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# EFFECT OF PHYSICAL PROPERTIES OF CRUST ON KAMPANGSAN SOIL ON THE IMPEDANCE OF EMERGENCE OF CORN SEEDLING

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# Effect of Physical Properties of Crust on Kampangsan Soil on the Impedance of Emergence of Corn Seedling

by

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Changes in physical properties of crust induced on a Ks soil were evaluated in the laboratory. From results of mechanical analysis, it appeared there was a tendency of accumulation of sand at the bottom, silt at the surface, and clay in the middle of the 2 cm. thick crust. Packing of particles was densest at surface of the crust and the density decreased with depth. The average density increased slightly as compared to original soil. Tests on distritbution of pore-size confirmed the profile of bulk density.

A pneumatic penetrometer was developped. It was used satisfactorily to measure penetration resistance of the crust. The penetrometer probe was fabricated to the size and shape of corn coleoptile so that emergence of the probe through crust from underneath simulated that of actual seedlings. Penetration force of the penetrometer increased as crust moisture decreased. The maximum penetration resistance (max.PR) and the penetration energy (PE) both exponentially increased as the crust moisture decreased. Ranges of max.PR and PE were from 2.104 - 40.013 N. and 1.000 - 21.981 N-cm., respectively, in response to change of moisture content from 23. 87 % to 6.41 % by weight. Flex points of the two curves were located at 15 % of moisture content,

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hence it was predicted as the critical moisture for seedling emergence.

Results from corn seedling emergence tests demonstrated that the predicted critical moisture coincided with inhibiting moisture content of the crust. The maximum emergence force exerted by a corn seedling was predicted to be 8.56 N. (0.873 kg.). This value corresponded to an apical pressure of 27.61 bars. Corn seedling to emerge from 2 cm. underneath the Ks soil crust at the critical moisture, it required that 5.32 N-cm. (0.053 Joules) of mechanical energy be spended. Normal ranges of penetration resistance that corn seedling experienced upon emergence tested in this experiment were between 3.22 - 8.56 N. of penetration force and 2.49 - 5.32 N-cm. of penetration energy depending upon moisture content of the crust.

## Introduction

Soils classified as Kampangsan (Ks) series cover large areas of Kampangsan Campus. These soils are potentially productive as far as P and K nutrient contents are concerned. Crop production constraints exists, since hard surface crusts are easily formed. For some reasons the surface aggregates are not stable in water. As it rains or the soils are surface irrigated soil particles disperse and repack resulting in a dense layer a few centimeters thick on the soil surface. This dense layer becomes hard upon drying and therefore form a crust. Severe impedance on emergence of seedlings was observed in the field provided that a short dry spell followed a heavy rain or irrigation.

In this experiment, some physical properties related to strength of the crust were examined. The penetration resistance and the penetration energy exerted by corn seedlings when emerging were predicted by means of a pneumatic penetrometer. Experimental tests on emergence of actual corn seedlings were also performed.

## Literature review

Causes and strength of crusts were studied by Carnes (1934) for several types of soil. It appeared that strength depended to a certain degree on silt content. Changes in physical properties of the crust were observed by Lemos and Lutz (1957). They showed that the fraction of finer particles tended to increase and that larger particles tended decrease in the crust.

A common method to produce crust in the laboratory is to slake soil in water (Carnes, 1934; Lemos and Lutz, 1957; and Morton and Buchele, 1960). Crust prepared differently yielded different strength. High modulus of rupture was the result of surface disturbance (Lemos and Lutz, 1957). Moisture content is another factor governing crust strength; negative; correlations have appeared in several reports (Hanks and Thorp, 1956; Lemos and Lutz, 1957; and Bennette et al., 1963).

Two indices are normally used to describe crust strength. There are the modulus of rupture (Carnes, 1934; Allison and Moore, 1956; Hanks and Thorp. 1956; Hanks and Thorp. 1957; and Lemos and Lutz, 1957) and the penetration resistance (Terry and Wilson, 1953; Hanks and Harkness 1956; Morton and Buchele, 1960; and Drew et at.,1971).



Morton and Buchele (1960) and Drew et al. (1971) fabricated a penetrometer probe and penetrated it upward through the crust to simulate a corn seedling emerging. Emergence force of seedling may be measured directly with a ring-force transducer (Drew et al., 1971 and Rathore et al., 1981).

It appeared in several reports that instantaneous thrust exerted by plant seedlings depended on species and existing crust strength. For example, a thrust of 0.6 lb. (2.7 N.) was reported for cotton (Drew et al., 1971), while a 50 % reduction in emergence rate of the same species was predicted to be 1.6 lb. (7.1 N.) of crust strength (Bennette et al., 1963). Reduction on emergence at the same rate for sorghum was found at 500 mbars modulus of rupture (Hanks and Thorp, 1957). Rathore et al. (1981) found the maximum thrust for soybean seedlings to be between 127 - 190 g. (1.25 - 1.86 N.) depending on species.

Size of laboratory experiment on emergence of seedling are often limited (Hanks and Thorp, 1956 and Bennette et al., 1963). Limitation dues mainly to difficulties in preparating crusts. Controversies were reported concerning the effect of depth of seed on emergence (Hanks and Thorp, 1957; Morton and Buchele, 1960; and Drew et al., 1971).

## Materials and method

### The pneumatic penetrometer

Assembly of pneumatic penetrometer is shown in fig. 1. The penetrometer probe was fabricated to be the average size and shape of corn coleoptile (0.2 cm. in diameter, 4.3 cm. in length, solid brass cylinder) except that it had a flat tip. This instrument was operated with the pressure manifold of a pressure membrane apparatus. As compressed air was regulated through a set of two regulators into the chamber, thrust created caused the piston (and the probe) to move against friction and spring recoil (the total resistance). The total resistance was evaluated as the penetrometer operated with no load and was then established as a linear function of probe displacement. Total resistance could be predicted at a given displacement by the use of a calibration equation (eqn.3) and be used as subtrating element of the air thrust as the net force at the probe tip was to be calculated (eqn.4). The range of validity of measurement was tested with a 2 kg. (19.62 N.), 0.1 g. sensitivity, top loading balance.

Preparation and tests of the crust

Soil was sieved through a 0.5 mm. sieve. Crust preparation was done in a box (fig. 2 a) by addition of water to the field capacity plus puddling while the surface was wet. Crusts of different moisture were obtained by varying time of evaporation in the laboratory. Test for penetration resistance was done on a test bench (fig. 2 b). Selected crust was wrapped with a sheet of aluminum foil, 2 holes (1 cm. diameter) being cut on the opposite sides to allow passage of the probe. The crust was laid upside-down on the bench, holes being alligned, as the probe moved through it.

The following physical properties were evaluated;

Particle density was evaluated by the method providing replacement of soil air by water plus boiling (pycnometers method)



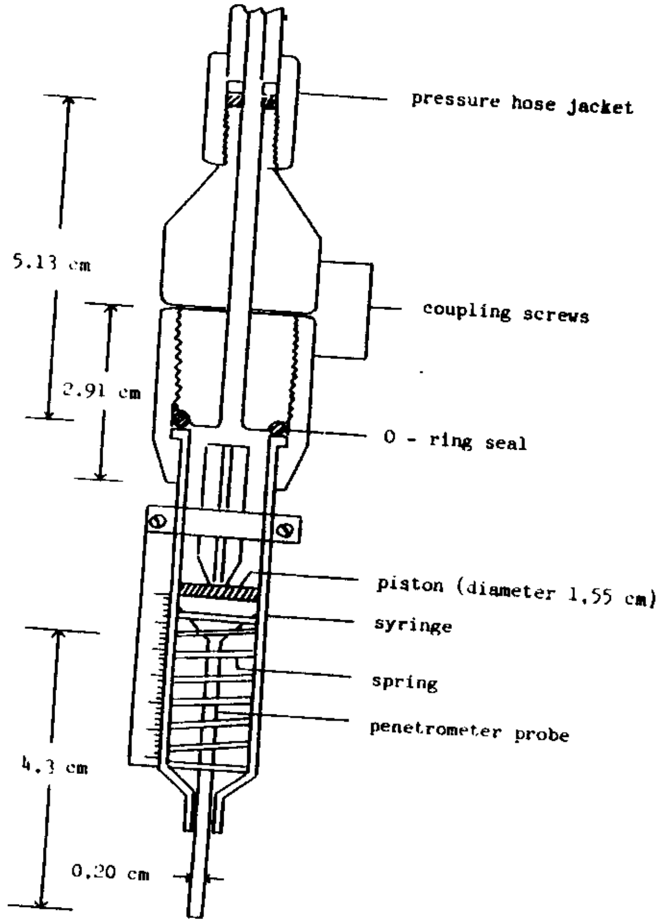


Figure 1. The pneumatic penetrometer assembly.

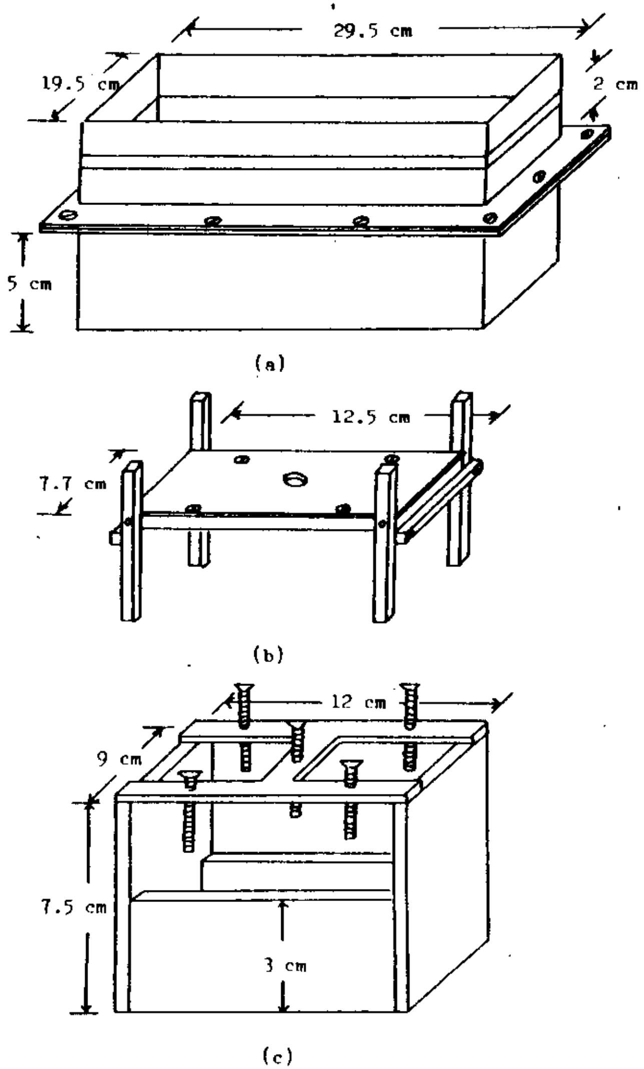


Figure 2. (a) The crust preparation box (b) the test bench,and (c) the press bed.



Moist bulk density (Dbm) was determined at existing field moisture content (around field capacity) by the undisturbed core method. Dry bulk density (Dbd) was determined using oven-dried clod and the paraffin method. The moist and dry bulk densities were measured also for the crust plate. The ratio of Dbm/Dbd of the plate was regarded as a conversion constance in order to transform Dbd of crust slices into Dbm. Composite samples of crust slices, 0 - 0.5, 0.5 - 1, 1 - 1.5 and 1.5 - 2 cm. depth intervals were collected for evaluation of the remaining properties.

Mechanical analysis was done by conventional pipette method. Time intervals of suspension sampling ranged from 5 sec. to 48 hr. grading the particles 0.1340 - 0.0007 mm. in equivalent sphrerical diameter.

Moisture characteristics was obtained at 6 pressure increments, from $\frac{1}{3}$ to 15 atm. Saturation pore diameter (d) in microns corresponding to a pressure (P) in atm. was estimated from,

$$d = \frac{0.3 \times 10^4}{1033\ P} \qquad (1)$$

The volume percentage of pores smaller than d, X was estimated from,

$$X = \frac{\theta v}{E} \times 100 \qquad (2)$$

where $\theta v$ = moisture content by volume,and

$E$ = total porosity of the moist soil

### Seedling emergence test

Impedance of crust on emergence of corn seedlings was tested in a press bed (fig. 2 c). Foundation soil, the size of the frame, was wrapped with aluminum foil. Six holes were punctured through the foil, 3 each in two rows, and germinating corn seeds (var. Suwan 1) were embedded in them. A perfect crust plate was laid on top of the foundation soil and pressed firmly by means of screws. The whole unit was kept in a moist plastic bag for 7 days before emergence count. Remnants of crust plate were collected for moisture determination.

## Results and Discussion

### Physical Properties

Listed in table 1 were the physical properties examined. Soil textural class was clay loam, moderately high in silt content. Particle packing in field condition yield a bulk density of 1.305 $g/cm^3$ when the soil was moist. The value increased to 1.561 $g/cm^3$ corresponding to 18 % of volumetric shrinkage upon drying. The Ks surface soil contained appropriate ratio of pores of different size, i. e., the macro -/ capillary -/ micropores in the order 29.75/ 41.25/ 29.00



Table 1. Physical properties of soil crust as compared to the original (Ks) soil.

| Physical property | Depth interval (cm.) 0 - 0.5 | 0.5 - 1 | 1 - 1.5 | 1.5 - 2 | original soil |
|---|---|---|---|---|---|
| Particle - size distribution (%) | | | | | |
| 0.5 - 0.02 mm. | 40.00 | 42.50 | 39.50 | 43.00 | |
| 0.02- 0.002 mm. | 28.10 | 23.25 | 26.25 | 24.00 | 25.40 |
| < 0.002 mm. | 31.90 | 34.25 | 34.25 | 33.00 | 33.35 |
| Moist bulk density | 1.389 | 1.339 | 1.302 | 1.297 | 1.305 |
| Dry bulk density ($g/cm.^3$) | 1.661 | 1.602 | 1.558 | 1.552 | 1.561 |
| Moist state total Porosity, E (%) | 45.7 | 47.65 | 49.10 | 49.30 | 48.98 |
| Dry state total porosity, E (%) | 35.07 | 37.37 | 39.09 | 39.38 | 38.98 |

Table 1 (continued)

| Physical properties | Depth **interval**(cm.) | | | | original soil |
|---|---|---|---|---|---|
| | 0 - 0.5 | 0.5 - 1 | 1 - 1.5 | 1.5 - 2 | |
| Volume percentage of pores with respect to total moist state pores (%) | | | | | |
| > 10 microns | 24.75 | 28.25 | 30.30 | 33.00 | 29.75 |
| 10 -0.2 microns | 39.45 | 38.85 | 39.70 | 38.75 | 41.25 |
| <0.2 microns | 35.80 | 32.90 | 30.00 | 28.25 | 29.00 |
| Soil moisture characteristics | | | | | |
| neg. $\phi_s$ (atm) | ........ | ........ | θv (%) | ........ | ........ |
| $\frac{1}{3}$ | 34.18 | 33.76 | 33.44 | 32.43 | 33.50 |
| 1 | 30.30 | 28.05 | 26.29 | 26.66 | 27.80 |
| 3 | 23.73 | 20.91 | 20.66 | 20.59 | 20.00 |
| 5 | 20.88 | 18.75 | 18.01 | 18.32 | 17.50 |
| 10 | 27.93 | 16.80 | 15.78 | 15.38 | 15.60 |
| 15 | 16.20 | 15.60 | 14.65 | 13.76 | 14.00 |
| Available water content (AWC) | 17.98 | 18.16 | 18.79 | 18.67 | 19.50 |



on percentage basis (table 1 and fig. 4). Plant available water content was 19.50% as estimated from the moisture chracteristics. All physical data tended to indicate that the soil was suitable as a growing medium of seeds.

Stratification into layers was formed in the crust as it was induced on soil surface (table 1, figs. 3, and 4). It seemed that the crust was divided into 2 layers at 1 cm. depth. The unintended division might occur by puddling. Discarding the appearance of this boundary, it seemed that sand was accumulated at the bottom (0.5 - 1 and 1.5 - 2 cm. depth intervals) and silt in the surface (0 - 0.5 and 1 - 1.5 cm. depth intervals) of the crust plate. Clay, on the other hand, accumulated in the middle of the crust. This phenomena could be explained by the fact that as soil particle dispersed, faster settling velocity of sand caused it to lay underneath silt. Clay to settle at the slowest velocity ought to accumulate on top of the others unless it had size smaller than voids between silt and sand. It appeared that clay could be leached down to a certain depth through voids. Crust appeared to be densest at it's surface and the density decreased with depth (table 1). Packing density of soil particles in the crust was confirmed by pore-size distribution (fig. 4). Bulk density of the crust plate slightly increased as compared to the original soil at the same moisture content.

Performance of the pneumatic penetrometer

The relationship between total resistance (friction+spring recoil) and probe displacement is shown in fig. 5. Total resistance (R) in Newtons could be described as a linear function of displacement (X) in cm. as followed,

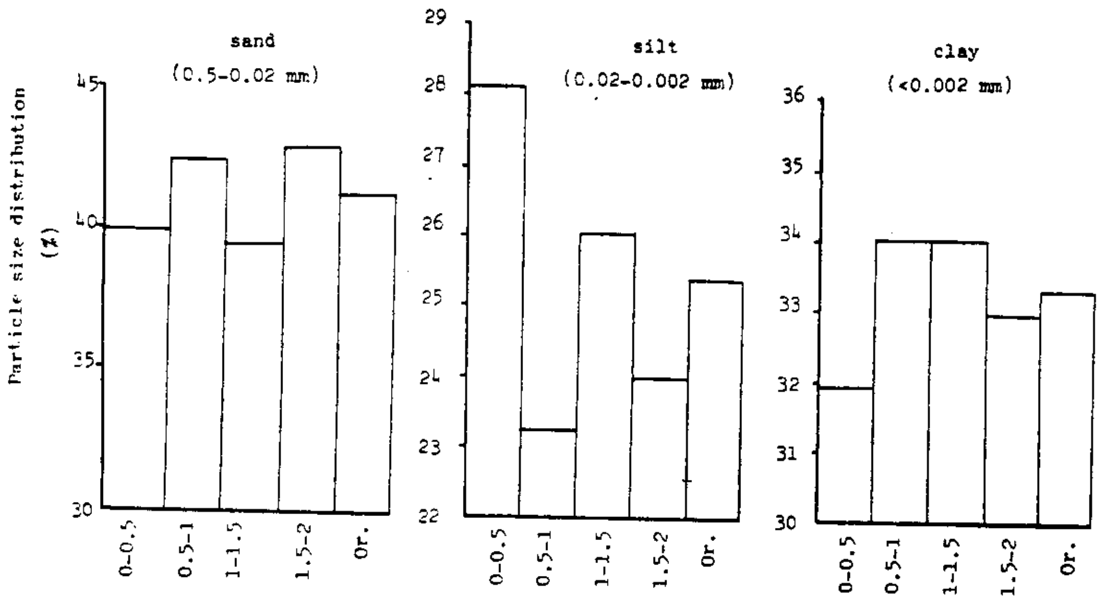


Figure 3. Particle - size distribution in crust slices, 0 - 0.5, 0.5 - 1, 1 - 1.5, and 1.5 - 2 cm. intervals as compared to the original Ks soil.



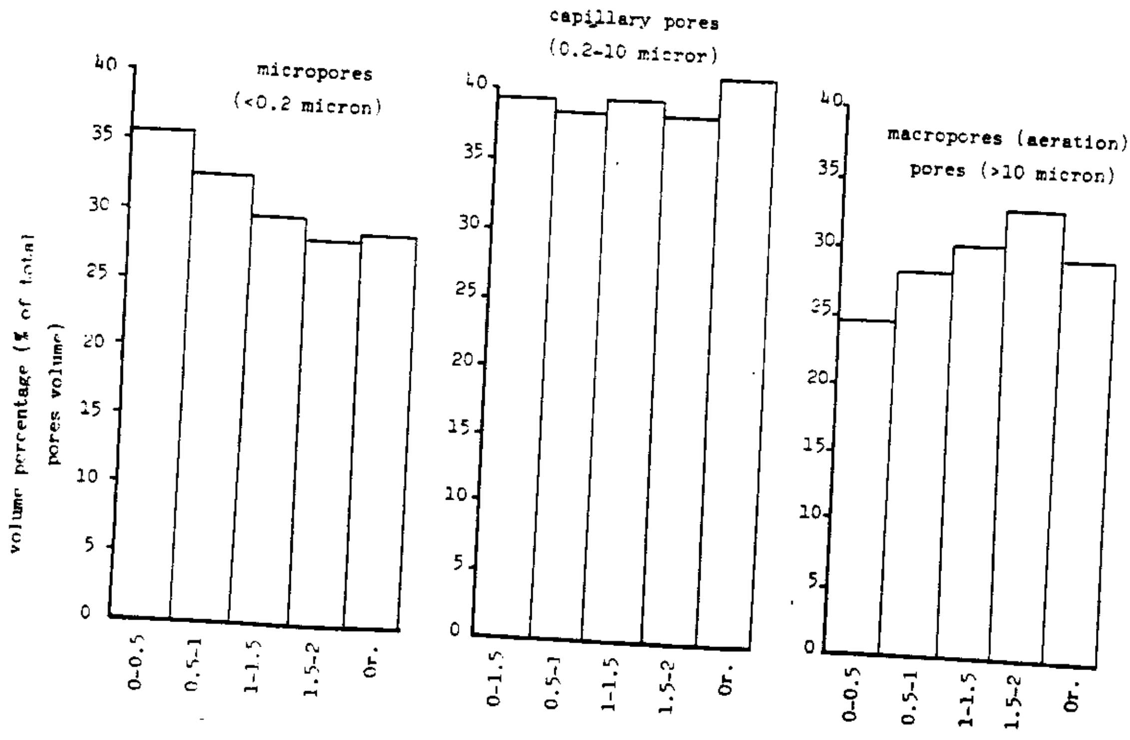


Figure 4. Pore - size distribution in crust slices, 0 - 0.5, 0.5 - 1, 1 - 1.5, and 1.5 - 2 cm. intervals as compared to the original Ks soil.

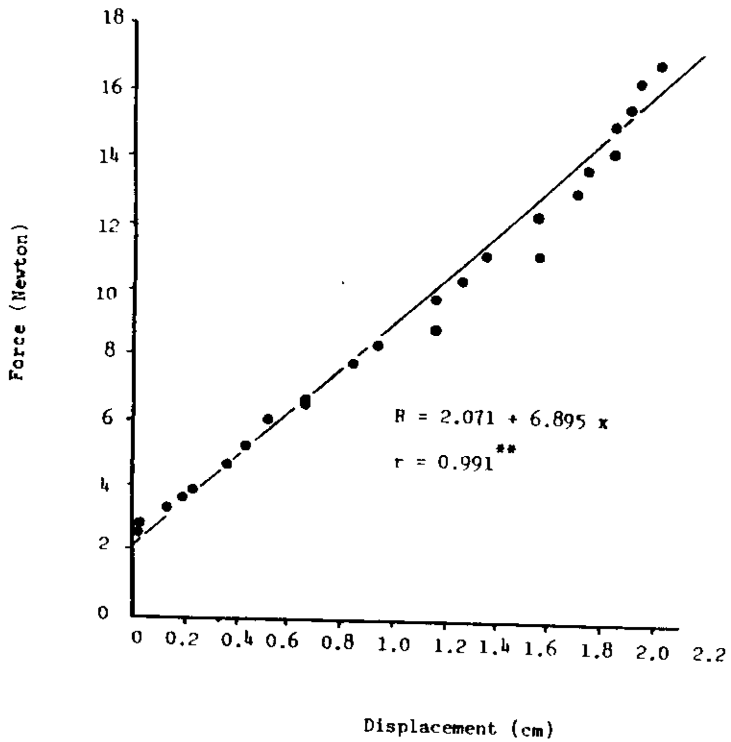


Figure 5. Relationship between the total resistance (R) in Newtons and the displacement (X) of the penetrometer probe in centimeters.



$$R = 2.071 + 6.895 X; \; r = 0.991^{**} \qquad (3)$$

Deduction from which, the friction and the spring constance were 2.071 N. and 6.895 N/cm., respectively.

As the penetroneter was operated against load, the net force (F) at the probe tip was the difference between the air thrust and the resistance. In other words,

$$F = 4.446 \, PA - R \qquad (4)$$

P and A represented air pressure (psi) and area of the piston (in.$^2$), respectively. The coefficient of the first term on the right of equation (4) was the conversion factor from lb. to N.

Substitution for values of R and A, equation (4) became,

$$F = 1.298 \, P - 6.895 \, X - 2.071 \qquad (5)$$

Equation (5) was used to estimate the net force at the probe tip from displacement of the probe and air pressure in piston chamber.

Fig. 6 illustrated the relation between the force being calculated and the corresponding load as thrust was applied against the balance pan. A very close to one-to-one relationship indicated that the penetrometer could be used with confidence for measurements of crust penetration resistance.

Penetration force as the probe penetrated through the crust at different moisture contents was plotted against depth of penetration (fig. 7 a and b). Failure characteristics was noticed to depend on crust moisture. For moisture contents higher than 12.73% crust appeared to bear

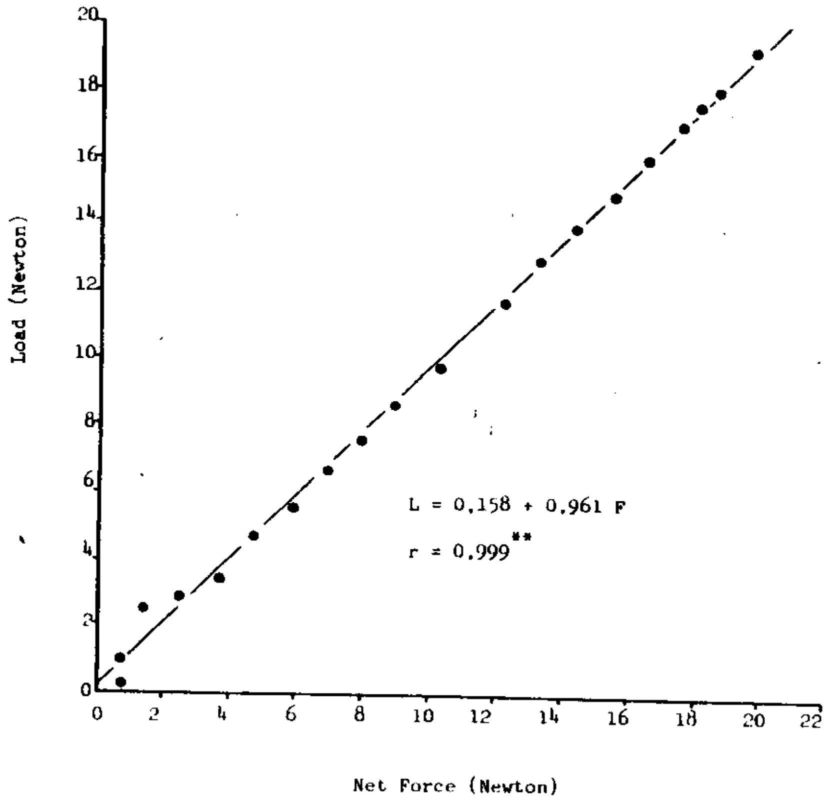


Figure 6. Validity test of the pneumatic penetrometer. Load was measured by 0.1 g. sensitivity electrical balance and net force was calculated by equation (5).



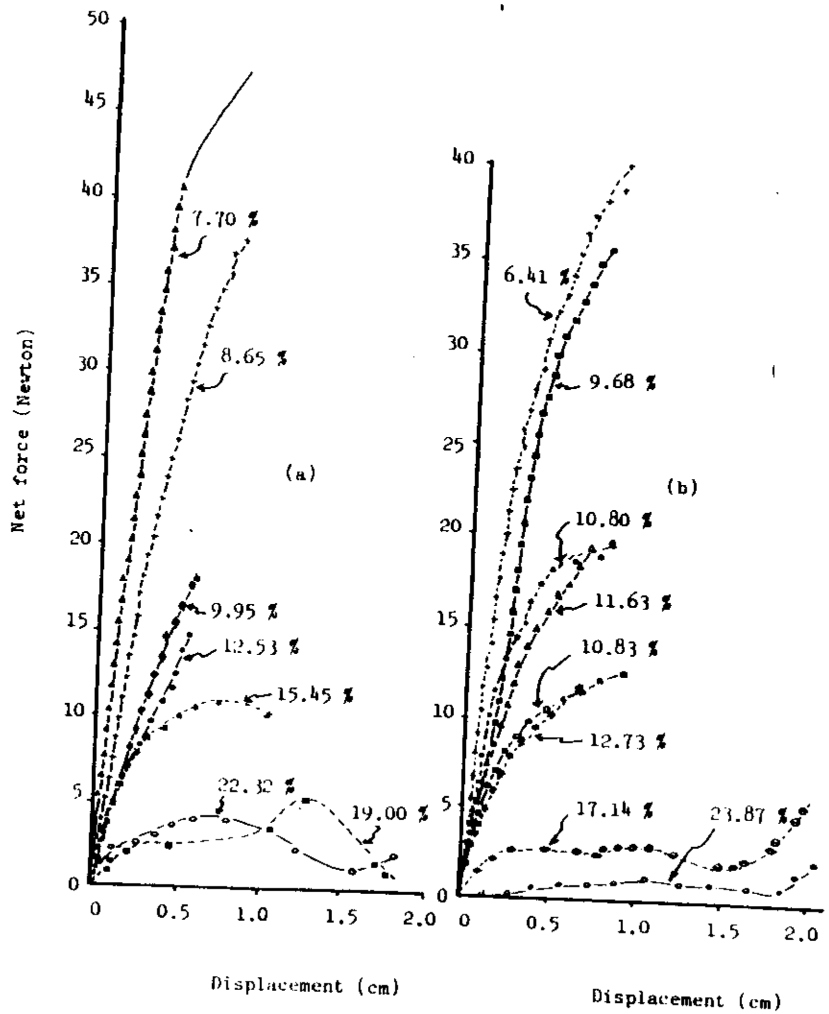


Figure 7. (a) and (b). Development of penetration force as penetrometer probe moved in the upward direction into the crust at different moisture contents.

some resistance after sheared. At this moisture content and lower, the crust sheared abruptly after the maximum penetration force was obtained. The remaining resistance in the former case was suspected as friction between adhered soil mass to the metal skin and that in the travelling path of the probe. Also it might be observed that for moisture contents lower than 17.14%, thrust per unit increment of depth increased significantly.

In order to demonstrate the effect of crust moisture on emergence force of the probe the maximum penetration resistance (max. PR) was plotted against moisture content (θw) (fig. 8). The exponential increase of max. PR upon reduction of crust moisture could be described by,

$$\ln(\text{max. PR}) = 8.327 - 2.272 \ln(\theta w); r = 0.958^{**} \quad (6)$$

The mechanical energy required for emergence of the probe was defined as the area underneath the penetration force-displacement curve from zero displacement (2 cm. depth) to shearing position. The penetration energy (PE) was then plotted against crust moisture (fig. 9). The same trend as above was observed in this case. The nagative exponential relation of PE on θw could be represented by,

$$\ln(\text{PE}) = 6.465 - 1.762 \ln(\theta w); r = 0.830^{**} \quad (7)$$

Ranges of max. PR observed was 2.104 - 40.013 N., and 1.000 - 21.981 N - cm. for PE in response to reduction of moisture from 23.87% to 6.41%. At 6.41% of moisture it required a thrust equivalent to a pressure as high as 129.07 bars to push a cylindrical object through the crust. It was observed that moisture content at the flex points on the two curves



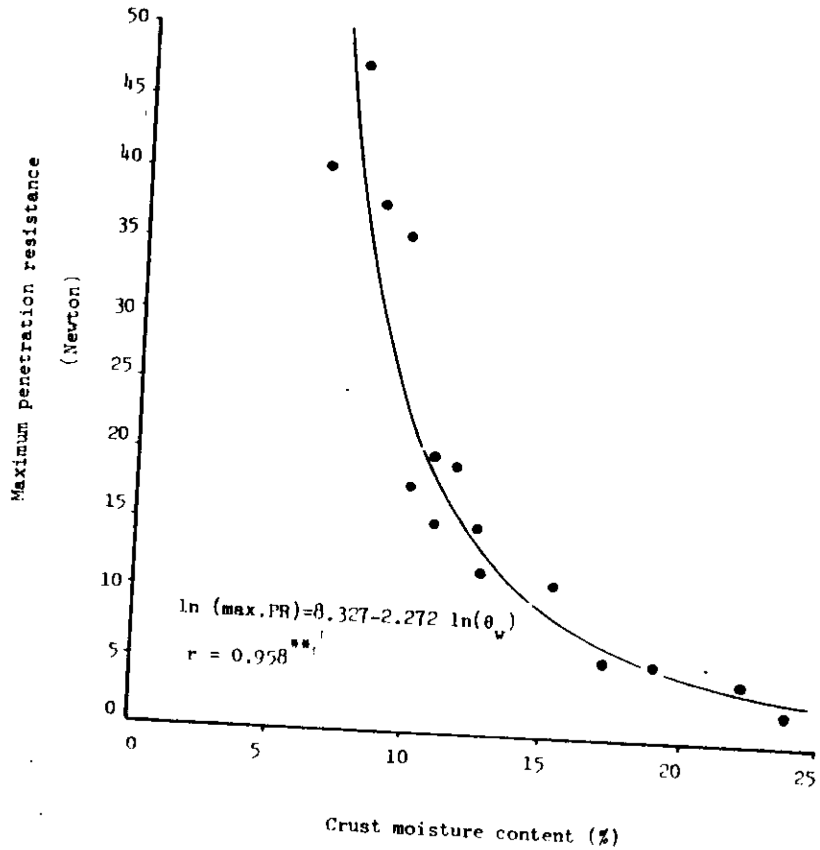


Figure 8. Dependence of the maximum penetration resistance (max. PR) on moisture content of the crust (θw).

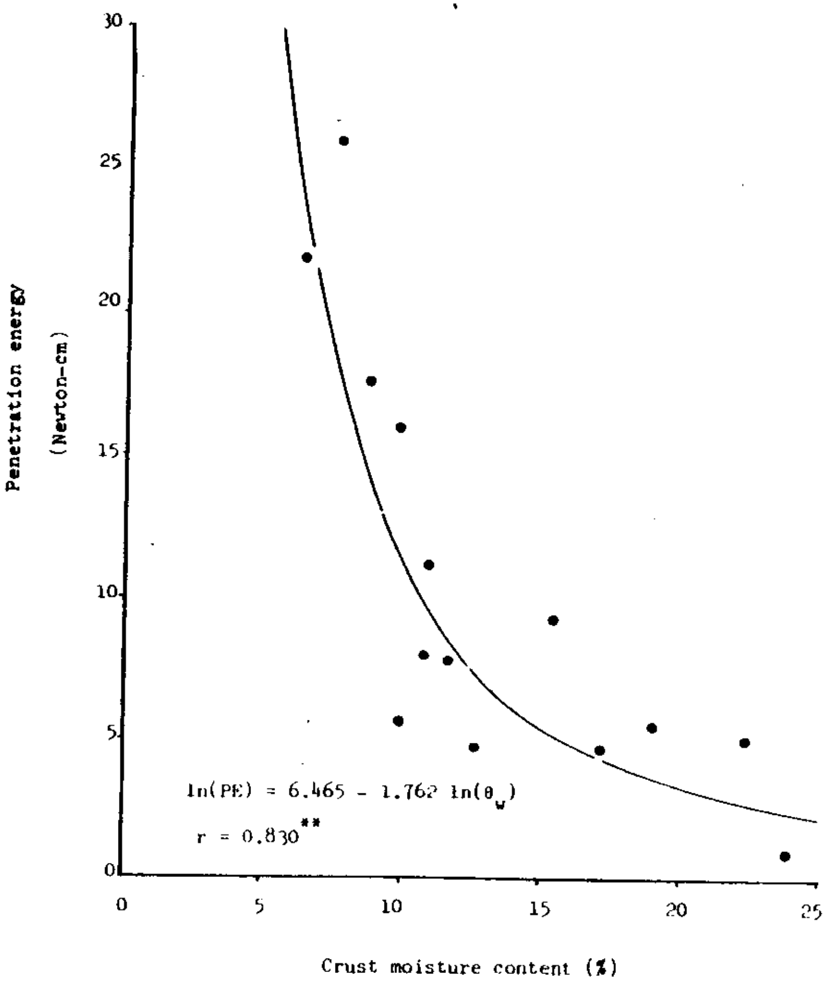


Figure 9. Dependence of the penetration energy (PE) on moisture content of the crust (θw).



was around 15%. Since this value denoted a sharp increment of the resistance, it seemed likely to be a critical moisture for seedling emergence.

Results of emergence test of corn seedling given in table 2 revealed that impedance began as crust moisture decreased to 20.87% and be pronounced at 15.18%. The critical moisture for emergence happened to coincide with the moisture content at flex points of the max. PR and PE curves. At this critical moisture a corn seedling managing to emerge under the crust must exert a thrust of 8.56 N. or an equivalent apical pressure of 27.61 bars. Corn seedlings must also develop a mechanical energy of 5.32 N - cm. (0.0532 Joules) for emergence from 2 cm. underneath the crust at the critical moisture. These values were predicted from equations (6) and (7), respectively, and were assumed to be the limits for corn seedling emergence, Comparing to the values of 7.1 N. for 50% reduction of cotton seedling emergence (Bennette _et al_., 1963) and the maximum emergence force between 1.24 - 1.86 N. of soybean seedlings (Rathore _et al_., 1981). should it be if the area of emerging organs of cotton and soybean seedlings were 2 and 4 times the area of the probe tip used in this experiment, the estimated apical pressure of the two species were 11.45 and 1.25 bars, respectively. Corn seedlings appeared to endure a higher magnitude of crust impedance.

Conclusion

The Ks soil crust was noticed to be stratified as it was induced on soil. Sand had a tendency to be accumulated at the bottom,

Table 2. The impedance of soil crust on emergence of corn seedling.

| Moisture (% by weight) | max. PR (N.) | Penetration pressure (bars) | PE (N - cm.) | No. fo emerged corn seedlings.* |
|---|---|---|---|---|
| 9.08 | 27.52 | 88.78 | 13.16 | 0 |
| 13.81 | 10.61 | 34.23 | 6.29 | 1 |
| 15,18 | 8.56 | 27.61 | 5.32 | 0 |
| 20.87 | 4.15 | 13.39 | 3.04 | 4 |
| 23.35 | 3.22 | 10.38 | 2.49 | 6 |

$\ln(\text{max. PR}) = 8.327 - 2.272 \ln(\theta w)$

Penetration pressure = 3.226 (max. PR), bars

$\ln(\text{PE}) = 6.465 - 1.762 \ln(\theta w)$

*out of a total of 6 sprouting seeds



silt at the surface, and clay in the middle of the crust plate. Bulk density was highest at surface of the crust and decreased with depth. Pore-size distribution data confirmed the density of particle packing.

Penetration resistance was evidently controled by crust moisture, The maximum penetration resistance and the penetration energy were found exponentially increased as crust moisture decreased. Flex points on the two curves occured at the moisture content at which the emergence of corn seedlings was inhibited.

The results of emergence test suggested that the moisture of surface layer of this soil must be kept higher than 20% during emergence of corn seedlings. This might be accomplished by frequent watering, mulching, or applying soil surface with chemicals of high hygroscopicity. Emergence and growth of seedlings in the field might be simultaneously controled by factors including climate, practices, and the soil itself. Impedance by surface crust is among those factors.

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