INFLUENCE OF TILLAGE PRACTICES ON YIELD, WATER CONSERVATION AND SOIL LOSS: RESULTS OF FIELD EXPERIMENTS IN THE EASTERN LOESS PLATEAU (HENAN PROVINCE, CHINA)

Y. Yao[A], W. Schiettecatte[B], J. Lu[A], Y. Wang[A], H. Wu[C], K. Jin[C], D. Cai[C], D. Gabriels[B], R. Hartmann[B], W.M. Cornelis[B], M. Baert[B], T. Buysse[B]
[A] Luoyang Institute of Agricultural Sciences, 5 Jun Min Road, Anle, Luoyang, P.R. China
[B] Department of Soil Management and Soil Care, Ghent University, Coupure links 653, B-9000 Ghent, Belgium
[C] Soil and Fertilizer Institute, Chinese Academy of Agricultural Sciences, 30 Baishiqiao Road, Beijing 100081, P.R. China

Abstract
In order to examine the effect of alternative tillage practices on crop yield, water conservation and soil loss, a field study was conducted over a period of 4 years. On field plots near Luoyang (Henan province, China) the following tillage practices were applied: reduced tillage, no-tillage, subsoiling and conventional tillage. Rainfall simulation experiments were done to examine the effect of tillage on runoff and soil losses. Negligible runoff amounts were observed on the no-tillage plot. Subsoiling reduced runoff and soil losses by more than 50, respectively more than 90 % compared to conventional tillage. Although soil losses under reduced tillage decreased by half compared to conventional tillage, the differences in runoff amounts were small. For every year of the field trial period, subsoiling was found to give the highest yields. On average, an increase of 11% was observed compared to conventional tillage. The average yield from the no-tillage plots was slightly higher than under conventional tillage, while a slightly lower yield was found under reduced tillage. Because yield is an important criterion in promoting alternative tillage practices towards farmers, subsoiling can be regarded as a promising measure to improve soil and water conservation in the Eastern Loess Plateau of China.

Additional Keywords: erosion, runoff, subsoiling, winter wheat

Introduction
In the Loess Plateau of China large areas are affected by soil erosion caused by overland flow (Shi and Shao 2000), but the application of conservation tillage techniques is becoming more widespread (Gao and Li 2003). However, conventional tillage is still frequently applied, by which the upper soil layer is turned after harvest and before sowing, resulting in an uncovered soil surface during July, August and September. These months are characterised by the highest rainfall intensities; more than half of the total annual rainfall occurs during this period. It emphasises the need to further explore and promote alternative tillage techniques which protect the soil during these erosive months. Several researchers have already indicated that tillage practices influence soil and nutrient losses considerably (eg. Mostaghimi *et al*., 1988; Richardson and King, 1995; Kisic *et al.*, 2002). Especially tillage techniques, in which most of the crop residues are left on the soil surface, are effective in erosion control. Besides the benefits on soil and water conservation, it is important that the yield is not negatively affected by the tillage practices. Preliminary results obtained by Cornelis *et al*. (2002) indicated already that alternative techniques like subsoiling can have a positive effect on water conservation. Lafond *et al.* (1996) stated that the improvement in grain yield under conservation tillage is directly related to the extra amount of water that is conserved, regardless of the crop. Subsoiling may therefore positively affect crop growth and yield.

The purpose of this study was to examine the effect of different tillage practices on runoff, soil losses and yield of winter wheat on field plots under simulated and natural rainfall. These results are needed to select and promote valid tillage alternatives, focusing not only on the aspects of soil and water conservation, but also taking into account short term benefits (eg. yield) which are important to the farmer.

Materials and Methods
Field plots
The field plots situated near Luoyang (Henan province; 113.0° East longitude, 34.5° North latitude), in the eastern part of the Chinese Loess Plateau, were constructed in 1999. The main soil characteristics of the site at the moment of construction are given in Table 1. Four plots (30 × 3 m), having a slope of 0.1 m m^{-1}, are under natural rainfall (P-plots). On every plot, winter wheat is cultivated but different tillage practices are applied: conventional tillage (CT), reduced tillage (RT), no-tillage (NT) and subsoiling (SS). The fertiliser application rates were 150 kg N ha^{-1}, 105 kg P_2O_5 ha^{-1} and 45 kg K_2O ha^{-1}.

Under CT a stubble of 10-15 cm remains on the field after harvest (May 25 -June 1), but the straw and ears are carried away. In the first week of July, the soil is ploughed and turned till 20 cm depth. Around October 1, the soil is ploughed and turned to 20 cm depth while at the same time organic and/or inorganic fertilizer is incorporated, followed by harrowing (seed bed preparation). Sowing of winter wheat is done before October 5. Under RT a stubble of 10-15 cm remains on the field after harvest (May 25 - June 1) and the straw is returned to the field after threshing. Around July 1, deep ploughing (25-30 cm) combined with harrowing (5-8 cm) is done. Winter wheat is sown between September 25 and October 5. Under NT a stubble of 30 cm remains on the field after harvest (May 25 - June 1) and straw is returned to the field after threshing. Between September 25 and October 5, direct sowing with fertilizer application is done. Under SS, a stubble of 25-35 cm remains on the field after harvest (May 25 - June 1). Around July 1, subsoiling is performed till 30-35 cm depth at 60 cm intervals. Between September 25 and October 5, direct sowing with fertilizer application is done.

Adjacent to the plots under natural rainfall, a similar set of erosion plots (15 × 1.8 m) were constructed at the end of September 2001 and used for rainfall simulation experiments (R-plots).

Table 1. Characteristics of the loess soil at the field plots near Luoyang (Henan province)

Depth (m)	0-2 µm ($g\ g^{-1}$)	2-50 µm ($g\ g^{-1}$)	50-2000 µm ($g\ g^{-1}$)	$CaCO_3$ ($g\ g^{-1}$)	OC ($g\ g^{-1}$)	pH(KCl)
0-0.02	0.143	0.748	0.109	0.113	0.0065	7.7
0.02-0.3	0.141	0.743	0.116	0.129	0.0045	7.8
0.3-0.6	0.138	0.745	0.117	0.142	0.0020	7.7
0.6-0.85	0.148	0.736	0.116	0.146	0.0025	7.8
0.85-1.3	0.140	0.745	0.115	0.135	0.0020	7.9

Field rainfall simulations

Because of the position of the field plots, rainfall was simulated on two adjacent field plots at the same time. A rainfall simulation system was used with 2 sprinkler booms, each being positioned at a height of 1.8 m above the middle axis of a field plot. On every sprinkler boom, nozzles were fixed every 1 m. Rainfall intensities of 176 and 88 mm h^{-1} were simulated using all, respectively half of the sprinkler nozzles. On every plot, two rainfall simulations were done with the same rainfall intensity, resulting in a total of 4 rainfall simulations per plot. The rainfall simulations lasted for 30 min. The experimental conditions of the different rainfall simulations are given in Table 2. The plots under CT and RT were bare during the rainfall simulation tests, while on the SS and NT plot the wheat stubble provided a soil cover of 50 %. Runoff discharge was recorded continuously and runoff samples of 5 l were taken after 2.5, 5, 7.5, 10, 15, 20, 25 and 30 min rain duration. Sediment concentration of the runoff samples was determined by evaporation at 105 °C.

Yield measurements

Within each field plot, three subplots of 1 m^2 (respectively in the upper, middle and lower part of the field plot) were harvested in order to determine the average yield of every plot. Statistical analysis of the data was done using the software SPSS v11.0.1 (SPSS, 2001).

Results and Discussion

Infiltration and runoff

Figure 1 shows the reduction in runoff under the different tillage practices compared to conventional tillage for the experiments mentioned in Table 2. The results clearly indicate that NT and SS have a beneficial effect on runoff reduction, which may be partly attributed to the higher soil cover by wheat stubble. However, Schiettecatte et al. (2003) showed that both soil cover and tillage affect the saturated hydraulic conductivity and therefore also the reduction of runoff. Application of RT reduced runoff in the first experiments but this effect diminished during the last experiments, possibly due to sealing of the surface soil by raindrop impact. The difference in runoff between RT and CT is rather surprising because the tillage practices under RT and CT are similar in July, i.e. prior to the rainfall simulations. The reduction in runoff by RT compared to CT can possibly be attributed to the incorporation of the straw, which is returned to the field after threshing. Under CT the straw is removed from the field.

Soil loss

Figure 2 shows the reduction in soil loss by the different tillage practices compared to conventional tillage for the experiments mentioned in Table 2. The results show that NT and SS strongly reduce soil erosion. Under NT almost

Table 2. Experimental conditions of field rainfall simulations

Date	Plot #	θi § (g g^{-1})	Rainfall intensity (mm h^{-1})	Code of experiment
23 August 2002	NT	0.141	176	run1, 176
23 August 2002	RT	0.087	176	run1, 176
25 August 2002	NT	0.201	176	run2, 176
25 August 2002	RT	0.175	176	run2, 176
28 August 2002	NT	0.162	88	run3, 88
28 August 2002	RT	0.168	88	run3, 88
29 August 2002	NT	0.217	88	run4, 88
29 August 2002	RT	0.202	88	run4, 88
3 September 2002	CT	0.140	176	run1, 176
3 September 2002	SS	0.172	176	run1, 176
5 September 2002	CT	0.252	176	run2, 176
5 September 2002	SS	0.265	176	run2, 176
7 September 2002	CT	0.259	88	run3, 88
7 September 2002	SS	0.295	88	run3, 88
9 September 2002	CT	0.244	88	run4, 88
9 September 2002	SS	0.288	88	run4, 88

[#] NT = no-tillage; RT = reduced tillage; CT = conventional tillage; SS = subsoiling
[§] θi = initial moisture content in the upper soil layer (0- 20 cm)

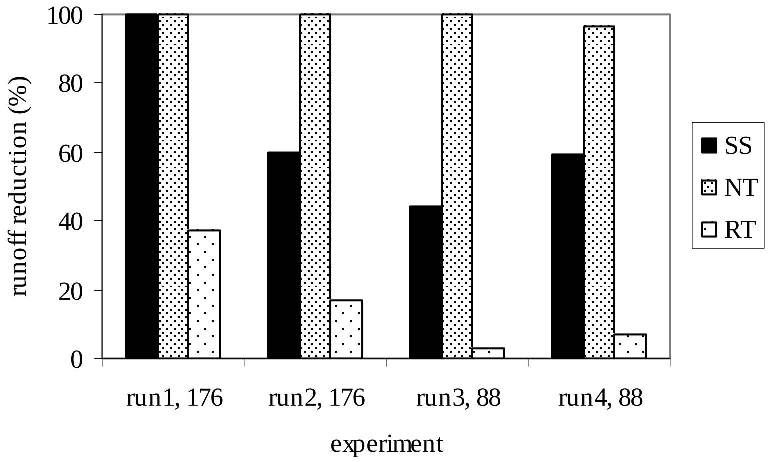

Figure 1. Reduction in runoff by different tillage practices (SS = subsoiling, NT = no-tillage, RT = reduced tillage) compared to conventional tillage, after a rainfall simulation of 30 minutes (experimental conditions are given in Table 2)

no runoff and soil loss occurred. SS diminished erosion by more than 90 %, while RT resulted in a soil loss decrease of 38 to 54 %. Comparing the results in Figure 1 and 2, shows that the reduction in soil loss is higher thanthe decrease in runoff. This indicates that, besides the saturated hydraulic conductivity, also the soil erodibility is affected by the applied tillage technique. This can partly be attributed to the wheat stubble on the SS and NT plots. Schiettecatte *et al*. (2003) showed that tillage has a supplementary effect on soil erodibility: the highest, respectively lowest erodibility value was found for CT and SS. The erodibility of NT could not be assessed because only negligible runoff amounts were measured during the experiments. McGregor and Greer (1982) also indicated that even when crop residues were left on the surface of conventionally tilled soils, they provided less protection against erosion than the accumulated residues from no-tillage and reduced tillage systems.

Yield of winter wheat

The average values of the yield measurements on the field plots are given in Table 3. On the R-plots, CT and RT resulted in the lowest yields, although not significantly different from the other treatments. On the P-plots, under natural rainfall, similar results can be observed for most years. For all years, SS resulted in the highest yields. Under NT, the wheat stubble remains more erect compared to SS. Rasmussen *et al.* (1997) concluded that under no-till, standing wheat residue decreased the winter wheat yield with 13 % compared with chopping or burning of the residue. Therefore, it was expected that in our study the standing wheat stubble would also have an important negative effect on the yield. However, according to the results in Table 3, it seems that this effect is of rather minor importance. On the other hand, farmers are less convinced to apply NT, due to the stubble, which hampers direct

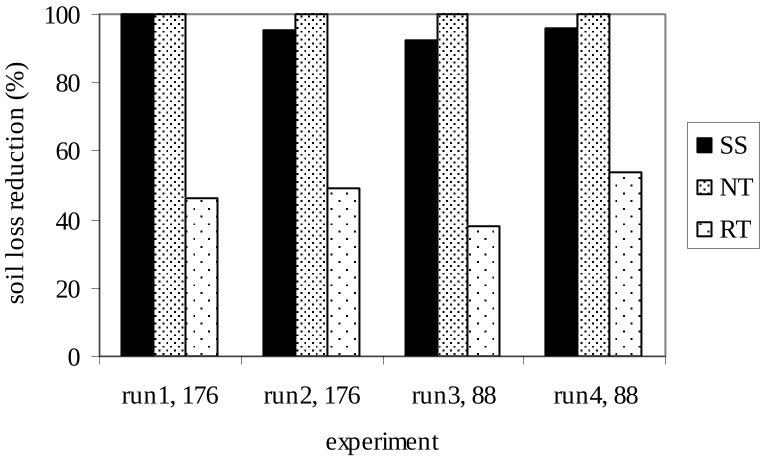

Figure 2. Reduction in soil loss by different tillage practices (SS = subsoiling, NT = no-tillage, RT = reduced tillage) compared to conventional tillage, after a rainfall simulation of 30 minutes (experimental conditions are given in Table 2)

sowing of the winter wheat. The yield results under NT show in most cases no significant differences with CT. The average yield on the P-plots under NT over all years was only 2.5% higher than on the CT fields, while under RT a decrease of 2% was observed compared to CT. In this regard, SS is more likely to be accepted by farmers because of the higher yields.

On average, SS resulted in a yield increase of 11% on the P-plots compared to CT. McGregor and Greer (1982) observed that the average grain yields on fields with no-till, respectively reduced till were about 1 and 11 % higher than under conventional tillage. Other researchers (Shipitalo and Edwards, 1998; Weisz and Bowman, 1999) did not observe significant differences in yield among different tillage systems. It should be taken into account however that the study area near Luoyang has an average annual rainfall of 571 mm (period 1971-1999), of which the main part falls during the months July, August and September (ie. in the fallow period). Small influences of tillage practices on water conservation during the fallow period will therefore have a more pronounced impact on the yield. Preliminary water balance data on the P-plots indicated that SS was the best practice in terms of water conservation; NT and CT gave intermediate results, whereas RT was the worst alternative (Cornelis *et al.*, 2002). These results are in agreement with the observations of the average yield data on the P-plots, confirming the statement of Lafond *et al.* (1996) that the improvement in grain yield with conservation practices is directly related to the additional amount of water that is conserved by the tillage practice.

Lafond *et al.* (1996) also state that further research is required on the manipulation of stubble height to enhance water conservation. The stubble height is not only important from a water conservation point of view. The harvest of the straw supplies an extra benefit to the farmer, which is “lost” under conservation tillage. In this regard further research is needed to find out to what extent the straw can be harvested or substituted by e.g. organic fertilizers, without loosing the beneficial effects of the tillage techniques on soil and water conservation.

Table 3. Average yield of winter wheat (g m^{-2}) on the erosion plots [#] (n = 3)

		Tillage practice [§]			
Plot	**Year**	**RT**	**NT**	**SS**	**CT**
R	2002-2003	464 ^{a} (21)	484 ^{a} (10)	498 ^{a} (9)	445 ^{a} (10)
P	2002-2003	435 ^{a} (18)	478 ^{b} (10)	486 ^{b} (5)	402 ^{a} (8)
P	2001-2002	447 ^{a} (14)	490 ^{a,b} (13)	548 ^{b} (21)	517 ^{a,b} (27)
P	2000-2001	405 ^{a,b} (7)	411 ^{a,b} (4)	425 ^{b} (8)	392 ^{a} (7)
P	1999-2000	369 ^{a} (3)	386 ^{a,b} (10)	459 ^{c} (16)	422 ^{b} (13)

[#] values between brackets indicate standard error; average values in the same row followed by the same letter are not significantly different according to Student-Newman-Keuls test (α = 0.05)
[§] RT = reduced tillage; NT = no-tillage; SS = subsoiling; CT = conventional tillage

Conclusions

Based on the field rainfall simulations it was found that runoff was strongly reduced by SS and NT, compared to CT. RT was less effective in runoff reduction, but decreased soil loss by 38 to 54% compared to CT. In general, it was observed that the alternative tillage practices reduced erosion more efficiently than runoff. According to the yield results, SS was the best practice with an average yield increase of 11% compared to CT. Under NT and RT a slightly higher, respectively lower yield was observed compared to CT. On the long term, NT may be considered as the best management practice, because of its importance on soil and water conservation, which ameliorates soil fertility on site and decreases negative off site consequences. However, SS is more likely to be accepted as a valid alternative of CT, due to its short term benefits regarding yield combined with the beneficial effects on soil and water conservation. Crop residues are an important aspect of conservation tillage, while on the other hand they may supply an extra benefit (eg. fodder) to the farmers. In this regard, further research is needed to examine the effect of the stubble height on soil and water conservation under SS.

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