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CONSERVATION TILLAGE PRACTICES ON A DRYLAND WINTER WHEAT FIELD IN NORTHERN CHINA: A SOIL-WATER BALANCE STUDY USING A TRIME® TUBE PROBE*

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A b s t r a c t. Soil erosion by water is a severe problem in the eastern loess belt of northern China and is to a large extent associated with improper soil tillage practices. Changing the current tillage practices could therefore reduce soil loss. However, this will 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, P.R. China, in order to evaluate the water balance under different soil tillage practices on a winter wheat field with a silty loam soil texture. Five tillage practices were applied: conventional tillage, no tillage, subsoiling, reduced tillage, and cultivation of an additional summer crop. The difference in water storage was determined using a Trime® Tube Probe. From data from two consecutive agricultural years between 1999 and 2001, it was concluded that subsoiling resulted in the highest increase in water storage and in the lowest evaporation during the fallow period between harvesting and sowing of the winter wheat. A two-crop rotation with peanuts also showed promising results. The no-tillage and conventional tillage gave intermediate results, whereas the reduced tillage was the worst alternative.

K e y w o r d s: dryland, silty loam, conservation tillage, soil-water balance, Trime® Tube Probe

NOMENCLATURE

ΔS – change in soil water storage (mm),
D – amount of capillary rise (if negative) or drainage (if positive) (mm),
ET – evapotranspiration (or evaporation in case of a bare soil) (mm),
H – hydraulic head (cm),

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I – applied irrigation water (mm),
$K(\theta)$ – hydraulic conductivity (mm h^{-1}),
L_i – lateral inflow (mm),
L_o – lateral outflow (mm),
P – precipitation (mm),
q_{zr} – soil-water flux at z_r (mm h^{-1}),
R – surface runoff (mm),
z – depth (cm),
z_r – maximum rooting depth (cm),
θ – volumetric soil water content (m^3 m^{-3} or vol%).

INTRODUCTION

In the dry farming areas of northern China, 80% of the farmland is suffering from severe land degradation, particularly from water and wind erosion. This degraded farmland is subjected to water erosion during the rainy season in summer and to drought during the crop-growing season in winter. Soil erosion has brought about severe topsoil loss, water runoff and a decline in the soil's fertility. It results not only from natural climatic and landscape factors, but is also due to human activities, including 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. Therefore, research on conservation tillage needs to be given more consideration in northern China in order to prevent further decline in land productivity. In many other regions of the world, the adoption rate of conservation tillage for agricultural sustainability is growing exponentially due to the needs of soil and water conservation (see e.g. [3]).

In the southeast and middle part of Shanxi in the semi-humid to arid area of northern China, studies on conservation tillage (including reduced tillage and no-till) in combination with design of appropriate machinery and agronomy studies have been carried out since the 1980's. These studies illustrated the advantage of reduced tillage practices for soil protection, water conservation, and crop yield improvement [1,2,6]. However, various tillage methods showed 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 hardly available.

In order to fill this gap, a five-year Sino-Belgian 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 of northern China. Field experiments for winter wheat were conducted to determine the effects of various tillage practices on conservation and use of soil water. This paper reports the preliminary results of a soil-water balance study conducted on different plots during two consecutive agricultural years between 1999 and 2001 and demonstrates the usefulness of the Trime® Tube Probe in soil-water balance studies.

MATERIALS AND METHODS

Experimental Site Conditions

The experimental plots are located in Songzhuang, Mengjin county, North of Luoyang (longitude 113° East, latitude 34.5° North), Henan Province, in the eastern loess belt of China, in the semi-humid to arid region of northern China (Fig. 1). The elevation of the loess belt is 130 to 2500 m above sea level. Around 58% of the area is mountainous, 31% is hilly and 10% consists of flat luvisols.

Fig. 1. Map of China, with study location near Luoyang (Henan Province)

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 Figure 2, where the average monthly precipitation data that were obtained from the Luoyang Dryland Farming Experimental Station are plotted for the last three decades. The minimum temperature is –23.5ºC and the maximum temperature is 43.7ºC. The annual potential evaporation is estimated to be 1262 to 1852 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.

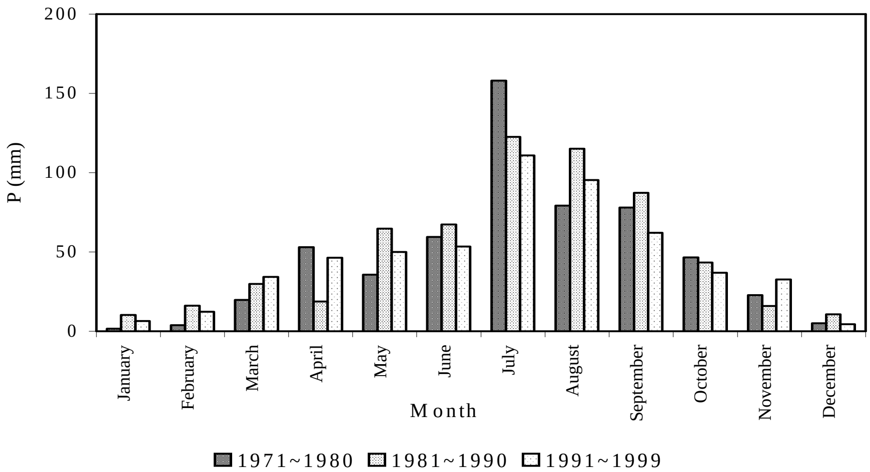

Fig. 2. Average monthly precipitation *P* over the last three decades at the Luoyang Dryland Farming Experimental Station

Experimental Design and Tillage Practices

The tillage experiments for winter wheat (Yumai No. 48) were conducted on five plots, 30-m long and 3-m wide, which were 1 m apart and located along the same contour line (Fig. 3). The five treatments included: reduced tillage (RT), no-till (NT),

Fig. 3. The five field plots with (from left to right) conventional tillage CC, subsoiling SS, two crops 2C, no tillage NT and reduced tillage RT; the pictures were taken in July 2001 which is the fallow period or, in case of the two-crop rotation, the peanuts growing period (in 2001)

a two-crop rotation with winter wheat and summer corn in the 1st year, and winter wheat and peanuts in the 2nd 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 (10-15 cm in height) and returning straw onto the field after wheat harvest in summer (May 25~June 1); deep ploughing (25-30 cm in depth) combined with harrowing (5-8 m depth) around July 1; direct sowing with fertiliser application in fall (September 25~October 5).
- *NT (no-till)*: leaving stubble (30 cm in height) and returning straw onto the field after wheat harvest in summer (May 25~June 1); 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); ploughing (25-30 cm depth) in combination with fertiliser application after corn harvest (September 25~October 5), followed by harrowing and sowing winter wheat. The crop in the first year (which was harvested already before 9-Sep-99) was summer corn. In the second year, peanuts were grown.
- *SS (subsoiling)*: leaving stubble (25-30 cm in height) on the field after wheat harvest in summer (May 25~June 1); subsoiling (30-35 cm depth) between rows (at 60-cm intervals) around July 1; direct sowing with fertiliser application in fall (September 25~October 5).
- *CT (conventional tillage)*: removal of straw after harvest, ploughing (20 cm in depth) and harrowing around July 1; ploughing (20 cm in depth) in combination with fertiliser application in fall (September 25~October 5), followed by harrowing and sowing winter wheat.

The Water Balance Equation

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

$$\Delta S = P + I - ET - R - D + L_i - L_o \qquad (1)$$

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.

The Trime® Tube Probe (TDR) for water-content measurement

Changes in water content were determined from water content profiles which were obtained using a Trime® Tube Probe (Imko, Germany) which is a modified TDR probe especially designed for water content profiling. The tube probe consists of a cylindrical PVC body which has four spring-mounted aluminium plates as TDR wave guides on opposite sides (Fig. 4). The two plates on each side have a total length of 18 cm, which corresponds to the length of the sphere of influence of the probe. Experiments in a loamy sand (with clay content of 5.7%, silt content of 8.3%, sand content of 86.0%, organic carbon content of 2.0% and a bulk density of 1.5 Mg m^{-3}) have shown that the diameter of the sphere of influence is 11 to 15 cm depending on the water content. It was further shown that the influence of temperature was negligible.

Fig. 4. Schematic view of the Trime® Tube Probe with indication of its electromagnetic field (source: http://www.imko.de)

The reflection curve of the generated electromagnetic pulse (with a frequency between 0.6 and 1.2 GHz) is determined by time measurements at distinct voltage levels, rather than by measuring voltage levels at distinct time domains as with the conventional TDR technique. This makes expensive electronic elements, such as track-and-hold units and A/D converters, not necessary.

The measurements are to be performed in 4.5 cm-wide TECANAT plastic access tubes which must be installed prior to measuring and which can be left permanently in the soil.

During the experiments, water content was measured at regular times at depths of 10, 20, 30, 40, 50, 70, 90 and 120 cm by using three access tubes per plot.

Other equipment and determination of other water-balance elements

Since the general practice in the area is rainfed agriculture, almost no irrigation water was applied. Precipitation was recorded with a tipping-bucket automatic rain gauge (Environmental Measurement Limited, UK). Runoff was monitored with automatic discharge gauges. Capillary rise and drainage at the maximum rooting depth were determined from the application of the Buckingham-Darcy equation:

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

where $K(\theta)$ is the hydraulic conductivity corresponding to the (volumetric) soil water content θ, dH/dz 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 [4,5], in which the saturated hydraulic conductivity was measured with a tension infiltrometer, and the water retention data with the sandbox apparatus (Eijkelkamp, the Netherlands) and pressure chambers (Soilmoisture Equipment, USA). The computed hydraulic conductivity values where cross-checked with hydraulic conductivity data obtained from the drainage component D at the maximum rooting depth (taken at 105 cm), which is equal to – ΔS between the rooting depth and the so-called plane of zero flux, if present. Tensiometers connected to Hg-manometers allowed to determine the hydraulic head and the hydraulic head gradients at the maximum rooting depth. The tensiometers were installed at the same depths where water 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 equation (1), when all other components are determined as described above.

RESULTS AND DISCUSSION

The lateral inflow and outflow was negligibly small during the complete measuring campaign. This was concluded from computation of equipotential lines that were based on hydraulic head measurements from the five sets of tensiometers in one of the plots. The drainage (or capillary rise) component was very low in all the plots as well and ranged from –0.5 mm to 1.3 mm per growing or fallow season. Four runoff events were recorded, and they appeared to be relatively large in the NT and RT plots, with respective values of 3.7 mm and 4.8 mm per event. This could possibly be attributed to lower infiltration rates on those plots.

In Figure 5, the measured precipitation P and change in soil water storage ΔS, and the evapotranspiration ET computed from equation (1), are given as a function of time for the different tillage practices and for consecutive years. Notice that during the first year, the measurements started on 19-Aug-99 (only in the case of the two-crop rotation, that was on 9-Sep-99) and that in the second year measurements were finished on 16-Apr-01.

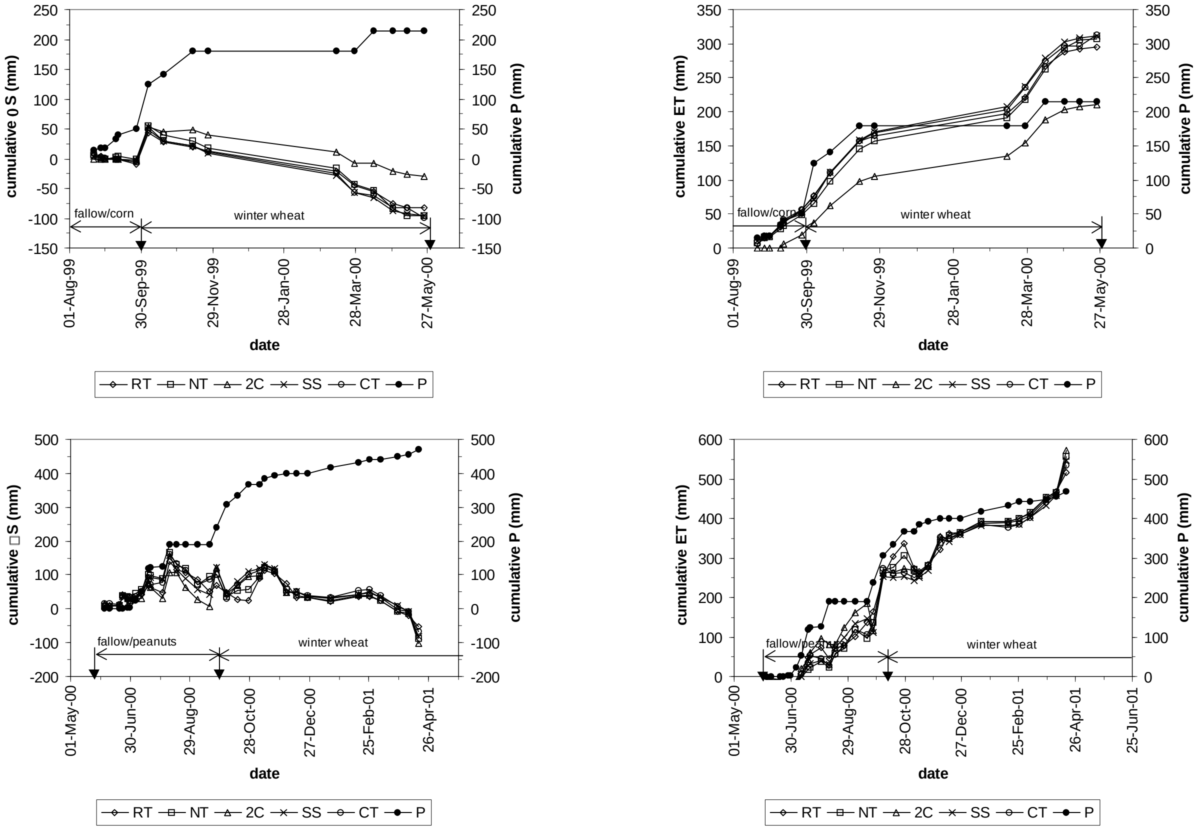

Fig. 5. Cumulative change in soil water storage *ΔS*, evapotranspiration *ET* and precipitation *P* for reduced tillage (RT), no tillage (NT), two-crop rotation (2C), subsoiling (SS) and conventional tillage (CT) for two years

At the end of the fallow period of the first year, the cumulative reduction in water storage was the largest for RT (–9.5 mm), followed by CT (–6.5 mm). The lowest reduction was observed with the SS and NT practices (respectively –2.7 mm and –1.2 mm). The relative low reduction in storage in the 2C rotation (–2.8 mm) is due to its lower initial water content at the start of the measuring campaign (which was 9-Sep-99), compared to the initial water contents in the other plots, and due to the water used by the summer corn. The total amount of evaporation was the 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 figure 6a, where the water-content profiles for 26-Sep-99, at the beginning of the crop season, are plotted for the different plots. As is shown in figure 6a, the water storage at the beginning of the growing season is the highest for NT and SS, somewhat lower for RT, and the lowest for the 2C rotation.

At the end of the winter wheat season of the first year, the cumulative reduction in soil water storage was highest for the NT, SS and CT practices, with ΔS for the complete winter wheat growing season ranging from –92.1 mm to –95.2 mm. However, this water is mainly used for transpiration of the winter wheat, as the other soil water balance components were very small. The RT practice showed a somewhat lower value of –73.6 mm and the 2C resulted in a value of –26.9 mm only. The relatively low soil water storage in the 2C plot at the beginning of the winter wheat season 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 during the growing season (191.1 mm). The *ET* values for the winter wheat growing season varied between 255.5 mm and 258.2 mm for the NT, SS and CT practices, and was 237.5 mm for the RT practice. As a result, the yield can be expected to be highest for NT, SS and CT, and lowest for 2C when using a rotation with summer corn.

When considering the water balance in the second year, the 2C practice in which winter wheat is rotated with peanuts now seems to perform much better. Of course, the highest reduction in ΔS can be observed for this practice due to the transpiration of the peanuts, but the relatively high amount of precipitation, and small irrigation doses of 8 mm at the end of the peanuts season, was enough to bring the soil water storage to a considerable level at the beginning of the winter wheat season. The cumulative increase in ΔS at the end of the fallow period was the highest for the 2C and SS practice (respectively 122.6 mm and 123.2 mm). The lowest value was observed for RT (69.9 mm). NT and CT showed intermediate results (respectively 100.9 mm and 100.7 mm).

During the subsequent winter wheat season, the reduction in water content was the highest for SS and 2C due to the large evapotranspiration that was observed during that season. 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 figure 6b, the water storage at the beginning of the winter wheat season is relatively high in the 2C system. This was due to the rather large increase in soil water storage at the end of the previous peanuts period (see above). This is also true for the SS practice, where the water content could increase substantially over the fallow period. The total *ET* during the winter wheat season was the lowest on the RT plot (315.3 mm), due to a relatively low water content at the beginning of the winter wheat season. The highest values were observed for SS and 2C (respectively 399.9 mm and 392.1 mm). The NT and CT practices showed intermediate results (respectively 360.3 mm and 366.4 mm). Consequently, the highest winter wheat yields are to be expected when applying SS or 2C when using a rotation with peanuts, and the lowest for RT.

The large differences in ΔS and *ET* between year 1 and 2 are partly due to the difference in the measuring period. In year 1, the campaign only started in the last month of the rain season, whereas in year 2, the whole rainy season was covered.

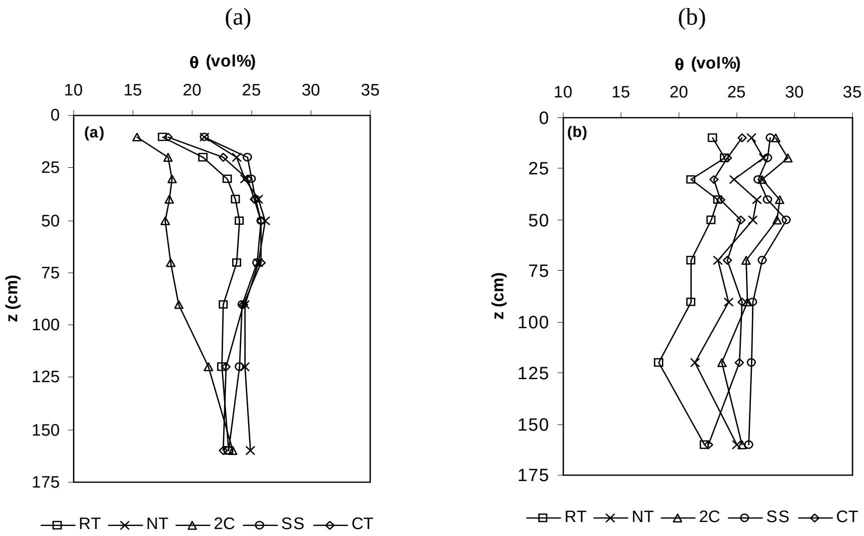

Fig. 6. Water content profiles showing water content θ vs. depth z of the five plots on 26-Sep-99 (a) and 25-Sep-00 (b)

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 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 are needed from coming years in order to accurately describe all the components of the water balance.

Finally, it could be concluded that a TDR device, such as the Trime® Tube Probe, is suitable to measure the water content and its changes in time under the weather and soil conditions in this study. It is a handy and relatively cheap device that could easily be used by locals.

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PRAKTYKA UPRAWY ZACHOWAWCZEJ NA POLU PSZENICY OZIMEJ W PÓŁNOCNYCH CHINACH: BADANIE BILANSU WODY GLEBOWEJ PRZY UŻYCIU SONDY RUROWEJ TRIME®

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S t r e s z c z e n i e. Erozja wodna gleb jest poważnym problemem na obszarze wschodniego pasa lessowego północnych Chin i w znacznym stopniu kojarzona jest ze stosowaniem niewłaściwych praktyk uprawowych. Zmiana dotychczasowej praktyki uprawowej mogłaby spowodować ograniczenie strat glebowych. Może się to jednak wiązać ze zmianą bilansu wodnego, a więc także dostępności wody dla roślin uprawnych, szczególnie w warunkach uprawy typu "suchego pola". Przeprowadzono badania polowe na pięciu poletkach zlokalizowanych na zboczu w pobliżu miejscowości Luoyang w prowincji Henan, w celu dokonania oceny bilansu wodnego w warunkach różnych praktyk uprawowych przy uprawie pszenicy ozimej na glebie pylasto-gliniastej. Zastosowano pięć sposobów uprawy: uprawę konwencjonalną, uprawę zerową, uprawę z pogłębiaczem, uprawę zredukowaną, oraz uprawę z płodozmianem letnim. Różnice w gromadzeniu wody w glebie określano przy użyciu sondy typu Trime® Tube Probe. Dane z dwóch kolejnych sezonów uprawowych w latach 1999-2001 wykazały, że uprawa z pogłębiaczem spowodowała największy przyrost pojemności wodnej oraz najmniejsze parowanie w okresie ugorowym pomiędzy zbiorem a wysiewem pszenicy ozimej. Płodozmian z orzeszkami ziemnymi dał także obiecujące wyniki. Uprawy zerowa i konwencjonalna dały wyniki pośrednie, a uprawa zredukowana stanowiła najgorszą alternatywę.

S ł o w a k l u c z o w e: "suche pole", glina pylasta, uprawa zachowawcza, bilans wody glebowej, sonda rurowa Trime® Tube Probe