General Design Criteria for Impact Tools to Increase Cloddiness Potential and Reduce Wind Erodibility of Sandy Loam Soils

Leon Lyles and J. D. Dickerson
MEMBER ASAE MEMBER ASAE

CLODDY soils generally are less wind erodible than noncloddy soils, with the degree of erodibility depending on the proportion, size, and bulk density of soil aggregates (1)*.

Tillage can produce clods, but their quantity and quality depend largely on the physical forces of cohesion. In turn, cohesive forces within soil are influenced by moisture, clay content, cementing agents, and bulk density.

Under field conditions it is often difficult to obtain clods when they are most needed, especially for sandy soils. Two laboratory studies (4, 5) have shown (a) that under optimum moisture conditions for compaction, cloddiness of disturbed soils can be increased by packing before tillage; (b) that commercial agricultural soil packers do not appreciably increase soil bulk density even at optimum moisture conditions, and (c) that large static packing loads are needed to obtain appreciable increases in soil bulk density.

Those studies suggest a need for a practical tillage tool or modification of present tools to increase soil bulk density. Weight requirements for rolling-type packers are prohibitive for farm operations. Impact loads have some potential, provided the size and weight of the component delivering the load can be determined and a suitable implement can be developed that is capable of delivering the necessary impact forces.

Some information on design criteria needed before considering the development of a prototype tool is presented.

Experimental Equipment and Procedure

The soil used in the experiment was a Farnum fine sandy loam, physical characteristics of which are indicated in Table 1.

The study involved three replications of three packing pressures, three packing component sizes, and two spacings between packing component centers. Packing pressures were 10 (P_1), 16 (P_2), and 30 (P_3) pounds per square inch and were obtained by applying static loads with an air cylinder (Fig. 1). Packing components were rectangular shapes of 8 (2 x 4-in.), 18 (3 x 6-in.), and 30 (3 x 10-in.) square inches designated A_1, A_2, and A_3, respectively. In use, they were oriented so that the longer dimension was normal to the direction of tillage. Spacings between packing component centers were 6 (S_1) and 10 (S_2) inches.

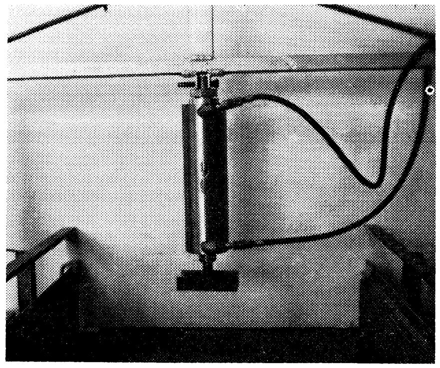

FIG. 1 Air cylinder used to apply various packing pressures.

Soil bulk densities (Fig. 2) were determined from two small-diameter cores per replication and from six to eight measurements per replication with a calibrated hand penetrometer. The penetrometer, which had a tip diameter of 0.48 cm, was inserted 0.5 cm into the soil.

Loose soil was placed in a tillage trough in two layers. The bottom 3-in. layer was rolled four times with a 200-lb smooth lawn roller. The top 6-in. layer was rolled twice before being packed and tilled to provide a uniform starting point and to smooth the surface. After applying the various packing treatments, the soil was immediately tilled about 5 in. deep with a full-size 2-in. chisel point. Soil moisture for all tests was near optimum moisture content for compaction (15.30 percent).

TABLE 1. SOME PHYSICAL CHARACTERISTICS OF FARNUM FINE SANDY LOAM SOIL

Characteristic	Value
Sand, percent	58.00
Silt, percent	25.50
Clay, percent	16.50
Liquid limit, percent moisture	35.03
Optimum moisture for compaction, percent	15.30
⅓ atmosphere, percent moisture	16.55
15 atmospheres, percent moisture	12.12
Maximum density, standard Proctor, pounds per cubic foot	107.80

Soil used was that thrown on the surface by tillage and that in the chisel path. It was placed in soil pans, air dried (60 to 65 C) and passed through a rotary sieve. Size distribution and mechanical stability (3) of clods were determined by sieving. The soil remaining in the tillage trough was passed through a ¼-in. screen and reused.

A relative measure of soil-packing effects on clod resistance to breakdown by simulated rainfall was obtained by exposing for 1 hour the mechanically stable clods greater than 6.4 mm in diameter to a 1.1-iph rainfall intensity in a laboratory rain tower. The clods were placed on 6.4-mm screen trays, weighed, exposed to rainfall, air dried (60 to 65 C), reweighed, and resieved. From those procedures, changes in size distribution, soil loss, and mechanical stability were determined. The quantity of soil loss during exposure is a relative measure of the resistance of clods to breakdown by raindrop impact. This resistance to breakdown will be called raindrop stability. It is expressed in percentage and defined as this ratio:

$$\frac{\text{Weight of clods after exposure to rainfall}}{\text{Weight of clods before exposure to rainfall}} \times 100$$

RESULTS AND DISCUSSION

Both percentage of clods greater than 6.4 mm in diameter and mechanical stability of the clods were increased by increasing packing pressures and packing component size and by decreasing the space between packing component centers (Fig. 3). Although the main effects (pressure, area, spacing) on percentage of clods greater than 6.4 mm in diameter and mechanical stability all were statistically significant at the 1 percent level, two of the three possible interactions for both percentage of clods and mechanical stability were also significant at the 1 percent level. The significant interactions weaken any conclusion drawn from the main effects on clod production or mechanical stability. Consequently, more useful information can be obtained

Paper prepared for publication in the TRANSACTIONS of the ASAE. Approved as a joint contribution from the SWCRD, ARS, USDA and the Department of Agronomy, Kansas Agricultural Experiment Station and published as article No. 960 in the journal series.
The authors—LEON LYLES and J. D. DICKERSON—are, respectively, research agricultural engineer and engineering technician, SWC, ARS, USDA, Manhattan, Kans.
* Numbers in parentheses refer to the appended references.

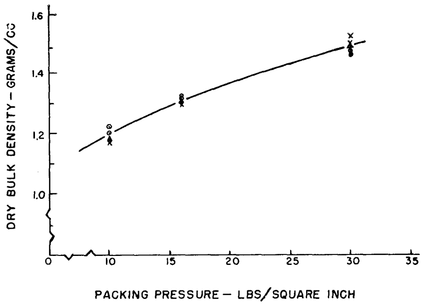

FIG. 2 Relation between packing pressure and dry bulk density for Farnum fine sandy loam at optimum moisture content for compaction.

from graphs that show various relationships between interacting variables and the dependent variable in question (Figs. 4, 5).

In clod production by chiseling, the three packing areas did not keep in step as the packing pressure changed (Fig. 4a). As packing pressure increased (except for A_2 at low pressure), more clods were produced with larger packing area. However, increase in cloddiness was at a constant rate for both packer spacings with increased packing pressure (Fig. 4b). Increasing the packing component area and decreasing the spacing between component centers combined to increase the area of soil receiving compaction. This explains the increasing difference in percentage of clods produced between S_1 and S_2 as the packing component area was increased (Fig. 4c).

The relationships among pressure-area, pressure-spacing, area-spacing, and mechanical stability of clods were similar to those for percentage of clods greater than 6.4 mm in diameter (Fig. 5). Apparently, higher soil density, larger packing component areas, and narrower spacing, which were effective in increasing the percentage of clods greater than 6.4 mm, were also effective in increasing the mechanical stability of the clods. However, physical explanations are not clear in all cases.

Although no extreme differences in raindrop stability were noted, clods formed at high packing pressures were slightly more stable than those formed at low pressure (Fig. 6a, 6b). Decreased resistance to breakdown by the clods formed at low pressure (P_1) with the largest packing component area (A_3) is probably due to the greater number of small clods produced and subsequently exposed to simulated rainfall. Visual observations of the trays during and after rainfall exposure indicated that most smaller clods had disintegrated and passed through the screens.

Mechanical stability of exposed clods after air drying is presented in Fig. 7a and b. It is not clear why the clods produced after packing at low pressures with the smallest packing component (A_1) were markedly more stable to rotary sieving after exposure to rainfall than clods produced by packing with the large components. The differences in stability were not evident before the simulated rainfall (Fig. 5a), nor evident (except for A_3 at P_1) in raindrop stability (Fig. 6a). Perhaps the explanation involves clod geometry and the rotary sieving method of determining mechanical stability. After the two rotary sievings required to determine initial size distribution and stability and after exposure to simulated rainfall, the clods produced by packing with A_1 were generally spherical in contrast to the rectangular shape formed by packing with the larger components. The slope of the rotary sieve permits spherical clods to pass through more rapidly with less opportunity for abrasion than the flatter, rectangular clods. Despite no precise explanation for differences in stability from the different packing components, it appears that fairly large

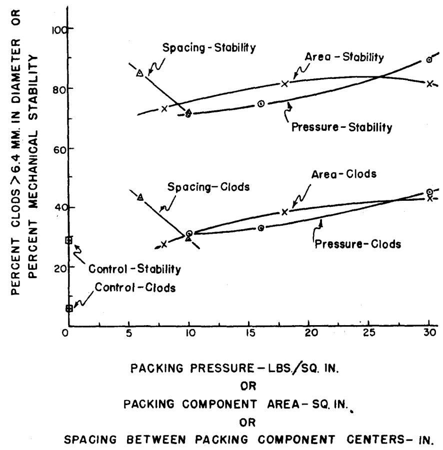

FIG. 3 Effects of packing pressure, packing component area, and spacing on soil cloddiness by chisel tillage.

packing pressures are essential to produce clods that are stable after exposure to rainfall.

Interpretations

One objective of the study was to provide information on design criteria for a prototype impact tillage tool. Basic questions involve what packing pressure, soil coverage, impact frequency, and impact stroke are necessary to increase soil bulk density and to produce appreciable quantities of clods large enough and stable enough to resist movement by wind and breakdown by the physical forces of soil abrasion, mechanical manipulation, and raindrop impact. To answer those questions, some criteria must be established to judge performance of any treatment used to increase soil cloddiness.

The percentage of clods greater than 0.84 mm in diameter is the simplest criterion for estimating erodibility of a soil by wind (2). For large, bare, smooth, unprotected fields, soils containing about 75 percent of clods greater than 0.84 mm in diameter are needed to hold average annual soil loss to 5 tons per acre (6). That corresponds roughly to 45 percent of clods greater than 6.4 mm in diameter, which was used as the evaluation criterion.

The intersection of the dashed lines with the curves in Fig. 4 at 45 percent clods greater than 6.4 indicates pressure, area, and spacing needed to reach that quantity of clods by chisel tillage. For the sandy loam soil studied at optimum moisture content for compaction, minimums for any combination of pressure-area-spacing were 22 psi, 17 sq in., and 8.2 in., respectively. Those values reject P_1, P_2, A_1, and S_2 completely and accept the $P_3A_2S_1$ and $P_3A_3S_1$ combinations.

General Requirements of a Prototype Tool

For sandy loam soils at optimum moisture content, a prototype tool should be capable of applying pressures of at least 22 psi per packing component. Higher pressures would be required for drier soils, but previous work indicates that packing loose sandy loam soil at moistures below 0.8 optimum moisture content produces weak, fragile clods (5).

Considering only the area of the strip where clods are produced and the packing component oriented as indicated earlier, the size of each component should be at least 17 sq in. and the area of soil coverage directly ahead of the chisel should be 50 percent or larger. Needed information about total coverage on a row or field basis cannot be deduced from this study. However, total field coverage at various row spacings, assuming only one packing component pass between

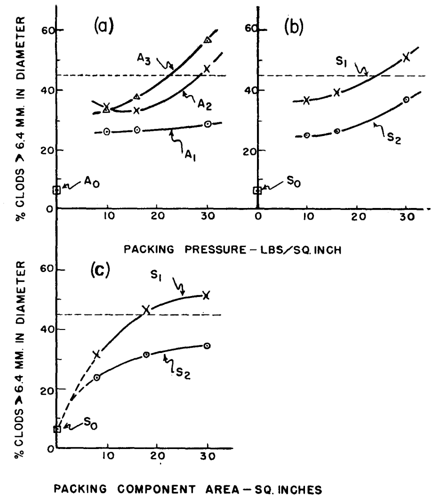

FIG. 4 Interactions between main effects (pressure, area, spacing) and percentage of clods greater than 6.4 mm in diameter produced by chiseling.

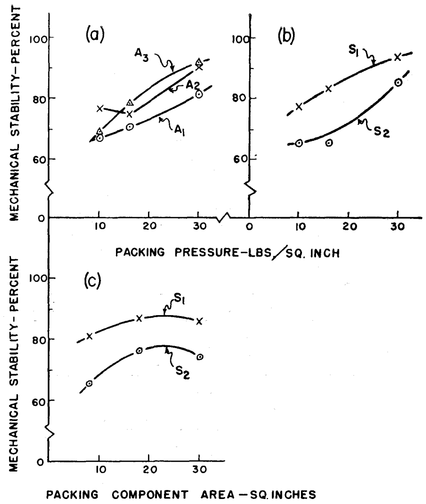

FIG. 5 Interaction between main effects (pressure, area, spacing) and mechanical stability of clods after chiseling.

rows and a 6-in. spacing between component centers, is as follows:

Component size, sq in.	Row spacing, inches 12	14	40
	Area coverage, percent		
18 (3 by 6-in.)	25.0	21.4	7.3
30 (3 by 10-in.)	41.7	35.7	12.5

Assuming 6 and 8-in. spacings between packing component centers, the application frequencies of the packing components for various implement speeds are as follows:

Spacing, in.	Implement speed, miles per hour 1	2	3	4	5
	Impacts per minute				
6	176	352	528	704	880
8	117	235	352	469	578

The packing components would penetrate the soil 2 to 4 in. depending on application pressures, initial soil looseness, and soil moisture. Those depths, plus some additional length for clearance, indicate that an impact stroke of at least 6 in. would be needed in a prototype tool.

Other dimensions and orientation of the packing components may be superior to those studied and may be required to meet possible application frequency limitations.

The question of packing component length normal to the direction of travel required to prevent the packed area from breaking out as a single or double "lump" cannot be answered from this study. Except for A_3 at 10, and 16 psi packing pressure, the soil packed with the 18-and 30-sq in. areas was generally bisected by the chisel as it passed through the soil. The soil surrounding the packed area apparently was too loose to offer sufficient resistance to prevent the packed area from being lifted upward in large lumps by the chisel. Fracturing the packed area into numerous smaller fragments would be preferable for wind erosion control (2). Consequently, more packing components smaller in area may be superior to fewer components of larger area.

These results indicate need for additional study on how to produce smaller clods that resist movement by wind and the need for quantitative information on the effects of clod density and clod size on their resistance to breakdown by rainfall impact.

Summary

The effects of packing pressure, packing component size, and spacing between packing components on clods produced by chisel tillage were studied in the laboratory to determine some general design criteria for an impact-type soil packer. The test soil was Farnum fine sandy loam at optimum moisture content for compaction. The percentage of clods greater than 6.4 mm in diameter, their mechanical stability, and their resistance to the breakdown by raindrop impact was used to evaluate treatments. Fort-five percent of clods greater than 6.4 mm was selected as the minimum standard by which to judge various treatments. Using that simple criterion, some tentative requirements for a prototype tool are:

1 Packing pressure—at least 22 psi per packing component
2 Packing component size (area) — at least 17 sq in. per component
3 Spacing between component centers — not more than 8 in.
4 Frequency of component application — from 350 to 700 impacts per minute.
5 Packing component impact stroke — at least 6 in.

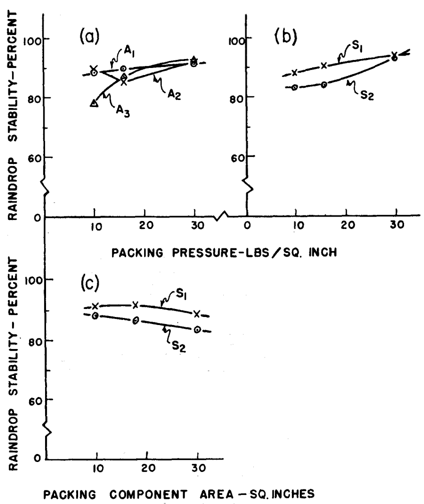

FIG. 6 Interactions between main effects (pressure, area, spacing) and raindrop stability of clods.

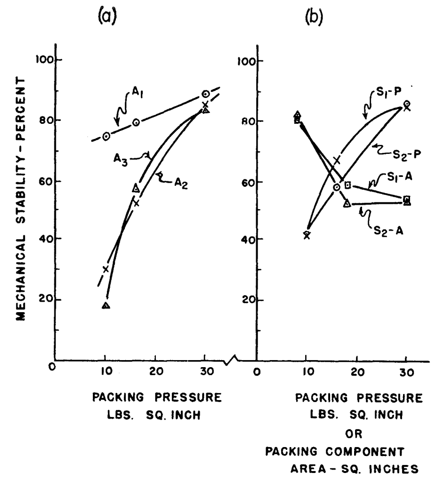

FIG. 7 Interactions between main effects (pressure, area, spacing) and mechanical stability of clods after exposure to simulated rainfall.

References

1 Chepil, W. S. Erosion of soil by wind. Yearbook of Agriculture, pp. 308-314, 1957.

2 Chepil, W. S. Soil conditions that influence wind erosion. USDA Tech. Bul. 1185, June 1958.

3 Chepil, W. S. Properties of soil which influence wind erosion: V. Mechanical stability of structure. Soil Sci. 72:(6)465-478, 1951.

4 Lyles, Leon and Woodruff, N. P. Surface soil cloddiness in relation to soil density at time of tillage. Soil Sci. 91:(3)178-182, 1961.

5 Lyles, Leon and Woodruff, N. P. Effects of moisture and soil packers on consolidation and cloddiness of soil. **Transactions of the ASAE** 6:(4)273-275, 1963.

6 Woodruff, N. P. and Siddoway, F. H. A wind erosion equation. Soil Sci. Soc. Amer. Proc. 29:(5)602-608, 1965.