Relations Between Trafficability and Physical Properties of Soils in Paddy Field

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The migration of laborers from rural to urban areas has caused an acute shortage of farm hands and simultaneously workers' wages have skyrocketed year by year in Japan.

On the other hand, more farmers have taken side jobs to augment their income. Therefore, mechanization of agriculture has been making remarkable progress to help facilitate labor dearth in agriculture.

In the past few years, the number of tractors has increased rapidly in conjunction with the paddy fields becoming larger in size by its land adjustment works.

The tractors are mainly used for levelling the ground, shirokaki (puddling) and plowing in the paddy fields.

Because paddy fields are inundated in summer time, they are not necessarily under suitable conditions for mechanized farm work compared with upland field. The physical conditions of the soil would immediately affect work efficiency. Therefore, it is necessary to know beforehand whether or not the soil condition is suitable for mechanized work prior to starting work. It is important to have a simple method to judge trafficability for this purpose.

Experiment research organs of the Ministry of Agriculture and Forestry conducted studies on readjustment of paddy fields using large-type tractors from 1964 for four years. Part of these studies was focused on the "relation between trafficability and physical properties of soils in the paddy field" to seek the standard for judging trafficability of tractors based on many measurement data.

The result of experiments are described as follows:

1) Purpose and experiment procedure

Studies on trafficability and development of soil gauge have already been made by Nagasaki, Tanaka[3),4),5)] and Kisu.[2)] However, since no wide range research has been made on the subject, the following experiments were conducted on representative soil types all over Japan.

The tractors used for the experiment were principally 30~40 ps. wheel and crawler types. For travel equipment girdles and half trucks were also employed. The main work process undertaken in the experiment was plowing (araokoshi) paddy field using bottom plow and rotary. Therefore, repetition of such work processes as crushing of clod, levelling of ground and turning tractors were excluded.

The cone index, rectangular plate sinkage, shear resistance, etc. are measured using the SR-2 type soil resistance tester developed by the Agriculture Mechanization Research Institute.

As to the quality of work, depth of plowing, breadth of plowing, travel reduction ratio, sinkage of running gear speed of work, etc. were gauged.

2) Relation between sinkage and travel reduction ratio of running gear

The driving force of tractors will depend on the vehicle condition, physical conditions of the paddy field, characteristics of the soil, etc. irrespective of wheel sinkage.

In the case of the paddy field where sinkage is great, traction of the tractor is the difference between the tractor's driving force and travelling resistance.

There is correlation between travelling resistance and the depth of sinkage. In propelling without load travelling is possible when tractor's driving force is greater than travelling resistance.

The relationship between sinkage and the travel reduction ratio of running gear of the wheel-type tractor for self-propelled without load is shown in Fig. 1.

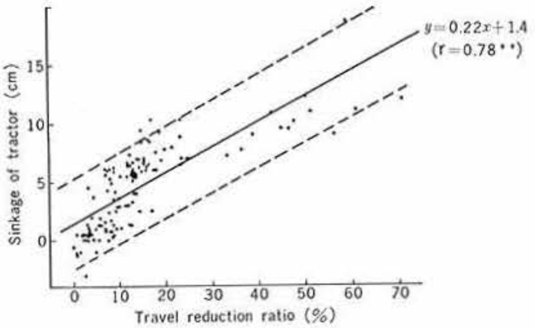

Fig. 1. Relation between sinkage of wheel tractor and travel reduction ratio for self propelled without load.

An approximate linear relationship is observed and correlation coefficient is +0.78, i.e., generally when sinkage of the running gear increases, travel reduction also rises.

Since sinkage is based upon lug base, there can be cases when sinkage is minus quantity. The broken line indicates the upper and lower limit of 90% significant level.

In the case of the wheel tractor, when sinkage of the tractor is less than 5 cm, the travel reduction ratio does not exceed 20% so it is possible to travel. However, when it exceeds 10 cm, the travel reduction ratio becomes 40% with much variation; thus, it is practically impossible to travel.

In order to limit the travel reduction ratio to less than 10%, it is necessary to keep sinkage less than 3 cm. Generally, the lines which indicate the relationship between sinkage and the travelling reduction ratio at the time of travelling for propelled without load and rotary tilling are considered to cross each other. It is considered that the reason why there is less travelling reduction ratio for the same sinkage, in the case of rotary tilling compared with plowing, is because of the propulsion of its tilling blade. Plowing operation is possible when the following relationship is maintained: Driving force−a travelling resistance=traction> working resistance.

3) *Relation between sinkage of tractor and cone index*

The relationship between the cone index and sinkage of the tractor shows minus correlation. As the cone index becomes smaller, sinkage augments and it increases rapidly over the certain value of the cone index.

As shown in Fig. 2, in the case of travelling

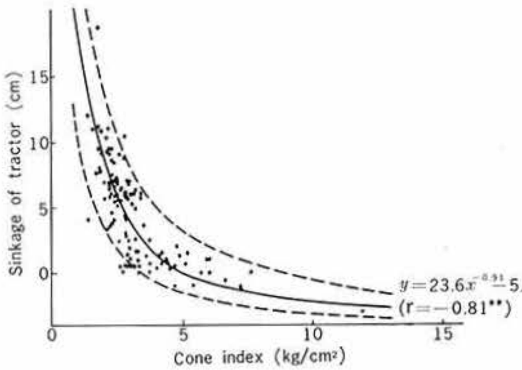

Fig. 2. Relation between sinkage of tractor for self propelled without load and cone index.

of the wheel-type tractor for propelled, the relation between the cone index and sinkage is hyperbola.

In the case of half truck and crawler, farm work is possible when the cone index is smaller than in the case of the wheel-type tractor.

In the case of rotary tilling for wheel type, a tractor with girdle or half truck, the cone index is the same or smaller compared with the case of travelling for propelled. In plowing, since work resistance is not constant, the value of sinkage varies a great deal. Especially in plowing by tractor with girdle, there is no correlation.

4) Relation between sinkage of tractor and rectangular plate sinkage

As the rectangular (or circular) plate resembles a tire rather than a cone, it would be possible to estimate the sinkage of the running gear by measuring this sinkage.

The relationship between sinkage of the tractor for propelled without load and the rectangular plate sinkage whose measurements are length 10 cm, width 2.5 cm and thickness 1 cm, is shown in Fig. 3.

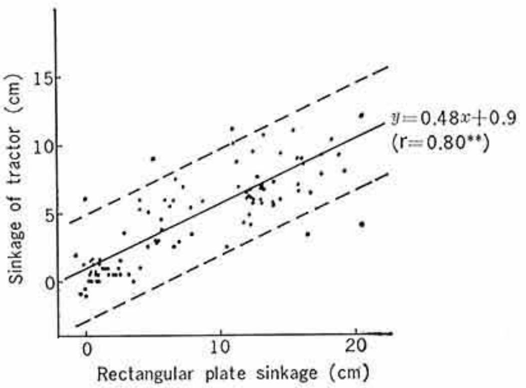

Fig. 3. Relation between sinkage of wheel tractor for self propelled without load and rectangular plate sinkage.

An approximate linear relationship is observed between them. In the case of various types of foot part, correlation is particularly high in the tractor with girdle and half truck.

In estimating sinkage of tractor, first to seek sinkage coefficient from specification of tractor, next attempt is made estimating the vehicle's sinkage by measuring the tractor's rectangular plate sinkage in the soil.

In such a case, very often appropriate figures are obtained for sinkage when a small rectangular plate is loaded with 30 kg (1.2 kg/cm^2). However, depending upon the soil conditions, this does not apply always.

5) Relation between travel reduction ratio and cone index

Since there is correlation between sinkage of the tractor and the travel reduction ratio and also correlation between sinkage and the cone index, it is anticipated that there would be correlation between the travel reduction ratio and the cone index.

The relation between the travel reduction ratio and cone index, in the case of the wheel-type tractor's travelling for propelled is shown in Fig. 4. When the cone index is less than

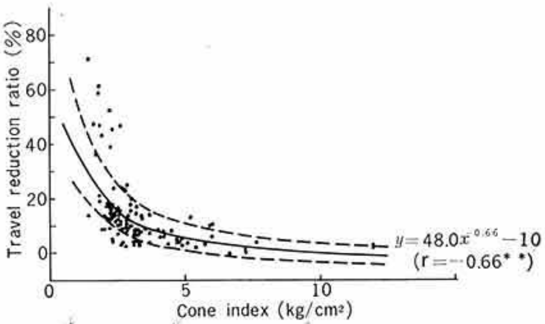

Fig. 4. Relation between travel reduction ratio of wheel tractor for self propelled without load and cone index.

2.5 kg/cm^2, the travel reduction ratio increases rapidly and when it reaches 4 kg/cm^2, the travel reduction ratio exceeds 10 per cent.

6) Relation between sinkage of tractor and consistency index

Soil water content does not primarily indicate the hardness of soil but the behaviors of soil such as flow and deformation when it is kneaded is controlled by the water content in soil. Therefore, it is anticipated that it would have close relation with the trafficability of tractor.

Generally, water content ratio to dry soil is used to indicate the water content in the soil but since it is used for the same soil, it cannot be utilized for comparison of different kinds of soil. Consequently, although it would seem appropriate to use pF instead, this method

Table 1. Standard for judging trafficability of tractor

Measuring item	The limits not available for farm work						The limits tolerable for farm work						The limits available for safety farm work					
	Wheel tractor					Crawler tractor	Wheel tractor					Crawler tractor	Wheel tractor					Crawler tractor
	Tire			Girdle	Half-truck		Tire			Girdle	Half-truck		Tire			Girdle	Half-truck	
	Self propelled	Rotary tilling	Plowing	Self propelled			Self propelled	Rotary tilling	Plowing	Self propelled			Self propelled	Rotary tilling	Plowing	Self propelled		
Depth of plowing (cm)	—	—	—	—	—	—	—	10<	12<	—	—	—	—	10<	12<	—	—	—
Travelling speed (m/sec)	—	—	—	—	—	—	—	0.4<	1.0<	—	—	—	—	0.4<	1.0<	—	—	—
Travel reduction (%)	20<	20<	40<	20<	5<	5<	20–10	20–10	40–20	—	—	—	10>	10>	20>	10>	3>	3>
Sinkage of tractor (cm)	12<	12<	10<	12<	12<	12<	12–3	12–3	10–3	—	—	—	3>	3>	3>	3>	3>	3>
Cone index (kg/cm²)	2.5>	2.5>	4.0>	2.0>	2.0>	1.5>	2.5–5.0	2.5–5.0	4.0–6.5	2.0–3.5	2.0–2.5	1.5–3.0	5.0<	5.0<	6.5<	3.5<	2.5<	3.0<
Rectangular plate sinkage (cm)	9.5<	10.5<	3.0<	11.0<	10.0<	15.0<	9.5–4.5	10.5–6.0	3.0–0	11.0–3.5	10.0–8.0	15.0–5.0	4.5>	6.0>	0>	3.5>	8.0>	5.0>
Consistency index determined by wet soil	0.2>	0.2>	0.4>	—	—	—	0.2–0.5	0.2–0.5	0.4–0.6	—	—	—	0.5<	0.5<	0.6<	—	—	—

Remarks:
1) Travel reduction was based on concrete or hard soil road.
2) Sinkage of tractor was measured from lug base.
3) Cone index indicates to the means of 0 to 15 cm vertically (angle of vertex is 30°, the base area is 2 cm²).
4) Consistency index $= \frac{\text{Liquid limit} - \text{Moisture content}}{\text{Plasticity index}}$.
5) Trafficability was judged by one of following factors such as cone index, rectangular plate sinkage, and consistency index.

involves a complicated process so that consistency index based on liquid and plasticity limits was used.

The relation between sinkage of the wheel-type tractor for propelled and the consistency index is approximately linear with $r=-0.62^{**}$ correlation coefficient. Although the range of fluctuation is pretty wide, it would still serve as a general index.

7) Standard for judging trafficability

By synthesizing and reviewing the above data, the standard for judging trafficability of tractor could be established as seen in Table 1, after stipulating the applicable conditions for work speed, plowing depth, travel reduction ratio, sinkage and expressing the soil conditions which would satisfy them in terms of the cone index and rectangular plate sinkage.

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