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

# SOIL CRUSTING IN WESTERN SAMOA. PART II — EXPERIMENTAL INVESTIGATON OF FACTORS INFLUENCING CRUST FORMATION

**S. G. REYNOLDS**

**South Pacific Regional College of Tropical Agriculture, Alafua, Western Samoa**

**Abstract**

The Alafua Penetrometer was used to measure relative differences in soil crust strength. Crust strength and thickness were shown to increase with increases in rainfall amount, drying time, droplet size, kinetic energy and soil clay and silt content. The investigations were designed to illustrate some of the factors influencing crust formation to a diploma level soil conservation class.

## INTRODUCTION

A number of studies have investigated factors that influence soil crusting (Ellison and Slater, 1945; Epstein and Grant, 1967), but usually only individual factors or one or two factors have been studied together. This paper examines crust formation in relation to a number of environmental factors. The main purpose was to illustrate some of the soil crust forming forces to a soil conservation class. Clear illustration of the main causal factors makes the implementation of control measures much easier.

A series of studies was carried out to examine crust formation in conditions where the environment could be regulated. Environmental parameters which were simulated included; amount of rainfall, droplet size, kinetic energy, length of drying period under shade and maximum radiation conditions, and different soil textural conditions. In each investigation all factors were held constant, except the one or two under study, which were varied and the resulting effect on crust formation recorded.

## MATERIALS AND METHODS

### *Measuring device*

Several mechanical devices have been developed to measure the stability and strength of soil crusts and the resistance that seedlings may encounter during emergence. Arndt (1965) used a beam balance, which measured the force needed to thrust a probe through surface seals. Richards (1953) and others measured the modulus of rupture, using it as an index of crusting. Taylor and Bruce (1968) and Fiskell *et al.* (1968) measured soil strength with penetrometers.

The measuring device used in this study is illustrated in Figure 1. Constructed from a 29cm long, 16.5cm diameter metal pipe closed at both ends, to which is

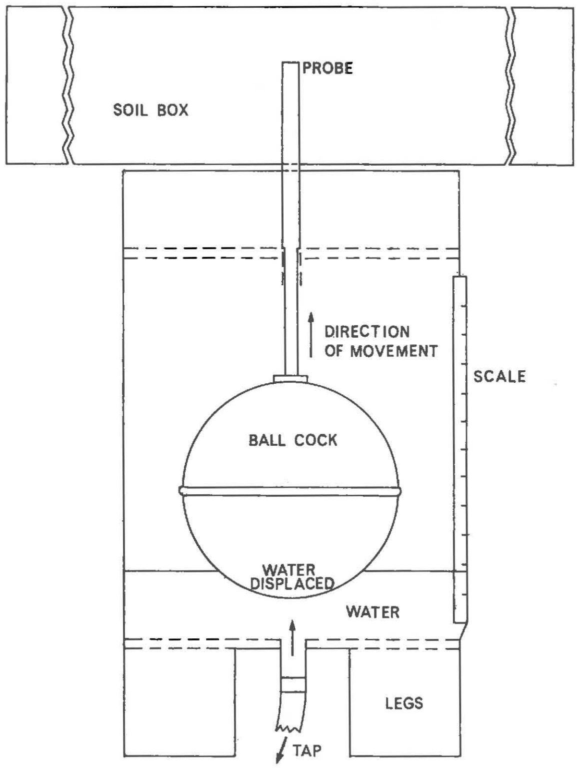


*Figure 1* The Alafua Penetrometer (all measurements half scale).

attached a graduated open-ended glass tube for observing water height, the instrument can be attached to a tap by rubber tube connected to the inlet hole in the base. A probe is attached by a length of rod to a ballcock inside the cylinder. When water is forced into the cylinder the probe rises and enters the detachable box in which soil crusts have been formed. The pressure required to rupture the crust surface is measured by calliper gauge as the height of water in the inserted glass tube and converted to lb/in$^2$ by reference to a calibration chart (see Reynolds and Cable, 1970). Measurements are taken at the moment the soil surface domes with the upward thrust of the probe. The instrument is capable of measuring pressures from 0 – 12lb/in$^2$. The present design can be improved by reducing the considerable amount of friction generated between the probe piston and its barrel, and by increasing effective probe length and the depth of the containers in which crusts are formed. Using the present instrument it is vital that all treatment boxes be filled to the same depth or different readings will result, irrespective of actual crust strength. Even with no crust development the probe has to move several centimetres to be visible at the surface and this is registered in lb/in$^2$. However, the instrument was adequate, for the demonstration of trends, in the present study.

Treatments were performed on soil in rectangular wooden boxes of size 24 x 12 x 3in., each of which had a centrally placed $\frac{1}{2}$in. diameter hole through which the probe entered the soil when each box was placed on to the penetrometer. All soil was sieved through a $\frac{1}{2}$in. sieve to eliminate stones which might interfere with probe penetration. Details of the factors investigated are outlined in Table 1 and described below. The thickness of the developed crust (if any) was measured

*Table 1* Details of treatments

| Treatment Investigated | Rainfall Amount (in) | Droplet Size (mm) | Height of Application (ft) | Length of Drying Time (days) | Place of Drying | Soil Texture |
|---|---|---|---|---|---|---|
| 1. Rainfall amount | 0, 2.4, 4.8, 9.6, 14.4 | about 4 | 3 | 6 | sun | loam |
| 2. Length of drying time in shade and sun | 2.4 | about 4 | 3 | 0, 1, 2, 3 & 4 | sun shade | loam |
| 3. Rainfall amount Droplet size | 1.2, 2.4 | about 4 & 0.5 | 3 | 3 | sun | loam |
| 4. Rainfall Kinetic Energy | 2.4 | about 4 | .5, 1, 2, 4, 6 | 3 | sun | loam |
| 5. Soil texture | 2.4 | about 4 | 3 | 3 | sun | sand, 9:1 sand to loam, 1:1 sand to loam, 1:9 sand to loam, loam. |

in centimetres and the penetrometer was used to estimate crust stability or the amount of pressure required to rupture it (presumably the greater this strength then the greater the energy required by a germinating seedling to break through the crust).

## FACTORS INVESTIGATED

*Rainfall amount*

Rainfall was simulated using a watering can of $1\frac{1}{2}$ gallons capacity with a 'rose' attached to the spout. Each treatment was replicated twice, water was applied from a common height of three feet and all boxes were left to dry in the sun for six days, and were protected from any falls of rain.

*Length of drying time in shade and sun*

Rainfall was simulated with the same device from the same height, each treatment receiving a uniform application equivalent to 2.4in. One half of the treatment boxes were placed in shade and the rest in the sun to dry for varying lengths of time. Each treatment was replicated twice and water was applied from a common height of three feet.

*Rainfall amount and droplet size*

Rainfall was simulated using the watering can and a one-gallon cylinder spray which produced a fine mist. Each treatment was replicated twice and water was applied from a common height of three feet. All boxes were left to dry in the sun for three days.

*Rainfall kinetic energy*

Rainfall was simulated with the watering can. Water was applied from different heights to represent different kinetic energy levels. The volume of water applied was equivalent to 1.2in rainfall. All treatments were replicated twice and boxes were allowed to dry in the sun for three days before measurements were taken.

*Soil texture*

Different mixtures of soil and sand were prepared. Rainfall was simulated with the watering can. An amount equivalent to 2.4in was applied to each box from a height of three feet. Treatments were replicated twice and boxes were allowed to dry in the sun for three days.

## RESULTS AND DISCUSSION

*Rainfall amount*

Results are shown in Figure 2. Both crust thickness and crust strength increased with an increase in the amount of rainfall. The reading of 1.5lb/in$^2$ recorded for the uncrusted soil receiving no rainfall is a reflection of the amount of

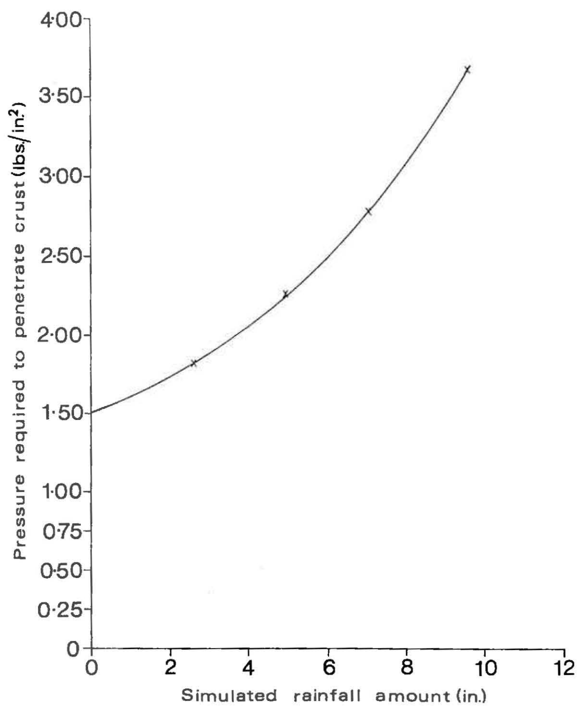


*Figure 2* **Relationship between amount of (simulated) rainfall and crust strength.**

water required to push the piston to the soil surface through several centimetres of soil. As crust thickness increases as the result of larger applications of water so the pressure increases from 1.5 to 3.6lb/in$^2$. The results suggest that the greater the amount of rainfall on an area of bare soil, followed by five or six days of drying, then the harder, thicker and more stable the crust formed on the soil surface. This finding is different from the conclusions of Arndt (1965) who reported "a surprising finding was that where a seal had formed as a result of very different amounts of water, intensities of watering and rates of drying, the force needed to cause emergence of the measuring device probe was approximately constant".

*Length of drying time in shade and sun*

The results are given in Table 2. Although crust strength increased with length of drying time in both maximum insolation (sun) and shade conditions, crust thickness seemed to reach a maximum after one or two days of drying and further drying only strengthened the existing crust. This was probably a reflection of depth

*Table 2* Influence of length of drying time (in sun and shade) on penetrometer readings and crust thickness.

| Days Drying | Sun | | Shade | |
|---|---|---|---|---|
| | Penetrometer readings lb/in² | Crust thickness cm | Penetrometer readings lb/in² | Crust thickness cm |
| 0 | 1.7 | 1–2 | 1.6 | 1 |
| 1 | 3.2 | 2 | 1.8 | 1.5 |
| 2 | 3.9 | 2–2.5 | 2.5 | 1–1.5 |
| 3 | 4.7 | 2–2.6 | 5.0 | 1–1.5 |
| 4 | 5.7 | 2–2.4 | 5.9 | 1–2 |

of drying. After one or two days the layer of soil disturbed by the falling droplets was dry enough to remain compact as a complete crust and further drying only strengthened this layer. After only one day the drying front had not reached the maximum depth of disturbed soil and where measurements were taken immediately after treatment, the crust layer was held together by the forces of compaction only.

### *Rainfall amount and droplet size*

The results in Table 3 demonstrate that the size of droplets is as important as the amount of rainfall. A rainfall of 1.2in falling as a mist with droplets smaller in size than 0.5mm caused no distinguishable crust to form, although the soil was

*Table 3* Influence of rainfall amount and droplet size on penetrometer readings and crust thickness.

| Rainfall Amount inches | Droplet Size mm | Penetrometer Readings lb/in² | Crust Thickness cm |
|---|---|---|---|
| 0 | — | 0.9 | * |
| 1.2 | <0.5 | 1.0 | * |
| 1.2 | 4 | 1.5 | 2.3 |
| 2.4 | <0.5 | 1.6 | 2.4 |
| 2.4 | 4 | 2.0 | 2.6 |

* No measurable crust.

slightly compressed as shown by the increase in the penetrometer reading. If the amount of rainfall is doubled then even the smallest droplet size causes some crusting of the soil. An increase in droplet size to 4mm increased crust thickness by 9% and crust strength by 25%. The increase in crust strength and thickness with increase in droplet size was also a reflection of rainfall intensity. The 1.2in and 2.4in of rainfall applied by cylinder spray took much longer to apply than when a watering can was used to produce the larger droplets. The set of low penetrometer readings was the result of using a set of shallower treatment boxes. This meant that there was less soil for the probe to penetrate, producing lower readings.

### *Rainfall kinetic energy*

Even with the small differences in the height from which simulated rainfall was applied, crust strength and thickness were shown to increase with simulated increases in kinetic energy (see Table 4).

*Table 4* Influence of rainfall kinetic energy on penetrometer readings and crust thickness.

| Height water applied from ft | Penetrometer readings lb/in² | Crust thickness cm |
|---|---|---|
| 0.5 | 1.3 | 1.0 |
| 1 | 1.3 | 1.2 |
| 2 | 1.4 | 1.2 |
| 4 | 1.5 | 1.3 |
| 6 | 1.5 | 1.4 |

*Table 5* Influence of soil texture on penetrometer readings and crust thickness.

| Soil (texture) mix | Penetrometer readings lb/in² | Crust thickness cm |
|---|---|---|
| Soil ... ... ... | 2.5 | 1.5 |
| Soil : sand (9 : 1) | 2.0 | 1.5 |
| Soil : sand (1 : 1) | 1.5 | * |
| Soil : sand (1 : 9) | 1.1 | – |
| Sand .. ... ... | 1.4 | – |

* No measurable crust

### *Soil texture*

Crusts formed where soil and a 9:1 soil-sand mix were used but not with the other treatments (Table 5).

## CONCLUSIONS

The Alafua penetrometer was designed to measure relative differences in crust strength. It is apparent that trends in the relationship between soil crust strength and thickness and a number of crust-forming factors have been demonstrated. The information generated served to identify a number of the factors and to illustrate processes to a soil conservation class. It has been shown that soil crusts become harder in response to increases in the amount of rainfall, length of drying time, droplet size, kinetic energy and an increase in soil silt and clay content. Soil crust thickness was often difficult to measure, but similar trends were apparent.


## ACKNOWLEDGEMENTS

The author wishes to thank Mr W. Cable for assistance with calibration and Mr F. Vitaoa for helping with the design and construction of the instrument. Mr I. F. Faasavalu assisted with the experimental investigations.


## REFERENCES


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

Ellison, W. D., and Slater, C. S., 1945: Factors that affect surface sealing and infiltration of exposed soil surfaces. *Agr. Eng.*, 26: pp. 156-7, 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.

Fiskell, J. G. A., Carlisle, V. W., Kashirad, R., *et al.*, 1968: Effect of soil strength on root penetration in coarse textured soils. *Trans 9th Int. Congr. Soil Sci.*, 1: pp. 793-802.

Reynolds, S. G., and Cable, W., 1970: The Alafua Penetrometer: an instrument for measuring soil crust strength. *S.P.R.C.T.A. Research Paper Series*, 4.

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

Taylor, M. M., and Bruce, R. R., 1968: Effects of soil strength on root growth and crop yield in the Southern United States. *Trans 9th Int. Congr. Soil Sci.*, 1: pp. 802-811.