Effects of Contour Plowing by Rotary Cultivator on Vertical Redistribution of Soil Organic Carbon

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Abstract: Simulated tillage and magnetic tracing techniques were applied to study the effects of contour plowing by rotary cultivator on vertical migration of soil organic carbon (SOC) on a steep hillslope in purple soil, revealing the relationship between SOC vertical and downslope movements. Contour plowing by rotary cultivator played an important role on downslope transfers of the soil, resulting in an obvious transformation of soil profiles with tillage depth at the summit position. The depth distribution of soil magnetic susceptibility showed that tillage brought about the vertical downward migration of the soil magnetic tracer. The intense tillage led to the vertically downward transfer of SOC, but vertical redistribution patterns differed from one another at different slope positions. Due to upward migration of parent rock debris and downslope transport of soil, SOC concentrations in the surface soil layer (0-10 cm) was reduced significantly at the summit position. For the backslope and footslope positions, SOC concentrations at 0-20 cm was reduced remarkably due to mixture effects of tillage and tillage erosion. SOC in the surface layer (0-5 cm) was decreased slightly at the toeslope position, but that at 5-20 cm increased significantly. This study indicated that the vertical movement of soil interacted with the downslope movement, which resulted in significant variation of SOC from the summit to toeslope positions.

1. Introduction
Tillage erosion is one of the main erosion patterns of purple soil slope farmland [1-7]. Numerous studies show that tillage erosion has an important impact on the migration and variation of soil organic carbon (SOC) in the slope surface [8,9]. SOC in plough layer migrates to the downhill along with tillage erosion, resulting in a decrease in SOC concentration of the plough layer in the tillage erosion area, while the SOC in the tillage deposition area increases or remains unchanged [10,11], and an increasing trend emerges of the SOC concentration in the subsurface soil [12]. At present, the studies focus on SOC migration along the slope caused by tillage, paying less attention to SOC vertical movement.

The quantitative study on the tillage erosion in purple soil is mainly concentrated on manual and animal-drawn tools, but less attention to rotary cultivator [13]. More studies on the relationship between the tillage erosion caused by large-scale mechanized tillage tools and the migration of SOC along the slope have been carried out in foreign countries [12]. The power connection of small rotary
cultivators differs from that of large-scale mechanized tillage tools, which may lead to different patterns of soil redistribution and then affect the process of soil organic carbon along the slope and vertical migration. Therefore, in this study, simulated tillage and magnetic tracing techniques were applied to study the effects of contour plowing by rotary cultivator on vertical migration of SOC in purple soil and reveal the relationship between downslope and vertical migration of SOC, providing data support for a comprehensive understanding of the relationship between purple soil tillage erosion and SOC migration.

2. Materials and methods

2.1. Experimental site
The experimental area is located in Xinqiao Town, Youxian District, Mianyang City, Sichuan Province. The terrain is dominated by low hills, at the elevation between 500 and 638 m. The soil type is calcareous purple soil of Chengqiang Rock Group (K1c). The climate type is a subtropical humid monsoon climate, with an annual average temperature of 16.1°C and an average annual precipitation of 986.5 mm. The tillage implements has gradually been changed from traditional animal-drawn tools to rotary cultivator.

2.2. Experimental design
A slope land, with a slope length of 18 m and a gradient of 15.12%, was selected and divided into two parts along the slope, one part used as a magnetic tracing area of which the width is 2 m, and the other one as a SOC research area of which the width is 5 m. The distance between the two areas was 2 m. In the magnetic tracing area, using a square method (1 m×1 m) of continuously laying from the top of the slope to the toe, the surface soil of 1 cm depth was uniformly mixed with the tracer, 200 mesh ilmenite powders. Then the soil magnetic susceptibility was measured six times on each site.

The main technical parameters of the experimental rotary cultivator are as follows: outline dimensions 1700 mm×1350 mm×900 mm, total weight 120 kg, rotary knife diameter 33.5 cm, engine power 6.3 kW. The contour plowing was operated 40 times continuously, ploughing from downhill, plowing back and forth along the contour line, cultivating to the hilltop, then returning from the space to the toe and carrying on tillage. The paths of each operation kept consistent, with a tillage depth of approximately 10-12 cm. The entire process was completed within 2 days with no rainfall.

Samples of soil profiles were collected at 1 m, 5 m, 10 m, 15 m and 18 m from the summit before and after tillage, respectively, using a soil-sampler (Eijkelkamp, Netherlands). Two sampling points were set in each position, and the same depth were combined into one mixed sample. GPS (T4 GNSS, China) was utilized to measure the topographic changes before and after tillage. The SOC concentration was determined by potassium bichromate titrimetric method, while the soil magnetic susceptibility was measured by a high-precision susceptibility meter (SM-30, Czech) with a sensitivity of 10⁻⁷ SI. The background values of soil magnetic susceptibility ranged from 0.15~0.29×10⁻³ SI, with an average of 0.22×10⁻³ SI (SD ±0.03).

3. Results

3.1. Soil redistribution pattern under contour plowing by rotary cultivator
After 40-operation contour plowing by rotary cultivator, the elevation at the summit (0 m) decreased by 0.17 m, exceeding the thickness of the original soil layer before tillage (0.16 m), while the elevation at the toeslope position (18 m) increased by 0.08 m. The elevation of the shoulder, back and foot of the slope had small changes (Figure 1). Contour plowing by rotary cultivator led to soil loss in the 0-5 m from the summit, no apparent changes in the 5~15 m from the summit, and the soil accumulation in the 15-18 m from the summit. After tillage, the relative elevation of the slope decreased from 2.34 m to 2.09 m, and contour plowing by rotary cultivator made the slope flat.
Figure 1. Changes in elevation before and after contour plowing by rotary cultivator

The depth of the soil profiles were 15.5-70.4 cm and 10.6-80.7 cm respectively, before and after 40-operation contour plowing by rotary cultivator, and it changed significantly after the contour plowing (Figure 2). The soil thickness of the slope top and the toe varied most significantly, with a decrease by 31.61% of the top and an increase by 14.67% of the toe, while those of the shoulder, back and foot of the slope were changed relatively small, respectively increasing by 1.20%, decreasing by 7.33% and 7.80%. These results show that soil redistribution resulting from contour plowing by rotary cultivator had obvious boundary effects.

For the summit position, soil magnetic susceptibility in the surface layer (0-5 cm) was apparently enhanced (Table 1), while that at 5-10 cm comparatively increased less. For the shoulder, backslope and footslope positions, soil magnetic susceptibilities at 0-15 cm are significantly enlarged, while those below the plough layer (>15 cm) basically had no change. For the toeslope position, soil magnetic susceptibilities at 0-20 cm were obviously increased. Comparing the magnetic susceptibilities of the same layer at different slope positions, the magnetic susceptibility at the toeslope position after tillage was distinctly greater than that of other positions.

| Depth (cm) | 1 m Pre-tillage | 1 m Post-tillage | 5 m Pre-tillage | 5 m Post-tillage | 10 m Pre-tillage | 10 m Post-tillage | 15 m Pre-tillage | 15 m Post-tillage | 18 m Pre-tillage | 18 m Post-tillage |
|-----------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 0-5       | 0.29            | 4.39            | 0.23            | 5.41            | 0.31            | 4.29            | 0.22            | 4.72            | 0.22            | 6.49            |
| 5-10      | 0.27            | 0.97            | 0.20            | 5.34            | 0.20            | 5.96            | 0.22            | 5.74            | 0.21            | 7.74            |
| 10-15     | 0.21            | -               | 0.22            | 0.39            | 0.29            | 1.80            | 0.23            | 0.72            | 0.24            | 6.02            |
| 15-20     | -               | -               | 0.17            | 0.18            | 0.19            | 0.19            | 0.20            | 0.18            | 0.22            | 0.49            |
| 20-25     | -               | -               | 0.18            | 0.19            | 0.19            | 0.19            | 0.23            | 0.23            | 0.23            | 0.23            |
| 25-30     | -               | -               | 0.19            | 0.20            | 0.20            | 0.21            | 0.20            | 0.20            | 0.22            | 0.22            |

3.2. Depth redistribution of SOC under contour plowing by rotary cultivator

Before tillage, the SOC concentration presented a diminishing trend with the increase of the depth at different landscape positions. After 40-operation contour plowing by rotary cultivator, the surface SOC concentrations of the 0-5 cm soil layer at different slope positions were reduced significantly compared with those before tillage and the reduction ranged by 11%-28%. In particular, all the surface SOC concentrations at 0-5 cm depth are less than those at 5-10 cm, except at the summit position (Figure 3). Compared with pre-tillage, the SOC concentrations of the soil layer at 5-20 cm depth also had marked changes after tillage, but different positions showed different characteristics. For the
summit position, the SOC concentration of the 5-10 cm soil layer decreased by 38%; For the shoulder position, the SOC concentrations (5-20 cm) increased by 15%; For the backslope and footslope positions, the SOC concentrations (5-20 cm) decreased by 26%; For the toeslope position, the SOC concentrations (5-20 cm) increased by 21%.

Figure 3. Depth distribution of SOC for 40-operation tillage at different landscape positions

4. Discussion

The soil erosion depth (0.17 m) at the summit position exceeded the thickness of the original soil layer (0.16 m) after 40-operation contour plowing by rotary cultivator. However, the soil profile has not disappeared but rather maintain the soil thickness equivalent to tillage depth, which indicated that tillage depth played an important role in maintaining the soil thickness at the summit position in purple soil. This is mostly attributed to thin soil layers and softy sediments. When the soil thickness is less than tillage depth induced by tillage erosion, the parent rock under the topsoil will be directly stripped by the rotary cultivator and mixed it into the tillage layer to make up the lost soil. Tillage made double effects on the topsoil by transport downslope and vertical transport of the soil, which enabled the soil thickness always in a dynamic equilibrium. Although an increase of tillage depth could elevate the amount of parent rock crushing and enhance the thickness of the soil layer, in the meanwhile tillage erosion would also be exacerbated, increasing the amount of the soil transported downslope [14]. The results in this study were obviously different from those of tillage by hoeing. After repeated hoeing, the soil layer at the summit was completely disappeared [7,8,15], due to the unidirectional downslope movement of the soil caused by hoeing along the slope. The erosion intensity resulting from hoeing was greater than that from contour plowing by rotary cultivator. In addition, the differences in tillage tools could also affect the results, with weaker effects on parent rock crushing by manual hoeing than rotary cultivator.

In the transect direction of slope, intense tillage led to soil loss in the upper part of the slope and soil accumulation in the lower part, indicating contour plowing by rotary cultivator plays a significant role in soil transport along the slope. The soil transport process could be divided into tillage erosion, tillage transport and tillage deposition areas. For the sloping landscape in this study, the uphill part 0-5 m from the hilltop was tillage erosion area, in which soil erosion was caused by tillage; the middle part
5-15 m from the hilltop was tillage transport area, which soil downslope transport is similar conveyor belt creating zero soil loss and gain [7]; the downhill part 15-18 m from the hilltop was tillage deposition area, where the soil accumulated because of tillage. In the vertical direction, the soil magnetic tracer transferred vertically downward under contour plowing by rotary cultivator, but the vertical transfer patterns differed from one another for tillage erosion, tillage transport and tillage deposition areas. For the tillage erosion area, the magnetic intensity of the soil in the 5-10 cm soil layer was apparently weaker than that in the 0-5 cm soil layer. This difference is mainly attributed to the dilution effects of the soil derived from parent rock detritus and upslope positions. For the tillage transport area, the soil magnetic tracers were uniformly distributed in the whole till layer due to mixture effects of tillage. For the deposition area, the soil magnetic tracers were increased at 0-20 cm, twice the depth of tillage, which was mainly due to the soil accumulation from the summit to the toeslope positions, making the soil in the original till layer being buried into the new till layer.

The depth distribution of SOC in the surface layer was changed markedly by contour plowing by rotary cultivator. After 40-operation tillage, the SOC concentration at the summit position decreased seriously. This was mainly attributed to soil downslope transport by tillage erosion, and in the meanwhile, the parent rock detritus with extremely low SOC content were added into the till layer, diluting its SOC. The SOC concentration in the surface layer (0-20 cm) at the backslope and footslope positions were reduced remarkably, which was due to mixing effects of tillage and low-concentration SOC downslope transport. The SOC concentration in the 0-5 cm surface layer at the toeslope position was decreased slightly, but that in the 5-20 cm soil layer increased significantly, mainly because of the dilution effects of SOC derived from upslope positions. The results of this study are similar to those of the simulated hoeing tillage in the purple soil [7, 15], however, due to the different gradients of the slope lands and tillage tools, the changes of SOC and depth distribution at different landscapes were different.

5. Conclusions
The depth distribution of soil magnetic susceptibility showed that contour plowing by rotary cultivator led to vertical downward migration of the soil magnetic tracer, but the vertical transfer patterns differed from one another for tillage erosion, tillage transport and tillage deposition areas. Due to the dilution effects of the soil derived from parent rock detritus and upslope positions, the magnetic intensity of the soil in the 5-10 cm soil layer was apparently weaker than that in the 0-5 cm soil layer at the tillage erosion area. The soil magnetic tracers were uniformly distributed in the whole till layer resulting from mixture effects of tillage at the tillage transport area. Because of the soil accumulation from the summit to the toeslope positions, the soil magnetic susceptibility of the 0-20 cm soil layer increased at the deposition area. Due to the downslope and vertical migration of the soil, SOC presented a similar distribution pattern. This study indicated that contour plowing by rotary cultivator gave rise to the downslope and vertical migration of the soil and SOC, making effects on each other.

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