Interrill Soil Erosion as Affected by Tillage Methods under Cotton in Greece

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ABSTRACT

The effect of reduced tillage, cover crop and planting direction on soil erosion was investigated in sloping cotton field in Larissa, Central Greece. The treatments were three tillage methods: conventional tillage using a plough, reduced tillage using a heavy cultivator, and reduced tillage using a disk harrow, with and without cover crop and tillage and planting of cotton to the contour or to the slope. Winter wheat or vetch was used as cover crops, drilled in autumn. Soil properties measured were dry bulk density, aggregate stability and water infiltration. Rain intensity, runoff and quantities and texture of soil sediment during rainy periods were also measured.

The results showed that runoff was affected by all studied parameters. Ploughing significantly increased soil loss but the presence of a winter cover crop significantly reduced these losses in all rain events. Soil losses during winter were three times higher using conventional tillage without cover crop compared to the same tillage system with cover crop. Use of reduced tillage to the contour with cover crop reduced soil loss under 1 t/ha-yr, the accepted soil formation rate. Rain kinetic energy is correlated to soil loss. Soil losses were qualitatively most important in the ploughed plot as the clay content of the sediment was significantly higher than the initial soil.

Keywords: Soil erosion, tillage, cover crop, tillage and planting direction

1. INTRODUCTION

Soil erosion is a major environmental problem worldwide. Soil moved by erosion carries nutrients, pesticides and other harmful farm chemicals into rivers, streams, and ground water resources (Nyakatawa *et al*., 2001). Soil erosion is one of the causes of soil fertility and productivity deterioration. Protecting soils from erosion is important to sustain human life.

Many Mediterranean countries are high-risk erosion areas. In Greece, soil erosion affects 3.5 million hectares experience (Mitsios *et al*., 1995), a figure amounting to 26.5% of the country's total land area. Kosmas *et al*. (1996), estimated that, since the early 1930s, the erosion rate in the sloping agricultural lands of Thessaly, has increased to 1.56- 2.21 t/ha-y due to cotton mono-culture.

As a result of heavy subsidization cotton has become the most lucrative arable crop in Greece. In Thessaly alone cotton monoculture takes up 90% of irrigated farmland, extending even to hillsides with 10% or more inclination. Cotton crop is entirely mechanized and under conventional tillage: Cotton stalks are chopped and ploughed in after harvesting during autumn, leaving the soil bare over the winter. Seedbed preparation takes place in spring, and planting in April. All treatments are performed along the slope. Large areas of land remain uncovered during wintertime, which is the rainy period of Central Greece, and in early spring as well due to the late crop establishment and growth. Irrigation with high-pressure guns also creates conditions of high soil erosion. The high kinetic energy of the applied water impacting on the soil surface compacts soil and detaches soil particles, causing pore blockage and soil infiltration rate reduction. The associated water application, with rates often exceeding the hydraulic conductivity of soils, generates runoff, sediment loss and soil erosion (Santos *et al*., 2003, Santos and Serralheiro, 2000). One of the strategies used to control surface runoff and minimize erosion has been to apply small amounts of water (Slack and Larson, 1981). By controlling soil infiltration, runoff and soil loss, drip irrigation seem to be able to moderate such risks in cultivated soils. The drip irrigation system is controlling the frequency and amount of irrigation (Tsoar, 1990). Studies (Matondo *et al*., 2005) showed that when considering the drip system there is 20% water saving by switching from sprinkler to drip irrigation system. Drip irrigation is often preferred over other irrigation methods because of the former's high water-application efficiency on account of reduced losses, surface evaporation and deep percolation (Rajput and Patel, 2005).

After a precipitation, the appearance of stones on the soil surface and the creation of small rills are easily observed. No agricultural, agronomical or other anti-erosion measures are taken at the present time to prevent soil loss during the critical winter period.

The factors that determine soil erosion are topography, weather conditions, soil properties, soil cover and management practices (Lal and Elliot, 1994). Particle detachment is affected by soil texture, soil water and organic matter content. Wischmeier and Smith (1965) argued that soil organic matter is the second most important factor affecting soil erodibility after soil texture. Soil organic matter binds the clay with the other soil particles to form stable aggregates and improves soil structure and aggregate stability. Soil tillage can affect soil structure and organic matter content. Tisdall (1991 and 1994) noticed that soil organic matter and microorganisms are higher in soils under reduced tillage than in soils under conventional tillage. Soil aggregates under reduced tillage are considered more stable than those of ploughed soil (Tisdall, 1991 & 1994). In fields with reduced or no tillage soil organic matter is more abundant in the soil surface layers as a result of plant residue decomposition. It prevents crust formation, increases soil porosity and infiltration rate (Smettem *et al.* 1992, Nyakatawa *et al.* 2001, Akinci *et al.,* 2004). Stable soil aggregates prevent the formation of surface crust while at the same time increase soil infiltrability (Le Bissonnais, 1996, Stott *et al*., 1999). The formation of soil crust increases runoff by reducing infiltration, thereby increasing the erosion potential, and is affected by soil texture and aggregate stability (Stott *et al.* 1999, Uson and Poch, 2000).

Smettem *et al.* (1992) and Nyakatawa *et al.* (2001) noted that winter cover crops improve the percentage of soil organic matter and limit soil loss by erosion. When bare soil is exposed to rainfall, raindrops cause a gradual degradation of the soil surface structure and the partial sealing of the surface layer with the formation of a thick surface crust. Rosa *et al.* (1999)

reported that the formation of soil crust is a common phenomenon when the soil did not enjoy the protection of a cover crop during the winter period. In recent years, attention has been focused on cover crop effectiveness with regard to soil erosion control. Most of the research has been conducted in northern climates with winter wheat, corn and soya, rotations. Research relevant to Mediterranean climate conditions under cotton cultivation was been limited. Daniel *et al.* (1999), Denton and Tyler (1997) found that cotton residues (Gossypium hirsutum L.) left on soil surface did not provide effective plant cover and thus, did not prevent soil erosion. However, sowing cotton on wheat or vetch plant residue reduced soil loss up to five times compared to that of bare soil (Bosch *et al.,* 2001). Daniel *et al*. (1999) have also noted that winter cover crops such as clover (*Trifolium incarnatum L*.), vetch (*Vicia vilosa L*), rye (*Secale cereale L*), and wheat (*Tricitum aestivum L*) provided sufficient plant cover and reduced soil erosion. Waters (1998) found that cotton plants sown in wheat residue reduce soil loss during irrigation by up to 70%. Cotton yields declined by as much as 4% for each centimetre of top soil loss (Brown *et al.,* 1985).

Aligning ploughing and planting to the contour can reduce soil loss from slopping land compared with tillage to the slope (Morgan, 1995). Muysen *et al*. (2002) reported that tillage erosivity increased exponentially with tillage depth for tillage to the slope, while the increase was linear for contour tillage. Numerous studies have shown that tillage by plough to the slope was the least desirable tillage method (Meyers and Wagger, 1996, Rejman, 1997) and that such practices often lead to higher erosion than tillage to the contour (Basic *et al*., 2004). But Alba (2003) found that the general assumption that tillage to the contour reduces erosion should be questioned, at least when considering mouldboard tillage in landscapes of complex topography. Moreover tillage and planting to the contour is only effective during storms of low rainfall intensity (Morgan, 1995). Protection against more extreme storms is improved by supplementing contour farming with cover cropping.

The Mediterranean climate is characterised by a complex pattern of spatial and seasonal variability, with wide and unpredictable rainfall fluctuations from year to year (Ramos and Martinez-Casasnovas, 2004). Imeson (1990) pointed out that the main climatic characteristics affecting the vulnerability of the Mediterranean region to erosion are the high intensity rainfalls that occur after a very dry summer and the high climatic fluctuation in short and long term, especially in rainfall quantity. The best estimation of rainfall erosivity is an index based on the kinetic energy of the rain (Van Dijk *et al*., 2002, Morgan 2001). Kinetic energy is the most appropriate variable for outlining the behavior of natural rainfall (Abu Hammad *et al*., 2005). The rainfall kinetic energy causes splash erosion through the detachment of the soil particles with the consequent aggregate disintegration and slaking (Van Dijk *et al*., 2002, Fornis *et al*., 2005).

From the literature it is clear that effective means to reduce erosion are, reduced or no tillage, effective use of cover crops and tillage and planting to the contour. In order to investigate the effects of tillage systems, use of cover crop and tillage and cotton planting direction on the soil erosion rate in a sloping field, an experiment was designed and carried out in Central Greece over the period of 1997-2000. An additional objective of this study is to investigate the soil loss in term of kinetic energy. The results of this experiment are reported in the present paper.

2. MATERIALS AND METHODS

The experiment was carried out over the period 1997 to 2000 on a slope of 5.5º (9%) in Thessaly. The soil was well-drained, very calcareous clay classified as Calcic Xerochrept, according to Soil Taxonomy (Soil Survey Staff, 1975). Table 1 shows the results of the analysis made in 0.0 - 0.3 m soil samples.

Table 1. Soil properties of the experimental site

Clay	Silt	Sand	Organic Matter	Bulk Density	Steady infiltrability	Soil Structure
%	%	%	%	(Mg m^{-3})	(0.1 m h^{-1})	
43 (1.9)	26 (0.7)	31 (1.2)	1.1 (0.3)	1.31 (0.1)	3.2 (0.6)	Stable*

* Means that soil aggregates are stable, with a medium grain size (2-5 mm) and granular (Soil Survey Staff, 1981)
Numbers in brackets indicate standard deviation

A randomized complete block design was used with three replicates. The treatments were:

- **A)** Three tillage systems: a) conventional tillage b) reduced tillage using a heavy cultivator and c) reduced tillage using a disk harrow
- **B)** Two cover crop treatments: a) plots with cover crop (C) and b) plots without cover crop (-).
- **C)** Two tillage and planting directions: tillage and planting a) along the contours (Cr) and b) along the slope (S).

The abbreviations list shows the abbreviations of all treatments used in the text (Table 2). Conventional tillage system consisted moldboard ploughing (P), to a depth of about 0.25 m in late autumn (November or December), and seedbed preparation in spring (middle of April) with one or more passes of the disk harrow, to a depth of about 60-80 mm. Finally, cultivator was used to prepare a smooth seedbed before planting.

Table 2. Abbreviations List

Abbreviation	Treatment Description
P-S	Use of plough without winter cover crop and tillage direction along the slope
P-Cr	Use of plough without winter cover crop and tillage direction along the contour
PCS	Use of plough with winter cover crop and tillage direction along the slope
PCCr	Use of plough with winter cover crop and tillage direction along the contour
H-S	Use of heavy cultivator without winter cover crop and tillage direction along the slope
H-Cr	Use of heavy cultivator without winter cover crop and tillage direction along the contour
HCS	Use of heavy cultivator with winter cover crop and tillage direction along the slope
HCCr	Use of heavy cultivator with winter cover crop and tillage direction along the contour
D-S	Use of disk-harrow without winter cover crop and tillage direction along the slope
D-Cr	Use of disk-harrow without winter cover crop and tillage direction along the contour
DCS	Use of disk-harrow with winter cover crop and tillage direction along the slope
DCCr	Use of disk-harrow with winter cover crop and tillage direction along the contour

In reduced tillage (1) a heavy cultivator (H) was used for tillage to a depth of 0.15-0.20 m late in autumn (November or December), followed by a disk harrow for seedbed preparation in April.

In reduced tillage (2) a disk harrow (D) was used for tillage to a depth of about 60-80 mm in late autumn (November-December), followed by a disk harrow for seedbed preparation in April.

The primary tillage took place on 5th December 1997, 14th December 1998, and 7th November 1999 for the first, second and third year, respectively. All plots were sown with cotton (Gossypium hirsutum cv. Zeta-2) in mid- to late April according to the general agricultural practice in the region. After primary tillage half of the plots were hand sown with a cover crop so that their surface was covered throughout the winter rainy period. Winter wheat was used the first year and vetch the second. In the third year wheat was used again because the vetch growth was limited compared to wheat. Seeds were broadcast to the soil surface without any tillage. A disk harrow was used to cover the seeds. Satisfactory plant populations were obtained, as was proved by earlier work by Gemtos *et al.* (1997). Soil coverage was satisfactory and exceeded the 40-50% of the soil surface required for soil erosion protection (Conservation Technology Information Center, 1997). All plots with winter cover crop were sprayed with herbicide (Glyphosate 36 sl 10 l/ha) in late March before the seedbed preparation. Soil tillage and cotton planting were practiced either along the slope or the contour. The experimental plots sized 22 m x 5 m =110 m^2, contained 4 cotton rows 1m apart. A small ridge, 20 cm high, bounded each plot. A plastic film was incorporated to avoid mixing of runoff from neighboring plots. Runoff was collected via tin troughs placed at the bottom slope edge of each plot and then led into large containers installed in the ground. The containers were emptied after each rainfall event. Water and sediment samples were taken for each rainfall event. Water runoff was automatically measured using tipping buckets placed between the troughs and the large plastic containers, and recorded in a data logger. In the same logger, the rainfall data were automatically recorded every 5 minutes by rain gauge. During runoff events two samples were collected from each container, after a good stirring to ensure homogeneity. The samples were placed in a furnace for three days at 105^{o}C, until all water had evaporated. Then sediment concentration was calculated. Particle-size analysis of soil and sediment was done with the hydrometer method (Bouyoucos, 1962). This method classifies soil particles according to their diameter as follows: sand 2.0–0.05 mm, silt 0.05-0.002 mm and clay<0.002 mm.

Weed growth was controlled by primary and secondary tillage. All treatments were sprayed with herbicide (prometryne 3.3 kg/ha and alachlor 5 kg/ha) before cotton sowing. During the cotton growing season the weeds were controlled by hand hoeing.

Drip irrigation was applied, and care taken to avoid any runoff by irrigation.

2.1 Mechanical and Chemical Soil Properties

Soil aggregate stability was measured every year. Measurements were carried out before and after the autumn tillage, and after the seedbed preparation in springtime prior to and after cotton sowing. The aggregate stability was measured with the method of wet sieving (Valmis *et al.,* 1988). Three sites in each plot were sampled to a depth of 100 mm. After air-drying, the 2.00 to 4.75 mm diameter aggregates were collected by dry sieving. The apparatus for wet sieving used in this investigation was a brass sieve with mesh opening of 0.25 mm. The sieve was lowered into water for 3 min presoaking. After presoaking the sieve was oscillated at 6 mm amplitude for 1, 2, 3 and 4 min while being sprayed with water. The soil that remained in the sieve represented the stable aggregates and the sand. It was dried and weighed. Sodium phosphate was used to destroy the stable aggregates. Then the soil was washed, so that sand only was left on the sieve.

Dry bulk density of the soil was measured by taking undisturbed samples in metallic rings (70 mm diameter, 30 mm height). Three samples from each plot were taken and averaged. Soil samples were air-dried and finely ground to pass a 0.1 mm sieve, and analyzed for organic C by the Walkley-Black dichromate oxidation procedure (Nelson and Sommers, 1982). Infiltration capacity of the soil was periodically measured *in situ* using a double cylinder infiltrometer (Bouwer, 1986) with diameters of the inner and outer ring 300 and 450 mm, respectively. The infiltration measurements were carried out at the beginning of the season just after primary tillage and in the spring after seedbed preparation and were repeated midway and at the end of the growing season (around July and October).

2.2 Estimation of Rainfall Kinetic Energy

Rainfall kinetic energy at time of raindrop impact is calculated from known values of rainfall intensity, range of drops sizes, velocity of drops at the time of incidence with the soil surface and angle of incidence. Since these values cannot be obtained, typically soil loss is related to rainfall intensity and duration only (Agassi and Bradford, 1999). Based on the work of Laws and Parsons (1943), Wischmeier and Smith (1958) obtained the equation (1), which estimates the kinetic energy KE (J $m^{-2}mm^{-1}$), per rainfall unit.

$$KE = 11.9 + 8.73 \cdot \log I \qquad (1)$$

where I is the rainfall intensity expressed in mm h^{-1} of a particular time interval, and KE expressed in J m^{-2} mm^{-1}.

To compute the kinetic energy of a storm, a division of the storm duration into small time intervals of uniform intensity was required. For each time period, knowing the intensity of the rain, the kinetic energy of rain at that intensity was estimated from the above equation. Kinetic energy of a time period multiplied by the amount of rain received, gave the kinetic energy for that time period, (KE_t, in J m^{-2})

$$KE_t = p \cdot KE \qquad (2)$$

where KE is the kinetic energy from equation 1 applied for each time period ($Jm^{-2}mm^{-1}$), and p is the corresponding amount of rain (mm).

The sum of the kinetic energy values (KE_t) for all the time periods of uniform rainfall gave the total kinetic energy of the rainfall, ΣKE_t

$$\Sigma KE_t = (KE_{t1} + KE_{t2} + \ldots + KE_{tn}) \qquad (3)$$

All data were analysed using the statistical software “Statgraphics” (STSC, 1998). Analysis of variance was performed. Means comparisons were performed using the Least Significant

Difference (LSD) procedure at the 0.05 probability level (P=0.05). Also Linear Regression Analysis was performed to identify relationships among the runoff and soil losses values and the factors under study using the statistical software GenStat 7th Edition (2003).

3. RESULTS AND DISCUSSION

3.1 Runoff and Soil Loss

The total precipitation (mm) as well as the rain duration (h) for each rainfall event which generated runoff, is presented in Table 3, for the three years of study. The year-to-year variability of total rainfall is generally high, which is typical in Central Greece.

Table 3. Rainfall characteristics for every rainfall event that induced runoff

Date of rainfall event (d/m/y)	Rain duration (h)	Total Rain height (mm)	Total Rainfall Kinetic Energy (ΣKE_t) (J/m^2)
30/5/1998	12	158	3561.9
10/6/1998	1.43	36.7	897.1
19/9/1998	0.41	24	660.5
13/10/1998	5.25	13.6	225.4
9/11/1998	38	42	708.9
4/12/1998	68.3	149	2982.2
14/1/1999	47	70	1329.6
18/2/1999	24.16	110	2512.1
20/3/1999	61	125	2499.4
30/3/1999	1.58	50	1288.3
15/4/1999	31.16	87.4	2398.2
22/5/1999	0.21	17	486.1
17/7/1999	6.4	58.8	1484.9
1/8/1999	2.58	42	1005.7
1/9/1999	5.75	46	958
22/10/1999	0.92	32	846.1
19/11/1999	25.8	88.1	2011.2
29/12/1999	19.25	45	933.1
20/2/2000	5.33	35.8	737.8
15/3/2000	0.25	29	877.6
12/4/2000	9.5	46.4	1016.2
10/5/2000	12	54.9	1155.2
16/6/2000	6	104.8	2583.7
22/7/2000	10	64	1425.5
25/8/2000	32	32	507.6

The first year (1997-1998) was a dry season, while the other two had the usual annual rainfall. Table 3 shows the calculated values of total rain kinetic energy (ΣKE_t) of each rainfall, using equations 2 and 3.

Table 4 shows the runoff in the various treatments. The annual rainfall in 1998 was 274 mm and the runoff ranged from 8.76 mm up to 27.57 mm, which corresponds to 3.2% - 10.1% of the annual precipitation. The corresponding figures for the year 1999, were 787 mm of rainfall, runoff 16.58 to 92.42 mm and 2.1% – 11.7% of the annual precipitation. For the year 2000, the rainfall was 500 mm, the runoff 8.29 to 46 mm that corresponds to 1.6% - 9.2% of the annual precipitation. Table 4 shows the soil loss for each treatment as well. It can be seen that all the ploughed treatments (P-S, P-Cr, PCS, PCCr) and the treatments H-S, H-Cr, over the three years should be considered as the most potentially erosive. The P-S shows the highest runoff and the PCCr the lowest. The remaining treatments (HCS, HCCr, D-S, D-Cr, DCS, DCCr) should be considered as potentially less erosive with the DCCr offering the best soil protection and the HCS the least within this group.

The tillage treatments to the contour gave less runoff and offered better soil protection than the treatments to the slope, as it was expected. The soil roughness caused by the plough or the heavy cultivator controlled a significant amount of runoff. The soil roughness works effectively in the period right after the tillage in late autumn and up to the end of the rainy period (October-May). This is why statistically significant differences were found in the runoff between the treatments with plough (P-S and P-Cr, PCS and PCCr) and the treatments with heavy cultivator (H-S and H-Cr, HCS and HCCr). The treatments to the contour gave in all cases lower runoff. However during that period, the soil roughness progressively lost its effectiveness and it eventually disappeared, though the rainfall impact differences still hold. These significant differences appeared in the last two years of the experiment (1998/1999, 1999/2000). In the first year (1997/1998) there were no statistically significant differences, as it was an extraordinary dry winter season from the time of ploughing to the first rainfall (30/5/1998). The years 1998/1999, 1999/2000 had a more even distribution of rainfall during the winter. Runoff for treatments with disking did not appear to follow the same pattern. The shallow tillage depth by disk harrow probably did not cause significant surface roughness to reduce runoff at low rainfalls.

During the three years of the experiment, DCCr treatment gave the lowest soil losses, while the P-S the highest (Table 4). The former gave an average annual soil loss over the three years of 0.3 t/ha-y, while the latter 13.5 t/ha-y, which exceeded the soil tolerance rate of 1 t/ha-y (Pimentel *et al.*, 1996). In the case of conventional tillage, the effect of cover crop was significant in reducing soil losses, as it was observed in the PCS (5.2 t/ha-y) and P-S (13.5 t/ha-y) treatments. Additionally, the effect of tillage and planting to the contour was also significant, as was observed in PCCr (4.0 t/ha-y) and P-Cr (10.3 t/ha-y) treatments.

In the case of reduced tillage, both with disk harrow and heavy cultivator, the effect of cover crop was more significant in reducing soil losses than in tillage and planting to the contour. The soil loss in plots with cover crop was in HCS 1.2 t/ha-y and in HCCr 0.9 t/ha-y, in DCS 0.6 t/ha-y and in DCCr 0.3 t/ha-y. Moreover, the effect of tillage and planting to the contour was in H-S 5.5 t/ha-y and in H-Cr 1.4 t/ha-y, as well as in D-S 1.0 t/ha-y and in D-Cr 0.9 t/ha-y.

Table 4. Annual runoff and % of the annual rainfall and soil loss of all treatments for the three years of the experiment

	1st year (1997-1998)			2nd year (1998-1999)			3d year (1999-2000)			
	Annual Rainfall: 274 mm			Annual Rainfall: 787.2 mm			Annual Rainfall: 500 mm			
Treatments	Runoff (mm)	Runoff (% of annual rainfall)	Soil Loss (t/ha)	Runoff (mm)	Runoff (% of annual rainfall)	Soil Loss (t/ha)	Runoff (mm)	Runoff (% of annual rainfall)	Soil Loss (t/ha)	Average Soil Losses (t/ha-y)
P-S	27.573 a	10.1	5.48 a	92.420 a	11.7	27.36 a	46.019 a	9.2	7.63 a	13.5
P-Cr	24.942 ab	9.1	2.93 b	63.512 d	8.0	22.40 b	27.376 d	5.4	5.45 b	10.3
PCS	22.044 bc	8.0	1.77 c	68.054 c	8.6	10.50 d	37.537 b	7.5	3.16 c	5.2
PCCr	21.707 c	8.0	1.05 d	51.187 e	6.5	8.84 e	21.403 f	4.2	2.02 d	4.0
H-S	22.148 bc	8.1	1.81 c	76.759 b	9.7	12.61 c	28.979 c	5.7	2.10 d	5.5
H-Cr	21.883 bc	8.0	0.71 e	60.867 d	7.7	2.66 f	24.264 e	4.8	0.86 e	1.4
HCS	20.225 cd	7.4	0.45 fg	41.704 f	5.2	2.45 f	20.833 f	4.1	0.55 fg	1.2
HCCr	17.688 d	6.4	0.32 fg	31.880 g	4.0	1.90 g	18.001 g	3.6	0.38 hi	0.9
D-S	14.460 e	5.3	0.55 ef	33.307 g	4.2	1.92 g	17.145 g	3.4	0.59 f	1.0
D-Cr	11.838 ef	4.3	0.48 ef	24.456 h	3.1	1.82 g	12.130 h	2.4	0.47 gh	0.9
DCS	12.546 e	4.6	0.22 gh	23.807 h	3.0	1.25 h	11.047 h	2.2	0.33 i	0.6
DCCr	8.764 f	3.2	0.09 h	16.586 i	2.1	0.62 I	8.298 i	1.6	0.15 k	0.3
LSD $_{(0.05)}$	3.163		0.248	4.004		0.392	1.115		0.109	

Means within columns followed by the same letter are not significantly different at the 0.05 level according to LSD Test

Over the three years of the study, the mean annual soil losses from the six treatments with the least soil losses (HCS, HCCr, D-S, D-Cr, DCS and DCCr), ranged from 0.3 to 1.2 t/ha-y, approached the soil tolerance rate of 1 t/ha-y (Pimentel *et al.,* 1996). This can be partly explained by the higher aggregate stability in those treatments (Table 5). Stable aggregates facilitate water infiltration and consequently reduce runoff. Cumulative infiltration was higher in disked plots compared to the ones tilled with heavy cultivator or ploughed (Fig. 1). This should be attributed to the higher proportion of intact soil macropores, together with crop residue coverage, which reduced the impact of raindrops on the soil surface. In addition, the increased aggregate stability makes soil detachment and dispersion more difficult.

Table 5. Tillage and cropping effects on soil aggregate stability (%)

Tillage practice[1]	Decemb 1998 after primary tillage	April 1999 before sowing cotton	June 1999 after sowing cotton	Oct 1999 at harvest time	Dec 1999 after tillage	April 2000 before sowing cotton	June 2000 after sowing cotton	Octob 2000 at harvest time
Mean value of plough with cover crop	9.15c	18.33e	22.20d	15.87cd	8.90c	16.98e	21.49e	15.00d
Mean value of plough without cover crop	9.32c	15.50d	20.40d	13.95d	9.33c	15.42d	20.79e	13.52d
Mean value of heavy cultivator with cover crop	18.30b	30.62b	34.25b	25.85a	18.21b	31.20b	30.61d	26.12a
Mean value of heavy cultivator without cover crop	18.70b	26.48c	29.80c	17.12c	19.08ab	25.23c	27.48c	17.75c
Mean value of disk- harrow with cover crop	20.85a	33.17a	37.97a	27.30a	21.22a	33.53a	36.47a	26.80a
Mean value of disk- harrow without cover crop	19.42ab	29.91b	32.62b	19.67b	21.13a	29.90b	34.35b	19.92b
LSD $_{(0.05)}$	1.83	1.45	1.92	2.27	2.33	1.42	1.84	1.99

[1]Tillage and planting direction is meaningless to the soil aggregate stability measurement

Means within columns followed by the same letter are not significantly different at the 0.05 level according to LSD Test

From Table 4, it can be seen that the high runoff events do not necessarily cause high soil losses. The PCS treatment for instance had much lower soil losses, than P-S and P-Cr, despite giving runoff at the same magnitude. Therefore, soil losses could not been explained only by taking into consideration the runoff amount. The regression analysis of soil losses and runoff in the period 1997 to 2000 during the experiment yielded the following equation:

$$\text{Soil Loss} = 0.018\ \text{Runoff} - 0.202, \text{ with an } R^2 = 0.48^{**} \qquad (4)$$

Equation (4) explains the 50% of soil loss variability. Previous studies have shown that soil loss was mainly affected by runoff, being significantly correlated with runoff amount, R^2= 0.46*** (Zhang *et al.*, 1998), R^2= 0.45*** (Van Dijk *et al.*, 1996), R^2=0.31*** (Dimoyiannis *et al.*, 2006). The remaining 50% is explained by other factors. Rainfall characteristics, such as rainfall's energy and soil surface characteristics, such as aggregate stability and coverage by residue cover crop, should be taken into account.

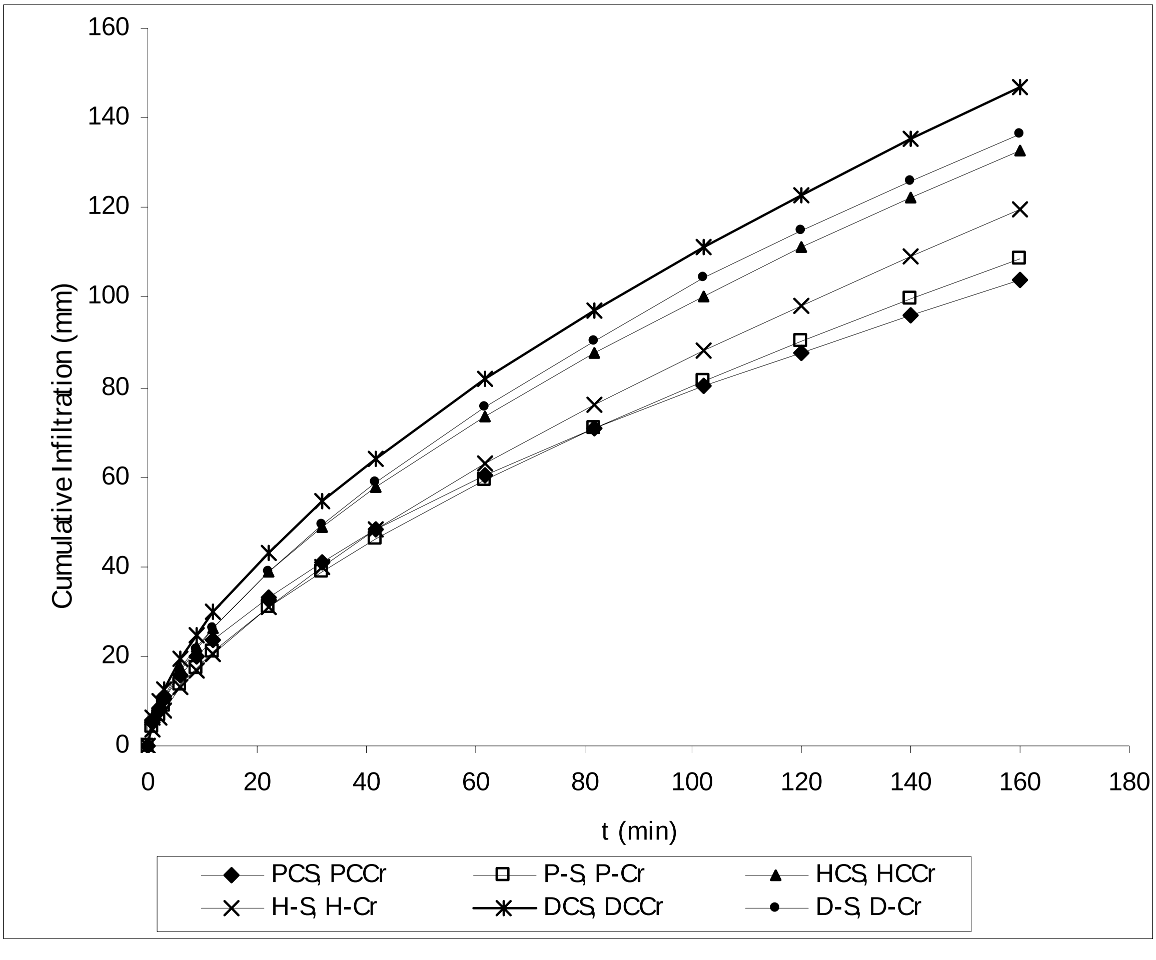

Figure 1. Cumulative Infiltration for the three tillage systems, with or without cover crop in April 1999

3.2 Rainfall Energy and Soil Loss

Tillage by plough in autumn made the soil surface more vulnerable to erosion. The inversion of the soil by the plough left the soil in a loose condition and bare. As time passed, the rainfall drops tended to destroy the aggregates of a ploughed soil without cover crop. It is also important to mention that continuous ploughing results in increasing organic matter degradation and diminishes soil aggregate stability. After three years of ploughed (P-S, P-Cr, PCS, PCCr) the organic matter content – partially decayed plant matter- decreased from 1.10% to 1.08%, while the organic matter content of heavy cultivator tillage (H-S, H-Cr, HCS, HCCr) increased from 1.10% to 1.23% and under disk harrow tillage (D-S, D-Cr, DCS, DCCr) from 1.10% to 1.30%. Hence even low energy rainfalls are able to produce soil losses, as can be clearly seen in Figures 2a and 2b, where the greatest soil losses were observed for the P-S and P-Cr treatments. On the contrary, the effectiveness of cover crop in absorbing and eliminating rainfall energy is seen in Figure 2c and 2d, for the PCS and PCCr treatments. The soil losses in the P-S and P-Cr treatments were 0.85 and 0.69 t/ha at 1000 J/m^2 rainfall kinetic energy, while for the same kinetic energy the soil losses in PCS and PCCr did not exceed 0.31 t/ha. At 2000 J/m^2 rainfall kinetic energy, soil losses were 1.71 and 1.14 t/ha in the P-S and P-Cr respectively, while for the same rainfall the soil losses in the PCS and PCCr did not exceed the 0.61 t/ha. At 3000 J/m^2, the soil losses in the P-S and P-Cr treatments were 3.45 and 1.88 t/ha, while the soil losses in the PCS and PCCr did not exceed 0.91 t/ha.

The fitted curves for P-S or P-Cr treatment (Fig. 2a and 2b), gave an exponential relationship with higher correlation coefficient, R^2, 0.60 and 0.35 for P-S and P-Cr respectively. The fitted curve under PCS or PCCr treatments gave a linear relationship. The exponential curve can be explained by the soil surface roughness and cover conditions. Thus rainwater initially gathered into ponds and runoff only began when the microrelief was filled. Finer particles (silt and mainly clay) remained in suspension in the ponds. On agricultural land, microrelief storage varies seasonally depending upon the type of tillage and the time elapsed since tillage since roughness is washed out by weathering and raindrop impact (Morgan, 1995). The initial low runoff values in ploughed plots and to a lesser extent in plots using heavy cultivator could be explained by the high roughness of the soil surface. Runoff cannot occur until rainfall exceeds ponding capacity at which point the collapse of the microrelief releases all the water and sediment. When the runoff reaches its highest value the clay fraction is carried in downwards layers.

The soil losses in plots with cover crop were higher during the winter period, before cover crop establishment (Fig. 2c and 2d). This stresses the importance of cover crops in controlling soil erosion in the fields that were prepared to grow cotton in the spring (Denton and Tyler, 1997). Cotton plant residues did not give enough soil protection against soil erosion (Daniel *et al.*, 1999). In Figures 2c and 2d one point is far away from the others, at rain kinetic energy of 2982 J/m^2. This effect was the result of a rainfall that occurred on 4th December 1998, when the wheat cover crop was not yet established. If this point is omitted in Figures 2c and 2d, we obtained the following equations and the corresponding R^2: for figure 2c $y=0.0003x + 0.0063$, $R^2 = 0.3236$ and for figure 2d $y=0.0003x – 0.0304$, $R^2 = 0.4696$.

In Figures 2a and 2b, there was a critical level of rainfall kinetic energy, around 1500 J/m^2. Beyond that the soil losses were very high. Below that level, the low soil losses were probably due to the effect of ploughing, which caused roughness and unevenness on the soil surface that stored water and stopped the runoff. The tillage to the contour could offer protection up to a certain level of rainfall height or rainfall intensity. The contour-orientated roughness is of the soil from plough or heavy cultivator tillage could contain a low intensity and height of rainfall, up to certain level. Beyond that level, the soil roughness was overcome and produced high runoff and soil losses. High soil losses were also produced by low height rainfalls of high intensity due to the effect of rainfall splash and limited infiltration. Jacinthe *et al*. (2004) also commented that high intensity rainfalls gave high soil losses.

The effect of reduced tillage with heavy cultivator treatments can be seen in Figure 3. The H-S treatment (Fig. 3a) gave much higher losses than the others three treatments. The soil loss in the H-S treatment was 0.31 t/ha for a rainfall of 1000 J/m^2 kinetic energy, while for the same kinetic energy the soil losses in the H-Cr (Fig. 3b), HCS (Fig. 3c) and HCCr (Fig. 3d) treatments did not exceed the 0.11 t/ha. At 2000 J/m^2 rainfall kinetic energy level, soil losses were 0.63 t/ha in the H-S, while not exceeding 0.21 t/ha for the H-Cr, HCS and HCCr. At the 3000 J/m^2, the soil losses in the H-S treatment were 1.26 t/ha, while they did not exceed 0.31 t/ha for the H-Cr, HCS and HCCr treatments. Omission of the rain event of the 4th December prior to cover crop establishment gave the following equations and the corresponding R^2, y=0.000005x + 0.0128, R^2=0.3667 for Figure 3c and y= 0.00005 x + 0.0051, R^2=0.4172, for Figure 3d.

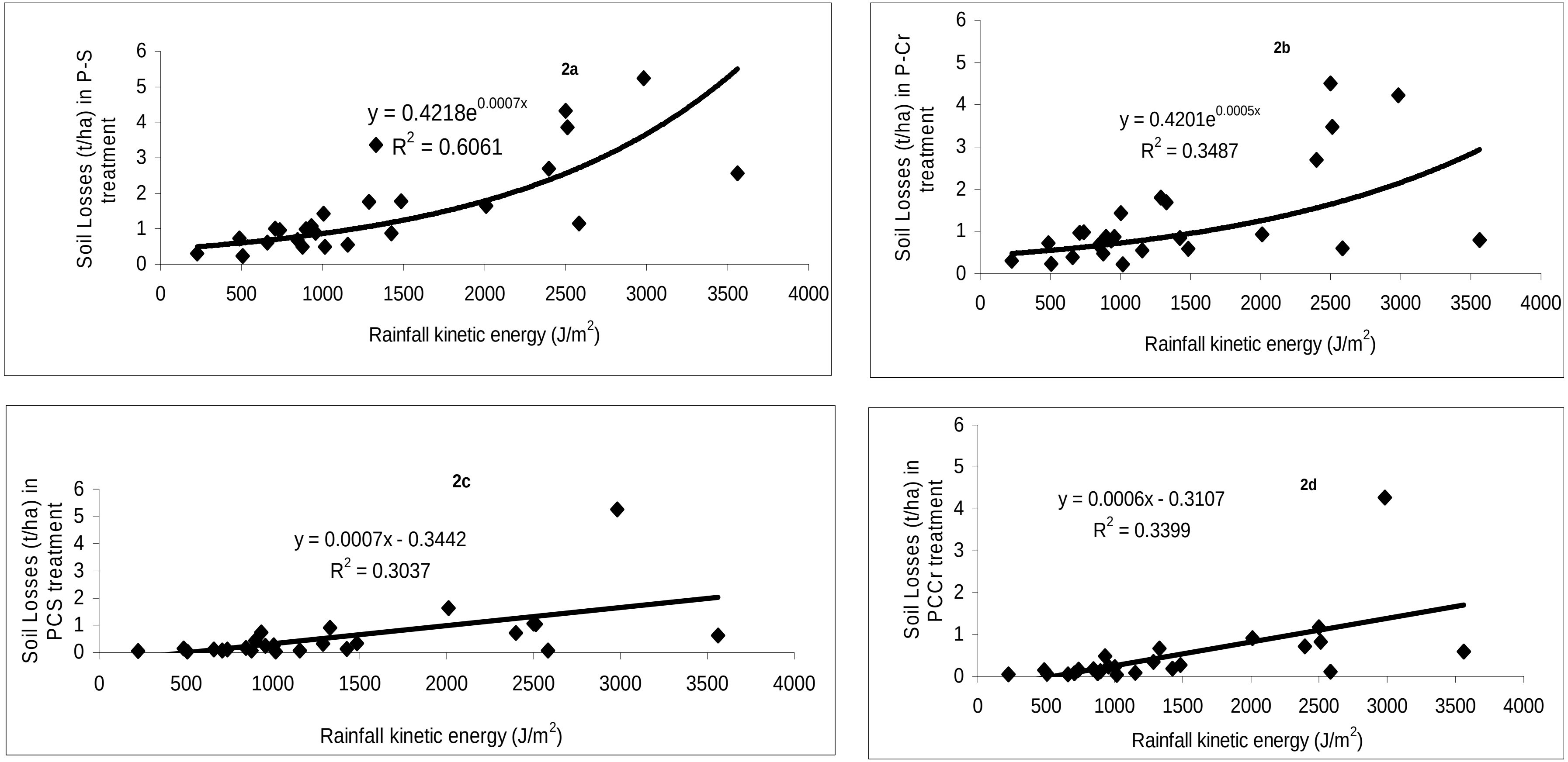

Figure 2. Event based soil loss as a function of the kinetic energy of the rainfall event in four treatments by plough: (a) P-S treatment, (b) P-Cr treatment, (c) PCS treatment, (d) PCCr treatment

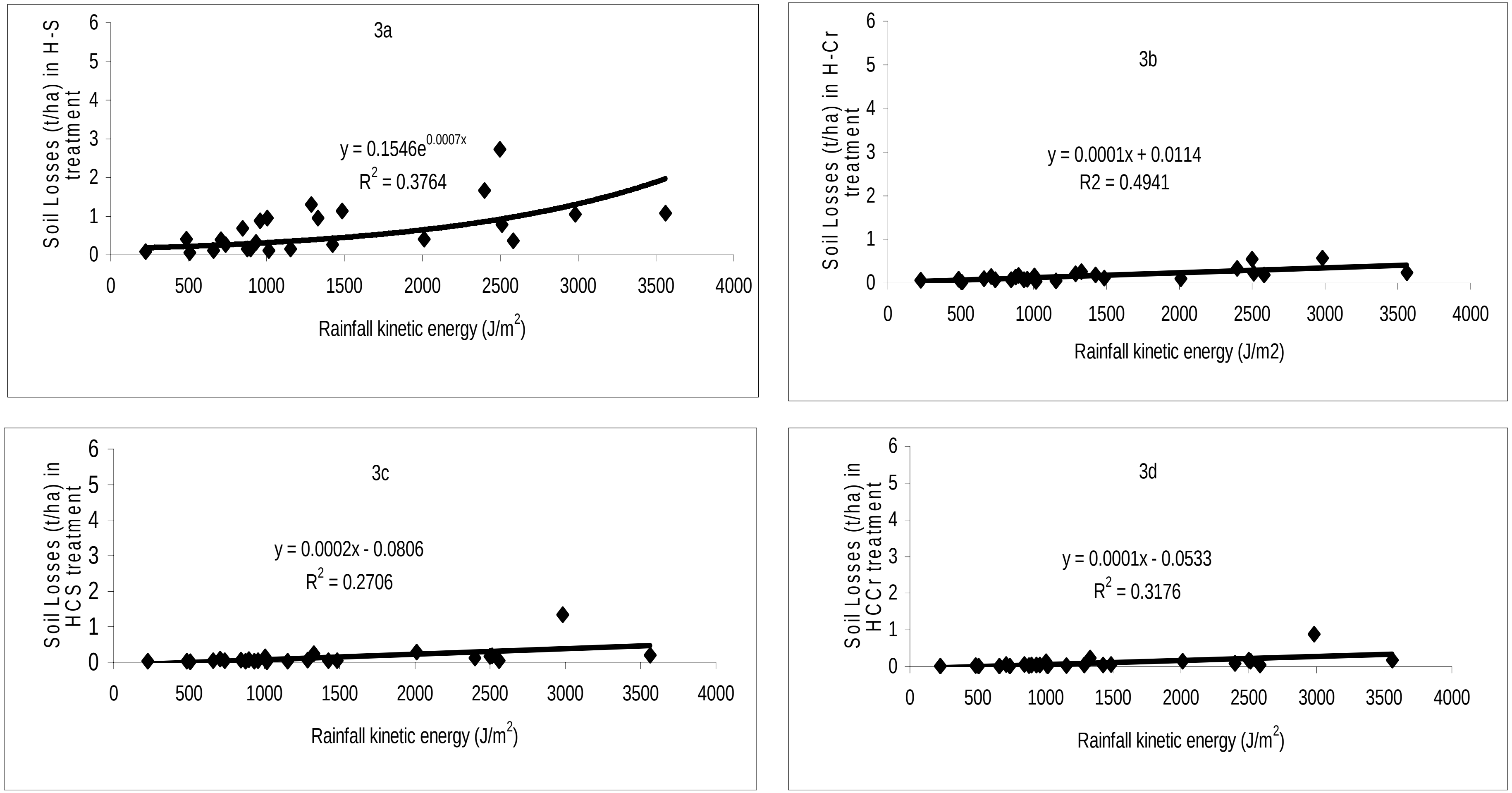

Figure 3. Event based soil loss as a function of the kinetic energy of the rainfall event in four treatments by heavy cultivator: (a) H-S treatment, (b) H-Cr treatment, (c) HCS treatment, (d) HCCr treatment

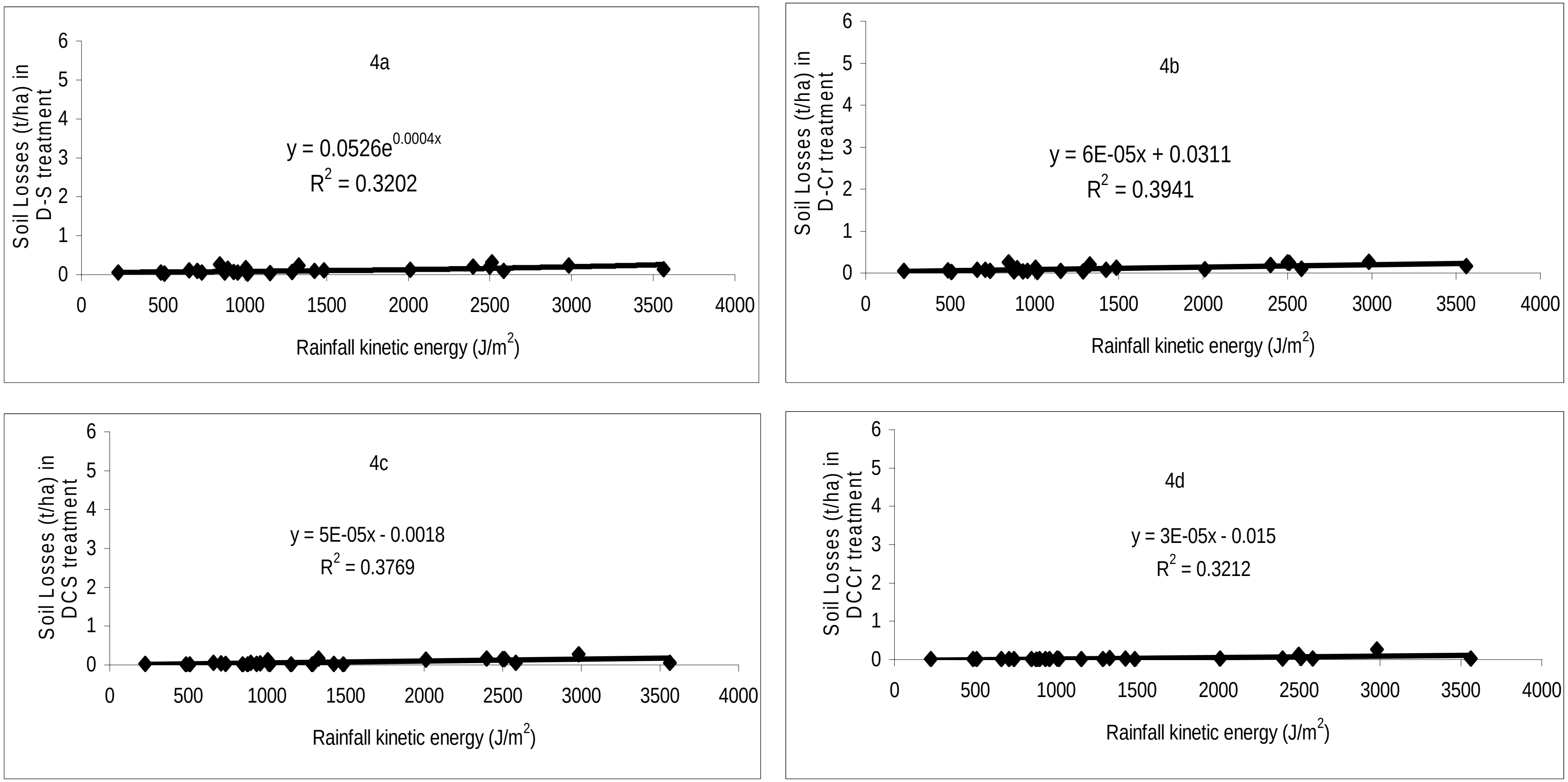

Figure 4. Event based soil loss as a function of the kinetic energy of the rainfall event in four treatments by disk harrow: (a) D-S treatment, (b) D-Cr treatment, (c) DCS treatment, (d) DCCr treatment

For the field under study, disk harrow tillage was the most effective and promising system for soil erosion control. The height and intensity of rainfall did not cause any soil losses, even at high kinetic energies (Fig. 4). This is supported by the soil characteristics, such as aggregate stability and high cumulative infiltration (Table 5 and Fig. 1). The successive annual additions of crop residues to the soil via disk harrowing caused an increase of soil surface organic matter and prevented the formation of surface crust, which in the long run increased infiltration and reduced runoff and soil loss.

3.3 The Qualitative Elements of Sediment Analysis

The initial mechanical analysis of the soil gave 43% clay, 26% silt and 31% sand. Table 6 shows the sediment mechanical analysis of the treatments. It is clear that in the ploughed plots, clay content was 10.4% higher than the initial clay content (43%) of the soil. In the plots with heavy cultivator 2.6% and in the plots with disk harrow there were no differences. It can be concluded that disk harrow could offer a good erosion prevention system. Meyer and Wischmeier (1969) reported that the runoff transporting power depends on the runoff's velocity, the soil surface slope, soil roughness and the size of soil particles. Most of the sediment being transported was derived from detachment by raindrop impact or runoff turbulence. The results (Table 5) indicated that the soil under ploughing presented the lowest aggregate stability and hence a greater tend to be broken by raindrop impact and to be a subsequently transported than the soil in the reduced tillage systems. Also, the crop canopy and residue cover in the reduced tillage plots, reduced raindrop impact and thus reduced soil particle detachment (Martinez-Meza *et al*., 2000). Sediment transported by runoff was reduced, which constitute the basis of conservation tillage. The lower energy available for erosion from the rainfall, together with the greater aggregate stability in reduced tillage plots could be the key factors in preventing aggregate break down by raindrop impact. Morgan (1995) observed that the finer particles are harder to erode because of the cohesiveness of the clay minerals of which they are comprised. But when there is neither winter cover crop nor residue cover and where soils have a low aggregate stability, as under ploughing rainsplash acts to detach finer particles and to transport them down the slope.

Table 6. Effect of tillage on the sediment produced

Tillage practice	% Clay	% Silt	% Sand
Initial Soil Analysis	43	26	31
Mean value of PCS and PCCr	47.00 a	27.50 a	25.50 a
Mean value of P-S and P-Cr	48.00 a	27.00 a	25.00 a
Mean value of HCS and HCCr	44.75 bc	27.75 a	27.50ab
Mean value of H-S and H-Cr	43.50 b	27.25 a	29.25 bc
Mean value of DCS and DCCr	43.00 c	26.25 a	30.75 c
Mean value of D-S and D-Cr	43.00 c	26.50 a	30.50 c
LSD $_{(0.05)}$	1.47	1.93	2.60

[1]Means within columns followed by the same letter are not significantly different at the 0.05 level according to LSD Test

During transportation down the slope the sand and to a lesser extent the silt particles, resist the movement because of their weight (Zhang *et al*., 2002). Even at a low velocity runoff, the clay fraction could be easily moved because of its small weight (Pathak *et al*., 2004). So the percentage of larger soil particles gradually declines as runoff moves down the slope (Mitsios, 1999, Su *et al*., 2004).

The silt content in the sediments, which ranged between 26.25% and 27.75% in all the treatments showed no significant difference from the initial 26%. However, there were significant differences in the sand content in the three tillage treatments. The sand decrease in the sediment among the three tillage systems (plough, heavy cultivator and disk harrow) was 20.5 %, 8.4 % and 1.2 %, respectively, in relation to the initial sand percent (31%) of the soil.

It is therefore obvious that, apart from the rain that unavoidably comes into contact with any soil surface and causes, under certain circumstances, the breakdown of soil aggregates, soil management contributes to a substantial increase in clay loss. Since clay is one of the most important soil constituents, the soil quality and soil productivity is permanently damaged. With reduction in the clay content, the soil became less consistent and less resistant to water erosion and consequently, there is a increase in soil erodibility (Zhang *et al*., 2004) and changes in the initial soil properties (Mitsios, 1999, Su *et al*., 2004).

4. CONCLUSIONS

From the presented results it can be concluded that:

- A combination of reduced tillage, cover crop and tillage to the contour can offer a reduction of soil loss to a level lower than the annual tolerance rate
- Reduced tillage and cover crops use must be obligatory for farmers cultivating sloping fields
- Winter cover crop is an essential tool to reduce erosion, when ploughing is unavoidable
- Conventional tillage leads to higher clay loss than reduced tillage with heavy cultivator and disk harrow, indicating higher soil fertility damage
- High runoff does not always coincide with high rainfall precipitation and does not necessarily cause high soil losses

5. REFERENCES

Abu Hammad Ah., T. Borresen and L.E. Haugen. 2005. Effects of rain characteristics and terracing on runoff and erosion under the Mediterranean. *Soil and Tillage Research*, Article in Press, Corrected Proof

Agassi M. and J.M. Bradford. 1999. Methodologies for interrill soil erosion studies. *Soil and Tillage Research*. 49: 277-287

Akinci I., E. Cakir, M. Topakci, M. Canakci and O. Inan. 2004. The effect of subsoiling on soil resistance and cotton yield. *Soil and Tillage Research* 77: 203-210

Alba S. De. 2003. Simulating long-term soil redistribution generated by different patterns of mouldboard ploughing in landscapes of complex topography. *Soil and Tillage Research* 71: 71-86

Basic F., I. Kisic, M. Mesic, O. Nestroy and A. Butorac. 2004. Tillage and crop management effects on soil erosion in central Croatia. *Soil and Tillage Research* 78: 197-206

Bosch D., T.L. Potter, C.C. Truman, C. Bednarz and G. Harris. 2001. Tillage effects on plant available water, cotton production and soil water quality. Http://www.cpes.peachnet.edu/sewrl/radio/rpt 2001.htm. USDA - *Agricultural Research Service.*

Bouwer H. 1986. Intake Rate: Cylinder Infiltrometer, In *Methods of Soil Analysis*, ed. Klute A., Part I, 2nd ed., Agronomy 9, ASA, SSSA, Madison, Wisconsin, pp. 825-844

Bouyoucos G.J. 1962. Hydrometer method improved for making particle size analysis of soil. Agronomy Journal 54: 464-465

Brown S.M., T. Whitwell, J.T. Touchton and C.H. Burmester. 1985. Conservation tillage for cotton production. *Soil Science Society American Journal* 49: 1256-1260

Conservation Techonology Information Center. 1997. National Crop Residue Management Survey: 1997 Survey Results. CTIC and NACD, West Lafayette, ID.

Daniel J.B., A.O. Abaye, M.M. Alley, C.W. Adcock and J.C. Maitland. 1999. Winter Annual Cover Crops in a Virginia No- till Cotton Production System: I. Biomass Production, Ground Cover, and Nitrogen Assimilation. *The Journal of Cotton Science* 3: 74-83

Denton H.P. and D.D. Tyler. 1997. Surface residue cover in West Tennessee no-till cotton fields. *Cotton Soil Management and Plant Nutrition Conference.*1997, Beltwide Cotton Conferences.

Dimoyiannis D., S. Valmis and N.G. Danalatos. 2006. Interrill erosion on cultivated Greek soils: modeling sediment delivery. *Earth Surface Processes and Landforms.* Article in Press

Fornis R, H. Vermeulen and Jan Nieuwenhuis 2005. Kinetic energy-rainfall intensity relationship for Central Cebu, Philippines for soil erosion studies. *Journal of Hydrology*, 300 (1-4): 20-32

Gemtos T.A., St. Galanopoulou and Chr. Cavalaris. 1997. Wheat Establishment after cotton with Minimal Tillage. *European Agronomy Journal* 8: 137-147

Imeson A.C. 1990. Climate fluctuations and soil erosion under Mediterranean conditions. *Erosion del suelo en condiciones ambientales mediterraneas*. UIMP, Valencia, p. 22

Jacinthe P.A., R. Lal, L.B. Owens and D.L. Hothem. 2004. Transport of labile carbon in runoff as affected by land use and rainfall characteristics. *Soil and Tillage Research* 77:111-123

Kosmas C.S., N. Moustakas, N.G. Danalatos and N. Yassoglou. 1996. The Spata Field Site: I. The Impacts of land use and Management on Soil Properties and Erosion. II. The Effect of reduced Moisture on Soil Properties and Wheat Production. In: *Mediterranean desertification and land use*, eds Brandt C.J. and Thornes J.B., 207-228, John Willey and Sons Ltd, London

Lal R. and W. Elliot. 1994. Erodibility and Erosivity. In : Soil Erosion Research Methods. *Soil and Water Conservation Society*, ed. R. Lal, 181-208, Ankeny, USA.

Laws J.O., Parsons D.A. 1943. The relationship of raindrop size to intensity. *Transactions American Geophysics* 24: 452-460

Le Bissonnais, Y. 1996. Aggregate stability and assessment of soil crustability: I. Theory and methodology. *European Journal of Soil Science* 47: 425-437

Martinez-Meza M., J. Alvarez Rogel, J. Albaladejo and V.M. Castillo 2000. Influence of vegetal cover on sediment particle size distribution in natural rainfall conditions in a semiarid environment. *Catena*, 38 (3): 175-190

Matondo J. J., P. Graciana and K.M. Msibi. 2005. Managing water under climate change for peace and prosperity in Swaziland. Managing water under climate change for peace and prosperity in Swaziland. *Physics and Chemistry of the Earth* 30: 943-949

Meyer L.D. and W.H. Wischmeier. 1969. Mathematical simulation of the process of soil erosion by water. *Transaction of American Society Agriculture Engineering* 12: 754-762

Meyers J.L. and M.G. Wagger. 1996. Runoff and sediment loss from three tillage systems under simulated rainfall. *Soil and Tillage Research* 39: 115-129

Mitsios J., Cr. Pashalidis and Kon. Panagias. 1995. *Soil Erosion - Mitigation techniques to soil erosion*. Edited by Zymel, Athens.

Mitsios J. 1999. *Edafology. Physical properties*. Vol. 5: 47-65, ed. Zymel, 2nd Edition, Athens.

Morgan RPC. 1995. *Soil Erosion and Conservation*. Longman Scientific and Technical, Longman Group UK Limited

Morgan RPC. 2001. A simple approach to soil loss prediction: a revised Morgan-Morgan-Finney model. *Catena* 44: 305-322

Muysen W. Van, G. Govers and K. Van Oost. 2002. Identification of important factors in the process of tillage erosion: the case of mouldboard tillage. *Soil and Tillage Research* 65 :77-93

Nelson D.W. and L.E. Sommers. 1982. Total carbon, organic carbon and organic matter. In: *Methods of Soil Analysis*, eds. Page A.L., R.H. Miller and D.R. Keeney, Part 2, Vol. 9, American Society of Agronomy, 2nd ed, Madison, Wisconsin, pp. 539-577.

Nyakatawa E.Z., K.C. Reddy and J.L. Lemunyon. 2001. Predicting Soil Erosion in conservation tillage cotton production systems using the revised universal soil loss equation (RUSLE), *Soil and Tillage Research* 57: 213-224

Pathak P., S.P. Wani, Piara Singh and R. Sudi 2004. Sediment flow behavior from small agricultural watersheds. *Agricultural Water Management*, 67 (2): 105-117

Pimentel D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Curz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saffouri, and R. Blair. 1996. Land use, erosion and water resources. In *Water Resources*, ed. A.K. Biswas, 37-71, McGraw-Hill, USA.

Rajput T.B.S. and N. Patel. 2005. Water and nitrate movement in drip-irrigated onion under fertigation and irrigation treatments. *Agricultural Water Management*, Article in Press

Ramos M.C. and J.A. Martinez-Casasnovas. 2004. Nutrient losses from a vineyard soil in Northeastern Spain caused by an extraordinary rainfall event. *Catena*, 55:79-90.

Rejman J. 1997. Runoff and soil loss under conventional tillage for cereal production in SE Poland. In: *Proceedings of the 14th ISTRO Conference*, Pulawy, Poland, pp. 89-93

Rosa D., F. Mayol, J.A. Moreno, T. Bonson and S. Lozano. 1999. An expert system/neural network model (ImpelERO) for evaluating agricultural soil erosion in Andalucia region, southern Spain. *Agriculture Ecosystems and Environment* 1451, pp. 1-16

Santos F. L. and Serralheiro R.P. 2000. Improving infiltration of irrigated Mediterranean soils with polyacrylamide. *Journal of Agricultural Engineering Research*, 76: 83-90

Santos F.L., Joao L. Reis, O. C. Martins, N. L. Castanheira, R. P. Serralheiro 2003. Comparative Assessment of Infiltration, Runoff and Erosion of Sprinkler Irrigated Soils. *Biosystems Engineering* 86 (3): 355-364

Slack D.C. and C.L. Larson, 1981. Modelling infiltration: the key process in water management, runoff and erosion: In: *Tropical Agricultural Hydrology* (Lal R., Russell E.W., eds). John Wiley and Sons Ltd, New York.

Smettem K.R.J., A.D. Rovira, S.A. Wace, B.R. Wilson and A. Simon. 1992. Effect of tillage and crop rotation on the surface stability and chemical properties of a red-brown earth (Alfisol) under wheat. *Soil and Tillage Research* 22: 27-40.

Soil Survey Staff. 1975. *Soil Taxonomy*. A Basic System of Soil Classification for Making and Interpreting Soil Surveys. Agriculture Handbook 436, USDA, Washington DC.

Soil Survey Staff. 1981. Examination and Description of soils in the field. Chapter 4, pp. 1-107. *Soil Survey Manual*, Issue 1, Directive 430V-SSM, USDA-SCS, Washington DC.

Stott D.E, A.C. Kennedy and C.A. Cambardella. 1999. Impact of Soil Organisms and Organic Matter on Soil Structure. In: *Soil Quality and Soil Erosion*, ed. Lal R., Soil and Water Conservation Society Ankeny, Iowa.

STSC 1998. *Statgraphics. Statistical Graphics System*, *Statistical Graphics Corporation*, Manugistics, Inc.

Su Yong Zhong, Ha Lin Zhao, Wen Zhi Zhao and Tong Hui Zhang. 2004. Fractal features of soil particle size distribution and the implication for indicating desertification. *Geoderma* 122 (1): 43-49

Tisdall J.M. 1991. Fungal hyphae and structural stability of soil Aust. *Journal of Soil Research* 29: 729-743

Tisdall J.M. 1994. Possible role of soil microorganisms in aggregation in soils. *Plant Soil* 159: 115-121

Tsoar, H., 1990. The ecological background, deterioration and reclamation of desert dune sand. *Agriculture Ecosystems Environment* 33: 147-170

Uson A. and R.M. Poch. (2000). Effects of tillage and management practices on soil crust morphology under a Mediterranean environment. *Soil and Tillage Research* 54: 191-196

Valmis S., P. Kerkidis and S. Aggelidis. 1988. Soil aggregate instability index and statistical determination of oscillation time in water. *Soil Science Society of America Journal* 52: 1188-1191

Van Dijk, P.M., Van der Zijp, M. and Kwaad, F.J.P.M. (1996). Soil erodibility parameters under various cropping systems of maize. *Hydrological Processes* 10 (8): 1061-1067

Van Dijk AIJM, LA. Bruijnzeel and C.J. Rosewell. 2002. Rainfall intensity-kinetic energy relationships: a critical literature appraisal. *Journal of Hydrology* 261: 1-23

Waters D. 1998. Cotton into wheat: less erosion and pesticide run-off. Grains Research and Development Corporation. *Ground Cover* Issue 24

Wischmeier W.H. and Smith D.D. 1958. Rainfall energy and its relationship to soil loss. *Transactions of the American Geophysical* 39: 285-291

Wischmeier W.H. and D.D. Smith. 1965. *Predicting rainfall - erosion losses from cropland east of the Rucky Mountains*. Agric. Handbook No. 282, USDA, Washington, DC.

Zhang G.H., B.Y. Liu, M.A. Nearing, C-H Huang and K.L Zhang. 2002. Soil detachment by shallow flow. *Transactions of the ASAE*, 45: 351-357

Zhang K., S. Li, W. Peng and B.Yu. 2004. Erodibility of agricultural soils on the Loess Plateau of China. *Soil and Tillage Research* 76: 157-165

Zhang X.C., M.A. Nearing, W.P. Miller, N.D. Norton and L.T. West (1998). Modeling Interrill Sediment Delivery. *Soil Science Society of American Journal* 62: 438-444