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# Reduced tillage practices without crop retention improved soil aggregate stability and maize (*Zea mays* L.) yield

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## ABSTRACT

Conservation agriculture has been advocated as an effective option for maintaining soil and environmental sustainability. However, the current farmer practice in Western Loess Plateau involves removal of crop residues. This study evaluated the influence of tillage systems without residue retention on soil properties and maize (*Zea may* L.) yield. The experiment was laid out in a randomized complete block design with four (4) treatments and three (3) replicates. Treatments were; conventional tillage (CT), rotary tillage (RT), subsoiling (SS) and no–till (NT). Data was taken during 2014, 2015 and 2016 cropping season. Subsoiling and no–till treatments increased soil carbon content by 15 to 29% in the 0–10 cm depth compared with rotary tillage and conventional tillage. Mean weight diameter (MWD) of aggregates were larger under SS and NT plots relative to CT plots. Maize biomass yield with SS was the greatest (20163.93 kg ha$^{-1}$), followed by NT (18896.74 kg ha$^{-1}$), RT (18215.34 kg ha$^{-1}$) and CT (16306.93 kg ha$^{-1}$); this resulted to SS increasing biomass yield by 7, 11 and 24% compared to NT, RT and CT, respectively. Subsoiling significantly increased grain yield by 21% and 18% on average compared with CT and RT, respectively. It can be concluded that reduced tillage without residue retention improved soil aggregate, mean weight diameter, carbon and nitrogen content resulting to increased crop yield under dryland cropping systems.

**Keywords:** Carbon; Nitrogen; Mean weight diameter; Tillage; Residue; Yield

## INTRODUCTION

Soil plays a crucial role in agricultural production; the quality and health of soil determine its agricultural sustainability and environmental quality. In dryland cropping systems of semi-arid environments such as the Loess Plateau, soil nutrient and water deficit are the main factors limiting successful crop establishment and yield (Sainju *et al*., 2009). This is due to low and unevenly distributed precipitation coupled with high evaporation in the Western Loess plateau of China (Wang *et al*., 2015; He *et al*., 2014). Also, continuous and intensive cultivation and suboptimal agricultural practices in response to the increasing population have led to serious deterioration of soil quality (Wang and Shao, 2013). Intensive farming and the continued removal of crop residues (Sharma *et al.*, 2005) in the Loess plateau has had immense effects on soil fertility (Major *et al*., 2010). Such processes are key contributing factor that reduces soil resilience and therefore may have long–term implications on food security to the rural communities (McBratney and Field, 2015). The low yield by virtue of declined soil productivity thus renders many cropping systems unproductive. Improved soil management practices such as residue retention (Paustian *et al*., 1997), tillage practices (Fuentes *et al*., 2011), appropriate N fertilization (Fernandez−Luqueno *et al*., 2009), and crop rotation (Lal, 2005) have been suggested to increase soil productivity. Among the important mechanisms to improve soil physical and chemical properties are tillage practices (Steduto *et al*., 2007; Rosner *et al*., 2008).

Tillage and residue management significantly influences crop growth and yields by changing soil structure and moisture removal patterns over the growing season. At present, many researchers have reported different results for soil moisture and infiltration properties, physical properties such as bulk density and crumb structure (Lampurlanés *et al*., 2001). Subsoiling tillage practices improves soil structure (Hou *et al*., 2012) and therefore soil water content (Mohanty *et al*., 2007). Reduced tillage or no−till with residue management have been increasingly used to reduce soil erosion (Reinbott *et al*., 2004) as well as increase water storage; and thus water–use efficiency (Hartkamp *et al*., 2004) for increased yield. However, the combination of no or reduce tillage and residue management is very rarely practiced on the Loess Plateau because of high demand of crop residue as livestock feed and as fuel for heating or cooking (Lal *et al*., 2000). This has led to the practice of no-till or reduced tillage without residue retention, a phenomenon which is becoming popular. There seems to be limited report on reduced tillage systems (rotary, subsoiling and no till) without residue retention on soil physical and chemical properties and crop yield on the Loess plateau. There is the need to develop technologies that plays an important role in maintaining, or where possible improving the productive capacity of soils on the loess plateau, where the soil is fragile. Given this context, the objectives of the present study was to assess the effect of reduced tillage practices without residue retention on soil aggregate stability, soil nitrogen and carbon content and crop yield.

## MATERIALS AND METHODS

### Experimental site

The field experiments were conducted at the Dingxi Experimental Station (35°28′N, 104°44′E and elevation 1971 m a.s.l.), Anding County, Gansu Province, northwest China. The semiarid Western Loess Plateau is characterized by a hilly landscape and is prone to erosion. The aeolian soil in that region is locally known as Huangmian (Chinese Soil Taxonomy Cooperative Research Group, 1995), which equates to a Calcaric Cambisol in the FAO (1990) Soil Classification, and is primarily used for cropping (Zhu *et al*., 1983). It is a sandy–loam with soil organic carbon < 7.63 g $kg^{-1}$ and Olsen P < 13.3 mg $kg^{-1}$, representing the major cropping soil in the district. Daily maximum air temperatures can reach up to 38 °C in July while minimum air temperatures can drop to negative 22 °C in January. Annual radiation is 5929 MJ/$m^2$ with 2477 h of sunshine and coefficient of variation is 24.3%; representing a typical semi–arid rainfed agricultural zone. The experimental site has a long history of continuous cropping using conventional tillage practices. Total rainfall for the cropping season was 280 mm in 2014, 274 mm in 2015, and 227 mm in 2016.

### Experimental Design

The experiment used a randomized complete block design with three replicates of four treatments. Treatments were: conventional tillage (CT), rotary tillage (RT), subsoiling (SS) and no–till (NT). Conventional tillage was the local farming practice which included two moldboard ploughs, harrowing, followed by tine tillage. Detailed treatment description is presented in Table 1. There were a total of twelve plots; each plot was 46 $m^2$ (4 m × 11.5 m) in size with alternate wide and narrow ridges (0.7 m and 0.4 m wide). All plots were mulched with plastic films at seeding, an innovative technology for boosting maize productivity in arid environments. Each of the treatments received 200 kg N $ha^{-1}$ in the form of urea (46%): 50% hand–broadcast at planting and 50% top–dressed before flowering. Phosphorus ($P_2O_5$) was applied to all plots at 150 kg $ha^{-1}$. The maize (*Zea mays* L., cv. Funong 821) was sown at a planting distance of 0.55 m x 0.35 m with a planting density of 52,000 plants $ha^{-1}$. Roundup (glyphosate, 10%) was used for weed control during fallow after harvesting as per the product guidelines. During the growing season, weeds were removed by hand. Pests and diseases were monitored and controlled as per conventional practice in the area. All other agronomic considerations were kept constant for all treatments. The experiment was initiated in 2012; however, this article reports the experimental yield data for 2014, 2015 and 2016 cropping season, whilst soil data on aggregate stability, C and N were reported for only the 2015 cropping season due to project running out of funds.

Soil samples were collected at two depths: 0-10 cm and 10-30 cm for aggregate separation and mean weight diameter calculation prior to sowing in 2015. Depth of 0-10 cm and 10-30 cm was used to know tillage effect on top-soil and sub-soil. Dry aggregate size distribution was determined by the standard dry–sieving method (Savinov, 1936). Undisturbed field–moist soil samples were air dried at room temperature until the soil moisture content reached about 8% and then 200 g samples of air–dried soil were spread uniformly on the uppermost of a set of nested sieves (> 2, 2–1, 1–0.5, 0.5–0.25 and <0.25 mm) by gently pressing the clod of soil by hand. The sieves were mechanically shaken (amplitude 1.5 mm) for 2 minutes to obtain dry sieve soil aggregates of different size fractions. The different fractions were weighted and dry MWD (mm) calculated as described by Van Bavel (1949):

$$MWD = \frac{\sum_{i=1}^{n} (\overline{R}_i w_i)}{\sum_{i=1}^{n} w_i}$$

Where R is the mean diameter of each size fraction size i (mm); W is the proportion of total sample weight occurring in the size fraction *i* and n is the number of size fractions.

Undisturbed soils samples were collected from two points at three depths (0–5 cm, 5–10 cm and 10–30 cm) in each plot using a soil corer (4.9 cm diameter) for determination of soil carbon and nitrogen content. The soil from the same depth were bulked and mixed. The samples were air dried, ground to < 2 mm, and then sub–sampled and ground to < 0.25 mm. Soil C and N content was determined with C and N analyzer (Elementar Vario Macro Cube, Hanau, Germany).

### Grain and biomass yield (kg ha$^{-1}$)

At physiological maturity, maize plants were hand–harvested from an area of 13.2 m$^2$ (4 m × 3.3 m) per plot. Physiological maturity was determined using crop phenology and physical observation (black layer visible, fully ripe, kernels hard and shiny) according to the standardized maize development stage system (Ritchie *et al*., 1997). The above ground biomass and grain yield were determined on dry weight basis by oven–drying at 105 °C for 45 min and then dried to constant weight at 85 °C. The grains were separated, air–dried, cleaned, weighed and the grain yield per hectare for each treatment was extrapolated. Harvest index (HI) was determined using equation described by Donald (1962):

$$\mathrm{HI} = \frac{\mathrm{GY}}{\mathrm{BY}}$$

Where: GY (grain yield, kg ha$^{-1}$) and BY (biomass yield, kg ha$^{-1}$) is expressed as a proportion of total–aboveground biomass on a dry weight basis.

### Statistical analysis

Data were analyzed with one–way analysis of variance (ANOVA) using SPSS analysis software (22.0 SPSS Inst. Ltd., USA). Means comparisons of treatments for measured variables were separated by LSD Test and significance differences were declared at probability level of 5%.

## RESULTS

### Soil aggregate fractions and mean weight diameter under tillage practices

Soil aggregate size distribution and mean weight diameter (MWD) in relation to different tillage systems in the 0−10 cm and 10–30 cm depth are shown in Table 1 and 2, respectively. Compared with CT, both NT and SS treatments significantly (*P*

< 0.05) had higher proportions of macro–aggregates > 2 mm (by 74 and 56%), and 1−2 mm (by 38 and 43%), respectively at 0–10 cm relative CT plots. Similarly, at 10–30 cm depth, macro–aggregates (> 2 and 2–1 mm) increased in SS and NT compared with CT plots. The proportion of the aggregates with a size of less than 1 mm for CT (74%) and RT (74%) significantly ($P < 0.05$) had higher compared to NT (62%) and SS (50%) at 0–10 cm depth. The MWD of the CT and RT treatments were significantly lower than the SS and NT treatments at both sampling depths (Table 1 and 2).

Table 1. Aggregate size distribution (mm) as determined by dry sieving in the 0–10 cm soil depth and mean weight diameter (MWD) under different treatments.

| Treatment | Aggregate size class (%) | | | | | MWD (mm) |
|---|---|---|---|---|---|---|
| | > 2 mm | 2−1 mm | 1−0.5 mm | 0.5−0.25 mm | < 0.25 mm | |
| CT | 12.22 | 13.65 | 23.18 | 24.25 | 26.71 | 0.93 |
| RT | 12.74 | 13.48 | 24.13 | 33.91 | 15.75 | 0.98 |
| SS | 21.26 | 18.78 | 20.74 | 20.47 | 18.75 | 1.28 |
| NT | 19.00 | 19.52 | 21.53 | 26.07 | 13.87 | 1.23 |
| LDS (0.05) | 2.48 | 2.53 | 2.94 | 6.95 | 2.52 | 0.09 |

Table 2. Aggregate size distribution (mm) as determined by dry sieving for the 0–30 cm and mean weight diameter (MWD) under different treatments.

| Treatment | Aggregate size distribution (%) | | | | | MWD (mm) |
|---|---|---|---|---|---|---|
| | > 2 mm | 2−1 mm | 1−0.5 mm | 0.5−0.25 mm | < 0.25 mm | |
| CT | 14.38 | 12.54 | 23.54 | 27.75 | 21.79 | 1.00 |
| RT | 14.83 | 11.82 | 24.27 | 26.80 | 22.28 | 1.01 |
| SS | 20.11 | 16.78 | 23.39 | 25.17 | 14.54 | 1.24 |
| NT | 17.33 | 14.02 | 21.22 | 26.15 | 21.27 | 1.10 |
| LSD (0.05) | 2.00 | 2.18 | 3.05 | 3.74 | 3.77 | 0.04 |

## Soil carbon and nitrogen under tillage practices

Tillage significantly affected soil C and N content at 0–5 cm and 5–10 cm, but seldom at 10–30 cm (Table 3). In 2014, soil C and N at 0–5 and 5–10 cm, were all significantly higher under NT and SS plots than under either RT or CT plots, which were not different from each other. There were no significant differences ($P < 0.05$) in soil C and N content between NT and SS treatments in 2014. Subsoiling and NT treatments significantly increased C content between 22% to 33% in 2014 and 8% to 26% in 2015 in the 0–5 and 5–10 cm soil depth, respectively.

Table 3. Soil total carbon and nitrogen measured at different soil depth (cm) in maize under different tillage

| Year | Treatment | C (g kg$^{-1}$) | | | N (g kg$^{-1}$) | | |
|---|---|---|---|---|---|---|---|
| | | 0-5 | 5-10 | 10-30 | 0-5 | 5-10 | 10-30 |
| 2014 | CT | 15.2 | 14.2 | 15.1 | 0.32 | 0.30 | 0.34 |
| | RT | 18.4 | 15.7 | 15.3 | 0.47 | 0.44 | 0.33 |
| | SS | 18.6 | 18.5 | 16.6 | 0.80 | 0.62 | 0.50 |
| | NT | 19.8 | 18.8 | 16.7 | 0.81 | 0.66 | 0.50 |
| | LSD (0.05) | 1.9 | 1.2 | 2.4 | 0.06 | 0.07 | 0.13 |
| 2015 | CT | 16.3 | 14.8 | 15.4 | 0.52 | 0.42 | 0.48 |
| | RT | 17.2 | 16.9 | 16.5 | 0.67 | 0.51 | 0.51 |
| | SS | 17.5 | 18.2 | 16.8 | 0.70 | 0.66 | 0.60 |
| | NT | 18.9 | 18.7 | 16.6 | 0.86 | 0.77 | 0.58 |
| | LSD (0.05) | 1.5 | 2.1 | 1.5 | 0.14 | 0.11 | 0.11 |

## Biomass and grain yield

Table 4 and 5 shows biomass, grain yield and harvest index over the 3 years of the study. Tillage, year and their interaction affected biomass, grain yield, and harvest index (Table 4). The biomass and grain yield were significantly higher in 2014, followed by 2015 and then 2016. This resulted to an increase of 13% and 54%

in grain yield and 12% and 67% in biomass yield compared to 2015 and 2016, respectively. Overall, reduced tillage had significant effect on biomass and grain yield compared with CT (Table 5). Forage yield under SS was the greatest (20163.93 kg ha$^{-1}$), followed by NT (18896.74 kg ha$^{-1}$), RT (18215.34 kg ha$^{-1}$) and CT (16306.93 kg ha$^{-1}$). This resulted to SS increasing biomass yield by 7, 11 and 24% compared to NT, RT and CT, respectively. On a lesser magnitude, NT and RT increased biomass yield by 16 and 12% compared with CT. Reduced tillage recorded higher grain yield compared to CT. Subsoiling significantly increased grain yield by 21% and 18% on average compared with CT and RT, respectively. On a lesser magnitude, NT significantly increased grain yield by 13% and 11% compared to CT and RT, respectively. Rotary tillage increased grain yield compared to CT but differences were not significant. Over the three study cropping seasons, grain yield was not statistically significant between SS and NT treatment.

Table 4. Analysis of variance for tillage practices, year and their interaction on biomass yield, grain yield and harvest index

| Sources of variation | Biomass yield | Grain yield | Harvest index |
|---|---|---|---|
| Treatment (T) | * | * | ns |
| Year (Y) | *** | *** | ns |
| T * Y | *** | * | * |

Notes: *, **, *** indicate significant difference at $P < 0.05$, $P < 0.01$, $P < 0.001$, respectively. n.s. indicate no significance difference at $P < 0.05$.

Table 5. Biomass yield, grain yield and harvest index in maize under tillage systems

| Treatment | Biomass yield | | | Grain yield | | | Harvest index | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2016 | 2014 | 2015 | 2016 | 2014 | 2015 | 2016 |
| CT | 18485 | 18261 | 12175 | 7379 | 6936 | 5324 | 0.40 | 0.38 | 0.44 |
| RT | 22775 | 19761 | 12110 | 7787 | 6949 | 5331 | 0.34 | 0.35 | 0.44 |
| SS | 23909 | 22343 | 14240 | 9813 | 8299 | 5598 | 0.41 | 0.37 | 0.39 |
| NT | 23365 | 18800 | 14525 | 8764 | 7738 | 5702 | 0.37 | 0.41 | 0.39 |
| LSD (0.05) | 1072 | 773 | 1249 | 1663 | 425 | 224 | 0.07 | 0.03 | 0.04 |

## DISCUSSION

### Effect of tillage practices on aggregate stability, C and N dynamics

Aggregate size distribution and stability are important indicators of soil physical quality (e.g. soil structure, aggregation and degradation) (Shrestha *et al*., 2007). In our study, the most dramatic effect of NT and SS treatments was its role in increasing the proportion of macro–aggregates and therefore the mean weight diameter (MWD), though the proportion of micro–aggregates (1–0.5 mm and 0.5–0.25 fraction) did not show significant increase. Macro–aggregates are less stable than micro–aggregates, and therefore more susceptible to the disruption forces of tillage (Cambardella *et al*., 1993). More stable aggregates in the upper surface of soil have been associated with reduced tillage soils than tilled soils and this correspondingly results in high total porosity under reduced tillage plots. Since, in the present study no mulch was present on the soil surface, what can explain the greater aggregate stability, from NT and SS soils?. The possible explanations of the greater soil aggregate stability with NT and SS soils are their lesser levels of soil disturbances as cited by Govaerts *et al*. (2009). Subsoilers are ideal in dry soils to break up compacted layer without destroying surface vegetation or mixing soil layers (USDA, 2008). Subsoiling fractures compacted soil without adversely disturbing plant life, topsoil, and surface residue. Fracturing compacted soil promotes root penetration by reducing soil density and strength, improving moisture infiltration and retention, and increasing air spaces in the soil. Compacted soils resulted in restricted root growth, poor root zone aeration and poor drainage that result in less soil aeration (Johnson *et al*., 1986).

NT and SS soils also had higher effect on soil C and N content, presumably due to enhanced physical protection of soil organic matter due to the less soil disturbance (Chaplot *et al*., 2012). Minimum tillage, compared with CT, does not only improve aggregate stability but also increased the concentrations of soil carbon and nitrogen content (Jacobs *et al*., 2009). By increasing macro-aggregation, NT increased organic carbon accumulation in soil. This agrees with Six *et al*. (2002) who reported that increased soil C levels under NT compared with CT are a result of a 1.5 times slower C turnover, partially induced by an increased macro-aggregation and a decreased macro-aggregate turnover, leading to a stabilization of C within micro-aggregates. The pattern of the results indicate that tillage systems that involve less physical disturbance help improve soil aeration, soil aggregate stability and conserve soil moisture.

### Effect of tillage on biomass and grain yield.

The success of a tillage system is directly related to the improvement of the soil physical and chemical properties which in turn might affect the growth and development of crops due to the different soil conditions created. Biomass and grain yield were significantly improved in SS and NT plots compared to CT plots; this was consistent across the three years of the study. Subsoiling and NT treatments increased biomass and grain yield because of favorable soil condition for crop growth. This is in agreement with Mohanty *et al*. (2011) who reported that the amount of N released to crops depends on the chemical composition of organic matter such as N content and C:N ratio. In the present experiment, improved N content under SS and NT might have increased the amount of N released and increased plant growth and development with increase in yield. Minimum tillage plots retain more water than tilled plots due to improved soil structure resulting in increased storage pores and consequently, to an increase of available water for plants and ultimately the agronomic yield (Kargas *et al*., 2012). Tillage impact on crop yield is related to its effects on root growth (Boone *et al*., 1994), water and nutrient use efficiencies (Davis, 1994). An increase in root length density has been found only in the upper soil layers of NT and reduced tillage systems compared to the CT system (Martınez *et al*., 2008). However as reported by Huang *et al*. (2008), avoiding tillage and retaining residue in rainfed conditions increased and stabilize crop yields.

The increase in grain yield may be related to improved soil physical and chemical structure. It is well established that reducing soil structural stability and carbon content could reduce root growth and may thus reduce water and nutrient acquisition (Kuchenbuch and Ingram, 2004) and reduce crop yield (Lipiec *et al*., 2003). This result demonstrates that SS and NT tillage practices are options for maintaining soil and environmental sustainability in resource strained farmlands.

## CONCLUSION

Evaluating the impact of tillage systems without residue returned on soil properties and crop yield is important to identify potential management interventions to reduce negative environmental impacts associated with dryland cropping system. No till and SS improved soil aggregate stability, nitrogen and carbon content. This resulted to improved grain and biomass yield. Subsoiling and no–till are therefore ideal management option for improving certain key properties of degraded Western Loess soils.

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