Effect of fragmentation and pacing at spot ploughing on dry soils

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Abstract. Seedbed preparation to achieve desired aggregate size requires many tillage operations when performed on dry soil. A very common implement used for the initial operation is the moldboard plough, subsequent passes may include disk, chisel ploughs, cultivators, rototillers and harrows. Therefore ploughing should form flat soil surface to ensure favorable conditions for performance of subsequent operations. Mechanical reconsolidation by fragmenting and packing at spot ploughing on dry soils was studied in a soil bin, and on loam soil in the field. The results show that in dry soil fragmentation by ploughing and packing is attained by tearing the natural clods from each other and by stressing and translocating them. The maximum bulk density after ploughing was about 964 kg m^{-3} , after ploughing and packing was about 1071 kg m^{-3} . Packing considerably reduced soil surface roughness from about 0.12m to 0.04m. Moreover, packing by rolling increased soil fragmentation from about 68.2 % (after ploughing) to 79.8 %. A series of experiments showed that the roller had only a slight influence on draught resistance. The spot ploughing draught were increased about 1.3% at this operating conditions.

1 Introduction

For second crops, as a rule, dry soils are ploughed just before drilling of summer-sown crops such as maize. Consequently, there is no time available for desirable reconsolidation of the ploughed soil by natural forces. A very common implement used in arid semiarid regions for the initial operation is the moldboard plough. In an dry; clod-forming soil, the soil bulk is made of large hard clods. Therefore seedbed preparation to achieve a desired aggregate size and reconsolidation requires many tillage operations when performed on dry soils. These operations may include disk, cultivators, chisel ploughs, harrows and other [1]. In summer time it takes more time, leads to evaporation of soil water and decreasing soil moisture content, negatively influences plant density and yield [2].

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The quality of soil preparation mainly depends on ploughing. The plough buries residues and weeds to create desired seedbed, it also improves soil aeration for providing enough oxygen to decompose plant residues left in the field.

However, conventional mouldboard ploughing has some shortcomings. The first is soil displacement caused by ploughing. In [3] are proposed theoretical analysis that at conventional mouldboard ploughing 1ha on the depth 0.30m only on displacement of soil spent up to 5.106 J. energy.

Secondly, conventional mouldboard ploughing does not form flat and smooth soil surface caused by soil displacement. It does not ensure favorable conditions for performance of following operations.

The third is the structural difficulty of combining with additional implements.

In addition to shortcomings of mouldboard ploughing may include vulnerability of the ploughed soil to erosion, forming compacted soil layer, more labor and energy input.

It is designed new concept plough to invert soil slice at the same position [4-12]. According to the new concept soil slice invert within its own furrow without lateral displacement.

There are several names for the ploughs satisfying new technology of ploughing: 'Frontal plough' [4, 7, 10, 12], 'Spot plough' [11, 13, 14], Inverting plough [15], 'Parallel plough' [16].

Benefits of the spot plough are symmetric alignment of the units [4, 7, 10, 12], potential for combining with other working implements [17], forming flat soil surface, reduce the draught [7, 10, 12, 18-26].

The work reported here attempts to estimate efficiency of spot ploughing on dry soils with supplementary working unit (roller) for fragmenting and packing of soil.

2 Materials and methods

The model of roller was tested in the soil bin. The roller was mounted on a moving trolley. The trolley was operated at speeds of $1.0-1.5 \text{ m} \cdot \text{s}^{-1}$. Soils were prepared by pressing by packers. Soil moisture content was about 16.4-20.0%, bulk density $800-900 \text{ kg} \cdot \text{m}^{-3}$, cone penetration resistance 0.3-0.4 MPa.

View of a roller is shown in Figure 1.

Fig. 1. Schematic view of the roller and its parameters (1) disk; (2) axis; (3) planks; D_r -diameter; h_{pl} -height of plank; γ_{pl} -installation angle of plank; b_s - width of section; B_r - width of roller.

The model spot plough with mounted roller was tested on loam soil in the field located at Samarkand region of Uzbekistan. The crops commonly grown are wheat and cotton for the last 40 years. Figure 2 shows model spot plough designed for field testing. It consists of two symmetrical main mouldboards (1 and 2), sub-mouldboards (3 and 4), roller 5, pressing springs 6; wheels 7.

Fig. 2. Schematic view of model spot plough combined with roller: 1, 2 – main moldboards; 3, 4 – sub moldboards; 5 – roller; 6 – pressing springs; 7 – wheel.

The vertical load on roller can be changed by compression of a springs. Soil type is typical grey soils (serozem), moisture content on horizons 0-0.10, 0.10-0.20, 0.20-0.25 m respectively was 12.7 ± 0.5 ; 13.5 ± 0.5 ; $14.2 \pm 0.5\%$, cone penetration resistance respectively 2.67 ± 0.2 MPa; 2.97 ± 0.3 MPa and 3.12 ± 0.3 MPa.

Spot plough plus roller combination experiments were carried out at the depth of tillage about 0.25 m, with a forward speed of about 1.65 ms^{-1} .

Soil parameters measured in the field and soil bin were:

- a) moisture content in the tilled layer;
- b) aggregate size distribution;
- c) bulk density;
- d) soil surface roughness;
- e) cone penetration resistance.

Aggregate size distribution was studied in 5 replications on each passes by collecting the tilled soil from blocks of $0.25 \times 0.5 \times 0.5$ m and by sieving it through a set of sieves of different mesh sizes. Aggregates less than 50mm were regarded as the characteristics of fragmenting degree.

Soil bulk density was measured by means of 100 cm^3 core samples from the 0 - 0.05m, 0.05-0.10, 0.10 - 0.15, 0.15-0.20 and 0.20 - 0.25 m depths.

Soil surface roughness was measured before and after ploughing and after rolling by plank reliefmeter of 1-m length fitted with vertical measuring rods with 0.05 m spacing. Average magnitude of 20 measurements in 5 replication regarded as characteristics of soil surface roughness.

Cone resistance was measured by penetrometer Goryachkin (cone angle 300, base area 3.2 cm^2) before ploughing, after ploughing and after rolling.

Draught forces were measured by integrating tenzometric Triangle designed by VISHOM [27].

3 Results and discussions

Laboratory experiments of roller were carried out in soil bin. Results of these experiments are presented in Figure 3.

Functioning of the roller generally depends on it’s diameter (D) (see Fig 3, a and b), number of plank (n_{pl}) (see Fig 4) and an installing angle (γ_{pl}) of planks (see Fig 5).

Penetration resistance T and bulk density ρ decreased with an increase in diameter of the roller The distance between planks increases with increase the diameter that reduced the penetration resistance, bulk density (see Fig 3, a), fragmentation of soil F , soil surface roughness increased (see Fig 3, b).

Variability of penetrate resistance ΔT was negatively related with the number of roller planks (see Fig. 4). The degree of fragmentation increased with an increase of number of plank, soil surface roughness decreased. At number of plank more than 10 changing rates of fragmenting and soil surface roughness reduced.

The influence of installing angle of the plank on fragmenting of soil not so big (about 4...5%), but on soil surface roughness is significant (see Fig. 5). Under small installing angles of the plank fragmentation improves due to compression of clods by plank, but under greater angles the displacement of soil clods by plank occurs. Herewith fragmentation is attained by tearing the natural clods from each other and by stressing and translocating them. In dry clod forming soils fragmenting of soil on ploughing generally occurs under the same circumstances.

Fig. 3. Influence of diameter D of roller on: (a) penetrate resistance T and bulk density ρ ; (b) fragmenting degree F and soil surface roughness S .

Fig. 4. Influence of number of planks n_{pl} on fragmenting degree F and variability of penetration resistance ΔT .

Fig. 5. Influence of installation angle of plank γ_{pl} on fragmenting degree F and soil surface roughness S .

As a result of laboratory studies for field test combined with spot plough roller was manufactured under following parameters; $D = 0,3\text{ m}$, $n_{pl} = 10$; $\gamma_{pl} = 19^0$

Field experiments of Spot plough plus roller allow to establish terms for their joint operation, degree of influence of roller on functioning of plough.

Figure 6 presents some typical penetrometer results (a) measurements of bulk density (b) obtained immediately after spot ploughing and rolling.

Fig. 6. Influence of vertical load on roller to penetrate resistance (a) and bulk density (b) just after spot ploughing and rolling: 1-control (spot ploughing only); 2,3,4 – after spot ploughing plus rolling (vertical load on the roller respectively 500N (2), 1000N (3), 1500N (4)).

The rolling increased soil penetrates resistance and bulk density. The depth of influencing and its magnitude depend on vertical load on the roller (weight of roller plus compression force of the springs). The maximum increasing of penetrate resistance occurs at 0.05-0.10m depth (see Fig.6,a). The maximum bulk density after ploughing was 964 kg m^{-3} at the depth 0.25m, caused by influencing of upper soil layer and by inverting dry compacted soil on the bottom of furrow. After rolling the maximum soil bulk density was 1071 kg m^{-3} at 0.10m depth (see Fig.6,a).

The fragmenting of soil increased with an increase in vertical load on the roller, soil surface roughness decreased significantly. However magnitude of vertical load on roller is limited of ensuring of stability of the spot plough on depth of the tillage. Main results of the studies are reflected in the Table 1.

Figure 7 shows cross-section of tilled layer. After spot ploughing, wave form of soil surface would occur. In the inverting soil slice is deformed, increases in volume, that leads to incomplete inversion of the soil. As a result soil ridge by height 0.08-0.14m is formed on the middle of main moldboards, which depends on forward speed, soil properties, depth of tillage. It is obviously seen for two passes of the plough (see Fig.7).

Fig. 7. Cross-section through the surface layer before (1) and after spot ploughing (2), after spot ploughing and rolling (3).

Table 1. Average values of compared tillage treatments.

Implements	Maximum bulk density, kg.m ⁻³	Maximum cone penetration. resistance, kPa	Soil surface roughness, m	Fragmenting, (% aggregates less 50 mm)	Average draught force*, kH
Spot plough	964	630	0.12	68.2	12.96a
Spot plough plus roller	1071	750	0.04	79.8	13.14a

* - at the working depth 0,25 m, width of two moldboards 1,05 m, forward speed 1,64 mc⁻¹

a- means with (a) are not significantly different.

The results of the studies show that after rolling fragmenting of soil increased about to 11,6%, soil surface roughness reduced about triple, but average draught force increased only to 1,3%. Therefore spot ploughing combined with rolling ensure favorable conditions for performance of subsequent operations.

4 Conclusions

Rolling combined with spot ploughing improves the quality of prepared soil, creates favorable conditions for performance of subsequent operations.

1. Soil surface roughness decreased by rolling significantly.
2. Soil fragmentation by rolling increased with an increase vertical load on the roller.
3. After rolling the maximum penetrate resistance and soil bulk density was found at 0.05-0.10m depth.

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