Strategies to sustain productivity of olive groves on steep slopes in the northwest of the Syrian Arab Republic

ABSTRACT

In the marginal Mediterranean areas of the northwest of the Syrian Arab Republic, land degradation is a serious problem, particularly on vulnerable agricultural land. The traditional land-husbandry practices have not kept pace with the intensification and expansion of olive production into steeper areas. In these areas, soil erosion by water and tillage is widespread, especially where the soil is left bare as result of intensive clear-tillage and where no land-conservation measures are applied. These conditions are prevalent in the northwestern hills of the Syrian Arab Republic.

In 1997, a small research project was started in Yakhour, a typical olive-producing village in the area. The aim was to develop, test and refine options for better land management that have the potential to stabilize and increase the productivity of the olive groves. The research followed a farmer-participatory approach that involved a large part of the community for selection of options and conducting controlled on-farm experiments with farmer consultation. Socio-economic studies and a survey of the land-users' perceptions of land degradation and constraints for the adoption of land-conservation measures confirmed that the land users were aware of the serious degradation of their agricultural land. Rainfall simulation studies revealed the high erodibility of the soils in the area.

In association with the farmers, two different comprehensive packages of soil- and water-conservation measures were designed for the olive groves. One was an "agronomic package" designed to increase vegetation soil cover (by vetch intercropping), reduce soil disturbance (by minimizing tillage), and enhance soil structure (by incorporating organic materials) and short-term chemical soil fertility (by application of mineral nitrogen, phosphorus, and potassium). A second "structural package" was based on designing and building earthen, semi-lunar-shaped water-harvesting bunds. This package was applied in addition to the first package. Emphasis was placed on those soil- and land-management practices that reduce soil erosion and help restore soil fertility.

After five years, the conservation measures had led to a marked improvement in the soil in terms of fertility, organic carbon content, and structure stability, while soil

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and nutrient losses had been reduced. The improved soil parameters were associated with a marked increase in olive productivity of 25–75 percent. As a result of the close cooperation with the villagers, the suitability of the measures to reduce soil erosion was successful and vetch intercropping has expanded in the village.

INTRODUCTION

Agriculture in West Asia has evolved over 10 000 years in the area known as the Fertile Crescent (White, 1970; Watson, 1974). This agriculture has been based on cool-season winter rainfall (Cooper *et al*., 1987). Cereal predominates, with barley in the drier areas and wheat in less dry areas. Cultivation of olives in this region can be traced back 5 500 years (Olive Bureau, 2000). The olive is well adapted to the Mediterranean environment. It is a hardy tree that can grow on poor, shallow soils and will survive periods of low rainfall (Olive Bureau, 2001).

Since ancient times, the northwest part of the Syrian Arab Republic has been a major olive-growing area with olives and olive oil being fundamental elements in Syrian cooking. The oil is of high nutritional value, containing natural antioxidants that make it retain its fragrance and taste over long periods. For Syrian agriculture, in the west and northwest, olive trees are the major source of income for small-scale farmers. The area planted with olives has increased substantially in recent decades and now totals 71 million ha of olive trees (51 million ha of which are fruit bearing) with a total production of 866 000 tonnes in 2002 (Olive Bureau, 2000).

Olive production in the northwest of the Syrian Arab Republic has created many opportunities for local farmers, including the provision of an easy-to-manage cash crop, labour availability during harvest, and a tree that is tolerant to both drought and severe conditions. The main causes of land degradation in the area are a combination of natural, social and financial inputs. One important reason is that olive production has reduced the area and number of intensive traditional crops, so many farmers have started growing olives. Other factors leading to land degradation include the introduction of government policies that have encouraged olive production on marginal lands and the increase in demand (by farmers) for cash crops.

Mechanization in olive production commenced in the 1970s. One important outcome was the reduced need for animals (particularly mules) that had traditionally been used for ploughing. As a consequence, there is now less requirement for animal fodder, e.g. barley, lentil and vetch stubble. Since the advent of mechanization, the practice of tractors ploughing downhill has become the norm (for safety reasons), particularly on the steeper slopes where a top-heavy tractor is less surefooted than the traditional mule. This has radically increased land degradation, reducing soil depths from 1 m to 25 cm in places. Although tillage is still seen as necessary for conserving soil moisture and controlling weeds, the issue is to minimize any harmful effects of tillage while maintaining the beneficial effects.

The development of reduced or conservation tillage over the past few decades has demonstrated that soil organic matter (SOM) need not be reduced or physical properties degraded despite tillage (Zibilske, Bradford and Smart, 2002; Franzluebbers, 2002). Indeed, in many instances, reduced tillage has been shown to increase soil carbon, thus contributing to soil stability and to carbon sequestration (Curtin *et al*., 2000). Within reduced-tillage systems, the manipulation of cropping systems using appropriate land management can also enhance SOM (Whitbread, Blair and Lefroy, 2002) and, thus, improve soil quality, resilience and sustainability. It is becoming increasingly recognized that, particularly in dryland agro-ecosystems, increasing the level of SOM is critical as it impinges on the physical, chemical, and biological processes of the soil. In cultivated soils, a decline in SOM invariably leads to a decrease in soil porosity and related parameters and an increase in bulk density (Tisdall and Oades, 1983). Under rainfed conditions, a decline in SOM leads to decreases in surface infiltration and, through the profile, hydraulic conductivity, with subsequent increased runoff and erosion.

Tillage continues to be a major factor causing SOM loss (Rasmussen and Collins, 1991). The process of repeatedly inverting and pulverizing soil exposes SOM to aeration and, thus, mineralization (Cannell and Hawes, 1994). While the impact of tillage leads to reduced biological and biochemical activity, the main factor is associated with aggregate destruction (Doran, Elliott and Paustian, 1998). Only recently, have farmers on the steeper hillsides become conscious of their increasingly unstable and declining yields. They failed to identify degradation as a real problem, hence, they did not implement traditional terracing and other conservation techniques already established in other regions. Farmers did realize the extent of erosion, but claimed that the investments needed to conserve the soil were too costly. It became clear that land degradation could only be stopped by conservation systems that would not only be seen to enhance olive productivity but also increase income for the farmers.

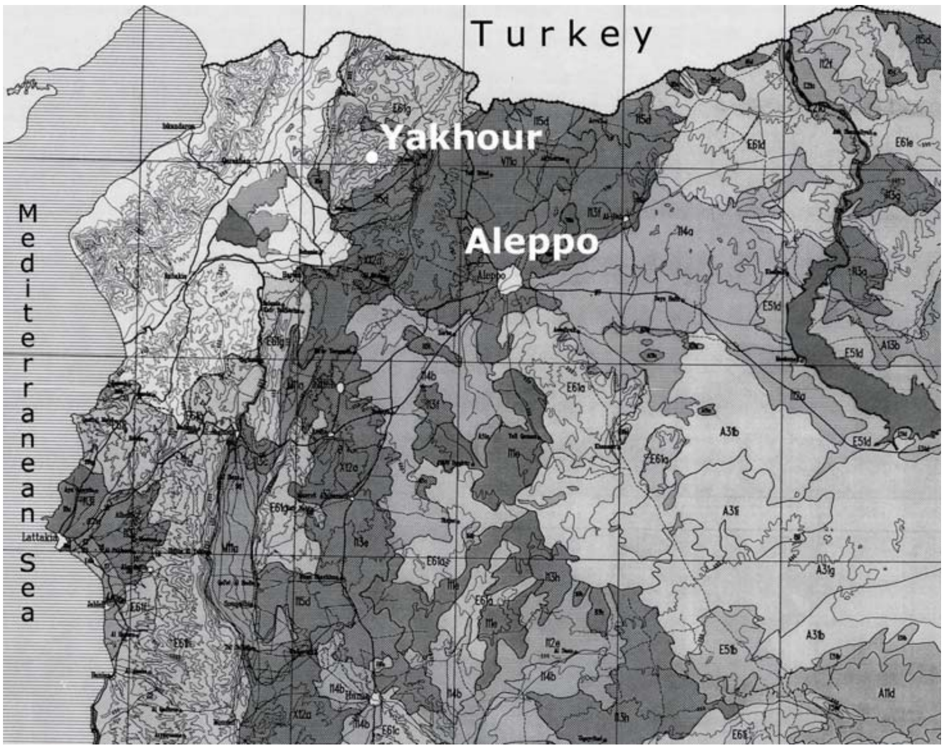
The objectives of this study are twofold: (i) evaluate (in association with farmers) different land-management options for protecting the hillsides in order to improve agricultural productivity, livelihoods and agro-ecosystems; and (ii) investigate the effect of applying these packages of land-management systems on soil fertility, soil structural stability, soil-water erosion, and soil and nutrient loss by water erosion.

MATERIALS AND METHODS

Study site

The study commenced in 1997, in the village of Yakhour in the northwest of the Syrian Arab Republic, close to Turkey, and about 125 km by car northwest of Aleppo (Figure 1). The area is typified by steep hillsides with flat divides and deeply incised

FIGURE 1
A portion of the FAO soil map of the northwest of the Syrian Arab Republic, showing the location of Yakhour village



valleys. The valleys are generally narrow, and in some sections, they are canyon-shaped. The topography tends to level out at the footslopes because of the accumulation of gravelly slopewash and talus deposits.

Climate and topography

The area has a Mediterranean-type climate, the altitude is about 500–700 m above sea level, and it receives an annual rainfall of 400–650 mm, concentrated between September and June. The mean annual temperature is 17 °C. The soil temperature regime is thermic and the moisture is xeric. The annual evaporation is about 1 200–1 600 mm.

Soils and vegetative cover

Entisols constitute the dominant soil order of the hillslopes, and the main soilscape units are lithic xerorothents and xerorochrept (Louis Berger International, 1982). The former are mainly medium-to fine-textured, mostly shallow soils of low and medium organic matter content, and the latter are well- to moderately drained, very shallow, light grey to dark greyish-brown, moderately fine-textured soils occupying the narrow summits and the upper slopes. The slopes in the two experimental sites range between 25 and 45 percent. In general, the soils are less than 30 cm thick, light grey to dark greyish-brown, and moderately fine-textured. The soils contain a few angular limestone fragments, which occupy approximately 10 percent of the solum. The limestone bedrock is found within 20 cm of the surface on the upper slopes.

The vegetative cover has been subjected to strong anthropogenic changes, including clearing of the native forest from about 1910 (De-Pauw, 2001). In the ensuing period, farmers have replaced native forest with olive groves, as well as almond, walnut and different forestry plantations.

Exploratory research

Socio-economic surveys in the olive-growing area of the northwest of the Syrian Arab Republic indicated that environmental concerns, such as soil erosion, were of low priority to the farmers. Their immediate interest was to secure and increase olive production with regular backstopping from the local team from the International Center for Agricultural Research in the Dry Areas (ICARDA).

Project design

Two farmers, deliberately chosen because they were not the acknowledged top growers in the village, each agreed to set aside an entire field for the experiments. Each field was divided into three sections, with 75 trees in each of the two research treatments and 50 trees in the farmer's own area. Each field was mapped intensively in 2001 and individual trees identified.

The details of the site management and the description of the structural and agronomic applied treatments in the different treatments (detailed in (Table 1), are summarized here:

- Site 1: Earthen semi-lunar waterharvesting bunds (akin to terraces) on a steep slope (40–45 percent). The main treatments were:
  - Treatment 1: terrace-like, no-tillage but with mineral and organic nutrient amendments through biannual sheep manure and annual fertilizer application,
  - Treatment 2: minimum tillage by Faddan (animal traction), two passes per year before planting and after harvesting the vetch,
  - Farmer practices: normal tillage by Faddan, 4–6 passes per year without any nutrient amendment;
- Site 2: Unterraced with moderate slope (24 percent). The main treatments were:
  - Treatment 1: two tillage passes with nutrient amendment through biannual manure and annual fertilizer application,

TABLE 1
Olive management comparisons by the ICARDA and Syrian Olive Bureau, Yakhour, the Syrian Arab Republic

	Site 1 - Terraced			Site 2 - Unterraced		
	Farmer Practice	**Treatment 1**	**Treatment 2**	**Farmer Practice**	**Treatment 1**	**Treatment 2**
Soil tillage (by mule across the slope)	Autumn, winter and spring	No tillage; small dam on lower side each tree	Autumn and spring across entire field; no dams or embankments round trees	Autumn, winter and spring	Autumn and spring only between trees	Autumn and spring across entire field
Cover crop	None	None	Vetch outside tree canopy; harrowed in April **	None	None	Vetch; ploughed in at spring tillage (April)
Fertilizer/ manure	None	Fertilizers* under canopy. Manure every 2 years on entire area	Fertilizer on entire area. No manure	None	Fertilizers* under canopy. Manure every 2 years on entire area	Fertilizer under tree canopy; no manure
Weed control	Soil tillage only	Herbicide when needed on basin area	No control; weeds grazed	Soil tillage only	Herbicide on untilled area as needed	Soil tillage only
Pest control	None	Insect traps (May/June); spray as needed	Insect traps (May/June); spray as needed	None	Insect traps (May/June); spray as needed	Insect traps (May/June); spray as needed
Pruning	Hard annual pruning	Light spring; summer cut unproductive branches	Light spring; summer cut unproductive branches	Hard annual pruning	Light spring; summer cut unproductive branches	Light spring; summer cut unproductive branches
Harvesting	By hand; no sticks; ground collection	Hand; no sticks; nets under trees	Hand; no sticks; nets under trees	By hand; no sticks; ground collection	Hand; no sticks; nets under trees	Hand; no sticks; nets under trees

Notes:
* Fertilizer application per tree, before the vegetative growth, according to Olive Bureau recommendation: mineral (annual): ammonium nitrate 33 percent – 1–2 kg of nitrogen at two rates in November and February, triple super phosphate 46 percent, and 1 kg of P_2O_5, potassium sulphate 50 percent – 1 kg of K_2SO_4; organic (biannual): sheep manure (30 kg/tree)
** Local variety, planted in November and harvested in April; 10 kg P_2O_5/1 000m^2 were applied to vetch before planting.

- Treatment 2: two tillage passes with nutrient amendment through a forage legume (vetch) with annual fertilizer application,
- Farmer practices: conventional tillage (4–6 ploughs) without any nutrient amendment.

Field sampling and laboratory analysis

All main plots (treatment) were sampled (0–20 cm) in April 2002 in the upper, middle, and lower parts of the plot in order to characterize the sites. Three combined soil samples were taken from each area of the plots, along the contour. Samples were then subdivided in two batches. The samples of the first batch were dried in the shade solely to lose excess moisture, but care was taken not to dry out the soil excessively. The first batch of soil samples was sieved through various mesh sizes (10, 5, 4, 2, 1, 0.5 and 0.1 mm) with minimum vibration for adequate fragment separation with minimal abrasion to determine dry-aggregate size distribution using a Retsch 3D series sieve shaker (Kemper and Rosenau, 1986). The results were calculated by geometric mean diameter (GMD) – the antilog of the sieve size at 50-percent passing.

Subsequently, proportional amounts of the dry-sieved aggregates were taken for wet-sieving, thus providing an index of macroaggregation. Fifty grams of soil sample were moistened slowly on filter paper placed on small dishes. After 30 minutes, the wet sieving process was conducted for 2 minutes with the sieves being shaken 100 times. The sieves were then removed from the tank and the aggregates taken from each sieve to measure the dry weight. Each test used four sieves of 2, 1, 0.5 and 0.2-mm mesh. The test was replicated three times for each soil sample.

Plate 1
The layout of the Gerlach troughs in the plots of the research site. Two Gerlach troughs, consisting of 2 m of collecting gutters, were dug into the soil at the bottom of slope position in each of the manure, vetch, and farmer-practice treatments

The second batch of soil samples was passed through a 2-mm sieve for the determination of water stable aggregates, hydraulic conductivity, and other soil physical and chemical measurements. Three replicates of 50 g of soil for each soil sample were wet sieved to provide the percentage of water stable aggregates, or microaggregation. Five replicates of each soil sample (each 500 g) were placed in plastic cylinders (80 mm in diameter and 120 mm tall) for determination of hydraulic conductivity, based on Klute (1986). The sieved soil was also used for determination of soil organic carbon (Walkley and Black, 1934), available phosphorus (Olsen-Bicarbonate method), total Kjeldahl nitrogen, inorganic calcium carbonate ($CaCO_3$) or calcium carbonate equivalent (CCE), and extractable potassium by the ammonium acetate exchangeable test (Ryan, Estefan and Rashid, 2001). The pH and electrical conductivity (pH_w and EC_w) were determined from a 1:1 (soil–water) suspension.

Water runoff, soil and nutrient loss were determined in simple unbounded plots, commonly referred to as "Gerlach troughs" (after their inventor). They consisted of a 2-m collecting gutter, dug into the soil surface and connected to five splitters likely to interfere to some extent with the flow conditions so there is a possibility of sediment being deposited within the system. One of them was extended to a 1-m^3 collecting container on the downstream side. The site homogeneity reduced the chance occurrence of minor depressions or rills and justified the sophistication in the construction of the gutters and containers, cost and construction, and reduced the number of replications to two unbounded plots for each treatment (Plate 1).

The unbounded plots were constructed in proper settings so that it was still possible to apply cultivation and other farm operations. Frequency of recording was based on accumulated rainfall erosive events in daily records that were aggregated into yearly totals. Respective samples were collected in one-litre or half-litre plastic flasks, being a mixture of water and suspended soil particles taken after stirring the mixture vigorously to avoid the settling of large soil particles and to keep the materials in suspension for estimating runoff and soil loss. Chemical and physical analyses were conducted to assess the nutrient loss, sludge and suspension texture and the runoff water quality.

Topographic survey

Topographic surveys were conducted in May 2002 and August 2003 on a 10-m grid within the catchment area of the two experimental sites. For Site 2, where the Gerlach troughs were mounted, the catchment was delineated and the slope length for two replicates of collecting gutters in each treatment was calculated and aligned with a 1-m sectional length (using SWAT 2000 for ArcView).

RESULTS

Measurements made in spring 2002 indicated that the application of sheep manure, incorporation of green manure (vetch intercropping) and chemical fertilization induced

TABLE 2
Average of soil physical parameters measured for different treatments in 2002

Location	Treatment	GMD[1]	Organic matter	Macro-aggregation[2]	Micro-aggregation[3]	Hydraulic conductivity
				(%)		(cm/h)
Site 1	Farmer	1.19	2.75	37.5	25.3	18.1
	Vetch	1.29	2.99	42.7	27.9	25.6
	Manure	1.33	4.38	47.8	32.9	35.2
Site 2	Farmer	0.85	2.90	37.5	25.8	17.7
	Vetch	1.10	3.32	40.3	27.0	24.3
	Manure	1.20	3.70	39.8	26.2	22.1
P (treatment)=		0.001	< 0.001	0.071	0.059	0.031
L.S.D. (treatments) =		0.11	0.48	5.4	3.2	7.65
L.S.D. (site) =		0.09	0.39	4.4	2.6	6.24
L.S.D. (treatments * site) =		0.15	0.68	7.6	4.6	10.82
C.V. (%) =		7.20	11.2	10.3	9.1	25.0

[1] Geometric mean diameter.
[2] Water-stable aggregate retained on 2-mm sieve.
[3] Water-stable aggregate retained on 0.2-mm sieve.

changes in SOM, and that these differences varied with imposed treatments (Tables 2 and 3).

In terms of the largest, water-stable aggregate size, sieved from the samples, the trends were consistent for the two sites and treatments. i.e. 47.8 and 42.7 percent with manure application and vetch in Site 1, and 39.8 and 40.3 in Site 2, and at each site reducing to 37.5 percent with farmer practice (Table 2).

Sieved microaggregate-size distribution generally agreed with the macroaggregation, with the greatest values for manure then vetch or green manure and the least being the farmer practices.

The lowest values for laboratory-measured hydraulic conductivity were observed with soil from the farmer practices in both sites, with the green manure treatments and sheep manure treatment in Site 2, together with the sheep manure treatment in the terrace site providing the greatest conductivities (Table 2).

Chemical analyses of the soil from the various treatments paralleled differences observed for the increases in SOM and related indices of soil structural and hydraulic properties (Table 3). Values of extractable potassium, available phosphorus, organic nitrogen and SOM increased greatly as a result of sheep manuring and less with vetch intercropping. The pattern for SOM content was similar for both sites being greatest in the sheep manure treatment (Table 3). With the sheep manure application in the terraced site, the increase was marginal (4.38 percent), and (3.73 percent) in the second site, and this remained the least in the farmer practice (2.75 and 2.9 percent) in both sites. The increase in SOM with the vetch intercropping in Site 2 was high (3.32 percent), but increased slightly in Site 1 (2.99 percent). Of concern were the changes in soil pH (Table 3), particularly the increased alkalinity in the manure and vetch intercropping treatments at both sites.

Measurements of water runoff and sediment yield (on the unterraced site) were calculated for four rainy seasons (2002–04). Data derived from accumulating rainfall erosive events during the whole rainy season (principally in 2003 and 2004) showed enormous water erosion (2 909 m^3/ha) combined with 58.3 tonnes/ha of sediment movement (loss) in the farmer treatment (Table 4). These quantities were reduced (to 1 653 m^3/ha and 1 297 tonnes/ha) with manure application and were the least with the vetch intercropping treatment (1 238 m^3/ha and 969 tonnes/ha). Moreover, analysis

TABLE 3
Average of soil chemical properties for the two sites with different treatments during 2002

Location	Treatment		pH	E.C.(1:1)	O.M.	$CaCO_3$	Olsen-P	Kjeld-N	NH_4-N	NO_3-N	Extr. K
			(1:1)	(dS/m)	(%)				(ppm)		
Site 1	Farmer	Upper part	8.4	0.26	2.88	50.8	17.7	1 297	4.9	14.2	77.1
		Middle part	8.5	0.24	2.77	50.8	24.9	1 241	5.2	15.4	89.1
		Lower part	8.3	0.26	2.59	50.8	19.9	1 174	4.4	13.9	71.4
	Vetch	Upper part	8.1	0.47	3.69	50.5	59.2	1 780	8.9	48.2	239.8
		Middle part	8.2	0.31	2.70	50.8	39.4	1 299	7.8	25.3	181.0
		Lower part	8.2	0.33	2.59	50.8	20.6	1 202	9.7	28.1	115.9
	Terraces or manure	Upper part	8.2	0.52	4.54	50.5	107.2	2 189	10.8	21.1	771.6
		Middle part	8.2	0.37	4.04	50.5	95.8	1 968	11.0	8.0	661.6
		Lower part	8.3	0.59	4.54	50.5	83.0	2 259	17.1	28.5	1 323.2
Site 2	Farmer	Upper part	8.2	0.29	2.59	50.8	11.1	1 145	6.0	15.8	55.9
		Middle part	8.3	0.27	2.98	50.8	17.2	1 376	8.5	13.9	102.0
		Lower part	8.5	0.21	3.12	50.8	16.7	1 346	5.8	13.2	89.1
	Vetch	Upper part	8.2	0.37	3.02	50.8	14.0	1 310	8.2	17.9	77.1
		Middle part	8.3	0.25	3.30	50.8	16.7	1 451	10.8	25.7	115.9
		Lower part	8.0	0.56	3.65	50.8	26.0	1 640	9.8	41.4	154.8
	Manure	Upper part	8.2	0.55	4.15	50.8	68.1	1 883	9.9	15.0	752.6
		Middle part	8.3	1.12	3.30	50.8	61.6	1 494	12.0	17.1	1 253.7
		Lower part	8.1	0.93	3.65	50.5	77.4	1 686	14.0	33.6	1 106.5
Site 1	Farmer		8.40	0.25	2.75	50.77	20.8	1 237	4.8	14.5	79
	Vetch		8.17	0.37	2.99	50.69	35.7	1 427	8.8	33.9	179
	Manure		8.23	0.49	4.38	50.53	95.3	2 139	13.0	19.2	917
Site 2	Farmer		8.33	0.26	2.90	50.77	15.0	1 289	6.8	14.3	82
	Vetch		8.17	0.39	3.32	50.77	18.9	1 476	9.6	28.3	116
	Manure		8.20	0.87	3.70	50.69	69.0	1 688	12.0	20.9	1 082
P (treatment) =			0.027	0.020	< 0.001	0.20	< 0.001	< 0.001	< 0.001	0.025	< 0.001
L.S.D. (treatments) =			0.14	0.21	0.48	0.11	14.1	243	2.3	11.4	234
L.S.D. (site) =			0.12	0.16	0.39	0.09	11.5	198	1.8	19.4	191
L.S.D. (treatments * site) =			0.20	0.29	0.68	0.15	19.9	0.343	3.3	16.2	391
C.V. (%) =			1.30	35.7	11.2	0.20	25.4	4.2	19.5	40.3	45.2

of the nutrient and organic matter contents of the sludge and suspended materials harvested with the different treatments in the unterraced site during 2002 and 2003 demonstrated the extent of nutrient loss with farmer practices (Table 5).

Discharged nutrient and organic matter of the sludge and suspended materials harvested with different treatments in the unterraced site during 2002 and 2003 are presented in Table 5. The SOM content of the detached materials in the farmer-practice treatments represents an increase (3.48 and 3.28 percent) versus 2.9 percent as assessed in the main soil (Tables 2 and 5). Values of organic matter in the discharge were less in the sheep manuring and vetch intercropping treatments which ranged between 3.2 and 3.6 percent compared with 3.3–3.7 percent of the treatment soil. It would appear that the discharge of organic nitrogen had the same trend as the organic matter redistribution.

TABLE 4

Water runoff and sediment yield per hectare of the subcatchment with different treatments during the 2000–04 rainy seasons

Season	Erosive events[1]	Treatment					
		Farmer (control)		Vetch		Manure	
		Water (m^3/ha)	Soil (tonnes/ha)	Water (m^3/ha)	Soil (tonnes/ha)	Water (m^3/ha)	Soil (tonnes/ha)
2000–01	5	507.8	11.9	37.9	0.2	166.7	3.1
2001–02	18	1 248.9	81	415.5	1.3	543.1	2.3
2002–03	35	2 693.3	15.1	969.1	4.7	1 297.2	6.5
2003–04	292[2]	2 908.9	58.3	1 237.7	14.1	1 652.5	32.7

[1] Daily records based on accumulating rainfall erosive events.

[2] Up to date (25 April 2004).

TABLE 5

Nutrient and organic matter of the discharged materials harvested with different treatments in the unterraced site during 2002 and 2003 seasons

Treatments	Season	O.M. (%)	$CaCO_3$ (%)	Kjel-N (ppm)	Olsen-P (ppm)	Extr. K (ppm)
Manure	2002	2.40	53.9	1 360	47.7	172.8
	2003	2.61	53.6	1 132	17.7	123.3
Vetch	2002	2.20	53.9	1 451	55.6	181.9
	2003	2.61	53.1	1 280	22.4	130.9
Farmer	2002	3.28	54.1	1 700	44.2	146.9
	2003	3.48	53.1	1 664	16.7	138.8

TABLE 6

Mean values of dissolved nutrients, cations, anions, pH_w, and EC in the runoff water, retained in the harvesting tanks for two runoff events in March and May 2002 for the different treatments

Treat.		pHw	E.C. (1:1)	K^+	Na^+	Ca^+	Mg^+	Cl^-	SO_4^{--}	HCO_3^-	CO_3^-	NH_4-N	NO_3-N
			(%)				(dS/m)				(ppm)		
Manure	Mar.	8.2	0.3	0.8	6.8	57.3	19.5	63.5	39.5	122.0	12.0	1.0	2.6
	May	7.8	0.5	7.3	180	50.4	4.0	71.7	146.6	106.8	6.0	1.1	11.9
Vetch	Mar.	8.1	0.3	1.5	6.8	59.9	11.3	64.8	27.2	109.8	15.0	1.4	2.9
	May	8.0	0.3	2.6	2.2	52.5	5.1	28.7	38.8	132.0	6.0	0.9	1.9
Farmer	Mar.	8.1	0.3	0.8	9.5	57.3	22.4	64.2	23.9	146.4	12.0	1.0	2.4
	May	8.0	0.3	2.7	2.2	50.4	9.2	30.2	50.3	112.9	6.0	0.6	5.0

The values of the other nutrients in the discharge such as available phosphorus and extractable potassium were not different from the initial soil values.

The dissolved nutrient quantities retained in the harvesting water tanks is evidently low (Table 6). However, these values as a proportion of the eroded soil cannot be explained in terms of the amounts of nutrient amendments added to the soil (Table 7), especially those removed from the farmer practices, being 2 029 kg/ha and 97 kg/ha of organic matter and organic nitrogen, respectively.

The total amount of nutrients removed from the sheep-manure treatment was 854 kg/ha of organic matter and 37 kg/ha of organic nitrogen. The lowest total nutrient loss was from the vetch intercropping treatment (Table 6).

TABLE 7

Comparative quantities of organic matter, organic and mineral nitrogen discharged as a result of soil losses and overland flows for different treatments during 2002 and 2003 seasons

Treatments		Soil discharge		Water discharge
		Organic matter	Organic nitrogen	Mineral nitrogen
		(kg/ha)		
Manure	2002	156.0	8.4	4.4
	2003	854.0	37.0	-
Vetch	2002	103.0	6.8	4.2
	2003	368.0	18.0	-
Farmer	2002	495.0	25.7	9.7
	2003	2 029.0	97.0	-

TABLE 8

Averages of soil texture for different treatments above the runoff gutters, with averages texture of sludge and suspended retained in the harvesting tanks

Particles	Clay	Silt	Very fine sand	Fine sand	Medium and coarse sand	Total sand
Fraction seizes	< 0.002 mm	0.002–0.05 mm	0.05–0.1 mm	0.1–0.200 mm	0.200–2.0 mm	0.05–2.0 mm
Treatments	**Catchment soil (%)**					
Manure	34.6	39.6	7.5	8.9	9.5	25.8
Vetch	35.0	40.0	7.6	8.7	8.7	24.9
Farmer	35.6	39.5	7.3	8.7	8.9	24.9
Sludge and suspension (%)						
Manure	32.1	46.3	7.9	4.6	9.0	21.6
Vetch	42.5	37.7	3.8	3.4	12.5	19.8
Farmer	45.0	38.0	3.4	3.1	10.4	17.0

FIGURE 2

Average production per tree of olive fruits for three different treatments in the unterraced site in three olive-bearing seasons, 1998–2002

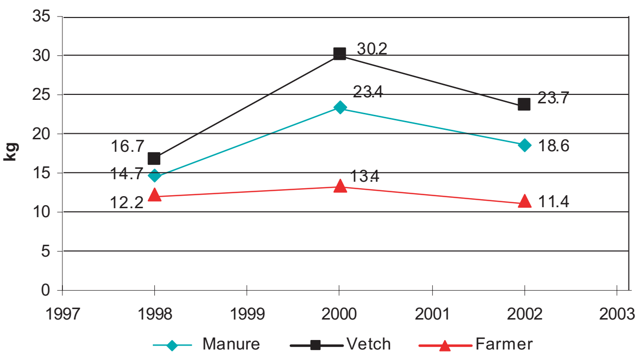


Plate 2

Olives harvested in November 2004 from the farmer, vetch and manure treatments. The olives from the manure and vetch treatments were larger in size and were earlier maturing than those from the farmer treatment

The texture of the detached soil is comparable with that of the initial soil textures determined (Table 8). Slight changes were depicted for the clay fractions and the lowest percentage existed with the manure application (32.1 percent), and a higher percentage reported with farmer practices (45 percent) while the detached clay of the vetch practices matched each of the sheep-manuring and farmer practices (42.5 percent).

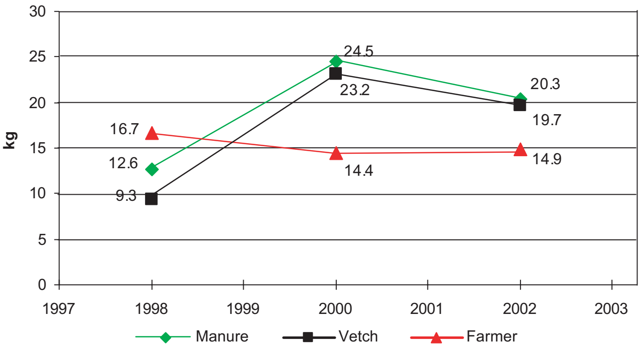
Increased olive productivity was the most pronounced output of the tested treatments. Marginal increases in olive production were reported in 2000 (Figures 2 and 3). In the vetch and sheep-manure treatments of the unterraced site, the increases ranged from 60 to 80 percent relative to the farmer practices in the unterraced site. However, the same treatments in the terraced site were 80–95 percent more than the farmer practices. In the terraced site, the increase in olive production exceeded 110–150 percent with the manure and vetch application. In 2002, the yield declined relative to 2000, but comparing the yield in the vetch intercropping and sheep-manure treatments in the unterraced site, the increases were still 27–42 percent more than the farmer practices. In the terraced site, the increases were 60–90 percent in the manure and vetch treatments. Olive quality was markedly better in the manure and vetch treatments with both having fruits that were larger in size and earlier maturing (Plate 2).

DISCUSSION

The GMD, macroaggregation and microaggregation indices correlated well with the changes in management practices, as tested in the Yakhour olive orchards and demonstrated improved soil physical conditions.

It was clear that the continuous farmer practices (from the time the olives were planted in the 1920s) had reduced soil quality, and thus diminished agricultural sustainability. The biennial application of sheep manure at a rate of 30 kg/tree (or 4.5 tonnes/ha) and an annual average of 4 tonnes/ha of green manuring of vetch biomass incorporated with the soil enhanced SOM.

FIGURE 3
Average production per tree of olive fruits for different treatments in the terraced site in three olive-bearing seasons, 1998–2002



The measured improvements in hydraulic conductivity, associated with growing legumes and with manure, leads to less runoff after the onset of autumn rains and better water-use efficiency as a result of improved water movement in the rootzone. Although the vetch was grown for only a limited period (November–April), the increased vegetative cover and established root system led to reduced overland flows and reduced quantities of soil and nutrient loss.

The increase in soil organic manure content helped to lower the soil pH slightly. In the alkaline conditions (pH > 8) prevailing on these slopes, organic derivatives and other locked-up nutrients such as phosphorus will become more readily available to boost yield if the pH can be lowered in the long-term, even by as little as half of a point.

The improved soil chemical and physical properties have been shown to induce positive changes in soil quality, as tested in the current range if management practices. Some may consider the changes small and slow. However, they have certainly improved olive productivity. The farmers' current land-management options will not succeed in protecting the land on hillsides and will certainly lead to reduced agricultural productivity. Improving olive productivity will increase the income of the farmers and, subsequently, will sustain livelihoods, the land and the environment.

Reduced cultivation in the new-style olive plantations is seen as a positive step in better land management. Tillage is seen as a main driver for land degradation in the Yakhour village, causing erosion to be omnipresent.

The reduction of soil tillage to two passes, in association with the planting of vetch and perhaps two applications of sheep manure (after harvesting and perhaps at the end of spring), will certainly lead to improved SOM levels.

The experimental treatments in this study are to be continued with new growers being encouraged to test the treatments under a wide range of management scenarios. Planning is underway to quantify soil loss, the soil being collected in natural vegetation strips (NVSs). More research is planned to evaluate the impact of traditional ploughing on sloping land, using mules that work along the contour.

By the beginning of 2004, another stage of farmer-participatory research on soil and water management with olive growers in the Yakhour area had already commenced. In this, both farmers and scientists are investigating, evaluating, and assessing the potential for adoption of the following technologies: NVSs, vetch intercropping, terracing, minimum tillage, and minimum pruning. This participatory research aims to improve the long-term sustainability of the soil and improve the productivity of olive production in the northwest of the Syrian Arab Republic.

CONCLUSIONS

As a result of the close cooperation and consultation with the villagers in the selected region, the suitability of introduced land-husbandry practices to reduce soil erosion and increase olive productivity has, apparently, been successful. In particular, the increase in vetch intercropping in the village can be cited as a success criterion. The trial of introduced management systems has indicated that legumes, sheep manure and chemical fertilization are potentially viable management options not only economically but also in terms of farmer acceptance and uptake as an alternative to farmer practices. Additionally, it has been demonstrated that the new practices have a positive effect on soil physical parameters and agricultural sustainability.

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Papers submitted to the seminar

Chemical and microbiological characterization of olive-mill waste-based substrata produced by the O.Mi.By.P. technology and their grounds amendment

ABSTRACT

An innovative technology for pomace and olive-mill wastewater recycling for agronomic goals was highlighted by the Oliveculture Section of the Institute for Agricultural and Forest Mediterranean Systems, National Research Council, Perugia, Italy, in the context of the European project Life Environment – Tecnologie Innovative per il Riciclaggio delle Sanse e delle Acque di Vegetazione (TIRSAV). Olive wastes without stones are mixed with appropriate hygroscopic organic wastes, producing a non-percolating and non-bad-smelling substratum, where aerobic microbial metabolisms occur. Substrata are packaged in net sacks, stored and amended on-site as requested by cultural conditions. In this work, two experimental storage systems were compared for physical, chemical and microbiological modifications: (i) outdoor stratification of net-sack substrata, protected against precipitation; and (ii) net-sack substrata piled inside a warmed greenhouse. In addition, different substrata were tested as amendment/fertilizer at a rate of 6 tonnes/year of dry matter per hectare in an intensive olive grove in comparison with a standard mineral fertilizing system, and vegetative and productive parameters were recorded over four years.

Important chemical changes occurred during the storage period: mass dehydration; increased pH and specific electric conductivity; and polyphenol degradation. Moreover, substrata presented an interesting content of plant nutrients, in particular potassium, nitrogen, calcium and microelements (magnesium, iron, manganese, zinc and copper). Micro-organisms in the raw olive-mill wastes had values in terms of colonies forming units (CFUs) of $9.4 \times 10^7 - 1.1 \times 10^8$ per gram of fresh weight, and were mainly yeasts. At milling, yeasts were the prevailing micro-organisms in the substrata, whereas during storage, both in the cold and warm conditions, bacteria seemed to become the most representative micro-organisms (1.8×10^8 CFUs), probably linked to the increase in pH, detected in the same substrata. Few moulds were present in the different storage conditions. Micro-organisms able to degrade aromatic compounds were also present at different times in the stored substrata. Vegetative and productive parameters, detected

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in the field experiment, showed no statistically significant differences between the standard mineral fertilizing system and olive-mill waste-based substrata amendments.

INTRODUCTION

Modern olive growing needs to consider the burden of disposing of olive-mill wastes in the form of wastewaters and virgin pomace (VP), the production of which, estimated on the basis of recent data from International Olive Oil Council (COI), is about 10 million tonnes in the European Union.

Olive-mill wastewaters (OMWWs) are composed of the physiological water of fruits (40–50 percent in weight), water added to facilitate oil extraction (traditional three-phase mills and three-phase water-saving mills) and of water used in cleaning processing plants.

OMWWs have a large content of pollutant and toxic compounds (D'Annibale *et al*., 1998). OMWWs contain macromolecules, such as polysaccharides, lipids and proteins, and a number of monocyclic and polymeric aromatic molecules generally referred to as phenolic compounds (Ronchero, Duran and Costante, 1974; Ehaliotis *et al*., 1999). Phenolic compounds are recalcitrant to biodegradation and partially responsible for the toxicity of OMWWs which is also due to lipidic compounds (Martirani *et al*., 1996). The toxicity of the OMWWs has been attributed to its phenolic constituents, which constitute from 1.5 to 8.0 g/litre (Di Goia *et al*., 2002). They inhibit seed germination and display phytotoxic effects caused by the phenolic substances and some organic acids, such as acetic and formic acids, which are often produced along with other microbial metabolites during storage (Capasso *et al*., 1995). Other important problems associated with OMWWs are their strong dark colour, which is mainly due to chromophoric lignin-related materials with different degrees of polymerization, and the emanation of a sharp characteristic odour (Sayadi, Zorgani and Ellouz, 1996). Micro-organisms have been exploited in different ways, both in aerobic and anaerobic conditions in order to decrease OMWW toxicity (Bertin *et al*., 2001; Andreozzi *et al*., 1998). A promising treatment technology is anaerobic biological digestion (Becarri, Majone and Torrisi, 1998) coupled with the aerobic treatment of OMWW phenolic compounds (Di Gioia *et al*., 2002; Borja *et al*., 1998).

The waste product VP is a solid by-product of olive-oil continuous extraction systems (decanter). In addition to water, it is composed of pulp residue, fragments of olive stones and small fractions of oil. This by-product is typically sent to pomace plants for further chemical oil extraction; a procedure responsible for negative impacts both on the environment, for the pollutant emissions, and the olive-oil market, for the very low olive-oil quality produced. New technology in the olive-oil extraction systems is represented by a two-phase continuous-extraction decanter that produces a better quality olive-oil associated with a moister virgin pomace (MVP). Pomace plants are disinclined to use MVP because of its large water content that hinders chemical residual-oil extraction. Hence, the problem of its disposal has arisen. Although controlled agronomic utilization of such by-products is allowed (Italian Law no. 574/96), handling problems do occur, such as percolation of the pomace during transportation and the emission of sharp bad odours during spreading after long periods of storage (Foppa Pedretti *et al*., 1997).

Given the above scenarios, the Oliveculture Section of the Institute for Agricultural and Forest Mediterranean Systems, National Research Council (ISAFoMCNR), has recently indicated a new technology (Altieri, Cultrera and Fontanazza, 2001; Altieri, Fontanazza and Cultrera, 2002) that facilitates the overcoming of difficulties in recycling raw olive-mill effluents for agronomic purposes. Research conducted in the context of the European project Life Environment – Tecnologie Innovative per il Riciclaggio delle Sanse e delle Acque di Vegetazione (TIRSAV) (TIRSAV, 2001) resulted in a process that provided capabilities of recycling all kinds of mill by-products (OMWWs, VP and

MVP) for land application. The process occurs at the milling level by mixing olive-mill by-products, without stones, with appropriate hygroscopic, natural organic wastes (straw, pruning residues, wool waste, and sawdust) to produce non-percolating and non-bad-smelling olive-mill waste-based substrata (OMWBS), packaged in net sacks, easy to transported, store on-site and manageable at district level.

In the current study, two experimental OMWBS storage systems were compared: (i) outdoor stratification of OMWBS net sacks, protected against precipitation; and (ii) OMWBS net sacks piled inside a warmed greenhouse, in order to study their physical, chemical and microbiological properties and modifications. Micro-organisms, bacteria, yeasts and moulds present in the cold and warm substrata were tested in terms of colonies forming units (CFUs) at different times during the storages, in order to detect those micro-organisms able to metabolize phenolic compounds present in the material obtained by using the olive-mill by-products processor (O.Mi.By.P.). In addition, different OMWBS were tested as to their efficacy as an amendment/fertilizer, applied annually on the ground in an intensive olive grove in comparison with a traditional mineral fertilizing system. For this purpose, vegetative (trunk diameter, and pruning-residue weight) and productive (yield) parameters were recorded over four years. In this context, soil organic matter (SOM) content was also monitored.

MATERIALS AND METHODS

Chemical characterization

The olive-mill wastes (OMWs) used in this experimentation came from a three-phase water-saving mill located in Valle dell'Angelo (Salerno, Italy). Different OMWBS, indicated as OMWBS (a), OMWBS (b) and OMWBS (c) were prepared by a O.Mi.By.P. prototype machine, as reported in Table 1.

Two different OMWBS storage systems were realized: (i) in outdoor conditions – the stratification on wood pallets of 30-kg OMWBS net sacks, protected against precipitation (cold storage); and (ii) 30-kg OMWBS net sacks piled inside a warmed greenhouse (warm storage). A temperature-data collector system was used in both storage systems.

The chemical characterization of raw materials and OMWBS was conducted according to standard analytical methods (DI.VA.P.R.A. 1992; Decreto Ministeriale, 1999; Singleton, Sullivan and Kramer, 1971)

Metal cations were determined using a Perkin-Elmer model AAnalyst 200 atomic absorption spectrometer equipped with deuterium-arc background correction. Air/acetylene flames were used as an atomization source. Measurements were performed using hollow cathode lamps (Perkin-Elmer) operated at 765.5 nm, with a current of 12 mA and a bandwidth of 0.7 nm for potassium; 285.2 nm, 25 mA and 0.7 nm, respectively, for magnesium; 422.7 nm, 25 mA and 0.7 nm respectively, for calcium; 589 nm, 12 mA and 0.2 nm, respectively, for sodium; 248.3 nm, 25 mA and 0.2 nm, respectively, for iron; 213.9 nm, 20 mA and 0.7 nm, respectively, for zinc; 279.5 nm, 30 mA and 0.2 nm, respectively, for manganese; and 324.8 nm, 10 mA and 0.7 nm, respectively, for copper. The spectrometer was controlled by AA WinLab 32 software. Background correction (AA-BG) was used for the elements detected at lower wavelengths (zinc, manganese, iron and copper), which could be more susceptible to interferences owing to molecular absorbance. The average and standard deviation of three absorption measurements were recorded for each sample.

TABLE 1
Composition of three experimental OMWBS, produced by O.Mi.By.P.

	Olive-mill wastes	Wool wastes	Straw	Sawdust
Substrata	(% weight)			
OMWBS (a)	72	5.0	11.5	11.5
OMWBS (b)	72	11.0	8.5	8.5
OMWBS (c)	72	0.0	14.0	14.0

Microbiological characterization

Sampling

Samples were collected from the different substrata, by respecting rules of asepsis, in sterile whirl packs (Nasco), maintained at 4 °C and immediately processed in the laboratory for microbial analyses.

Growth media

Growth of micro-organisms was tested on Sabouraud medium (Oxoid) containing 10 g of mycological peptone, 40 g of glucose, and 15 g of agar per litre of deionized water, at pH 5.6, and on Tryptic Soy (TSA) (Difco) medium containing 17 g of tryptone, 3 g of soytone, 2.5 g of dextrose, 5 g of sodium chloride, and 2.5 g of dipotassium phosphate per litre of deionized water, at pH 7.3. Media components were suspended in deionized water and warmed slightly to dissolve completely, then sterilized at 121–124 °C for 15 minutes.

Slurry preparation

Two grams from each sample, collected both from the cold and warm storages, were aseptically transferred in a 50-ml sterile tube (Falcon) containing 18 ml of sterile physiological solution (NaCl 0.9 percent) and stirred at 80 r.p.m. overnight at a temperature corresponding to storage conditions.

Serial dilutions and plating

One millilitre of suspension from each slurry was added to 9 ml of physiological solution until the dilution 10^{-5}, and 100 µl from the highest two dilutions were Figure d on Petri dishes containing the two different solid media described above. Figure s were then incubated at 28 °C for the sampling of the origin; at 28 and 37 °C for time zero and for the following sampling of the cold storage; at 37 or 52 °C for the warm one. CFUs were then counted after 48 hours of incubation, and reported per gram of fresh weight. All colonies on Figure s showing differences for colour, margin, shape and thickness were harvested and maintained at -80 °C in the presence of 30 percent of sterile glycerol.

Growth on caffeic acid

Enrichment cultures were conducted in a liquid mineral medium containing 0.4 g of NH_4Cl_2, 0.5 g of KH_2PO_4, 0.4 g of NaCl, 0.33 g of $MgCl_2{\times}6H_2O$, and 1 ml of trace element solution (20), in the presence of 2 g/litre of caffeic acid (Sigma) as the sole carbon and energy source. Cultures showing turbidity were observed by optical microscopy (Leitz, Diaplan) with an objective 100× and immersion oil. Cultures showing growth were maintained at -80 C in the presence of 30 percent of sterile glycerol.

Field experiment

A field experiment was conducted in an intensive olive grove (600 plants/ha) located in Doglio (Montecastello di Vibio, Perugia, Italy) at Casteldoglio Farm. Water deficiency was supplied by a drip irrigation system, and farm management provided natural permanent cover grass, periodically mowed and left on top the soil as an amendment. Doses of 6 tonnes (dry matter) per hectare of different OMWBS (a), (b) and (c) were applied to the ground in plots of 30 olive plants with three repetitions, after a three-month storage period. Plots without fertilizing and with standard mineral fertilization (180 kg of urea per hectare) were used as controls. Vegetative (trunk diameter measured at 30 cm from the ground and pruning-residue weight) and productive (yield) field data were collected from five randomly chosen pre-marked plants per plot.

Soil samples (0–20 cm depth) were collected annually from each plot and analysed to determine total organic carbon by the Springer-Klee method, expressed as organic matter (percent). Vegetative and production data were statistically analysed using the Student-Newman-Keuls test, performed by SAS.

RESULTS

Both cold- and warm-storage temperature monitoring was performed by two different data collector systems. OMWBS (b), OMWBS (c), and air temperature in the cold and warm storage conditions are reported in Figure 1 and Figure 2, respectively. Both storage systems showed OMWBS temperatures greater than air, particularly in the warm one, where OMWBS temperatures greater than 40 °C were detected during the first 15 days of the storage period. A faster decrease in OMWBS temperature was detected in the cold-storage conditions.

A chemical characterization of OMWs, wool waste (WW), straw, sawdust, stone and OMWBS, collected at production time, was performed and is reported in Table 2. OMWBS showed a water content of 63.5–67.3 percent, a pH of 5.4–5.6, EC of about 1.5 dS/m and a content of nitrogen and potassium of the ranged 1.07–1.96 percent and 2.31–2.61 percent, respectively. Moreover, some chemical parameters detected on OMWBS (b) and OMWBS (c) at different storages time, in cold and warm storage conditions, are reported in Table 3 and Table 4, respectively. Polyphenol degradation and pH increase were recorded in both storage conditions.

FIGURE 1

OMWBS (b), OMWBS (c) and air temperature recorded in warm storage condition

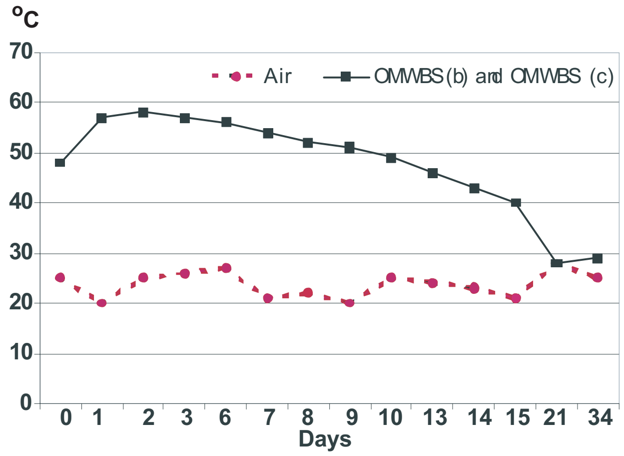
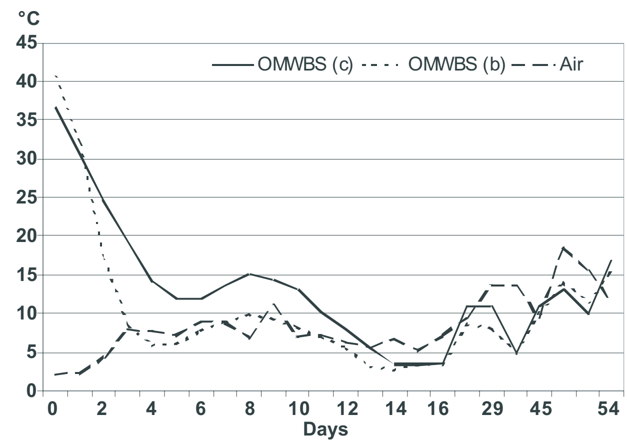


FIGURE 2

OMWBS (b), OMWBS (c) and air temperature recorded in cold storage condition



Micro-organism content was reported as CFUs per gram of fresh weight, and showed values of 9.4 × 10^7 and 8.7 × 10^7 in Sabouraud and TSA medium, respectively in OMWWs plus pomace, collected at the moment of olive milling. Among hygroscopic wastes organic materials, the values for CFU content per gram of fresh weight in Sabouraud and in TSA media of straw, sawdust and wool waste are given in Figure 3.

Samples collected at the moment of olive milling and Figure d on Sabouraud medium, showed total values of 2.5 × 10^8 CFUs × $(g)^{-1}$ for OMWBS (a); of 2.9 × 10^8 for OMWBS (b) and of 2.4 × 10^8 for OMWBS (c) (Figure 4). The same analyses conducted in TSA medium showed total CFUs × $(g)^{-1}$ of 2.6 × 10^8; 3.0 × 10^8; and 3.0 × 10^8 respectively in OMWBS (a), OMWBS (b), and OMWBS (c) (Figure 5). Values of CFUs × $(g)^{-1}$ of OMWW plus pomace, as well as values of CFUs × $(g)^{-1}$ of bacteria, yeasts, and moulds grown in Sabouraud and in TSA are reported in Figures 4 and 5, respectively.

At different times, samples from OMWBS (b) stored in cold conditions were collected, starting from the beginning of the storage, after 15 days and after 60 days,

TABLE 2
Chemical characterization of raw OMWs, wool waste and OMWBS

		OMWs	WW	Straw	Sawdust	Stone	OMWBS (a)	OMWBS (b)	OMWBS (c)
Moisture	%	76.39	14.60	32.50	17.10	26.20	64.10	67.29	63.47
pH		4.69	7.08	nd	6.70	5.31	5.50	5.66	5.41
EC	dS/m	1.19	1.20	nd	0.08	0.53	1.51	1.56	1.51
Dry matter base:									
Salinity	meq (100 g)$^{-1}$	63.12	17.56	nd	1.20	8.90	52.45	59.47	54.56
Ash	%	5.55	10.89	9.76	0.56	0.78	11.39	15.77	9.59
TOC	%	47.23	44.56	45.12	49.72	49.61	44.30	42.12	45.21
Nitrogen	%	0.76	5.24	0.34	0.15	nd	1.34	1.96	1.07
Carbon/Nitrogen		61.94	8.50	133	331	nd	33.13	21.53	42.19
Fat	%	3.73	nd	nd	nd	1.27	4.01	4.89	4.37
Phenols	%	2.60	nd	nd	nd	0.12	0.79	0.71	0.69
Potassium	%	2.10	1.38	1.25	0.06	0.24	2.31	2.61	2.40
Calcium	%	0.15	0.13	0.20	0.18	0.11	0.51	1.12	0.43
Magnesium	ppm	729	405	1 600	427	170	2 148	2 903	2 269
Sodium	ppm	104	515	890	13	36	605	722	445
Iron	ppm	200	706	170	77	88	2 239	3 809	1 891
Manganese	ppm	7	37	45	nd	4	59	88	46
Zinc	ppm	21	85	nd	nd	30	43	104	46
Copper	ppm	24	8	3	nd	25	15	28	21

nd = not detected.

TABLE 3
Chemical characteristics of OMWBS in cold storage condition

		OMWBS (b)			OMWBS (c)		
	Storage day	0	15	56	0	15	56
Moisture	%	67.28	64.68	64.04	65.47	64.34	63.28
pH		5.66	6.91	6.85	5.41	7.01	7.12
EC	dS/m	1.56	1.33	1.35	1.51	1.35	1.46
Salinity*	meq (100 g)$^{-1}$	59.46	47.02	46.94	54.55	47.20	49.68
Phenols*	% caffeic acid	0.71	0.22	0.27	0.69	0.28	0.15
Temperature	°C	40	3	11	37	3	10

* Quantities are referred to dry matter base.

TABLE 4
Chemical characteristics of OMWBS in warm storage condition

		OMWBS (b)			OMWBS (c)		
	Storage day	0	12	26	0	12	26
Moisture	%	62.58	40.02	23.76	76.83	60.25	68.54
pH		5.40	7.46	7.55	7.11	8.95	9.21
EC	dS/m	1.56	2.00	1.88	0.39	1.70	1.46
Salinity*	meq (100 g)$^{-1}$	52.17	41.69	30.87	21.28	53.38	56.24
Phenols*	% caffeic acid	0.70	0.35	0.20	0.60	0.10	0.09
Temperature	°C	58	50	29	47	50	29

* Quantities are referred to dry matter base.

showing values of 1.3×10^8, 3.9×10^8 and 2.4×10^8 of total CFUs × (g)$^{-1}$ respectively, in Sabouraud medium (Figure 6). Values of CFUs × (g)$^{-1}$ detected for bacteria, yeasts, and moulds are also reported in Figure 6. CFUs × (g)$^{-1}$ from the same samples were also detected in TSA medium, showing values of 8.6×10^7, 1.6×10^8, and 3.6×10^8 at the beginning of the storage, after 15 and 60 days respectively (Figure 7). Values of CFUs × (g)$^{-1}$ detected for bacteria, yeasts, and moulds are also reported in Figure 7.

Warm storage of the OMWBS (b) was checked in order to detect microbial content in Sabouraud medium at the beginning of the storage, after 12 and 28 days, showing values of 1.3×10^8; 3.2×10^8 and 5.2×10^8 of the total micro-organisms expressed as CFUs × (g)$^{-1}$ (Figure 8). Values of CFUs × (g)$^{-1}$ detected for bacteria, yeasts, and moulds are also reported in Figure 8. Growth of micro-organisms present in OMWBS (b) stored in warm condition were also checked in TSA medium and the CFUs × (g)$^{-1}$ showed values of 8.6 × 10^7, 1.6 × 10^8, and 3.6 × 10^8 at the respective sampling times (Figure 9). Values of CFUs × (g)$^{-1}$ detected for bacteria, yeasts, and moulds are also reported in Figure 9.

Enrichment cultures in mineral medium in the presence of 2 percent of caffeic acid as the sole carbon and energy source, conducted with samples collected from different substrata, at different temperatures, showed microbial growth at temperature incubation of both 28 and 37 °C (data not shown).

Table 5 reports data collected from the experimental field on vegetative and productive parameters. The data showed no differences in terms of cumulated 2000–03 yield between plots yearly amended with OMWBS and fertilized control, except the OMWBS (b) plot that showed, as expected, a greater yield (8 kg/plant) than unfertilized control plot (4.6 kg/plant). No statistical differences were detected for the vegetative parameters (cumulated 2001–04 pruning residues, weight, and trunk diameter). Table 6 shows the evolution in SOM detected on soil samples collected yearly from all experimental plots.

DISCUSSION

Both storage systems gave an increase in OMWBS temperature in the first days of storage owing to intensive aerobic microbiological activity, even though it was strongly reduced by the cold storage condition (lower air temperature). This was confirmed by a higher micro-organism content measured on OMWBS samples stored in the warm condition.

Different OMWBS showed a good content of macronutrients and micronutrients, particularly for OMWBS (b), rich in nitrogen (1.96 percent), potassium (2.61 percent),

FIGURE 3
Micro-organism content of OMWWs + pomace and hygroscopic organic additives, referred to fresh matter base

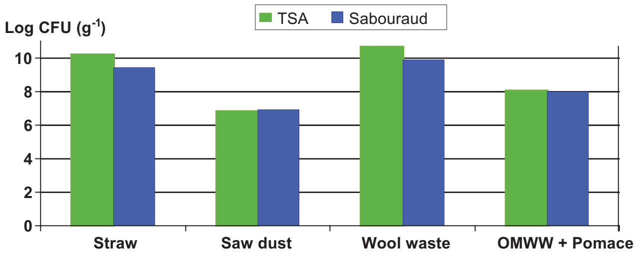


FIGURE 4
Micro-organism content of OMWWs + pomace and different OMWBS evaluated in Sabouraud medium, referred to fresh matter base

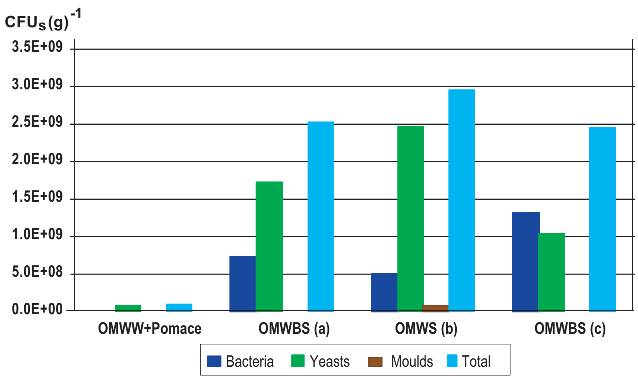


FIGURE 5
Micro-organism content of OMWWs + pomace and different OMWBS evaluated in TSA medium, referred to fresh matter base

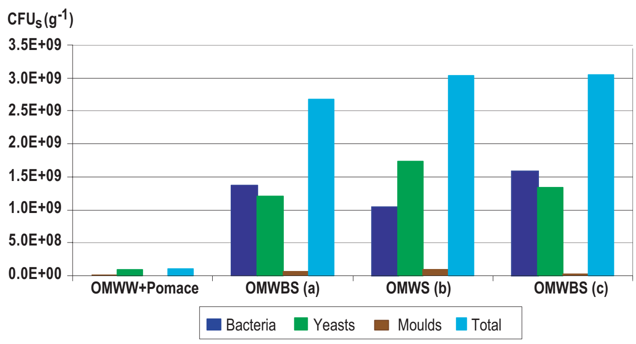


FIGURE 6
Micro-organism content evolution on OMWBS (b) in cold storage condition, evaluated in Sabouraud medium, referred to fresh matter base

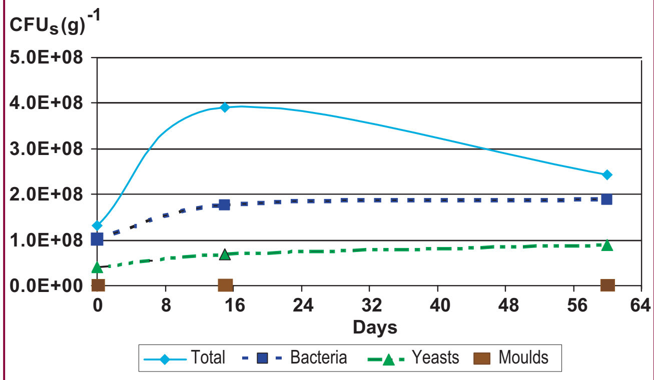


FIGURE 7
Micro-organism content evolution on OMWBS (b) in cold storage condition, evaluated in TSA medium, referred to fresh matter base

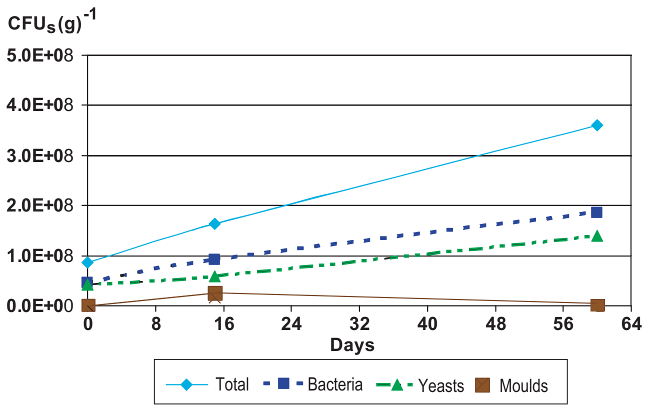
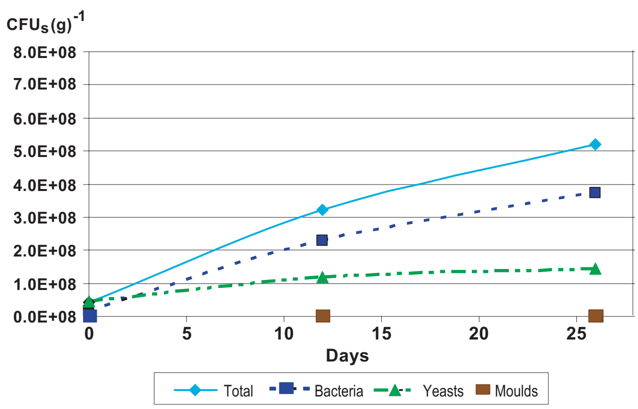


FIGURE 8
Micro-organism content evolution on OMWBS (b) in warm storage condition, evaluated in Sabouraud medium, referred to fresh matter base



magnesium (2 903 ppm) and iron (3 809 ppm. Moreover, OMWBS (b) showed a relative increase in pH during the storage period, changing from about 5.5 to about 7, and from 5.4 to 7.5, respectively, in cold and in warm storage conditions. The high pH detected in OMWBS (c) stored in the warm condition was unusual and was probably caused by to a pollution of raw OMWs by alkaline detergent used for cleaning the mill. This was also confirmed by the anomalous high sodium content detected in OMWBS (c) since its production (data not reported). OMWBS EC values ranged about 1.5 dS/m during all monitored periods; a value considered compatible with agronomic purposes.

OMWWs and sawdust showed a lower content of micro-organisms relative to straw and wool wastes, as expected, considering the origin of the different material. Yeasts were the most representative micro-organisms in OMWWs, as previously reported for yeasts isolated from olives (Nychas *et al.*, 2002), and they seemed to be persistent during the cold storage of the OMWBS (b) and OMWBS (c). This could suggest an active role of yeasts involved in the substrata changes and pH values or others changes. Micro-organisms present in the fruits are probably good inhabitants of the original material and they are well adapted to pH values, humidity, salinity, and, in general, to the original conditions. The fact that these micro-organisms are still present at different sampling times is probably the result of adaptation to the original material in terms of enzymes able to degrade substrata (Nychas *et al.*, 2002).

At the time of milling, differences in quantities of CFUs in OMWWs and those present in OMWBS (a), OMWBS (b) and OMWBS (c) were evident and showed the immediate growth of different micro-organisms pre-existent in the hygroscopic additives. Yeasts appeared to be the predominant micro-organisms, relative to bacteria. Yeasts are probably able to use different components of substrata as energy sources and they are present in high percentages. This is evident in Sabouraud medium for OMWBS (a) and OMWBS (b), 80 and 95 percent yeasts of the total CFUs respectively, and for the latter also in TSA medium, 60 percent of yeasts were detected.

An intensive metabolic activity of the substrata was detected, in particular during the initial phases, as revealed by high internal temperatures of substrata inside the greenhouse. Comparison of cold storing of OMWBS (b) in Sabouraud medium and in TSA medium higlights an increase from 1.3×10^8 to 2.4×10^8 and 5.2×10^8 of CFUs, mostly bacteria, whereas at the beginning yeasts were the predominant micro-organisms. Those changes in OMWBS (b) seem to be related to an increase in pH values, varying from 5.66 at the beginning, to pH 6.85 in cold, and 7.55 in warm storage. The prevalence of bacteria is evident in the warm storage samples Figure d on TSA medium, where the increase is from 4.6×10^7 to 4.0×10^8 CFU $\times$ $(g)^{-1}$ after 28 days of incubation, in accord with the increase in pH values.

Different enrichment cultures showed growth of micro-organisms, bacteria, yeasts and moulds using caffeic acids as the sole carbon and energy source, as previously reported (Álvarez-Rodríguez *et al.*, 2003). The fact that the activity of metabolism of this aromatic compound, typically present in OMWWs, is detected at different times of storages suggests an interesting microbial activity of the aromatic compounds, probably related to the changes in the composition of the substrata. On the other hand, microbiological activity was also detected in stored olive oil, where the ß-glucosidase from the yeasts *Saccharomyces cerevisiae* and *Candida wickerhamii* was responsible for the disappearance of the bitter taste owing to enzymatic hydrolysis of oleuropein (Ciafardini and Zullo, 2002).

Vegetative and productive data from the experimental field showed that OMWBS amendments can effectively surrogate a standard olive-grove mineral fertilizing system without compromising productivity and plant growth. Moreover, SOM content was enriched, with a maximum increase detected on OMWBS (b) plots (from 2.58 to 3.4 percent).

FIGURE 9
Micro-organism content evolution on OMWBS (b) in warm storage condition, evaluated in TSA medium, referred to fresh matter base

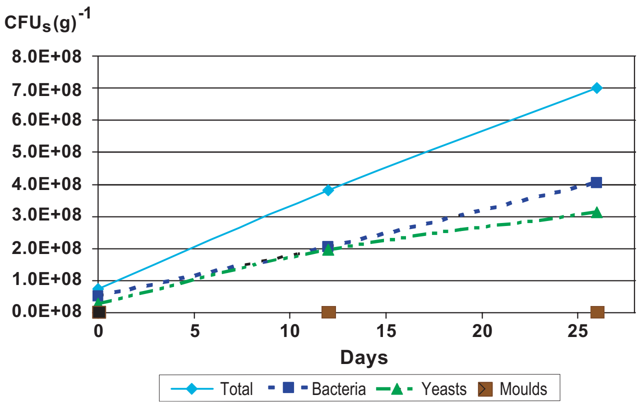


TABLE 5
Cumulated mean of vegetative and productive parameters measured amended annually with 6 tonnes/ha (dry matter) of different OMWBS, intensive olive-grove experiment

	Yield 2000–03	Pruning residues 2001–04	Trunk diameter 2004
	(kg/plant)		(cm)
OMWBS (a)	6.0ab	20.6a	10.9a
OMWBS (b)	8.0a	17.9a	10.1a
OMWBS (c)	5.3ab	18.0a	10.6a
Fertilized control	7.2ab	20.8a	10.8a
Unfertilized control	4.6b	17.4a	10.5a

Note: Data flanked by the same letters are not significantly different according to Student-Newman-Keuls test, for P = 0.05.

TABLE 6
Organic matter content detected on soils amended annually with 6 tonnes/ha (dry matter) of different OMWBS, intensive olive-grove experiment

	Soil organic matter (%)	
	2000	mean 2001-2004
OMWBS (a)	2.58*	2.92
OMWBS (b)		3.40
OMWBS (c)		2.94
Fertilized control		2.60
Unfertilized control		2.40

* Value referred to all plots at field experimental starting time.

Studies on degradation capability of substrata by micro-organisms are in progress, and microbial studies of amended grounds will be done in order to detect the impact of micro-organisms of substrata on the microbial population of grounds.

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