Soil Physical Properties and Machine Performances

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The measurements of soil physical properties are not clear at present, and moreover the measuring techniques themselves are not established and standardized yet.

Furthermore, soil measurement must not be finished simply as measurement of soil, but it is necessary to clarify the effects of soil properties on the performance of agricultural machines.

As the relations between soil properties and machine performances are not clarified yet, it is impossible to apply a test result obtained at a certain district to other districts. This makes it difficult to establish the general theory on machine performances in spite of a number of similar tests conducted in many places.

By making clear the relation between soil and machine, it will be possible (1) to predict the machine performance in any soil condition, (2) to design or select the machine which will exhibit the required performance in any given soil condition, and (3) to compare the test result on a certain soil condition with the ones on different soil conditions.

SR-2 soil resistance tester

The requirements for *in situ* soil measuring instrument are as follows:

1) The measured value should have close correlation with machine performance.
2) It should be able to express soil properties by a single value (except for theoretical analyses).
3) The instrument should be as simple as possible.
4) It should be able to make a number of measurements in a short time.
5) It should have a rugged construction and be able to be used in muddy condition.
6) Personal effect should be least.
7) The treatment of data should be easy.

The following methods are widely adopted at present for measuring soil physical properties *in situ*.

Cone—static or dynamic penetration.
Plate—rectangular or disk.
Shear—vane, ring, truss, etc.
Simple method—footprint depth, finger or pencil penetration.

A measuring instrument called SR-2 soil resistance tester (Fig. 1), which is portable and can be operated simply and rapidly, was devised at the Institute of Agricultural Machinery[1]. It can be used for measuring cone penetration (top angle 30°, base area 2 and 6 cm^2), rectangular plate sinkage (25×100 and 50×100 mm), and shear and frictional resistance (ring type). The length of the instrument is 65 cm and weight is 6.4 kg.

The conversion of cone index (soil resistance to cone penetration divided by cone base area) between different size of cone with the same top angle (30°) can be done by the following equation:

$$C_i = C_{i_0} + 2.7\left(\frac{1}{A} - \frac{1}{A_0}\right) \qquad (1)$$

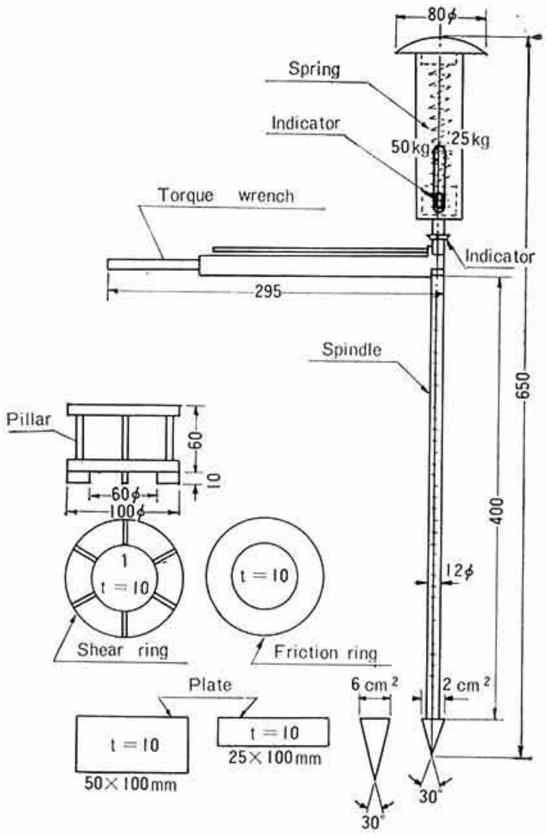

Fig. 1. SR-2 soil resistance tester

where c_i : cone index (kg/cm²) when base area is A (cm²)

C_{io}: cone index (kg/cm²) when base area is A_o (cm²)

Shear or frictional resistance can be calculated from ring torque by the following equation:

$$S=\frac{300\,T}{2\pi(r_1^3-r_2^3)}\doteqdot\frac{T}{2} \qquad (2)$$

where, S: shear or frictional resistance (kg/cm²)

T: torque (kg/cm²)

r_1: outer diameter of ring=5 cm

r_2: inner diameter of ring=3 cm

Field test

The relation between machine performances and soil constants measured with this instrument are as follows:

Trafficability

The cone index has a hyperbolic relation with the sinkage of tractor, and the rectangular plate sinkage has a linear relationship[3]. Thus, knowing the cone index or plate sinkage, the trafficability of tractor can be predicted from Table 1.

Traction

The relationship between soil constants and the traction performance of tractor on four

Table 1. Prediction of trafficabillity[3]

Instrument	Operation	Trafficability		
		Easy	Possible	Impossible
Cone Index (kg/cm²)	Rotary tilling	More than 5.0	2.5～5.0	Less than 2.5
	Plowing	More than 6.5	4.0～6.5	Less than 4.0
	Plowing (with girdle)	More than 3.5	2.0～3.5	Less than 2.0
Plate Sinkage (cm)	Rotary tilling	Less than 6.0	6.0～10.5	More than 10.5
	Plowing	0	0 ～3.0	More than 3.0
	Plowing (with girdle)	Less than 3.5	3.5～11.0	More than 11.0

Note: Cone: top angle 30°, base area 2 cm², mean value in the range of 0 to 15 cm depth

Plate: rectangular plate 10×2.5 cm, pressure 1.6 kg/cm²

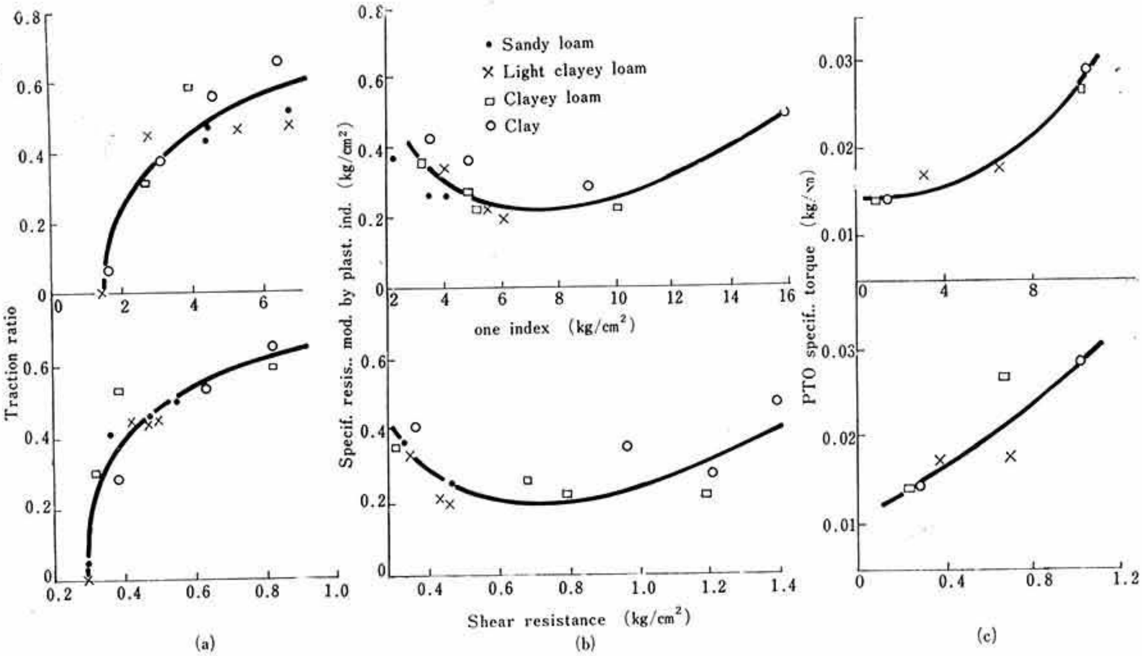

Fig. 2. Relation between soil constants and power requirements[2)]

different types of soil are shown in Fig. 2(a). The traction performance is represented by the traction ratio (drawbar pull divided by tractor weight) at 50 per cent travel reduction, which is considered as the practical limit, for the purpose of expressing by a single value. The relations between traction ratio and cone index and shear resistance are expressed by the following equations in the case of high lug tire:

$$T_r = 0.65 - \frac{0.87}{C_i^3} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (3)$$

and

$$T_r = 0.65 - \frac{0.016}{S^3} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (4)$$

where, T_r : traction ratio (at 50% travel reduction)

C_i : cone index (kg/cm²)

S : shear resistance at 25 kg normal load (kg/cm²)

Fig. 3 shows the same relationship comparing the ordinary and the high lug tires. It shows clearly the difference by lug height

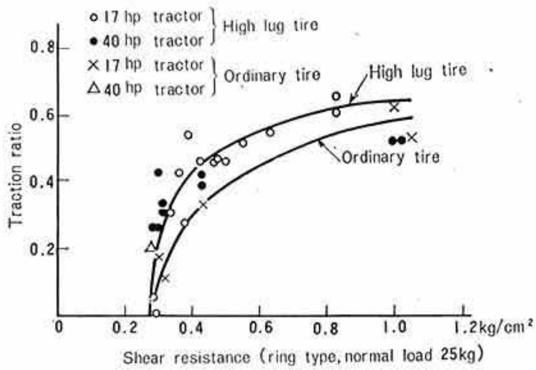

Fig. 3. Relation between traction ratio and shear resistance

without being disturbed from types of soil and tractor. The equation for the ordinary tire is

$$T_r = 0.65 - \frac{0.058}{S^2} \quad \cdots\cdots\cdots\cdots\cdots \quad (5)$$

Plowing

The specific resistance of a bottom plow (16″×1) in four different types of soil of various water contents were plotted against cone penetration, rectangular plate sinkage and shear resistance, but the curves for each types of soil did not coincide with each other.

By examining more precisely, it was found that the specific resistance is larger when the soil contains more clay.

On the basis of this fact, by trying to multiply the content of soil particles smaller than 0.005 mm of diameter to the specific resistance of plow, the curves coincided independent of soil types.

Consequently, by knowing the clay content of soil, the specific resistance of plow can be predicted by measuring the cone index or shear resistance.

However, as the measurement of clay content *in situ* is not easy, utilization of plasticity index which is considered to be easier in measuring was devised.

Relationship between clay content and plasticity index is as follows:

$$I_p = 0.8C - 4.5 \quad \ldots\ldots\ldots\ldots\ldots \quad (6)$$

where, I_p: plasticity index (%)

C : clay content (%)

Thus, the specific resistance modified by plasticity index is expressed by

$$F' = F\left(1 - \frac{I_p + 4.5}{80}\right) \quad \ldots\ldots\ldots\ldots \quad (7)$$

or

$$F = \frac{80\,F'}{75.5 - I_p} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

where, F : specific resistance of plow (kg/cm²)

F': specific resistance of plow modified by plasticity index (kg/cm²)

The relations between cone index or shear resistance and specific resistance of plow modified by plasticity index are shown in Fig. 2(b) and are expressed by the following equations:

$$F' = \frac{C_i^2}{600} + \frac{1}{C_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

and

$$F' = \frac{S^2}{5} + \frac{1}{10\,S} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

The procedure for predicting the specific resistance of plow is as follows: Cone index or shear resistance is first measured and the specific resistance modified by plasticity index F' is obtained from eq. (9) or (10), or from Fig. 2. The specific resistance F can be calculated from eq. (8) by knowing F' and I_p.

Rotary tilling

The specific torque in PTO shaft (torque divided by sectional area of tilled soil) when the tractor is used for rotary tilling operation in three types of soils of various water contents in relation to cone index and shear resistance is shown in Fig. 2(c) and can be expressed by the following equations:

$$T_s = \frac{C_i^2}{7,000} + 0.013 \quad \ldots\ldots\ldots\ldots\ldots \quad (11)$$

and

$$T_s = \frac{S^{1.5}}{56} + 0.013 \quad \ldots\ldots\ldots\ldots\ldots \quad (12)$$

where, T_s : specific torque in PTO shaft (kg-m/cm²)

Conclusion

The trafficability and the traction ratio of tractor, the draft of plow and the torque of rotary tiller can be predicted fairly well from cone index, plate sinkage or shear resistance of the soil.

References

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3) Kokubun, K.: Relations between trafficability and physical properties of soils in paddy field. *JARQ*, 5(3), 33–37 (1970).