# Soil erosion under different tillage methods in central Croatia

I. Kisić, F. Basić, O. Nestroy, M. Mesić and A. Butorać

# Die Bodenerosion bei unterschiedlichen Verfahren der Bodenbearbeitung in Zentral-Kroatien

## 1. Introduction and research goal

The primary goal of the investigations is to determine the characteristics of erosion on a Stagnic Luvisol, and then to answer the question whether it is possible, and to what extent, to reduce erosion to a tolerable level by applying different tillage methods. Due to its physical composition (high content of fine sand), chemical properties (calcium carbonate deficiency, low content of organic matter) and very low aggregate stability, this soil type is very prone to water erosion on sloping terrains (SIDIRAS et al., 1988; BORK, 1989; KWAAD et al., 1998; REJMAN, 1997; FLEIGE and HORN, 2000). BASIC et al. (1991), KLIK et al. (1996), SHIPITALO and EDWARDS (1998) have proved that the conventional up and down the slope ploughing is the least favourable tillage method. It leads to the highest erosion, whereas ploughing across the slope and no-tillage are much more effective in terms of erosion control. Dealing with the problem of erosion on arable areas (MOLDENHAUER and WISCHMEIER, 1969; CHISCI and BOSCHI, 1988; SOILLEAU et al., 1994) maintain that high erosion losses are most likely to occur in growing spring crops.

### Zusammenfassung

An einem Standort, einem Pseudogley (Stagnic Luvisol) in Zentral-Kroatien (Umgebung von Daruvar), wurden während fünf Jahren die Bodenverluste durch Wassererosion bestimmt. Infolge ungünstiger physikalischer wie chemischer Eigenschaften neigen diese Standorte zur Verkrustung und zu erosivem Abtrag. Auf Versuchsparzellen mit Hackfrüchten bzw. Sommerkulturen wurden weit höhere Abtragswerte gemessen als auf jenen mit Winterkulturen sowie bei Untersaat (Sojabohne in Weizen) unter gleichen Verfahren der Bodenbearbeitung. Als kritischer Termin ist die Zeitspanne vom Anbau bis zum vollen Blattschluß durch die Kultur zu sehen. Aufgrund des Vergleichs der unterschiedlichen Verfahren der Bodenbearbeitung sind neben einer pfluglosen (Direktsaat) Wirtschaftsweise Konturbearbeitung sowie die Anlage von Untersaat als optimale Erosionsschutzmaßnahmen an Pseudogley in Zentral-Kroatien zu empfehlen.

**Schlagworte:** Bodenerosion durch Wasser, Bodenbearbeitungsverfahren, Zentral-Kroatien.

### Summary

Soil loss quantity was recorded during the five-year investigation cycle on a Stagnic Luvisol. Due to its unfavourable physical and chemical properties, this soil type is prone to crust formation and to intensive erosion by water on sloping terrains. Appreciably higher yearly rates of soil erosion were recorded in the growing of low-density row spring crops than in high-density winter crops and double-cropping (e.i. in ploughing up and down slope for maize 38.55 t ha$^{-1}$; soybean 38.15 t ha$^{-1}$; winter wheat 0.53 t ha$^{-1}$; oil-seed rape 0.4 t ha$^{-1}$ and double cropping 6.55 t ha$^{-1}$. In ploughing across the slope soil erosion was: 11.69 t ha$^{-1}$ for maize; 5.35 t ha$^{-1}$ soybean; 0.07 t ha$^{-1}$ winter wheat; 0.13 t ha$^{-1}$ oil-seed rape and 0.18 t ha$^{-1}$ for double cropping.). The time immediately following the sowing of spring crops is the most critical period, which is the period when highest soil loss occurs (approximately 70% of the total yearly erosion). Summing up all advantages and drawbacks of the studied tillage methods, we recommend no-tillage and ploughing across the slope for wider application on this soil type.

**Key words:** Water erosion, Tillage methods, Stagnic Luvisol, Central Croatia.

## 2. Materials and methods

The trial was set up in the summer of 1994, after the oil-seed rape harvest, in the area of Daruvar, Central Croatia[1]. Erosion was measured on a Stagnic Luvisol (FAO, 1990), on six enclosed trial plots, according to USLE (WISCHMEIER and SMITH, 1978), viz. on a 9 % slope, length 22.1 m, width 1.87 m, or a plot area of 41.3 m$^2$. Plots were enclosed by a sheet-metal wall, which was removed before each tillage treatment and installed after tillage. The fence is set up so as to ensure that soil suspension cannot penetrate the trial plot from the sides or run off from the enclosed plot area. Special equipment enabling separation and filtration of soil suspension has been set up on the lower part of each trial plot, clean water is collected in a separate container, while solid drift remains on the cloth serving as filter. To facilitate the usage of agricultural machinery, the trial plots were set 15 m apart in order to enable easy turning of the tractor with the longest trailing implement. Six different tillage methods were investigated:

- **The check plot (fallow – BF)**, according to USLE, which was tilled up and down the slope. Tillage practices applied include: ploughing to a depth of 30 cm, discing and seedbed preparation with a harrow, but the soil kept bare. This is the method in which maximum erosion was expected.
- **Ploughing up and down the slope to a depth of 30 cm (PUDS)**. Discing, seedbed preparation with a harrow and sowing were performed in the same direction.
- **No-tillage (NT)**, sowing with a special seeder into dead mulch up and down the slope. Two to three weeks before sowing weeds were eradicated by total herbicides.
- **Ploughing across the slope to a depth of 30 cm (PAS).** This was the same as the PUDS method, except for the different ploughing direction.
- **Very deep ploughing across the slope to a depth of 60 cm (VDPAS).** In contrast to all other ploughing practices, which were done with multi-furrow ploughs, a single-bottom plough was used in this method.
- **Subsoiling to a depth of 60 cm**, subsoiler tines spaced 70 cm apart **(SSPAS)**, with ploughing across the slope to a depth of 30 cm. In the last three tillage methods (PAS, VDPAS, SSPAS), discing, seedbed preparation and sowing were performed across the slope.

On the experimental plots (except for BF), crops were grown in the following crop rotation: 1995 – maize (*Zea mays* L.), 1996 – soybean (*Glycine hispida* L.), 1996/97 – winter wheat (*Triticum aestivum* L.), 1997/98 – oil-seed rape (*Brassica napus var oleifera* L.), and 1999 – spring barley (*Hordeum sativum* L.) with soybean (*Glycine hispida* L.).

Before undertaking all practices for the crop sown in a particular year, soil samples were taken from the arable layer in each tilling method for determination of the texture (SOIL SURVEY STAFF, 1975) and some chemical properties of tilled soil: pH in KCl, content of humus (ISO, 1996), as well as the content of available phosphorus and potassium (AL-method – EGNER et al., 1960). Table 1 provides the

Table 1: Texture of Stagnic Luvisol from experimental plots (average of 12 data)
Tabelle 1: Korngrößenverteilung am Untersuchungsstandort (Stagnic Luvisol)

| Soil horizon | Depth cm | particle size distribution, % | | | | Texture |
|---|---|---|---|---|---|---|
| | | Coarse sand (2–0.2 mm) | Fine sand (0.2–0.02 mm) | Silt (0.02–0.002 mm) | Clay (< 0.002 mm) | |
| $A_{ch}+E_{cg}$* | 0–24 | 1.8 | 58.6 | 24.2 | 15.4 | Sandy loam -SL |
| $E_{cg}+B_{tg}$ | 24–35 | 2.1 | 57.1 | 26.0 | 14.8 | Sandy loam- SL |
| $B_{tg}$ | 35–95 | 0.5 | 54.5 | 25.4 | 19.6 | Sandy loam- SL |

* According to FAO, 1990.

Table 2: Chemical properties of Stagnic Luvisol from experimental plots (average of 12 data)
Tabelle 2: Chemische Daten vom Untersuchungsstandort (Stagnic Luvisol)

| Soil horizon* | Depth cm | pH in KCl | Organic matter, g kg$^{-1}$ | mg 100 g$^{-1}$ soil | |
|---|---|---|---|---|---|
| | | | | $P_2O_5$ | $K_2O$ |
| $A_{ch}+E_{cg}$ | 0-24 | 4.21 | 16 | 10.56 | 10.00 |
| $E_{cg}+B_{tg}$ | 24-35 | 4.20 | 14 | 9.02 | 8.98 |
| $B_{tg}$ | 35-95 | 4.81 | 6 | 5.69 | 6.18 |

* According to FAO, 1990.

average values of texture and Table 2 the soil chemical properties for each layer. The texture is silty loam without texture differentiation over the whole depth. Soil is very acid in the arable layer and acid in the $B_g$ horizon. There is a low humus content in the plough layer, medium phosphorus availability, and good potassium availability. Availability of these nutrients is low in the subsoil layer. Statistical processing of the research results was done by the method of standard deviation (S.D.).

## 3. Results and discussion

### 3.1 Runoff and soil loss in growing maize

In the first year (1995), soil loss was recorded on eight occasions in maize (Table 3). High runoff and substantial soil loss were recorded for all tillage methods in June. This is attributed to loose surface soil structure due to soil freezing during the open furrow period in winter, and particularly to the sparse vegetational cover (less than 15 % of soil). During June, 75 % of total erosion was recorded in PUDS, more than 80 % in NT and PAS, and over 90 % in VDPAS and SSPAS. Methods with tillage across the slope (PAS, VDPAS, SSPAS) had appreciably less runoff and lower erosion, which may be related to greater infiltration and slower running off of water down the slope in these methods.

With increase of plant cover, the differences in runoff and soil loss between treatments increased. Standard deviation values for yearly soil loss are higher in BF and PUDS than in the NT and across the slope methods. Rain that fell on 23 August 1995 had highest intensity. In BF, as much as 92 % of rain ran off, which caused the highest soil loss in the first year of research period. In cropped methods the soil surface was protected by maize, which covered 70–80 % of the soil surface. August is the hottest month of the year and a soil water deficit was recorded in methods with maize. This helps to explain the lower runoff and soil loss compared with BF. In methods with PAS, the runoff was less than 35 %. Plant cover was approximately the same as in the PUDS method, but in all PAS methods the type of tillage played an additional role in reducing runoff and soil loss. Soil loss was very low in all cropped methods except for PUDS, showing that maize was not able to fully protect the soil in this case. Rainfall on 8/9 September 1995 with 75.4 mm was the highest daily rainfall in 1995. For all tillage methods (except for BF) runoff was low, with small quantities of soil loss. This can be primarily ascribed to the fully developed plant cover.

### 3.2 Runoff and soil loss in growing soybean

As soybean is sown approximately at the same time as maize, this is one of the reasons why roughly the same runoff and soil losses were recorded under this crop as in maize (Table 4). Ten days after soybean was sown (11 May 1996), the second runoff event was recorded. Rain was characterised by the highest half-hour intensity (12.9 mm) in that year. The recorded situation was identical to that of the preceding year with maize at the same time. As the soil cannot take up so much rain in so short period, intensive runoff occurs. Its extent will primarily depend on the tillage method and sowing direction applied in trial methods. The plant cover factor does not affect the quantity of erosion drift since it has not yet been formed. The highest almost

Table 3: Effect tillage methods on runoff (mm) and soil loss (t $ha^{-1}$) in maize (1995)
Tabelle 3: Einfluß der Bodenbearbeitungsform auf den Abfluß (mm) und den Bodenverlust (t $ha^{-1}$) bei Körnermais (1995)

| Date of runoff and soil loss | Rainfall | | | Runoff (in mm) and soil loss (t $ha^{-1}$) of methods | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Duration | max. 30 | BF | | PUDS | | NT | | PAS | | VDPAS | | SSPAS | |
| | mm | $h^{min}$ | min. int. | Runoff mm | Soil loss t $ha^{-1}$ | Runoff mm | Soil loss t $ha^{-1}$ | Runoff mm | Soil loss t $ha^{-1}$ | Runoff mm | Soil loss t $ha^{-1}$ | Runoff mm | Soil loss t $ha^{-1}$ | Runoff mm | Soil loss t $ha^{-1}$ |
| 9.6.95 | 11.6 | $0^{20}$ | | 10.0 | 12.12 | 11.2 | 10.12 | 8.3 | 6.02 | 5.4 | 3.31 | 5.7 | 7.74 | 4.2 | 0.92 |
| 15.6.95 | 22.1 | $3^{20}$ | 8.2 | 17.8 | 22.53 | 14.5 | 18.45 | 11.9 | 12.36 | 5.1 | 6.22 | 5.0 | 11.89 | 4.8 | 1.73 |
| 23-24.6.95 | 29.6 | $18^{50}$ | 2.5 | 5.0 | 1.45 | 7.1 | 0.49 | 1.2 | 0.01 | | | | | | |
| 23.8.95 | 27.2 | $0^{40}$ | 20.4 | 24.9 | 30.92 | 16.5 | 4.22 | 14.1 | 1.10 | 8.9 | 0.62 | 3.8 | 0.08 | 4.3 | 0.05 |
| 29.8.95 | 34.0 | $12^{15}$ | 7.0 | 23.1 | 19.3 | 17.3 | 1.07 | 10.5 | 0.54 | 1.7 | 0.01 | 5.8 | 0.08 | | |
| 8-9.9.95 | 75.5 | $13^{20}$ | 14.6 | 55.8 | 37.94 | 10.6 | 1.95 | 13.6 | 1.76 | 15.1 | 1.20 | 9.8 | 0.74 | 6.8 | 0.12 |
| 14-15.9 2 | 3.3 | $23^{40}$ | 0.9 | 9.3 | 0.32 | 9.8 | 0.11 | | | | | | | | |
| 21.9.95 | 52.4 | $8^{05}$ | 12.8 | 40.3 | 21.74 | 11.0 | 2.25 | 8.4 | 0.91 | 7.3 | 0.32 | 5.2 | 0.54 | 2.6 | 0.12 |
| **Total** | 275.7 | | | **186.3** | **146.32** | **88.3** | **38.55** | **77.8** | **22.81** | **43.5** | **11.69** | **35.3** | **21.07** | **22.8** | **2.94** |
| | | | S.D. | 16.4 | 13.0 | 3.6 | 6.2 | 4.0 | 4.2 | 4.0 | 2.1 | 2.1 | 4.3 | 1.5 | 0.7 |

Table 4: Effect tillage methods on runoff (mm) and soil loss (t $ha^{-1}$) in soybean (1996)
Tabelle 4: Einfluß der Bodenbearbeitungsform auf den Abfluß (mm) und den Bodenverlust (t $ha^{-1}$) bei Sojabohne (1996)

| Date of runoff and soil loss | Rainfall | | | Runoff (in mm) and soil loss (t $ha^{-1}$) of methods | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Duration | max. 30 | BF | | PUDS | | NT | | PAS | | VDPAS | | SSPAS | |
| | mm | $h^{min}$ | min. int. | Runoff mm | Soil loss t $ha^{-1}$ | Runoff mm | Soil loss t $ha^{-1}$ | Runoff mm | Soil loss t $ha^{-1}$ | Runoff mm | Soil loss t $ha^{-1}$ | Runoff mm | Soil loss t $ha^{-1}$ | Runoff mm | Soil loss t $ha^{-1}$ |
| 18.11.95 | 30.9 | $9^{20}$ | 3.8 | 3.0 | 0.05 | 8.7 | 0.09 | 5.6 | 0.01 | 4.7 | 0.01 | 1.9 | 0.01 | 4.4 | 0.09 |
| 11.5.96 | 25.1 | $1^{50}$ | 12.9 | 21.9 | 31.72 | 22.8 | 37.12 | 12.9 | 13.34 | 12.1 | 5.14 | 11.2 | 4.85 | 9.3 | 2.52 |
| 16.5.96 | 11.2 | $5^{20}$ | 3.9 | 3.3 | 0.20 | 1.7 | 0.22 | 2.4 | 0.02 | | | | | | |
| 27-28.5.96 | 12.8 | $5^{50}$ | 3.7 | 3.9 | 0.41 | 1.5 | 0.16 | 0.3 | 0.03 | | | | | | |
| 13.6.96 | 13.5 | $2^{05}$ | 11.1 | 4.6 | 1.32 | | | | | | | | | | |
| 15.7.96 | 9.6 | $0^{40}$ | 2.8 | 1.7 | 2.01 | 0.9 | 0.01 | 0.6 | 0.02 | | | | | | |
| 31.7.96 | 45.8 | $5^{50}$ | 9.5 | 36.4 | 33.19 | 5.2 | 0.26 | 8.6 | 0.08 | 2.3 | 0.02 | | | | |
| 17.8.96 | 28.3 | $7^{55}$ | 4.8 | 11.8 | 6.41 | 0.7 | 0.01 | 2.4 | 0.03 | | | | | | |
| 1.9.96 | 50.4 | $6^{55}$ | 8.1 | 39.2 | 19.51 | 23.9 | 0.03 | 3.2 | 0.01 | 2.8 | 0.02 | 3.0 | 0.05 | 2.4 | 0.08 |
| 10.9.96 | 18.8 | $13^{10}$ | 2.1 | 0.7 | 0.01 | | | | | | | | | | |
| 12-13.9.96 | 62.5 | $15^{30}$ | 8.9 | 29.8 | 9.09 | 5.5 | 0.21 | 3.4 | 0.01 | 4.8 | 0.15 | 6.7 | 0.26 | 5.8 | 0.19 |
| 22-23.9.96 | 40.5 | $16^{05}$ | 3.7 | 28.6 | 4.20 | 16.6 | 0.01 | 3.5 | 0.004 | 10.6 | 0.003 | 5.0 | 0.01 | 10.1 | 0.04 |
| 24-25.9.96 | 13.1 | $5^{50}$ | 3.0 | 9.7 | 0.79 | 5.2 | 0.002 | 3.5 | 0.002 | 0.7 | 0.001 | 2.4 | 0.005 | | |
| 12-13.10.96 | 17.7 | $11^{10}$ | 3.6 | 15.8 | 1.28 | 11.9 | 0.02 | 2.4 | 0.002 | 2.4 | 0.01 | 6.5 | 0.02 | | |
| **Total** | **380.2** | | | **210.6** | **110.12** | **104.7** | **38.15** | **48.7** | **13.55** | **40.5** | **5.35** | **36.8** | **5.20** | **32.1** | **2.92** |
| | | | S.D. | 13.2 | 11.1 | 8.0 | 10.2 | 3.4 | 3.7 | 3.9 | 1.7 | 3.0 | 1.7 | 2.8 | 1.1 |

identical amounts runoff (11 May 1996) were recorded in BF and PUDS methods (Table 4). For all other methods, the tillage method (NT) and direction of tillage (PAS, VDPAS, SSPAS) reduced runoff, and thereby also the occurrence of soil loss. Standard deviation values for runoff and for soil loss are higher in BF and PUDS than in NT and across the slope methods, where they are almost identical (Table 4).

Like in the preceding year, most of the soil loss on PUDS, NT, PAS, VDPAS and SSPAS was recorded immediately after soybean was sown (ca. 30 days). Over 95 % of total soil loss was recorded within a month after planting, regardless of the ploughing direction.

As September 1995 was rainy (19 rain days), five erosive events were recorded. Their common characteristics are as follows. High surface runoff in BF and PUDS, with an obvious difference in soil losses in these two methods. Soil losses were much lower in the PUDS. Plant cover was clearly the major factor in that decrease. In other methods, in addition to plant cover, also the applied tillage method influenced lower runoffs and lower soil losses. The results obtained for runoff and soil loss for spring crops are in agreement with the results of other authors: (MOLDENHAUER and WISCHMEIER, 1969; LAFLEN and MOLDENHAUER, 1979; MCDOWELL and MCGREGOR, 1984; SOILLEAU et al., 1994; BASIĆ et al., 1997; KWAAD et al., 1998; FLEIGE and HORN, 2000).

### 3.3 Runoff and soil loss in growing winter wheat

The first runoff as well as the recorded soil loss in 1997 were very low, in contrast to the state recorded for the same intensity and amount of rainfall in May after the sowing of the two preceding row spring crops. The runoffs recorded in the winter period were somewhat different from the preceding ones and call for additional explanation (Table 5). The difference relates to the characteristics of rains falling in this period of the year. Namely, rain is of longer duration but of substantially lower intensity. Since the year was warmer than usual and the soil was not frozen, rain had earlier saturated the soil and continuing surface runoff started at the moment of full soil saturation with water, triggering off soil translocation, which was most expressed in black fallow due to the (non)existence of plant cover. Low rain intensity was main reason for the low surface runoff and thereby also low soil losses for all tillage methods.

For these reasons, the yearly SD values for runoff are very similar, although in BF and PUDS methods they are slightly higher.

High quantity and low intensity precipitation, and vice versa, was recorded in the spring period (23 May and 23 June 1997). In all cases, however, runoff and soil loss were low (Table 5). In addition to tillage, we tend to give advantage to plant cover in stopping runoff in such cases. The crop in question is a high-density winter crop (7.5 million plants/ha), which covers the soil completely and prevents more intensive runoff during this period of the year. If

Table 5: Effect tillage methods on runoff (mm) and soil loss (t ha$^{-1}$) in winter wheat (1996/97)
Tabelle 5: Einfluß der Bodenbearbeitungsform auf den Abfluß (mm) und den Bodenverlust (t ha$^{-1}$) bei Winterweizen (1996/97)

| Date of runoff and soil loss | Rainfall | | | Runoff (in mm) and soil loss (t ha$^{-1}$) of methods | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Duration | max. 30 | BF | | PUDS | | NT | | PAS | | VDPAS | | SSPAS | |
| | mm | $h^{min}$ | min. int. | Runoff mm | Soil loss t ha$^{-1}$ | Runoff mm | Soil loss t ha$^{-1}$ | Runoff mm | Soil loss t ha$^{-1}$ | Runoff mm | Soil loss t ha$^{-1}$ | Runoff mm | Soil loss t ha$^{-1}$ | Runoff mm | Soil loss t ha$^{-1}$ |
| 29-30.10.96 | 11.8 | $3^{40}$ | 3.2 | 1.5 | 0.01 | 9.3 | 0.004 | 7.5 | 0.003 | | | | | 9.3 | 0.006 |
| 18.11.96 | 23.1 | $9^{05}$ | 1.9 | 1.5 | 0.02 | 2.4 | 0.03 | 3.7 | 0.01 | | | 5.6 | 0.006 | 4.7 | 0.002 |
| 14.12.96 | 32.1 | $18^{10}$ | 1.2 | 25.4 | 12.21 | 20.7 | 0.19 | 17.2 | 0.015 | 7.3 | 0.03 | 9.7 | 0.19 | 5.4 | 0.10 |
| 20-21.1.97 | 15.1 | $13^{20}$ | 2.3 | 10.4 | 4.01 | 3.4 | 0.16 | 1.7 | 0.001 | 1.9 | 0.002 | | | 1.5 | 0.01 |
| 26-27.2.97 | 26.8 | $12^{45}$ | 2.5 | 11.8 | 5.21 | 3.5 | 0.09 | 3.2 | 0.06 | | | | | 2.1 | 0.01 |
| 23.5.97 | 27.7 | $7^{30}$ | 3.8 | 8.6 | 3.88 | 3.3 | 0.02 | 3.4 | 0.02 | 1.2 | 0.01 | | | | |
| 23.6.97 | 21.7 | $10^{10}$ | 2.9 | 7.7 | 1.39 | 1.1 | 0.006 | 0.4 | 0.002 | | | | | | |
| 19.6.97 | 28.8 | $5^{50}$ | 17.2 | 23.9 | 37.01 | 2.7 | 0.09 | 5.0 | 0.03 | 4.9 | 0.03 | 5.5 | 0.06 | 0.5 | 0.01 |
| 23.6.97 | 14.3 | $2^{00}$ | 7.3 | 7.7 | 7.58 | 1.6 | 0.006 | 6.6 | 0.03 | 1.3 | 0.001 | | | | |
| 7-8.7.97 | 23.5 | $20^{20}$ | 2.3 | 1.1 | 0.001 | | | | | | | | | | |
| 13.7.97 | 24.7 | $1^{00}$ | 16.4 | 7.7 | 6.39 | 0.7 | 0.004 | 3.3 | 0.02 | 2.1 | 0.002 | | | | |
| 18.7.97 | 19.4 | $3^{10}$ | 5.9 | 11.1 | 8.97 | 1.1 | 0.006 | 3.5 | 0.02 | 0.7 | 0.001 | 0.7 | 0.038 | 0.6 | 0.002 |
| **Total** | **269.0** | | | **118.2** | **86.68** | **49.8** | **0.53** | **55.5** | **0.21** | **24.4** | **0.07** | **21.5** | **0.30** | **24.1** | **0.14** |
| | | | S.D. | 7.5 | 9.7 | 5.6 | 0.1 | 4.3 | 0.02 | 3.2 | 0.01 | 3.2 | 0.1 | 3.0 | 0.03 |

runoff does occur, it will cause only slight soil loss. Runoff data for the NT method point to a somewhat higher runoff for this method (19 and 23 June 1997) compared to other methods of wheat cropping. The reason is to be looked for in the cropping method. Since no tillage is applied in this method, the soil is not loosened and is hence more compacted. Consequently, larger quantities of water run off down the slope than in other methods. This is in agreement with the results obtained by LAL (1994) and MARTIN (1999). It is noteworthy, however, that soil loss is at the same level as in other methods.

### 3.4 Runoff and soil loss in growing oil-seed rape

In fall 1997 oil-seed rape was sown on the field. This is a winter crop of high plant density (3.5 million plants/hectare). The first runoff event (11 August 1997) was recorded a few days before oil-seed rape was sown (Table 6). Immediately after the wheat harvest, shallow ploughing (to 10 cm), the so-called stubble cleaning, was applied. Rain that fell (11 August 1997) was of high intensity – 21.4 mm of rain fell within 15 minutes. However, with the exception of the NT method, the runoff was very low only with a slight soil loss. This was caused by the shallow ploughing, the uneven spots of which obstruct more intensive runoff. NT (direct sowing) was the reason why in summer and autumn months, when the soil is dry and more compacted (high soil water deficit), higher runoff occurred than in other methods. It is noteworthy, however, that soil losses were at the level of other methods, since plant cover reduced the runoff rate.

Several subsequent runoffs and soil losses of the winter period (1997/98) had common characteristics. The data from Table 6 point to a very low runoff and even lower soil loss (except for BF). Slightly higher SD values for runoff were recorded in the BF; PUDS and NT methods, while SD values for other methods were almost identical.

Rain that fell in the spring (8 March, 9 and 19 April; 25 May 1998) was also of low intensity. Since oil-seed rape had developed in the meantime and covered 80–95 % of the soil, runoff was recorded only in the BF, PUDS and in NT methods. Due to the low rainfall intensity, runoff did not exceed 10 % of rainfall. Although the highest half-hour intensity (19.6 mm) of that year was recorded on 1 July 1998, no runoff was recorded in methods involving tillage and sowing across the slope. This was due to the fully developed plant cover over the soil, so that the rain hit the soil with less force, dripping down the plants and then ran off down the slope.

Based on the foregoing, it is obvious that methods involving up and down the slope tillage applied in the production of spring crops had higher surface runoff and erosion compared to tillage across the slope, on the one side, and the growing of winter crops, on the other. These results are in agreement with the results obtained by other authors (SIDIRAS et al., 1988; BASIĆ et al., 1991; KLIK et al., 1996; REJMAN, 1997).

Table 6: Effect tillage methods on runoff (mm) and soil loss (t ha$^{-1}$) in oil-seed rape (1997/98)
Tabelle 6: Einfluß der Bodenbearbeitungsform auf den Abfluß (mm) und den Bodenverlust (t ha$^{-1}$) bei Ölraps (1997/98)

| Date of runoff and soil loss | Rainfall | | | Runoff (in mm) and soil loss (t ha$^{-1}$) of methods | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Duration | max. 30 | BF | | PUDS | | NT | | PAS | | VDPAS | | SSPAS | |
| | mm | h$^{min}$ | min. int. | Runoff mm | Soil loss t ha$^{-1}$ | Runoff mm | Soil loss t ha$^{-1}$ | Runoff mm | Soil loss t ha$^{-1}$ | Runoff mm | Soil loss t ha$^{-1}$ | Runoff mm | Soil loss t ha$^{-1}$ | Runoff mm | Soil loss t ha$^{-1}$ |
| 11.8.97 | 21.4 | $0^{15}$ | | 1.5 | 0.58 | 1.4 | 0.002 | 11.0 | 0.31 | 0.3 | 0.01 | 0.6 | 0.1 | 0.3 | 0.001 |
| 31.8.97 | 24.4 | $3^{30}$ | 4.0 | 0.6 | 0.007 | 0.7 | 0.007 | 1.1 | 0.002 | 0.1 | 0.002 | | | | |
| 11-12.10.97 | 51.6 | $15^{40}$ | 6.1 | 16.3 | 4.89 | 7.3 | 0.21 | 4.5 | 0.002 | 1.5 | 0.07 | 0.6 | 0.008 | 0.3 | 0.02 |
| 13-14.11.97 | 68.1 | $20^{10}$ | 2.3 | 32.6 | 14.69 | 17.9 | 0.06 | 7.1 | 0.005 | 0.7 | 0.015 | 1.9 | 0.03 | 4.0 | 0.014 |
| 4.12.97 | 19.1 | $6^{45}$ | 2.5 | 9.7 | 1.01 | 4.5 | 0.012 | 4.9 | 0.002 | 1.2 | 0.002 | 0.4 | 0.0001 | 0.9 | 0.002 |
| 13.12.97 | 20.6 | $7^{10}$ | 1.8 | 11.4 | 3.13 | 3.4 | 0.005 | 1.8 | 0.002 | | | | | 1.0 | 0.002 |
| 27-28.12.97 | 26.8 | $14^{25}$ | 1.2 | 17.9 | 2.39 | 1.0 | 0.003 | 1.5 | 0.004 | | | | | | |
| 19-20.1.98 | 26.7 | $22^{10}$ | 1.9 | 16.9 | 4.28 | 0.5 | 0.03 | 0.7 | 0.005 | | | | | | |
| 2-3.3.98 | 28.5 | $11^{25}$ | 1.6 | 22.8 | 7.30 | 1.4 | 0.03 | 1.7 | 0.006 | 1.1 | 0.013 | 1.3 | 0.012 | 1.6 | 0.022 |
| 8.3.98 | 20.5 | $13^{50}$ | 2.6 | 18.3 | 9.09 | 1.6 | 0.02 | 1.9 | 0.007 | 1.1 | 0.014 | 0.9 | 0.015 | 1.6 | 0.018 |
| 8-9.4.98 | 25.4 | $14^{15}$ | 1.7 | 7.3 | 0.24 | 1.3 | 0.002 | | | | | | | 0.5 | 0.0001 |
| 18-19.4.98 | 14.5 | $12^{10}$ | 1.7 | 5.2 | 0.09 | 0.7 | 0.002 | 1.2 | 0.001 | | | | | | |
| 24-25.5.98 | 23.1 | $23^{40}$ | 3.4 | 4.9 | 0.05 | 0.6 | 0.0001 | 1.0 | 0.0001 | | | | | | |
| 9.6.98 | 16.0 | $2^{25}$ | 8.5 | 3.0 | 1.01 | 0.9 | 0.005 | 1.0 | 0.002 | | | | | | |
| 23.6.98 | 13.1 | $3^{10}$ | 3.0 | 2.5 | 0.03 | 0.7 | 0.003 | 1.1 | 0.002 | | | | | | |
| 1.7.98 | 20.8 | $0^{35}$ | 19.6 | 8.4 | 1.02 | 1.0 | 0.002 | 3.0 | 0.008 | | | | | | |
| 14.7.98 | 21.5 | $2^{50}$ | 13.7 | 10.8 | 4.29 | 0.6 | 0.003 | 1.3 | 0.001 | | | | | | |
| **Total** | **442.1** | | | **190.1** | **54.1** | **45.5** | **0.40** | **44.9** | **0.34** | **6.1** | **0.13** | **5.6** | **0.17** | **10.2** | **0.08** |
| | | | S.D. | 8.4 | 3.9 | 4.2 | 0.05 | 2.7 | 0.1 | 0.5 | 0.02 | 0.5 | 0.03 | 1.1 | 0.01 |

### 3.5 Runoff and soil loss in double-cropping (spring barley with soybean)

In the last research year, when so-called double crop (spring barley with soybean) was sown on the trial field, 17 erosive rainfall events were recorded. Runoff and soil loss data are presented in Table 7.

The highest erosion was recorded during May and June, though both crops were at that time already sown on the trial field. More than 85 % of total erosion was recorded in all tillage methods (except for NT) in June. Only 29 % of total annual erosion was recorded in NT in this period. More than 50 % of soil loss was recorded in this method in 15–16 May 1999, which seems to be related to the tillage method applied, as well as to the slightly higher rain intensities in May.

Standard deviation values indicate that there is no substantial difference in runoff, whereas the soil loss values are divided into two groups (Table 7). Standard deviation values for BF, PUDS and NT are very similar while those for other methods are fully identical. In double-cropping involving across the slope tillage and NT, the same level of erosion was recorded as in the preceding years, when high-density winter crops were grown on the trial field. Somewhat higher erosion than for winter crops was recorded in the methods with up and down the slope tillage and sowing but slightly lower than for low-density spring crops. The recorded value, indicates that soil losses were below the tolerance level for this soil type (SCHWERTMANN et al., 1987; AUERSWALD et al., 1991).

The described facts should be taken into account in the practical application of the obtained results, primarily with respect to the crop sequence applied.

## 4. Conclusions

Six different soil tillage methods were included in a long-term field trial with the aim to investigate their influence upon soil erosion. These methods were: 1. Check plot (black fallow-BF), 2. Ploughing up and down the slope (PUDS), 3. No-tillage (NT), 4. Ploughing across the slope (PAS), 5. Very deep ploughing across the slope (VDPAS) and 6. Subsoiling across the slope (SSPAS).

The presented results show that erosion processes on a soil of high erodibility, such as a Stagnic Luvisol, can be reduced to a tolerable level by choosing an appropriate tillage method.

Over five trial years, the highest erosion was recorded in BF. On that treatment yearly erosion was: 146.32; 110.12; 86.68; 54.10 and 36.52 t ha$^{-1}$ from first to last investigation years. In PUDS the soil losses were 38.55 t ha$^{-1}$ for maize, 38.15 t ha$^{-1}$ soybean; 0.53 t ha$^{-1}$ winter wheat, 0.40 t ha$^{-1}$ oil-seed rape and 6.55 t ha$^{-1}$ double cropping. In NT treat-

Table 7: Effect tillage methods on runoff (mm) and soil loss (t ha$^{-1}$) in double crop (spring barley with soybean – 1998/99)
Tabelle 7: Einfluß der Bodenbearbeitungsform auf den Abfluß (mm) und den Bodenverlust (t ha$^{-1}$) bei Mischkultur (Sommergerste mit Sojabohne, 1998/99)

| Date of runoff and soil loss | Rainfall | | | Runoff (in mm) and soil loss (t ha$^{-1}$) of methods | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Duration | max. 30 | BF | | PUDS | | NT | | PAS | | VDPAS | | SSPAS | |
| | mm | $h^{min}$ | min. int. | Runoff mm | Soil loss t ha$^{-1}$ | Runoff mm | Soil loss t ha$^{-1}$ | Runoff mm | Soil loss t ha$^{-1}$ | Runoff mm | Soil loss t ha$^{-1}$ | Runoff mm | Soil loss t ha$^{-1}$ | Runoff mm | Soil loss t ha$^{-1}$ |
| 9.9.98 | 27.7 | $12^{10}$ | 3.5 | 14.6 | 1.26 | 1.0 | 0.006 | 4.1 | 0.005 | | | 2.6 | 0.002 | | |
| 18.9.98 | 27.1 | $11^{50}$ | 2.3 | 15.1 | 1.74 | 5.8 | 0.006 | | | | | | | | |
| 2.11.98 | 22.8 | $15^{05}$ | 4.1 | 26.8 | 0.08 | 2.4 | 0.002 | 16.6 | 0.010 | 2.8 | 0.004 | 1.3 | 0.0001 | 3.5 | 0.004 |
| 14.11.98 | 30.0 | $14^{45}$ | 3.1 | 16.7 | 0.06 | 3.4 | 0.004 | 13.1 | 0.002 | | | | | | |
| 14.1.99 | 15.4 | $10^{55}$ | 1.9 | 2.8 | 0.02 | 0.9 | 0.004 | 2.0 | 0.003 | | | | | | |
| 7.3.99 | 11.1 | $7^{15}$ | 1.4 | 3.1 | 0.01 | | | | | | | | | | |
| 19.4.99 | 29.8 | $7^{25}$ | 10.4 | 8.7 | 0.57 | 7.1 | 0.18 | 1.7 | 0.008 | | | | | 1.8 | 0.014 |
| 23-24.4.99 | 35.0 | $17^{50}$ | 7.4 | 8.8 | 0.01 | 0.7 | 0.005 | | | | | | | | |
| 15-16.5.99 | 53.1 | $4^{50}$ | 5.3 | 4.8 | 0.23 | 1.8 | 0.18 | 2.5 | 0.190 | | | 1.4 | 0.018 | | |
| 20-21.5.99 | 42.5 | $3^{05}$ | 13.5 | 9.8 | 3.63 | 5.4 | 0.17 | 7.1 | 0.005 | | | 1.1 | 0.005 | 1.8 | 0.004 |
| 11.6.99 | 38.0 | $1^{40}$ | 17.1 | 16.7 | 5.17 | 0.7 | 1.48 | 7.0 | 0.014 | | | | | | |
| 15.6.99 | 37.2 | $3^{50}$ | 20.0 | 11.1 | 4.18 | 5.5 | 1.11 | 1.1 | 0.009 | | | | | | |
| 21-22.6.99 | 58.2 | $20^{45}$ | 7.7 | 21.1 | 16.80 | 12.5 | 3.32 | 2.5 | 0.004 | 3.1 | 0.18 | 2.6 | 0.20 | 2.5 | 0.13 |
| 22-23.7.99 | 29.4 | $6^{50}$ | 8.7 | 5.6 | 1.96 | 2.7 | 0.04 | 4.4 | 0.005 | | | | | | |
| 13.8.99 | 37.9 | $11^{20}$ | 8.7 | 13.5 | 0.84 | 3.1 | 0.04 | 2.4 | 0.008 | | | | | | |
| 10.9.99 | 19.2 | $8^{35}$ | 2.6 | 1.4 | 0.02 | | | | | | | | | | |
| 4.10.99 | 22.1 | $7^{40}$ | 3.0 | 6.7 | 0.04 | 1.2 | 0.003 | 1.9 | 0.002 | | | | | | |
| **Total** | **536.5** | | | **187.4** | **36.52** | **54.2** | **6.55** | **66.4** | **0.26** | **5.9** | **0.18** | **8.9** | **0.23** | **9.7** | **0.15** |
| | | | S.D. | 6.7 | 4.0 | 6.6 | 4.2 | 6.8 | 4.4 | 5.6 | 0.7 | 7.6 | 0.7 | 4.9 | 0.7 |

ment soil losses were 22.81 t ha$^{-1}$ for maize, 13.55 t ha$^{-1}$ soybean; 0.21 t ha$^{-1}$ winter wheat, 0.34 t ha$^{-1}$ oil-seed rape and 0.26 t ha$^{-1}$ for double cropping. In PAS soil losses were 11.69 t ha$^{-1}$ for maize; 5.35 t ha$^{-1}$ soybean; 0.07 t ha$^{-1}$ winter wheat; 0.13 t ha$^{-1}$ oil-seed rape and 0.18 t ha$^{-1}$ for double cropping. VDPAS resulted in soil losses of 21.07 t ha$^{-1}$ for maize, 5.20 t ha$^{-1}$ soybean; 0.30 t ha$^{-1}$ winter wheat; 0.17 t ha$^{-1}$ oil-seed rape and 0.23 t ha$^{-1}$ for double cropping. SSPAS gave the best results, soil losses were: 2.94 t ha$^{-1}$ for maize, 2.92 t ha$^{-1}$ soybean; 0.14 t ha$^{-1}$ winter wheat; 0.08 t ha$^{-1}$ oil-seed rape and 0.15 t ha$^{-1}$ for double cropping.

Appreciably higher soil loss was recorded in low-density spring row crops (maize and soybean) than in high-density winter crops (wheat and oil-seed rape) and double crop (spring barley with soybean) in the same tillage methods. The results also show seasonal (monthly) variability in the event of soil erosion. The highest soil losses occurred during the period from sowing to the stage when 15 % of soil were covered with row crops (May – first decade of June). In growing winter crops, there are no high risk periods for erosion, while soil losses are uniformly distributed throughout the growing season. Spring row crops will still be dominant in the crop rotation. It is important that a balanced tillage system (NT and PAS) and an appropriate crop sequence are applied on sloping terrains. Summing up all the advantages and drawbacks of the studied tillage methods, we recommend NT and PAS for wider application in crop production on this soil type.

## Acknowledgements

This research was accomplished with the support from the Federal Ministry of Science and Transport – Austria and from the Institute of Engineering Geology and Applied Mineralogy, Graz, University of Technology, Austria.

## Note

1 The equipment for this investigation was donated by the Federal Ministry of Science and Transport – Austria

## References

AUERSWALD, K., E. NILL and U. SCHWERTMANN (1991): Verwitterung und Bodenbildung als Kriterien des tolerierbaren Bodenabtrags. Bayer. Landw. Jb. 68, 609–627.

BORK, H. R. (1989): Soil erosion during the past millenium in central Europe and its significance within the geomorphodynamics of the Holocene. Catena Supplement 15, 121–131.

BASIĆ, F., I. KISIĆ, A. BUTORAĆ and M. MESIĆ (1997): Soil erosion by different tillage methods on stagnosol in Croatia. Proceedings of the 14th Conference of ISTRO, Pulawy, Poland, 63–67.

BASIĆ, F., I. SALINOVIC, I. BASIĆ, A. KELLKEYYELAH and A. BUTORAĆ (1991): Possibilities of Soil Conservation by Means of Different Tillage Methods on Acric Ferralsol of the Ethiopian Plateau. Proc. of the 12th Conf. of ISTRO, Ibadan-Nigeria, 58–60.

CHISCI, G. and V. BOSCHI (1988): Runoff and Erosion Control with Hill Farming in the Sub-coastal Apennines Climate. Soil & Tillage Research 12, 105–120.

EGNER, H., H. RIEHM und W. R. DOMINGO (1960): Untersuchungen über die chemische Bodenanalyse. II Chemische Extraktionsmethoden zur Phosphor- und Kaliumbestimmung. Kungl. Lantbrukshögskolans Annaler 26, 45–61.

FAO (1990): FAO-Unesco Soil Map of the World. Revised Legend. World Soil Resources, Report 60. FAO/Unesco/ISRIC, Rome.

FLEIGE, H. and R. HORN (2000): Surface runoff, erosion and loss of nutrients in traffic ruts of agricultural soils (Luvisols) in a hilly moraine landscape in Germany. Proc. of 15th ISTRO Conf., topic 5, Forth Worth, USA, CD.

ISO (1996): Soil Quality – Determination of content of organic matter using chloride bichromate solution. ISO/CD 10694, Geneve.

KLIK, A., F. FILA, N. SPATNY, J. ROSNER and O. W. BAUMER (1996): On-Site and Off-Site Effects of Different Tillage Methods under Austrian farming Conditions. International Annual Meeting ASAE, Phoenix, Arizona.

KWAAD, F. J., M. VAN DER ZIJP and P. M. VAN DIJK (1998): Soil conservation and maize cropping systems on sloping loess soils in Netherlands. Soil & Tillage Research 46, 13–21.

LAFLEN, J. M. and W. C. MOLDENHAUER (1979): Soil and Water Losses from Corn-Soybean Rotations. Soil Sci. Soc. Am. J. 43, 1213–1216.

LAL, R. (1994): Water management in various crop production systems related to soil tillage. Soil & Tillage Research 30, 169–185.

MARTIN, P. (1999): Reducing flood risk from sediment-laden agricultural runoff using intercrop management techniques in northern France. Soil & Tillage Research 34 (3–4), 233–245.

MCDOWELL, L. L. and K. C. MCGREGOR (1984): Plant nutrient losses in runoff from conservation tillage corn. Soil & Tillage Res. 4(1), 79–90.

MOLDENHAUER, W. C. and W. H. WISCHMEIER (1969): Soybeans in corn-soybean rotation permit erosion but put blame on corn. Crops Soils 21, 6–20.

REJMAN, J. (1997): Runoff and Soil Loss under conventional Tillage for Cereal Production in SE Poland. Proc. of 14th ISTRO Conf., Pulawy Poland, 89–93.

SCHWERTMANN, U., W. VOGL und M. KAINZ (1987): Bodenerosion durch Wasser. Vorhersage des Abtrags und Bewertung von Gegenmaßnahmen. Stuttgart.

SIDIRAS, N., G. KAHNT and E. KUBLER (1988): The effects of different soil tillage systems, crop rotations and short term cover crops on soil losses and runoff. J. of Agronomy and Crop Science 160 (1), 22–28.

SHIPITALO, M. J. and W. M. EDWARDS (1998): Runoff and erosion control with conservation tillage and reduced-input practices on cropped watersheds. Soil & Tillage Research 46 (1), 1–12.

SOILLEAU, J. M., J. T. TOUCHTON, B. F. HAJEK and K. H. YOO (1994): Sediment, nitrogen and phosphorus runoff with conventional and conservation tillage in small watershed. J. Soil & Water Con. 49, 82–89.

SOIL SURVEY STAFF, Soil Taxonomy (1975): A Basis System of Soil Classification for Making and Interpreting Soil Surveys, USDA-Soil Cons. Service, Agriculture Hand. 436.

WISCHMEIER, W. H. and D. D. SMITH (1978): A Universal soil-loss equation to guide conservation farm planning. Int. Congr. Soil Sci.,Trans., 7 Int. Soc. Soil Sci., Madison, 418–425.

## Addresses of Authors

**Dr. Ivica Kisić**, Faculty of Agriculture, Svetosimunska 25, 10 000 Zagreb, Croatia; email: ikisic@agr.hr

**Prof. Dr. Ferdo Basić**, Faculty of Agriculture, Svetosimunska 25, 10 000 Zagreb, Croatia.

**Univ. Prof. Dr. Othmar Nestroy**, Technische Universität Graz, Rechbauerstraße 12, A-8010, Graz.

**Dr. Milan Mesić**, Faculty of Agriculture, Svetosimunska 25, 10 000 Zagreb, Croatia.

**Prof. Dr. Andjelko Butorać**, Faculty of Agriculture Svetosimunska 25, 10 000 Zagreb, Croatia.

Eingelangt am 19. März 2001
Angenommen am 14. Juli 2002