/75 season, covering the depth zones 0–300, 300–600 and 600–900 mm. The same procedure was followed during the 1975/76 season at fortnightly intervals and for the depth zones 0–100, 100–300, 300–500 and 500–700 mm. The 700–900 mm depth zone was not considered because profile studies revealed only a few roots deeper than 700 mm. During the 1976/77 season Bourdon-gauge tensiometers were employed with their 50 mm-long cups placed at depths of 100–150, 250–300, 550–600 and 750–800 mm. The tensiometers were placed at or near a point on each treatment plot where all the important soil properties have been determined previously (Van Huyssteen & Weber, 1980a).

RESULTS AND DISCUSSION

Meteorological observations: The data for four growing seasons are summarized in Table 1. Generally, about two-thirds of the rainfall of the growing seasons occurred during the months September to November, the balance being spread unevenly over the remaining months. The highest monthly rainfall of 106,1 mm was recorded in November 1976, compared to a range of 22,2 to 36,9 mm during other years. In accordance with the high rainfall in 1976/77, the average quarterly maximum air temperatures for November, December and January 1976/77 were considerably lower (ca. 3 °C) than those of the other seasons.

The mean monthly maximum relative humidity was always high during the nights, resulting in mean seasonal maximum relative humidities of higher than 90% in all four seasons. The mean seasonal minimum relative humidities varied between 40,7 and 49,4% for the four growing seasons.

In accordance with the high relative humidities, the seasonal Class-A-pan evaporation was rather low, varying between 1385 and 1670 mm.

Converting these Class-A-pan evaporation figures to theoretical soil moisture deficits by using a mean seasonal crop factor for vines of 0,25 (Van Zyl, 1975), and assuming that 100% of the seasonal rainfall infiltrates into the soil, the following values were obtained.

Growing season	*Soil moisture deficit (mm)*
1973/74	246,9
1974/75	149,5
1975/76	231,8
1976/77	4,8

In reality the soil moisture deficits were higher, since light showers of summer rain definitely do not reach the soil surface but are intercepted by the vegetation (Van Eeden, 1970). It is evident that 1976/77 was a favourable season as far as soil moisture storage from precipitation is concerned.

Water Infiltration: The infiltration rate may be considered to be a parameter integrating various soil physical properties of the same solum, provided that (i) it is determined during the growing season, (ii) sufficient water and time are allowed to wet the soil uniformly and completely down to required depths, and (iii) a large surface area is used in order to minimize border effects. Since this experiment was designed to be a dryland field trial, these conditions could not be met because of the risk of water supply to the adjacent vines. The determinations had, therefore, to be carried out in early spring, with small volumes of water, using a double ring infiltrometer and for no longer than 30 minutes. This could, of course, only wet a very limited surface area and a limited depth but had the advantage that the measurements could be replicated several times per treatment.

Fig. 1 demonstrates that the infiltration rate was rapid on all treatment plots but that there were marked differences between treatments. Infiltration rate was the slowest on the herbicide (B4) plots on account of the crusts on the soil

TABLE 1
Climatic data of four vineyard growing seasons—Nietvoorbij, Stellenbosch

Season	Month	Total Rainfall (mm)	Mean airtemp.		Mean Rel. Hum.		A-pan evaporation	
			Max. (°C)	Min. (°C)	Max. (%)	Min. (%)	mm/month	mm/day
1973/74	Sept.	62,0	18,2	7,7	95	54	123,0	4,1
	Oct.	26,1	23,8	11,6	91	50	192,2	6,2
	Nov.	22,2	26,0	13,8	89	48	294,0	9,8
	Dec.	33,6	26,7	14,5	90	48	257,3	8,3
	Jan.	5,3	27,6	15,4	95	52	310,0	3,1
	Feb.	10,9	30,3	15,9	95	46	257,6	9,2
	March	10,4	27,9	13,7	93	45	235,6	7,6
Total/Mean	Sept.-March	170,5	25,8	13,2	92,6	49,0	1 669,7	7,9
1974/75	Sept.	78,5	17,9	7,4	93	42	111,0	3,7
	Oct.	66,8	20,1	9,5	94	58	145,7	4,7
	Nov.	36,9	24,5	12,7	95	61	234,0	7,8
	Dec.	14,5	26,7	14,2	92	63	260,4	8,4
	Jan.	24,3	27,0	15,0	90	43	272,8	8,8
	Feb.	7,5	30,0	16,3	91	40	277,2	9,9
	March	10,8	27,7	14,5	87	39	254,2	8,2
Total/Mean	Sept.-March	239,3	24,8	12,8	91,7	49,4	1 555,3	7,4
1975/76	Sept.	21,0	21,2	9,8	89	42	159,0	5,3
	Oct.	62,2	20,3	10,0	94	42	164,3	5,3
	Nov.	33,3	23,4	12,4	94	43	216,0	7,2
	Dec.	5,8	26,7	14,4	89	39	322,4	10,4
	Jan.	0,0	30,3	16,1	87	36	347,2	11,2
	Feb.	8,2	27,8	14,8	90	40	243,6	8,4
	March	50,4	24,9	14,1	90	43	198,4	6,4
Total/Mean	Sept.-March	180,9	24,9	13,1	90,4	40,7	1 650,9	7,7
1976/77	Sept.	85,4	18,6	9,5	95	54	90	3,0
	Oct.	20,3	21,9	11,4	92	43	189,1	6,1
	Nov.	106,1	20,0	11,2	92	41	174,0	5,8
	Dec.	71,4	24,9	13,8	93	45	241,8	7,8
	Jan.	10,4	26,2	14,2	95	48	254,2	8,2
	Feb.	30,5	28,2	16,5	95	48	218,4	7,8
	March	17,2	26,8	14,3	92	45	217,0	7,0
Total/Mean	Sept.-March	341,3	23,8	13,0	93,4	46,3	1 384,5	6,5

surface but was still adequate to prevent run-off of rain water under the prevailing precipitation rates, in spite of the 12% slope. This indicates that the dry and dense soil crusts can easily be soaked and penetrated by rain falling 30 minutes or longer. The fastest infiltration rate was measured on the permanent sward (B6) plots. This may be ascribed to the occurrence of vertical channels left by decaying roots of weeds, and the well-structured top soil layer consisting of water stable aggregates which formed a large and mechanically highly resistant macropore volume (Van Huyssteen & Weber, 1980a).

The infiltration rate on the clean cultivation (B5) plots was similar to that on the sward plots. Because of the highly compacted and nearly impermeable tillage pan at 200–300 mm depth in the B5 plots (Van Huyssteen & Weber, 1980a), this high infiltration rate would not apply for deeper layers.

Field water capacity and soil moisture tension: The field water capacities (FWC) and the respective soil moisture tension (SMT) values of the top 0–100 and 100–200 mm layers, as well as their means over the entire depth of all profiles, are presented in Table 2. It appears from these results that differences in FWC between treatments were only small, viz. 3,4% between the highest and the lowest value in the first layer and 2,2% in the second. Although these differences are small, the FWC values show a clear trend in the 0–100 mm layers, in that the higher values were obtained on the minimum tillage plots and lowest value on the conventionally tilled plot. This finding may be ascribed to the presence of water stable and mechanically resistant aggregates under minimum tillage, compared to the virtually total absence thereof under clean cultivation. Therefore, the pore size distribution is stable in the former but appeared to be utterly unstable in the latter.

TABLE 2
Field water capacities (FWC) and their soil moisture tensions (SMT) in the top soil layers of differently cultivated field plots, as determined *in situ*

Treatment	Depth (mm)	Water contents at FWC		SMT (kPa)
		Mass %	Volume %	
Straw mulch (B3)	0–100	16,2	25,4	4,0
	100–200	14,9	25,1	7,5
	Mean: Entire profile		24,6	
Herbicide (B4)	0–100	16,2	24,8	4,3
	100–200	14,9	22,9	4,0
	Mean: Entire profile		23,5	
Clean cultivation (B5)	0–100	17,1	22,7	5,7
	100–200	14,5	23,9	9,0
	Mean: Entire profile		23,6	
Sward (B6)	0–100	17,1	26,1	4,0
	100–200	14,5	24,1	5,5
	Mean: Entire profile		23,4	

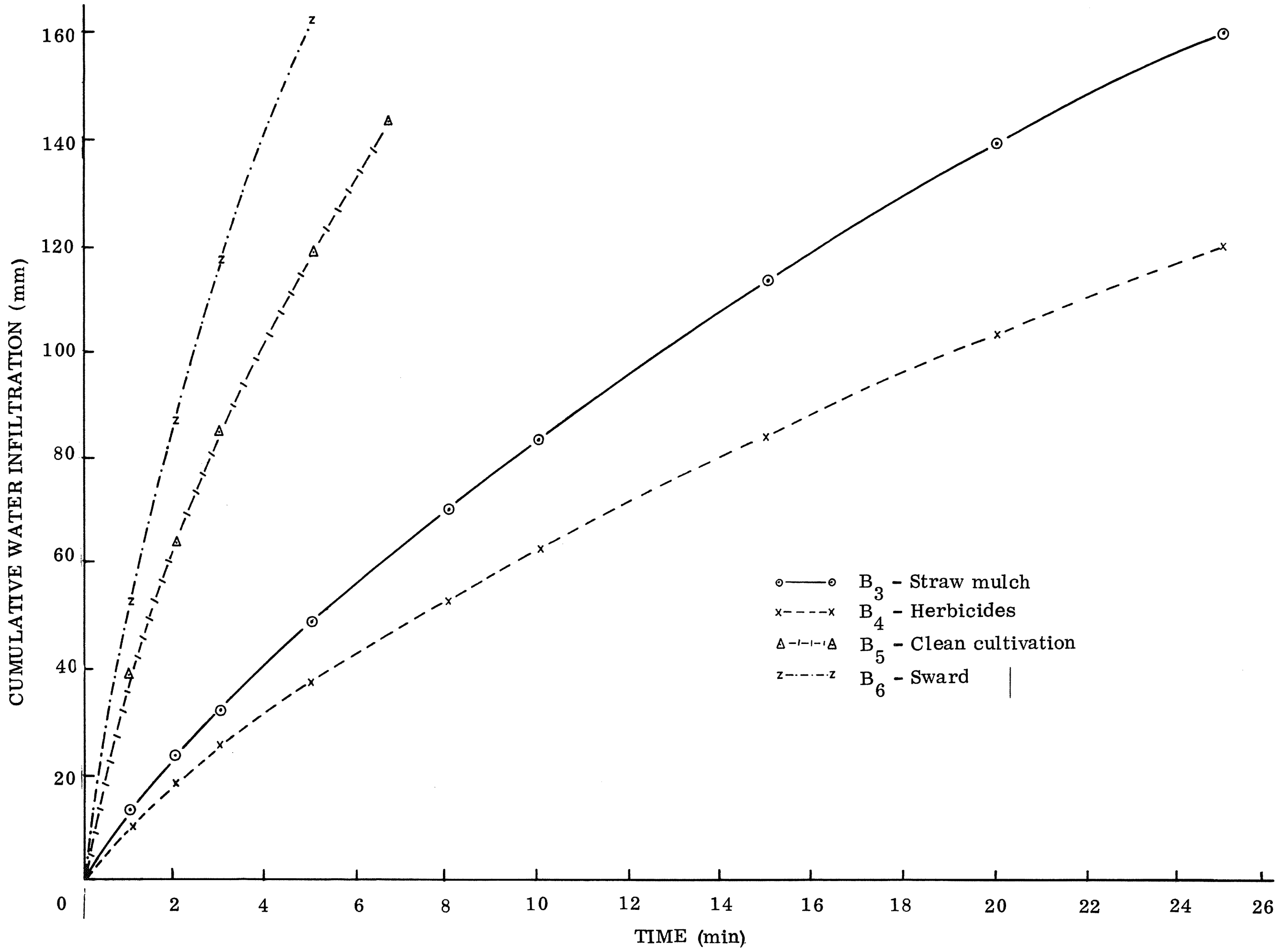

FIG. 1
Cumulative water infiltration with time on differently cultivated plots.

Furthermore, the soil moisture tension at FWC in both layers of the clean cultivated plots was unproportionally higher than that in the same layers, also at FWC, of the three minimum treated plots. This observation is in accordance with the findings of Ehlers (1973) that, at the same moisture content, the soil moisture tension of a non-cultivated top soil layer is generally lower than that of a cultivated one. Therefore, the vines in the straw mulch, herbicide and sward plots not only found more water absolutely but could also absorb the same amount of water with less energy spent than those in the clean cultivated plots.

Soil moisture fluctuation and depletion observations:
During a wet season; Representative graphs of soil moisture depletion and corresponding tension fluctuations with time in different soil layers of the four treatments during the wet 1976/77 season (341,3 mm rainfall) are presented in Fig. 2 and Fig. 3, which are complementary. Fig. 2a and Fig. 2b show the gravimetrically determined soil moisture depletion during this season for the 250–300 and 550–600 mm soil layers, respectively, whereas Fig. 3b and Fig. 3c show the soil moisture tension fluctuations for the same layers. Additionally, Fig. 3a and Fig. 3d show the tensiometrical values for the 100–150 mm and 750–800 mm soil layers, respectively. Average values for FWC and PWP are represented by the horizontal lines in Fig. 2, while values of both soil moisture "constants" are indicated by means of arrows on the right hand side of the figure.

Apart from the soil moisture contents higher than FWC at the onset of the observation period the curves for the 550–600 mm layer (Fig. 2b) show that the herbicide (B4) and straw mulch (B3) treatments had the highest soil moisture content throughout the season. Perhaps on account of the exceedingly high transpiration coefficients of the weeds (Van Huyssteen, 1977), the sward (B6) treatment had the lowest soil moisture content. Although not so clear as at 550–600 mm depth, the same pattern seems to exist in the 250–300 mm soil layer (Fig. 2a).

It can, therefore, be inferred that the minimum tillage treatments B3 (straw mulch) and B4 (herbicide) conserved water from winter and summer rains much longer than the B5 (clean cultivation) and B6 (sward) treatments. This is affirmed by the corresponding soil moisture tension graphs (Fig. 3b & Fig. 3c) which show that the tensiometric curves of the straw mulch (B3) and herbicide (B4) treatments are at a considerably lower level than those of the clean cultivation (B5) and the sward (B6) treatments for the greater part of the season. This effect was especially distinct in the uppermost layer (100–150 mm), and was still markedly apparent even in the deepest layer (750–800 mm), as is shown in Fig. 3a and Fig. 3d, respectively. Moreover, the soil moisture content in the upper layers

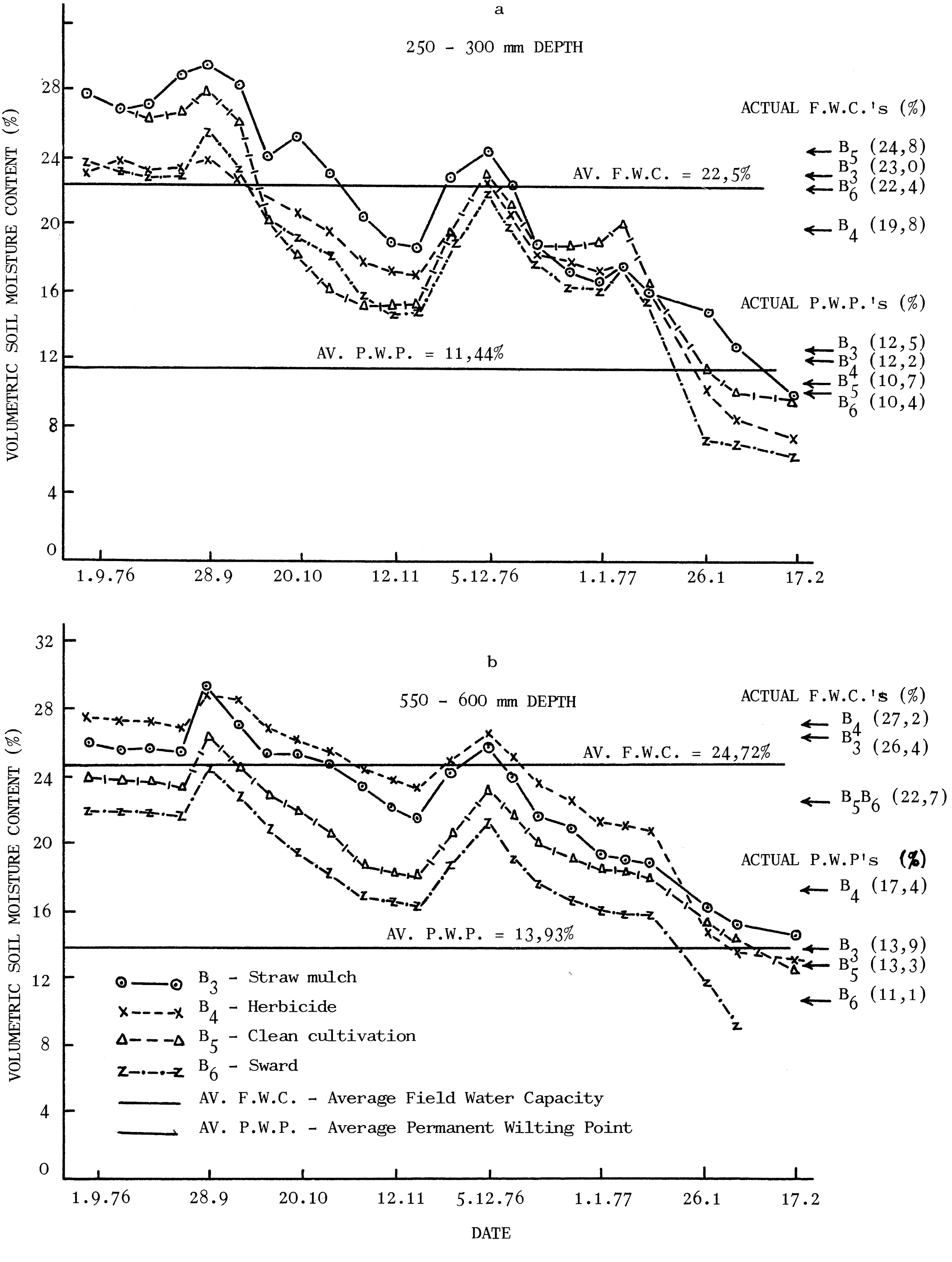

FIG. 2
Soil moisture fluctuations and depletion during the relatively "wet" 1976/77 growth season.

a

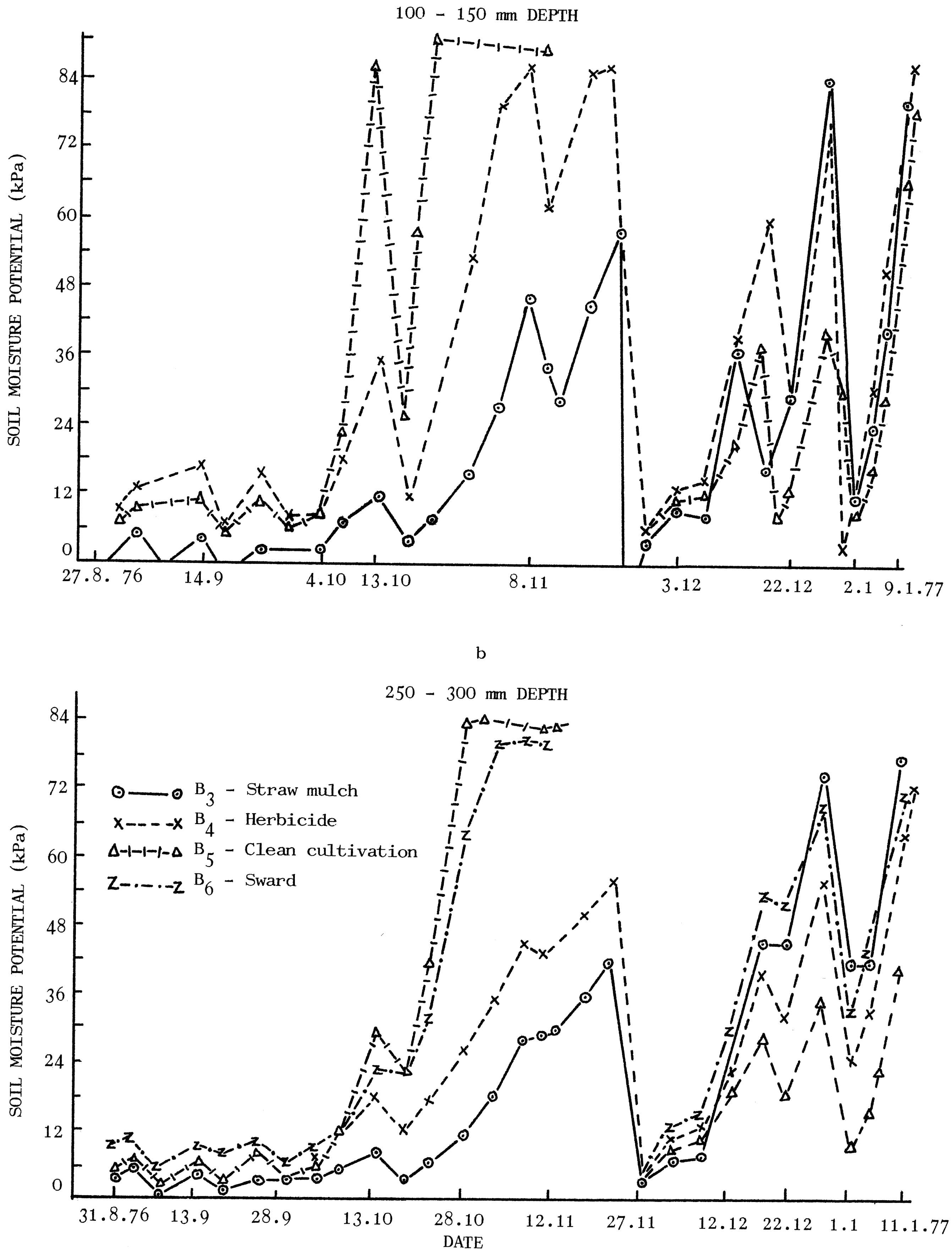

FIG. 3 (a-b)

Changes in soil moisture potential with time during the "wet" 1976/77 season.

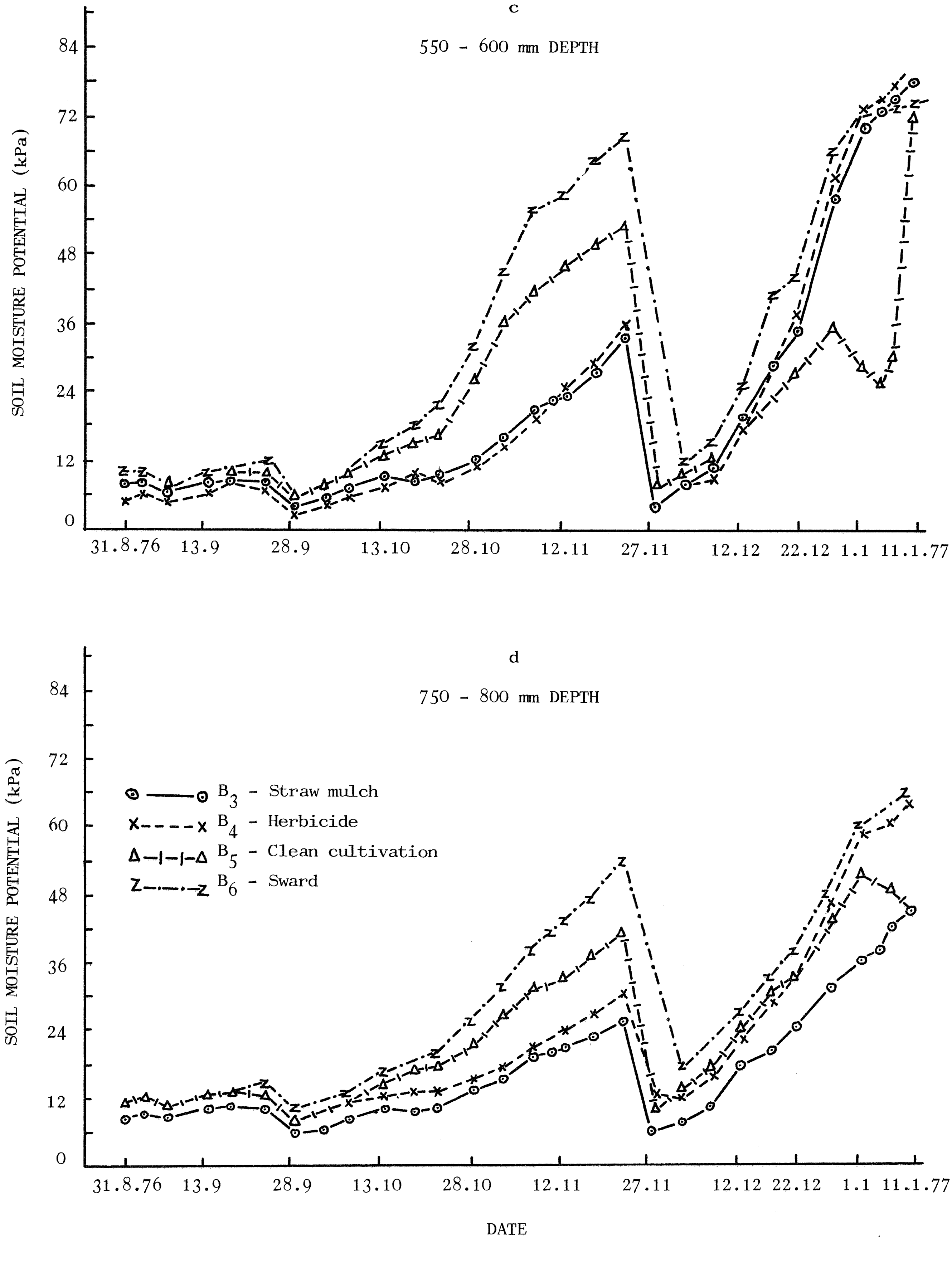

FIG. 3 (c-d)
Changes in soil moisture potential with time during the "wet" 1976/77 season.

(100–150 and 250–300 mm) remained high enough to prevent the tensiometers from reaching the critical 85 kPa limit, when they cease working, only under the B3 treatment, while these values were already reached in October in the B5 and B6 treatments.

Up to the end of November 1976 the soil moisture tension fluctuations of the straw mulch (B3) and herbicide (B4) plots followed the same trend in the lower two soil layers (750–800 and 550–600 mm), with the B3 curve a little lower than that of B4. This might have been due to the fact that the effective evaporating soil surface of the straw mulch (B3) plots was virtually nil, while the dense surface crust of the herbicide (B4) plots served as a barrier to water vapour transfer from the soil to the atmosphere. However, in the second and first soil layers (150–300 and 100–150 mm), increasingly larger differences between these two treatments were recorded (Fig. 3b & Fig. 3c), with the straw mulch (B3) curve running at a much lower level than the herbicide (B4) curve. The B3 treatment, therefore, appears to be more efficient than the B4 treatment. This may be ascribed to the additional effect of surface straw, because complete weed control was attained in both the B3 and B4 treatments. As a result of the better moisture regimes the vines in the straw mulch and herbicide treatments grew exceptionally well compared to those in the clean cultivation (B5) and sward (B6) treatments.

However, from December onwards, the trend in the soil moisture tension was reversed. Fig. 3a, 3b and 3c show, contrary to all expectations, that in the upper three layers (100–150, 250–300 and 550–600 mm) the tensiometer curves of the clean cultivation (B5) treatment were at the lowest level, thus indicating a higher water content than under the minimum treatments. This surprising phenomenon may be due to the moisture utilization at a much faster rate by the vines in the B3 (straw mulch) and B4 (herbicide) treatments in order to mature the much bigger crop that was eventually obtained from these plots (Van Huyssteen & Weber, 1980b). Since no roots extended below 700 mm depth in any treatment plot, soil moisture conditions remained unchanged at the 750–800 mm measurement level from December onwards (Fig. 3d).

During a dry season: The extent to which the "total actually available moisture" (TAAM) of the entire soil profile was depleted under the different treatments during the dry 1975/76 growth season (180,9 mm rainfall as against 341,3 mm during the wet 1976/77 season) is demonstrated in Fig. 4. The "actually available moisture" (AAM) of each layer down to 700 mm depth was calculated using the following equation:

(MC vol % − PWP vol %) × LT/100 = mm AAM

where, MC = moisture content actually determined,
PWP = permanent wilting point
LT = thickness of the individual soil layer in mm, and
AAM = actually available moisture in mm,

and added up to give the TAAM in the profile. In Fig. 4 this stage (PWP) is indicated by a horizontal line.

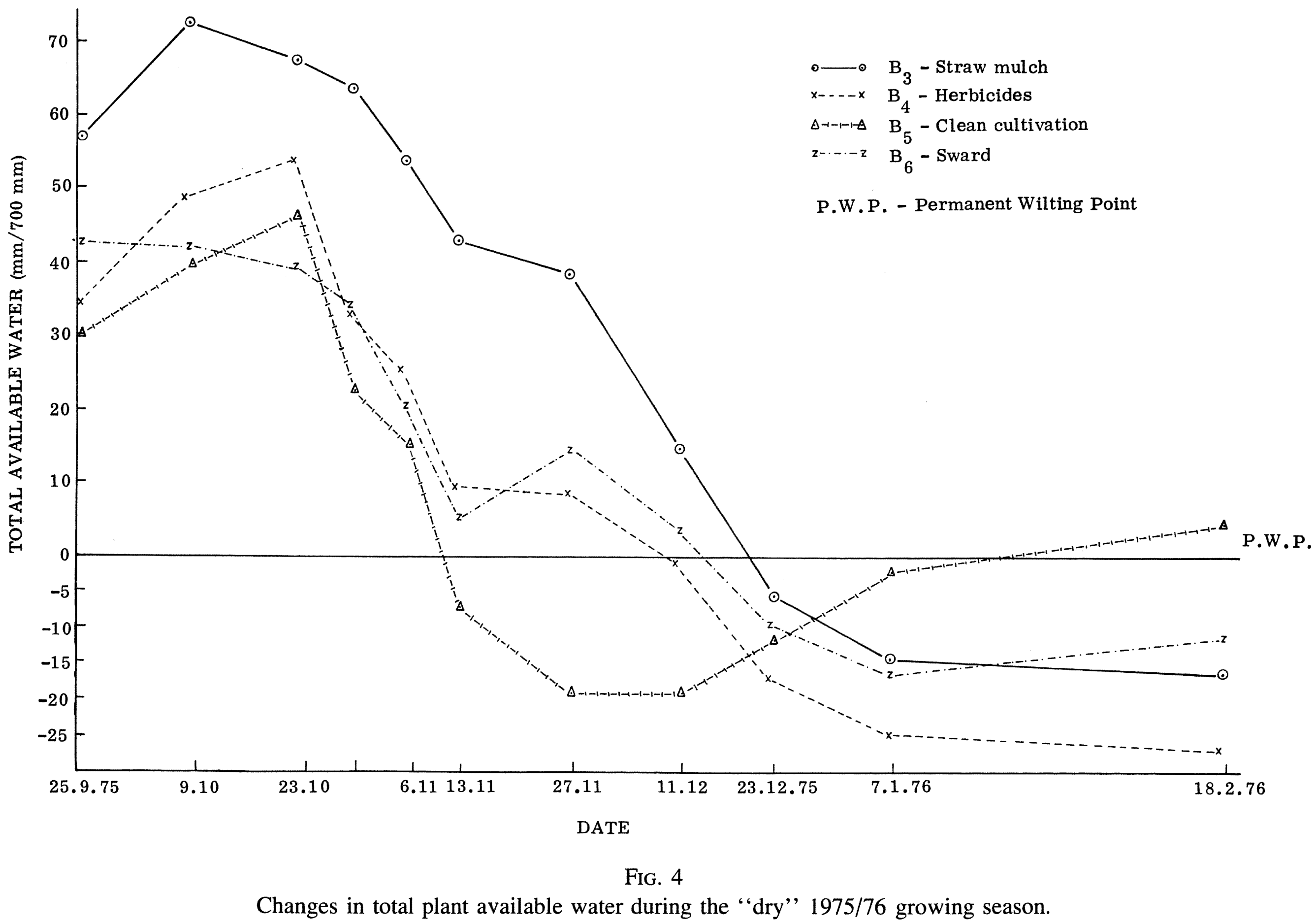

FIG. 4
Changes in total plant available water during the "dry" 1975/76 growing season.

It is interesting to note that at any time during the dry 1975/76 season, except the fortnight from 12 to 26 October, the TAAM content in each of the three minimum tillage profiles was higher, and in the case of B3 much higher, than in the clean cultivation (B5) profile, and that the TAAM in the former outlasted that of the latter with up to 42 days, as is indicated by the vertical dotted lines in Fig. 4. On the other hand, the TAAM depletion curve (Fig. 4) of the B5 treatment shows a remarkable restoration after the TAAM content fell far below PWP after 10 November, 1975. The same phenomenon was observed during the wet 1976/77 season, albeit over a much shorter period of time (Fig. 3a, 3b & 3c), and during the 1974/75 season (results not published). No explanation will be attempted in this paper.

The longer conservation of TAAM by the minimum treatments B4 (herbicide) and, particularly, B3 (straw mulch) was reflected in this dry season, too, by the healthier appearance and much stronger development of the above-ground parts, especially the much denser leaf canopy of the vines (Van Huyssteen & Weber, 1980b), than was observed on the B5 (clean cultivation) and B6 (sward) plots. The larger leaf canopy in the B3 and B4 treatments shadowed the soil surface optimally, and might have contributed to the soil moisture conserving effect by keeping the soil temperatures lower than in the B5 and B6 treatment plots.

SUMMARY AND CONCLUSION

The effects of three minimum tillage practices and one conventional cultivation method on soil moisture conservation in a dryland vineyard under the climatic conditions of the coastal regions of the Western Cape, were studied. The following results are noteworthy:

(i) The straw mulch treatment caused the soil moisture not only to outlast that of the other three treatments up to six weeks, but also provided a supply of easily available water of sufficient volume to produce healthier and stronger developed vines with much higher yields than were obtained from the herbicide, clean cultivated and sward plots.

(ii) Vines on the herbicide treated plots compared well with those of the straw mulch treated plots. Soil moisture depletion curves determined gravimetrically as well as tensiometrically yielded a similar pattern in both dry and wet seasons, and indicated that mechanical soil tillage with implements, has, at least as far as soil moisture conservation and weed control is concerned, no effect equal to the application of herbicide.

(iii) The clean cultivation treatment produced less favourable results. At a very early and plant-physiologically most important growth stage, soil moisture was substantially depleted, which resulted in weaker and less vigorous vines than on the two minimum treatment plots. The cultivation with implements succeeded in keeping the vineyard free of water competing weeds but failed in its commonly accepted main purpose, viz. to conserve soil moisture. This soil management method, therefore, appears to be redundant.

(iv) The benefits of permanent sward on soil physical conditions were shown by Van Huyssteen & Weber (1980a) to be the best, but the reverse was true as far as the effect of this treatment on soil moisture conservation is concerned. Heavy transpiration losses caused by the sward resulted in the soil moisture store to be exhausted to such an extent that there was virtually no available soil moisture left when the vines needed water most urgently, viz. during the swelling stage of the berries, about mid-November.

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