EARTH SCIENCE JOURNAL Vol. 5, No. 1, 1971

SOIL CRUSTING IN WESTERN SAMOA. PART I — SOME EXAMPLES OF CRUSTING AND METHODS OF CONTROL

S. G. REYNOLDS
South Pacific Regional College of Tropical Agriculture,
Alafua, Western Samoa

Abstract

The problems and effects of soil crusting in Western Samoa are discussed. Illustrations of typical crust features include the glazed or 'frosted' surface of certain crusts, and dispersion mosaics. Surface mulches and fine wire mesh frames were investigated as control measures to dissipate the considerable kinetic energy of falling raindrops before they reach the soil surface. Soil crusting was much reduced by these control methods. Mulching increased the germination percentage of dwarf beans, and frames the germinating percentage of lettuce and cabbage over untreated plots; the yield of dwarf beans was increased by 80 per cent using a mulch of coconut fronds.

INTRODUCTION

The ability of heavy rainfall to disperse soil aggregates and pack bare soil surfaces is widely recognised. The dispersion products, mostly fine particles, form a film or pan at the soil surface. This thin compacted surface skin becomes hard when the soil dries out. This process is known as soil panning, capping, sealing or crusting.

Some publications refer to the phenomenon in very general terms (Bennett, 1947; Stallings, 1957; Kohnke and Bertrand, 1959; Webster and Wilson, 1966). In temperate regions there has been a considerable amount of detailed research and investigation (Hendrickson, 1934; Duley, 1939; Ellison, 1944; Ellison and Slater, 1945; Richards, 1953; Baver, 1956; McIntyre, 1958; Gerard, 1965; Tackett and Pearson, 1965; Burwell *et al.*, 1966; Epstein and Grant, 1967; Evans and Buol, 1968; Myhrman and Evans, 1969; Moldenhauer and Kemper, 1969). However, the number of specific investigations in the tropics is very limited. These include the work carried out in Australia by Arndt (1965a and b) and Barley *et al.* (1965); also, Roblin (1966) has described a dense 2 mm thick crust in Trinidad.

In Western Samoa, more people are beginning to grow vegetables as food crops. As vegetable production is very susceptible to changes in soil structure (Cowans *et al.*, 1965), the prevention of soil crusting is a problem of increasing importance. This paper presents some examples and effects of soil crusting as well as methods which are being used in an attempt to prevent its formation. A later paper describes a series of simple experimental investigations of environmental factors which influence crust formation. These were used to collect data for teaching information about soil crusts to a soil conservation class and to prepare teaching aids for extension purposes.

DESCRIPTION AND EFFECTS OF CRUSTING

The preparation of seedbeds in agriculture involves various manipulations of the soil so that a good tilth is provided in the top few inches. The structural condition of this seedbed is one of the keys to the successful growth of crops; the soil must have adequate aeration, sufficient moisture, and must allow ready infiltration of rainfall. Usually, considerable effort in time and expense goes into the working of the topsoil before a crop is sown or planted. If the properties of the topsoil are changed to any extent then crop growth may be affected and a re-working of the soil may be necessary.

In Western Samoa where heavy tropical rainfall can break down and disperse the aggregates in this cultivated layer (McIntyre [1958] has described a sequence of events leading to crust formation), the formation of crusts is a common occurrence. As the wet soil dries out following heavy rainfall the packed soil surface quickly hardens and takes on a glazed or 'frosted' appearance (Figure 1). Crusts have been measured varying in thickness from a few millimetres to 1 centimetre or more.

Often soil crusting is accompanied by the appearance at the soil surface of what may be called 'dispersion mosaics,' where the coarse soil particles have been concentrated, the fines having been washed into pore spaces (Figure 2). These patterns, which are easily seen from a distance, bear some slight resemblance to the patterned ground features of colder areas (Washburn, 1956). As the crust dries out cracks form which often penetrate some distance down into the soil body.

The beating action of raindrops in dispersing soil particles, compresses the top soil, thus in effect lowering the soil surface. This is illustrated in Figure 3. The white polythene mulch has protected the soil beneath it, apart from slight compression, while the area subjected to the beat of the raindrops has been lowered by 1.5 to 2.8 cms, over a period of two and a half months. The structural condition of the soil in the protected and unprotected areas is clearly different. Stunted onion plants are shown in the crusted strip.

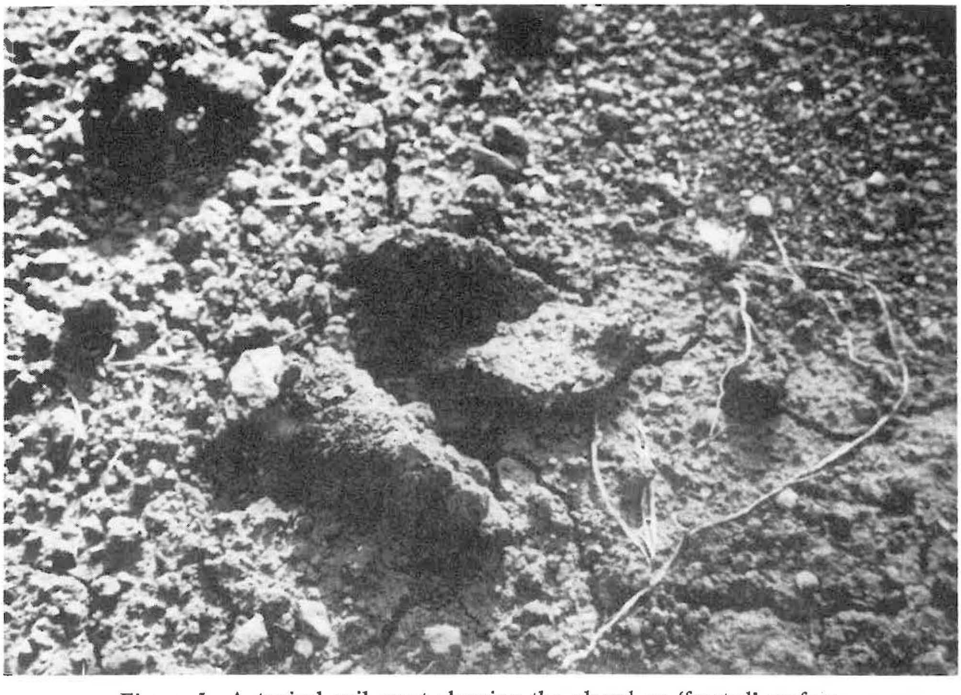

Figure 1 A typical soil crust showing the glazed or 'frosted' surface.

The formation of soil crusts can have a number of other important effects. If the sealing takes place just after seeds have been sown then the emergence of seedlings may be impeded or even prevented (Cowans *et al.*, 1965). In a recent trial dwarf beans were replanted three times before successful germination was achieved, because soil crusting prevented their emergence. On two occasions germination took place in the soil but the seeds' reserves of energy were used up in trying to penetrate the hard surface crust and the beans withered below ground level. When the crust was broken by light recultivation and the beans resown for the third time successful germination was achieved.

If a crust is formed just after seedlings have emerged, then they may die of heat girdling, because soil particles are packed tightly together and are also in contact with the seedling stem. The increased conductivity of the crust means that the plant is subjected to extremes of heat as the temperature of the layer rises rapidly in hot sunshine.

Crusting may result in reduced gaseous exchange between the soil and the atmosphere causing seedling respiration problems. This was discussed in a recent paper by Reynolds (1970) as one of the possible causes of the marked susceptibility of bean plants to a fungal wilt on unmulched plots where crusts formed readily.

The cracks which begin to develop as the crust dries out penetrate deeply into the soil body. Movement of soil blocks separated by fissure systems may cause actual physical damage to the plant roots, possibly severing them completely if movement is severe enough.

Sealing of the surface affects the infiltration capacity of soils (Duley, 1939; Moldenhauer and Kemper, 1969). A compact surface is responsible for low infiltration rates and high runoff. Reduced intake results in a drier soil and the increased runoff may cause soil erosion if the land has a slight gradient.

CONTROL MEASURES

Two methods for preventing soils from crusting have been investigated. These used surface mulches, and wire mesh-covered frames above the soil surface. Both were attempts to dissipate the considerable kinetic energy of tropical rainfall before it reached the soil. The mesh frame caused large raindrops to be broken up before they reached the soil, and the surface mulch received the impact of raindrops, protecting the soil beneath.

Mulch

A mulch is a loose covering of material applied to the soil surface to increase crop yields by modifying environmental conditions. The ability of a mulch to dissipate raindrop energy depends very much on the nature of the mulch. Thus coconut fronds are flexible, resist deformation and protect the soil, whereas polythene sheet tends to absorb and conduct the effects of rainbeat to the soil beneath, causing a degree of crusting which, however, is much less than on exposed bare soil.

It is often difficult to relate crop yields and the degree of protection from soil crusting afforded by various mulch materials because of the many physical, chemical and biological effects that mulch can have on a soil. Increased crop

Figure 2 A typical soil crust showing surface 'dispersion mosaics'.

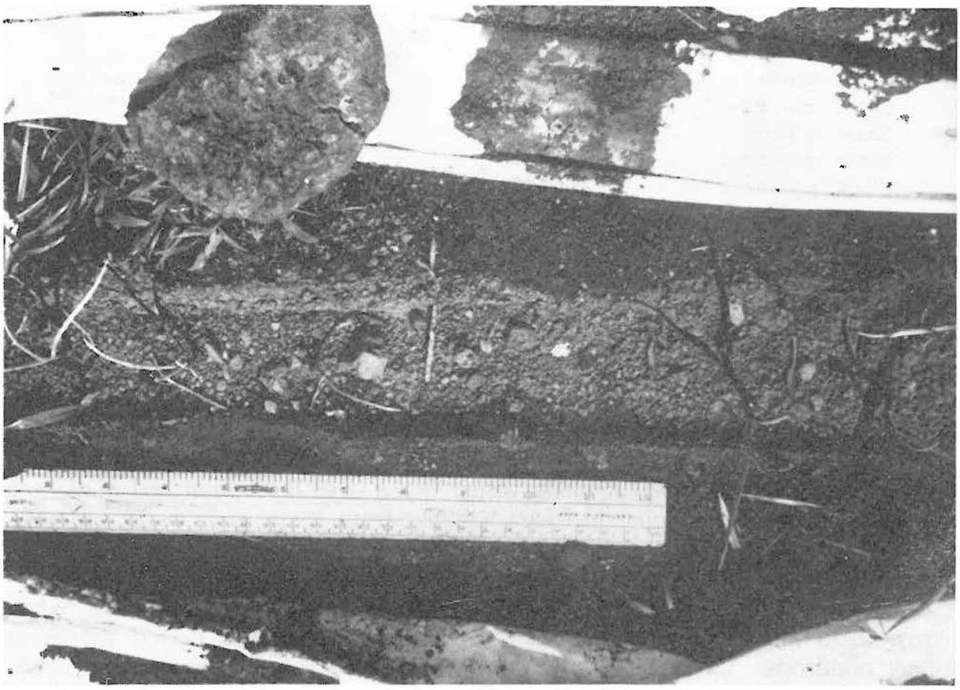

Figure 3 The lowering of the soil surface caused by soil crusting, in the exposed 3in wide area between two polythene sheets.

yields and improvements in quality have been attributed to moisture and nutrient conservation (Ekern, 1967; Hopkinson, 1968), weed control (Tiedjens, 1950), temperature regulation (Johnson *et al.*, 1966), winter protection and pest and disease control (Geraldson *et al.*, 1966; Reynolds, 1970). Several trials were undertaken to study the effects of mulching on soil crusting and on crop yields. Data from a trial using dwarf or bush beans and the eight treatments given in Table 1 are outlined below.

Table 1 Details of the mulch treatments

Treatment	Approximate thickness or depth (in)	Details
Wood shavings	1	A mixture of wood shavings and saw-dust from locally sawn timber.
Grass cuttings	2	Sun-dried grass.
Polythene sheet	0.0015	Clear polythene sheet painted with a glossy white paint.
Polythene sheet	0.0015	Black — normally used with pineapples.
Coconut fronds	1	Sun-dried fronds — larger midribs removed.
Stones	3	Stones of weathered basalt, size 3in.
Aluminium foil	0.0015	Silver side uppermost, grey side down.
Control (no mulch)	—	Weed-free soil.

Beans (*Phaseolus vulgaris* var. 'Contender') were sown in double rows in six adjacent 30 x 3ft beds at a spacing of 10 x 24in. The beds were subdivided into 24 7½ x 3ft plots with 20 bean plants per plot. A simple randomised block design was used with three replications of the eight treatments. The mulches were put down before germination, and small openings were left to allow for seedling emergence. Beans were sown on April 11, 1970, and a germination count taken on April 22. Between these dates 7½in of rain fell, including over 3in on April 13.

Table 2 The influence of mulch on bean germination and yield.

Treatment	Germination (%)	Weight of beans (g.)	Increase over control (%)
Wood shavings	92	5076	8
Grass cuttings	95	5205	11
White polythene	90	7462	59
Black polythene	87	6871	46
Coconut fronds	98	8478	80
Stones	93	6501	38
Aluminium foil	95	7089	51
Control (no mulch)	78	4699	0

The control plots developed crusts of more than 1 cm in thickness, sufficiently thick to affect the germination percentage. The data in Table 2 show that dried coconut fronds afforded the most protection (98% germination) and the unmulched plots the least protection (78% germination). The protection of the mulches is also reflected in the yield data in Table 2. The coconut frond mulch gave an 80 per cent increase in weight of harvested beans over the unmulched plots with the other mulches producing increases ranging from 8 per cent to 59 per cent.

Mesh frame

Wooden frames of size 8 x 3ft with 2 mm square wire mesh stretched tightly across them were set up on posts above the soil to act as a partial barrier to falling raindrops. Large raindrops were dispersed by the fine mesh and reached the ground as a mist of fine droplets. It was found that the height of the frames above the soil surface was important. If they were too high water collected on the underside of the frame, forming very large droplets which caused drip damage on the soil surface; if they were too low then little room was left for the growing plant. A height of 36 inches above ground surface was selected as the best compromise — trials showed that heavy rain falling through mesh screens at this height did little physical damage to the soil surface.

A trial was established to compare the germination and early growth rates of three varieties of cabbage and one lettuce variety, with and without mesh frames. Each variety was replicated twice making a total of eight rows, each 20 feet long and two feet apart. Eight feet of each row was sheltered with mesh frames and eight feet was open, the remaining four feet of row served as guard areas, one foot at either end of the row and two feet separating the sheltered and unsheltered sections.

Seeds were planted on April 30, 1970, after seven days without rain. All rows were lightly watered to speed germination. A few hours after sowing 1in. of rain fell in several hours, and between sowing and germination counts on May 7, 2.42in. fell. The effect of the heavy rain was to compress the unsheltered surface soil into a compact pan and expose many seeds which had been sown at a depth of $\frac{1}{4}$ to $\frac{1}{2}$ inch. Many seeds in the unsheltered rows failed to push up through the crust or were scorched by the sun because of their exposure at the surface. The structure of the soil under the mesh frames was practically unchanged and germination was rapid. Data for number of seeds germinating and average height of seedlings on the protected and unprotected soil are given in Table 3.

Table 3 The influence of mesh frames on germination and early growth of cabbage and lettuce seedlings

Crop	Number germinating Frame	Number germinating No frame	Increase over No frame (%)	Average height (cm) Frame	Average height (cm) No frame	Increase over No frame (%)
Cabbage:						
var. a ...	102	45	127	3.2	1.3	146
var. b ...	598	240	149	4.1	1.9	116
var. c ...	275	65	323	4.1	1.7	141
Lettuce ...	445	262	70	2.2	0.8	175

Mesh frames are shown to increase germination of lettuce and cabbage seed by between 70% and 323% depending on the variety. Average height of seedlings on May 7 was increased by 116% to 175% by the mesh frames. It is probable that a part of the effect of the screens was the result of a lowering of surface temperature because of shading as well as the prevention of crust development.

CONCLUSIONS

It has been shown that surface sealing or soil crusting is very common on bare soil exposed to heavy tropical rain in Western Samoa. If vegetable growing is expanded in village communities then use of surface mulch or wire mesh frames or screens is recommended to increase seed germination percentage and the early growth rates of seedlings. The cheapest form of mulch is a cover of dried coconut fronds, with the larger midrib portions removed. This has been shown to give higher germination percentages and heavier yields than other mulches with dwarf beans. Mesh frames are better suited to crops like cabbage and lettuce because of the very small seedlings produced and the need for thinning or transplanting.

REFERENCES

Arndt, W. 1965a: The nature of the mechanical impedance to seedlings by soil surface seals. *Aust. J. Soil Res.* 3: pp 45-54.

————, 1965b: The impedance of soil seals and the forces of emerging seedlings. *Aust. J. Soil Res.* 3: pp. 55-68.

Barley, K. P., Farrell, D. A. and Greacen, E. L. 1965: The influence of soil strength on the penetration of a loam by plant roots. *Aust. J. Soil Res.* 3: pp. 69-79.

Baver, L. D. 1956: *Soil Physics.* John Wiley & Sons, New York and London.

Bennett, H. H. 1947: *Elements of soil conservation.* McGraw-Hill Book Co., New York and London.

Burwell, R. E., Allmaras, R. R., Sloneker, 1966: Structural alteration of soil surfaces by tillage and rainfall. *J. Soil Water Conserv.* 21: pp. 61-63.

Cowans, K. D., Ririe, D., and Vomocil, J., 1965: Soil crust prevention aids lettuce seed emergence. *Calif. Agri.* Jan.: pp. 6-7.

Duley, F. L. 1939: Surface factors affecting the rate of intake of water by soils. *Soil Sci. Soc. Am. Proc.* 4: pp. 60-64.

Ekern, P. C. 1967: Soil moisture and soil temperature changes with the use of black vapour barrier mulch and their influence on pineapple (*Ananas comosus* L. Merr.) growth in Hawaii. *Proc. Soil Sci. Soc. Amer.* 31; pp. 270-275.

Ellison, W. D. 1944: Studies of raindrop erosion. *Agri. Eng.* 25: pp. 131-136, 181-182.

Ellison, W. D. and Slater, C. S. 1945: Factors that affect surface sealing and infiltration of exposed soil surfaces. *Agr. Eng.* 26: pp. 156-157, 162.

Epstein, E. and Grant, W. J., 1967: Soil losses and crust formation as related to some soil physical properties. *Soil Sci. Soc. Amer. Proc.* 31: pp. 547-550.

Evans, D. D., and Buol, S. W., 1962: Micromorphological study of soil crusts. *Soil Sci. Soc. Amer. Proc.* 32: pp. 19-22.

Geraldson, C. M., Overman, A. J. and Jones, J. P., 1966: Combination of high analysis fertilisers, plastic mulch and fumigation for tomato production on old agricultural land. *Proc. Soil Sci. Soc. Fla.* 25: pp. 18-24.

Gerard, C. J., 1965: The influence of soil moisture, soil texture, drying conditions and exchangeable cations on soil strength. *Soil Sci. Soc. Amer. Proc.* 29: pp. 641-645.

Hendrickson, B. H., 1934: The choking of pore spaces in the soil and its relation to runoff and erosion. *Trans 15th Ann. Meeting Am. Geophys. Union* Part II: pp. 500-505.

Hopkinson, D., 1968: Experiments on mulching sisal with black polythene in Tanganyika. *Exp. Agric.* 4: pp. 143-150.

Johnson, W. H., Hedden, O. K. and Wilson, J. D., 1966: How liquid mulches affect soil moisture retention, temperature and seedling growth. *Agr. Eng.* 47: pp. 196-199.

Kohnke, H., and Bertrand, A. R., 1959: *Soil Conservation.* McGraw-Hill Book Co., New York and London.

McIntyre, D. S., 1958: Soil splash and the formation of surface crusts by rain drop impact. *Soil Sci.* 85: pp. 261-266.

Moldenhauer, W. C., and Kemper, W. D., 1969: Interdependence of water drop energy and clod size on infiltration and clod stability. *Soil Sci. Soc. Amer. Proc.* 33: pp. 297-301.

Myhrman, M. A., and Evans, D. D., 1969: Hexadecanol in soil — its locational stability and influence on modulus of rupture. *Soil Sci. Soc. Amer. Proc.* 33, 2: pp. 203-205.

Reynolds, S. G., 1970: The effect of mulches on Southern blight (*Sclerotium rolfsii*) in dwarf bean (*Phaseolus vulgaris*). *Trop. Agric.* 47, 2: pp. 137-144.

Richards, L. A., 1953: Modulus of rupture as an index of crusting of soil. *Soil Sci. Soc. Amer. Proc.* 17: pp. 321-323.

Roblin, A. J., 1966: Crusting of U.W.I. Field Station Soils. *Q. Rep. U.W.I. Sch. Agric.* pp. 19-22.

Stallings, J. H., 1957: *Soil Conservation.* Prentice-Hall, N. J.

Tackett, J. L., and Pearson, R. W., 1965: Some characteristics of soil crusts formed by simulated rainfall. *Soil Sci.* 99: pp. 407-413.

Tiedjens, V. A., 1950: Aluminium foil mulch. *Brooklyn Bot. Gdn. Rec.*, 6; pp. 198-200.

Washburn, A. L., 1956: Classification of patterned ground and review of suggested origins. *Bull. Geol. Soc. Amer.* 67: pp. 823-866.

Webster, C. C., and Wilson, P. N., 1966: *Agriculture in the Tropics.* Longmans, London.