The Water Balance as Affected by Conservation and Conventional Tillage Practices on Slope Fields in the Drylands of North China

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Abstract: Soil erosion by water is a severe problem in the eastern loess belt of Northern China, particularly on agricultural land. The erosion problems are to a large extent associated with improper soil tillage practices. Changing the current tillage practices could therefore reduce soil loss. This will, however, also affect the water balance and hence the available water for crop growth, particularly in dryland farming systems. A field study was carried out on five plots on a slope field near Luoyang, Henan province, China, in order to compare the water balance under different soil tillage practices. The terms of the water balance were determined from August 1999 until April 2001. From October to June all plots were under winter wheat. After harvesting, four soil tillage practices were applied: conventional tillage, no tillage, subsoiling and reduced tillage. A two-crop rotation of winter wheat and summer corn or peanuts was applied as well. Analysis of the different components of the soil water balance enabled to determine the most suitable practice for crop growth. The results, though preliminary at this stage of the study, show that subsoiling resulted in the highest increase in moisture storage and lowest evaporation during the fallow period. The two-crop rotation with peanuts also showed promising results, mainly due to decreased evaporation of the soil surface. The no-tillage and conventional tillage gave intermediate results, whereas the reduced tillage was the worst alternative.

Keyworks: dryland, loess soil, slope land, conservation tillage, water balance

1 Introduction

The rate of adoption of conservation tillage for agricultural sustainability is growing exponentially in many regions of the world due to the needs of soil and water conservation (see e.g. Garcia-Torres *et al.*, 2001). In the dry farming areas of northern China, where severe land degradation, particularly wind and water erosion, occurs on 80% of the farmlands, research on conservation tillage is given more consideration to prevent a further decline in land productivity.

Much of the farmland in the dryland area of North China is suffering from severe water erosion during the rainy season in summer and seasonal drought during the crop-growing season. Soil erosion has brought about severe topsoil loss, water runoff and land degradation including a decline in its fertility, as a result of not only natural climatic and landscape factors, but also human activities (such as conventional over-tillage). Conventional farming practices with extensive cultivation and little use of crop residue exacerbate soil, water and nutrient losses, causing decreases in water availability, soil fertility and crop productivity.

Since the 1980's, studies on conservation tillage (including reduced tillage and no-till) in combination with design of appropriate machinery and agronomy studies have been carried out in the Southeast and middle part of Shanxi in the semi-humid to arid area of northern China. These studies illustrated the advantage of reduced tillage practices for soil protection, water conservation, and crop yield improvement (Gao *et al.*, 1990, 1991; Cai *et al.*, 1994, 1995, 1998; Wang, 1995, 1998, 2000).

However, various tillage methods have had different effects on soil and water conservation, crop growth and yield production, depending on the local conditions of soils and climates. Information on effective erosion-resistant types of conservation tillage on the eroded slope farmland of the semi-humid to arid regions is still ample available.

In order to fill this gap, a five-year Sino-Belgium co-operation project (1998—2003) was started on the eroded farmland area around Luoyang, Henan province in the eastern loess plateau of China, located in the semi-humid to arid region. Field experiments for winter wheat were conducted to determine the effects of various tillage practices on conservation and use soil water.

2 Materials and methods

2.1 Experimental site conditions

The experimental plots are located in Songzhuang, Mengjin county, North of Luoyang (113° East longitude, 34.5° North latitude), Henan Province, in the eastern loess belt of China, in the semi-humid to arid region of North China. The elevation of the loess belt is 130 to 2,500 m above the sea level. Around 58% of the area is mountainous, 31% is hilly and 10% consists of flat luvisols. The average annual precipitation in the area varies from 560 to 864 mm, with high rain intensities and frequent rainstorms in summer. This is illustrated in Fig. 1, where the average monthly precipitation data that where obtained from the Luoyang Dryland Farming Experimental Station are plotted for the last three decades. The minimum temperature is -23.5 ºC and the maximum temperature is 43.7 ºC. The annual potential evaporation is estimated to be 1,262 to 1,852 mm. The average air humidity is 65%. The tillage experiments were conducted on a silty loam soil with a 10% slope. The clay, silt and sand content was 14.4%, 74.2% and 11.4% respectively and almost constant until 1.8-m depth. The organic matter, total N, available N (NH_4^++NO_3^-), Olsen' s P and available K content of the soil were 11.5 g • kg^{-1}, 1.10 g • kg^{-1}, 82.5 mg • kg^{-1}, 6.1 mg • kg^{-1} and 139.5 mg • kg^{-1} respectively. The soil pH was 8.8.

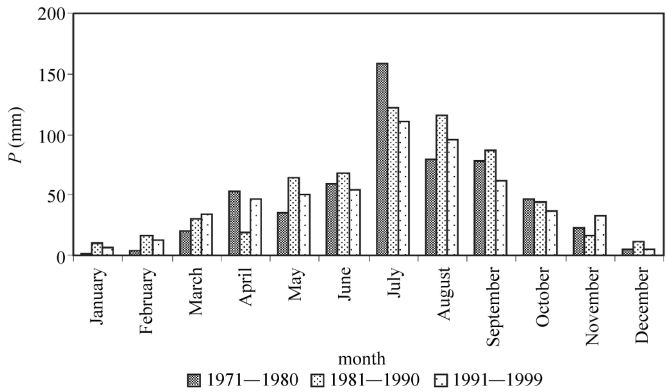

Fig. 1 Average monthly precipitation *P* over the last three decades at the Luoyang Dryland Farming Experimental Station

2.2 Experimental design and tillage practices

The tillage experiments for winter wheat (Yumai No.48) were conducted on five 30m long and 3m wide plots which were 1 m apart and located along the same contour line. The five treatments included: reduced tillage (RT), no-till (NT), a two-crop rotation with winter wheat and summer corn in the 1^{st} year, and winter wheat and peanuts in the 2^{nd} year (2C), subsoiling (SS), and conventional tillage (CT). The fertiliser application rates were 150 kg N ha^{-1}, 105 kg P_2O_5 ha^{-1}, and 45 kg K_2O ha^{-1}. The treatments can be described as follows:

— RT *(reduced tillage)*: leaving stubble (10cm—15cm in height) and returning straw on the field after wheat harvest in summer (May 25—June 1); deep ploughing (25m—30m in depth) combined with harrowing (5m—8m depth) around July 1; and direct sowing with fertiliser application in fall

(September 25—October 5).

— NT *(no-till)*: leaving stubble (30 cm in height) and returning straw on the field after wheat harvest in summer (May 25—June 1); and direct sowing with fertiliser application in fall (September 25—October 5).

— 2C *(2 crops/year)*: sowing summer corn/peanuts after winter wheat harvest (May 25—June 1); and ploughing (25cm—30cm depth) in combination with fertiliser application after corn harvest (September 25—October 5), followed by harrowing and sowing winter wheat.

— SS *(subsoiling)*: leaving stubble (25cm—30cm in height) on the field after wheat harvest in summer (May 25—June 1); subsoiling (30cm—35cm depth) between rows (at 60cm intervals) around July 1; and direct sowing with fertiliser application in fall (September 25—October 5).

— CT *(conventional tillage)*: removal of straw after harvest, ploughing (20cm in depth) and harrowing around July 1; and ploughing (20 cm in depth) in combination with fertiliser application in fall (September 25—October 5), followed by harrowing and sowing winter wheat.

2.3 The water balance equation

The water balance of a soil profile over a given period Δt is generally written as:

$$\Delta S = P + I - ET - R - D + L_i - L_o \tag{1}$$

where ΔS is the change in soil water storage, P is the precipitation, I is the applied irrigation water, ET is the evapotranspiration (or evaporation in case of a bare soil), R is the surface runoff, D is the amount of capillary rise (if negative) or drainage (if positive), and L_i and L_o are the lateral inflow and outflow respectively. All components are expressed in units of length (mm). Note that D refers to water flow at a given depth, which is generally taken as the maximum rooting depth z_r, and is equal to $q_{zr}\,\Delta t$, where q_{zr} is the soil-water flux at z_r.

Since the general practice in the area is rainfed agriculture, no irrigation water was applied. Precipitation was recorded with a tipping-bucket automatic rain gauge (Environmental Measurement Limited, UK[1]). Runoff was monitored with automatic discharge gauges. Changes in moisture content were determined from moisture-content profiles which were obtained with a Trime® tube-probe (Imko, Germany), which is a modified TDR probe. Moisture content was measured at depths of 10, 20, 30, 40, 50, 70, 90 and 120 cm and by using three access tubes per plot. Capillary rise and drainage at the maximum rooting depth were determined from application of the Darcy equation:

$$q_{zr} = -K(\overline{\theta})\,\frac{\mathrm{d}\overline{H}}{\mathrm{dz}} \tag{2}$$

where $K(\theta)$ is the hydraulic conductivity corresponding to a (volumetric) soil moisture content θ, $\mathrm{d}H/\mathrm{d}z$ is the hydraulic-head gradient, and the overbars denote time-averaged values. The hydraulic conductivity was computed by using the well-known Mualem-van Genuchten equation (Mualem, 1976; van Genuchten, 1980), in which the saturated hydraulic conductivity was measured with a tension infiltrometer, and the moisture retention data with the sandbox apparatus (Eijkelkamp, the Netherlands) and pressure chambers (Soilmoisture Equipment, USA). Tensiometers connected to Hg-manometers allowed to determine the hydraulic head and the hydraulic-head gradients at the maximum rooting depth, which was taken to be 105 cm. The tensiometers were installed at the same depths where moisture content was measured. In order to plot downslope equipotential lines for determination of the lateral soil-water flow, one plot contained five sets of tensiometers. Finally, evapo(transpi)ration could be readily computed from Eq. (1), when all other components are determined as described above.

3 Results and discussion

Water balance of the difference tillage practices

In Table 1, the different components of the water balance that were computed by applying Eq. (2)

[1] Mention of company names is for the convenience of the reader and does not constitute any endorsement from the authors

are given. Note that lateral flow is not included in Table 1. From the equipotential lines that were based on hydraulic head measurements from the five sets of tensiometers in one of the plots, it was concluded that lateral inflow and outflow was negligible small. The other components are calculated for the fallow and growing season of the first and second year of the project. Notice that during the first year, the measurements started at 19-Aug-99 only (in case of the two-crop rotation, this was at 9-Sep-99) and that in the second year measurement were finished at 25-Apr-99. It should also be stressed here that the data are only preliminary since the flux at maximum rooting depth could not be measured during part of the dry season. This was due to the non-functioning of the tensiometers at matric heads below –850 cm. With respect to the two-crop rotation, the crop in the first year (which was harvested already before 9-Sep-99) was summer corn. In the second year, peanuts were grown. Notwithstanding some problems with data recording, the computed values allow to observe some interesting trends with regards to the change in water storage and evaporation.

Table 1 Components of the water balance for reduced tillage (RT), no tillage (NT), two-crop rotation (2C), subsoiling (SS) and conventional tillage (CT)

Tillage	start period	end period	ΔS (mm)	P (mm)	RO (mm)	D (mm)	ET (mm)
RT	19-Aug-99	26-Sep-99	-9.5	50.8	3.2	0.1	57.0
NT	19-Aug-99	26-Sep-99	-1.2	50.8	3.7	0.1	48.3
2C	9-Sep-99	26-Sep-99	-2.8	17.0			19.8
SS	19-Aug-99	26-Sep-99	-2.7	50.8	0.2	0.1	53.2
CT	19-Aug-99	26-Sep-99	-6.5	50.8	0.4	0.1	56.8
RT	26-Sep-99	24-May-00	-73.6	164.2	0.0	0.3	237.5
NT	26-Sep-99	24-May-00	-95.2	164.2	0.0	1.3	258.2
2C	26-Sep-99	24-May-00	-26.9	164.2			191.1
SS	26-Sep-99	24-May-00	-93.4	164.2	0.0	0.0	257.6
CT	26-Sep-99	24-May-00	-92.1	164.2	0.0	0.7	255.5
RT	1-Jun-00	25-Sep-00	69.9	239.0	4.8	0.0	164.3
NT	1-Jun-00	25-Sep-00	100.9	239.0	1.9	0.3	135.9
2C	1-Jun-00	25-Sep-00	122.6	239.0			116.4
SS	1-Jun-00	25-Sep-00	123.2	239.0	3.7	1.2	110.9
CT	1-Jun-00	25-Sep-00	100.7	239.0	2.2	-0.5	136.6
RT	25-Sep-00	25-Apr-01	-84.3	231.0			315.3
NT	25-Sep-00	25-Apr-01	-129.3	231.0			360.3
2C	25-Sep-00	25-Apr-01	-161.1	231.0			392.1
SS	25-Sep-00	25-Apr-01	-168.9	231.0			399.9
CT	25-Sep-00	25-Apr-01	-135.4	231.0			366.4

In the fallow period of the year 1999, the reduction in water storage was largest for RT (–9.5 mm), followed by CT. The lowest reduction was observed with the NT practice. The relative low reduction in storage in the 2C rotation is due to its lower initial moisture content at the start of the measuring campaign (which was 9-Sep-99), compared to the initial moisture contents in the other plots, and due to the water used by the summer corn. The drainage (or capillary rise) component, which could be measured along the complete fallow period, was very low in all plots. Two runoff events were recorded, and it appeared to be relatively large in the NT and RT plots. This could possibly be attributed to lower infiltration rates on those plots. The total amount of evaporation was lowest for the NT practice (48.3 mm) followed by SS (53.2 mm), which resulted in the largest water storage at the beginning of the crop-growing season for these practices. This is illustrated in Fig. 2a, where the moisture-content profiles at 26-Sep-99, at the beginning of the crop season, are plotted for the different plots. As is shown in Fig. 2a, the water storage at the beginning of the growing season is highest for NT and SS, somewhat lower for RT and lowest for the 2C rotation. This explains the relatively low change in water storage and water use by winter wheat in the 2C rotation, and hence the low evapotranspiration on that plot. As a result, the yield can be expected to be lowest in the 2C practice and highest for NT and SS. However, also the CT shows good results.

When considering the water balance in the fallow period of the year 2000, it seems that the increase in water storage was highest in the 2C and the SS system. The large increase that is observed in the 2C system may be due to the low evaporation of the soil as it is almost completely covered by a peanut canopy. However, a small amount of irrigation water (about 8 mm in total) has been added to the plot. The evaporation of the soil was highest for the RT practice, and lowest for SS. NT and CT showed intermediate results. Two runoff events have been recorded. Runoff was highest on the RT plot. During the subsequent winter wheat season, reduction in moisture content was highest for SS and 2C due to a large evapotranspiration that was observed there. The rather large increase in soil water storage that was observed in the fallow period could hence be used for transpiration of the winter wheat. As is illustrated in Fig. 2b, the water storage at the beginning of the winter wheat season is relatively high in the 2C system. This was due to the rather low evaporation during the previous fallow period (see above). This is also true for the SS practice, where the moisture content could increase substantially over the fallow period. The change in water storage was lowest in the RT plot, due to a relatively low moisture content at the beginning of the winter wheat season. The NT and CT practises showed intermediate results.

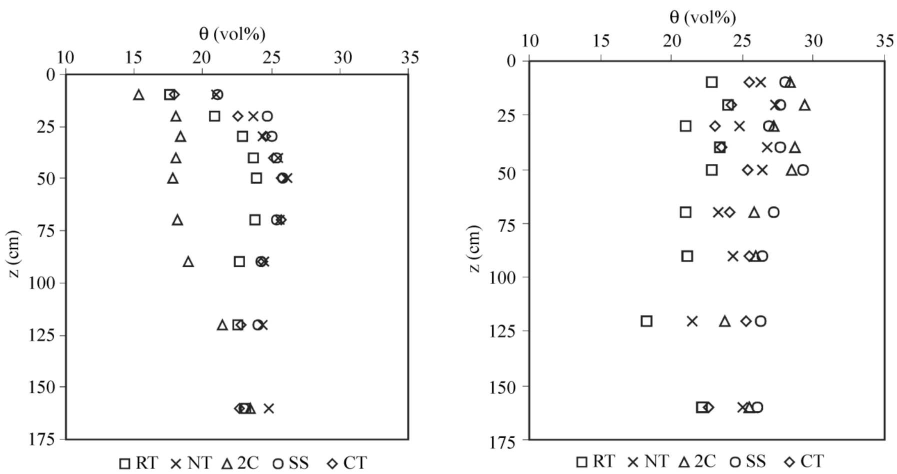

Fig. 2 Moisture content profiles showing moisture content θ vs. depth z of the five plots at 26-Sep-99 (a) and 25-Sep-99 (b)

4 Conclusions

From the preliminary water balance data that were obtained in this study, it can be concluded that subsoiling is the best practice in terms of water conservation. It results in the highest increase in water storage during the fallow period, and hence most water will be available to the winter wheat in the growing season. The two-crop rotation with peanuts as a summer crop also shows some promising results. The water storage at the beginning of the winter wheat season is relatively high, due to a low evaporation of the soil in the fallow period. Furthermore, there is an additional economic benefit from the peanuts. Finally, the no-tillage and conventional tillage gave intermediate results, whereas reduced tillage was the worst alternative.

However, it should be stressed that the presented results allow to draw some general conclusions only. More detailed and regularly recorded data is needed from coming years in order to accurately describe all components of the water balance.

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