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Effects of Irrigation and Plastic Mulch on Soil Properties on Semiarid Abandoned Fields

E. S. van der Meulen, L. Nol, and L. H. Cammeraat*

ABSTRACT

The Guadalentín Basin in Spain is one of the driest areas of Europe and has problems with high evaporation rates, and high risks of desertification exist including soil quality loss and soil erosion. Farmers in this semiarid region use polyethylene covers on their irrigated croplands to reduce evaporation to enhance crop yield. When farmers abandon the acres, they leave the plastic covers on the fields. Up to now research has been concentrating on the effects of plastic covers on crop yield and microclimate under these covers but there is little known about the effects of plastic covers and irrigation on soil quality, erosion susceptibility, and hydrology after abandonment of these fields. The research question in this paper is: How do the former irrigation practices and plastic soil covers affect organic C content, aggregate stability, hydrological properties, and erosion susceptibility? Organic C content and aggregate stability are important soil quality parameters that are easy to measure. Beside these two parameters, soil crusting, infiltration rates, and sediment yields have been determined for a set of irrigated fields that have been abandoned at different times (up to 20 yr) and where plastic covers have been used. The properties of these fields were compared with control sites with comparable periods of abandonment and substrate, but where only classical rain fed cropping systems have been applied. It was expected that leaving plastic remains in the soil after abandonment would be harmful to soil quality and would lower infiltration. The first associations with seeing the plastic are those of garbage and pollution. In fact, most of the indicators of soil quality considered in this survey turned out to be better or the same on the fields where irrigation and plastic covers had been used, when compared with control fields. Organic C contents were up to 40% higher on fields where plastic sheets remain and soil aggregates were more stabile. Fields where plastic had been mixed with the soil by tillage showed lower erosion susceptibilities.

The Guadalentín Basin in Spain (Fig. 1) is one of the driest areas of Europe. It suffers from problems such as desiccation, soil erosion, and overexploitation of ground water, which has lead to high risks of desertification and exacerbated by the effects of land use change (Brandt and Thornes, 1996; Geeson et al., 2002). A major point of concern is the impoverishment of soil quality and increase of soil erosion and water loss due to degrading topsoils. The area has shown high erosion rates, which is illustrated by the repeated silting up of reservoirs (López-Bermúdez et al., 2002).

Farmers increasingly change from traditional rain-fed agriculture to irrigated crops (Oñate and Peco, 2005). To reduce evapotranspiration from the soil, farmers use black polyethylene coversheets (0.3–0.4 mm thickness) that also control weed growth, increase soil temperature, and enhance crop yield. Besides the shift from rain-fed to irrigated agriculture, more and more acres are being abandoned. When farmers abandon their irrigated fields, they leave the plastic covers on the fields.

Up to now research has been concentrating on determining the effects of plastic covers on crop yield and microclimate under these covers (Tarara and Ham, 1999; Al-Karaghouli and Al-Kayssi, 2001; Green et al., 2002), but there is yet little known about the effects of plastic covers and irrigation on soil quality properties, erosion, and hydrology in semiarid regions.

We hypothesize that plastic bearing soils in abandoned fields have lower organic C concentrations and less stable aggregates than soils without plastic. Plastic soil covers are likely to hamper infiltration of rainwater into the soil and thus enhance concentrated runoff. Soil quality definitions have been proposed by several authors (e.g., Doran et al., 1996; Karlen et al., 1997; Filip, 2002). In this study soil quality will be defined as follows: the capacity of a living soil to function within its capacity and within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Plastic soil covers are likely to hamper infiltration of rainwater into the soil and thus enhance concentrated runoff. The research presented in this paper focuses on how former land use practices applying plastic sheets on the soil surface, affect erodibility, infiltration, and soil quality. Erodibility is defined as the resistance of the soil to both detach and transport (Morgan, 1995).

MATERIALS AND METHODS

Description of the Study Sites

The research took place on abandoned agricultural fields at two different locations near Lorca, in the upper Guadalentín catchment (Fig. 1) in the Murcia province, SE Spain. The first study area is situated between Zarcilla de Ramos and La Paca, at the foot of the hills Las Hermanicas (‘H site’) and has a substrate of Quaternary sediments with nearby outcrops of Triassic intrusive rocks and gypsum. Quaternary alluvial and lacustrine sediments dominate the geology around the second field site, which is situated near the border of Puentes Reservoir (‘L site’; Embalse de Puentes). The climate is semiarid; annual rainfall is 270 mm yr^{-1} and potential evapotranspiration is >900 mm yr^{-1} (López-Bermúdez et al., 2002). Most agriculture in the area is rain-fed, except for the expanding

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Abbreviations: CND, counted number of drops; HC8, Hermanicas site, control plot, 8 yr abandoned; HC20, Hermanicas site, control plot, 20 yr abandoned; HP5, Hermanicas site, plastic covered plot, 5 yr abandoned; HP20, Hermanicas site, plastic covered plot, 20 yr abandoned; LC2, Lake site, control plot, 2 yr abandoned; LC5, Lake site, control plot, 5 yr abandoned; LP2, Lake site, plastic covered plot, 2 yr abandoned; LP5, Lake site, plastic covered plot, 5 yr abandoned; TDR, time domain reflectometry.

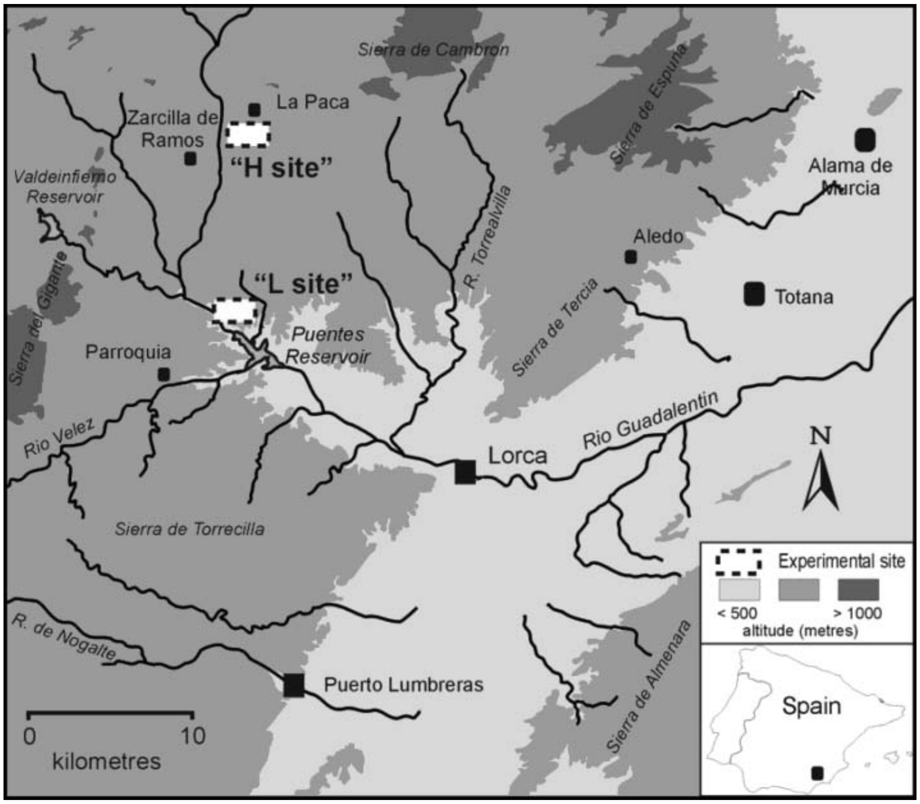

Fig. 1. The study area and the two field sites; the lake area near Puentes Lake or Embalse de Puentes (L site), and the area of Las Hermanicas between Zarcilla de Ramos and La Paca (H site).

fields with irrigated cash crops such as broccoli (*Brassica oleracea*) or watermelons (*Citrullus nalatus*).

Experimental Set-Up

Two types of fields where drip irrigation had been applied in combination with plastic covers were selected. At the Hermanicas site, plastic had been mixed with the soil by tillage. In the Lake area, the plastic has been left as sheets. Besides, fields that could act as control fields with no irrigation and plastic cover history were selected. Landscape positioning, soil type, and geology were important factors that were kept constant between the control and (formerly) plastic covered sites.

To obtain an idea of the effect of time on possible results of the presence of plastic in the soil, place for time substitution has been applied. This implies the use of sites having uniform substratum that are in different stages of a process or time series (in this case time since abandonment). Information on former land use of the field sites was obtained from farmers, shepherds, and landowners.

General field characteristics can be found in Table 1. The codes used for the research fields explain respectively site location (Hermanicas or Lake), whether the field was covered with plastic, was irrigated (plastic) or not (control), and the age of abandonment. The fields vary in size from 1000 to 3000 m^2. In all cases drip irrigation was applied.

The substratum of the Hermanicas fields is of colluvial/alluvial origin. After the last harvest the plastic has been plowed through the soil. At field HP20 the plastic was mainly found between the 0- and 13-cm depth and at field HP5 between the 0- and 11-cm depth. The fields have been partly revegetated following natural succession of annuals and shrubs (predominantly *Artemisia barrelieri* Besser) and the vegetation cover and natural succession reflect the period of abandonment. The fields are located on flat bench terraces northwest of Las Hermanicas, with small height steps (0.5 m)

Table 1. General characteristics of the field sites.†

Site	Treatment	Abandonment	Soil type‡	Former land use	Landform
		yr			
Hermanicas	Plastic (p)	5	PG	Lettuce (*Lactuca sativa*) (i)	Flat (<1°); bench terrace
	Plastic (p)	20	PG	Paprika (*Capsicum annuum*) (i)	Flat (<1°); bench terrace
	Control	8	PG	Cereals (*Hordeum Vulgare*; = barley > 95% of cover)(*r*)	Flat (<1°); bench terrace
	Control	20	PG	Grapes (*Vitis vinifera*) (i)	Flat (<1°); bench terrace
Lake	Plastic (s)	2	XC	Lettuce (i)	Flat (<1°); bench terrace; piping beginning
	Plastic (s)	5	XC	Broccoli (*Brassica oleracea*) (i)	Flat (<1°); bench terrace; severe piping
	Control	2	XC	Cereals (*r*)	Flat (<3°); bench terrace
	Control	5	TX	Cereals (*r*)	Flat (<1°); bench terrace; piping beginning

† p = plastic plowed through soil; s = plastic as sheet on surface or soil; i = irrigated; *r* = rain-fed crop. PG = Petrogypsic Gypsiorthid (USDA), Petric Gypsisol (FAO); XC = Xerollic Calciorthid (USDA), Haplic Calcisol (FAO); TX = Typic Xerorthent (USDA), Calcic Regosol (FAO).

‡ Soil Survey Staff (1992) and FAO (1989).

between the terraces. The control fields for HP20 and HP5 are HC20 and HC8, which are located southeast of Las Hermanicas and have a history of rain-fed crops without plastic covers.

The Lake fields LP5, LC5, LP2, and LC2 are situated about 12 km southwards of Las Hermanicas. These fields are located near the Puentes Lake. The fields are part of a complex of bench terraces in recent lake deposits. Characteristics of the lake fields can be found in Table 1. The fields LP5 and LP2 contain a plastic layer that is almost intact and that is present at a depth of 0.02 to 0.05 m. On the lower edge of LP5, collapsed pipes occur varying from the 0.5- to 2-m depth, with a radius of 1 to 6 m (Fig. 2). These erosion features have also been observed on other fields with plastic covers in the same bench terrace system.

Field Methods

The selected field sites have been described for soil, surface, and vegetation characteristics. Soil sampling was performed to obtain soil material for the laboratory tests. These were collected from the upper 10 cm for each field at five spots and bulked for physical and chemical analysis. Soil samples for the determination of soil organic C have been taken for each field under vegetation and under bare soil at a depth of 5 cm, each for five replicates. Additional soil samples were collected for soil aggregation studies, at each field from the topsoil (0–5 cm) and from the underlying layer (5–10 cm), for both vegetated and bare surfaces. For each of these four sites, samples of 30 aggregates were composed. Bulk density was determined from undisturbed soil samples of the topsoil (0–5 cm) that were taken using 100-cm^3 metal cores. Three samples from each field have been used to obtain an average bulk density per field site. The limited number of bulk density measurements doesn't allow for statistical comparison between the control and treatment sites.

To obtain data on infiltration rates, surface runoff, and sediment production rainfall simulations were performed on plots measuring 0.5 m^2, using an "Amsterdam type" dripping plate simulator (Bowyer-Bower and Burt, 1989) having equally distributed dripping points made of capillaries, creating drops ranging in size between 2 and 5 mm with a falling height of approximately 1.3 to 1.5 m. The kinetic energy was determined at 0.166 W m^{-2} at a rainfall intensity of 48 mm h^{-1}. For each pair of plastic bearing field and control field, simulations have been repeated at two different rainfall intensities: about 30 and 45 mm h^{-1} for HP20 and HC20; 20 and 55 mm h^{-1} for HP5 and HC8; 20 and 40 mm h^{-1} for LP5 and LC5. Demineralized water was used to prevent flocculation of the dispersion sensitive soils (Shainberg et al., 1981). During the simulations, the soil moisture of the sprinkled plots was monitored every 5 min at the 2- and 5-cm depth using a multiplexed TDR system (Heimovaara and Bouten, 1990). At both depths, three sensors with a l0-cm length were installed horizontally from the borders of the plots. The fields LP2 and LC2 were not evaluated using rainfall simulations. Outside the sprinkled plots soil moisture content was measured for the upper 10 cm using TDR. The measurements were repeated six times under vegetated surface and six times under bare surfaces. For the gypsum containing soils the TDR results have been calibrated whereas standard calibration curves were used for the other soils (Heimovaara and Bouten, 1990). Runoff, infiltration, and soil moisture measurements were carried under a limited number of experiments, which makes statistical analysis of these parameters between treatment and control areas impossible.

Fig. 2. Collapsed pipes at the edges of a field (LP5) on plastic covered soils, with a continuous plastic sheet still present at a depth of about 1.5 to 5 cm.

Surface crusts were classified in the field following Valentin and Bresson (1992). Resistance of the crusts against sheer and pressure strength was measured by using a sheer vane and a penetrometer. Measurements were repeated ten times for each type of crust. Vegetation coverage and the occurrence of species have been determined by using a 1-m^2 counting grid (0.10-m resolution) at five randomly selected sites per field.

Laboratory Measurements

The sediment load generated during the rainfall simulations, was collected from a gutter and weighed after drying at 105°C.

Bulk samples were used for texture analysis and were not decalcified, as $CaCO_3$ contents were larger than 50%. After wet sieving, the fraction larger than 0.106 mm was too small to divide into more classes than 0.106 to 2 and >2 mm. The fraction <106 μm was further analyzed in the Microscan II Quantachrome particle analyzer (Cammeraat and Imeson, 1998; Boix-Fayos et al., 1998). The soil samples were characterized with respect to particle-size distribution of water stable particles and microaggregation.

Macroaggregate stability (4–4.8 mm) was measured by applying the drop test of Low (1954). The drop-test involves counting the number of water-drop impacts (CND) required to break down a soil aggregate to a certain state of disruption. Thirty aggregates per sample point were subjected to the CND procedure (Imeson and Vis, 1984). The results of the drop test have been converted into a stability index with values between 0 and 1. An index of 1 indicates that all aggregates from a sample survived the maximum of 50 drop impacts. The data have been corrected for surface coverage. Significance of differences between treatments was tested with the Mann Whitney U-test.

Bulk density has been determined using the 100-cm^3 undisturbed cores following standard laboratory procedures (Blake and Hartge, 1990). The limited number of samples makes statistical analysis impossible.

For the water retention characteristics, water contents were measured for two different matrix suction ranges. For matrix suction -1 to -1.66 hPa, the under pressure method has been applied, and pressure cells were used to apply the overpressure method (Klute, 1990) for -1000 to $-16\,000$ hPa. For this procedure, the same samples as for bulk density have been used. Measurements were processed in the software program pFFit (Freyer, 1990) to obtain the water retention curve. The pFFit program uses the Van Genuchten equation to calculate the water retention curves (van Genuchten, 1980).

The gypsum contents of the soil samples from the fields at Las Hermanicas were measured semi quantitatively through the precipitation of $CaSO_4$ in acetone, present in the fraction <2 mm (Soil Survey Staff, 1996). This test has not been performed on samples from the fields near Puentes Lake, as gypsum was not present in this area.

Because of the presence of gypsum in some soils, the Allison method was chosen for measuring organic C content (Allison, 1935). This method is based on the oxidation of organic matter by chrome-acid ($K_2Cr_2O_7$ dissolved in sulfuric acid). By using a colorimeter, and an existing calibration diagram that compares extinction and C content (mg), the amount of organic C can be determined. Significance of differences between treatments was tested with the Mann Whitney U-test.

RESULTS

Fields with Plastic Plowed through the Soil (Hermanicas Site)

Differences in texture are small between the fields and treatments. On average 85% of the texture is smaller than 106 μm. The fine fraction is slightly coarser for the fields with plastic (Fig. 3). Microaggregates are in general more abundant at the control fields than at the plastic fields. There is no significant difference in texture between the upper 5 cm of the soils and the underlying layer at 5 to 10 cm.

The ratio between vegetation cover and bare soil surface is lower for the control field HC20 compared with HP20, whereas the ratio for the plastic bearing field HP5 is lower than for HC8 (Table 2). Two types of crusts are present in the study area; slaking/depositional crusts and cryptogamic crusts. Table 3 shows that most of the crusted surface near Las Hermanicas consists of cryptogamic crusts. The differences in crust strength are indecisive with respect to type of crust as well as between control fields and plastic treated fields.

The results of the gypsum determination showed high variance and are therefore not useful as exact figures. But a difference exists between the plastic covered fields northwest of Las Hermanicas and the control fields east of the hills, where the gypsum content of the soils is about two times higher.

The organic C content of the soils in the whole study area is low, between 11.8 and 19.9 g kg^{-1} (Fig. 4). The organic C content on former plastic covered fields is significantly higher (up to 40% higher) than on control fields.

The aggregate stability data (Table 4) show that in most cases aggregate stability at the 5- to 10-cm depth is significantly higher on former irrigated fields with plastic in the soil than on control fields. At the 0- to 5-cm depth, aggregate stability is in most cases significantly higher on control fields. Besides, aggregate stability is higher (not significant) under vegetation than under bare soils.

Bulk density figures are presented in Table 2. The bulk densities of soils that contain plastic are lower than the bulk densities of their control fields. The difference between the plastic covered fields and the control fields tends to increase with time since abandonment. No decisive answer can be given whether this trend is significant due to the limited amount of samples studied.

The water retention curves in general did not show significant differences between the treatments (Fig. 5). However, the theoretical water availability (i.e., between pF 2 and 4.2) has been calculated from data of the water retention curves and Table 2 shows higher values for the plastic bearing field.

Table 2 shows that control fields have higher soil moisture contents than the plastic covered fields. According to the TDR measurements during the rainfall simulations, the soil at HP20 had taken up about the same amount of water as the soil at HC20. Runoff amounts at HC20 were on average 95% higher (Fig. 6). When comparing HP5 and HC8, runoff was higher at the plastic covered field, while infiltration was also much higher than at HC8.

Time to ponding was longer at the simulation plots of HP20, compared with control field HC20 (Table 2). The difference between HP5 and HC8 was small and time to ponding took a little longer at HP5.

Fields with Plastic Cover as Sheet (Lake Site)

Differences in texture are small between the fields and treatments. On average 95% of the texture is <106 μm. There is a large difference in texture on field LP5 between the upper 5 cm and the underling layer (Fig. 3). The fraction between 5 and 9 μm is dominant between the 0- and 5-cm depth, whereas the texture is less well sorted in the silt fraction, between the 5- and 10-cm depth, below the in situ plastic sheet.

The ratio between vegetation cover and bare soil surface on LP5 is higher than on LC5, whereas the ratio on the fields with 2 yr since abandonment is almost equal (Table 2). Two types of crusts are present in the study area; slaking/depositional crusts and cryptogamic crusts. Ninety five percent to 98% of the crusted surface in the Lake area was classified as slaking/depositional crusts. The differences in sheer and pressure resistance for the slaking crusts are in most cases indecisive.

The organic C content of the soils in the Lake area is low, between 6.6 and 11.0 g kg^{-1} (Fig. 4). The organic C content is significantly higher on former plastic covered fields (up to 40% higher), except for the fields that were abandoned 2 yr before the survey. Organic C contents at the Lake site are significantly lower than on the Hermanicas site, irrespective of their treatment (Table 4).

The aggregate stability data (Table 4) show that for the fields with 5 yr of abandonment, aggregate stability is significantly higher on the former irrigated field with plastic in the soil than on the control field.

Except for the fields that were abandoned 2 yr ago, the bulk densities of soils that contain plastic tend to be slightly lower (not significant) than the bulk densities of their control fields (Table 2). Differences are very small, with a 1% lower density for LP5 in comparison with LC5, and a 1% higher density for LP2 in comparison with the control field.

The water retention curves show that saturated water contents are about 10% lower than at the fields around Las Hermanicas (Fig. 5). The fields that were abandoned 2 yr before the start of this research had a totally

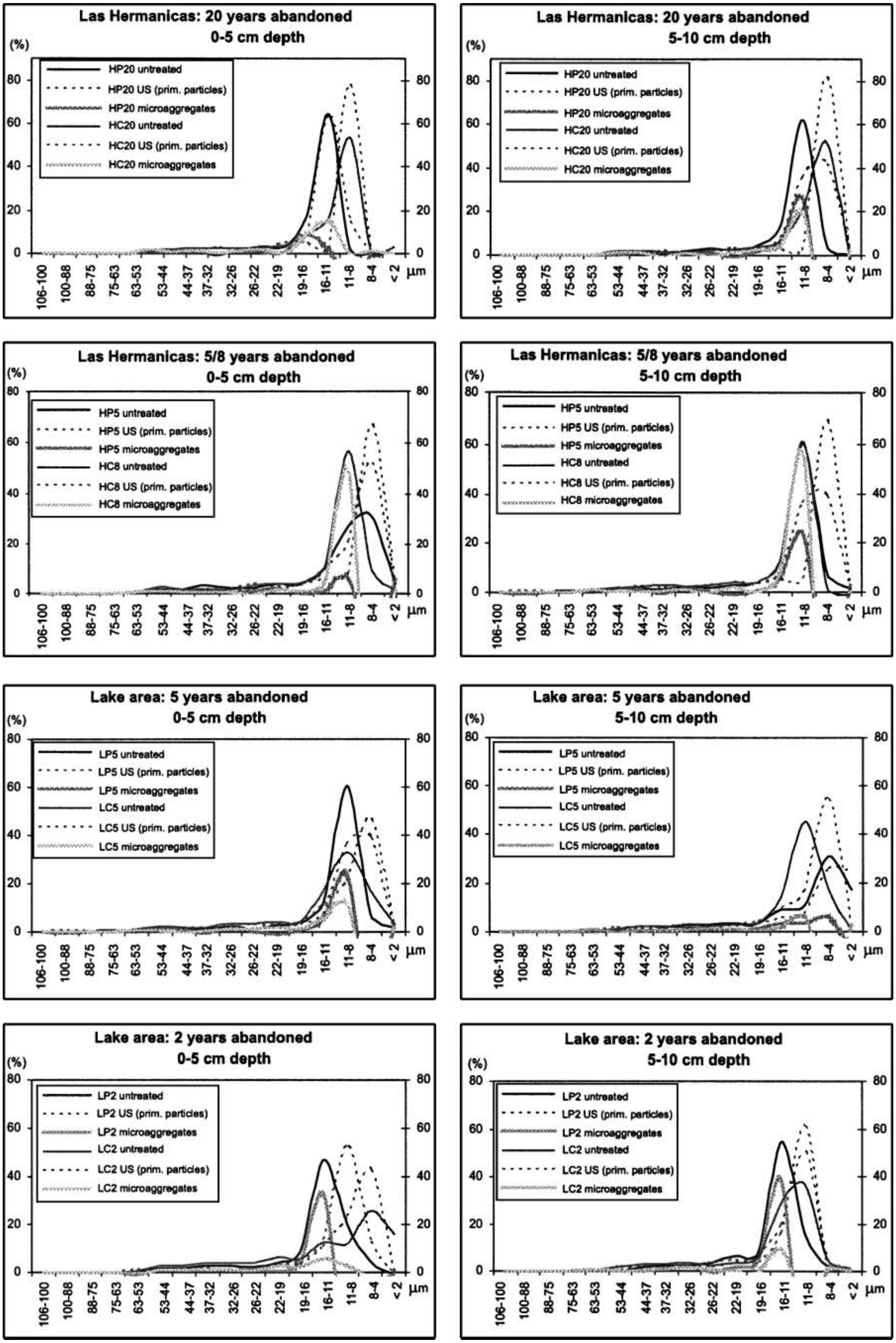

Fig. 3. The particle size distribution for the fraction <0.106 mm, obtained by Microscan, for the plastic fields (20PH, 5PH, 5PL, 2PL) and the accompanying control fields (20CH, 8CH, 5CL, 2CL). Results are presented for the untreated samples, samples treated with ultrasound (US), which represents the texture distribution of primary particles and microaggregates.

Table 2. Surface cover and soil hydrological properties for the different plots. Veg., vegetated; θ_i, initial soil moisture content; $\delta\theta$, soil moisture content change during simulations; θ_{av}, available water content; n.a., not analyzed.

	Cover veg.	Cover crust	Bulk density	θ_i veg	θ_i bare	$\delta\theta$†	θ_{av}	Ponding time
	%	%	$Mg\ m^{-3}$	$m^3 m^{-3}$	$m^3 m^{-3}$	$m^3 m^{-3}$	$m^3 m^{-3}$	s
HP20	71	21	1103	0.082	0.058	0.020	0.25	291
HC20	51	44	1247	0.106	0.055	0.021	0.19	164
HP5	31	62	1137	0.055	0.017	0.033	0.22	204
HC8	69	24	1150	0.072	0.045	0.001	0.18	223
LP5	76	20	1338	0.061	0.053	0.015	0.15	470
LC5	26	68	1340	0.047	0.029	0.009	0.18	276
LP2	33	60	1248	0.009	0.052	n.a.	0.17	n.a.
LC2	35	60	1283	0.035	0.028	n.a.	0.17	n.a.

† Increase of soil moisture during rainfall simulation.

Table 3. The resistance of the two types of crusts to shear and pressure strength.

	Cryptogamic crust			Slaking/depositional crust		
	crusted cover	sheer resistance	pressure resistance	crusted cover	sheer resistance	pressure resistance
	%	$N\ cm^{-2}$		%	$N\ cm^{-2}$	
HP20	92	4.5	3.9	8	4.8	3.2
HC20	90	4.8	4.8	10	4.3	4.7
HP5	40	3.1	2.5	60	5.2	3.4
HC8	80	5.5	5.1	20	4.0	3.8
LP5	3	3.6	3.9	97	3.4	3.6
LC5	5	2.6	3.9	95	2.4	3.1
LP2	5	n.d.	n.d.	95	3.9	3.7
LC2	2	n.d.	n.d.	98	6.0	5.4

different water retention curve than all the other fields. In this case, the plastic covered field had lower water contents than the control field for the whole range of matrix suction values. The theoretical water availability is equal for both fields. When comparing the 5-yr-old fields, higher water availability was calculated for the plastic bearing field.

Table 2 shows higher soil moisture contents at the plastic covered fields near the Lake site. According to the TDR measurements during the rainfall simulations, the soil at LP5 had taken up more water than the soil at LC5. However, more water is available to plants at the control field. Less runoff (Fig. 6) and more infiltration at the 5-cm depth have been measured on field LP5 in comparison with field LC5. Time to ponding was longer at the plastic covered field (LP5) compared with the control field.

DISCUSSION

Soil Quality Properties

In the upper 5 cm of the soil of the 5-yr abandoned plastic covered Lake site (LP5), the clay content is 27% higher than the clay content of the corresponding control field LC5. This might explain the somewhat better aggregate stability of LP5. The less well-sorted texture of LP5 at 5 to 10 cm below the plastic sheet, compared with 0 to 5 cm can be attributed to the fact that precipitation and overland flow can only reach the soil through gaps in the plastic sheet. This concentrated subsurface flow can easily wash out particles in the fine silt fraction. Pilgrim and Huff (1983) measured increased sediment concentrations in subsurface flow in silt-loam soils, consisting mainly of particles between 4 and 8 μm. It was mainly the fraction 5 to 12 μm that has been washed out of the soil profile of LP5 at 5 to 10 cm. This resulted in pipes that collapsed at the edge of the field, as shown in Fig. 2. The difference in texture distribution between the two layers is caused by surface sedimentation of the eroded material from the upslope field where the same processes occur.

The organic C content levels are significantly different between the Hermanicas site and the Lake site, and a difference exists between samples of vegetated soil and uncovered soil. Many authors observed a clear contrast in organic C between bare and covered sites in open semiarid rangeland areas (Bochet et al., 1999; Cerdà, 1998; Pierson et al., 1994). When returning to the observation that (formerly) plastic covered fields had higher organic C levels (HP20, HP5, and LP5) than their control fields, the question arises whether remains of the polyethylene sheets in the samples have contributed to the measured organic C levels in the Allison test. The polyethylene sheet remains have been removed as much as possible from the samples that were used for the Allison test, and the maximum amount of organic C contributing from fresh polyethylene sheets is, when mixed with the upper 20 cm of the soil, $<1.0\ g\ kg^{-1}$. This has only a limited influence on the organic C contents in the soil. Although the fertilizers associated with irrigation may have boosted vegetation initiation after abandonment, also increasing below ground biomass, it is not likely that this has long-term effects on the organic matter pool as many studies have shown an initial decline of organic matter directly after abandonment. It

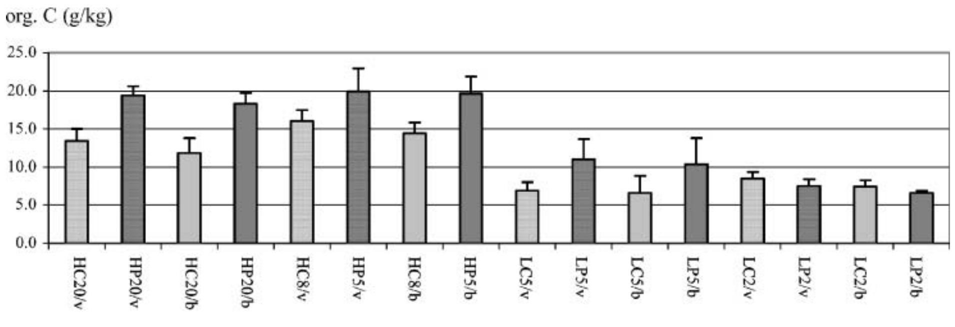

Fig. 4. Organic C content (with standard deviation) for the plastic covered fields and control fields. 'v' = under vegetation; 'b' = underneath bare surface; 0 to 5 and 5 to 10 refer to centimeter depth; H = Hermanicas site and L = Lake site.

Table 4. Organic C content and aggregate stability of soils sampled under vegetated (v) and bare soil (b) for the different fields. Control and plastic covered plots are compared as well as vegetated versus bare areas.

	Org. C v; 0–5 cm		Org. C b; 0–5 cm		Stab. index v; 0–5 cm	Stab. index b; 0–5 cm	Stab. index v; 5–10 cm	Stab. index b; 5–10 cm
	g kg^{-1}							
	Mean	SD	Mean	SD				
HP20	19.4*	1.2	18.3*	1.5	0.72*†	0.23	0.49*	0.30*
HC20	13.5*	1.6	11.8*	2.0	0.48*	0.36	0.46*	0.22*
HP5	19.9*	3.0	19.6*	2.3	0.40*	0.25*	0.49*	0.25*
HC8	16.0*	1.5	14.4*	1.4	0.74*	0.50*	0.46*	0.64*
LP5	11.0*	2.7	10.4*	3.4	0.71	0.89*	0.91	0.90*
LC5	6.9*	1.1	6.6*	2.2	0.76	0.69*	0.81	0.60*
LP2	7.5*	0.9	6.6*	0.3	0.79	0.70	0.79	0.78
LC2	8.5*	0.8	7.4*	0.9	0.54	0.59	0.59	0.84

* Significant difference between related pairs of plastic covered and control field of similar age at $p = 0.05$ significance level.

† Underlining means significant difference in aggregate stability between vegetated and bare areas in the same plot and depth at $p = 0.05$ significance level.

has been proven that the use of plastic covers also does enhance crop yields in semiarid regions, for example with bush beans (Raeini-Sarjaz and Barthakur, 1997). On the fields HP20 and LP5, significant higher organic C contents compared with the control fields can be related to a larger vegetation cover; a factor stressed by many authors (e.g., Haynes and Swift, 1990).

Soil aggregates were stronger at the Lake site than at the Hermanicas site with gypsum containing soils. The higher aggregate stability at the irrigated fields, with the exception of field HP5, can partly be contributed to the higher organic C contents (Fig. 3). There is a relation between increasing time since abandonment and higher abundance of cryptogamic crusts. The Hermanicas fields have a higher age of abandonment and they are in a further stage of vegetation succession than the Lake site fields. The abundance of cryptogamic crusts might be a result of either differences in the succession stage or differences in parent material between the Lake and Hermanicas site. The vegetation cover at the Hermanicas fields is also on average higher (not significant) than at the Lake fields. The difference between the plastic covered fields and the control fields for bulk density suggest an increase with time since abandonment. Comparing the fields HP5 and HC8, the difference in aggregate stability could be related to the type of crusts. Crusts cover the whole area of bare soil on both fields, but on HP5 60% of the crusted surface consists of slaking/depositional crusts and 40% cryptogamic crusts whereas merely 20% of the crust area of HC8 was recognized as slaking/depositional crust. This matches with the aggregate stability data, which showed higher stability for the soil of HC8. The lower aggregate stability at HP5 is remarkable considering the higher clay content and higher organic matter content. The strong microaggregation in the soil of the control field seems to control aggregate stability. Differences in aggregate stability at the most recently abandoned fields (LP2 and LC2) and the fields HP20 and HC20 cannot be related to the extent and type of crusting, which is almost equal for the plastic covered and the control fields.

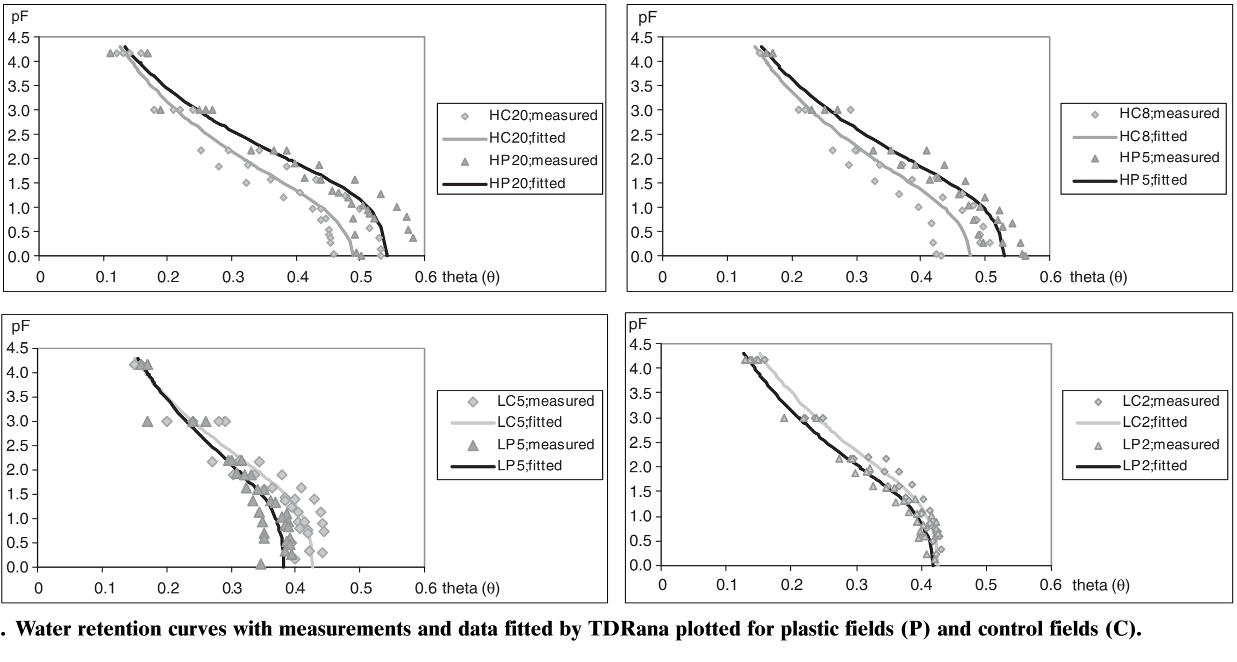

Fig. 5. Water retention curves with measurements and data fitted by TDRana plotted for plastic fields (P) and control fields (C).

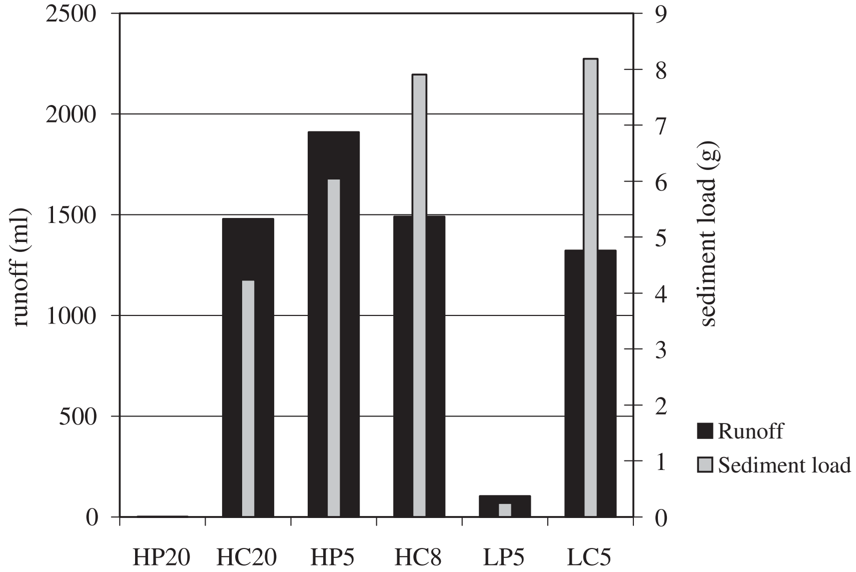

Fig. 6. Total runoff and sediment yield from the rainfall simulation experiments.

Hydrological Properties

Time domain reflectometry measurements (Table 2) show higher soil moisture contents at the irrigated fields near the Lake site, where plastic is present as an intact sheet. At the Hermanicas site, where plastic remains have been plowed through the soil, control fields show higher soil moisture contents than the plastic covered fields. It has to be mentioned that the TDR-measurements sampling volume of the sensors is small and that soil moisture in general shows spatial heterogeneity. However, field observations confirm higher soil moisture contents at plastic covered fields in the lake area.

All comparisons showed higher runoff and sediment yields for the control fields, except for the runoff on plots HP5 and HC8 (Fig. 6). For the latter two plots this is not matching with the results of the increase in soil moisture (Table 2), assuming that all water used for the simulation will infiltrate or stream to the runoff gutter. Possibly, not all runoff water was transported to the gutter at HC8 or water only infiltrated between the 0- and 2-cm depth. The sediment yield is however higher at field HC8 (Fig. 6).

Less runoff has been measured on the Lake fields LP5 in comparison with field LC5. This was an unexpected result as the plastic sheets at the Lake site are still in place and relatively undisturbed. The control fields showed signs of heavy trampling by grazing animals, which has been affecting the surface on the control fields so strongly, that the microtopography of the plots was of major concern in terms of runoff and also may have resulted in compaction of the topsoil, hampering infiltration.

It took on average more time to reach 100% ponding on the fields with former irrigation and plastic cover (Table 2), probably as a result of the lower portion of slaking/depositional crusts at the simulation plots, more interception by vegetation and the higher available water capacity (porosity) of the soil (Table 2), enabling capillary and gravimetric flow.

The TDR measurements during the rainfall simulations showed on average a stronger increase in water content at 5 cm on the fields with a plastic cover, which also indicates better infiltration at those fields (Table 2).

Erosion Susceptibility

Since the soils of the former irrigated fields with plastic sheet remains are potentially moister than their control fields, and have more stable aggregates, they are expected to have a lower susceptibility for erosion.

Showing higher organic C contents, higher infiltration rates, higher aggregate stability, and small amounts of runoff, the 20 yr abandoned plastic covered Hermanicas field (HP20) has lower susceptibility for erosion than the soil at the corresponding control field (HC20), which is confirmed by the sediment yield obtained during the rainfall simulations.

Eight year abandoned control field HC8 probably had higher erosion susceptibility than the corresponding plastic covered field HP5 according to the high sediment yield at HC8. The texture of HC8 is finer and therefore easier to transport by erosive agents.

At the Lake sites, where the plastic cover has not been plowed through the soil, the 5-yr abandoned plastic covered site LP5 showed higher erosion susceptibility than its control field LC5, because of the strong crusting, the smaller vegetation cover and the evidence of erosion pipes and gullies on the terrace rim of the field. The soil of the recently abandoned plastic covered irrigated field LP2 is expected to be more resistant to erosion than its control field LC2, due to higher organic matter content and aggregate stability.

Plastic Remains in the Soil

Leaving the plastic sheets at the surface (Lake sites), that cover the whole surface after abandonment will not be advantageous to soil quality because it prevents rainwater to infiltrate homogeneous into the soil. It will

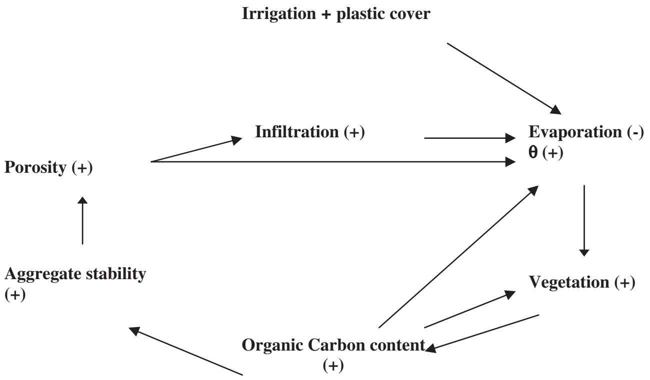

Fig. 7. The measured indicators of soil quality give rise to this theory about the effects of irrigation combined with evaporation reduction by plastic soil surface covers in the past. The effects are still reinforcing each other.

infiltrate through preferential flow paths, associated with former drop irrigation tube linings and holes, causing concentrated runoff. Such runoff can lead to serious erosion phenomena, especially in dispersion sensitive soils, as shown by the collapsed pipes at the plastic covered field LP5 (Fig. 2). However, soil quality parameters as discussed above indicate that soil organic C and soil aggregation still are better in soils where the plastic is present.

At the Hermanicas site plastic has been plowed through the soil after abandonment. At first sight this looks like pollution and one would expect this to be disadvantage to soil quality. However, for the soil quality parameters that were measured during this research, no negative effects of the presence of plastic were found. In fact, there are clear indications that the former irrigation system, together with the use of plastic has positive effects on soil quality. Those effects keep reinforcing each other, even after abandonment of the fields and leaving the plastic in the soil. Plastic sheet remnants in the soil are capable of retaining water by physically obstructing capillary rise, whereas these do not obstruct downward gravitative flow. This leads to higher soil water contents and higher microbiological soil activity. That will consequently create better conditions for plants and plant roots, which will create more macropores. As a result of enhanced plant growth the soil organic C content is ascending as well, initiating a positive feedback loop improving soil quality.

Chemical pollution of soil or soil water is not to be expected from the polyethylene itself, as it is a chemical only existing of H and C atoms. No contaminating or toxic elements like chlorine and benzene are present in this type of plastic. Besides, polyethylene is one of the most chemically inert of all plastics and therefore is extremely chemical and corrosion resistant. However, in the plastics sheets chemical additives might have been used to decrease UV sensitivity as well as for other purposes. The environmental risk of these additives is not known, partly because sheets have been applied from different manufacturers. The possible adverse effect on animal health as a result of the digestion of plastics while grazing is also to be considered.

CONCLUSIONS

This research provides several sound indications of the positive effects of the former application of irrigation combined with plastic covers on agricultural fields. It was expected that leaving plastic remains in the soil after abandonment would be harmful to soil quality. The first associations with seeing the plastic are those of garbage and pollution. In fact some important indicators of soil quality like organic C content and aggregate stability turned out to be better or the same on the fields where irrigation and plastic covers have been used, and where the plastic is still present, compared with control fields, whereas other parameters showed indecisive results (bulk density, crust strength).

Leaving the plastic as sheets can lead to erosion as a result of concentrated runoff. There is however no reason to assume that leaving the sheets after tillage will be harmful to soil quality and the susceptibility to erosion of the soils where plastic remains are plowed through the soil was lower. However the environmental risk of chemical additives used in polyethylene sheets is unknown.

The results of the measurements concerning soil quality indicators give rise to a theory about the effect of irrigation in combination with evaporation reduction by plastic covers in the past in the southeast of Spain (Fig. 7). When irrigation was used in combination with plastic soil surface covers to enhance crop yield, evaporation was reduced. This resulted in higher soil moisture content that improved plant growth. Better vegetation development led to higher organic matter contents, which in turn is an important factor concerning aggregate stability and water holding capacity. Because of the formation of stronger aggregates, macroporosity became higher and water availability for plant roots was improved.

After the break down of the plastic sheet by tillage and abandonment of the fields by farmers, the beneficial circumstances for vegetation growth remained, and they are still reinforcing each other. The high organic C content, higher aggregate stability, and porosity still improve hydrological conditions, thereby creating a more advantageous environment for vegetation and soil fauna. It is expected that the plastic remains within the soil are still preventing evaporation of the soil moisture to some extent by disconnecting pores.

It is likely that the soil of a plastic covered field like HP20 is more resistant to both wind- and water erosion because of the better vegetation cover and aggregate stability, higher infiltration, and less soil loss. It is important that the plastic sheets are plowed through the soil during tillage. Leaving the polyethylene sheet undisturbed on the soil surface will lead to concentrated flow and may lead to extensive pipe and gully erosion.

Despite the soil quality improvement observed for the site where the plastic sheets have been incorporated in the soil by tillage, the visual pollution, and the wind transport of plastic from these fields to their surroundings however remain problematic.

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