Three-stage Subsoil Interval Mixing Plough for Improvement of Planosol*

— Part 1: Draught and Moment —


Abstract

To improve planosol soil conditions, a new Three-stage Subsoil Interval Mixing Plough (hereafter, TSIM-plough) was developed in 2010. The TSIM-plough resolved three problems encountered by the original Three-stage Subsoil Mixing Plough (hereafter, TSM-plough) developed in 1996. That is addition of an extra first plough body to the previous design TSM-plough. Firstly, its working width was increased from 460 mm to 920 mm with an extra first plough body installed. Secondly, its calculated draught moment caused on the tractor was reduced, thus allowing the tractor to running straight more easily. Thirdly, the ground trafficability increased with the improved layering of soft and hard subsoil solum, and tractors for harvesting no longer sank under wet field conditions even in the first year of operation.

[Keywords] planosol, subsoil interval mixing, soil hardness, draught requirement, draught moment

I Introduction

Planosol, which is a special soil group characterized by white sub-structure and clayey subsoil, is widely distributed in the Heilongjiang and Jilin provinces of the People’s Republic of China near the border with Russia. Tseng (1963) reported that planosol was similar to soils already described as “Lessivage” (France), “Pseudo-gley” (Germany), “Тцепсосоопсая” (Russia) and certain clay pan soils (USA). In the newest Chinese soil taxonomy, it has been classified into the alfsisol class, cold alfsisol subclass and albic cold luvisol class (Gongzitong et al., 1999). It is a low yield soil.

Planosol has a strong differentiation in its solum. Fig. 1 shows the planosol of a cultivated field at State Farm 853 in the Hongxinglong district. The first horizon (Ap) is a humic soil that is suitable for plant growth and has a thickness of about 200 mm. The second horizon (Aw) is a lessivage soil that is dense and impermeable and has a thickness of about 200 mm. The third horizon (B) below about 400 mm depth is diluvial heavy clay (Akazawa, 1986; 1987).

With the impermeable Aw horizon, plants suffer both from drought and excess moisture. The soil hardness (penetration resistance) of the Aw horizon is more than 5.0 MPa (cone penetrometer, 30° cone angle, 16 mm base diameter). Roots of plants cannot penetrate the Aw horizon, while soil micro organisms cannot live beneath it (Zhao et al., 1983).

Araya (1991) investigated the structure of planosol and found the particle size distribution of the Aw horizon was well suited for soil compaction. Soil compaction is a physical phenomenon, established in powder technology, where small particles fill the pore spaces of frame structure produced with larger particles. As a result, the bulk density of soil increases. The Aw soil has a bidisperse (binary) mixture in which mainly silt forms the frame structure and clay fills the pore spaces. To disturb the bidisperse mixture characteristics of the Aw soil, the Aw and B horizons should be mixed one-to-one, and the clay percentage should be increased (Zhao et al., 1989). Fig. 2 shows a Three-stage Subsoil Mixing Plough (TSM-plough), which was developed in 1996-1998 to improve planosol (Araya et al., 1996a; 1996b; 1996c; 1996d; 1996e; 1996f; Jia et al., 1998a; 1998b; Liu et al., 1998a; 1998b). The TSM-plough can mix the second (Aw) and the third (B) horizons of planosol in a one to one ratio, while leaving the first (Ap) horizon undisturbed. With the mixed clay from the B horizon into Aw horizon, the subsoil hardness

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no longer recovers to its original level (Zhao et al., 1989) and hence, a long-term improvement of planosol can be obtained by the use of the TSM-plough.

Since the initial development of the TSM-plough, the authors have been focusing on its large-scale extension in the planosol farmland area (Liu et al., 2001; Jia et al., 2005). However, three issues were found that required attention. 1) Its working (operating) width was 460 mm (just one-third of that of conventional subsoilers), and so its operational cost was nearly three times as expensive as the subsoilers. As a result, its large-scale extension was limited in practice. 2) The great draught moment caused on the tractor by the plough draught made it difficult for the driver to keep the tractor running straight. 3) The TSM-plough sometimes produced an excessively soft subsoil. This triggered poor trafficability for vehicles under waterlogged conditions and subsequently delayed the timing of harvesting, especially in the first years after operation.

In order to resolve these three problems, a Three-stage Subsoil Interval Mixing Plough (TSM-plough, Fig. 3) was developed in 2010. An extra 1st plough body was installed on the right side of the TSM-plough. With this mechanism, soft and hard subsoil solums are produced. The perpendicular distance between the axis of the resultant force of all tillage resistance acting on the TSM-plough bodies and the tractor centre (Fig. 9) is sharply decreased, and the draught moment imparted on the tractor will be also decreased.

In the autumn of 2010, a small (2 hm²) test field was constructed with this TSIM-plough at the State Farm 853 in the Three-river Plain of Heilongjiang Province, P.R.C. In the spring of 2011, a large-scale test field (20 hm²) was constructed at the same farm. In this paper, draught and moment of the TSIM-plough are discussed, and the effects on soil and crops with the treatments will be reported in a subsequent paper.
II TSIM-plough

1. Plough assembly

Fig. 4 shows the schematic diagram of the TSIM-plough. The detailed dimensions of the 1st, 2nd, and 3rd plough bodies were given in a previous paper (Araya et al., 1996e). An extra 1st plough body which is identical to the original 1st plough body was mounted on the right side of the original TSIM-plough. However, there is a difference of 50 mm in working depth between the two 1st plough bodies (Fig. 4a); the extra 1st plough tills the Ap horizon to 150 mm deep, while the original 1st plough tills the Ap horizon to 200 mm depth. With this difference in working depth, soil surface after operation can be kept flat. With the newly installed extra 1st plough body, the total working width is increased from 460 mm to 920 mm. The TSIM-plough produces two rows of subsoil: the subsoil tilled and mixed by the 2nd and 3rd plough bodies (working width is 300 mm) and untilled subsoil which is 620 mm wide (Fig. 4b).

2. Operation mechanism

The process of the operating mechanism of the TSIM-plough is shown schematically in seven stages in Fig. 5. Firstly, the extra 1st mouldboard plough body tills the Ap horizon (150 mm in depth, and 460 mm in width) [Fig. 5(2)], and the original 1st mouldboard plough body tills an adjacent Ap horizon (200 mm in depth and 460 mm in width) [Fig. 5(3)]. With the 2nd and 3rd plough bodies which are set behind the original 1st plough (Fig. 4b), the Aw and B horizons of subsoil are tilled and mixed together [Araya et al., 1996e; Fig. 5(4), 5(5) and 5(6)]. Subsequently, the extra 1st mouldboard plough body tills the next Ap horizon, inverting it to cover the mixed subsoil in the preceding furrow. Then, the original 1st mouldboard plough body tills the next Ap horizon covering the untilled subsoil [Fig. 5(7)]. Thus, the tilled and untilled subsoil solums are obtained. This soil improvement by the TSIM-plough will be treated every five to seven years (Araya et al., 1996f) and so, the untilled subsoil solum will be gradually tilled and mixed.

III Materials and Methods

The TSIM-plough was mounted on a tractor (Fig. 6) which was used to support the plough but did not provide power. This was drawn by another tractor through a traction dynamometer which installed strain gauges (capacity 100 kN, Araya et al., 1996e) Hence, only the horizontal force (draught) of the plough was measured once a reduction for the running resistance of the supported tractor was made.

To determine the draught of each of the four plough bodies separately and all of them together, the extra 1st plough body was operated alone, following removal of the original 1st, 2nd

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Fig. 4 Schematic diagram of TSIM-plough; measurements in mm; (a) side view; (b) plane view
and 3rd plough bodies. The original 1st plough body was then set, and the draught of the extra and original 1st plough bodies was then determined together. The 2nd plough body was then set, and the draught of all three plough bodies was then determined together. The 3rd plough body was then set, and the total draught of all four plough bodies was then determined together.

Fig. 5 Schematic diagram of mixing Aw and B horizons by TSIM-plough; measurements in mm

The working depth of the two 1st plough bodies was set at 150 mm and 200 mm from the soil surface and that of the 2nd plough body at 200 mm from the bottom of the original 1st plough body (Fig. 4a). The working depth of the 3rd plough body was then set at 200 mm from the bottom of the 2nd plough body. Three to five experiments were carried out for each condition.

Fig. 6 Traction test of TSIM-plough using a traction dynamometer

Fig. 7 Soil penetration resistance (cone penetrometer, 30º cone angle and 16-mm base diameter); see points P and Q in Fig. 5(7)

The mean soil penetration resistance (soil hardness) before ploughing, is shown in Fig. 7. At depths from 200 to 400 mm, there was an Aw horizon where the soil penetration resistance was more than 5.0 MPa (a cone penetrometer having 30º cone angle and 16-mm base diameter). At depths below 400 mm, there was B horizon where the soil penetration resistance was about 4.0 MPa, which was less than the Aw horizon.

IV Results and Discussion

1. Draught

The results of the draught test of the TSIM-plough are
The results of draught of the TSM-plough was very similar as Fig. 8 without the draught of the extra 1st plough body (elimination).

The running resistance of the wheel tractor (Fig. 6) on which the plough was mounted was about 10 kN. There was not a great difference between the draught of the extra and original 1st plough bodies which tilled the Ap horizon and the working depths were 150 mm and 200 mm, respectively. Both of these plough bodies nearly showed the same resistance at about 10 kN. The draught of the 2nd plough body, which tilled the Aw horizon and the draught of the 3rd plough body, which tilled the B horizon, were each also about 10 kN. For this combination, a good draught balance was achieved since each plough body required about 10 kN draught, giving a total draught of about 40 kN except the running resistance.

2. Soil penetration resistance

The soil penetration resistance after ploughing is also shown in Fig. 7. That at point P [Fig. 5(7)], where the Aw and B horizons of the subsoil were not tilled, was much lower at

![Diagram](image-url)
the Ap horizon alone (0-200 mm deep) than before ploughing. That at the point Q [Fig. 5(7)] where the Aw and B horizons of the subsoil was tilled and mixed, was much lower at all horizons (0-600 mm deep) than before ploughing.

3. Draught moment predicted

The draught moment caused on the tractor with the draught produced on the plough bodies is shown in Fig. 9. Assuming that the plough body generates also suction and side force but the horizontal force (draught) plays an important part of the draught moment, and plough resistance acts roughly at the middle of its working width.

The predicted draught moment $M_{TSM}$ of the TSM-plough (Fig. 9a) is

$$M_{TSM} = lF_{TSM}$$  

where $l$ is the perpendicular distance from the traction centre and $F_{TSM}$ is the total draught of TSM plough bodies.

The predicted draught moment $M_{TSM}$ of the TSIM-plough (Fig. 9b) is

$$M_{TSM} = lF_{TSM} + (l - 0.46) F_{TSM}$$

where $F_{TSM}$ is the draught of the extra 1st plough.

The perpendicular distance $l$ was 0.58 m for a Russian D75 tractor and a Chinese TS02 tractor, and the predicted values of Eqs. (1) and (2) are 17.4 kN.m and 9.4 kN.m, respectively. The perpendicular distance $l$ was 0.88 m for a larger Chinese TE150 tractor and USA JD tractor, and predicted values of Eqs. (1) and (2) are 26.4 kN.m and 21.4 kN.m, respectively. Thus, tractor driving will be easier for the TSIM-plough than the TSM-plough.

It is the best way to determine the angle of the steering wheel of a tractor during ploughing to know the amount of the draught moment objectively. This test results will be reported in a subsequent paper.

V Summary and Conclusions

To improve the planosol conditions for farming, a new Three-stage Subsoil Interval Mixing Plough was designed and built in 2010. The TSIM-plough successfully overcame issues unresolved by the original Three-stage Subsoil Mixing Plough (TSM-plough) developed in 1996. Firstly, its working width was increased from 460 mm to 920 mm with an extra first plough body installed. Secondly, its calculated draught moment on the tractor was decreased, which will allow the tractor to move more straight. Thirdly, the ground trafficability increased with the interval of soft and hard subsoil. 1. Draught requirement of the TSIM-plough was reasonably increased. The total draught of the TSM plough was about 30 kN and that of the TSIM-plough was about 40 kN without running resistance.

2. With a new arrangement of the plough bodies of TSIM-plough, the perpendicular distance of plough bodies from the traction centre was shortened, and the calculated draught moment caused on the tractor was decreased. Thus, easier tractor driving will be obtained.

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