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THE EFFECT OF SOIL MOISTURE CONTENT ON POWER REQUIREMENT AND WHEEL-SLIP OF TRACTOR[1)]

(Pengaruh Kadar Air Tanah terhadap Kebutuhan Tenaga dan Slip Roda Traktor)

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ABSTRAK

Penelitian tentang kebutuhan tenaga dan slip roda traktor telah dilaksanakan di kampung Pulung Kencana, Kecamatan Tulang Bawang Tengah, Kabupaten Lampung Utara, Propinsi Lampung, pada musim penghujan tahun 1979. Jenis tanah tempat penelitian adalah podsolik merah kuning dengan tekstur liat dan ditumbuhi dengan alang-alang. Penelitian menggunakan rancangan petak terpisah dengan dua faktor yaitu kadar air tanah (10, 15, 20, 25 dan 30%) pada petak-petak utama dan kedalaman pembajakan (10, 15 dan 20 cm) pada sub-petak. Penelitian diulang sebanyak 4 kali. Lebar dan kecepatan pembajakan ditetapkan masing-masing 20 cm dan 5,4 km/jam. Hasil penelitian menunjukkan bahwa tahanan tanah minimum diperoleh pada kadar air 16,1% yakni 747,1 kg_f pada kedalaman 10 cm, untuk kedalaman 15 cm minimum pada kadar air 15,3% yaitu sebesar 867,3 kg_f dan untuk kedalaman 20 cm tahanan tanah minimum pada kadar air 15,4% yaitu sebesar 977,8 kg_f. Pada kadar air dibawah 15% tanah menjadi keras sehingga membutuhkan tenaga lebih besar untuk menarik bajak, sedangkan pada kadar air tanah diatas 20% tanah banyak melekat pada bajak yang dapat menyebabkan tahanan menjadi tinggi. Slip roda traktor minimum pada kadar air tanah 15,7% yaitu sebesar 5,2% pada kedalaman 10 cm, untuk kedalaman pembajakan 15 cm slip roda traktor minimum pada kadar air 14,6% yaitu sebesar 8,7%, untuk kedalaman pembajakan 20 cm slip roda traktor minimum pada kadar air 15,7% yakni sebesar 13,5%. Makin kecil dan makin besar kadar air dari kadar air minimum diatas maka makin besar slip roda traktor. Diketahui pula bahwa makin besar tahanan tanah makin besar slip roda traktor dan hubungannya linear.

INTRODUCTION

Soil is one of the important environmental factors that has a mutual relation with plants (Anonymous, 1971). Soil supports plant growth and plays as a medium from where plants obtain nutrient elements and water required for their normal growth (Hagan et al., 1972).

A condition favorable for the growth of upland crops requires improvement of the soil structure by preparing the land with tools as well as power at the proper soil moisture condition. Land preparation means to mechanically bring the soil into a condition suitable for the plants.

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Soil characteristics affecting tilling operations are resistance to weight, cohesion, adhesion and resistance to the slice. All these characteristical affects are expressed by the power required for drawing the plow and is affected by humidity and colloidal effects of the soil (Bainer *et al.,* 1960).

Soil draft resistance is the power which is paralleled with the course of the tractor when tilling the land (Tri Purwadhi, 1973). As a dynamic system, the soil will react physically when mechanical force is applied to it. The relation between soil draft resistance and the power required for land tilling is significant in increasing the efficiency of agricultural equipments.

Experiences show that most agricultural equipments drawn by animal power broke down and were used only in one season and should be replaced for the following season. This happened also with tractor drawn agricultural equipments, where parts of the tractor could be damaged.

The wheels of the tractor slip when the tractor operates with reduced forward motion or in other words, when the wheels' revolution does not correlate with the distance covered. This generally happen when the soil is too wet, or too dry to till. This slip of the wheels causes a reduction of the working efficiency of the tractor.

Soil moisture is the percentage of water by weight in the soil to the weight of the soil. Soil moisture percentage can be of wet or dry weight basis. Soil consistency is a term used for the manifestation of physical powers, cohesion and adhesion on the soil at various soil moisture. Soil consistency covers soil characteristics such as soil draft resistance to pressure plasticity and soil stickiness.

Consistency limit is also meant as Atterberg limit which is expressed in percent moisture. Flowing limit or upper plastic limit means the water content of the soil becomes semi fluid. Plastic limit or lower plastic limit is soil moisture level where the soil can be formed into sausages or a water content level between looseness of soil and plastic consistency. Sticky limit is a soil moisture level where the soil does not stick to other articless (Black *et al.,* 1965). The soil moisture level is higher than the field moisture capacity. The plastic consistency represents the optimum soil moisture condition for land tilling (Brady, 1974).

The objective of this experiment is to study the effect of soil moisture conditions at various plowing depths on soil draft resistance and wheel slip during the plowing operation.

METODOLOGY

A split-plot design was used with soil moisture as the main factor and plowing depth as the second factor. There were 4 replications. The study was carried out at village Pulung Kencana, Subdistrict Tulang Bawang Tengah, District of North Lampung Utara, Province of Lampung during the wet season 1979.

The soil is classified as red yellow podzolic and clayey in texture. The area is flat and covered by "alang-alang". Before the experiment was started the cogon grass (*Imperata cylindrica*) or "alang-alang" was cut and then burned.

The treatments tested in this study were soil moisture namely 10, 15, 20, 25 and 30% (wet basis) as main plots and depths of plowing namely 10, 15 and 20 cm as subplots. The plowing width was fixed at 20 cm, and the speed of tractor during plowing was 5.4 km/hour or 1.5 m/sec.

Equipment used were a 4-wheel 45 hp tractor IH354, a 9 hp Kubota hand tractor, a drawbar dynamometer, a stopwatch, a soil moisture meter and measuring tape.

Measuring the soil draft resistance was done by fixing the drawbar dynamometer between the 4-wheel tractor and the hand tractor as shown in Figure 1.

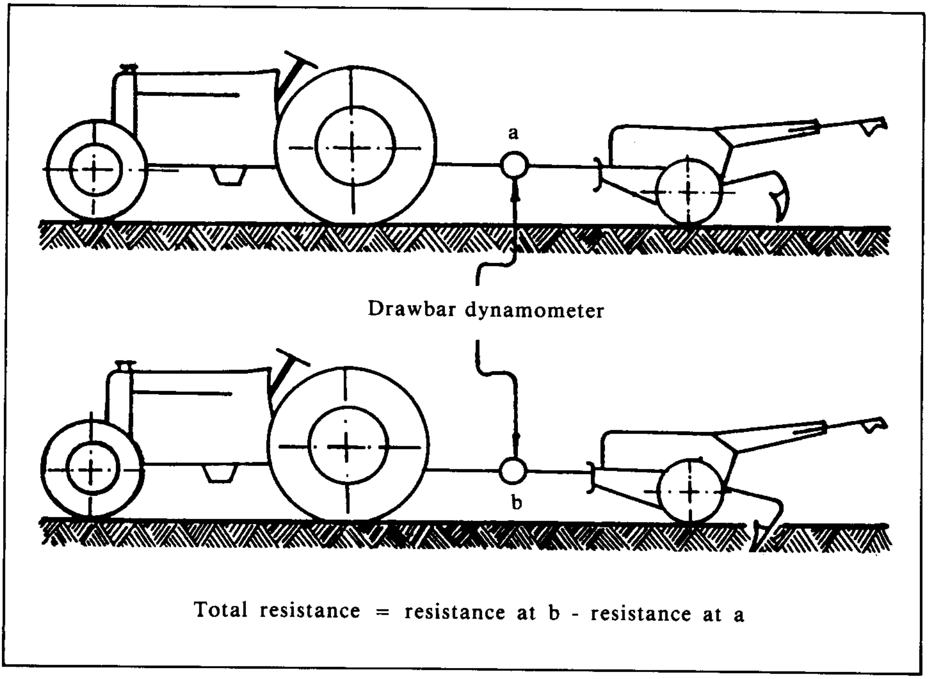

Figure 1. Schematic sketch showing how the soil draft resistance was measured using drawbar dynamometer.

The following formula was used to study the required drawing power (8):

$$KTr = \frac{\text{Resistance (kgf)} \times \text{speed (m/sec)}}{75} \qquad (1)$$

where, Ktr = required drawing power (hp).
Resistance = total soil draft resistance.
Speed = speed of tractor.

The wheel slip was calculated using the following formula (11):

$$S = \frac{D_1 - D_2}{D_1} \times 100\% \qquad (2)$$

where, S = wheel slip of tractor.
D_1 = distance covered per 10 revolutions of the wheels at hard soil where the tractor is not working.
D_2 = distance covered per 10 revolutions of the wheel at experimental soil where the tractor is working.

RESULT AND DISCUSSION

Soil Draft Resistance

The results of soil draft resistance movements varied for various soil moisture levels and plowing depths. The average soil draft resistance values are shown in Table 1. Results of the experiment showed a significant difference of soil draft resistance for various soil moisture levels and plowing depths. The highest resistance was obtained when soil moisture was at 30% and at a plowing depth of 20 cm. The high draft resistance was caused by the sticking of the soil to the plow as well as by the volume of soil that was sliced and turned over.

Table 1. Average soil draft resistance (kg_f) at various soil moisture levels and plowing depths. Lampung Utara, 1979 wet season.

Plowing depth (cm)	Soil moisture (%)				
	10	15	20	25	30
10	815.0[b]	787.5[b]	750.0[a]	922.5[c]	1175.0[h]
15	920.0[c]	907.5[c]	825.0[b]	1137.5[g]	1290.0[j]
20	1040.0[f]	992.5[e]	967.5[d]	1225.0[i]	1400.0[k]

cv Soil moisture (%) 2,30
Plowing depth (cm) 1,71

Means with the same letters do not differ significantly at 5% level according to DMRT.

In all plowing depths the soil draft resistance is generally higher at 25% and 30% soil moisture levels. Soil draft resistance at 10% soil moisture level is also high but not as high as the 25% and 30% level, which is due to the hard soil that was cut and turned over as they were hardly separable. Soil at 15% and 20% soil moisture levels were easily tilled and their resistance is therefore small. The relationship between soil moisture and soil draft resistance at three stage of plowing depths are shown in Figure 2.

The plowing depth is also a factor which contributed to high soil draft resistance. This is mainly because of large volume of soil that was cut, tilled and plowed. The deeper the cut the higher the soil draft resistance that was observed.

Soil analysis carried out at the physical soil laboratory of the Soil Research Institute in Bogor, showed that the average plastic limit of the soil occurred at 22.8% while the average moist limit occurred at 36.3%. At this stage the soil begins to become moist being saturated with water where it is better to use a rotating blade to do the tilling (Baver *et al.*, 1972).

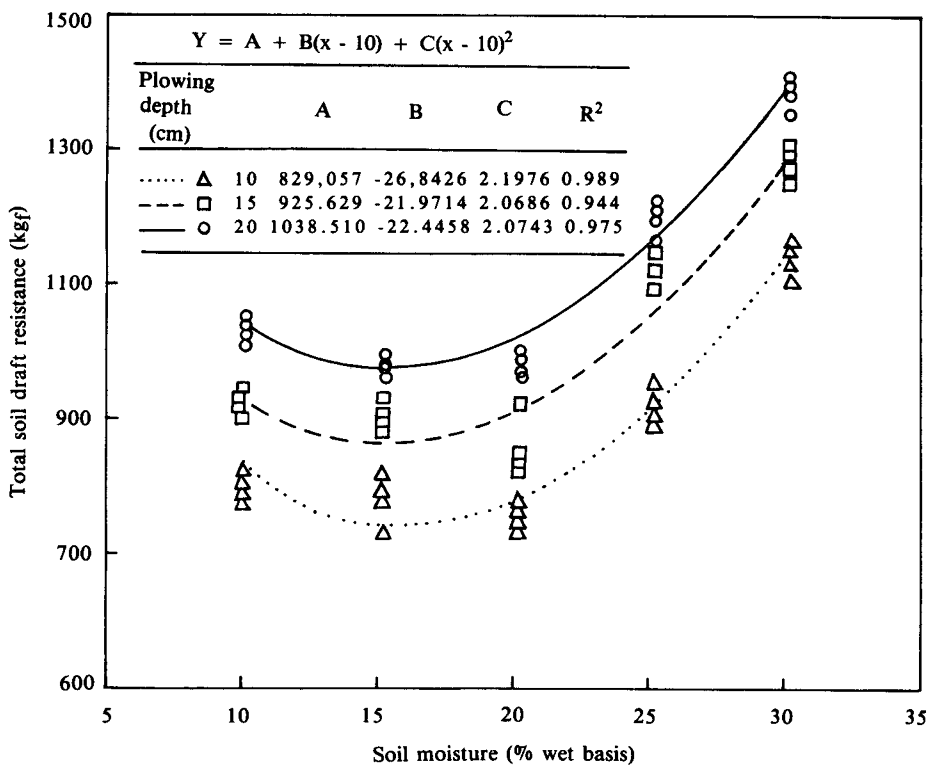

Figure 2. Relationship between soil moisture and soil draft resistance at three levels of plowing depth.

If the soil draft resistance is calculated using the equations in Figure 2, the minimal can be reached at 16.1% namely 747.1 kg_f at a depth of 10 cm while at a depth of 15 and 20 cm the respective values are 867.3 kg_f at 15.3% and 977.8 kg_f at 15.4% soil moisture were reached. Looking at the average resistance in Table 1, it could be noted however, that the actual minimal soil draft resistance is around 20%.

The soil draft resistance is in linear proportion with power requirements, that is the higher the soil draft resistance, the higher the power required to draw the plow. When the soil draft resistance of each soil moisture level and slice depth in Table 1 are considered by using Formula (1), the power requirements can be computed as shown in Table 2.

Table 2. Power requirements at various levels of soil moisture contents and plowing depths. Lampung Utara, wet season 1979.

Soil moisture (%)	Plowing depth (cm)	Power requirement	
		(hp)	(kW)
10	10	16.3	12.2
	15	18.4	13.7
	20	20.8	15.5
15	10	15.8	11.7
	15	18.2	13.5
	20	19.9	14.8
20	10	15.0	11.2
	15	16.5	12.3
	20	19.4	14.5
25	10	18.5	13.8
	15	22.8	17.0
	20	24.5	18.3
30	10	23.5	17.5
	15	25.8	19.2
	20	28.0	20.9

In general, soil draft resistance is expressed in kg_f/cm^2. The data generated is the total soil draft resistance. So the soil draft resistance values in Table 1 should be divided by the total area of plowed soil cut which is computed by multiplying the width by the depth of the slice. The result is the soil resistance per unit area (Table 3).

Table 3. Soil resistance in (kg_f/cm^2) as affected by soil moisture content and plowing depth. Lampung Utara, 1979 wet season.

Plowing depth (cm)	Soil moisture (%)				
	10	15	20	25	30
10	2.7	2.6	2.5	3.1	3.9
15	2.1	2.0	1.8	2.5	2.9
20	1.7	1.6	1.6	2.1	2.3

When a soil at 20% moisture level is plowed using animal power, the power required for a slice of 15 cm width and 10 cm depth at a speed of 0.56 m/sec is:

$$KTr = \frac{15 \text{ cm} \times 10 \text{ cm} \times 2.5 \text{ kg}_f/\text{cm}^2 \times 0.56 \text{ m/sec}}{75}$$

is 2.8 hp or 2.08 kW. According to Moens (1978), a pair of animals with a weight of 400 kg each will provide 0.8 kW or 1.1 hp which means that they can not plow the land. It can be plowed by the two animals when the width and depth and the speed are decrease according to the available power provided by the animals.

Slip of Tractor Wheels

The result of measuring and calculating the slip of the tractor wheels vary at different soil moisture and plowing depth as well as in measuring and calculating the soil draft resistance. The calculated mean wheel slip is shown in Table 4. Soil moisture varying between 10 to 30% at certain plowing depth shows significant difference.

Table 4. Means of wheel slip (%) at various soil moisture and slice depth. Lampung Utara, 1979 wet season.

Plowing depth (cm)	Soil moisture (%)				
	10	15	20	25	30
10	8.5^{b}	4.6^{a}	7.4^{b}	13.1^{d}	24.1^{g}
15	10.8^{c}	8.1^{b}	10.5^{c}	16.8^{e}	32.6^{h}
20	15.9^{e}	15.6^{e}	16.4^{e}	19.6^{f}	37.4^{i}

cv Soil moisture (%) 11.19
Plowing depth (cm) 4.66

Means with the same letters do not differ significantly at 5% level according to DMRT.

Except at a plowing depth of 20 cm, the slip of the wheel is lowest when the soil moisture is 15% where the soil resistance is minimal and the tractor operating normally without resistance. The wheel slips are highest at 30%, and

25% moisture content. The wheel slips are the same at 10% and 20%. According to Wanders (1978), the slip in a sandy clayey soil is 16%.

Similar to the soil draft resistance, the wheel slip is greatly affected by the plowing depth. This is due to the greater soil draft resistance at a deeper slice. The deeper the slice, the greater is the wheel slip. At a depth of 20 cm, there is no significant different of the wheel slip at 10, 15, and 20% soil moisture level. The relation between soil moisture and slip of wheel is shown in Figure 3.

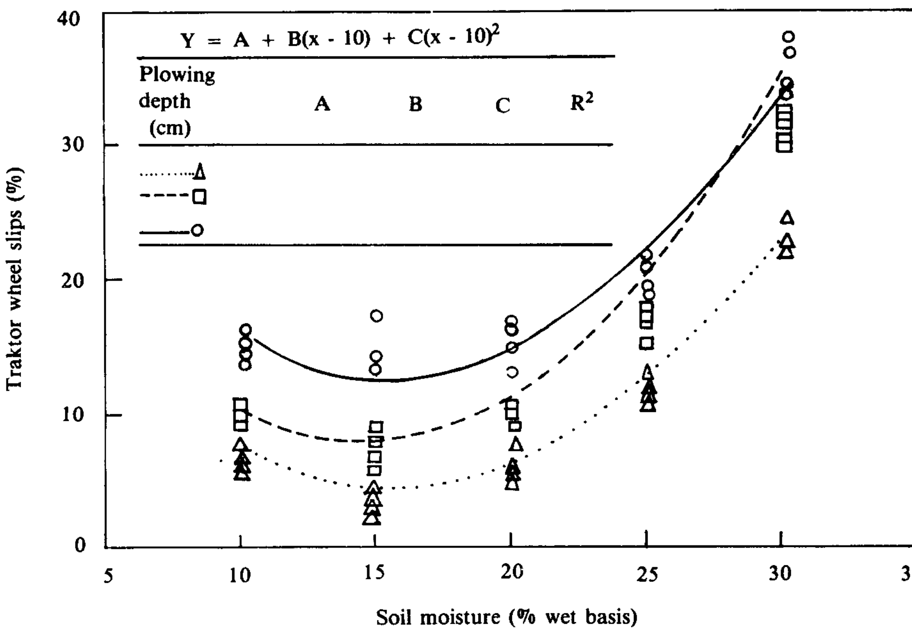

Figure 3. Relationship between soil moisture and wheel slip of tractor at 3 different plowing depths.

The wheel slip is greater at 15% soil moisture than at the 10% level due to greater soil draft resistance at 15% than at 10% soil moisture level. The greater the soil draft resistance, the greater is the wheel slip and its linear relation as showed in Figure 4.

At 25% and 30% soil moisture, the wheel slip tends to increase because of the soil resistance as well as due to the semi muddy condition of the soil where the wheels sometimes revolve without moving forward, especially at the 30% soil moisture.

When the equation of the relation between the soil moisture and the wheel slip in Figure 3 are calculated at their minimals by reducing the equations at their first differentiation, a minimal wheel slip of 15% at all plowing depths will be found (Table 5).

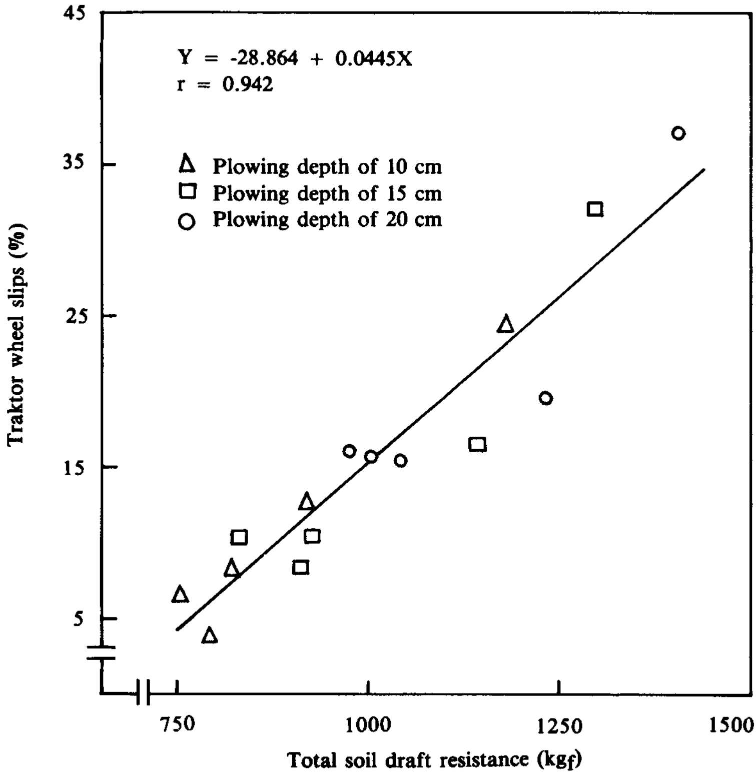

Figure 4. Relationship between soil draft resistance and wheel slip of tractor.

Table 5. Minimal soil moisture and wheel slip at 3 stages of plowing depth. Lampung Utara, 1979 wet season.

Plowing depth (cm)	Soil moisture (%)	Wheel slip (%)
10	15.7	5.2
15	14.6	8.7
20	15.7	13.5

When a wheel slip occurs due to the soil condition while the tractor itself is still capable to operate, Stone and Gulvin (Stone & Gulvin, 1977) recommended to load heavy things (iron) or fill the rear wheel with water to prevent the slip. This recommendation is limited to dry soil condition only. According to past experiences, additional load may even bury the tractor when operated on a high soil moisture of 25% to 30%. Tractors operating in flooded fields should be equipped with floating wheel to prevent wheel slip and sinking of the tractor.

CONCLUSION

Soil draft resistance is greatly affected by soil moisture and plowing depth. Soil draft resistance is minimal at 15% and 20% moisture at all tested plowing depths namely 10, 15, and 20 cm. Decrease and increase of soil moisture content will increase soil draft resistance which in turn also increase the required power for pulling the plow.

Of all the soil moisture tested, the highest soil draft resistance occurred at 30%, followed by 25% when the soil at this condition sticks to the plow. At 10% the soil is hard to slice or turned over resulting in high soil draft resistance and a high power requirement.

Similar to the measurement soil draft resistance, the minimal wheel slip at all depth levels occurred when the soil moisture was at 15%. Increase and decrease of soil moisture results in increasing the wheel slips. The wheel slip is greatly affected by the soil moisture condition, that is the higher the soil draft resistance, the higher the wheel slip. At a plowing depth of 20 cm, there is no significant different at soil moisture level of 10%, 15% and 20%.

Plowing of the soil should be done when the soil moisture is at 15% to 20%, since the soil in these moisture condition is easily sliced, digged up, and turned over in the plowing process, having lower soil draft resistance and wheel slip compared to when done at higher or lower soil moisture condition.

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