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EFFECT OF TILLAGE TOOL GEOMETRY ON SOIL POROSITY

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A b s t r a c t. Field clay loam and sandy loam were tilled with tillage blades at different rate angles and depths. The loosened soil porosities at different depths were determined in situ in the soil furrow.

In the clay loam, the effects of depth of tillage and their interactions on soil porosity were highly significant at the 1% level. In the sandy loam, the effects of the interactions of the tool rake angle with the blade width, the depth of tillage and their interactions on soil porosity were highly significant at the 1% level. In both soils, there were great significant differences between the porosities of the untilled soils and those of the tilled soils. It was therefore possible from these results to design and operate tillage implements to achieve the required tilled soil porosity and subsequent conditions. The importance of this is that tilled agricultural soil susceptibility to erosion by wind and water can effectively be minimized.

INTRODUCTION

It has been known since man first cultivated crops that tillage operations were beneficial to crop production whenever the soil porosity was adequately changed. Most tillage operations leave the soil in a ridge soil configuration because of the positioning of the individual tools. The tillage systems that produce the largest clods, lowest bulk density and roughest surface also produce the greatest macro porosity [10]. The micro porosity is increased with tillage operations that produce small clods.

Porosity (void ratio) has frequently been used as an index property of granular materials. In soil tillage mechanics, this index becomes very important when considering the susceptibility of the tilled soil to all forms of erosion and compaction. This may suggest that two samples from the same granular mass, having the same void ratio or porosity should have the same mechanical behaviour. However, this is not generally supported experimentally [4, 6, 11, 15]. The porosity of granular soil materials is no doubt an important variable which characterizes the corresponding soil deformation behaviour. Allmaras *et al.* [2] have suggested that the two parameters of soil condition that are important to management of soil water in the interrow zone are the porosity of the tilled soil layer and the roughness of the soil surface. Defining overall soil porosity as the ratio of all voids to the total volume of soil, and aggregate porosity as the ratio of voids within the aggregate to the volume of the aggregate, Lin [9] observed that the aggregate porosity of a virgin soil was higher than that of a cultivated soil. He concluded that virgin soil also had a higher overall porosity than cultivated soil of any type.

In relating the importance of porosity to plant growth it was observed that any soil porosity of less than 10-15% would reduce plant growth. Kemper and Derpsch [8] observed that when soils were tilled, the soils' natural porosity was destroyed and soon compaction would develop in the lower horizon of the top soil. Such a process was accelerated by a reduction in organic matter and by high rainfall. The soil compaction could impede water infiltration in the other wise permeable soils, and could lead to a complete loss of the top soil during the vegetative period of annual crops.

In the cited literature, it was evident that in the different types of soils, the loosening effect which changed the tilled soil porosity depended upon such factors as the angle of installation of the tool and the stroke length of the blade. It was also evident that a thorough knowledge of the effect of tillage tool geometry on soil porosity has not been properly established to enable the tool designer and user to select the appropriate tools for different soil types and tilled conditions. Such a knowledge is very necessary in Nigeria where there has been a recently developed interest in large scale farming and in use of farm machinery. Furthermore, in the Nigerian situation where the soils in the northern part are susceptible to erosion by wind while the soils in the southern part are susceptible to erosion by water, the extent of soil loosening and porosity by the various pieces of tillage machinery must be appreciated by the farm machinery manufacturers and users.

The objective of this study was therefore to experimentally determine in two field soil types, the effect of tillage tool geometry on the soil porosity at different furrow depths. The tillage blade width, rake angle and the depth of tillage constituted the geometry of the chisel tine used in the study.

METHODS AND MATERIALS

Chisel shaped tillage blades of 6.3 cm, 12.7 cm and 20.3 cm widths were used at rake angles of 20^{o}, 25^{o}, 30^{o} and 35^{o} to loosen clay loam and sandy loam field soils at depths of 15 cm and 25 cm. The design and construction of the tillage tools have been described by Ijioma [7]. The tillage implements were constructed in the Department of Agricultural Engineering of McGill University, Montreal, Canada.

A random combination of tillage geometries produced a total of 24 treatment combinations of blade width, rake angle and depth of tillage. The 24 treatment combinations and a zero tillage control treatment made up a block of 25 treatment field plots. The control treatment plot was added for comparative purposes. There were three blocks in each field laid out in a randomized complete block design. The three blocks also corresponded to three soil moisture content ranges which resulted from natural precipitation and the periodic spacing of the experiments. Each tillage operation in a plot was done using the corresponding tillage treatment combination. The moisture content before tillage was by core sampling within 0 - 5 cm depth whereas the moisture content after tillage was at depth intervals of 5 cm down to 30 cm in the furrow. The porosities at depth intervals of 5 cm in the furrow were calculated from radiation counts on a Troxler 3401 direct transmission gamma ray moisture density gauge. From the moisture contents after tillage and the *in situ* radiation counts, the soil densities and the corresponding porosities at different depths were determined. The radiation counts were determined at three different locations along the plot in order to determine the average porosity of the soil in the plot. Because of the readings at depth intervals in the furrow, statistical analysis of the results was by a split plot design on the randomized complete block.

The soil porosity was calculated as follows from the furrow density readings:

$$n = 1 - \rho d/\rho s \qquad (1)$$

where n - porosity, ρd - dry denstiy, ρs - mean particle density of soil solids.

The particle density was determined with a pycnometer, following the American Society for Testing and Materials, procedure D 854-52 [5]. The average particle density was 2.65± 0.02 for the sandy loam and 2.75 ± 0.02 for the clay loam.

RESULTS AND DISCUSSION

The statistical analyses in Table 1 showed that the effects of the depth of tillage, depth in the furrow and the interaction of the depth of tillage with the depth in the furrow on the clay loam porosity were highly significant at the 1 % level. The table also showed a great significant difference at the 1% level between the porosities of the soils in the zero tillage control plots and the tilled clay loam and sandy loam plots.

Tables 2 and 3 showed the significant differences at the 1 % level and the 5 % level between the main effects of the depth in the furrow, the width of the tillage blade, the rake angle and the depth of tillage on the porosities of the tilled soils. The statistically established polynomial regression equations relating the soil porosity to the tillage tool geometry were of the form:

$$n=0.529+1.313\,WD-0.183\,W+0.309\,A-0.385A^2 \quad (2)$$

in the clay loam; and

$$n = 0.576 + 2.777\,WD - 0.544\,W + 0.295\,A - 0.274\,A^2 \quad (3)$$

in the sandy loam, where W - blade width, D - depth of tillage, A - rake angle.

Table 1. Summary of analysis of variance[a] on effects of tillage tool geometry on soil average porosity at different depths in the furrow

Source of variation	Degrees of freedom	Sum of squares		F values	
		Clay loam soil	Sandy loam soil	Clay loam soil	Sandy loam soil
Total	374	0.586	0.621		
RAWD combination (Main plot unit)	26	0.260	0.332	4.87**	5.21**
Block (R)	2	0.057	0.171	13.88**	34.88**
Control (C) versus AWD combination	1	0.126	0.064	61.39**	26.11**
Rake angle (A)	3	0.000	0.011	0.49	1.50
Blade width (W)	2	0.004	0.003	0.97	0.06
A x W	6	0.014	0.063	1.14	4.28**
Depth of tillage (D)	1	0.037	0.019	18.03**	7.75**
A x D	3	0.006	0.003	0.97	0.41
W x D	2	0.006	0.0002	1.46	0.04
A W D	6	0.008	0.001	0.65	0.07
error a (R x AWD combination)	48	0.099	0.118		
P in RAWD combination (sub plot unit)	100	0.115	0.067	2.06**	1.29*
Control (C) versus P in AWD comb.	4	0.004	0.006	1.79	2.89*
Depth of reading (P)	4	0.045	0.007	20.16**	3.38*
A x P	12	0.006	0.003	0.90	0.48
W x P	8	0.006	0.006	1.34	1.45
A x W x P	24	0.011	0.018	0.82	1.45
D x P	4	0.016	0.007	7.17**	3.38**
A x D x P	12	0.008	0.004	1.19	0.64
W x D x P	8	0.007	0.008	1.57	1.93*
A x W x D x P	24	0.013	0.008	0.97	0.64
error b (R x P (AWD))	200	0.112	0.104		

[a] Split plot design analysis; * Significant at the 5 % level; ** Significant at the 1 % level.

The line graphs of the depth in the furrow versus the soil porosity for the various tillage tool geometries in the clay loam and sandy loam showed that the tilled soil porosity was significantly higher than that of the untilled soil (Figs 1-6). In the clay loam (Figs 1-3), the porosity decreased slightly width at the same depth of tillage and rake angle. For the same tillage blade at the same depth, the sandy loam porosity increased with the decrease in the rake angle of the blade. The sandy loam porosity increased with the increase in the depth of tillage for a certain blade width at a certain

Table 2. Main effects of tillage tool geometry on clay loam soil average porosity+ at different depths in the furrow

Level of significance	Depths of furrow and geometry of tillage tool				
	Depths of furrow ++ (cm)				
	5	10	15	20	25
	0.62	0.62	0.64	0.64	0.65
0.01	c	c	b	b	a
0.05	c	c	b	b	a
	Rake angle ≠≠ (degree)				
	20	25	30	35	
	0.64	0.64	0.63	0.64	
0.01	a	a	a	a	
0.05	a	a	a	a	
	Blade width * (cm)				
	6.3	12.7	20.3		
	0.64	0.63	0.64		
0.01	a	a	a		
0.05	a	a	a		
	Depth of tillage ** (cm)				
	15	25			
	0.63	0.65			
0.01	b	a			
0.05	b	a			

+ Duncan's new multiple range test; ++ each value is the mean of 75 observations; ≠≠ each value is the mean of 90 observations; * each value is the mean of 120 observations; ** each value is the mean of 180 observations. In a row, means with the same letter are not significantly different at the level of significance specified.

with an increase in the blade width at the same depth of tillage and rake angle. When tilled with a tillage blade of the same width and at the same rake angle, the clay loam soil porosity increased with the increase in the depth of tillage. In Fig. 3, the clay loam soil porosity increased with the decrease in the rake angle of a tillage blade of a certain width and at a certain depth of tillage. In the sandy loam (Figs 4-6) the soil porosity increased with the increase in the blade rake angle. In both the untilled and tilled sandy loam, the soil porosity decreased with the increase in depth in the furrow. However, the rate of decrease in the tilled sandy loam porosity was lower than that of the untilled soil. The change in the clay loam porosity was not as significant as that of sandy loam. Further graphical relationships between the tillage tool geometry and the soil porosity could be shown from the empirical relationships in Eqs (2) and (3).

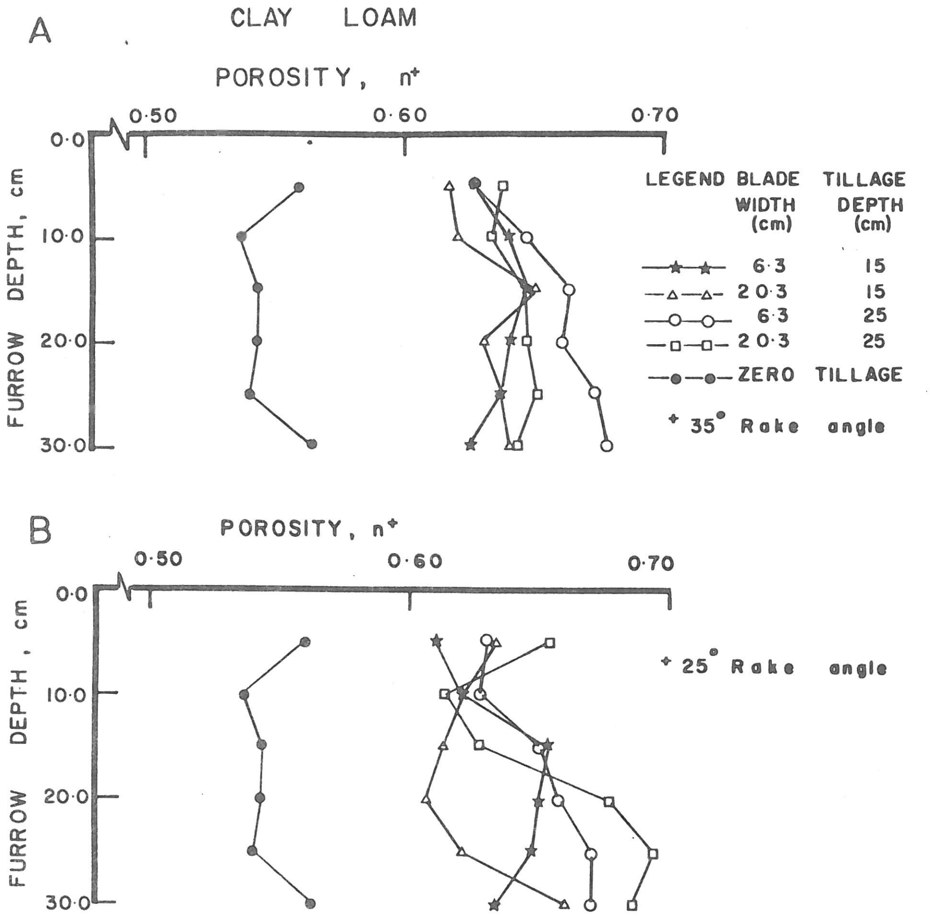

Fig. 1. Effect of width of a blade at 35° (A) and 25° (B) rake angle on the porosity of clay loam at different depths.

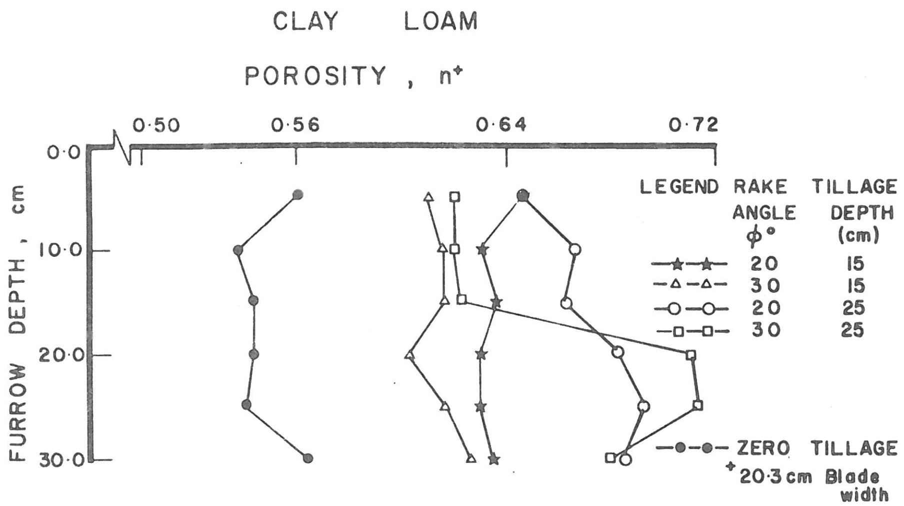

Fig. 2. Effect of rake angle of a blade of 203 mm width on the porosity of clay loam at different depths.

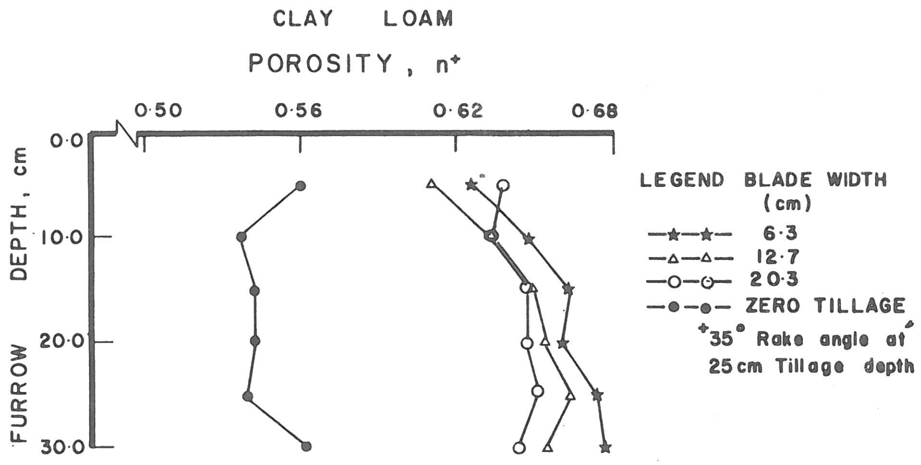

Fig. 3. Effect of width of a blade at 35° rake angle on the porosity of clay loam at different depths.

Table 3. Main effect of tillage tool geometry on sandy loam soil average porosity at different depths in the furrow

Level of significance	Depths of furrow and geometry of tillage tool				
	Depths of furrow^{++} (cm)				
	5	10	15	20	25
	0.58	0.58	0.58	0.58	0.59
0.01	b	b	a	b	a
0.05	b	b	a	b	a
	Rake angle $^{\neq\neq}$ (degree)				
	20	25	30	35	
	0.59	0.59	0.58	0.58	
0.01	a	a	a	a	
0.05	a	a	a	a.	
	Blade width* (cm)				
	6.3	12.7	30	35	
	0.59	0.59	0.58	0.58	
0.01	a	a	a	a	
0.05	a	a	a	a	
	Depth of tillage** (cm)				
	15	25			
	0.58	0.59			
0.01	b	a			
0.05	b	a			

For footnotes, see Table 2.

The above findings seem to agree with the findings of Ahmad and Paul [1], Amir *et al.* [3], Spoor [12], Swain [13] and Taylor *et al.* [14] in other related soil-tillage studies. It was observed in the field soils that during the loosening of the sandy loam with a wide blade and the loosening of the clay loam with a narrow blade, large clods were moved upwards in the profile and small clods downwards. These actions led to a segregation or sorting and mixing of the soil. Because these movements depended upon the size, shape and position of the tillage blade, the soil loosening and pore spaces varied from one soil to another and thus the degree of mixing also varied. As explained in literature a curved tillage blade would for example bring up soil particles higher than

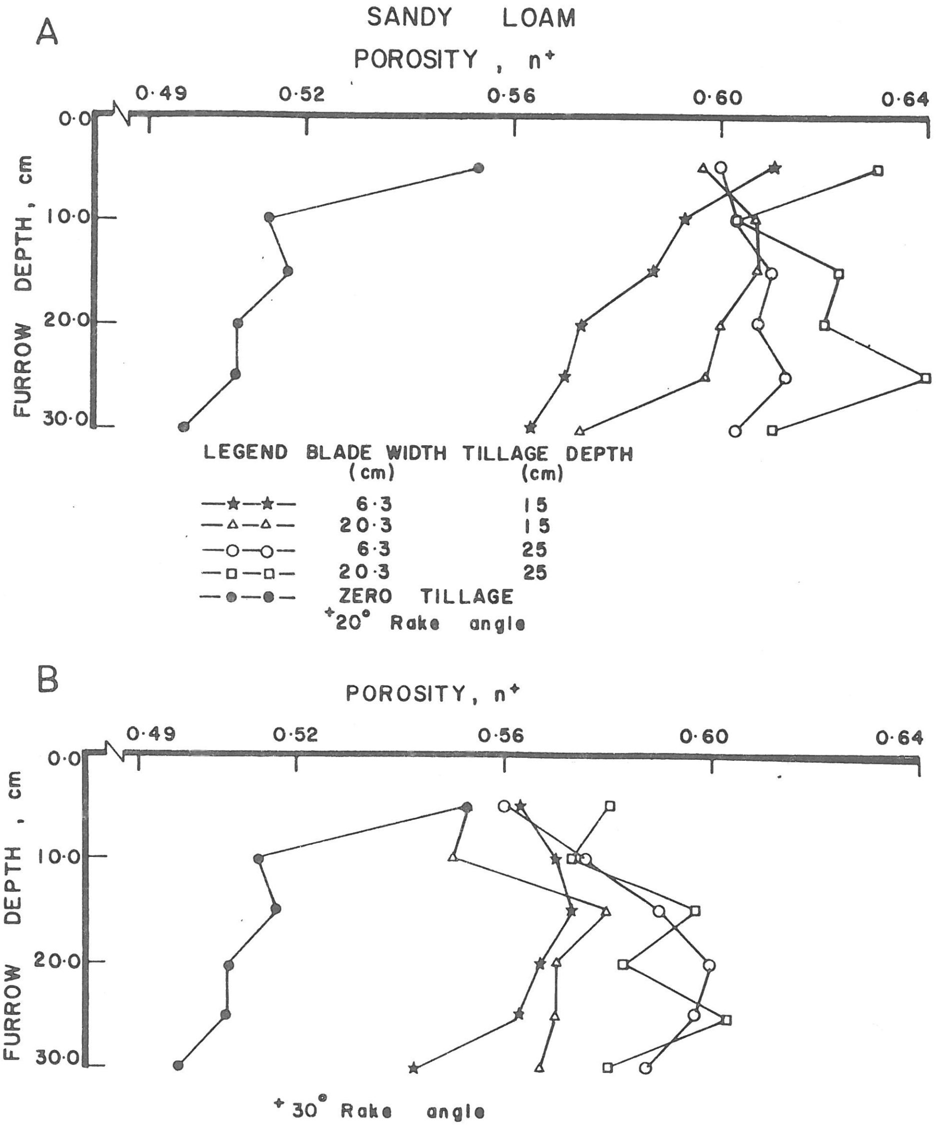

Fig. 4. Effect of width of a blade at 20° (A) and 30° (B) rake angle on the porosity of sandy loam at different depths.

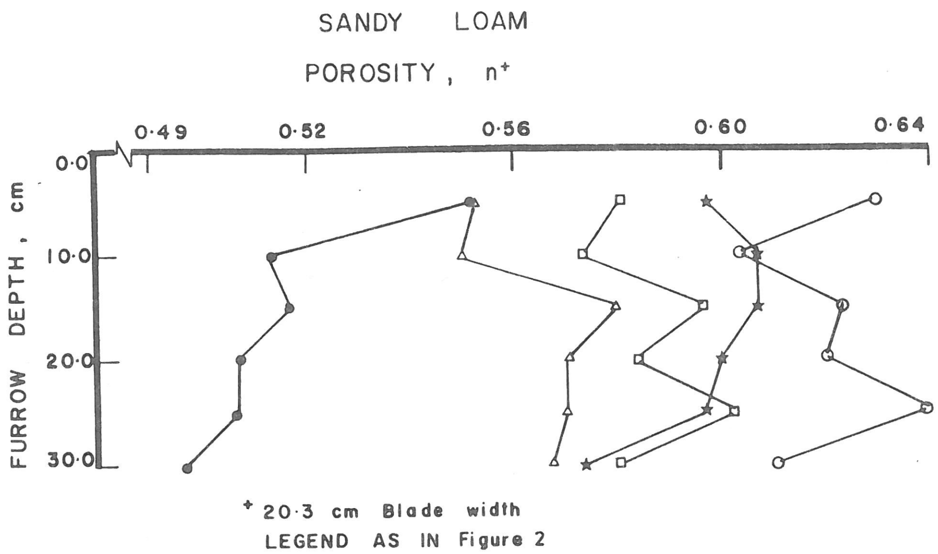

Fig. 5. Effect of rake angle of a blade of 203 mm width on the porosity of sandy loam at different depths.

a sharply bent tillage tool and thus influence the mixing effect. It is therefore reasonable to conclude from the above that for each cultivation operation, there is an ideal implement shape to transform the soil when working in a particular consistency state. In certain areas, there may not be the need to pulverize the soil extensively; in this way it is possible to avoid developing unnecessary porous soil granules that are susceptible to erosion by wind or to instability in water. The fact that the tilled sandy loam porosity decreased with depth showed that the top sandy loam soil might become more

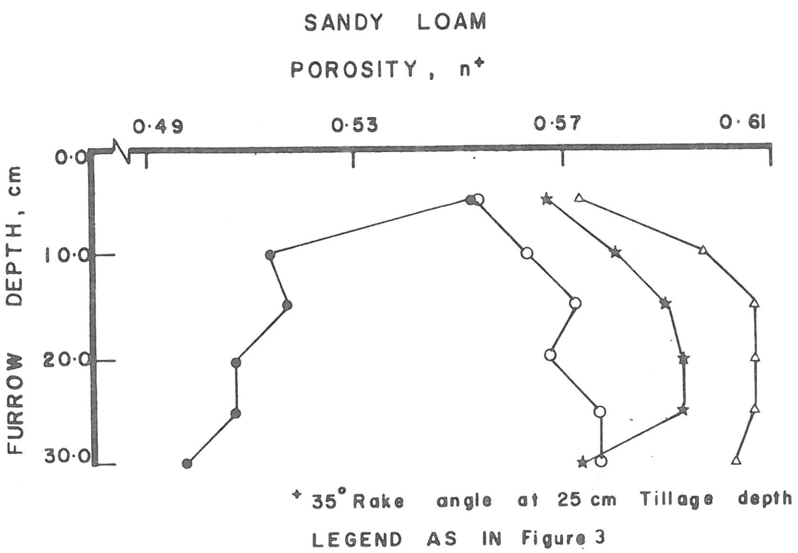

Fig. 6. Effect of width of a blade at 35^{O} rake angle on the porosity of sandy loam at different depths.

susceptible than the subsoil to wind effects. There would also be the possibility of the fine particules in the porous tilled top sandy loam being easily transported downwards during water infiltration. This could lead to instability of the top soil and pan formation in the subsoil. In the absence of relatively uniform porosity in the clay loam, the tilled clay loam would be susceptible to deterioration and instability in water due to poor water movement from the top soil to the subsoil. The less porous tilled top clay loam would deter water movement to the more porous tilled subsoil. There is therefore the need for proper selection of the appropriate tillage tools for different soil cultivations.

CONCLUSIONS

The results of the experiments and the analyses showed how the same implement used at different depths and angles of approach into the soil produced different soil environments. Although the effects of the depth of tillage on both soil porosities were highly significant at the one percent level, the effects of the interactions of the rake angle, the blade width and the depth of tillage were more significant on the sandy loam porosity than on the clay loam porosity. Relating soil porosity as the structural condition of the soil to both wind and water erosion, this study has provided a relative guide for the tillage tool designer and user in the selection of appropriate tool geometries for different soil environments. The established empirical relationships between tillage tool geometry and soil porosity make it possible to predict the level of tilled soil porosity as a function of tool geometry.

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