Importance of olive-oil production in Italy

INTRODUCTION

From a geographical point of view, the prime area of Italian olive production is located between 30 and 45 °N, which in general is the geographical distribution of suitable areas for olive-tree production in the northern hemisphere (Figure 1). In the Mediterranean area, Italy represents the central point of olive production because of its history and environmental conditions. As such, it can be considered as an open laboratory producing the latest and most advanced technologies able to support, for itself and for the world, the development of olive-production techniques and practices.

Olive species are considered to have originated in the Near East Mediterranean area (specifically Minor Asia, between Pamir and Turkstain). However, Italy (and in particular Sicily and Magna Grecia) can be considered the area of greatest economical importance. Olive production commenced in Italy in the VIII–VII century BC and gained considerable economic importance thanks to, first, the Phoenicians, and, later, the Greeks. At the same time, olive production developed along the coastal and subcoastal areas of the eastern Mediterranean Sea, including southern European and northern African countries, advancing later with the Romans to the northern areas of Italy, Spain, France and the Balkans (Figure 2) (Blázquez Martínez, 1996).

FIGURE 1

Geographical distribution of suitable areas for olive-tree production in the world

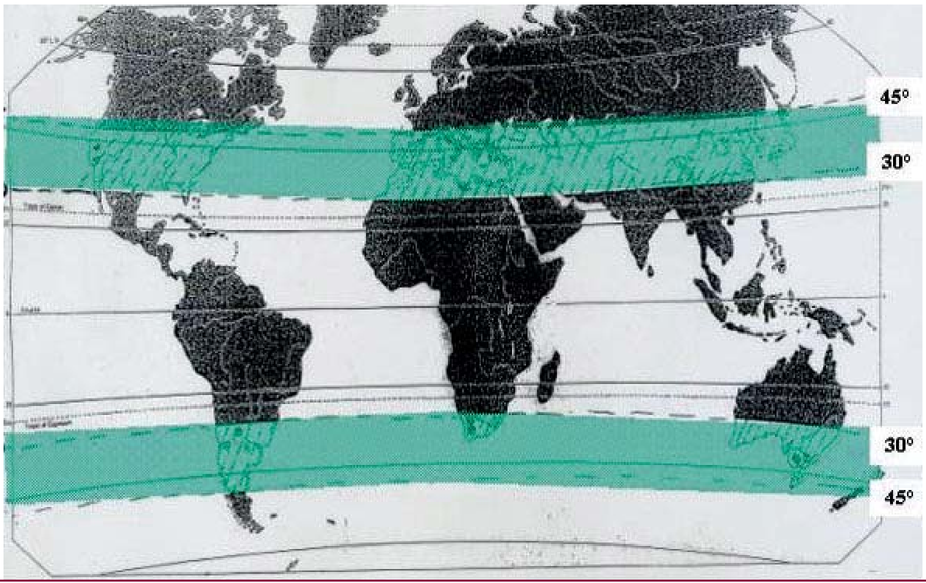

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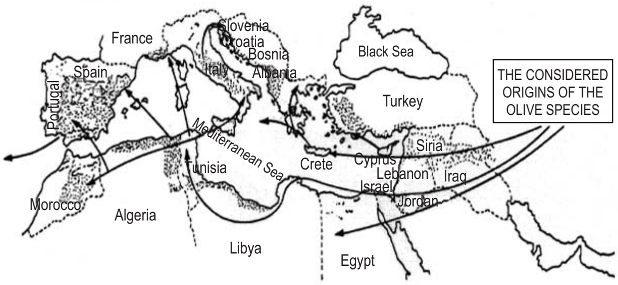
FIGURE 2

Evolution through the millenniums of olive-tree production in the Near East and the Mediterranean basin



OLIVE PRODUCTION: EXTENSION, CONSUMPTION AND EXPORTATION

Today, Italian olive production covers approximately 1 700 000 ha, 80 percent of which are located in southern Italy, where Puglia represents the most important region, with about 370 000 ha, followed by the Calabria (about 186 000 ha) and Sicily (about 160 000 ha). These three regions account for more than 60 percent of Italian olive production.

In the centre-north of Italy, the most important regions for olive-tree production are Tuscany (about 108 000 ha), Lazio (about 87 000 ha), Campania (about 81 000 ha), and Abruzzo (about 44 000 ha). The other Italian regions, except Piedmont and Valle d'Aosta that have no olive production, cover a relatively small area: Sardinia (about 39 000 ha), Basilicata (about 31 000 ha), Umbria (about 28 000 ha), and Liguria (about 14 000 ha).

In terms of olive-oil production, Italy ranks second in the world (after Spain), producing an average oil quantity over the last four years of 550 000 tonnes, mainly represented by extra-virgin and virgin olive oils.

In terms of olive yields, the Puglia region is the leader with about 250 000–300 000 tonnes of olive oil per year, although the region is characterized by alternate bearing. Calabria and Sicily follow with about 150 000 and 50 000 tonnes/year, respectively.

As regards olive-oil consumption, Italy is the world leader with a consumption of 650 000 tonnes, corresponding to about 12 kg per head of population.

Italy exports about 300 000 tonnes of olive oil per year. Therefore, taking into account the internal consumption and the amount of olive oil exported, Italy must necessarily import a large amount of oil, usually more than 500 000 tonnes/year. These imports are from other producer countries in the European Union (EU), such as Spain and Greece, and other countries, such as Tunisia and Turkey; countries characterized by production greater than their internal consumption.

Italian olive-oil exports are directed towards different countries, mainly the United States of America, Japan, Canada and Australia, where the oil imported from Italy has gained a strong position in recent years in comparison with oil imported from Spain, Greece and Tunisia.

It is important to note that national and international marketing in Italy is controlled by the national and multinational oil industries that use the traditional Italian trademarks.

Specific to the extra-virgin olive oils produced in Italy – characterized by different chemical and organoleptic properties, depending on environmental, genetic, agronomical and technological factors – special position must be given to the oils that are classified as Protected Denomination of Origin (DOP) and Protected Geographical Indication (IGP). There are 24 DOP from a variety of olive-producing regions and only 1 IGP in Tuscany (Table 1). Total annual production of both DOP and IGP olive oils is currently estimated at about 3 400 tonnes, 40 percent of which is represented by Tuscany IGP. The household consumption of DOP and IGP extra-virgin oils is about 600 tonnes/year. In terms of organic olive oil, the other product sector of extra-virgin oils, its production area is about 77 000 ha, mainly in Calabria, Puglia, Tuscany, Sicily, Sardinia and Campania. The production of such oil is estimated at 25 000 tonnes/year and household consumption is about 1 000 tonnes/year. The surplus DOP and IGP oil production is destined for export (Autori Vari, 2003).

GEOGRAPHICAL AND ENVIRONMENTAL DISTRIBUTION OF OLIVE PRODUCTION

Taking into account the climate needs of different olive species, it is possible to distinguish three different olive production macro areas in Italy where, because of climate, it is possible to record different olive performance. In relation to social factors and marketing organization, it is possible to observe different typologies within the three areas that correspond to the main geographic areas of the country: (i) southern and insular; (ii) central-southern; and (iii) central-northern.

The southern and insular area, as reported above, is the largest in terms of production area. The area includes Sicily, Sardinia, Calabria, Puglia and Basilicata, considered the warm climate subarea for olive cultivation. Some internal areas of Sicily, Sardinia, Calabria, Basilicata and the coastal area of Puglia are considered as medium climate areas (Figure 3).

In this first area, because of the favourable climate for olive production, it is possible to obtain high yields where plant-water needs are satisfied through irrigation.

In the past, large areas of southern Italy were characterized by low-quality olive oil. However, recent technological improvements both in the field and in extraction processes (Di Giovacchino, Sestili and Di Vincenzo, 2002) have led to a remarkable increase in olive-oil quality, particularly in the production of extra-virgin oils in Sicily, Sardinia, Puglia and Calabria.

In terms of marketing, oil from southern Italy achieves low values owing to poor marketing strategies. However, it is possible to observe successful marketing by some operators that reach high a standard in terms of oil quality.

The central-southern area includes lower Lazio, Abruzzo, Campania and

TABLE 1
List of Italian regions with EU-approved DOP and IGP

	Denomination	Typology	Region
1	Aprutino Pescarese	DOP	Abruzzo
2	Colline Teatine	DOP	Abruzzo
3	Bruzio	DOP	Calabria
4	Lametta	DOP	Calabria
5	Cilento	DOP	Campania
6	Colline Salernitane	DOP	Campania
7	Penisola Sorrentina	DOP	Campania
8	Brisighella	DOP	Emilia Romagna
9	Sabina	DOP	Lazio
10	Canino	DOP	Lazio
11	Riviera Ligure	DOP	Liguria
12	Laghi Lombardi	DOP	Lombardy
13	Collina di Brindisi	DOP	Puglia
14	Dauno	DOP	Puglia
15	Terra di Bari	DOP	Puglia
16	Terra d'Otranto	DOP	Puglia
17	Monti Iblei	DOP	Sicily
18	Valli Trapanasi	DOP	Sicily
19	Val di Mazara	DOP	Sicily
20	Chianti Classico	DOP	Tuscany
21	Terre di Siena	DOP	Tuscany
22	Umbria	DOP	Umbria
23	Veneto	DOP	Veneto
24	Garda	DOP	Veneto, Lombardy, Trentino A.A.
25	Toscano	IGP	Toscana

FIGURE 3
Distribution of olive-cultivation areas in Italy with reference to climate

Molise. It is considered the medium climate subarea for olive cultivation, except for some coastal areas in Campania, which are included in the warm subarea (Figure 3).

In general, the environmental conditions of this area ensure optimal productivity. Maximum yields are gained with supplemental irrigation, based on seasonal conditions and plant requirements. In terms of marketing, the full value of the product has not been achieved yet owing to a lack of concentration of product and adequate marketing strategies. In this area, fresh olive and oil marketing can be observed – better than in the northern areas of the country where the production tends to be low.

The northern area includes the central-northern olive-producing regions of Lazio, Marche, Umbria, Tuscany, Liguria, Emilia Romagna, Lombardy and Veneto. In general, the oil production in this area is much lower than in the other two areas. From the climate point of view, this area can be included in the cold subarea, except for the coastal areas of Liguria and south of Tuscany (Figure 3). Generally speaking, the environment is not suited to maximum productivity in terms of olive quantity and annual bearing. It is possible to observe recurring damage from cold weather, which can sometimes destroy flowering buds and, partially or totally, the canopy. The oil is generally of medium to high quality, depending on the local tradition of good-harvesting practices and oil-extraction processes, particularly in Tuscany, Umbria, northern Lazio, Liguria and Lake Garda.

The extra-virgin olive-oil quality of this extreme area of olive growing commands medium and high prices. However, olive growing in this region is not always profitable owing to the low productivity of the olive orchards and the high cost of production (Fontanazza, 1986; 2000).

ITALIAN OLIVE PRODUCTION: CONDITIONS AND PRODUCT QUALITY

The production of olives in Italy, in terms of agronomic scenarios, is quite complex. It is possible to consider the situation as a mosaic where the tesserae (the small tiles of the mosaic) are spread over a national surface, with necessary modifications for olive and olive-oil production in each different geographical area. Increasingly, national and international consumers are differentiating specific extra-virgin olive oils in relation to their specific region of origin. For example, some people speak about extra-virgin olive oil from “Chianti”, and other Italian or foreign consumers seek varietals of extra-virgin olive oils, specifying Tonda Iblea oil, or Frantoio oil rather than Casaliva or Taggiasca or Moraiolo oils. In these examples, the genetic origin of the product automatically links to the production area and, as a consequence to Sicily, Tuscany, Lake Garda, Liguria and Umbria, respectively.

As mentioned above, different Italian oils are typically correlated to the three areas of cultivation, to the climate subareas and even more to the different microclimate conditions. These differences relate more or less to the influences of the Adriatic, Tyrrhenian and Ionian Sea or to different soil formations that can modify the classification of the three macro areas. In order to better understand such concepts, it is sufficient to remember that in Calabria, Sicily, Puglia, and Sardinia olive trees can be grown on flat land, at sea level, up to 700–800 m above sea level (a.s.l.), in hilly sites. Moreover, the same varieties produce high-quality oils that can be different owing to differences in climate and seasonal weather, again linked to elevation.

In the pre-Apennine areas of central-north Italy, such as Umbria, Tuscany and Marche, the climate area suited for olive-tree cultivation is restricted to the zone from 200–250 m a.s.l. to 400–450 m a.s.l. In this environment, the nature of the oils produced is linked essentially to different genotype characteristics, their mix in the field, and how the oil blends are produced.

In the Lombard lakes area, and more precisely in the Garda and Iseo areas, there are specific environmental conditions that facilitate profitable olive growing. Central to this are the large dimensions of the lakes and the short growing season, and particularly the mild summer temperatures and the quite high rainfall in late summer and autumn. All of this, in combination with local varieties, produces an extra-virgin olive oil characterized by a medium–light fruity, scarcely pungent, sweet flavour.

ITALIAN OLIVE GERMPLASM

As mentioned in the introduction, the production of olives in Italy may be considered as an open laboratory with many different olive-growing systems, and a very large number of varieties from many different areas.

In spite of many past attempts to classify Italian germplasm, the full number of varieties grown in the different Italian olive areas remains unknown. The estimate is 250–300 varieties, grown over a wide variety of areas. However, in each olive-growing area there are normally main varieties, secondary ones, and sometimes ecotypes more or less represented.

In fact, in Italy, more than any other country, very few areas grow specific varieties alone. There are examples in the northern Bari Province (Puglia), where the Coratina variety is almost the only variety grown, or in the Belice Valley (Sicily), where 90 percent of olive plants are represented by the Nocellara del Belice variety.

Olive varieties can be distinguished in terms of their use in three different types: (i) table varieties; (ii) oil varieties; and (iii) double-purpose varieties. In Italy, table types include: Ascolana Tenera, Bella di Cerignola, Giarraffa and S. Agostino; oil types include: Frantoio, Leccino, Dritta, Coratina, Cerasuola and Bosana; and double-purpose types include: Moresca, Tonda Iblea, Nocellara Etnea, Nocellara del Belice, Itrana and Carolea (Jacoboni and Fontanazza, 1981).

In all Italian regions, oil production is prevalent. However, table-olive production is restricted to specific areas where the soils are fertile and there is a good plant-water supply. In Sicily, table-olive production occurs in the east, where they grow the variety Nocellara Etnea, and, in the west, where they grow Nocellara del Belice. In Puglia (Foggia Province), they grow the table variety Bella di Cerignola. In Calabria, the double-purpose variety Carolea is grown. In Sardinia, the double-purpose varieties Tonda di Cagliari and Nera di Gonnos are grown. An “oasis” of specific table-olive production occurs in Ferrandina (Basilicata), where they grow the double-purpose variety Maiatica. In the provinces of Latina and Rome (Lazio), the double-purpose variety Itrana is grown, while in Ascoli Piceno (Marche), the very ancient table variety Ascolana Tenera is cutivated.

THE TWO OLIVE-PRODUCTION TYPES IN ITALY

Considering environmental, social and economic situations, it is possible to distinguish, as is the case in other Mediterranean countries, two different types of olive-growing areas:

- ➢ marginal olive-growing areas;
- ➢ suitable olive-growing areas.

Both types are strictly linked to the evolution of olive-tree production through the centuries.

Marginal olive-growing areas

The marginalization of olive production in Italy is linked to geographical and climate considerations that make some areas less than ideal for olive production, even with modern technology. In some cases, these areas are suitable considering their climate and pedologic situation. However, steepness of slope leads to unprofitability because of the large amounts of labour required and quite low yields. Increased costs of labour and cultivation have caused these areas to become increasingly marginal, with some running the risk of abandonment.

This type of olive production, which must be most properly defined, is that of multipurpose olive production. In Italy, about 350 000 ha of olive production are concentrated in areas characterized by a high risk of environmental degradation. These areas are represented by: the coastal and internal hilly areas of Liguria, the Gargano promontory in Puglia, the Cilento territory in Campania, the Locride territory in Calabria and the territories of Nebrodi and Madonia in Sicily, and, in addition, the pre-Apennine territory from the towns of Assisi to Spoleto in Umbria and the upper part of Lake Garda.

Under these marginal conditions, olive groves are often cultivated under specialized production systems with dense plantations, e.g. as in Liguria and Umbria. Several stability factors have been introduced to protect the land from degradation. The olive trees are characterized by very wide and relatively superficial root systems (to prevent soil erosion and landslides). Careful consideration has also been given to the infrastructure connected with olive production, e.g. the design of terraces, and drainage systems. In addition, olive species in this territory reflect the ancient production systems with many centenarian olive plants. Such age and security characterize the landscape and represent a cultural patrimony, according to the modern concept of cultural heritage that is assigned to the natural landscape and, particularly, to the agrarian one created by people over the centuries.

Suitable olive production areas

These areas represent about 70 percent of Italian olive production, characterized by optimal climate and pedologic conditions. They are located mainly in the south of the country. The situation in the area suitable for olive cultivation is completely different from that of the marginal lands. Where water is available, then the soil and climate conditions are strongly favourable for olive production, with strong and wide impacts on the culture of the regions – agronomic, social and economic.

At present, olive production in the suitable area in Italy presents different kinds of groves with a predominance of old and sometimes very old plants of low efficiency. The plantations commonly have irregular distance between rows, and the plants are difficult to manage with modern techniques. As a consequence, production is low and spasmodic. There are some difficulties in controlling fruit quality, applying appropriate harvesting, and transporting olives at reasonable cost. In this situation, yield performance is quite low. There are also organizational problems in marketing, related to the changeable production year by year. This, of course, is in strong contrast to the suitability of the areas, which can achieve different production performances by using appropriate models of olive cultivation (Fontanazza, 2000).

TECHNOLOGICAL EVOLUTION OF OLIVE PRODUCTION IN ITALY

In the last 30 years, the technological evolution in Italy and in other advanced olive-producing countries such as Spain, Greece and Israel, has moved from traditional olive groves to new olive-production systems classifiable as two fundamental models: (i) medium-density plantation, adapted for mechanical harvesting using trunk shakers combined with umbrella or with nets put under trees to catch the fruits; and (ii) high-density plantation adapted for full mechanization and especially for continuous harvesting using straddle machines.

In both models, the selection of varieties is fundamental to achieving the appropriate shape of the canopy in order to obtain the maximum productivity and quality of oil and, of course, adaptation for full mechanization.

While in the medium-density plantation, traditional varieties may be used, either by choosing suitable ones or waiting for new, more appropriate varieties, in the high-density plantation the choice of the varieties is fundamental because they must be compatible with the straddle harvesting machines.

While the intensive model of olive production is largely widespread in the countries where olive production is well advanced and in the new olive-growing countries (Australia, Argentina, Chile, South Africa and the United States of America), the high-density plantation groves are currently in evolution mainly in Italy, Spain, Australia and Chile. Close inspection of this model should assist the development of a medium-high return to investment in the suitable areas, located above all in the flat areas or in gently sloping hill country.

As a consequence of the high cost of straddle harvesting machinery and its efficiency, this type of olive production must be planned on a large scale. Moreover, it is absolutely necessary to have appropriate varieties, genetically adapted to different environments. For this reason, considerable effort needs to be invested in genetic improvement. This is quite complicated in the case of olive species because of the lack of low vigour and dwarfing characteristics present in the traditional germplasm, while only a few new varieties with these characteristics are currently available (Fontanazza, 2002).

OLIVE PRODUCTION SUSTAINABILITY

Whatever olive production models are applied, sustainability of production must be pursued. This cultural condition, referred to as environment protection, must be combined with a medium to high productivity and high-quality production, obtained with costs that ensure an economic profit. In this regard, advanced olive-production systems (with genetic olive improvement), will guarantee the achieving of set goals, while the advanced olive-production models being applied at the moment envisage safe, environmentally aware and protective practices. Such practices include: appropriate soil management by judicious use of rippers in olive-grove plantations; ensuring a good amount of basic nutrients such as phosphorus and potassium; and also increasing organic matter levels to increase soil resiliency and reduce mineral fertilization. Associated with these practices, emphasis is also required on:

- appropriate choice of varieties in relation to environmental conditions, characterized by: tolerance/resistance to parasites;
- reduced and fractionated yearly ground nitrogen fertilization, in order to stimulate faster plant growth;
- localized irrigation systems with reduced water supplies related to real plant needs and to the biological plant cycle;
- appropriate soil management providing reduced superficial tillage at the beginning of olive plantation and subsequently providing a natural permanent cover grass, periodically mowed and left on top of the soil;
- recycling (by dropping on the soil surface) of pruning residues and olive-mill wastes, according to appropriate technologies (Altieri *et al.*, 2004) in order to reduce mineral fertilization.

If the above practices are implemented, modern olive-production systems can be considered ecologically compatible, and especially considering that the olive is an evergreen plant capable of surviving for very long time accumulating carbon as lignin in its woody structure. In addition, olive wood is combustible, so at the end of the production cycle, it can be used as an industrial product of high economic value. Each of these outcomes is readily achievable where olive groves are regulated by an economic cycle, with a 30–35 year production time, renewable through coppicing of the trunks and renovation of the canopy through basal suckers.

These are the types of continuing evolutions that Italian olive production is slowly and steadily achieving. However, it must be emphasized that because of the lack of political inputs, the olive-production system risks remaining immobilized, also as a consequence of EU economic integration of farm profits with, as has been observed in Italy, a low input in terms of innovations. On the other hand, in Spain for example, national politics and EU financial support have stimulated a strong renovation of olive groves with an estimated 600 000 ha of new plantations. In part, these are substitutions of old orchards and, in part, new olive-growing areas in the south and north of Spain. Moreover, the other EU olive-growing countries, such as Greece, Portugal and France, have introduced major innovations in olive production.

There are valid examples of new plantations in Italy, in almost all olive-producing regions. In these, clear results are evident, demonstrating the validity of technological innovation in olive production, especially where the new plantations are realized with full mechanization (pruning and harvesting included).

The economic validity of technological innovations in olive growing, based on the criteria of intensive fully mechanized cultivation, can be seen in the "new" non-Mediterranean olive-growing countries of Argentina, Australia, Chile, Mexico, New Zealand, South Africa and the United States of America. Rapid development in the last ten years has been based firmly on fully mechanized, intensive olive-grove models in combination with the use of innovative, continuous oil-extraction technologies based on the decanter principle. All of these achieve large reductions in labour and energy needs and costs, while ensuring the production of high-quality olive oil (Uceda-Ojeda, Hermoso-Fernàndez and Gonzàlez-Delgado, 1994). Such technologies in the production and transformation sectors come mostly from Italy (Fontanazza and Cipriani, 2004).

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The role and importance of integrated soil and water management for orchard development

INTRODUCTION

Successful orchard production and mitigation of land degradation begins with what local farmers and local communities do on the ground. It requires the adoption of technologies, interventions and policies that address the social, environmental and economic dimensions of the problem in an integrated way.

Farmer associations, including women, and other stakeholders must be involved on the ground, but also at all higher levels of intervention, including the creation of an enabling policy and regulatory framework, as well as financial packages to promote the programmes. Integrated soil and water management has to be scientifically sound in order to ensure credibility in the conservation and policy community. It also has to be viable economically in order to ensure farmer adoption and continued sustainability of the interventions, including reducing conflict between farmers and livestock keepers over natural resources.

Integrated soil and water management is essential to enhancing soil quality, sustaining and improving food production, maintaining clean water, and reducing increases in atmospheric carbon dioxide (CO_2). Vineyard and olive-orchard yields are linked closely to soil productivity, which in turn is strongly dependent on the management provided. The following factors need to be in optimized for good soil condition, and thus optimal plant growth: water infiltration and retention capacity; soil density; soil porosity; soil structure; and soil health (biological factors).

Soil improvement will be linked with associated activities such as water harvesting, soil and water conservation measures, enhancement of on-farm biodiversity and ecosystem functioning, and access to improved vineyards and olive-tree varieties within a farming systems context. These may be integrated with land-management practices outside farm plots in order to improve watershed functions, share resources equitably and preserve habitat for wildlife (as well as protection for farmers from wildlife in areas adjacent to nature reserves).

This strategy in the Mediterranean region will require the training of large numbers of local people to serve as extensionists in their communities, and to facilitate farmers' access to specialized technical information, research findings and experience under similar conditions, and technical knowledge in other communities. Training could also include additional topics on nutrition, health, and group development.

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SOILS

Soils in good health, well structured and with good levels of organic matter, show an active chemical and biological process maximizing aggregation of particles, increasing soil stability and favouring the release and uptake of mineral elements and water.

The soil physical properties are important to maintaining the productivity of the land. The degradation of these properties has considerable effects on plant growth, yield and the quality of olive-tree and vineyard fruits regardless of the nutritional state of the soil.

The restoration of degraded soil physical properties takes considerable time and cost. At the same time, physical degradation can increase the risk of water or wind soil erosion with consequent impact on society. Consider the many, recent media stories on flooding and landslides, inundating towns and cutting roads, linked to the denudation of hillslopes. Indeed, safeguarding the soil resource for future generations is the main task of land managers.

In general, for good tree-crop growth, the soil needs to be loose, with good aggregation to facilitate the circulation of air, water and nutrients and the penetration of roots. Plants that grow in this type of soil spend less energy forcing their roots into the soil and extracting water held at high suctions. Water is needed for germination of the seeds as well as for crop growth. Soil-water retention depends on soil type and its management.

Strongly degraded soils with reduced and non-interconnected porosity, and reduced levels of organic matter, do not have the capacity to store as much water as they should, and thus have less water available for crop growth. In arid regions, with low rainfall, soil moisture is of vital importance. In general, tillage activities have a negative effect on soil water, as cultivation tends to not only cause soil compaction, so reducing plant-available water supplies, but also by turning the soil, stored water is lost through evaporation.

Soil-structure degradation, often called soil compaction, is regarded as the most serious form of land degradation caused by conventional farming practices (McGarry, 2001). Paradoxically, of all types of land degradation, soil-structure degradation is reversible and its occurrence preventable or at least controllable.

The main causes of soil-structure degradation are the effects of agricultural tyres and implements, particularly working in moist-to-wet soil conditions when the soil is most vulnerable to deformation (McGarry, 2003). There is maximum potential for soil compaction in conventional cropping systems because most crops are cultivated in moist soil. This is usually to kill weeds or prepare seedbeds. At both times, there is a strong risk of soil compaction as the moist soil is in a weak and degradable condition.

In mechanized orchard-production systems, the continual use of tillage implements, especially disc ploughs, disc harrows, mould-board ploughs and rotovators, over long periods of time frequently results in the formation of dense plough pans containing few pores large enough to be penetrated by crop roots. The plough pans develop just below the depth to which the soil is tilled and often have smooth upper surfaces with sealed pores, caused by the smearing action of mould-board ploughs. The degree of compaction depends on the pressure exerted by the implements on the soil and the soil-moisture content at the time.

RAINWATER-USE EFFICIENCY

Another significant cause of reduced production levels and, at times, crop failure for vines and olive trees in the Mediterranean region is low and erratic rainfall. However, in many areas, crop- and land-management practices are not designed to optimize water flow into, and its retention within, the rootzone of the crop. Thus, poor yields are related to an insufficiency of soil moisture rather than to an insufficiency of rainfall.

Tropical and subtropical rainfed agriculture depends on an adequate supply of water in the rootzone of the soil. It has been estimated that soil water is the limitation to crop production in approximately three-quarters of the world's arable soils and is the main factor responsible for low yields in the seasonally dry and semi-arid tropics and subtropics.

The rainfall that infiltrates into the soil forms part of the soil water, of which some may be used by plants for transpiration, some may return to the atmosphere through evaporation from the soil surface, and some – where sufficient infiltration occurs – may move beyond the rootzone to the groundwater.

Rainwater that runs off the land moves downhill towards river courses, contributing to peak flows, and is of great concern. Runoff is not only a waste of rainfall that could have contributed to crop production and groundwater supplies, but it frequently causes floods or damage to roads and farmland, and erodes soil that is redeposited in river courses and reservoirs downstream.

Increased infiltration and retention of soil moisture in the rootzone will result in:

- ➢ improved yields, through maximized rainfall utilization;
- ➢ groundwater recharge – thus securing the water level in wells and the continuity of river and stream flows;
- ➢ reduced risk of yield losses through drought.

PROTECTING THE GROUND AND PROMOTING BIOLOGICAL ACTIVITY

Cover crops have direct and indirect effects on soil properties, particularly on their capacity to promote an increased biodiversity in the agro-ecosystem.

Cover crops are grown during fallow periods, between the harvesting and planting of commercial crops, utilizing available moisture in the soil. Their growth is interrupted either before the next crop is sown, or after sowing the next crop, but before competition between the two crops begins. Cover crops energize crop production, but they also present some challenges.

A living or dead vegetative soil cover absorbs most of the energy of the raindrops that fall on it and by the time this rainwater reaches the soil below, its ability to disintegrate soil aggregates and detach fine particles is greatly reduced. Consequently, where stubble is retained or cover crops grown, there is little or no clogging of surface soil pores by detached particles, and little deposition of soil particles that would form a crust on the surface.

The physical contacts between a cover and the soil surface obstruct the movement of the runoff, slowing it down, giving more time for infiltration and so reducing the volume of runoff. Thus, two aspects of surface cover can be distinguished:

- ➢ all surface cover absorbs the energy of raindrops and so prevents the loss of pore spaces into which rainwater can infiltrate;
- ➢ contact cover slows down any runoff, giving more time for infiltration.

The degree of contact cover is especially important on steep slopes, on soils with naturally low infiltration rates, and on degraded soils with surface crusts or seals of low porosity. The conservation effects of forests stem not so much from the presence of the trees themselves but from the litter of fallen leaves, twigs and branches, plus any low-growing vegetation. Where the soil surface has not been damaged by trampling, less rainwater will run off and more will infiltrate into the soil.

Furthermore, it is the contact cover that is immediately accessible to soil macro-organisms and can stimulate their activity. Thus, greater numbers of biopores are likely to be formed in association with cover crops, leading to more rapid water infiltration and movement within the soil.

This is why the removal of vegetative cover from the soil and major disturbances, such as tillage or the incorporation of residues, mulches or other organic matter, drastically reduces these positive effects, leaving the bare soil vulnerable to the impact of raindrops, and the consequent runoff and erosion.

SOIL AND WATER MANAGEMENT IN VINEYARDS

Integrated soil and water management plays a key role in achieving long-term sustainable and profitable vineyard production, which safeguards the environment and ensures a high-quality product. Recent experiments have shown that appropriate soil and water management reduces excessive use of external inputs, protecting soil structure, porosity and quality for crop yield and resulting in improved soil fertility. The nutritional status of a vineyard can have a strong influence on the chemical and organoleptic characteristics of wine.

In contrast, conventional soil management in vineyards has a negative effect on the environment. Indeed it promotes contamination with chemical residues, alters microflora and microfauna by reducing both the number of species and their biomass, reduces organic matter content and promotes soil compaction. Continuous tillage using conventional cultivation techniques can give rise to a loss of organic matter and, as a result, can substantially reduce soil fertility and the ability of the soil to supply nutrients. Large amounts of fertilizer are needed to compensate for the loss of these nutrients and the quality of the final product can be scarce with consequent reduced income. Greater quantities of chemicals are also needed because of severe disease attacks in vineyards managed with soil tillage.

Soil compaction, poor aeration and gaseous exchange rates limit the movement and storage of water, reduce organic matter cycling, restrict root growth (reduce soil depth), and reduce fertilizer efficiencies (either plant roots cannot reach the fertilizer or the applied nutrients remain locked-up in the compacted soil because of reduced soil water dynamics). The result is weak plant growth and a lack of vigour.

Matching soil conditions with plant indicators

Good root penetration is needed for adequate water uptake. It can be limited by soil compaction, increased mechanical resistance, and reduced and non-interconnected soil aeration. Furthermore, increased mechanical resistance limits plant uptake of nutrients, greatly reduces fertilizer efficiencies and increases the susceptibility of the plant to root diseases. Thus, soil conditions, moisture availability and cultural practices play a key role in determining root growth.

Shoot length, number of buds and plant health are influenced by the physical-chemical fertility of soil. For example, leaf colour is related strictly to water and nutrient availability and especially to nitrogen content — the better the soil fertility, the greener the leaf. The number of flowers is related to soil physical status; its intensity depends on energy and plant-available carbohydrates, which relate in part to soil fertility (physical, chemical and microbiological). Shoot length is an expression of plant vigour and general plant growth, which are regulated by nutrient and water availability. Moreover, although flower development at budding is influenced in part by climate conditions and the amount of stored reserves, it depends considerably on soil conditions and root functionality.

Diseases, especially Botrytis bunch rot, which is caused by the fungus *Botrytis cinerea,* can cause serious losses on susceptible grape varieties. Berries of white cultivars become brown and dried-up, and those of purple cultivars develop a reddish colour. Under high relative humidity and moisture, infected berries usually become covered with a grey growth of fungus mycelium. Disease attack seems to be more common in vineyards managed with soil tillage rather than in those with permanent cover crops. Indeed soil health in vineyards is also related to microbial populations capable of suppressing soil-borne disease. Microbes that live in the plant rhizosphere, the surrounding soil influenced directly by the root, can contribute to soil-disease suppressiveness, reducing the effect of many soil-borne diseases.

Disease control by rhizosphere microbial communities has also been shown to extend to systemic and foliar diseases through the activation of the chemical and physical defence mechanisms of the plant. Soil-disease suppressiveness may be induced by cultural practices that increase soil organic matter (SOM), increasing the biodiversity of the soil and the competitive ability of the indigenous microbial community on the root. Continuous plant covers such as permanent swards increase SOM, leading to improved soil microbial activity and biodiversity.

The effects of cover crops in vineyards

Cover cropping not only aids in reducing soil erosion and water runoff, but also in suppressing soil-borne disease by: increasing the micro-organism biodiversity; improving soil physical characteristics and particle aggregation; enriching the organic matter content; and reducing inorganic fertilization and root mortality.

One of the limiting factors of cover crops in vineyards is the competition for minerals and water availability where the management is inadequate. These phenomena determine deep modifications of the nitrogen content of the wine with effects on the alcoholic fermentation. To solve this problem, different mixes of cover crops, including leguminous species that supply nitrogen, should be evaluated in different areas.

To reduce competition, cover crops or natural weeds can be controlled by herbicide application or by cutting 2–3 times during the period of major nutrient scarcity.

Production costs of vineyards

Continuous tillage using conventional cultivation techniques can give rise to a loss of organic matter and, as a result, can substantially reduce soil fertility and the ability of the soil to supply nutrients. Large amounts of fertilizer are needed to compensate for the loss of these nutrients, and the quality of the final product can be scarce with consequent lower income. Greater amounts of chemicals are also needed because of severe disease attack in vineyards managed with soil tillage.

SOIL AND WATER MANAGEMENT IN OLIVE ORCHARDS

High-yielding olive trees develop buds of optimal length, promote flowerbud induction, give a good percentage of fruiting, and stimulate fruit development. Hence, maintaining good availability of water, nutrients and carbohydrates during the crop cycle is essential to avoid any shortfall in bud formation.

Good soil-management practices are needed to improve olive growth and productivity by providing adequate nutrients and water to the plant. The soil has to maintain a good structure, allowing roots to explore a constant volume. The soil should be well aerated, with regulated ratios of water and soil water; not too much water to induce erosion and waterlogging, and not too little to safeguard the olive-tree functionality, especially during the crucial periods of plant development and fructification.

Matching soil conditions with plant indicators

Although many plant indicators depend on climate factors and the cultivar and agronomic practices, there are a number of soil conditions that influence canopy volume and trunk perimeter at the flowering stage that can be useful visual indicators of soil quality. Indeed, poor soil aeration and gaseous exchange rates, limited movement and storage of water, and erosion as a result of structural degradation reduce plant growth and vigour. It is particularly useful where climate factors (frost damage) have not limited crop development. Poor soil aeration and resistance to root penetration as a result of structural degradation reduce plant growth and vigour.

Plant vigour influences root development considerably. However, soil conditions and cultivation practices play a key role in determining root growth. Furthermore, increased mechanical resistance limits plant uptake of nutrients, greatly reduces fertilizer efficiencies, and increases the susceptibility of the plant to root diseases. Compaction and consolidation of the soil at rootzone level increase mechanical resistance and impede soil aeration. Good root penetration is needed for adequate water uptake and would be limited by soil compaction, mechanical resistance and impeding soil aeration. Furthermore, increased mechanical resistance limits plant uptake of nutrients, restricts the production of several plant hormones in roots, greatly reduces fertilizer efficiencies, and increase the susceptibility of the plant to root diseases.

In olive orchards, shoot length, number of buds and plant health are influenced by the physical-chemical fertility of the soil. The presence of large numbers of flowers is a good indicator of potentially large yields. Flower induction starts the year preceding olive production. Its intensity depends on energy and carbohydrate availability and the presence of specific hormones necessary to drive the bud apex toward inflorescence production. Carbohydrate availability depends on climate conditions, variety, and diseases, but also on water and nutrient amount and physical status of the soil. Once again, soil fertility (physical, chemical and microbiological conditions) is crucial to determining enhanced plant productivity.

Root rot caused by *Armillaria mellea* is the one of the most serious disease and results in a more-or-less rapid tree decline. Symptoms of this root rot on above-ground parts of the plant generally appear as stunting, yellowing, or browning leaves, which may drop. Roots infected with *Armillaria mellea* have white to yellowish fan-shaped mycelyal mats between the bark and the wood. Dark brown to black rhizomorphs can sometimes be seen on the root surface. Poor soil aeration, high level of soil saturation, and high mechanical resistance to root development caused by soil-structural degradation increase root-rot pathogens.

Effect of cover crops on olive production

Cover cropping is the most suitable soil-management practice to protect the soil surface from erosion, to preserve the environment, to reduce production costs, and to enhance the quality of olive oil.

However, cover crops could compete with olive trees for minerals, water and fertilizer if they are not well managed. In the centre-south of Italy, in the absence of irrigation during the hottest months, competition for water could occur during flowering, fruit formation and development, so limiting the final yield. To avoid this competition, a temporary cover crop or natural vegetation can be grown from September to April, which is the wettest period, and can be controlled during the hottest period by herbicide application or 2–3 cuttings.

An alternative method involves one or two hoeings during the hot period. This facilitates natural weed covering and could be satisfactory in limiting the competition for water. The cultivation should be no more than 10 cm deep, so as not to damage the root system, hence modifying the canopy/root rate with reduced vigour and crop yield. Moreover, hoeing can be useful for incorporating organic and mineral fertilizer as well as controlling diseases caused by fungi and bacteria living in the soil.

Production costs of olive orchards

Tillage and fertilizer inputs account for some of the most significant costs in any cropping operation, and can increase significantly with increasing soil degradation. As degradation increases, the density and strength of the soil increase and, as a result, the soil becomes more resistant to tillage forces. Moreover, the size, density and strength of soil clods also increase with increasing loss of soil structure.

Continuous cropping using conventional cultivation techniques can increase losses of organic matter and, as a result, can substantially reduce soil fertility and the ability of the soil to supply nutrients. Large amounts of fertilizer are needed to compensate for the loss of these nutrients.

Reductions in crop yield are often not recognized as the result of the degradation of soil structure. Growers often assume that plant nutrition is at fault and increase their production costs by applying extra amount of fertilizers.

PROMOTING INTEGRATED SOIL AND WATER MANAGEMENT

Experience indicates that farmers are willing to invest in land management and crop interventions where the economic returns are adequate. Local people will undertake their own planning of investments, and have access to external financial support in cash, kind or other forms to implement those plans. Monitoring methods will be put in place both to inform the communities' own learning process, and to document progress towards achieving the expected results.

Implementing a programme to promote integrated soil and water management in orchards requires that governments mandate soil cover and no-till or provide financial incentives to farmers. The European Union has a large subsidy programme to preserve soil quality. The debate as to whether current funding is sufficient to pay for soil restoration is still in a preliminary stage. Incentives and subsidy programmes must be consistent and long-lived because soil productivity gains are easily reversed. Creative policies that combine short- and long-term incentives, extension programmes, education, and changes in public norms will be required. Aid programmes should place far greater emphasis on subsidizing and providing technical and other assistance for soil restoration. As an option that wins globally and locally, adoption of no-till farming deserves attention now.

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Comparative assessment of practices and their effects using a soil visual assessment

INTRODUCTION

This paper is a preliminary step in the development of a farmer-usable methodology for soil visual assessment (SVA). An SVA describes and evaluates the morphological condition of soils in the field. This is a more rapid and immediate method of soil assessment than the conventional sets of soil physical measurements commonly used, e.g. bulk density, water infiltration, and soil strength.

Emphasizing morphological descriptions not only facilitates rapid analysis of a soil's current condition but, based on comparative assessments of agricultural ground with relatively "untouched" adjoining tree or fence lines, also permits impact statements, evaluating current land practices (McGarry, 1993). Continuing the evaluations with time facilitates trend analysis, particularly as farm practices change as a result of impact statements. Rapidity also ensures that either small areas are investigated in detail or large areas are evaluated quickly. The simplicity of the techniques and the everyday nature of the equipment needed to excavate and then describe the soil ensures that the system is usable by farmers, hence providing ownership and subsequent use of the collected information to increase their understanding of the impact of their management on their soil.

With SVA, the emphasis is on the assessment of soil physical condition (soil structure units and porosity) as well as soil colour, root development, soil fauna and organic matter status. The system is firmly founded on decades of pedological (soil description) methods and practices, where most countries have a system of describing and semi-quantifying soil condition. A recent review lists 11 such systems: 3 from the United Kingdom, 2 from Australia, and 1 each from France, the Netherlands, New Zealand and Switzerland (Box 1).

The aim of developing the SVA system presented here, and the main difference between this system and most of those presented by Batey (2004), is simplicity. It is foreseen that the main users of this current system will be farmers in developing countries. As an example, an immediate application of the SVA system being developed here is within the Land Degradation Assessment in Drylands (LADA) project of FAO. The LADA project aims to assess and combat land degradation in drylands particularly via the development and building of "land monitoring tools". Within the project, the aim is not only to take the best of these descriptors but also the most robust, readily teachable (in participatory farmer workshops), most widely transferable (between LADA countries and within country sites), and cross-check the SVA scores and soil photographs with simple yet scientifically tested soil measurements. As such, the SVA system aims to fill the need for a simple, repeatable, low-cost monitoring system to

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BOX 1

Methods used to describe and evaluate the physical condition of soil in the field

1. Direct field assessment of soil physical conditions: T. Batey.
2. The visual assessment of soil structure in the field (the Peerlkamp Scale): T. Batey.
3. SOILpak method for assessment of soil conditions: D.C. McKenzie.
4. A guide to tillage management based on surface soil types: J. Lawrie, B. Murphy and I. Packer.
5. Visual soil assessment (VSA): T.G. Shepherd.
6. Soil Quality Management System (SQMS): M. Beare.
7. Le profil cultural: Morphological characterization of cultivated structure at the field scale: H. Boizard, G. Richard and J. Roger-Estrade.
8. Soil quality scoring procedure: B.C. Ball and J.T. Douglas.
9. Visual soil assessment – spade analysis: L.K. Munkholm.
10. Assessment of soil structure by visual classification of aggregates: P. Weisskopf.
11. Visualise your soil (BIZ) – from observation to management: C.J. Koopmans, J. Bokhorst and E. Herres.

Source: From Batey, 2004.

capture the condition of and trend in (and extent and ramifications of) soil degradation, organic matter and soil biota (both natural/inherent and anthropogenic) in cropping, grazing and woodlands, worldwide.

METHODS

The SVA system is still in the development phase. However, the general aim is to compile a "field test kit" for use by farmers "on-farm". The system has two levels of methods and tests. The first set is the "core" tests of the system. Depending on time, budget, availability of apparatus and operator skills, all or selected measures from the second set of tests should also be conducted. It will be essential to establish a firm link between the SVA scores from the first set of methods and the quantified data from the second set.

It is envisaged that the test kit will consist of procedures and apparatus to qualify and score:

- soil structure size, type and grade (e.g. "weak crumb", "strong platy" and "massive"),
- soil porosity size, type and intensity,
- soil texture (e.g. clay, sandy loam, and loamy clay),
- soil depths (of visible layers, especially degraded layers),
- soil colour.

In addition, a set of "simple yet scientifically based" measures will be included in the kit. The cost of the necessary components for these tests will determine users' choice of tests included in this part of the kit.

The measurement apparatus and instructions will concern:

- water infiltration,
- soil organic matter status (especially labile carbon) (Weil *et al*., 2003),
- soil biota (earthworm counts per unit volume),
- soil slaking and dispersion (Field, McKenzie and Koppi, 1997),
- soil strength (perhaps the most difficult aspect because of known water-content interactions),
- soil pH (items included: the field kit of the Commonwealth Scientific and Industrial Research Organisation [CSIRO], barium sulphate, and indicator fluid).

The kit will contain a scoring system and score sheets for each of the above descriptors and measures.

Descriptors and measurement detail

The morphological descriptions will be based primarily on the evaluation of a block of soil removed by a spade. The spade technique is described in the SOILpak manual (McKenzie, 1998). Essentially, a spade with a flat (although usually slightly curved) blade is used to remove an intact "block" of soil, commonly up to 30 cm deep and 25 cm wide. The soil is left on the blade of the spade for subsequent observations.

First, using a measuring tape (or stick graduated in centimetres), the location of any visible soil layers are assessed and measured in terms of colour, soil structure (see below), root density, etc.

Then, as described by Batey (2004): "Begin at the original surface and break the spadeful of soil gently apart by hand. The criteria used are the size, shape, porosity and cohesion of aggregates and lumps (Box 2), the degree of dispersion and breakdown of surface tilth and the amount of root development. The assumptions made are that fine and medium crumb-sized aggregates, high porosity and the absence of a surface crust are beneficial to root development and crop growth. Overall, the test assesses the quality of the soil as a medium for root growth."

BOX 2

Five features, recordable in the field, to describe soil structure form

Type of pedality provides a description of ped shape, e.g. platy, granular, lenticular and polyhedral.

Size is the average least dimension of peds, used to define class intervals, e.g. small (0–2 mm) or medium (2–5 mm).

Grade is the degree of development and distinctness of peds, used to express the relative difference between the strength of cohesion within peds and the adhesion between adjacent peds. This is highly dependent on current water content. So, commonality of water contents between descriptions is to be aimed for.

Fabric is commonly restricted to Vertisols (cracking clays). It records the lustre of ped faces, e.g. earthy, sandy, rough or smooth.

Orientation is most commonly used for Vertisols, where peds in the subsoil commonly lie at 45° to each other.

Source: from McGarry, 2002.

As the soil is gently manipulated, the components specified in Box 3 need to be specified and all observations recorded (a photograph is most useful).

The scoring system is currently under discussion. However, scores are attributed to each of the variables noted in the soil, such as structure type, root penetration/ development, and earthworm counts, and multiplied by weighted values.

The soil measurements to be included in the SVA system are also under discussion. However, early considerations of three will be presented here. These three represent perhaps the most important indicators of soil structure / physical state, i.e. soil stability to wetting, water infiltration, and soil organic matter status.

Soil stability to wetting

There are two main types of aggregate collapse when water is added to soil: (i) slaking, which describes the breakdown of aggregates into microaggregates; and (ii) dispersion, which describes the breakdown of aggregates into the primary soil particles of sand, silt and clay. The differentiation between slaking and dispersion is most important. Generally, the products of slaking can reform to produce larger aggregates, whereas dispersion into primary particles is irreversible and results in undesirable, massive structure. On the soil surface, dispersed soil appears as a hardsetting layer or a surface crust. It is a major impediment to water penetration and plant growth, particularly of young, emerging plants.

The determination of the slaking or dispersive nature of a soil is commonly a laboratory test. However, an appreciation of the phenomenon can be gained in a short time during soil description in the field (Field, McKenzie and Koppi, 1997). The procedure is as follows. Drop an air-dried aggregate from the layer under investigation into a dish (e.g. a saucer) or a small clear container (cup) containing water (use rainwater

BOX 3

Components of soil structure and other observations to be recorded as part of on-farm assessment of soil condition

Ease of fracture

Well-structured soil will part along natural faces (the aggregates part from one another). Poorly structured soil breaks or snaps where you apply the force. Well-structured dry soil crumbles easily – it is friable.

Be aware of the effect of current soil water content on this evaluation. Moist and wet soil can be teased apart easily if it is well structured. Poorly structured wet soil will stretch like plasticine or tear to leave rough surfaces.

Roots

Where roots follow cracks, grow around aggregates and do not penetrate them, then structure is poor. Note any abrupt changes in direction or number of roots.

Porosity

If pores are visible to the eye, then they are large enough to allow the movement of water, nutrients, air and roots to move into and through aggregates. Pores will look like small pits or dark dots on the faces of aggregates. Well-structured soil has numerous pores. Pore size can be measured and recorded.

Ped shape

The shape of unbroken aggregates reveals the quality of structure. Cube-shaped, rounded, lenticular and polyhedral aggregates indicate good structure, while platy or massive aggregates indicate poor structure.

Ped size

Small aggregates indicate good structure. Large aggregates indicate poorer structure.

To assess: Break a lump of soil into smaller and smaller pieces, using moderate hand pressure. Take note of the size of the lump just before you begin tearing through the fabric of the soil, leaving a fine grainy surface rather than a shiny face. This is the point at which you are no longer breaking soil along natural fracture planes – you are tearing the aggregate apart. Wet soil can be difficult to examine.

Earthworms

Although not a direct measure of soil-structure condition, note earthworm numbers, type (where known), and size and distribution of burrows and caste material.

Source: based on McKenzie, 1998.

or local irrigation water). After each of 10 minutes and 2 hours (when possible) of immersion, a visual judgement is made of the degree of dispersion on a scale of 0–4 on each occasion (10 minutes and 2 hours). The two scores are added together giving a range of scores from 0 to 8. The total indicates the following:

- 0 indicates no dispersion;
- 1 is slight dispersion, recognized by a slight milkiness in the water adjacent to the aggregate;
- 2 is moderate dispersion with obvious milkiness;
- 3 is strong dispersion with considerable milkiness and about half of the original aggregate volume dispersed outwards;
- 4 is complete dispersion, the original aggregate completely dispersed into clay, silt and sand grains.

Water infiltration

A major determinant of the cropping potential of a soil is the rate and amount of water that can infiltrate either through the soil surface or within the soil profile. The following method has been devised by Cook (CSIRO, Australia). The aim was to derive a simple method for the rapid estimation of soil hydraulic conductivity. Simplicity, both in apparatus required and field method, was essential. Although operationally simple, the method is firmly based on fundamental, globally tested and accepted soil physical principles.

TABLE 1

Simple estimation of *K* on the basis of 3-D flow from a pond

Time for 50 mm of water to be gone from ring with radius 50 mm	Hydraulic conductivity – K (mm/h)
< 10 min.	> 36 (fast)
> 10 min., < 2 h	> 3.6 (medium)
> 2 h	< 1 (very slow)

TABLE 2

Simple estimation of *K* on the basis of 1-D flow from a pond

Time for 50 mm of water to be gone from ring with radius 50 mm	Hydraulic conductivity – K (mm/h)
< 30 min.	> 36 (fast)
> 30 min., < 10 h	> 3.6 (medium)
> 10 h	< 1 (very slow)

The method considers two scenarios:

1. A ring is only pressed lightly into the soil surface (three-dimensional flow).
2. A ring is pushed in to a considerable depth (greater than the diameter of the ring), so that the flow is essentially one-dimensional.

Cook advises using the three-dimensional method where possible as results will be obtained more quickly and the time data are more sensitive to the hydraulic conductivity. The one-dimensional method is more appropriate where soil cracking or the aggregation of the soil makes it difficult to seal the ring onto the soil without leaks occurring.

Field equipment is a 1 × 50 mm radius ring (usually metal with a sharpened tip), a container holding exactly 50 mm of water, and a watch. Tables 1 and 2 present summary hydraulic-conductivity data for each of the three- and one-dimensional scenarios, respectively.

Soil organic matter status

Most of the functions associated with soil quality are strongly influenced by soil organic matter, especially the small portion that is termed active organic carbon (Weil, Web site). Techniques have developed to fractionate carbon on the basis of lability (ease of oxidation), recognizing that these subpools of carbon may have greater effect on soil physical stability and be more sensitive indicators of carbon dynamics in agricultural systems than total carbon values (Weil *et al*., 2003). Moreover, the link between indices of soil physical condition and labile carbon fractions has been investigated where comparisons of never-cropped land and adjoining farmland across three soil types reported a substantial loss of carbon with cropping, particularly labile (permanganate oxidizable) carbon.

Weil *et al*. (2003) have developed a "field kit method" for the determination of potassium permanganate oxidizable carbon. This is the technique that will be developed for use in the SVA system, particularly aiming to replace the required technology (a hand-held colorimeter) with a range of colour (purple) chips – to represent the range of results found in field soils.

CONCLUSIONS

The early stages of producing a simple yet robust, farmer-usable SVA system have been presented. Descriptive, qualitative information based on soil morphological descriptions of spade-excavated soil profiles will be cross-checked and validated with a set of simple, yet scientifically based and known, environmentally vital, field measurements. The outcome will be a part resolution of a continuing need for a simple, low-cost monitoring system for capturing the condition of and trend in, and extent and ramifications of, soil degradation and organic matter decline (both natural/inherent and anthropogenic) in the cropping, grazing and woodlands of the world.

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Soil and water management for olive orchards in Portugal – an overview

INTRODUCTION

Tillage with disc harrows and cultivators is the traditional method for weed control and land levelling in Portuguese olive orchards (Plate 1). These practices leave the soil with no protection for long periods of the year, including the rainy season. It is also commonly believed that these practices promote soil water intake. However, tillage pulverizes soil aggregates, contributing to undesirable compaction (Plate 2), accelerating soil erosion, and wasting time and energy. During the olive-production process, tractors and other farm machinery need to perform different activities in wet soil when trafficability is a problem.

The depth and amount of soil disturbance from a tillage operation influence soil moisture. Losses are proportional to the depth of soil loosening. Mixing the soil by discing causes great soil-moisture losses. Intensive tillage accelerates the drying out of the soil surface and pulverizes the soil structure. Pulverized, fine powdery surface soils are susceptible to erosion and crusting, and the crusting reduces water intake. Generally, soils with faster infiltration rates, higher levels of organic matter and an improved soil structure have greater resistance to erosion.

Soil erosion may be a continuous and slow process that remains relatively unnoticed, or it may occur at a rapid rate causing serious, immediate loss of topsoil. The loss of soil from olive orchards affects machine and labour activity and is reflected in reduced olive production, reduced surface water quality for human consumption or irrigation purposes, and damage to drainage infrastructures.

Rainfall and runoff are the principal causes of soil water erosion. The impact of raindrops on the soil surface breaks down soil aggregates and disperses the aggregate material. The splash of raindrops as well as runoff water can easily remove lighter aggregate materials, such as fine sand, silt, clay and organic matter. Greater raindrop energy and subsequent runoff dislodge and move the larger sand and gravel particles. Short-duration, high-intensity thunderstorms have the potential to cause large amounts of soil movement. Runoff can occur where there is excess water on a slope that cannot be absorbed into the soil or retained on the surface. The tendency to consolidate small


Plate 1
A Portuguese olive orchard in September.

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Plate 2
Surface compaction in an olive orchard after mechanical harvesting.

olive orchards into larger ones often results in longer slope lengths, leading to increased erosion potential from increased water velocity with subsequent increased capacity for sediment movement.

During winter and early spring, runoff can be intense in Portuguese olive orchards as vegetative cover is minimal. Plant and residue cover protects the soil from raindrop impact and splash, tending to slow down the movement of surface runoff and allowing excess surface water to infiltrate. Partially incorporated residues and residual roots are also important as these provide channels that allow surface water to move into the soil.

Rill erosion results where surface runoff concentrates to form small yet well-defined channels. These channels can increase in size into gullies and became a nuisance factor for normal machinery movement within the orchard (Plates 3 and 4). Olive farmers frequently use a disc harrow to try to cover the rills. As only finely aggregated soil is used in this procedure, it is common for all of this soil to be eroded in the following rainfall season, and for the process of rill formation to re-commence. Operations with farm machinery adjacent to gullies can be quiet hazardous (tractor roll-over) when cropping or attempting to reclaim lost land.

ROLE AND IMPORTANCE OF SOIL AND WATER MANAGEMENT IN OLIVE ORCHARDS

In dry olive-farming conditions, water intake and its storage during the rainy season are very important to facilitating growth and the ripening of the olives during the following long, dry season. In Mediterranean climate conditions, it is of particular importance to determine the best management practices that simultaneously reduce soil disruption, erosion and carbon loss, without reducing productivity and yield, while permitting water intake during the rainy season.

Conservation practices reduce wind speed, reduce the rate and amount of water movement, and increase soil organic matter (SOM) levels. No one conservation management system is suited to all situations. This is because of differences in soil type, topography, type of farming operation, and climate.

Plate 3
Rill and gully erosion in a Portuguese olive orchard

Cover crops in olive orchards help to reduce the erosive forces of both raindrops and the wind through preventing the rain from hitting the soil surface directly and by acting as a windbreak. Root systems, especially grasses, stabilize the soil, reduce soil loss, and improve soil-water intake. Cover crops and their residues, particularly on slopes, form small dams that help to retain water runoff, reduce soil erosion, and contribute to soil water intake. Natural cover crops that include grass-legumes improve soil structure, and this is reflected in increased aggregate stability and an associated ability to withstand erosion events.

Several land-management practices can be used to reduce soil erosion. Contour ploughing, strip cropping or terracing may be considered in olive orchards. Controlling soil erosion will: sustain or improve olive yield per tree and per hectare; reduce drainage costs; increase organic matter levels and retain nutrients and chemicals. It will increase machine working days and performance, as well as contributing to improved water quality.

Plate 4
Another example of rill and gully erosion in a Portuguese olive orchard

OLIVE-TREE CHARACTERISTICS

After 3–4 years of growth, olive trees form a fascicular root system, which continues to develop with age. In heavy-textured (clay) and poorly aerated soils, roots tend to be concentrated near the soil surface, whereas roots are found at greater depths in lighter-textured soils. Lateral roots can be up to 12 m long as they seek water and nutrients. In traditional tillage systems, the ability of trees to grow into large volumes of soil is countered by the use of disc harrows and cultivators that have strong potential to damage and disturb the root system.

Yields of olive trees vary from year to year and from tree to tree. Until recently, Portuguese olive farmers preferred increased yields per tree rather than per hectare. In old orchards, the trees were managed to be low density and to have large tops. Mechanical harvesting of such trees is difficult or even impossible and harvesting continues using manual labour. Every year, thousands of these types of olive trees are not harvested, contributing to the low olive yield per hectare as presented in FAO statistics. Today, olive farmers are replanting their orchards at greater plant densities in order to facilitate full mechanization.

Olive trees are commonly grown without irrigation in areas with an annual rainfall of 400–600 mm. However, these levels of precipitation are frequently insufficient to meet the needs of olive trees. Hence, the potential yields are low. In dry conditions, the only water reservoir available to the trees is that stored in the rootzone.

Management practices should be designed to maximize water storage in the rootzone during the rainy season. Soil water intake can be improved by providing a ground cover that utilizes crop residues on the soil surface. Surface debris increases water infiltration by breaking up raindrops and delaying runoff. The presence of grasses also increases water penetration by promoting larger pores in the soil. Contour cultivation may also be used to lengthen the time that free water remains on the soil surface, giving the water a better chance to penetrate the soil. Cover crops and their residues should be kept on the soil surface for as long as possible. They shade the soil, providing a reflective cover to dissipate the solar energy that would otherwise evaporate water from the soil. In addition, they reduce the wind speed, so water-vapour loss is also reduced. Where a strip of cover crops is left in the row, seeds can mature and form a seed bank to ensure continuation of the cover crops. This strip can also increase the soil moisture content by retaining soil moisture within the standing crop and facilitating increased water entry through macropores and root channels. Moreover, increased levels of SOM content improve soil structure and water infiltration. Grasses and legumes with their abundant rooting systems will increase the organic matter content of the soil in the long term with subsequent improvements in soil aggregation.

Alternate fruit bearing is very common in systems with old trees under rainfed conditions. Alternate bearing is less pronounced with adequate water supply during active growth periods, with good soil, favourable climate conditions and adequate management practices (including pruning).

THE PORTUGUESE REALITY

Portugal, with a total area of olive orchards of 430 000 ha, ranks fourth in world production. This represents about 8 percent of the land area under olive production in the southern member states of the European Union. However, olive-oil production represents only about 2 percent of the olive oil produced in the same area.

There are four main regions of olive production in Portugal, with Alentejo, in the south of the country, representing 40 percent of the area of olive orchards planted. There are considerable differences between the four areas and between the different farms within the areas. These differences concern: the physical characteristics of the orchards; soil and water management practices; the level of mechanization; and environmental effects. Olive farms range in size from very small (< 0.5 ha), which is a common size in the north, to large farms (> 200 ha), which are common in southern Portugal. They also vary from traditional, low-intensity orchards to intensive, highly mechanized plantations.

Two main types of plantations can be considered:

- ➢ traditional plantations, represented by having very old trees planted on marginal soils with high labour input and little viability in economic terms, most of them likely to be abandoned;
- ➢ intensified traditional plantations that still use traditional methods of weed control and soil and water management, are intensively exploited, and that use pesticides and fertilizers. There is a tendency to intensification that is reflected in increased tree density, irrigation and mechanical harvesting.

Intensive modern plantations can also be found. These tend to have smaller tree varieties, planted at very high densities (about 2 000 trees/ha), and are irrigated and managed under an intensive and highly mechanized system. However, they represent only a small percentage of the area of olive production in Portugal.

Inappropriate weed-control and soil-management practices performed in intensified traditional systems have potentially negative environmental impacts, principally in the form of soil erosion, runoff, degradation of habitat, and exploitation of water resources. These practices, combined with the inherently high risk of erosion in many olive-farming areas, have resulted in reduced soil fertility and considerable runoff of soil and agrochemicals into rivers and water storages.

For weed control and land levelling, olive farmers perform excessive spring cultivations using disc harrows and cultivators. Is also commonly believed that cultivation helps soil water intake and conserves soil humidity. However, these practices seem to have little or no benefit other than weed control. In fact, these practices dry out the soil surface to the depth of tillage and promote soil compaction that can be readily observed in the 20–30 cm depth.

Under non-irrigated conditions, which were the most common in the past and are still frequent, fewer than 100 trees/ha was the normal density. In new orchards, with improved soil conditions and irrigation, 300 trees/ha is the most common density. In the last five years, in the Alentejo region, 530 000 trees covering 8 500 ha of olive orchards were replaced by 1 852 500 new trees, with a tripling in tree density. These new plantations are irrigated and require intensive use of agrochemicals, soil and water. Another 30 000 ha of new olive orchards are expected to be planted by 2006, half of them in the Alentejo region. All will be planted in good soils using modern, intensive systems.

It is common for olive farmers to irrigate their orchards without scientific consideration of the frequency and quantity of water supply. Water resources are used without conservation criteria.

In the absence of appropriate farming practices, the future for the Portuguese olive sector is one of intensified production with very strong potential for negative land and environmental effects. Efforts are needed to convince the farming community that practices have to take soil and water conservation into account.

PORTUGUESE EFFORTS TO CHANGE TRADITION

Research into soil and water management is currently underway in an attempt to understand the impact of agricultural management practices on olive production, including tillage, cover crops and residue management, and their effects on groundwater and surface-water quality and on crucial soil properties, particularly soil carbon content.

Farmers are being encouraged to adopt practices that maintain soil cover, increase SOM, reduce surface runoff, and eliminate chemical contamination of soil and water.

Of the research projects now in place, most of them are managed by the agricultural universities in participation with the Ministry of Agriculture and several research stations. A 30-ha experimental olive orchard has been planted in Alentejo in order to study aspects related to varieties, plant density, pruning methods, cover crops, and soil and water management.

Among others, the objectives of the current research projects are: to monitor the transpiration of young and adult drip-irrigated olive orchards using the heat pulse technique and to find the relationships between measured canopy dimension variables (LAI and LAId) and evapotranspiration. Within these main objectives, the principal aims are:

to compare the heat-pulse technique of evaluating sap-flow velocity (plant transpiration) with the whole-of-orchard evapotranspiration using the water balance method;

- ➢ to use an indirect assessment of olive water requirements involving the measurement of leaf water potential as a stress indicator under different irrigation treatments;
- ➢ to compare traditional soil management with alternative practices, principally to prevent soil erosion;
- ➢ to increase levels of SOM;
- ➢ to encourage the development of wild species of Portuguese flora with good characteristics;
- ➢ to increase the water available to the olive trees;
- ➢ to improve soil structure;
- ➢ to reduce the amount of herbicides used and their influence on the environment;
- ➢ to develop farm machinery for olive harvesting that works over the strip of the cover crop to reduce widespread soil compaction and to increase machine trafficability.

In addition, field days have been organized with the participation of technicians and farmers in order to demonstrate the techniques under study and to transfer the pertinent information to the end users.

CONCLUSIONS

It is expected that the intensification and expansion of Portuguese olive production will continue. It is important that the negative environmental effects associated with this intensification should be reduced through the use and application of appropriate farming practices.

The implementation and ongoing maintenance of practices to achieve and promote environmental improvements in olive production will be a difficult task. The foremost challenge is the continuation of traditional practices and an associated low level of farmers' knowledge of new practices. Tradition offers resistance to the adoption of new technologies. However, it is important that farmers realize that these new practices will maximize olive quality and yields, minimize soil erosion, and enhance the quality of surface water.

In association with changes in land-, water- and crop-management practices in the Portuguese olive industry, there is an associated need for both policy development and implementation to promote sustainable olive farming, as well as the integration of environmental concerns into the policy and production sectors.

Soil-moisture regime in dryland vineyards of Catalunya (Spain) as influenced by climate, soil and land management

ABSTRACT

Vineyards, under dryland conditions for wine and cava production, have been and still are one of the main crops in the region of Catalunya (northeast Spain). In the last few decades, as a consequence of policies of the European Union, many areas with vineyards have been abandoned, while in others the cropping practices have been intensified, frequently with large changes in land and soil management. These changes have affected mainly the hydrology of the cropped lands, and especially the soil-moisture regime, with effects on the quantity and quality of grape production. The effects are more marked because of the high variability and concentration of rainfall events in the local Mediterranean climate.

The results of evaluations and monitoring of soil hydrological properties and processes in two of the main areas with dryland vineyards for high-quality cava (Alt Penedés) and wine (Priorat) production in Catalunya are used in order to deduce and simulate the soil-moisture regime. This regime is evaluated under different and changing conditions of climate, soil, land management and soil conservation practices. The interpretation is based on the different soil water requirements of vines during their annual growing cycle, and on the potential erosion processes. It is concluded that the different tested soil- and water-management and conservation practices may have positive or negative effects depending on the other soil and climate factors. These effects must be evaluated or simulated before recommending or adopting any new management or conservation practice.

INTRODUCTION

Vineyards for dryland grape/wine production are a traditional crop in the steeply sloping agricultural lands of Catalunya (northeast Spain). At presently, there are about 100 000 ha of vineyards in Catalunya, mostly under dryland conditions, which accounts for 8 percent of the total production of Spanish wine (by volume) and 99 percent of cava production. In Catalunya, as in other regions of Mediterranean Europe, dryland vineyards have undergone great changes in the recent decades. In part, as a consequence of the policies of the European Union (EU), some cropped lands have been abandoned. However, in others, with vineyards dedicated to producing high-quality wine and cava, the cropped area has increased, with more intensive and highly mechanized agricultural systems (Pla and Nacci, 2003). In some cases, limited irrigation has been introduced (mostly drip irrigation) but only as a remedial practice where there is extreme drought. As a result of terracing and levelling with bulldozers to change the

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topography of slopes to facilitate water retention and mechanization, large volumes of soil have been removed. This has affected the hydrological properties of the soils and the natural drainage of the lands, favouring erosion and mass movements, although mainly restricted to extreme events (Pla and Nacci, 2001; Nacci, Ramos and Pla, 2002). Moreover, there is a trend of an increasing frequency of dry years and more aggressive extreme rainfall events, apparently as a consequence of general climate changes in the Mediterranean region (Ramos, 2001).

Tillage has been the traditional practice to resolve several, perceived in-field issues: to control weeds; to loosen compacted and crusted surface soils in order to increase rainwater infiltration; to reduce losses of water by evaporation; and to improve the rooting depth of vines. The benefits of no-tillage in association with green cover crops are recognized, particularly to protect the soil surface against direct raindrop impact, to increase the soil organic matter (SOM) content, and to reduce runoff and surface erosion. However, it is considered that in dryland vineyards it may cause more water deficiencies and insufficient nitrogen supply, particularly in dry years (Rupp and Fox, 1999). Moreover, it is known that in certain circumstances a green cover crop or cover residues can increase the survival rate of pathogens, and favour the development of mildew. Experience in the Catalunya region has shown that the use of some herbicides in association with no-tillage, particularly in areas with less than 500 mm rainfall and in soils with low organic matter and light textures, may cause phytotoxicity problems in the vines.

The work reported here presents the actual and potential effects of these changes in land management on soil and water conservation as studied in two representative areas (Alt Penedés and Priorat), covering the range of the more common soils, topography, climate and land-management changes in dryland vineyards of Catalunya (Spain) and of many other Mediterranean regions. These studies included evaluations of soil and land hydrological properties and processes through field and laboratory measurements and field monitoring. The studies were integrated using flexible models based on hydrological processes to deduce the potential effects on soil surface and mass erosion, and on the soil-moisture regime affecting the sustainability, quantity and quality of grape and wine production under changing scenarios of climate and land conditions (Pla, 1997, 2002).

MATERIALS AND METHODS

Experimental areas

The study areas were located in commercial fields representative of two of the regions (Alt Penedés and Priorat) of Catalunya, where the area under vineyards for high-quality wine and cava production has increased in the last 20 years (Plates 1, 2 and 3). Accompanying this large increase in vine area has been a drastic change from traditional practices, including the introduction of new varieties. At present, there are about 30 000 ha of vineyards in Alt Penedés, and 5 000 ha in Priorat. In both regions, the climate is Mediterranean semi-arid. The average annual rainfall is about 600 mm, and it is very irregularly distributed, with the greatest rains in autumn–winter, a very dry summer, and with large variabilities in totals from one year to another (400–750 mm in Alt Penedés and 300–900 mm in Priorat). Rainfall is typified by many storms in autumn, and occasionally

Plate 1
Changes in management of vineyards in the Alt Penedés region.

in spring, of high concentration and intensity. Climate change may increase the irregularity of this rainfall, the frequency of dry years and the probability of extreme events. These phenomena have been observed in both regions in the last 25 years. The extrapolation to the future of past or historical information may be unreliable because of greenhouse effects on climate change. In any case, the past information about extraordinary events is of concern in view of both the lack of long-term measurements and the low quality of the measurements (Gallart, 1990).

The water use of vines through the growing season is characterized by lessened requirements in the periods before bloom and after harvest until autumn, and a maximum consumption in the mid-part of the growing season. Where the reserve water capacity of the soil in the rootzone is not sufficient, reduced amounts of rainfall during the main growth season (June–August) may lead to a long-term soil-water deficit This deficit can affect growth, production and maturation, in spite of the natural survival capacity of vines under drought conditions (Maigre, Aerny and Murusier, 1995).

Plates 2 and 3
Tillage and erosion (no cover) and green cover in transformed vineyards of the Alt Penedés region.

In order to decrease the costs of the scarcely available manual labour, to increase production and to accelerate all operations, the current trend is towards full mechanization of all practices, including harvesting. This requires guided vine lines with lateral pruning, with rows 2.4–3.2 m apart, and spacing of 1.2–1.4 m between the plants. This gives a much lower soil-surface protection than the traditional planting systems, although the protection is low in both cases in autumn–winter when the heavy storms usually occur. Mechanization also requires long and straight lines, sometimes in favour of the slope. In order to proceed to a fully mechanized system, there is a need for heavy land levelling or terracing operations, with drastic changes in the surface drainage network and on the effective rooting depth and surface soil properties (Nacci, Ramos and Pla, 2002; Pla and Nacci, 2003).

In the Alt Penedés region, the topography of the area is strongly undulated, and even hilly, with cropped fields on 4–20-percent slopes, and altitudes of 250–400 m above sea level (a.s.l.). The soils generally have minimal profile development, mainly as a result of levelling operations for smoothing the land surface for mechanization. These soils, formed from calcareous lutites, are inherently low in organic matter (< 1.5 percent), high in silt (40–60 percent) and very rich in calcium carbonate. They have a strong susceptibility to surface sealing (Ramos, Nacci and Pla, 2000), resulting in large runoff and surface-erosion rates. Periodical tillage does not encourage root growth in the surface 15–20 cm of soil, which is maintained in a loose condition for most of the year to increase rainfall water infiltration, to decrease evaporation of deeper soil water, and to control weeds.

One practice for water conservation, found in some areas, is the use of bench terraces (2–3 m wide and 15–20 cm deep) across the slope, every 10–15 vine rows (depending on the slope) where the weeds are not removed. The purpose is to absorb and deviate runoff water and sediments coming from the upland rows. These terraces, made of loose surface soil, frequently suffer mass movements, especially after extraordinary rainfall events. The resultant gullies receive concentrated surface runoff and subsurface flow of water coming from more elevated parts of the field.

In the Priorat region, the climate is also semi-arid, and the topography is mountainous with cropped areas on 10–80-percent slopes, at 200–650 m a.s.l. Soils are developed on slates and schist, are not calcareous, but they are slightly acid, very poor in organic matter, and very stony (20–60 percent by volume), sometimes with a gravely pavement in the soil surface. Fine soil fractions, mainly smectite clays, increase with soil depth, which is generally less than 50–60 cm, on top of a strongly weathered and fragmented rock.

Traditionally, the vineyards in the Priorat region are planted with varieties producing wines of high graduation and good quality, but low yields (usually less than 3 Mg/ha). The planting pattern mainly follows the contour lines, in very small individual fields, with vines and lines 2–3 m apart. The original relief and slopes are normally retained, and the only conservation structures are non-continuous stone walls. These are located across the drainage ways and in places where local experience says there is a danger of soil movement by surface or mass erosion. In the past, the land between vine rows was removed, generally after harvest, by ploughing the surface 10–15 cm. Today, this practice has almost disappeared, except where a gentler slope allows the use of a small tractor, and herbicides are used to control weeds. As a result of continuous no-tillage, the vine roots tend to concentrate on the surface soil, where the effects of drought or poorly distributed rainfall are more marked.

The new plantations of vines in the Priorat region are established to facilitate mechanical operations in the vineyards, aiming for increased soil-water retention and greater and more stable grape and wine production. Bench terraces are built, 2–5 m wide, depending on the slope, with very steep and unstable embankments. These necessitate forest clearing for new vineyards, followed by the removal of large volumes of soil and underground rock using heavy bulldozers. One to three rows (2–3 m apart) of vines are planted in the terraces, generally of newly introduced and more productive varieties that are planted with 1.2-m spacing between plants. In most cases, the very steep embankments of the terraces are not protected, except by the slow re-growth of natural vegetation. The effects of these drastic changes on the relief and soils for new plantations, and of the changes in land management in the traditional plantations, are being studied under different field and laboratory conditions.

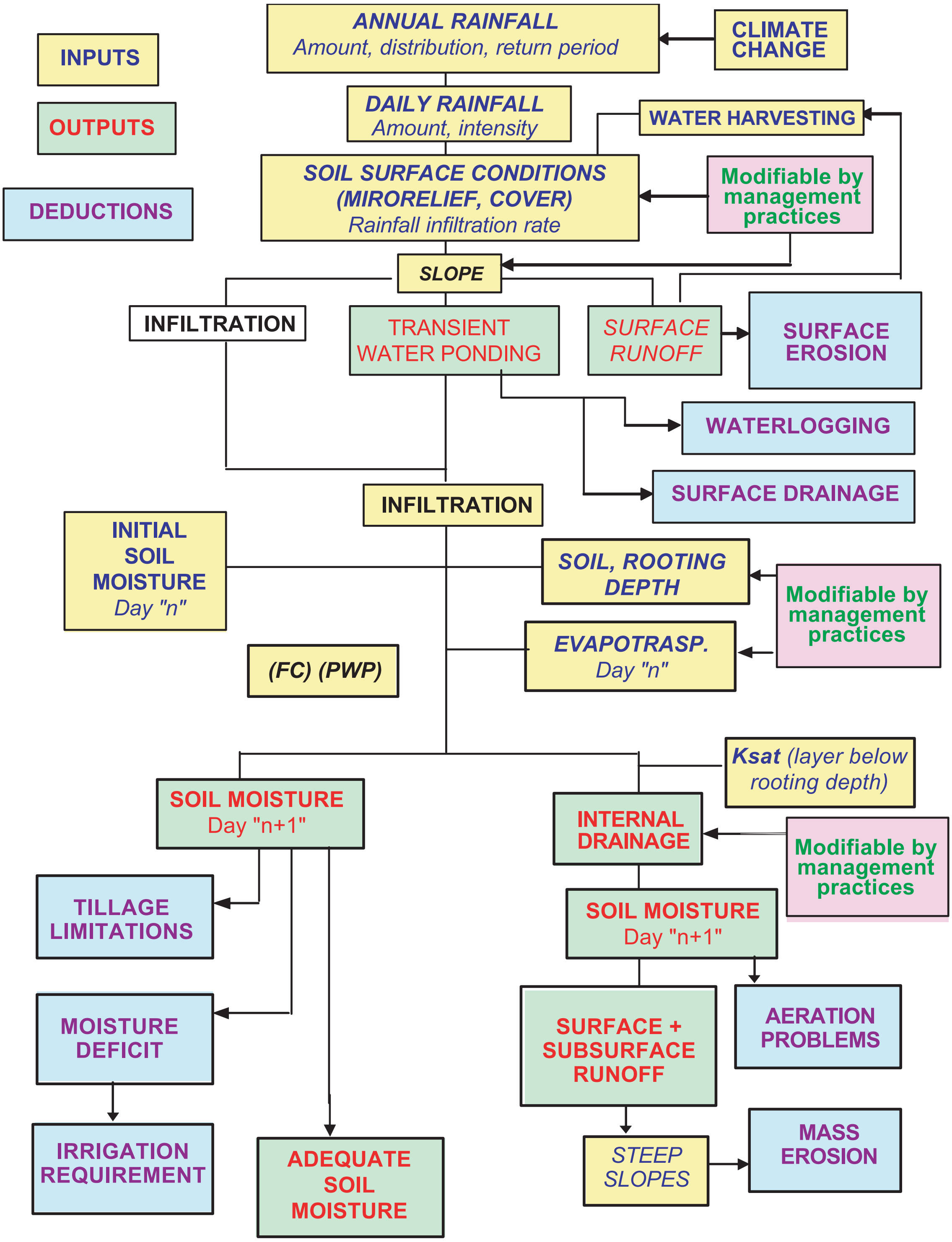
Measurements and experiments

Most of the problems of soil and water conservation in the Alt Penedés and Priorat regions are associated with the effects of climate change and of soil- and cropping-management practices on the soil-water regime. Measurements and continuous monitoring of appropriate soil hydrological parameters and rainfall characteristics have been conducted at field sites, complemented with laboratory measurements. These have been used as a basis for the application and validation of a model (SOMORE) (Figure 1), which allows the simulation and prediction of the soil-moisture regimes, and of the associated potential problems of soil erosion and of water supply to the vines at different growth stages (Pla, 1997; Pla and Nacci, 2001). In many cases, adaptations and changes in the methodologies have been required in order to make adequate measurements, particularly under field conditions.

In this paper, we present both the results of field measurements and continuous monitoring from selected sites in commercial fields, as well as the results of simulation modelling of the range of more common conditions of soils, slope and management. Several treatments were included: the present clean-tillage management (NC), the potential use of green cover grass (C) during the resting period (R), followed by cover (utilizing the killed grass residues) during the rest of the growing periods. Presented

FIGURE 1

Flow diagram of a conceptual model (based on hydrological processes) to predict the soil-moisture regime and to assess the potential soil- and land-degradation processes



Ksat: **saturated hydraulic conductivity;** FC: **field capacity;** WP: **water retention at 0.15 Mpa;** PWP: **water retention at 1.5 Mpa;** PL: **plastic limit;** LL: **liquid limit;** SAT: **saturation**.

Source: Adapted from Pla, 1997.

TABLE 1
Rainfall distribution in selected extreme dry and rainy growing seasons (return period: five years) of grapevines during the last ten years in the Alt Penedés and Priorat regions

	Monthly rainfall												
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Year
	(mm)												
Alt Penedés													
Dry (D)	29	0	106	53	20	8	32	40	9	22	4	85	408
Rainy (H)	130	150	135	118	0	17	44	19	57	9	44	0	723
Priorat													
Dry (D)	81	19	0	12	28	15	53	67	10	8	17	63	333
Rainy (H)	370	63	62	20	15	24	46	51	7	48	12	15	733

here are selected growing seasons in each region. These are the driest (D) and the rainiest (H) during the last ten years, with return periods of about five years. In the selected rainy seasons (H), the rainfall was highly concentrated (> 70 percent of the total annual rainfall) in autumn (Priorat) and in autumn to early winter (Alt Penedés) (Table 1).

In the Alt Penedés region, two soil conditions were considered: (i) the essentially non-disturbed area (AP-1); and (ii) a highly disturbed (by land levelling) area (AP-2), with slopes 6–10 percent. A further treatment was in one of the small bench terraces (AP-T) built every 10–15 rows (Table 2).

In the Priorat region, two soils were selected in the sloping (30–60 percent slope) lands, with effective rooting depths of 70 cm (P-1) and 40 cm (P-2), in a field with traditional management system. In addition, one soil was investigated in a neighbouring bench-terraced land (P-T) (Table 2).

The data from these experimental sites were fitted using a water balance model (Figure 1) to predict the water requirements of the grapevines and cover crop, during the approximate different growing periods of vines (with slight differences according to year, region and variety) for wine production in those areas:

- ➢resting period (R), October–February (approx.);
- ➢budburst – bloom period (Bu–Bl), March–April (approx.);
- ➢bloom – veraison period (Bl–Ve), May–July (approx.);
- ➢veraison – harvest – fall period (Ve–H–F), August–September (approximately).

The given values of water requirements (ET) for vines correspond to the more common range of requirements under semi-arid Mediterranean climate (Nacci, 2001). The water requirements for the green cover crop correspond to those of a well-developed rye crop.

TABLE 2
Soil characteristics and hydrological properties in selected sites of the Alt Penedés and Priorat regions

	Slope	Effective rooting depth (95% roots)	Available water retention capacity	Saturation	Rain infiltration rate		Saturated hydraulic conductivity(subsoil)
					No cover	Cover	
	(%)	(cm)	(mm)	(mm)	(mm/h)		(mm/h)
Alt Penedés							
AP-1	6	20–80	200	240	20	50	3.0
AP-2	10	15–60	120	150	5	20	3.0
AP-T	0	0–20	70	80	-	50	0.4
Priorat							
P-1	50	0–70	82	140	66	66	1 280
P-2	30	0–40	61	96	62	62	702
P-T	0	0–70	110	210	100	100	743

RESULTS AND CONCLUSIONS

Tables 3 and 4 show the values of the different calculated components of the soil-water balance during the different growing periods of vines for wine production in the different selected seasons, under variable soil and management conditions. It is shown that, in all cases, the only possibility to have a green cover (C) between the vine rows, is during the resting period (R), and that if a cover were maintained for the rest of the year, it would need to be killed with a selective herbicide, not toxic to the vines. It is evident that the use of a green cover crop in the resting period would increase the possibilities of drought in the critical Bl–Ve period in drier years (D) in soils with lower available water retention capacity (AWC) (associated with soil characteristics and effective rooting depth), and in climates with greater water requirements (ET) of the vine. A positive effect of the green cover crop, in many cases, would be a reduction in the water runoff losses (RUNOFF) and in the accompanying soil water erosion.

TABLE 3

Soil-water balance components in relation to crop-water requirements in the grapevine growth, selected years and sites of the Alt Penedés region

Growing period	Resting	Budbreak–Bloom	Bloom–Veraison	Veraison–Harvest–Fall	Total
			(mm)		
ET (Cover)	**130**	**140**	**419**	**250**	**(639)**
ET (Vine)***	**10–20**	**40–45**	**200–265**	**95–100**	**(340–430)**
Rain (Dry)	**208**	**40**	**71**	**89**	**408**
AP-1 (NC)					
Runoff	75	0	0	0	(75)
Drainage	56	0	0	0	(56)
Deficit (ET)	0	0	0	0–5	(0–5)
AP-1(C)					
Runoff	0	0	0	0	(0)
Drainage	0	0	0	0	(0)
Deficit (ET)	0*	0*	0 (70–135*)	0**	(0)
AP-2 (NC)					
Runoff	160	10	8	65	(243)
Drainage	0	0	0	0	(0)
Deficit (ET)	0	0	27–97	61–66	(88–163)
AP-2 (C)					
Runoff	0	0	0	0	(0)
Drainage	98	0	0	0	(98)
Deficit (ET)	0*	0 (60–65*)	9–79**	6–11**	(15–90)
Rain (rainy)	**533**	**61**	**85**	**44**	**723**
AP-1(NC)					
Runoff	110	0	3	0	(113)
Drainage	189	15	0	0	(204)
Deficit (ET)	0	0	0	0–39	(0–39)
AP-1 (C)					
Runoff	0	0	0	0	(0)
Drainage	320	15 (0*)	0	0	(335)
Deficit (ET)	0*	0*	0 (4–9*)	0–26**	(0–26)
AP-2 (NC)					
Runoff	292	12	14	9	(327)
Drainage	47	9	0	0	56
Deficit (ET)	0	0	9–74	51–56	(60–130)
AP-2 (C)					
Runoff	0	0	0	0	(0)
Drainage	310	21 (0*)	0	0	(331)
Deficit (ET)	0*	0 (0*)	0–60 **	46–51**	(46–111)
AP-T (C)					
Runoff (SAT.)	250	0	0	0	(250)
Drainage	190	0	0	0	(190)
Days (SAT):	20 days	0	0	0	(20 days)

Note: * = green cover crop; ** = dry cover;*** = range: depending on variety and soil moisture stress; SAT = soil saturated with water).

TABLE 4

Soil-water balance components in relation to crop-water requirements in the grapevine growth periods, selected years (D: dry; H: rainy) and sites of the Priorat region

Growing period	Resting	Budbreak–Bloom	Bloom–Veraison	Veraison–Harvest–Fall	Total
			(mm)		
ET (Cover)	130	140	419	250	639
ET (Vine)***	10–20	40–45	200–265	95–100	340–430
Rain (Dry)	**140**	**65**	**88**	**80**	**333**
P-1 (NC)					
Runoff	0	0	0	0	(0)
Drainage	76	20	0	0	(96)
Deficit (ET)	0	0	30–95	15–20	(74–149)
P-1 (C)					
Runoff	0	0	0	0	(0)
Drainage	0	0	0	0	(0)
Deficit (ET)	0*	0 (87–92*)	59–129**	15–20**	(74–149)
P-2 (NC)					
Runoff	0	0	0	0	(0)
Drainage	97	25	0	0	(122)
Deficit (ET)	0	0	51–116	15–20	(66–136)
P-2 (C)					
Runoff	0	0	0	0	(0)
Drainage	0	0	0	0	(0)
Deficit (ET)	0*	0 (100–105*)	67–137**	15–20**	(82–157)
P-T (NC)					
Runoff	0	0	0	0	(0)
Drainage	70	20	0	0	(90)
Deficit (ET)	0	0	2–67	15–20	(17–87)
P-T (C)					
Runoff	0	0	0	0	(0)
Drainage	0*	0	0	0	(0)
Deficit (ET)	0*	0 (75–80*)	47–117**	15–20**	(62–137)
Rain (rainy)	**530**	**70**	**108**	**25**	**733**
P 1- (NC)					
Runoff	142	0	0	0	(142)
Drainage	303	30	0	0	(333)
Deficit (ET)	0	0	10–75	70–75	(80–150)
P -1 (C)					
Runoff	0	0	0	0	(0)
Drainage	315	30 (0*)	0	0	(345)
Deficit (ET)	0*	0 (28–33*)	10–75**	70–75**	(80–150)
P-2 (NC)					
Runoff	132	0	0	0	(132)
Drainage	298	30	0	0	(328)
Deficit (ET)	0	0	31–96	70–75	(101–171)
P-2 (C)					
Runoff	0	0	0	0	(0)
Drainage	300	30 (0*)	0	0	(330)
Deficit (ET)	0*	0 (49–54*)	10–75**	70–75**	(80–150)
P-T (NC)					
Runoff	0	0	0	0	(0)
Drainage	450	30	0	0	(480)
Deficit (ET)	0	0	0–47	52–57	(52–104)
P-T (C)					
Runoff	0	0	0	0	(0)
Drainage	320	30 (0*)	0	0	(350)
Deficit (ET)	0*	0 (0–5*)	0–47**	52–57**	(52–104)

Note: * = green cover crop; ** = dry cover;*** = range: depending on variety and soil moisture stress).

The small absorption terraces in the Alt Penedés (AP-T) may reach conditions triggering mass movements (days with soil moisture greater than the liquid limit, high runoff under saturation, and high potential internal drainage), mainly in the resting period (R) of the rainier seasons (H).

In the bench terracing of the Priorat region (P-T), with more effective rooting depth of vines and greater available water retention capacity, there would be less probability of drought in the drier (D) years. In extremely humid years, especially with continuous and concentrated rainfall in the resting period (R), there would be potential conditions (high internal drainage following soil-moisture conditions close to saturation on the soil profile for prolonged periods) for triggering landslides in the non-protected embankments of the terraces. A green cover crop in that period, using part of the excess water, would decrease the possibility of landslides.

In general, it may be concluded that the new, fully mechanized, land-management and cropping practices in the dryland vineyards of the Alt Penedés and Priorat regions of Catalunya result in drastic changes in the soil-moisture regime. The major effects are on surface runoff, surface erosion and mass movements, and in the retention of rainfall water in the soil for utilization by the grapevines. Analysis, based on appropriate *in situ* evaluations of climate characteristics and of soil hydrological properties and processes, complemented with the use of simple simulation water-balance models based on those processes, may be very useful, and even indispensable, for an adequate planning of more sustainable land use and management for grape/wine production, or other alternative uses. The study reported here investigated different previewed scenarios of changing climate and agricultural policies with strong potential to cause changes in land use and management in the Mediterranean region.

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