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A Width of Cut Analysis on the Performance of a Rotary Strip Tiller

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ABSTRAK

Kertas kerja ini menerangkan kajian tentang kesan lebar bilah terhadap prestasi bajak putar. Kajian ini adalah sebahagian daripada penyelidikan yang dilakukan oleh pengarang mengenai pembajakan tanah dengan menggunakan bajak jenis putar. Dengan menggunakan satu piring bilah, bilah-bilah yang direkabentuk telah diuji pada beberapa gabungan kelajuan antara piring bilah dan traktor dalam sebuah tangki tanah yang diubahsuai menyerupai batas semaian. Hasil kajian yang diperolehi bagi setiap gabungan kelajuan berasingan menunjukkan peningkatan bererti dari segi penggunaan kuasa apabila bilah dilebarkan. Dari segi kuasa tentu, semakin lebar bilah yang digunakan kuasa tentunya semakin menurun. Tahap kehancuran tanah tertinggi dicapai dengan menggunakan bilah terkecil pada jarak pemotongan yang paling pendek.

ABSTRACT

This paper describes a soil bin study on the effect of blade widths upon rotary tiller performance which forms part of the research undertaken by the author on rotary tillage. Blades used were designed and tested at several forward and rotor speed combinations using a single rotor flange. Results obtained for each combination of forward and rotor speed show significant increase in power consumption as cutting width increased. In terms of specific power, however, the wider the cutting widths the lower the specific power values. The highest degree of soil pulverization was caused by the smallest width at the smallest bite length.

INTRODUCTION

One of the major problems associated with seedbed is the aggregate size which must be fine enough so that after germination the very young crops are able to grow through the soil to secure nutrients and water and its top growth able to break through the crust on soil surface. For seedbeds, it is generally accepted that an aggregate size of 10 mm is required (Russell, 1961). However, it is still impossible to predict what tillage operations are necessary to convert soil in a given condition into a seedbed as the soil structure produced by any given tillage implement depends on a number of factors including the history of cropping and the moisture content (Ojeniyi, 1979).

The rotary cultivator is a tool that possibly holds the answer to some of the problems associated with tillage of the soil around very young crops because of its shallow working operation. This is supported by the fact that while the introduction of the farm tractor has not greatly influenced the design of the basic tillage implements, few successful attempts at applying the available tractor power directly to the implement have been made, the most successful being the rotary cultivator (Hendrick, 1971). Hendrick further reported that if the power efficiency of rotary tools is to be increased, a number of relationships that exist must be investigated. Among other things, he suggested that "..... field efficiency in seedbed preparation may be increased through shallower operation at higher speeds or through preparing seedbed strips without an unreasonable increase in power requirement ...... ". Review of the previous investigations reveal that no fundamental work carried out so far concluded on seedbed trip tilling and precision shaped raised beds for planting crops (Ahmad, 1980). Hence, Hendrick's suggestion has clearly stressed the need for a critical study on the important criteria for the design of cutting tool which has hardly been touched on. Consequently, if the rotary cultivation is to be significantly improved as a strip tilling device, a closer look must be taken as its mode of operation and the factors that contribute to its effectiveness.

Following from the above, the objectives of this investigation were;

i. To find the power requirement of the various cutting widths at different forward and rotary speeds.

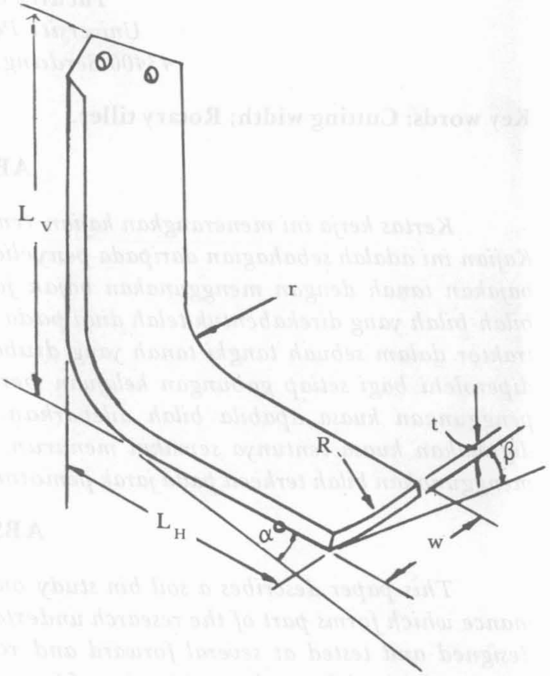
ii. To determine the effect of cutting width on the resultant cold size.

It was anticipated that this work would lead to the discovery of an optimum width having low power requirement, high rate of work whilst at the same time having the capacity to produce finer tilth approaching seedbed condition for a power driven tine in rotary tillage.

MATERIALS AND METHODS

Blade Design

As the criterion for the present work has been the engineering aspect of investigating strip tillage, blades of different cutting widths were designed and fabricated. Simplification in design was sought as the objective of this preliminary work was to obtain the fundamental knowledge of blade performance. The complex three dimensional shape of a rotary cultivator blade has been defined (Beeny and Khoo, 1970) as shown in *Fig. 1*.



L_V = Effective vertical length (mm)

L_H = Blade cutting width (mm)

R = Curvature of a section through the blade (mm)

r = Curvature between L_V and L_H (mm)

t = Thickness and sharpness of blade (mm)

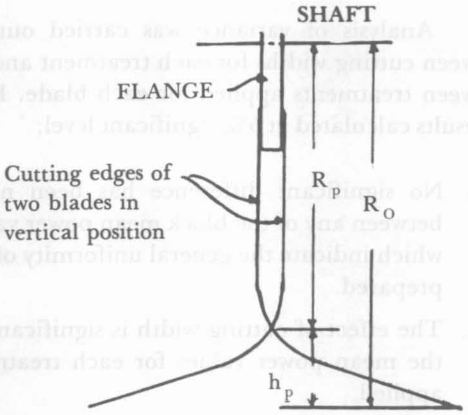
w = blade span (mm)

α = sweepback angle (degrees)

β = clearance angle (degrees)

Fig. 1: A typical rotary cultivator blade showing design parameters (BEENY and KHOO, 1970).

One of the crucial factors considered in the design was the depth of tillage since it plays a vital role in the disturbance and mixing of soil as well as in the cutting of roots. As rotary tools are three dimensional (because of intermittent operation both along the path of movement of the machine and across the width of the machine) ridginess is unavoidable. The regions of untilled soil as shown in *Fig. 2* can be overcome by having a uniform depth. To achieve this the effective horizontal length was modified and made perpendicular to the vertical length. The blade span of 75 mm was selected (conventional blade span ranges from 60 – 90 mm). A sharpening angle of 15° for minimum compressive stress (Spoor, 1969) and a clearance angle of 20° (Sohne, 1957) for least power requirement were selected.



R_O = Radius of tiller (mm)
h_p = Height of ridge (mm)
R_p = Ridge to centre of rotor shaft (mm)

Fig. 2: The ridginess created by rotary tiller blades in the bottom of a furrow in the vertical transverse plane (GILL and HENDRICK, 1976).

Experimental Design

The experiment carried out comprised three blade widths (56.8, 107.6 and 209.2 mm) and a single shank (6 mm) in combination with five treatments varying in alpha ratios (ratio of peripheral speed to forward speed) and three bite lengths. Three bite lengths of 25, 50 and 75 mm were chosen as beyond these values, a major portion of the clods produced would be either too small in size for seedbed condition in the case of bite lengths lower than 25 mm or too big in size in the case of bite lengths greater than 75 mm. The shank was included in order to obtain the comparison of power requirements as blade widths were increased. The experimental work consisted of sixty runs completed over three replicated blocks. Each block comprised twenty runs whereby five treatments were applied to each individual blade. The treatments applied were as given in Table 1.

Tests were carried out on the effect of blade cutting widths on the rotor power requirement as well as the resultant soil aggregates at constant bite lengths (given by treatments T_2, T_3 and T_4). Treatments T_1, T_2, T_3 and T_5 were

TABLE 1
Treatments applied

Treatments	Forward speed V (mm/s)	Rotational speed, N (RPM)	Bite length ℓ (mm)	Alpha ratio λ
T_1	66	80	25	38
T_2	66	40	50	19
T_3	150	90	50	19
T_4	133	80	50	19
T_5	150	60	75	13

applied to find out the effect of changing the length on rotor power requirement and the soil aggregates at constant forward speeds. These treatments would also give information on the effect of rotational speeds on rotor power requirements. It was also of interest to study the effect of changing the bite length on power and soil aggregates requirement at constant rotor speed (by changing the forward speed) using treatments T_1 and T_4. The bite length (or tilling pitch) can be calculated from

$$\ell = \frac{V}{N} \cdot \frac{60}{Z}$$

or

$$\ell = \frac{V}{N} \cdot \frac{2\pi R_o}{z}$$

where

V = machine forward speed (mm/s)
N = blade rotational speed (RPM)
Z = number of blades which would cut identical paths if V = O
U = blade peripheral speed (mm/s)
R_o = radius of tiller (mm)

Details of soil properties used are as given in Table 2.

RESULTS AND DISCUSSION

Effect of Cutting Width on Mean Power Values

Referring to *Fig. 3*, the increments in power for increasing cutting widths would be attributed to the higher cutting force. For each combination of forward and rotor speed, increasing the cutting width to 50 mm from the shank alone initially reduced the mean power requirement. Beyond this, the increment in cutting width caused the power to increase significantly.

Analysis of variance was carried out between cutting widths for each treatment and between treatments applied for each blade. From results calculated at 5% significant level;

i. No significant difference has been noted between any of the block mean power values which indicate the general uniformity of soil prepared.

ii. The effect of cutting width is significant on the mean power values for each treatment applied.

iii. For each cutting width, the treatments applied were significant on the mean power values at 5% significant level.

TABLE 2
Mechanical Properties of Experimental Soil

Cohesion C (kPa)	Angle of shearing resistance ϕ (°)	Adhesion a (kPa)	Angle of Soil Metal friction δ (°)	Soil Bulk Density γ (kg/m^3)			Penetrating Resistance (MPa)					
							at 75 mm depth			at 150 mm depth		
				(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
18	22°	0.7	18°	1989	1973	1963	1.32	1.39	1.35	1.17	1.19	1.18

Position (1) and (3) = 0.5 m from ends of tank
Position (2) = centre of tank
Soil type = sandy clay loam
Moisture content = 12.2%
No. of passes = 2
No. of experiments = 20
Pressure of compacting ram = 6 MPa

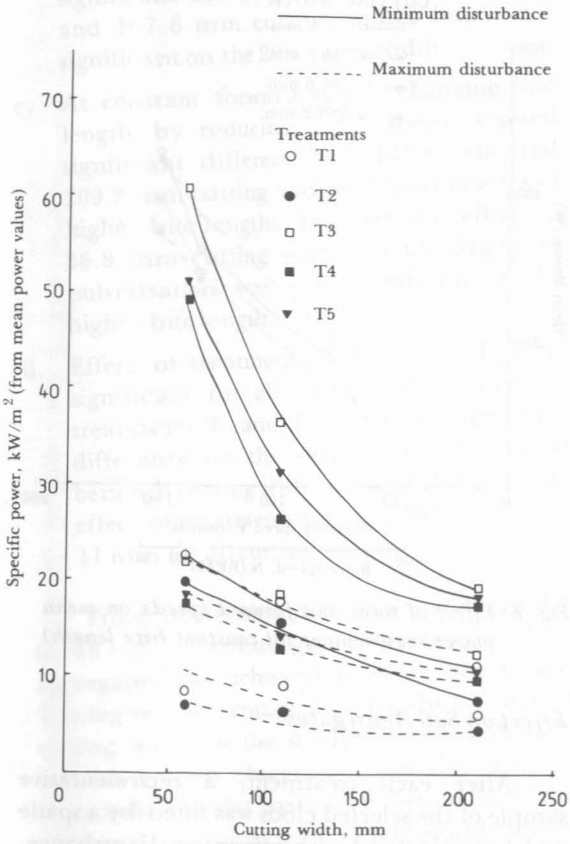


Fig. 3: Relation of specific power to cutting width for various treatments

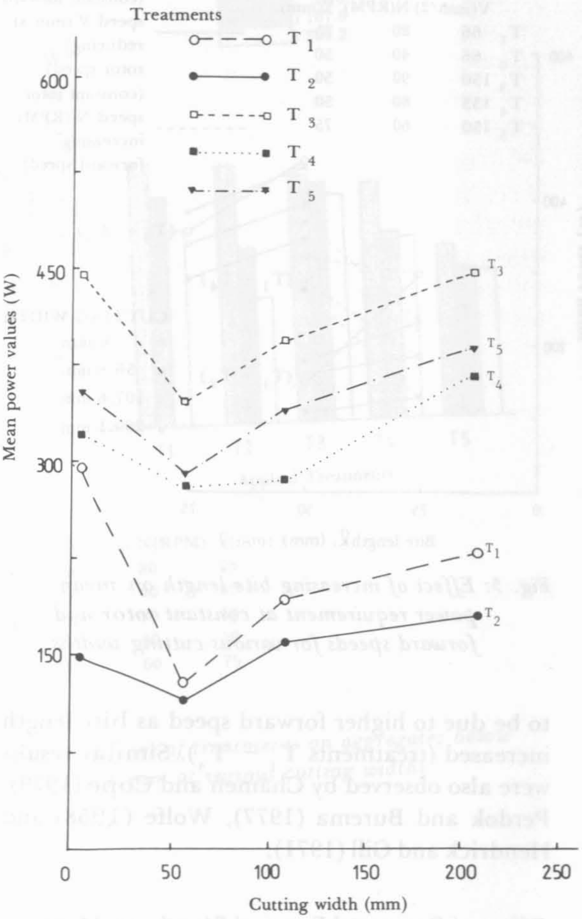


Fig. 4: Relation of mean power values to cutting width for various treatments

Although the power requirement increased with blade cutting width, when the volume of soil disturbed and specific power were considered, the results show that the larger the cutting widths, the lower the specific power *(Fig. 4)*. The high power consumed by the shank alone can be explained by the higher cutting and draught forces encountered due to difference in soil failure laterally around the shank. This phenomenon had been observed by other researchers notably Godwin (1974) and Godwin and Spoor (1977).

Effect of Bite Length on Mean Power Values

The results obtained from mean power values show that at constant forward speed, increasing bite length would reduce the power consumption. The main reason for the power reduction appears to be due to the lower rotor speed (given by treatments T_1 – T_2 and T_3 – T_5 as shown in *Fig. 5*). The results of Harral (1977) however, indicate that power increases with bite length. This contrasting effect could be attributed to the somewhat larger diameter of rotor used which tended to increase the length of cutting path and hence increased the power requirement. Harral, however, attributed this high loss largely on the moisture content being greatest in wet conditions presumably because of soil sticking to the blade as large clods which then accelerated and carried over the rotor.

Fig. 5 also shows that at constant rotor speed, the increase in power requirement seemed

From an overall standpoint, the results clearly illustrate the trend towards using smaller cutting widths for a finer degree of soil pulverization and agreement with the hypothesis postulated that smaller widths, smaller bite lengths and higher rotor speeds would increase the degree of soil breakdown. However, in terms of energy requirement, small cutting widths consumed a significantly higher value compared to larger cutting widths which tended to increase soil disturbance area. This increase in width, however, was not compatible with the degree of soil breakdown required and gave a comparatively poorer percentage of aggregates formed. In order to minimize the energy requirements for a given operation, the following suggestions could be made: –

i. Blade cutting width used, should be as small as possible.
ii. Bite length should conform with tilth requirements.
iii. Rotor speeds should be as slow as possible.

CONCLUSIONS

1. For each combination of forward and rotor speed, the power requirement increased almost linearly with cutting width.
2. In terms of specific power, the wider the cutting width, the lower were the specific power values.
3. Reducing rotational speed at a constant forward speed, (therefore increasing the bite length) significantly reduced the power requirement for all cutting widths.
4. Increasing the bite length at constant rotor speed by increasing the forward speed, significantly increased the power requirement.
5. For a constant bite length of 50 mm, increasing rotor and forward speeds increased the power requirements.
6. For minimum power requirements, rotor speed should be as low as possible operating at the maximum bite length conforming to the tilth desired.
7. At constant bite length, increasing rotor and forward speeds increased soil pulverization for the wider cutting widths but no significant change was observed for the smallest cutting width.
8. At constant forward speed, increasing the bite length by lowering the rotor speed reduced the degree of soil pulverization for all cutting widths.
9. At constant rotor speed, increasing bite length by increasing forward speed, reduced the degree of soil breakdown for all cutting width.
10. For all cutting widths, greater fragmentation of soil aggregates was achieved at lower bite length, the most being caused by the smallest cutting width (56.8 mm) at a bite length of 25 mm.

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