TILTH MELLOWING

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Summary

Effects of weathering action, mainly wetting and drying cycles, on the strength of the clods produced by tillage are studied. Experiments were carried out on sandy loam soils at two sites in South Australia, and on silt loam and clay soils at Wye College, England.

It is found that tillage increases the amplitude of soil water content fluctuations. These bigger soil water content fluctuations resulted in a decrease in the clod strength and this in turn modified the size distribution of the clods produced by tillage in the South Australian soils. The decrease in clod strength, as measured by the drop shatter test, was followed by an increase in the proportion of the smaller aggregate size fraction produced by a second implement pass.

It is suggested that, for soils in which the increase in the soil water content fluctuations after the first tillage implement pass decreases clod strength, a further implement pass should be delayed for several days. By doing this, the soil can be tilled with minimum energy and cost to produce a good seed bed.

Introduction

THE term tilth mellowing is used here to describe the reduction in clod or aggregate strength, which often occurs as a result of the weather, after a soil has been tilled. Although there is little specific information on this phenomenon, there have been a number of observations of it. For example, Russell (1957) wrote 'for making the crumbs, the operative agents are climatic, and the purpose of cultivation is to put the soil into such condition that they can act most effectively . . . the alternate wetting and drying affected by the rain and the wind prompts the formation of stable crumbs; the resulting swelling and contractions cause cracks which weaken the clods and if now they are struck by a hoe or harrow while just sufficiently moist they fall into smaller fragments which can be further worked down'.

According to Jones *et al.* (1941) seed bed preparation in the Houston clay of the U.S.A. is difficult. Ploughing turns up large clods, and only nature, by wetting and drying, can reduce the strength of these clods without excessive cost and energy consumption. Fountaine *et al.* (1956) also stressed the dependence of the farmer on weathering action to reduce clod strength to a value where breakage is possible. Baver *et al.* (1972) noted that some farmers allowed their land to dry thoroughly, and then rewet slowly. When the soil dried again, it would be more easily tilled to produce a good seed bed.

Although these processes seem to have great practical importance, there

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is still limited quantitative data. Lyles and Woodruff (1961) are probably the only workers to have demonstrated a decrease in the size distribution and mechanical stability of clods due to weathering action. However, they did not interpret their data in terms of tilth mellowing, probably because the aim of their experiment was to study the resistance of soil to wind erosion.

Arndt (1964) studied some physical problems of the lateritic red earths around Katherine in Northern Australia. He used the term 'physical conditioning' to describe the action of natural wetting and drying in modifying the physical properties of a soil. He suggested that during the physical conditioning process large clods are reduced by slaking and cultivation, and at the same time the dusty fraction is partly aggregated by wetting and intense sun drying.

The aims of the experiments described here were to determine the extent to which tillage can modify the amplitude of soil wetting and drying in the field, and the extent to which this can lead to a reduction in the strength of the clods produced by tillage.

Materials and methods

Soils

Experiments were done in South Australia in the spring (September–October) 1978 and winter (June) 1979 on the Urrbrae fine sandy loam at the Waite Agricultural Research Institute (34° 58′ S, 138° 38′ E). A third experiment was done at the Charlick Experiment Station at Strathalbyn, 50 km further south, in the autumn (May) 1979. Urrbrae loam is a red brown earth, and Strathalbyn soil is a shallower red brown earth typical of a lower rainfall area (Stace *et al.*, 1968).

Further experiments were done in England at Wye College, Kent in the autumn (September) 1979. These trials were done in Olantigh field on a brown calcareous silt loam of the Coombe series, and in Burgate field on a calcareous surface-water gleyed clay of the Wicken series. Burgate field is renowned for its difficulty of working. Usually, weathering over a winter with freezing and thawing is needed between primary and secondary tillage. Some properties of these soils are given in Table 1.

TABLE 1
Composition and Atterberg limits of the soils

Soil		*Proportions of oven dry soil %*				
Site	*Series*	*<20 µm*	*<2 µm*	*organic matter*	*Plastic limit (%)*	*Liquid limit (%)*
Urrbrae		49	17	1.7	19.5	26.5
Strathalbyn		36	12	2.8	17.9	30.0
Olantigh	Coombe	N.D.	N.D.	N.D.	24.5	N.D.
Burgate	Wicken	N.D.	N.D.	N.D.	43.7	N.D.

Tillage

In South Australia, at the Urrbrae site, the soil had been bare since the previous tillage one year earlier and was tilled with a tine cultivator; at Strathalbyn, the soil supported pasture for a number of years and the first implement pass was with a chisel plough, and the second pass was with a tine cultivator. At both sites tillage was done on day 0 to a depth of about 10 cm.

In England, the soils of the Coombe and Wicken Series had both been sown to wheat in the previous season, and the soils (with their stubble) were tilled with a tine cultivator to a depth of about 8 cm.

Measurement of wetting and drying

Natural wetting and drying was used. The top soil dried during the day by the action of solar radiation, wind, *etc.* and wetted during the night by capillary action from below, condensation, *etc.* In addition, wetting was also caused by occasional rainfall.

The amount of wetting and drying of the top soil was calculated from the daily changes in soil water content. Water contents were measured gravimetrically from 50 g samples collected from the top 10 cm in South Australia and from the top 1 cm in England. $k = 6$ samples (1978 exp.) and $k = 5$ samples (1979 exp.) were collected at each time in South Australia, and $k = 5$ samples were collected at each time in England. The maximum daily water content, W_{max}, was assumed to occur in the early morning and the minimum daily water content, W_{min}, was assumed to occur in the afternoon. We have some unpublished work which supports these assumptions. Thus, sampling was done at 0900 h and 1700 h in South Australia and at 0800 h and 1600 h in England.

The amount of wetting and drying, ΔW_i, in any given day, i, was calculated from

$$\Delta W_i = |W_{max(i-1)} - W_{min(i-1)}| + |W_{max(i)} - W_{min(i-1)}| \qquad (1)$$

The cumulative amount of wetting and drying $\Sigma_j \Delta W$ that the soil had undergone between tillage and day j was calculated from

$$\sum_j \Delta W = (\Delta W_1 + \Delta W_2 + \ldots \Delta W_i \ldots \Delta W_j) - j(4\sigma/\sqrt{\pi k}) \qquad (2)$$

The final term is an error term which allows for sampling variation from a random population of top soil water contents. The values of σ for the tilled and untilled plot of the Urrbrae experiments were 0.85 per cent and 0.98 per cent (1978), and 1.01 per cent and 0.95 per cent (1979). For the Olantigh and Burgate soils the values of σ were 0.73 per cent and 2.1 per cent.

Because of transportation problems, changes in water content were not measured at the Strathalbyn site.

Drop shatter test

The strengths of clods from the tilled layer were determined by the drop shatter test (Marshall and Quirk, 1950; Gill and McCreery, 1960; Ingles, 1963). Several clods were collected from the tilled plots at various numbers of days after the first tillage. These had therefore been subjected to different amounts of wetting and drying since tillage. To minimise any effects resulting from differences in soil water status of the samples, the clods were wetted by capillary action, and then dried to a water matric potential of -100 kPa in a pressure plate apparatus for 2 days. The drop shatter test consists of dropping the clods from a height of 200 cm, and then measuring the resulting clod size distribution by dry sieving.

Changes in the strength of the clods were also evaluated by measuring the size distribution of the clods produced by a second implement pass after different numbers of days since the first tillage. The hypothesis was that the clods would have been weakened by natural wetting and drying since the first tillage and that they would then be more easily broken down by the tillage implement. Thus, there should be a greater amount of the smaller fraction produced by the second implement pass after some time of this natural weathering. After the second implement pass, one sample (Urrbrae 1978) and 3 samples (Strathalbyn, Urrbrae and Wye 1979) of tilled soil of about 10 kg were collected each time from between the tractor wheel tracks to a depth of about 10 cm. Clod sorting was done by dry sieving into the following size ranges: >40.0 mm (measured individually with a rule), 9.5–40.0 mm; 6.7–9.5 mm; 4.0–6.7 mm; 2.0–4.0 mm; 1.0–2.0 mm and <1.0 mm. The weight of each group was expressed as a percentage of the total weight of the sample.

Temperature cycling

Tillage increases the amplitude of both the water content fluctuations and the temperature fluctuations in the top layer of the soil. In order to try to isolate which factor is primarily involved in the mellowing of tilth, the effects of temperature changes on the mechanical properties of soil aggregates were tested in the laboratory.

The experiments were done on natural and artificial aggregates from the A horizon of Urrbrae loam. Natural aggregates of 10–13 mm diameter were used, and artificial aggregates of about 10 mm diameter were made by remoulding by hand at 20 per cent water content. To eliminate any confounding effects resulting from age hardening, these aggregates were pre-aged at a potential -100 kPa in a pressure plate apparatus for 2 weeks. Then both the natural and artificial aggregates were air-dried.

The air-dried natural and artificial aggregates were treated as follows: control (1), the aggregates were kept at a constant temperature of 10 °C; control (2), the aggregates were kept at a constant temperature of 50 °C; and aggregates were subjected to temperature cycling between 10 °C and 50 °C for 1, 2, 3 and 4 cycles.

To minimize any affects resulting from the difference in water status, the measurement of aggregate strength was done after these aggregates were subjected to a potential of -153 MPa over saturated $CaCl_2$ solution in a desiccator for 2 weeks. Aggregate tensile strength was measured by crushing the aggregates (16 aggregates for each treatment) between flat parallel plates until fracture occurred (Dexter, 1975). The tensile strength,

Y, was calculated from the equation

$$Y = 0.576F/d^2 \tag{3}$$

where F is the force required to crush the aggregate, and d is the aggregate diameter.

Results and Discussion

Effects of tillage on soil wetting and drying

In the experiments at the Urrbrae site, comparisons were made between the amounts of wetting and drying which occurred on the tilled plots and on adjacent untilled soil. This yielded the ratio

$$\Sigma\Delta W_{\text{tilled}}/\Sigma\Delta W_{\text{untilled}} = 1.79 \text{ for } 1978 \tag{4}$$

and

$$\Sigma\Delta W_{\text{tilled}}/\Sigma\Delta W_{\text{untilled}} = 2.09 \text{ for } 1979. \tag{5}$$

Similar comparisons at the English sites (for the smaller depth of soil) yielded

$$\Sigma\Delta W_{\text{tilled}}/\Sigma\Delta W_{\text{untilled}} = 1.83 \text{ for Olantigh field,} \tag{6}$$

and

$$\Sigma\Delta W_{\text{tilled}}/\Sigma\Delta W_{\text{untilled}} = 1.49 \text{ for Burgate field.} \tag{7}$$

The objective of the remaining experiments was to determine the extent this increased weathering by increased water content fluctuations could mellow these soils.

Drop shatter test

This test was only done on the Urrbrae fine sandy loam. It was found that the additional natural wetting and drying of soil after tillage which is given by Equations (4)–(7), decreases the strength of the clods produced by tillage. As the clods experienced increasing amounts of wetting and drying they were more easily broken and the proportion of smaller aggregates produced by the drop shatter test increased as shown in Fig. 1. The results were fitted to the equation

$$P_{\delta(\Sigma\Delta W)} = P_{\delta(0)} + A[1 - \exp(-k\Sigma\Delta W)] \tag{8}$$

where $P_{\delta(\Sigma\Delta W)}$ and $P_{\delta(0)}$ are the proportion of clods smaller or larger than diameter, δ, after the clods were subjected to wetting and drying of $\Sigma\Delta W$ and 0 respectively, and A and k are adjustable parameters. With clods of <4.0 mm in diameter, the resulting equation was

$$\begin{aligned} P_{\delta(\Sigma\Delta W)} = \underset{(\pm 2.6}{18.5} + \underset{(\pm 3.2)}{24.6}\,[1 - \exp(-\underset{(\pm 0.009)}{0.027}\Sigma\Delta W)] \end{aligned} \tag{9}$$

and this is shown by the smooth curve in Fig. 1.

The decrease in clod strength can also be seen from the decrease in the

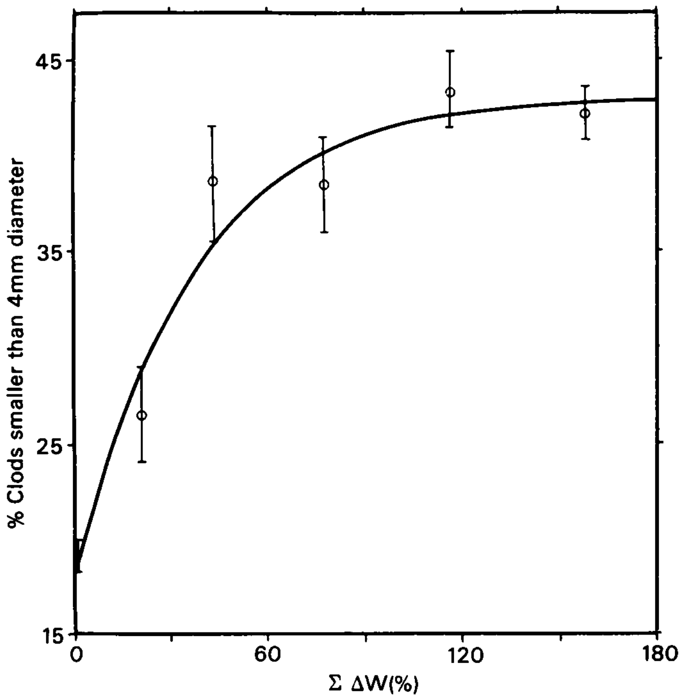

FIG. 1. Effect of wetting and drying on clod strength of Urrbrae loam as shown by the increase in the proportion of the <4.0 mm size fraction resulting from the drop shatter test with increasing $\Sigma\Delta W$. The circles are measurements (means of 6 measurements) and the continuous curve is the fit of Equation (8); bars are 2SE.

amount of energy required to break the clods to produce a certain value of size distribution. To study this for the 1979 experiment, aggregates were dropped from heights: 60, 120, 180 and 240 cm. The energy, $E(J)$, dissipated was calculated by multiplying the clod mass (kg), the height of the drop (m), and the acceleration of gravity (9.81 ms^{-2}).

Plotting the mean weight diameter, d (mm), of the clods produced by the drop shatter test against the logarithm of input energy, E, gave a straight line

$$d = C - B \log_{10}E \qquad (10)$$

where C and B are adjustable parameters.

The resulting parameters C and B, which are given in Table 2, decreased with increasing amounts of wetting and drying of the clods. This shows that wetting and drying decreased the amounts of input energy required to produce clods with a certain value of mean weight diameter (MWD). For instance, it can be seen from Fig. 2 that to produce aggregates with MWD of d = 15 mm, an input energy of 1.78 J was required for clods which had not been subjected to additional wetting and drying, whereas only 0.56 J was required for clods which had been subjected to a wetting and drying of $\Sigma\Delta W$ = 26.8 per cent after tillage. This is a reduction of about two thirds.

TABLE 2

The value of C and B parameters and coefficient of determination of Equation (10) for the drop shatter test on Urrbrae loam as influenced by the amount of wetting and drying as expressed by Σ ΔW

Σ ΔW (%)	C	B	r^2
0	18.2	−14.4	0.98
21.7	17.9	−14.1	0.97
26.8	15.7	−11.7	0.98
35.9	15.1	−13.1	0.97
43.3	14.8	−9.8	0.93
60.8	15.0	−12.0	0.94

The decrease in the strength of clods with wetting and drying can be explained in terms of the formation of micro-cracks. It is known that wetting and drying a soil causes swelling and shrinkage to occur. Since swelling and shrinkage is not equal throughout the mass of the clods, it may produce cracks which reduce the strength of the clods. It is important

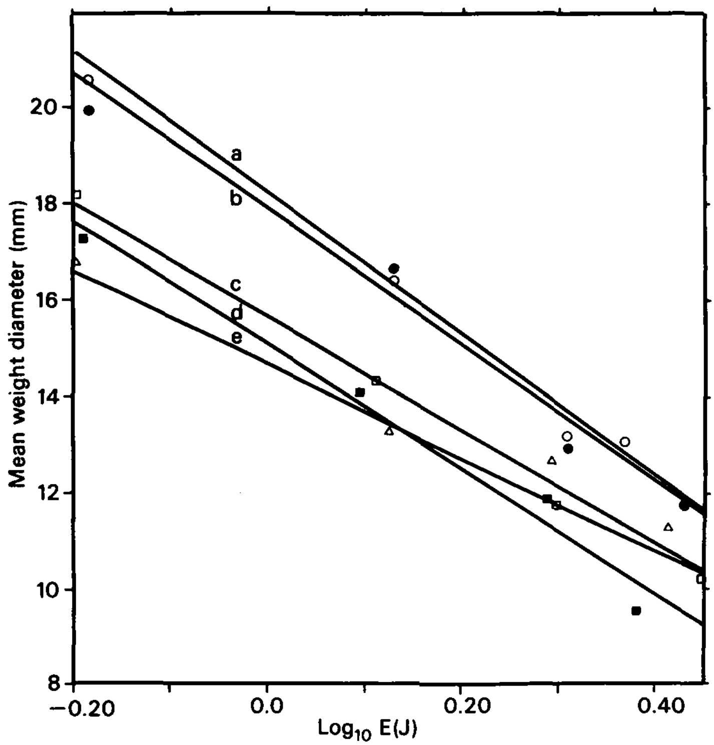

FIG. 2. Effect of wetting and drying (as measured by $\Sigma\Delta W$) on the relationship between log $_{10}$ energy and mean weight diameter of clods produced in Urrbrae loam after the drop shatter test; $\Sigma\Delta W$ = a) 0.0 per cent, b) 21.7 per cent, c) 26.8 per cent, d) 35.4 per cent e) 43.3 per cent.

to realise that this is not necessarily the gross swelling and shrinkage of normally-swelling clays. We believe that even the minute 'residual' shrinkages are sufficient for crack initiation and propagation. The occurrence of cracks resulting from drying clods has also been noticed by Wilton (1963). Larson and Allmaras (1971) have suggested that as water is lost from a soil, there is a decrease in specific volume creating horizontally oriented tensile stress. Shrinkage cracks may then form along vertical planes where the soil may be wetter and has a lower tensile strength. A statistical crack theory for soil tensile strength has been developed by Braunack *et al.* (1979).

Lyles and Woofruff (1961) also found a decrease in the mechanical stability of clods due to weathering action. They showed that the resistance of clods to weathering action (through wetting and drying) increased with increased clod density. Further, they showed that the decrease in the mechanical stability of the clods was very marked in silty clay loam and sandy loam, but was less in a clay soil.

Tillage and soil mellowing in South Australia

As expected, the change in clod strength was followed by the change in the size distribution of the clods produced by the second implement pass. With increasing time after the first tillage, and consequently with increasing

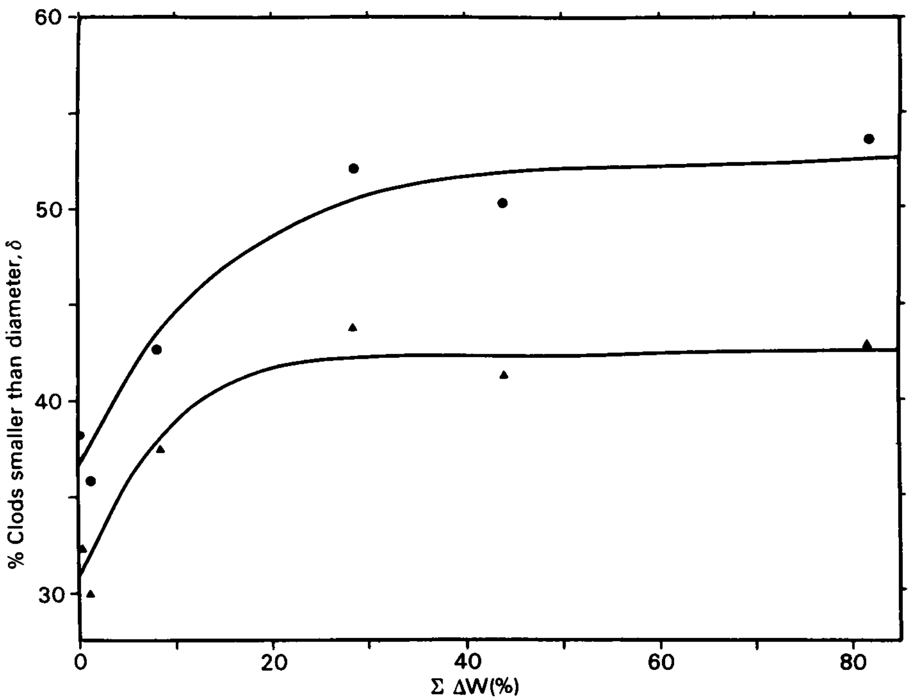

FIG. 3. Effect of wetting and drying (as measured by $\Sigma\Delta W$) on the proportion of clods smaller than diameter, $\delta < 4$ mm (▲) and $\delta < 6.7$ mm (●) produced by the second implement pass (Urrbrae, 1978). The continuous curves show the fits of Equation (8).

TABLE 3

The value of $P_{\delta(0)}$, A and k parameters of Equation (8) for the Urrbrae experiments

Clod diameter (mm)	$P_{\delta(0)}$ 1978	$P_{\delta(0)}$ 1979	A 1978	A 1979	k 1978	k 1979
>9.5	56.4 (±1.4)	44.0 (±1.2)	−17.3 (±2.3)	−15.1 (±1.9)	0.05 (±0.02)	0.04 (±0.01)
<6.7	36.8 (±1.5)	49.1 (±1.1)	16.0 (±2.2)	13.8 (±1.8)	0.07 (±0.03)	0.04 (±0.01)
<4.0	30.8 (±1.3)	40.8 (±0.9)	11.7 (±1.7)	13.7 (±2.1)	0.12 (±0.06)	0.03 (±0.01)

amounts of additional wetting and drying, the clods were more easily shattered by the mechanical impact of the tillage implement. This resulted in an increase in the proportion of the smaller aggregate size fraction, and a corresponding decrease in the proportion of the larger size fraction as shown in Fig. 3.

These data were fitted to Equation (8), and the resulting values of $P_{\delta(0)}$, A and k for the clods with the diameter of <6.7 and <4.0 mm are given in Table 3, and the resulting Equation can be seen in Fig. 3.

The result of the 1979 Urrbrae experiment was similar to that of the 1978 experiment. A slight difference was that the major change in the clod size distribution did not occur until several days after the first implement pass when the soil had been subjected to a larger amount of wetting and drying.

In the first few days after the first implement pass there was always a cloudy and rainy day, and it is assumed that during this period the clods did not dry sufficiently for cracks to develop. The amounts of wetting and drying when the second implement pass was done at 5 days after the first pass was large enough ($\Sigma\Delta W$ = 21.7 per cent compared with $\Sigma\Delta W$ = 7.9 per cent in the 1978 experiment when the second implement pass was done 3 days after the first pass) to cause a reduction in strength. However, this mostly originated from wetting which is probably less likely to initiate cracks. As a consequence, the strength of the clods did not decrease, and no change in the size distribution was produced by the second implement pass. This suggestion can be supported by the result shown in Fig. 2. It can be seen that the amount of energy to produce clods with the same MWD is about the same with the clods that had not been subjected to wetting and drying as with those which had been subjected to a wetting and drying of $\Sigma\Delta W$ = 21.1 per cent.

Another factor which may affect these size distribution changes is the soil water content at the time of tillage. The importance of soil water content in determining the size distribution of clods produced by tillage implements has been discussed elsewhere (Bhushan and Ghildyal, 1972). For the Urrbrae red brown earth, Ojeniyi and Dexter (1979) found on the same plot that tillage at 17.0 per cent water content (or 0.9 of the Plastic Limit) produces the smallest proportion of large clods. Further, they showed that tillage at 15.8 per cent water content produced about 57 per cent of clods larger than 4.0 mm in diameter, whereas tillage at 18.3 per cent water content produced 66 per cent of clods larger than 4.0 mm in diameter, with the implement they used.

The soil water content at the time of tillage for the first, second, third and fourth treatment in the 1978 experiment was 15.0 per cent (when the second pass done at day 0 immediately after the first pass, or $\Sigma\Delta W = 0.0$ per cent), 15.7 per cent (day 1, or $\Sigma\Delta W = 0.4$ per cent), 15.6 per cent (day 3, or $\Sigma\Delta W = 7.9$ per cent), and 19.2 per cent (day 8, or $\Sigma\Delta W = 28.5$ per cent). In the 1979 experiment it was 15.9 per cent (day 0), 14.0 per cent (day 1, or $\Sigma\Delta W = 4.6$ per cent), 18.6 per cent (day 5, or $\Sigma\Delta W = 21.7$ per cent), and 20.9 per cent (day 8, or $\Sigma\Delta W = 26.8$ per cent).

From the 1978 experiment, it was expected that the major change in the size distribution of the clods produced by the second pass would occur in the 3rd or 4th day after the first pass. Unfortunately the soil water content on these days was too high for tillage (19.5 per cent on day 3, and 19.6 per cent on day 4). Even when tillage was done on days 5 and 8, the soil water content was still too high (18.6 per cent and 20.4 per cent respectively). This data was fitted to Equation (8) and produced the 1979 values of $P_{\delta(0)}$, A and k given in Table 3 and the curves in Fig. 4.

A decrease in clod strength due to wetting and drying occurred also in the Strathalbyn experiment. Thus delaying the second implement pass a

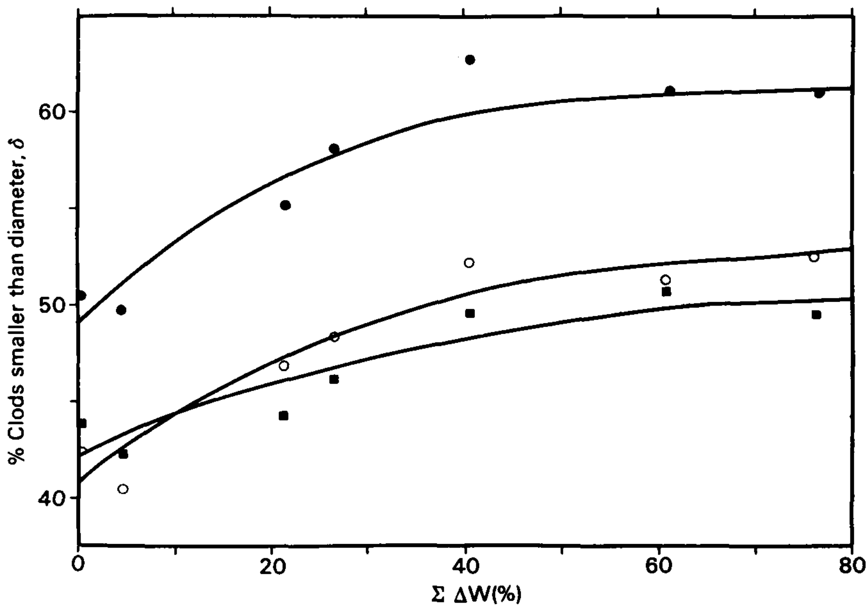

FIG. 4. Effect of wetting and drying (as measured by $\Sigma\Delta W$) on the proportion of clods smaller than diameter, $\delta < 4$ mm (○) and $\delta < 6.7$ mm (●) produced by the second implement pass (Urrbrae, 1979). The contribution of wetting and drying alone in increasing the proportion of clods <6.7 mm is shown by (■) and the continuous curves show the fits of Equation (8).

TABLE 4

The value of $P_{\delta(0)}$, A and m parameters of Equation (11), for the 1979 Strathalbyn experiment

Clod diameter (mm)	$P_{\delta(0)}$	*A*	*m*
>9.5	69.7	−12.7	0.46
	(±1.6)	(±1.9)	(±0.17)
<6.7	24.4	10.5	0.50
	(±1.4)	(±1.6)	(±0.19)
<4.0	18.3	7.6	0.45
	(±1.1)	(±1.3)	(±0.19)

few days after the first pass increased the proportion of smaller aggregates. The result was very similar to that of the 1978 Urrbrae experiment. The major change in the size distribution of the clods produced by the second pass occurred a few days after the first pass. The soil water content at tillage for the first, second, third and fourth treatment was 13.7 per cent (day 0), 13.6 per cent (day 1), 13.9 per cent (day 2) and 14.4 per cent (day 4).

Since the changes in soil water content were not measured, Equation (8) was modified to

$$P_{\delta(t)} = P_{\delta(0)} + A[1 - \exp(-mt)] \qquad (11)$$

with t being the time in days after the first pass. The resulting values of $P_{\delta(0)}$, A and m are given in Table 4, and the curve is shown in Fig. 5 For comparison, the results of the Urrbrae experiments (1978 and 1979) were fitted to Equation (11) and the resulting values of $P_{\delta(0)}$, A and m are given in Table 5.

There was a tendency for an increase in clod strength one day after the first implement pass. This was shown by the decrease in the proportion of the smaller fraction when the second pass was done on this day, as shown in Figs 3, 4 and 5. It is suggested that a small loss of water from soil is not able to initiate crack formation, but may just cause soil particles to move closer together. Since the attractive forces, which determine the cohesion forces, increase with decreasing distance between particles, this process results in an increase in strength. Wilton (1963) observed that at first, drying a clod results in an increase in the shear strength, and the clod becomes tougher, and more difficult to break. An increase in the shear cohesion (c) and friction angle (ϕ) due to slow drying has also been found by Camp and Gill (1959).

Besides the decrease in the strength of the clods, the increase in the proportion of the smaller aggregate fraction produced by the second pass was caused by the action of wetting and drying itself. It seems that the stresses and strains developed during wetting and drying were able to disintegrate the clods into smaller aggregate units (Table 6).

Arndt (1964) found that wetting and drying of clods modified the structure of a tilled soil, shown by the decrease in the surface roughness of

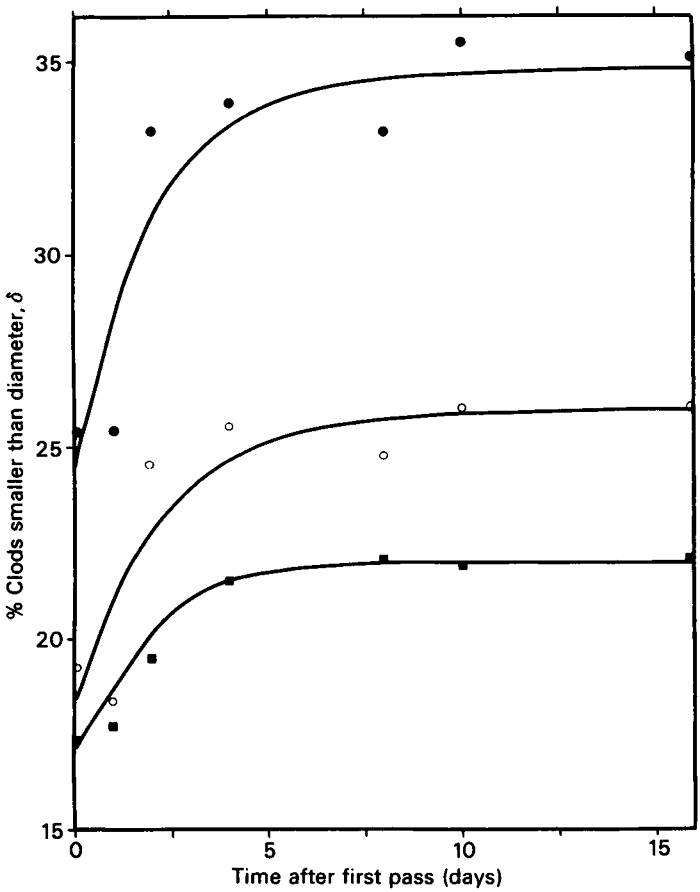

FIG. 5. Effect of time after the first implement pass on the proportion of clods smaller than diameter, $\delta < 4$ mm (○) and $\delta < 6.7$ mm (●) produced by the second implement pass (Strathalbyn, 1979). The contribution of wetting and drying alone in increasing the proportion of clods <6.7 mm is shown by (■) and the continuous curves shown the fits of Equation (11).

TABLE 5

The value of $P_{\delta(0)}$, A and m parameters of Equation (11), for the Urrbrae experiments

Clod diameter (mm)	$P_{\delta(0)}$		A		m	
	1978	1979	1978	1979	1978	1979
>9.5	57.3 (±2.3)	43.9 (±1.0)	−18.9 (±3.6)	−14.0 (±1.3)	0.15 (±0.09)	0.16 (±0.04)
<6.7	36.0 (±2.6)	49.2 (±1.0)	17.5 (±3.7)	12.8 (±1.3)	0.18 (±0.13)	0.16 (±0.04)
<4.0	30.2 (±2.5)	40.9 (±0.9)	12.6 (±3.0)	12.0 (±1.2)	0.27 (±0.20)	0.13 (±0.03)

TABLE 6

Effect of wetting and drying alone (as shown by Σ ΔW) on clod size distribution in the tilled plot. The 1978 Urrbrae experiment

$\Sigma \Delta W$ (%)	% clods with diameter (mm)		
	>9.5	<6.7	<4.0
0	54.2	33.5	27.1
43.9	53.8	41.6	33.9
109.7	41.8	50.3	40.1

a tilled soil. Fox (1964) has suggested that due to non-uniform wetting and drying throughout the bulk of a normally-swelling soil, the associated swelling and shrinking create regions of failure during drying. Further, he demonstrated that clods with the diameter of 12–25 mm were prevalent when the bulk field sample was moist, but as these clods dried to the water potential of about −3.2 MPa, they spontaneously broke into aggregates with the rather uniform diameter 2.0–4.0 mm.

To study the contribution of wetting and drying alone in modifying the size distribution of the clods produced by the first tillage, the clod size distribution prior to the second implement pass was measured in the 1979 experiment. The result was fitted to Equation (8), for the Urrbrae experiment, and to Equation (11) for the Strathalbyn experiment. The resulting equations were

$$P_{<6.7(\Sigma\Delta W)} = \underset{(\pm 1.0)}{41.9} + \underset{(\pm 3.1)}{10.7}\,[1 - \exp(\underset{(\pm 0.015)}{-0.023}\Sigma\Delta W)] \qquad (12)$$

for the Urrbrae experiment, and

$$P_{<6.7(t)} = \underset{(\pm 0.8)}{16.9} + \underset{(\pm 0.9)}{5.2}\,[1 - \exp(\underset{(\pm 0.22)}{0.51}t)] \qquad (13)$$

for the Strathalbyn experiment, where t is the time in days since the original tillage.

It can be seen in Figs. 4 and 5 that wetting and drying alone contribute about 40 per cent of the total increase in the proportions of aggregates with diameters of <6.7 mm.

Tillage and soil mellowing in England

The results of the experiments at Wye College differed from those in South Australia. There was no significant change in aggregate size distribution with the second implement pass on either soil with up to five days of weathering.

The cumulative water content changes of the top lcm of soil were $\Sigma\Delta W$ = 36 per cent at both sites in this period. This negative result might be expected on the difficult strong soil of Burgate, but not on the lighter soil of Olantigh field. Clearly, the appropriate amplitudes of water content changes for internal micro-cracking were not attained in these soils. This might be a consequence of the climatic conditions prevailing during the experiment and/or a consequence of the values of certain key physical properties of these soils resulting, perhaps, from their mineralogy and chemistry.

Effects of temperature cycles

It was found that temperature cycles affected the tensile strengths of both natural and artificial aggregates by less than 3 per cent. This result supported the hypothesis that the decrease in clod strength is chiefly caused by crack formation due to the increase in the amplitude of soil water content fluctuations after the first tillage.

Conclusions

We have shown that tilling soil increases the amplitude of the water content fluctuations and thus 'put(s) the soil into such a condition that (climatic agents) can act most effectively' (Russell, 1957).

These water content fluctuations can reduce significantly the strength of clods, as measured by the drop shatter test, in some soils. The increase in the amplitude of temperature fluctuations, which also follows tillage, appears not to be directly implicated in these observed reductions in clod strength.

A practical application of this effect is to wait for several days between tillage operations and to let natural processes do a significant amount of 'tillage' with no cost or effort.

This mellowing of tilth effect does not appear to work equally on all soils, and further work is needed to determine more precisely those factors which control it. The possibility would then exist for modifying difficult soils to take full advantage of natural tilth mellowing.

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