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ENERGY EFFICIENCY AND LIFE CYCLE ANALYSIS OF ORGANIC AND CONVENTIONAL OLIVE GROVES IN THE MESSARA VALLEY, CRETE, GREECE.

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Thesis

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Abstract

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The objective of this study is to determine what makes olive production systems more energetically efficient and environmentally friendly. Since the achievement of sustainable orchard production is a process of continuous improvements in which unsustainable practices are progressively eliminated while maintaining business profitability, a 'cradle to farmgate' approach, in both energy accounting and life cycle analysis was used to determine efficient and ecologically sound cultural practices.

Energy efficiency measures the technical performance of the agrosystem. If it could be improved, environmental damage could be reduced while, at the same time, agronomic performance could be ameliorated. In order to verify these hypotheses, methodologies and questionnaires were set up to investigate two farms management approaches (organic versus conventional) on the hills and on the plain of the Messara Basin. Data obtained from interviews, field observations and soil analysis were used to calculate potential environmental impacts of the different farming systems.

It was found that the organic groves are twice as much efficient, in terms of energy, as the conventional ones. With the organic cultural practices, the average result obtained for the energy efficiency study is 6 Joules per Joule (J/J), compared to 3 as an average for the conventional groves. Meaning that 1 non-renewable energy unit, in Joules (J), used in the organic production systems results in 6 J of olives.

When analyzing the environmental impact categories (eutrophication, acidification, global warming, erosion, biodiversity loss, energy and groundwater depletion), it was noticed that improvements could be made by farm management types, with respect to resource depletion categories and emission of acidifying compounds. Organic production obtained a better score for the majority of the environmental impact categories. Erosion potential was found to be really higher than tolerable ecological limit. Also, two cultural practices have been highlighted for being ecologically sound: cover-cropping and chopping, incorporation of pruning residues.

Concerning the relationship between energy efficiency and environmental impacts, the only conclusion that could be drawn is the influence of higher energy efficiency on the emission of greenhouse gases contributing to global warming.

The general conclusion is that the combination of energy efficiency study with a Life Cycle Analysis is a valuable tool for the development of sustainable production systems, as these incorporate technical and ecological assessments.

Keywords: Energy efficiency, Life cycle analysis (LCA), Sustainable farming systems, Environmental impacts, Olive production, Organic farming.

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Iannis was studying insect populations, comparing organic and conventional olive groves, in the same institute. He has been really friendly and he made my task more joyful. I would also like to thank his father; although we could not understand each other, he showed me a lot of affection, he will always be in my heart.

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CONTENTS

INTRODUCTION

Modern agriculture and particularly oliviculture in Crete, as in many olive producing regions in the Mediterranean Basin, face agronomic, ecological, and socio-economic problems. These problems are due to a lack of respect for food quality, agrosystem processes'capacity and the environment (Vassiliou, 2000), as the conventional production usually aims at maximum yield level and financial returns.

Consumers are increasingly sensitive to these problems, leading to demand for organic products on the market. The perspectives of ecological olive production seem satisfactory as economic costs do not increase at the farm level (Kabourakis, 1993). Besides, there are market premiums for organic olive products (olive oil, table olive and olive paste) and the market for organic products is growing quickly. Furthermore, with the introduction of agri-environmental laws within the European Union, economic incentives are given to growers to farm ecologically.

For these reasons, there are good opportunities for more environmentally sound olive grove management. Nevertheless, there is a serious lack of research on what truly makes agricultural activities more environmentally friendly. Therefore, this study aims at defining methodologies (Life Cycle Analysis and energy efficiency study) to assess the ecological benefits or drawbacks of olive farming with a holistic approach, characterizing the cultural practices involved in the processes of environmental loads, comparing the groves'type (organic and conventional) on the basis of their environmental burdens, and finally, relating the two methodologies used: Life Cycle Analysis and energy efficiency.

Research question :

How do the types of olive productions (organic versus conventional) influence the energy efficiency and environmental impacts?

Hypotheses :

- Since environmental burdens can be considered as a sink for the agrosystem, loss of material and energy are in contradiction with its efficiency.
- Energy efficiency, or the energy content of the crop per unit of non-renewable energy used, is a good indicator of effective resource management.
- The organic orchards are more energy efficient than the conventional ones.
- The organic orchards are less harmful to the environment than the conventional ones.

Objectives :

- Identify orchard type leading to high energy efficiency,
- Assess the environmental loads of the different olive grove systems,
- Characterize the cultural practices involved in the processes of environmental loads,
- Compare the groves' type to their environmental burdens,
- Relate the two assessment approaches: Life Cycle Analysis and energy efficiency.

1. Olive farming

1.1. Production of olives and its environmental effects

1.1.1. Olive production in Europe

Olive production is a significant land use in the southern member states of the European Union (EU) with important environmental, social and economic considerations. The main areas of olive oil production are Spain (2.4 millions ha) (Table 1), followed by Italy (1.4 million ha), Greece (1 million ha) and Portugal (0.5 million ha). France is a much smaller producer with 40 000ha.

The percentage of national UAA (useful agricultural area) occupied by olives is 7% and 9% in Spain and Italy respectively, but around 20% in Greece. Whereas 6.5% of all farms in Spain have olives as a part of their production, this rises to 15% in Greece and 37% in Italy.

Table 1: Production of olive in Europe (IOOC, 2001):

	Olive area (hectares) (1)	*Oil production (tonnes) (2)*	*Producers (1)*	*Approx. % world olive oil output (2)*
Spain	2 423 841	535 000	396 899	28
Italy	1 430 589	467 000	998 219	24
Greece	1 025 748	307 000	780 609	16
Portugal	529 436	35 000	117 000	2
France	34 421	2 000	19 271	<0.1
EU	5 449 035	1 346 000	2 311 998	70

(1) EC figures from "Oliarea" survey, quoted in Agricultura, 2000.
(2) Polidori *et al.*, 1997. Production figures are annual average 1990/91 to 1995/96, IOOC estimates.

Plantations that produce table olives cover a far smaller area than those producing olive oil. In Spain, less than 6% of the total area is devoted to table olive production whereas the figure in Italy is less than 3%.

The EU currently dominates the global market, producing over 70 per cent of the world's olive oil. Tunisia, Turkey and Syria are the only other producers of significance, accounting for over 20 per cent of world production.

The average size of olive groves in the EU countries is extremely small. In Italy, the average olive grove is less than 1ha, 1.8ha for Portugal. However, large olive holdings are also an important part of the sector even though there are few of them.

Olive farming provides an important source of employment in many rural areas of the Mediterranean, including many marginal areas where it is either a principal employer or an important part-time employer, which can be combined with other activities such as tourism. Olive farming is also an important part of local rural culture and heritage in many areas, and is being maintained and "valorized" through labeling schemes in some cases (EFNCP,2000).

However, this employment is far from secure. In more productive regions, continued mechanization (especially of harvesting and pruning) in more modern systems is leading to a considerable reduction in labor requirement, which is likely to be accentuated in the near future. In marginal areas, employment in olive farming is seasonal and low-paid, and aging populations and emigration are leading to reduced availability of labor. For similar reasons, the cultural and heritage values are also being lost in many areas of the Mediterranean Basin.

1.1.2. ENVIRONMENTAL EFFECTS OF OLIVE FARMING IN EUROPE

With appropriate management, olive farming can contribute to the conservation of natural resources and values. But the tendency in recent years has been towards environmental degradation as a result of bad farming practices, the expansion of intensive plantations and the marginalization of low-input farms.

Almost the whole of 2,250 million euros of the EU Common Agricultural Policy (CAP) budget for olives is spent on production subsidies, paying farmers according to the amount of olives they produce, a policy that encourages intensification of production, irrigation and the expansion of olive growing.

"Intensive olive farming is a major cause of one of the biggest environmental problems facing Europe today" said Elizabeth Guttenstein, WWF's European Agriculture Policy Officer. "Olive farming could be a model for environmentally and socially sustainable land use in the Mediterranean region. Instead EU subsidies for olive farming are driving the Mediterranean environment to ruin." (EFNCP, 2000). The problems related to environment are described below in four parts: Soil, Water, Air and Biodiversity.

1.1.2.1. SOIL

Soil erosion is one of the most serious and widespread environmental problems in the Mediterranean region. Erosion reduces the soil’s productive capacity, making it necessary to use more fertiliser. Topsoil, fertilizers and herbicides are washed into watercourses and water bodies, causing widespread pollution (Garcia Torres, 1999). In extreme cases, soil erosion leads to desertification, or serious degradation of the soil, once this situation is reached, recovery is extremely difficult, and the capacity to support vegetation is lost.

In intensified olive plantations, farmers usually keep the soil bare of vegetation all year round, by regular tillage. This is mostly up and down the slope rather than following the contours. Severe erosion takes place with the arrival of torrential autumn rains on bare soils that have been cultivated to a fine tilth by summer harrowing. Erosion is most extreme on steep slopes, where many plantations have been established without supporting terraces. But even on relatively flat land and on terraces, severe soil erosion can result from inappropriate soil management.

Intensive tillage not only exposes the soil to the erosive effects of rainfall, it also increases the soil vulnerability by reducing its organic matter content, especially when combined with the use of non organic fertilizers and residual herbicides. The decline in the organic matter content of many soils in southern Europe, as a result of intensive cultivation practices, has become a major process of land degradation, according to the European Soil Bureau (1999).

Effective solutions to soil erosion are available. In some cases, relatively small changes in farming practices may be sufficient, such as shallower and less frequent tillage, and the maintenance of a grass cover on the soil at the most critical times of the year. Research shows that these measures can lead to an increase in yields at the same time as tackling the environmental problem (Pastor *et al.*, 1997).

In some situations, the construction of small earthworks may be necessary to control water run off, implying costs for the farmer. In extreme cases, it may be advisable to turn steeply sloping land over to forest (with low intensity management, such as light grazing to prevent fires), which is the most effective protection against erosion.

Traditionally, terraces were created with supporting stonewalls, to enable the cultivation of hillsides in upland areas without excessive soil erosion. These terraced systems are still common in many parts of the Mediterranean region, and represent an enormous historic investment of human time, energy and skills. But their maintenance is labour-intensive and abandonment is quite common in marginal areas. This can lead to landslips and sometimes to desertification; for example, when it is followed by repeated wild fires or over-grazing by sheep and goats. Support measures are needed which maintain the economic viability of traditional systems without encouraging intensification, and which reward the conservation of existing terraces.

In Greece, large areas of land have been cleared in recent years (EFNCP, 2000) for new olive plantations and are subsequently eroded by gullies. Upland areas with olives on shallow soils are especially vulnerable to erosion because of intensive tillage and soil compaction from farm machinery (EC, 1992; Yassoglou, 1971). Soil erosion is caused in some areas when intensive goat and sheep grazing follows the abandonment of traditional plantations.

*1.1.2.2. **WATER***

There are two main problems related to the impact of the olive farming on water, pollution by run-off and leaching of fertilisers and pesticides to surface and ground waters and over exploitation of ground and surface waters for irrigation.

The pollution of surface waters by fertilisers is an important consequence of soil erosion caused by olive cultivation, as confirmed by numerous publications. Residual herbicides, such as Simazine, are widely used in intensified-traditional and modern intensive olive plantations. These chemicals remain highly concentrated in the top 5-15 cm (Cirio, 1997), even after several months, and are washed into streams, rivers and reservoirs with the soil that is eroded with rain. Soil run-off from olive plantations into reservoirs also leads to important economic costs, as in the case of the silted-up Guadalén reservoir in Jaén, Andalucia (Pastor *et al.*, 1997).

Nitrogen inputs in the most intensive, irrigated olive farming can reach high levels (up to 350 kg per hectare in extreme cases), so experience from arable farming systems suggests that a problem of groundwater pollution by eutrophication is likely to exist in some olive areas. However there is little monitoring or research of ground water pollution in intensive olive plantations (EFNCP, 2000 and Kabourakis, 2000).

Excessive applications of nitrogen fertilizers in continuous cultivation without cover cropping can lead to nitrogen leaching. Nitrogen leaching may pollute surface and ground water with hazardous compounds. Excess of potassium and phosphorous fertilizers contaminates also the soil with these macronutrients. This contamination may create nutrient deficiency in olive trees and even leaching of these nutrients to surface and groundwater (Androulakis and Loupasaki, 1990; Gavalas, 1978; Kedros *et al.*, 1988). Soil and water can be contaminated by the random uses and the overdoses of synthetic fertilizers and other agrochemicals (Vassiliou, 1998).

The exploitation of ground and surface waters for irrigation is an enormous environmental problem in the Mediterranean region. Irrigation is expanding rapidly in the olive sector and is contributing to the unsustainable use of water resources that have already been degraded by other agricultural sectors. Although the quantities used per hectare are relatively low compared to arable cropping, irrigated olive plantations cover an increasingly large area in some regions and their total impact on water resources is considerable.

Angelakis *et al*. (1998) report that in parts of Messara plain there has been a dramatic drop of 20 metres in the groundwater level since 1985, although it is not known to what extent olive irrigation has contributed to this over-exploitation. Deep wells for irrigation have been installed in many fields especially in the plain and surrounding hills, converting what used to be dry olive trees cultivation to drip-irrigated cultivation. The rise in yield in olive groves has been achieved at the cost of a dramatic reduction in the groundwater level, as there is no effective control on the amount of water that is extracted.

Furthermore, the increasing demand for irrigation water leads to an indirect impact on the environment through the construction of new reservoirs (EFNCP, 2000). In southern Spain and Portugal, several major dam-building projects have been identified as the principal threat to the survival of the Iberian lynx (*Lynx pardinus*), an endemic Iberian species on the verge of extinction and strictly protected under the EU Habitats Directive (WWF, 1999).

1.1.2.3. AIR

There is no data concerning the effects of the olive tree cultivation on air quality, although its impacts should be low, the following factors should be considered:

- Air pollution from burning pruning residues, the leaves and twigs washed from the olives before processing. The total volume of material burned is considerable but so far no analysis has been made of the resulting air pollution.

- Air pollution resulting from chemical treatments; especially aerial spraying against olive fly.

- Carbon dioxide emissions resulting from tractors, especially in the case of repeated tillage (Fernandez Quintanilla, 1999).

1.1.2.4. BIODIVERSITY

Reasons for diversity loss:

Monoculture and the high concentration of olive trees in certain areas of Crete as well as high plantation density increase the risk of damage from pests and pathogens (Kedros *et al*., 1988) since the self-regulation mechanisms of the agro-system become disrupted, and therefore the use of pesticides becomes necessary.

Biodiversity tends to be high in traditionally managed olive plantations as their structural diversity (trees, understorey, patches of natural vegetation, dry-stone walls, etc.) provides a variety of habitats (EFNCP, 2000). The older trees support a high diversity and density of insects that, together with the tree's fruit, provide an abundant supply of food (Parra, 1990). The low level of pesticide use allows a rich flora and insect fauna to flourish, which in turn provides a valuable food source for a variety of bird species.

However the intensive application of techniques for increasing production (especially frequent tillage and heavy herbicide and insecticide use) has a strongly detrimental effect on ground flora and on insect populations and results in a very considerable reduction in the diversity and total numbers of flora and fauna. Some of the agro-chemicals used in conventional olive farming, such as Dimethoate and Fenoxycarb, have been found to cause a dramatic reduction in a wide spectrum of insect species, including several which have a beneficial role in controlling pests' species (Cirio, 1997).

The rationalisation of olive production through replanting or clearing is regularly practiced in Crete (EFNCP, 2000). This is usually accompanied by the clearance of remaining patches of natural vegetation, field boundaries, rocky areas and dry-stone walls, leading to a significant loss of wildlife habitat, and the erosion of the "ecological infrastructure" of the groves (Kabourakis, 1999).

IMPACT ON FAUNA

Rationalisation can be detrimental to bird species that breed in the gnarled trunks of old trees (e.g. little owls) or breed or feed in the vegetation around the bases of trees (Quail and Partridge), or between the trees on semi-open ground (Woodlark and Stone Curlew) as many of these features are lost or modified through this process (Pain, 1994).

The use of Cretan olive plantations as a food source by very large numbers of migrant passerine birds, both from northern and central Europe and from Africa, is really important as a stage (Farina, 1981). Where pesticides are used intensively to control specific herbivorous insects, the overall insect population inevitably suffers and the food source for birds is reduced. Moreover, research (Farina, 1981 and Pain, 1994) seems to show that birds feeding on olives do not have a significant impact on production. The fruits taken are generally over-ripe, fallen to the ground and/or have been attacked by olive fly, and are therefore of little value. Birds may even help to control pests by eating infected fruits.

IMPACT ON FLORA

The number of sheep and goats in the island has almost doubled between 1961 and 1991 (Agricultural Statistical Service, 1992) and this trend is currently continuing, while the number of cows has decreased. Under extreme conditions, overgrazing can affect the health of the plant communities, even producing a change in species'composition. The decline in vegetation by overgrazing can result in a loss of these plants. Among the herbaceous family are *Leguminosae* which contribute to nitrogen fixation in the soil and increase organic matter, and *Graminae*, which help to maintain soil structure, provide good conditions for soil flora and fauna, and give shelter for insect species.

Shepherds damage the forest and natural grasslands by deliberately setting fires to eradicate woody vegetation and encourage growth of grass, which they then overgraze. Once the land is stripped of its cover and the soil is loosened, autumn and winter rains begin to wash away the topsoil. Grove and Rackham (1996) report that from the early eighties onward there has been a significant increase in the frequency and magnitude of forest fires in Crete. Man has regularly employed fires as an important tool in land reclamation and utilisation for cultivation and grazing, because a fire may temporarily increase land productivity (Angelakis *et al*., 1996). After fire some species generate rapidly (herbs and grasses), generating favourable conditions for grazing, but the number of shrubs and trees is decreased (Grove and Rackham, 1996).

1.1.3. OLIVE FARMING IN THE MESSARA VALLEY, CRETE

1.1.3.1. OVERVIEW OF THE CRETAN OLIVE SECTOR

In Crete olives are cultivated since antiquity, as archaeological evidence form the Minoan era shows. Today, Olive production occupies around 70% of the total cultivated land. Olives are cultivated in coastal areas and often in slopy orchards at the foothills of the mountains. Olive orchards are often combined with vineyards, arable and grazing land. The soils are rocky and often shallow and eroded.

There are about 30 million olive-trees in Crete, cultivated by approximately 95,000 families. 80-90 % of the Cretan olive oils is of high quality contrary to other producing countries, where good quality is met at a percentage of only 20 to 30% (Kapellakis, 2000). The average annual production in Crete reaches 100,000 tons, almost 40% of the total production of Greece. A quantity of 5,000 to 10,000 tons is exported annually, mainly to America and certain European countries (ibid.).

The Cretan olive growers' cooperative is facing increasing financial problems due to inadequate management and marketing policy, and a lack of state structural policy for the olive sector. Thus, financial aid favors the processing sector rather than the growers. The majority of exported olive oil that is produced in Crete is sold in bulk, due to the inadequate marketing of export products of the cooperatives and lack of promotion by the state. Therefore, olive oil receives lower added value and prices than it potentially could, although its quality is of high standard.

The financial problems of olive oil producers are also due to the current economic situation characterized by the stable price per unit of olive oil and decreasing incomes since the price of inputs increase, although the total production and productivity increase. Additionally, growers' incomes are highly dependent on subsidies (Kabourakis, 1996).

In Crete, 50% of the total labor force is employed in agriculture compared with 22.2% at the national level (CPER, 1991). Agriculture, however, is at a major crisis. Two symptoms may be identified: deterioration of rural income and employment, and deterioration of the environment, nature and landscape. The latter is mainly due to specialization and intensification in agricultural production, which creates deterioration of the environmental quality that is the strength of the island for development.

1.1.3.2. THE ORGANIC OLIVE PRODUCTION SECTOR

Attempts have been made since the early eighties to reverse the negative effects of olive and olive oil production and of conventional agriculture in general by the introduction of organic farming. During this period, the first organic growers appeared, scattered throughout Greece (Milhou, 1987). Their initial target was to convert olive cultivation to organic systems or at least to maintain traditional olive systems with either very little or no external inputs, thus characterizing them as "organic". Their efforts to disseminate the "new" agriculture were not always fruitful in spite of the market opportunities they were offering through their connection with the European organic market.

Initially, in the late eighties, the first commercial organic projects and the implementation of EU Reg. 2092/91 and 2078/92, at the beginning of the nineties were the principle factors that boosted organic agriculture in Greece and in Crete, transforming the organic movement from a system of values to a certification system (Lampkin *et al.*, 1999).

In 1993, at Messara plain, on the island of Crete, the Ecological Olive Production Systems (EOPS) concept was designed, developed and applied. EOPS was introduced not only under the pressure to overcome the shortcomings of conventional olive production but also to transform the current frame of allowances and prohibitive rules that apply to much organic agriculture. EOPS considers agricultural production to be multi-dimensional where technical, socio-economic, ethical, cultural and political aspects come together and affect the production process (Kabourakis, 1996). It envisions an environmentally sound, long-term agroecosystem where the socio-economic needs of the growers should be met, giving them social perspectives and stimulating regional development (Kabourakis, 1996).

Initially, EOPS was designed and established during an innovative on-farm research project by E. Kabourakis and introduced in the Messara area in 1993. EOPS is based on the EU Research Network on Integrated and Ecological Arable Farming Systems prototyping methodology (Vereijken, 1994; 1995; 1997; 1998) and on an ecological knowledge system. One year after the introduction of EOPS into the area, the Cretan Agri-environmental Group was founded, a network to disseminate EOPS and giving it a legal status. In 1998, the "Organic Farmers of Messara" Cooperative was founded; its 100 members are the first farmers in the area to adopt EOPS.

1.1.3.3. DESCRIPTION OF THE MESSARA BASIN

A. LOCATION

The Messara Basin constitutes the most important (both in size and productivity) agricultural area in Crete. It lies in the central-southern part of Crete (Prefecture of Iraklio) and consists of a narrow stretch of land, running from east to west, approximately 398 km^2. It is located from 23º30' to 26º19' longitude and from 34º54' to 35º41' northern latitude (see Figure 1). It is drained by the Geropotamos River to the west and by the Anapodaris River to the east and is bounded to the west by the sea (Gulf of Messara), to the north by the foothills of the Mount Ida (2,456 m), to the south by the Asterousia mountain chain (979 m) and to the east by the foothills of the Dikti Mountain (2,148 m). Lying between two stretches of high ground to the north and south, Messara Basin resembles a long corridor, and can be examined as a river basin model (Kapellakis, 2000).

B. GEOLOGICAL CHARACTERISTICS

It is an alluvial Basin mainly composed of quaternary deposits (from modern era), bordered to the north by a hilly area of silty-marley gneiss and by schist and limestone formation to the south. The large limestone massif of Mount Ida has practically no hydrological relationship with the Messara Basin (Yassoglou, 1971).

C. CLIMATE CONDITIONS

The Messara Basin has a semi-arid climate, classified as a subtropical Mediterranean, with mild moist winters and dry hot summers. The average annual precipitation level is approximately 600mm and mostly occurs from November to February (Kapellakis, 2002). The average annual evaporation is around 1,700 mm. Winds typically come from the west, northwest, and are mostly arid and warm but due to the increased rate of evaporation, appear to be subjectively cooler (Kapellakis, 2002). The percentage of dead calm days is approximately 35%. Average winter temperature is 10ºC, whereas for summer it ranges at 28ºC (Kapellakis, 2000; Kornaros, 2002).

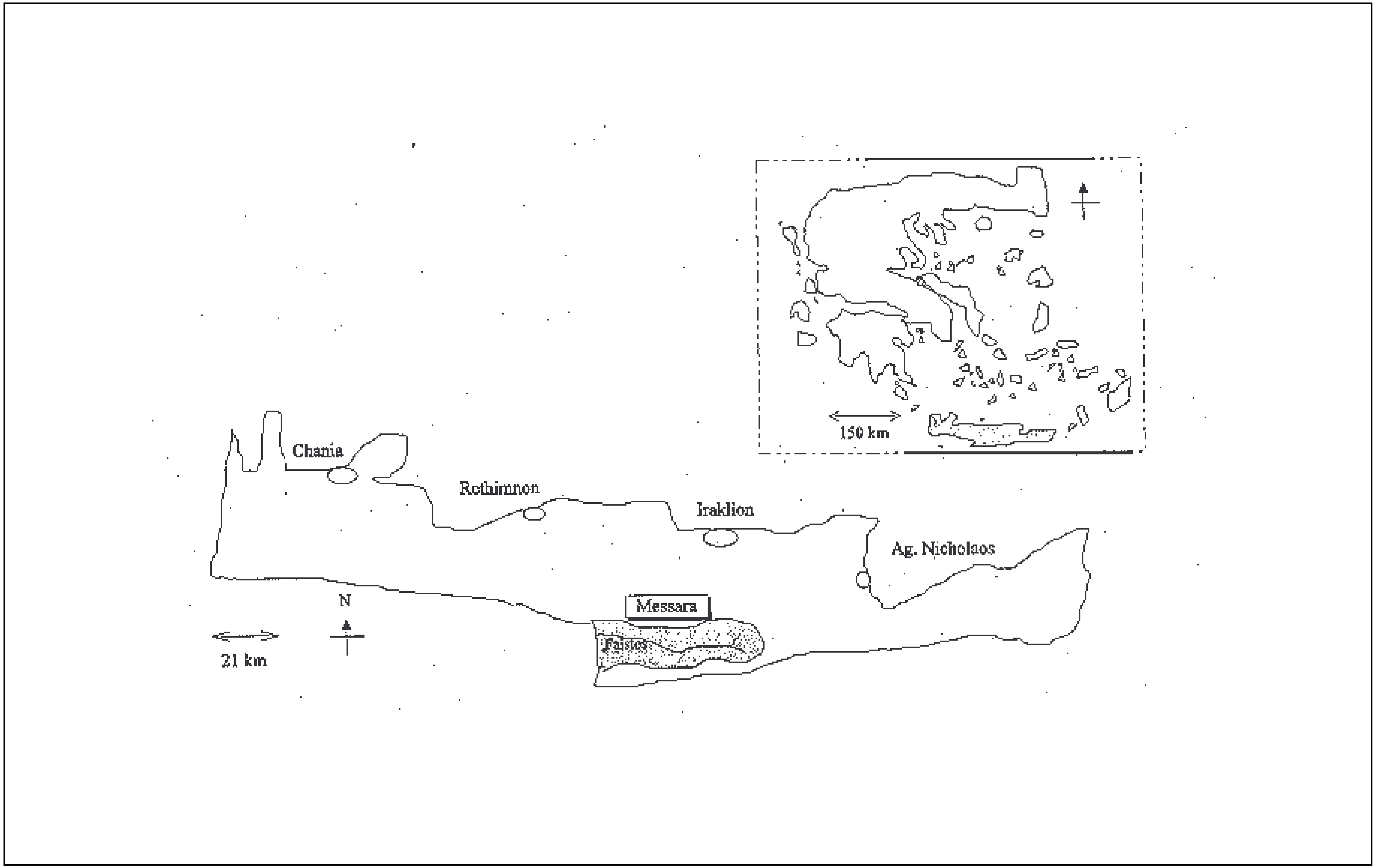

Fig.1: Map of the study area

D. WATER RESOURCES AVAILABILITY

The total water use in Messara Basin is estimated to be 50 million m^3/yr, of which almost 90% is considered to be irrigation water, while domestic, touristic and industrial use represents only a small portion (Angelakis *et al.*, 1996; Chartzoulakis *et al.*, 2001). There are significant imbalances in water availability and demand, where 73% of annual rainfall occurs between November and February (Kornaros, 2001) yet both agriculture and tourism require increased supplies during the summer when water availability decreases significantly. Additionally, although the basin contains several aquifers, the water table in the last ten years has fallen by up to 30 m during dry years (Vardavas *et al*., 1997).
There have been two studies carried out in the Messara Basin. The first was made by the FAO in 1971, with the aim of assessing whether pumping could lower groundwater levels sufficiently to enable agricultural development (the Basin was a swamp at this time), using a simple numerical groundwater model based on the work of Tyson and Webber (Tyson and Webber, 1963). The second was done as a part of the GRAPES project (Groundwater and River Resources Action Programme on a European Scale), aiming at explaining the groundwater level decline of the previous decade, using the numerical model AQUA 3D. The results are reported in the Table 2 below.

Table 2: Model of groundwater balance for 1971 and 1993 (Acreman, 2000):

PROCESSES		1971 FLOWS (10^6m^3/y)	1993 FLOWS (10^6m^3/y)
INPUT	Stream bed infiltration	8	1.4
	Groundwater leakage	10.4	10.4
	Irrigation return	1.5	6.6
	Direct infiltration	10	2.7
	Total	**29.9**	**21.1**
OUTPUT	Abstraction	5	22
	River and spring flow	16.9	5.3
	Groundwater flow	9.3	5.4
	Total	**31.2**	**32.7**

From the above Table, it is apparent that water abstraction, including agriculture, quadrupled in the 20 years period. This has been possible by the construction of water management items retaining river and spring flow from 16.9 to 5.3 Mm^3/y. Nevertheless, the onset of a period of extended drought will probably cause the aquifer to fail at some pumping stations (Acreman, 2000). Also, climate change scenario predicts a significant reduction of rainfall, representing the most aquifer recharge input, during winter months. Consequently, demand should be reduced at 1/3 of 1993 abstraction rate (Acreman, 2000).

E. LAND SENSITIVITY TO DESERTIFICATION

The high erosion rates occurring in Mediterranean areas are attributed to the climatic regime and to the existing generally poor vegetation cover. Semi-arid and sub-humid landscapes, as the Messara region, by definition are water-limited and therefore are potentially sensitive to environmental change and its effect on biomass production (Angelakis *et al.*, 1996). The considerably high variation in erosion rates in the hilly area of Messara valley reflects the great importance of total rainfall as well as land use and parent material.

Extensive hilly areas with shales-sandstones or flysh substratum perform smaller erosion risk. The soils are moderately fine-textured, permeable, and have a moderate to rich vegetation cover (Angelakis *et al.*, 1996). However, if the natural vegetation is removed (fires, forest clearance, etc.), the areas on flysh are very susceptible to gully erosion and landslides. Studies of erosion rates on soils formed on above parent materials demonstrated that soils on marls exhibited higher run-off rates and sediment loss under similar slope grades and management practices as compared to other materials (Kosmas *et al.*, 1995).

Removal of vegetation cover is probably the most crucial cause of soil erosion, soil degradation and desertification (Angelakis *et al.*, 1996). Studies of biomass production in soils with different parent materials along catenas demonstrated that lands on marls are very susceptible to degradation. The soils cannot support any annual vegetation, particularly in dry years, despite their considerable depth and high productivity in normal and wet years (Kosmas *et al.*, 1993). On the contrary, soils on conglomerates and shales-sandstones, despite their normally low productivity, may supply appreciable amounts of previously stored water to the stressed plants and to secure a not negligible biomass production especially in dry years.

Soils on shales-sandstones and conglomerates usually contain rock fragments in different amounts depending on landscape position and degree of erosion. The presence of rock fragments especially on the soil surface is very important for two reasons. On the one hand, because during dry years there is a conservation of an appreciable amount of soil and water from evaporation through surface mulching (Kosmas *et al*., 1993). On the other hand, there is a direct effect on soil erosion rates depending on the size of the rock fragments (Moustakas *et al*., 1995).

1.2. Olive tree characteristics

1.2.1. Tree phenology

Olive yield and production are highly variable from year to year. Alternate bearing accounts for part of this variability. In the "on" year, trees produce abundant flowers and set more fruit than can grow to marketable sizes. In addition, the large crop of fruit draws down carbohydrate reserves, causing sub-normal shoot growth. A large crop also delays fruit maturity and increases the chance of losses due to early-Fall frosts.

Since olive trees develop fruit buds on the previous year's shoots, repressed shoot growth diminishes the crop potential for the next year, the "off" year. The alternate-bearing pattern in olives, however, occurs less dependably than among certain other tree crops, such as pecans and pistachios. Sometimes, olive trees produce large (small) crops for several years before yielding a small (large) crop.

Alternate bearing can be somewhat controlled with various pruning, irrigation, tree spacing and varietal choices and a dry year can easily be corrected with additional irrigation. However, each variety reacts in its own way to such factors and having a small spread of varieties reduces the possible economic effects. Several investigations have been conducted to ascertain the effect of different weather components on the productivity of olive trees; the most relevant fact is the role of role of winter chilling in releasing olive floral buds from dormancy (Rallo *et al*., 1994).

1.2.2. Pruning practices

The objective of pruning is to increase fruit yield and facilitate harvest. This management is the same for both organic and conventional olive groves. Pruning can spread a bacterial disease known as olive knot with infected tools during rainy months; thus, special attention should be paid to disinfection in between trees. The problem of alternate bearing can also be avoided with careful pruning every year.

Pruning of the olive is tailored to the 3 different phases in the lifetime of the tree (Rebour and Pansiot, 1961):

1) Little or no pruning during the juvenile period when it does not bear fruits and has strong vegetative growth.
2) Light pruning during the mature stage when it reproduces, when the trees are at their peak productivity and when the shoot development is adequate.
3) Heavier pruning during old age to rejuvenate the tree.

Pruning normally aims at:

- Allowing the optimum amount of air and light into the tree to maximize fruit production and minimize disease.
- Removing non-fruit-bearing branches to reduce light competition with the fruit-bearing wood that is one-year-older.
- Reducing the tendency to alternate bearing.
- Containing the shape and size of the tree for efficient management.
- Removing suckers and dead wood.

1.2.3. Nutrient and water requirements

A. Nutrient requirements

Although the olive tree is known to grow well even in poor soils, its productivity depends on the interaction between a number of components including tree characteristics, its foliar nutrient status and availability of nutrient in soil (Jasrotia *et al.*, 1999). Several Research workers have reported increased tree vigor in olive tree following nitrogen (N) fertilization (Climato *et al.*, 1990; Sarmiento *et al.*, 1994). Soil application of N was observed to stimulate the assimilation process of carbohydrates and thus ascribed a higher growth rate. The annual application of N fertilizer to olive orchards is not necessary to obtain good production and growth when leaf N is above the sufficient threshold (Fernandez-Escobar and Marin, 1999).

Different levels of potassium (K) and phosphorus (P) also exert a significant influence on various growth parameters including trunk cross section area, tree volume and shoot extension growth. The role of K in increasing water uptake and consequently in cell expansion is established (Jasrotia *et al.*, 1999).

B. Water requirements

The long period of summer drought in olive-growing regions means that irrigation nearly always pays, even when annual rainfall is comparatively high. For, though the tree is particularly resistant to drought, it survives it only at the expense of the crop.

Irrigation is essential when the physical condition and depth of the soil do not allow sufficient water reserves to be built up during the rains. Thus clay soils, where light rains penetrate only a short distance and become lost by direct evaporation, or sandy soils with a rock pan at less than 80 cm depth, can scarcely be used without recourse to irrigation, even in rainy climate (Pansiot and Rebour, 1961).

1.3. ORGANIC FARMING PRACTICES

The current organic olive cultivation in the Messara Valley is based on traditional knowledge, scientific improvements, as foreseen by the Ecological Olive Production Systems or EOPS developed by E. Kabourakis (Kabourakis, 1996), and is ruled by the regulation (CEE) n°2092/91 on organic agriculture (see Appendix 1). Traditional olive production systems are ecologically and economically sustainable because they are based on an ecological knowledge system (Roling and Wagemakers, 1998). They can be characterized as mixed, combining perennial and annual crops, and animal (Kabourakis, 1998) (see Figure 2). Animal feed is produced on the farm or locally, while animal products are processed locally and their by-products, such as animal manure, contributed to the fertility of the farmland.

1.3.1. ORGANIC FERTILIZATION

Animal manure, compost, cover crops and pruning residues are used for fertilization in organic olive orchards. Soil fauna and flora are enriched with the use of cover crops, animal manures and compost. In the Messara Valley, organic matter content has been increased gradually in organic olive orchards from 0.5-1% to 2%-3%, depending on soil management and soil type (Kabourakis, 1999). These increased organic matter levels are due to the application of animal manure and compost, the incorporation of the pruning and other grove residues into the soil as well as the use of cover crops. Mixtures of leguminous plants with cereals are sown, in rotation, in autumn and managed in spring time.

There are two ways of fertilizing the organic grove soil: cover cropping with green manure or spreading of organic materials. Also, periodically, it may be required to add minimal amounts of mineral fertilizers of phosphorous or potassium (such as rock phosphate and patend kali), depending on soil types. Fertilization in ecological farming is done to maintain a high level of soil fertility and indirectly for olive tree nutrition. The fertilization plan must be combined with soil management (irrigation and soil tillage). Both fertilization types start at the beginning of autumn in order to allow the dilution of nutrients in the soil solution during the rainy season. The practice and techniques are explained in the Figure 2 in the next page.

1.3.1.1. ORGANIC MATERIALS

The organic materials (sheep and goat manure, compost, processed seaweed, dust, leavesand wood residues) are scattered around the olive trees and cover almost the whole ground surface in dense system of planting (200-300 trees/ha) (Kabourakis, 1996). In the traditional low-density system the materials are scatered around the trees in a circle covering two times the diameter of the canopy (ibid.).

They are incorporated into the soil with a cultivator. The quantity to be applied depends on the soil fertility of the grove, which can be estimated by soil analysis, nutritional condition of the olive trees, leaf analysis, the species used as green manure and the type of organic material used. An extensive and irrational use of animal manure tends to be avoided as it can cause pollution of surface and groundwater.

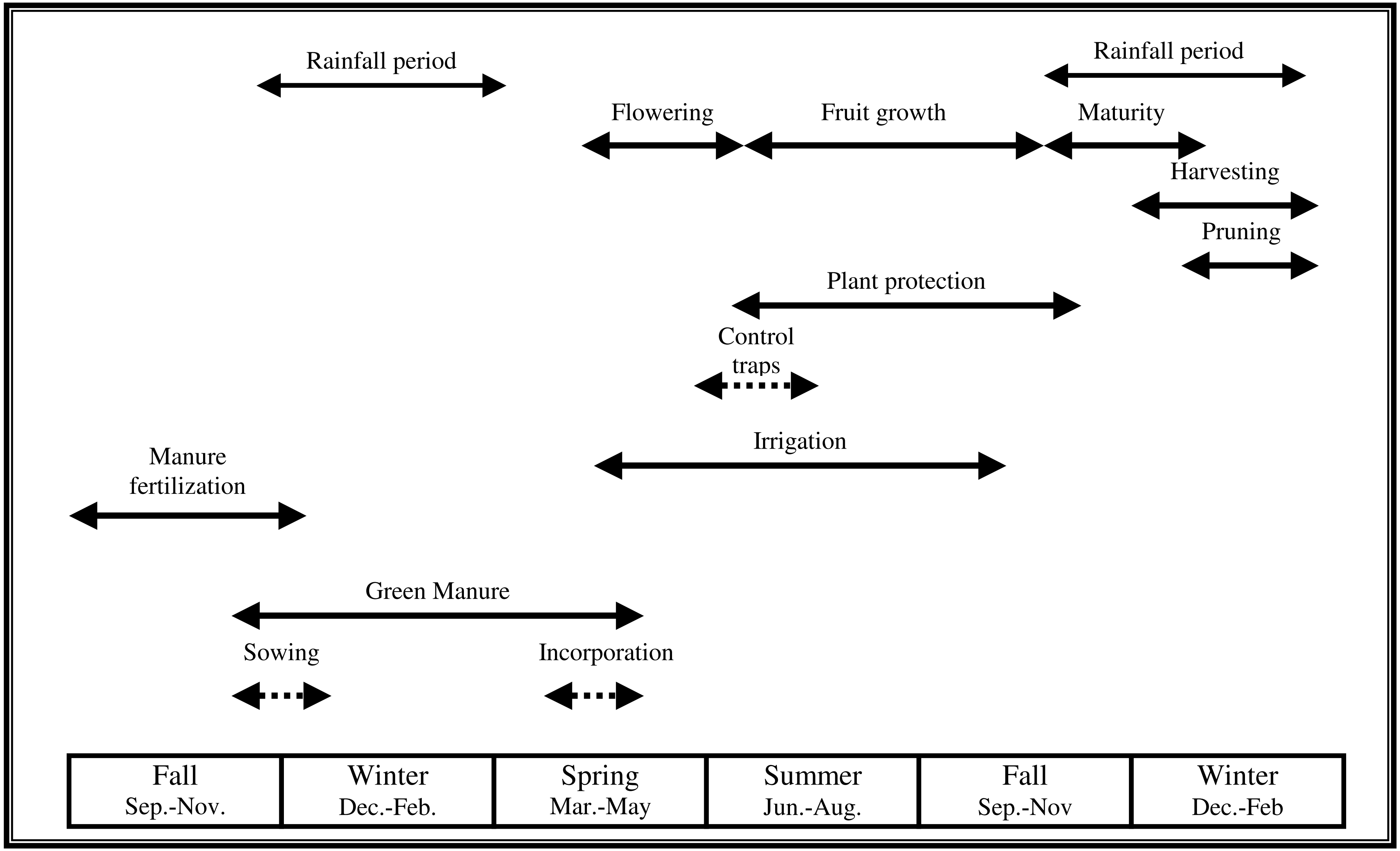

Fig.2: Growth cycle of the olive tree and timing of cultural practices in organic olive groves (from Kabourakis, 1993).

1.3.1.2. GREEN MANURE

The use of green manure as cover crop for the fertilization of the grove soil offers many advantages to the grower:

- Maximizes use of space (Dudley and Nagel, 1992);
- Provides continuous ground cover and therefore decreases erosion and weed growth;
- Enables better absorption of rainfall and water conservation;
- Offers shelter and food to beneficial insects and parasites of the olives enemies;
- Improves soil structure; and, of course,
- Fertilizes the soil.

Green manure plants are sown after the first autumn rain when the soil is ready for cultivation. They are incorporated before full flowering and the end of the rainy season. The fertilization plan generally includes legumes and *Graminae* within a five-year rotation scheme.An example is given below (Kabourakis, 1996):

1st year	**2nd year**	**3rd year**	**4th year**	**5th year**
Vetch (legume)	Vetch and barley (legume/*Graminae*)	Fava beans (legume)	Lentils (legume)	Barley (*Graminae)*

1.3.2. BIOLOGICAL PEST CONTROL

Insect pests and pathogen control in ecological olive production is done by controlling populations and strengthening tree. It is then based on prevention through stimulating diversity (providing beneficial insects to the ecosystem), cultivating methods and provision of balanced tree nutrition. Intervention with biological substances can be used if an infestation appears of such level that production might be threatened since most pests and diseases reduce oil quality and can cause severe crop loss.

<u>There are 4 basic principles for prevention of pests (Kabourakis, 1996):</u>

1) **Biodiversity development** through covercrop, weed management and infrastructure management, giving shelter to beneficial insects. Infrastucture management, or in other words the development and maintenance of a natural network within the olive groves (field margins and hedges), and covercrop management create conditions for the survival of pests' natural ennemies by increasing spatially and temporally habitats and food supply (Vereijken, 1994). This principle is of paramount importance for preventing sooty mould (*Fumago vagans*), a fungi developing on scales' (*Saissetia oleae*) honeydew, and for the olive fly (*Bactocera olea*e), a dipter spawning its eggs in olive fruit, whose population could be controlled with the help of insectivores such as birds.
2) **Appropriate pruning**, with emphasis on good shaping pruning, which secures good air circulation and sufficient sunlight penetration. This cultivation practice is specially recommended to prevent cryptogamic diseases such as sooty mould (*Fumago vagans*) and peacock (*Spinaloceae oleaginae*).

3) **Appropriate irrigation schedule**, which would avoid trees' water stress and sensitivity to external pathogens. An excessive irrigation stimulates the appearance and the increase in population of pests such as fungi or olive fly (*Bactocera oleae*).

4) **Balanced nutrition**, strengthening trees' natural defense against pests and pathogens.

There are four control methods:

1) **Mass trapping** used to decrease the olive fly (*Bactocera olea*e) population with use of sexual lure or color attractive traps.
2) Use of **organic compounds** such as Bt (*Bacillus thurigiensis*) against a moth (*Prays oleae*) whose life cycle is particularly destructive for the reproductive part of the olive tree: Arrambourg reports a case of severe moth attack causing 95% of crop loss (Arrambourg, 1984).
3) Use of **mineral substances**, allowed by EU n°2092/91, such as Bordeaux mixture (copper solution) against fungal diseases, mineral oils or a solution of petroleum and soap against scale (*Saissetia oleae*).
4) **Release of sterile male or natural ennemies** such as the hymenopter *Metaphycus Bartletti* who spawn its eggs in the scale (*Saissetia oleae*) parasiting it and killing it during hatching.

1.3.3. WEED CONTROL AND SOIL MANAGEMENT

The management of the olive grove floor is of paramount importance, especially in arid and steep slope areas of Crete. The risk of erosion and loss of biodiversity is a threat for the ecological olive grove. Tillage, maintenance of terrasses, covercropping (for weed and run off control), and maintenance of natural habitats contributes to health of the ecosystem, but also to the aesthetical value of the landscape.

The grove surface should be seen as a network of beneficial elements, such as stone walls for hilly groves, which retain soil from the upper parts, and of undisturbed areas. Corridors form a linear network in the grove and are constituted by field margins, hedges and ditches. This is important for the circulation and source of food for animals and insects within the whole grove.

Also, a non-linear natural area is left uncultivated in order to favor diversity of plant species such as wild fruit trees (almond or pear trees), aromatic plants and wild flowers (i.e. *Thymus capitatus*, *Laurus nobilis*) (Kabourakis, 1996). This spatial plant diversity contributes to diversify useful insects, such as pollinizers and auxiliary insects, bird species and other animals.
Those areas managed as natural habitats, apart from giving shelter to birds, animals and beneficial insects, create a buffer to the cumulative effects of the agricultural practices contributing to the landscape's natural attractiveness (Francis *et al*., 1990; Gliessman, 1990). The minimum land area to be managed as natural habitat in ecological olive groves is 4% for the plain and 8% for the hilly groves, including buffer strips, field margins, ditches and hedges (Vassiliou, 1998).

1.4. CONVENTIONAL FARMING PRACTICES

1.4.1. FERTILIZATION

The amount of fertilisers used per tree varies a lot and depends on trees'variety, size and age as well as fertilizer prices, expected olive yield and olive oil prices. Conventional farmers tend to ignore leaf or soil analysis in order to determine the amount of fertilizers that should be used. A routine fertilization includes kg/tree of ammonium sulphate fertilizer (N-P-K) (21-0-0) applied usually from December to January in the first year. During the following years 3kg/tree of a combined synthetic fertilizer (11-15-15) is applied during November-December (see Figure 3) for the Koroneiki variety. For Throuboelia variety, the same fertilization pattern is used but in twofold quantities (Klein and Lavee, 1977; Androulakis and Loupasaki, 1990).

1.4.2. PEST CONTROL

Conventional plant protection is done with the use of agrochemicals usually in the case of pest or disease symptoms, aiming at the absolute control of pest and pathogen populations while no preventive measures are taken (Elena, 1990).

The olive fly (*Bactocera olea*) is controlled with 3-5 bait sprays by the State's routine program every year. Until the summer 1992, the plain and the surroundings hills of Messara Valley were air sprayed because of the relief of the area (Vassiliou, 1998). A solution of 0.1% fenthion and 2% dacona in water or dacus bait food attachment for air sprays is used until August, then dimethoate replaces fenthion. For ground sprays, the solution is even stronger, 0.25%-0.30% fenthion and 2-3% food attachment. Apart from bait sprays, 1-3 cover sprays are done with the same insecticide but without the food attachment (Alexandrakis, 1990).

Sooty mold (*Fumago vagans*) is a very common problem, which appears because of high tree densities and insufficient pruning. It is controlled with a cover spray containing 0.032-0.048% methidathion during July (Elena, 1990).

1.4.3. WEED CONTROL AND SOIL MANAGEMENT

In conventional groves weed control is done by continuous ploughing and use of herbicides. The groves are ploughed once in autumn to clean the grove floor from undesirable weeds, which get tangled up with the nets used for harvest (Vassiliou, 1998). They are additionally ploughed once, twice or more times depending on the weather and the natural vegetation biomass during spring to avoid competition for nutrients and water with the tree. For ploughing, usually a rotator is used which creates a hard pan, destroys soil structure and disturbs the surface root system of the trees. Herbicide use follows ploughing as an additional way of controlling weeds and it is especially a common practice in hillside groves where the use of machinery is difficult (GEO.C.G., 1990).

The wild flora and fauna are often considered unnecessary and many conventional growers have a negative attitude to flora other than olive trees in the plantation (Vassiliou, 1998). Extensionists and agrochemical dealers promote the idea of 'clean' fields and consider that weeds and other natural vegetation spots should be cleared either by extensive use of machinery or agrochemicals, while animals or birds are considered pests and should be eliminated (Sfikas, 1989, 1992; Grove and Rackham, 1993).

Although conventional practices could be oriented in such a way that soil erosion is reduced, notably by taking care and rebuilding terraces or ploughing, there is often a lack of organic matter due to the absence of organic manure and cover cropping. In arid environments, such as the Mediterranean climate, where the biological activity and the production of organic matter are already low, the susceptibility for water erosion by run off is high. The soil tends, then, to be loose on the top layers and more susceptible to be washed away during a storm. Also, the application of herbicide on the dry stone walls, built to hold the terraces' soil, eliminates the plants growing that participate in the whole structure. The dry stone wall's resistance to the huge pressure of the upper terrace fills is then reduced.

The use of herbicide on the terrace walls can be detrimental to the health of the grove. They are themselves a habitat for the development of many wild animal and vegetal species. Walls are preferred sites for many lichen. These pioneers favor the accumulation of organic materials and give way to the establishment of more demanding species, such as bryophytes and saxicolous species. A lot of invertebrates find walls a perfect habitat and most of them are preyed by reptiles such as lizards and snakes, cold-blooded creatures which are attracted to the dry spaces where the stones are warmed by the sun. Weasels and stone martens use walls as a hunting ground to feed on mice (Lécuyer, 2000).

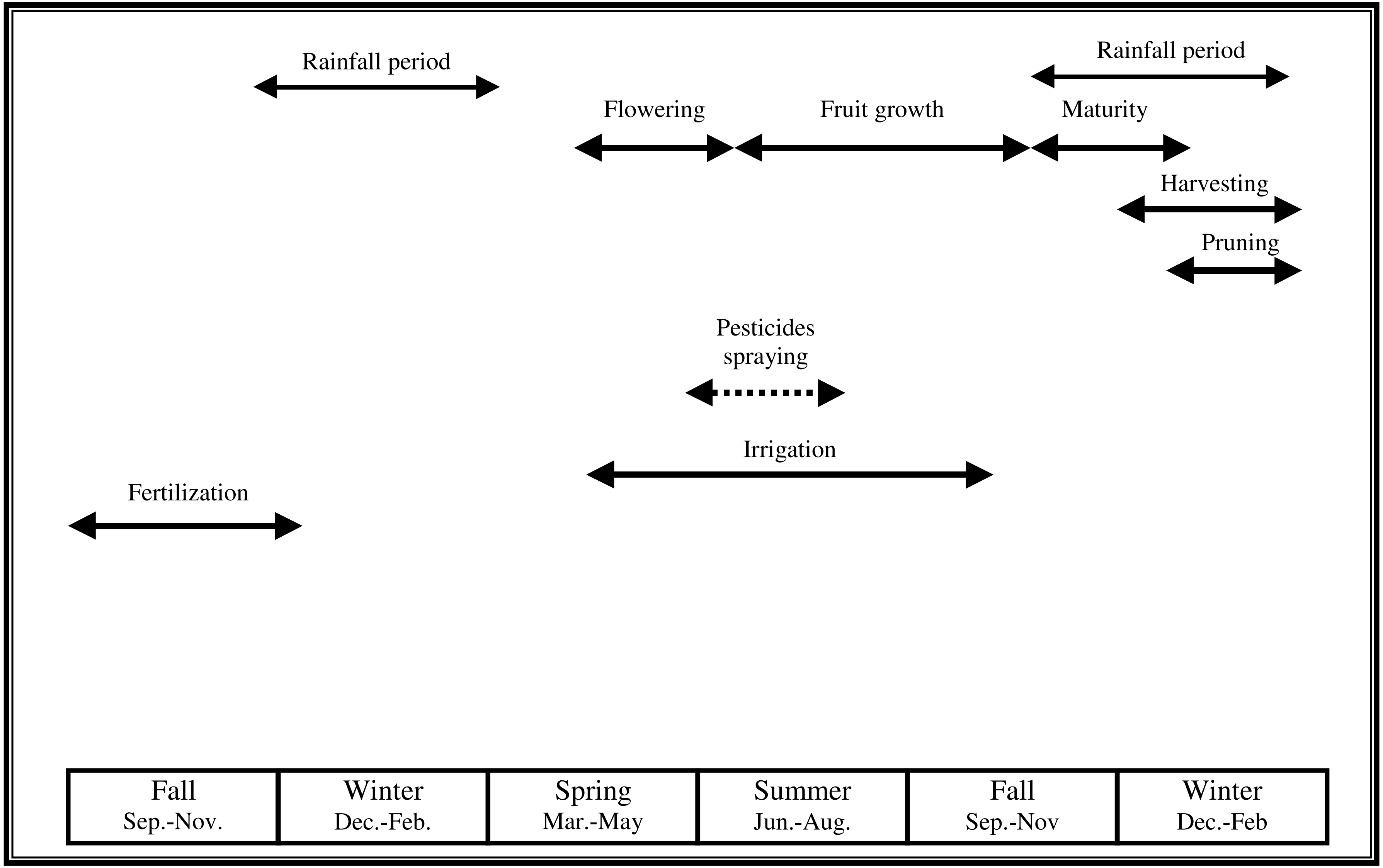

Fig.3: Growth cycle of the olive tree and timing of cultural practices in Conventional olive groves (from Kabourakis, 1993 and author).

2. Energy efficiency study for agricultural production systems

2.1. Definition of energy efficiency for agricultural activity

2.1.1. Energy efficiency concept applied to agrosystems

In the decade between 1974 and 1984, a number of research projects were carried out on energy use in the agricultural production and food processing sectors. The first «oil shock» in 1973 and awareness of agriculture's dependence on fossil fuels stimulated this research (Wells, 2001).

Nowadays, this shortage of oil supply is no longer the main problem, but is replaced by concerns such as the dependency on fluctuating prices and the contribution to global warming. Therefore, the agroecosystem is more conceptualized as the interface between environment and human society (Ulgiati *et al.*, 1993). During the process of production, the environment sustains some transformations (or impacts) that may not lead to long term stability of the agrosystem.

Energy analysis is a relevant method to consider agriculture in a sustainable perspective. It provides a relevant view of the complementarity of a mixed farm, efficiency of agricultural practice, benefits from inter-farm cooperation the emissions of greenhouse gases (contributing to global warming), and also socio-economic aspects, as non-renewable energy can be replaced by human labour.

Ecological sustainability is far from being only a question of energy (Risoud, 1999), but also of land, water, social and economic returns. A combination of energy data with figures from other domains (such as the Life Cycle Inventory) is interesting to define and assess farming management from the point of view of ecological sustainability.

2.1.2. Application of energy efficiency to agricultural activity

Along with forestry, agriculture is the only human activity which may produce more energy than it consumes, thanks to photosynthesis (Risoud, 2000). Accounting all the non-renewable energy spent to obtain the farm inputs, from the extraction of raw materials to the final product available at the entrance of the farm, the method also considers the gross energy of the agricultural product that are exported outside the farm. The energy analysis provides a global view on the efficiency of farming process (Risoud, 2000).
Energy analysis considers the farm as a user and a producer of energy simultaneously. The equation of the energy efficiency is given below:

$$\text{ENERGY EFFICIENCY} = \frac{\text{GROSS ENERGY CONTENT OF USEFUL PRODUCT}}{\text{NON - RENEWABLE ENERGIES USED TO PRODUCE IT}}$$

The desired range is equal or superior to 10 (Kabourakis, 1993), and is achievable with best ecological means. This range means that when 1 Joule of non-renewable input is introduced in the agrosystem, 10 Joules of olives will be produced.

The next step involves settin, the agrosystem boundaries including the most relevant energetic inputs. The output, or functional unit, is expressed in Joule as the inputs so the ratio is dimensionless. Boundaries for the study of energy flows at the farm level (see Figure 4) are set in order to show the effects of farmer decision and behavior (mainly technical choice) on the production process(Lambert, 1995).

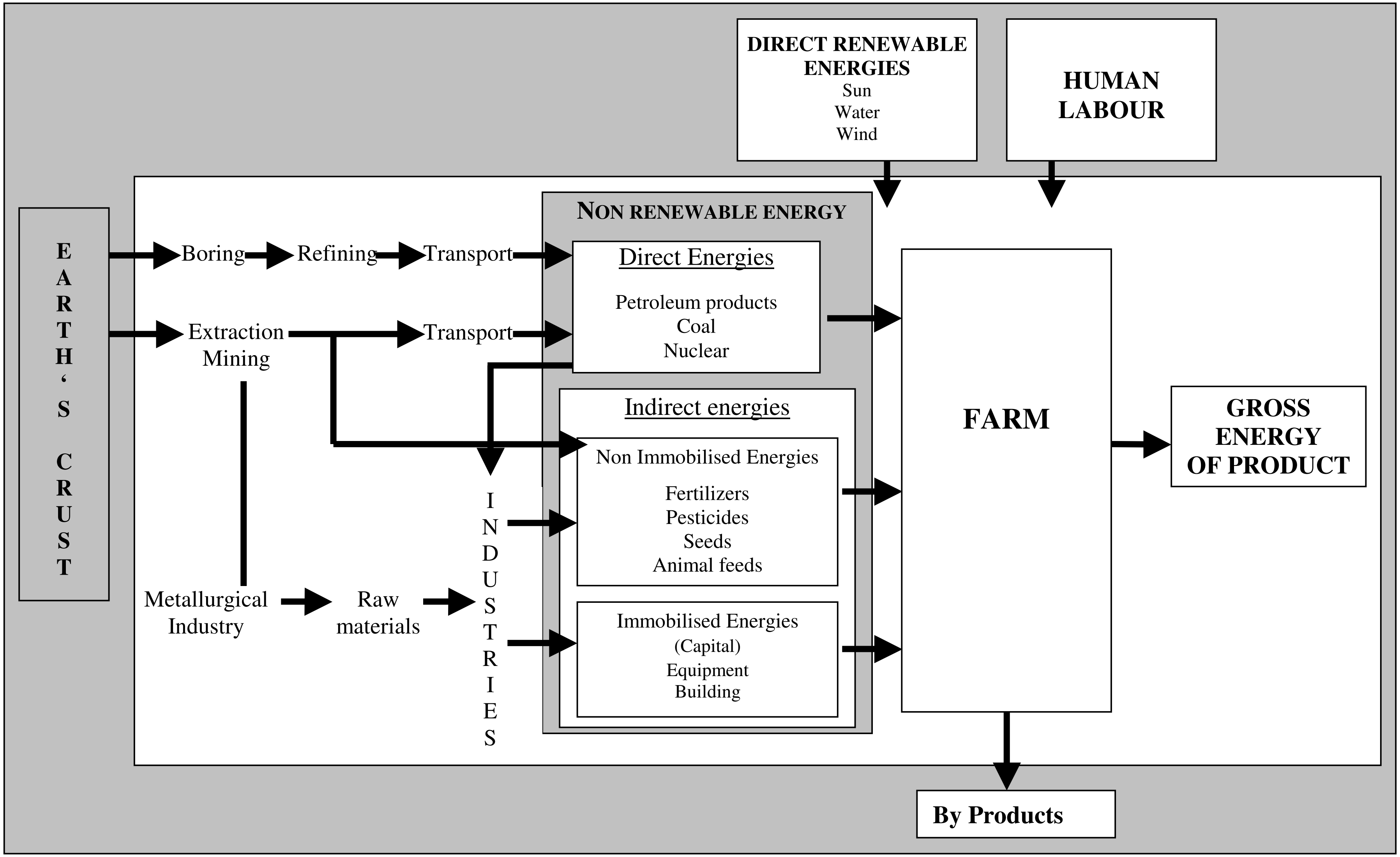

Fig.4: Limits of agricultural system (Lambert, 1995).

2.1.3. LIMITATIONS OF ENERGY EFFICIENCY ANALYSIS

The main limitation of the method for energy efficiency calculation is that it only includes economical relevant inputs, like fossil fuels and fertilizers (Stout, 1992; Leach, 1976). Another limitation is that partial energy flows are not taking into account environmental energy sources and services. It is also a «top-down» approach, where the energy accounting scheme, even if it relies on thermodynamic principles, inevitably depends on human values and perception (Frischknecht, 1998).

Data from the whole pathway of the energy, from mining to delivery, are difficult to obtain. Also, the aggregated data are reachable as consumer energy, as opposed to primary energy. There are then difficulties in the allocation to the proper source of energy (part of renewable/ non-renewable).

Finally, indicators of the embodied energy of an indirect or capital energetic input are barely existent and the attribution of an energetic value is sometimes subjective. Finally, the attribution of a working lifespan for capital items such as a tractor is left to the appreciation of the farmer but has no scientific basis.

2.2. ENERGY EFFICIENCY AND SUSTAINABILITY IN AGRICULTURE

As sustainable development implies a less specialized economy to emphasize complementarities; in order to use local resources more rationally, a less centralized organization to decrease transport, it should be revealed for a part in the outcome of the energy efficiency analysis (Risoud, 2000). Among the sustainability categories, a high energy efficiency contributes to a lower external input dependency per unit product resulting in a higher stability of food supply, lower environmental burden (at least for carbon dioxide emission) and a higher local employment.

2.2.1. ENERGETIC DEPENDENCY AND RESOURCE DEPLETION

Energy is required in agriculture on a massive scale. In fact, agriculture would not be possible without the input of human power, animal power or mechanization. Vast amounts of energy are also consumed in the processing and distribution of food, with cooking, freezing and transportation representing a large part of energy use in bringing food from the field to the table.

The price of increased agricultural productivity has been increased energy dependency, particularly dependency on fossil fuels. For example, traditional rice culture in the Philippines has an annual non-renewable energy requirement of around 173 MJ/ha for a yield of 1,250 kg/ha or 0.14 MJ/kg of rice (Stout, 1990). By comparison, modern rice culture in the United States requires an annual energy input of 64,885 MJ/ha for a yield of 5,800 kg/ha or 11.19 MJ/kg (Wells, 2001). Thus, although the modern system is 4.6 times more productive per hectare it requires 79 times the energy use per kilogram of product. Similar comparisons for maize production reveal a five-fold increase in productivity but a 33-fold increase in energy use per unit of production.

Projections of the availability of fossil energy resources are discouraging. A recent report published by the U. S. Department of Energy based on current oil drilling data indicates that the estimated amount of oil reserves has plummeted. This means that instead of the 35-year supply of oil resources, that was projected about ten years ago, the current known reserves and potential discoverable oil resources are now limited to less than 15 years' consumption at present levels (Giampetro and Pimentel, 1994) Thus, fuel price could raise drastically. This would dramatically affect agriculture already heavily dependent on fossil energy based inputs (mainly fertilizers, Nitrate and phosphate extraction and transport) (Günther, 2000).

2.2.2. ENVIRONMENTAL RISK

Probably one of the most pressing global threats to the environment at this moment is climate change. A primary contributor to this problem is carbon dioxide, a by-product of combustion-based energy generation (ILEA, 2001). The increasing substitution of energy for labour in agriculture contributes to global warming by increasing atmospheric pollution, such as the emission of methane, nitrous oxide, ammonia and products from biomass burning (Conway and Pretty, 1991; IPCC, 1990). The single main cause of global warming is carbon dioxide, estimated to contribute about half of the projected warming over the next 50 years (Pretty, 1995).

2.2.3. STABILITY OF FOOD SUPPLY AND LOCAL EMPLOYMENT

These two effects of the energy efficiency are grouped together in this paragraph; Indeed, they are linked as direct socio-economic consequences of the farm energetic strategy. The stability of food supply is one of the food supply sustainability indicators, also with quality and quantity. This indicator increases when the economic and ecological vulnerability of the local farms increases. The economic dependency of the farmer to the energetic input prices combined with the ecological dependency of the agrosystem on artificial inputs, tend to impair the stability of food supply by the farm (Günther, 2000).

With a more energy efficient farm, mutual exchanges of feeds and organic manure are assured between farmers inside the same region, limiting transportation of inputs and use of chemicals (Risoud, 2000). This implies a more endogenous economic development, based on local resources, meaning the improvement of local work and wealth distribution and the development of small-scale farms, which are more suited to high peak labor requirements. Nevertheless, as the energy efficiency has a positive socio-economic effect on a local scale, on the short term the regional and national consequences are slightly negative since several sectors are dependent on the supply of non-renewable energy inputs. However, on the longer term, regional and national employment is stabilized (Wade *et al*, 2000).

2.3. PURPOSE OF THE ENERGY EFFICIENCY ANALYSIS IN THE STUDY

2.3.1. QUANTIFY ENERGY FLOWS IN THE AGROSYSTEM

Making an inventory of the cultural practices is the basis of the quantification of energy flows within the farm and materials involved in the production process by calculating the embodied energy during production of materials and transports. Then, a transformation is applied to the rate of activity (hour or kilogram/ha/year) to obtain an energy rate (MJ/ha/year). This leads to the characterization of the real non-renewable energy content and the efficiencies of the different farm management operations.

2.3.2. COMPARE ENERGY EFFICIENCIES OF THE DIFFERENT OLIVE FARM TYPES

The comparison of the results obtained from organic and conventional farms should show the contribution of the activities to the efficiency of the system. The energy efficiency of the agrosystems should show intrinsic abilities of self-regulation and complementarities, sparing farmer interventions with non-renewable inputs (Günther, 2000).

2.3.3. DETERMINE PROCESSES LEADING TO ECOLOGICAL-ECONOMIC BENEFITS

Although interaction and complex processes take place during the production of olives for olive oil, the complementarities involved among the agrosystem can be highlighted. As an example, the use of manure stresses the complementarity of the grove and the animals thus, cover crop for grazing is planted and less energy and artificial nutrients are used. In this case, the energy efficiency is increased.

3. LIFE CYCLE ANALYSIS (LCA) FOR AGRICULTURAL PRODUCT

3.1. DEFINITION OF LCA

Life Cycle Analyses for food products are a fairly recent phenomenon. Andersson (1998) and Jungbluth (1998) have made inventories of food LCA projects, all of which were carried out during the 1990s. The application of LCA to food production systems makes some special demands on the methodology (e.g. Audsley *et al*., 1997; Cowell and Clift, 1997; Andersson, 1998).

As stated by Wackernagel and Rees (1996), 'the first step toward a more sustainable world is to accept ecological reality and the socio-economic challenges it implies'. To achieve a more sustainable society, tools to evaluate strategies and monitor progress are required (Andersson, 2000). One such tool is LCA, whose methodology has improved substantially since the 90's. A 'Code of practice' has been published (Consoli *et al*., 1993) as well as several guidelines (e.g. Heijungs *et al*., 1992; Vignon *et al*., 1993; Lindfords *et al*., 1995; and Wenzel *et al*., 1997). There is also a journal specialised in the publication of LCA related articles, the LCA Journal.

The scope of an LCA is the evaluation of all the extractions from and emissions into the environment that occur during the life cycle of the product, service or function to be analysed. Impacts are assessed according to their potential effects and not according to the real damages. This is due to the fact that extensive site-dependent factors would have to be considered for an assessment of real damages, increasing the amount of data required for an LCA beyond practicable limits (Goedkoop *et al*., 1998).

There are four main phases within Life Cycle Analysis (see Table 3 below): goal and scope definition, inventory analysis, impact assessment and interpretation (Van den Berg *et al*., 1995). During the first phase, goal and scope definition, the purpose of the study, the target group, the object to be studied and the level of detail or scope of the study are determined.

During the second phase, inventory analysis, a process flowchart need to be drawn, the data collected, the system boundaries checked and the data processed. The process flowchart schematically represents in a qualitative way all the relevant processes involved during the life cycle of the product. It includes the processing steps and material flows of the production of the product itself as well as the resources, components, consumption and wastes produced. Step 3 is the calculation of contributions using models and comparing results to reference values (normalization) and the aggregation of all the potential impacts value (valuation). Step 4 is the identification of significant issues and the checking of method consistency, data completeness and results sensitivity.

Table 3: LCA phases (ISO, 1998):

PHASES OF THE LCA	TASKS
Goal and scope definition	Determination of the purpose of the study, the target group, the object and the scope of the study
Inventory analysis	Drawing of process flowchart, collection of data, checking system boundaries, processing data
Impact assessment	Relating and aggregating the outcome of the inventory analysis to environmental issues through classification and characterisation (optionally also normalisation and valuation)
Interpretation	Structuring and interpretation of results, identifying areas of possible improvement

3.1.1. ECOLOGICAL ASSESSMENT TOOL

Life Cycle Analysis is one of the tools of Environmental Systems Analysis. It "provides a systematic framework which helps to identify, quantify, interpret and evaluate the environmental impacts of a product, function or service in an orderly way" (Van den Berg *et al.*, 1995). The environmental impacts considered span the entire life cycle of a product, service or function and LCA is therefore considered as analysing the impacts from 'cradle to grave'.

The procedures of Life Cycle Analysis were standardised (see Appendix 2) starting in 1997 by the International Standard Organisation (ISO). The ISO 14040 series regulates the framework (ISO 14040), goal and scope definition and LCA inventory (ISO 14041), Life Cycle Impact Assessment (ISO 14042) and the interpretation step of LCA (ISO 14043) (Marsmann, 2000).

LCA is mainly a tool used for describing environmental impacts. Examples of other environmental systems analysis tool includes Risk Assessment, Environmental Impact Assessment (EIA), Environmental Auditing, Substance Flow Analysis, and Material Flow Analysis (see e.g. Wrisberg and Gameson, 1998, and Moberg *et al.*, 1999 for a discussion on related tools). What makes LCA unique is the «cradle-to-grave» approach combined with its focus on products, or rather the functions that products provide.

LCA follows the entire life cycle of a product in order to analyze the causes of related problems, to compare improvement options, to design a new product or to choose between comparable products (Guinée *et al.*, 2001). Wider applications include the use of LCA in eco-labelling programs, eco-design and environmental management.

One of the advantages of LCA is that it avoids "problem shifting" from one stage in the life cycle to another, from one environmental issue to another and from one location to another (Wrisberg *et al.*, 2000). This is because it takes the entire life cycle of the product and all extractions from and emissions to the environment during that life cycle into account. Another strength is the clear distinction between scientific information and subjectively influenced value choices, as well as the possibility of conducting an LCA quantitatively or qualitatively (Wrisberg *et al.*, 2000).

3.1.2. LIMITATIONS OF LCA

LCA approach has met high expectations but its results are often criticized (Udo de Haes, 1993; Ayres, 1995; Ehrenfeld, 1998; and Krozer and Vis, 1998). This criticism must be taken seriously in order to evaluate the role of LCA as a decision support tool for authorities and companies (Finnveden, 2000). LCAs may, for example, be criticized on the grounds that they do not produce the kind of information that is envisaged by the ambitious LCA definition, also that the results obtained are not reproducible.

There are difficulties for a proper conclusion to many LCA, indeed, the methodology used can be criticised following three major types of reasons (Finnveden, 2000):

1) Sometimes, not every relevant environmental impact is considered.
2) There are uncertainties in :
    a) data,
    b) methodology for the inventory analysis and the impact assessment, and
    c) description of the studied system.
3) The weighting elements involve ideological and ethical values that can not be objectively determined. Methodological choices have to be made, but they introduce uncertainties in the results. Some of these choices are value choices, whereas others are more technical. Cultures,

frames and paradigms influence these choices (Hofstetter, 1998; Tukker, 1998).

It has been suggested that LCA probably has its best use as a tool for learning rather than a tool for supporting consumer and trader decisions (Baumann, 1998). In other words, LCA can not produce a conclusion of the type «Product A is environmentally preferable to product B» even if this happens to be the case. However, it is expected that LCA can increase the environmentally related knowledge of the studied system, identify critical parts (or ‘key issue’), and separate important parts from less important ones. Thus, it can be considered as a tool to obtain crucial information for the decision making process for farm management.

3.2. LCA IN AGRICULTURE ON THE FARM LEVEL

3.2.1. RELATION OF AGRICULTURE & ENVIRONMENT

Agricultural production is not a pure ‘cradle to grave’ process. Therefore, LCAs in agriculture must be more than a method ‘to evaluate environmental burdens by identifying and quantifying energy and materials used and wastes released to the environment’ (definition by the LCA Journal). For agricultural application, the main life cycle aims at enhancing and ensuring nature’s process. Thus there are a lot of ‘inner life cycles’ in the production process (Haas *et al.*, 2000).

Besides the specific agricultural background, the difference between classical product-LCAs and process-LCA of farms or production systems causes problems with classical impact categories. In classical LCA, ‘land use’ and ‘waste’ are impact categories considered as essential (Klöpffer and Renner, 1994), but they are not generally appropriate for agricultural LCAs (Geier *et al.*, 1998; Geier, 2000) because they do not function as central environmental impacts of agriculture (Haber and Salzwedel, 1992). The impact category ‘land use’ in the meaning of land consuming is not appropriate for agriculture since there could be top soil creation by the farming activity and a good management of the soil leading to the improvement of the land.

3.2.2. AGRICULTURAL RESOURCES

The impact of agriculture on the environment is a major issue because the ecological health of natural resources and habitats is already overstrained. In general, the agricultural impact on nature is well known (Haber and Salzwedel, 1992), and a set of agri-environmental indicators has been developed for national monitoring systems (OECD, 1997; Rudloff *et al.*, 1999). Compared to industry, agricultural production resources, for example, soil fertility, seeds and cattle, are self-produced. Farmyard manure, the main ‘waste’ of livestock keeping, is valuable fertilizer for plant production (as long as livestock units are adjusted to the farm area).

3.2.3. SUSTAINABILITY ISSUE

One of the definitions of sustainable development is "meeting the needs of the present without compromising the ability of future generations to meet their own needs.” This commitment to future generations facilitates excellent stewardship of resources. The only means of measuring fully the ecological sustainability of total production systems is Life Cycle Analysis (LCA). The contribution to regional and global pollution is assessed at every stage, from planting to farmgate, by the application of LCA for chemical pollutants (Van Emden and Peakall, 1996), agro-environmental effects and resources depletion.

The achievement of sustainable orchard production is a process of continuous improvement in which unsustainable practices are progressively eliminated, while maintaining business profitability (Wearing, 1997). That is in this perspective that the study has been carried out, identification of sustainable practices through the analysis of energy and material flows.

3.3. PURPOSE OF THE LCA IN THE STUDY

3.3.1. DEVELOP ECOLOGICAL ASSESSMENT TOOL FOR OLIVE GROVES

The first purpose of the application of a Life Cycle Analysis to the olive production system is the adaptation of an existing methodology already in use in Europe, but mainly in northern countries, to the case of a Mediterranean island, Crete. Also, creating a set of relevant indicators for the characterization of cultural practices environmental impacts. There has been no study integrating environmental issues on this crop. Thus, the assessment of the environmental burden of olive production is completely new.

3.3.2. QUANTIFY AND COMPARE ENVIRONMENTAL BURDENS

One of the main aims of the study is the determination of the ecological effects of organic versus conventional olive production. It is then of paramount importance to be able to quantify the contribution of the different impact categories in order to compare different farm types. Also, the farm impacts are related to the functional units, the surface (ha) and the production (tons of olives) in order to compare environmental burden with the same referential unit.

There are some published environmental comparisons of organic versus conventional production of agricultural crops (Büchel, 1993; Lundström, 1997; Haas *et al.*, 2001). The yield level is an important factor for the outcome of these comparisons. Büchel made an environmental comparison of organic, integrated and conventional wheat cultivation. The crop yield was approximately 30% lower for organic farming, while the yield in conventional farming was 25% higher than for the integrated farming. When the total emissions were compared, the organic wheat cultivation caused more emissions per kilogram of wheat (CO, N-emissions, particles and waste) than integrated and conventional production (Büchel, 1993).

3.3.3. DETERMINE ECOLOGICALLY SOUND PRACTICES

This study will hopefully help to generate information on the magnitude and interrelations of the environmental impacts of the different life cycle steps. Emissions of gases to the atmosphere, emissions of eutrophying substances to water, physical conditions of the agrosystem for production and diversity and the use of resources (soil, non-renewable and water), have been listed by Holmberg *et al.* as 'Socio-Ecological Principles for sustainability' (Holmberg *et al.*, 1996). In this study, these impacts will be assessed and related to the cultural practices or to the life cycle step involved. Eventually, best practices can be underlined, whereas those contributing to unsustainability are denounced.

4. MATERIALS AND METHODOLOGIES

4.1. MATERIALS

4.1.1. OLIVE GROVES

A. PLAIN GROVES

The majority of plain groves in the Messara Valley are new plantations. They have been planted the last three decades as in the past a greater part of the western Messara was a wetland, inappropriate for olive cultivation (Kabourakis, 1993). Microclimate of the plain is wet with less rainfall and lower temperatures during winter than the surrounding hills. Besides, frost occurs late in winter and early in spring because of the cold northern wind coming from Mountain Ida. During the summer, the microclimate is dryer with higher temperatures than the hills.

Plain groves are cultivated on deep fertile soils. Irrigation is required for increased yields, as water is the main limiting yield factor during dry summer months (FAO, 1972). Wild vegetation and animals have almost completely disappeared from groves because of intensive land use and of high synthetic agrochemical inputs.

Regarding cultivation practices, cover crops in plain groves have the same sowing and reproduction cycles as the ones in hilly groves. Fertilization takes place at the same period in both groves, but fewer amounts of fertilization materials is required in hills because of a higher soil fertility (Kabourakis, 1993). Harvesting and pruning is performed on similar dates in both groves.

B. HILLY GROVES

A large proportion of hilly groves are old low density (extensive) plantations, while the rest are young high density plantations, often irrigated, similar to the plain groves. Usually leveling earthworks are done without care before the plantation of high-density groves, which destroys natural habitats and increases soil erosion (Kabourakis, 1993).

The microclimate of the hills is mild with higher rainfall and higher temperatures during winter than the plain. During summer it is cooler and with lower temperatures than the plain. Wild vegetation and animals occur mainly in uncultivated rocky land and small natural areas of the hills where there are more species and higher diversity than the plain groves.

C. TYPE OF GROVES STUDIED

Two organic and two conventional orchards are analysed in this study, there are no replications. Among the organic orchards, one is situated in the plain, slightly more intensive (higher planting density) and another one on the hills. Among the conventional orchards, which are both intensive (high planting density), even on the hills, one is situated in the plain and the other one on the hills. The diagram below sums up the different treatments:

	ORGANIC	CONVENTIONAL
HILL	**1 farm**	**1 farm**
PLAIN	**1 farm**	**1 farm**

4.1.2. MEASUREMENTS

Only soil analysis have been carried out, because it is the only 'state' data that is required for the calculation of the potential topsoil loss by water erosion.

Soil analyses for each grove have been carried out for the calculation of potential erosion. These analyses are done at the laboratory of Soil Science and Geology department of the Wageningen University. The structure of the soil is measured, separating clay, sand, fine sand and silt of the collected samples. This analysis is done with a Coulter LS 230 particle size analyzer in a fluid module.

4.1.3. QUESTIONNAIRE

Questionnaires directed to organic and conventional farmers have been provided in (Annex 6). These questionnaires are meant to gather useful quantitative information of the farms' charcteristics. The structure is formed of more or less 4 parts : firstly, questions are asked about the farm identity (size, situation…), secondly questions about cultural practices and their frequency are asked, in a third part, as subsidiary questions the farmer is asked for social and economic information (number of workers employed, subsidies and selling price). At the end of the interview, qualitative informations are retrieved on the form of a free discussion.

4.2. METHODOLOGIES

4.2.1. SURVEY METHODOLOGY

Olive groves were first chosen, in concertation with M. Kabourakis from the organic production department of the NAGREF institute of Heraklion. The attempt was to find representative groves in the regional context. Then the questionnaire was prepared and questions were asked to the farmers, in Greek, during the farm visit which lasted maximum 1 hour including the inspection of the grove and collection of soil samples.

4.2.2. METHODOLOGY OF THE ENERGY EFFICIENCY ANALYSIS

4.2.2.1. IDENTIFICATION OF THE ENERGY SOURCES (INPUTS)

The total primary energy input implies that all forms of energy, calculated at the source (i.e. at oil wells, power station, etc.) and required for farm operation, are included in the analysis. The different energy inputs are listed below. The exception is "free" solar energy for crop growth, which is excluded. Therefore, total primary energy includes energy losses during conversion processes such as oil refining and electricity generation.

DIRECT ENERGY	INDIRECT ENERGY	CAPITAL
-Fuel for tractor	-Fertilizers, organic and mineral	-Tractor
	-Seeds sown as cover crop	-Machinery

4.2.2.2. *QUANTIFICATION OF THE INPUTS*

DIRECT ENERGY INPUTS:

<u>Fuel for tractor</u>

- Type of tractor (engine power) is often given in horsepower (1 horsepower = 0.746 kilowatt, 1 kilowatt = 3.6 MJ/h).

- Number of working hour per hectare, by the tractor:

  - Number of hours x power of the engine = energy spent in a year for the whole surface (kJ).
  - Then, an extra 23% allowance, accounting for fugitive uses such as extraction, processing, refining and transport of crude oil and final products, is applied to the value calculated (Keedwell, 2001).
  - Energy spent divided by the area cultivated = energy spent per area unit (kJ/ha).

INDIRECT ENERGY INPUTS:

- Nature of the material used (manure or mineral fertilisers, biocides: herbicides and pesticides).

- Embodied energy of the different materials is available in the literature:

  - Manure, essentially from goat and sheep in the organic groves, has an energy content of 154 kcal/kg or 644 MJ/t (Pimentel, 1980) but this value is the calorific energy content of the manure and does not represent the embodied non-renewable energy. The assumption is made that the ratio output of manure/input of non-renewable energies embodied in the feed (grass and concentrates for stable sheep and goat) is equal to 10; the value is then 64.4 MJ/t.

  - Mineral fertilizers' sequestered energy has been also calculated (47.1 MJ kg^{-1} mineral-N, 15.8 MJ kg^{-1} P_2O_5 and 9.3 MJ kg^{-1} K_2O)(Audsley *et al.*, 1997 and Patyk, 1996).

  - Cover cropping seeds embodied energy is assessed following the type of cover crop. In determining the energy coefficient of seed it is necessary to distinguish between the metabolizable energy content of the seed and the energy required to grow the seed. For this study, seeds are considered as an input to the ecological olive orchard system (the cover crop is not harvested but returned to the ground). It is most appropriate to measure the amount of energy required to grow the seed excluding solar energy inputs, an average of 0.15 MJ/kg seeds is used for this study (Dawson cited in Wells, 2001).

CAPITAL INPUTS

For all capital items the same general methodology was followed. This involved estimating the total mass of each component of each item of capital and multiplying by an appropriate energy coefficient that represents the sum of embodied, manufacturing and maintenance energy costs (Annex 2). The annual capital energy charge to the property is then calculated by dividing by the expected working life of the item by assuming straight-line depreciation.

- Tractor embodied energy is given as an international average 144 MJ/kg (Mc Chesney *et al*., 1978) including 60% for repairs and maintenance over the life of the vehicle. Rather than compile a list of all tractors encountered in the survey and their mass, an alternative method was developed to estimate the mass of the vehicle based on the rated power output. Most farmers know the rated power of their machines or these can be obtained from dealer information if required. Rated power was expressed in horsepower (hp) rather than kilowatts (kW) as most farmers and dealers are still more familiar with this unit of measuring power. Wells gives the equation of the conversion of power (in hp) to the mass (kg) of the tractor (Wells, 2001):

$$\text{Mass (kg)} = 40.8 \text{ Power (hp)} + 190 \qquad (R^2=0.94)$$

- Machinery energy content was estimated to be 80 MJ/kg (Doering, 1980). The average weight of the implements used for cultivation purposes is determined to the nearest 100 kg and their life span is assumed to be 20 years.

4.2.2.3. IDENTIFICATION OF THE ENERGY DESTINATIONS (OUTPUTS)

⇒ Product: quantified by the functional unit: MJ of olives produced. 1 kg of olive corresponds to 1.7 x 10^3 kcal or 7.1 x 10^3 kJ (7.1 MJ), since 1 calorie = 4.18 J. (Ugliati *et al*., 1994).

4.2.2.4. CALCULATION OF THE ENERGY EFFICIENCY

Energy efficiency equation (Risoud, 2000):

$$\text{ENERGY EFFICIENCY} = \frac{\text{GROSS ENERGY CONTENT OF USEFUL PRODUCT}}{\text{NON - RENEWABLE ENERGIES USED TO PRODUCE IT}}$$

4.3. METHODOLOGIES OF THE LIFE CYCLE ANALYSIS

The life cycle analysis (LCA) is a holistic approach of the quantification of emissions, material and energy consumption involved in the production. For this study, LCA will be a powerful methodology to assess the environmental loads and energy efficiency of the different olive production structures and types. Among the methodologies used for such assessment such as emergy (Odum, 1992), exergy, embodied energy analysis, LCA permits the most detailed and systemic evaluation of environmental impacts. Concerning the energy efficiency analysis, LCA is also able to obtain relevant insight of the production but not in economical or social term (Guinée *et al.*, 2000).

4.3.1. GOAL AND SCOPE DEFINITION

A PURPOSE

The purpose of an agricultural LCA is to determine the differences in resource use (and usefulness) and environmental impacts between the different production systems. In this study, the types and structures of olive production systems in Crete are analysed. The research center EPSRD, local farmers and policy makers should benefit from the results of this analysis.

The reason for carrying out this study is the need for more understanding of the energy and material flows in the olive production system, their efficiency of use and their fates concerning the environment. The main goal is the identification of improvement possibilities in further development of the ecological olive orchard prototypes

B FUNCTIONAL UNIT

The functional unit measures the performance of the system and provides a reference to which the input and the output are normalised. The functional unit is defined in the following way: 1 kcal (or kJ) of olives leaving the farm gate (Kabourakis, 1996). The latter will be used for energy analysis, whereas for environmental impacts, the surface unit (ha) and the production unit (ton of olives) will be used as functional unit.

C STUDIED OBJECTS

For this study, two kinds of olive production systems will be analysed: organic and conventional. Among the organic orchards, two kinds of structures are taken into account: hilly and plain, both intensive, and the same structures for the conventional ones.

D SCOPE DEFINITION

⇒ System boundaries:

Normally, the assessment of the life cycle of a product includes the processing, distribution, use, maintenance, recycling, and final disposal of the product (namely the olive). For this study, the main objective concerns the evaluation of the efficiency and the potential environmental impacts associated with inputs and outputs of the system at the farm level. Consequently, the approach cannot be seen as a “cradle-to-grave” but as “cradle-to-farm gate”.

In order to determine the environmental load and the energy efficiency of the different systems, it is necessary to define the system under study (see Figures 5 and 6) and draw a flowchart of the olive production systems.

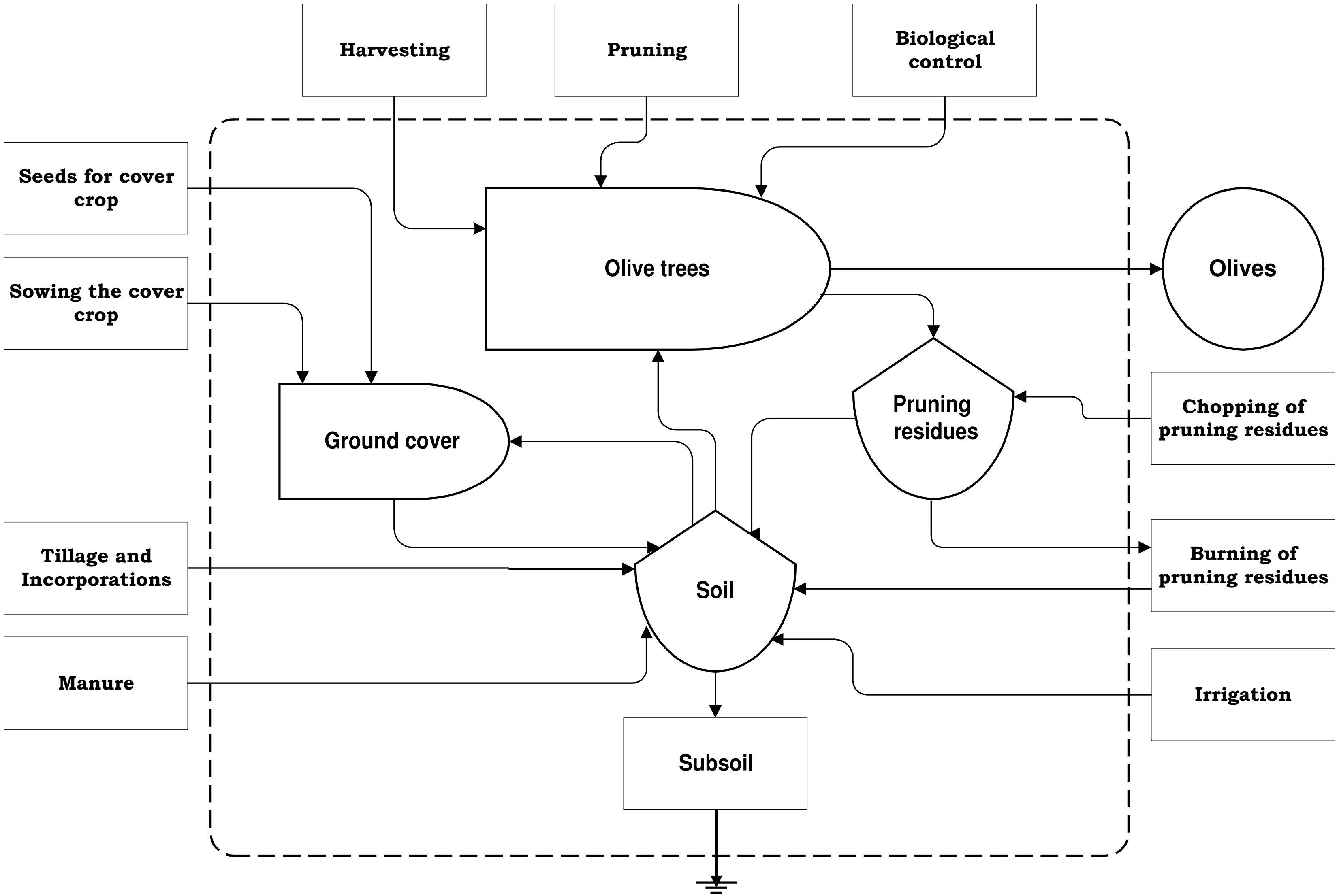

Fig.5: Organic orchard practices flow diagram.

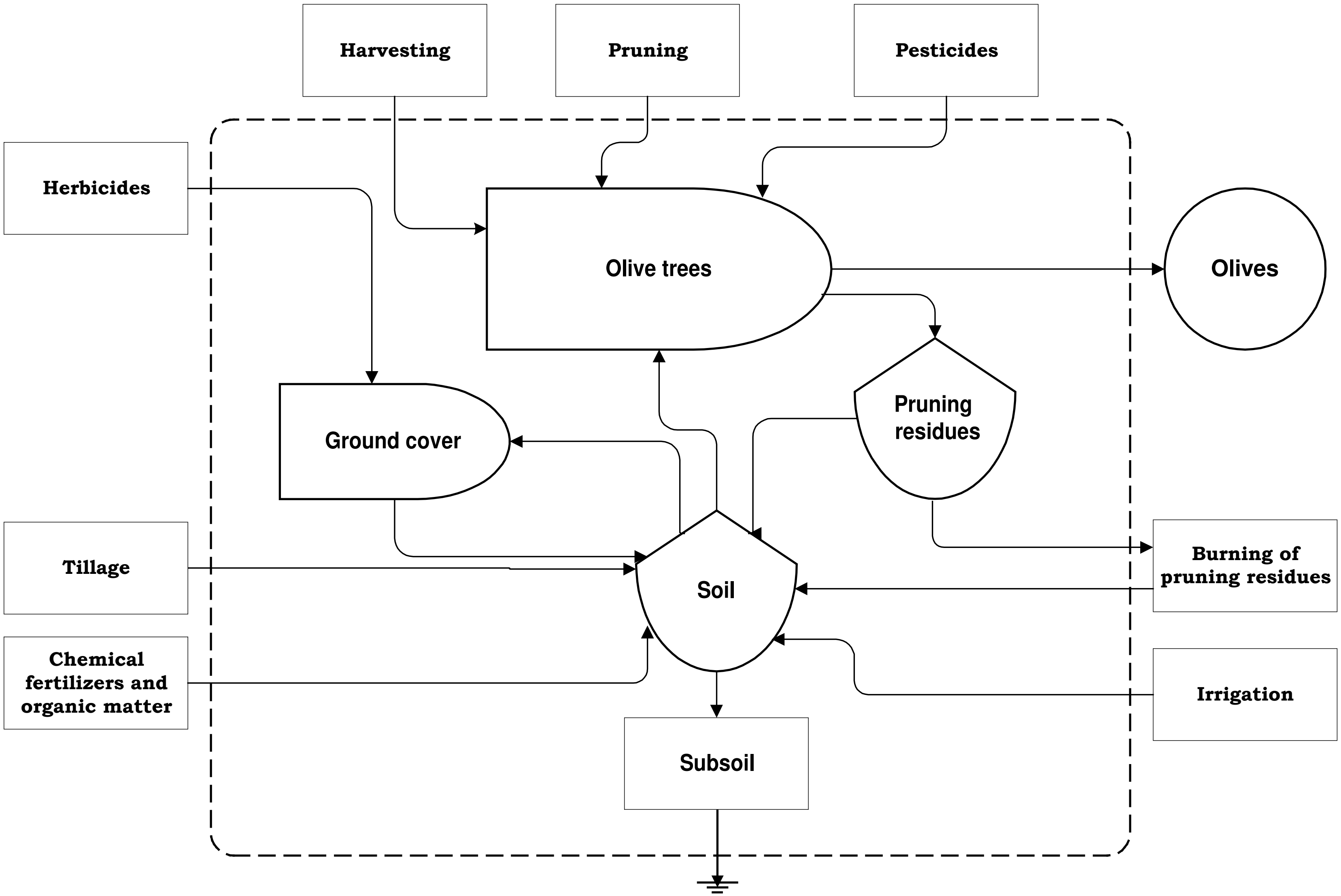

Fig.6: Conventional orchard practices flow diagram.

⇒ Excluded processes:

- ✓ Construction of roads and buildings necessary for the olive production is not taken into account because of its negligible effect on the environment and low contribution to energy efficiency.
- ✓ Production of biological control agents or devices for pest and disease management is not taken into consideration because of its poor contribution to the analysis.
- ✓ Production of biocides and its spreading is not taken into account since the quantities sprayed are negligible (Kabourakis, pers. comm.). Moreover, the conventional farmers are not responsible for this task, rather the government sends technicians to do the spreading within the framework of a regional pest control program.
- ✓ Production of electricity used by the irrigation pumps is not included since the percentage of non-renewable resources used to produce it is variable during the year and from one place to another.
- ✓ Energy and emissions due to the irrigation system (pump, pipes and tubes) are not calculated in this study. It has been stated that there is no difference between organic and conventional groves concerning the use of irrigation materials, then its calculation is negligible in this study.

4.3.2. Inventory analysis

There are four steps in the process of a life cycle inventory (EPA, 2001):

Step 1: Develop a flow diagram (see Figures 5 and 6),
Step 2: Develop a Life Cycle Inventory (LCI) including the data collection plan:

Data from the conventional and organic farms will be collected in the form of interviews, questionnaires for the energy efficiency assessment and on-farm measurements for the environmental impact assessment.

Step 3: Collect data,
Step 4: Evaluate the LCI results.

4.3.3. Impact assessment

There are six steps in the Life Cycle impact Assessment (EPA, 2001):

Steps	**Activities**
1	Select and Define impact categories
2	Classification
3	Characterization
4	Normalization
5	Grouping
6	Weighting

STEP 1: SELECT AND DEFINE IMPACT CATEGORIES:

A CATEGORY SELECTION

Table 4: Life Cycle Impact Categories (EPA, 2001 and author):

TYPE	CATEGORY	CHARACTERIZATION FACTORS	APPLICATION FOR THIS STUDY
Ecological health	Global Warming	Global Warming Potential	Applicable
	Acidification	Acidification Potential	Applicable
	Eutrophication	Eutrophication Potential	Applicable
	Ozone depletion	Ozone Depleting Potential	For industry (CFC emissions)
	Ecotoxicity	LC_{50}	Not Applicable
	Photochemical pollution	Photochemical Oxident Creation Potential	Not Applicable
Agro-environmental effects	Biodiversity	Biodiversity Index (not in literature)	Applicable with adaptations
	Erosion	Loss of topsoil	Applicable
	Salination	Salination potential	Not Appropriate
Resource depletion	Fuel and mineral ore	Resource Depletion Potential	Applicable
	Water consumption	Water use Index (not in literature)	Applicable with adaptations
	Land use	Solid waste (disposal in landfill)	For industry
Human health	Human toxicity	LC_{50}	Not Applicable
	Smell	Qualitative Index	For industry
	Noise	Decibel exposure Index	For industry

B CATEGORY DEFINITION

Among the different impacts related to agricultural activity three main components have been chosen for this study:

Ecological	Agro-environmental	Resource use
Eutrophication	Biodiversity	Energy use
Global warming	Erosion	Groundwater depletion
Acidification		

C EXPLANATION FOR THE CHOSEN CATEGORIES

Eutrophication potential

Eutrophication is also called “nutrient enrichment” or “nutrification” and is defined as the emission of nutrients, mainly leached by water but also by air, to terrestrial and aquatic ecosystems (Finnveden and Potting, 1999).

The eutrophication by nitrogen has three major effects:

- Changing the **composition of the surrounding vegetation**.
- **Nutrient imbalance** in the soil leads to susceptibility regarding drought, diseases and pests.
- Leaching to **groundwater and to other biotopes** (Monteny, 2000).

Global warming potential

The potential contribution of an agricultural activity to global warming is mainly due to CO_2, CH_4 and N_2O emissions to the atmosphere. CH_4 emissions are related with animal production, in perennial tree orchards without grazing animals, these emissions are produced during the manure fabrication, and then it is taken into account when manure is used. These gases retain the heat re-emitted by earth to space and create the greenhouse effect. At the same time, the orchard also constitutes also a sink for carbon dioxide by photosynthesis, however, this will not be taken into account for the assessment of this impact.

Acidification potential

Acidification is the emission of gasses into the air, which damage the wider environment by combining with other molecules in the atmosphere and returning in the surface as "acid rain" (Audsley *et al.*, 1996). Emission of sulphur oxides (SO_2) and ammonia (NH_3) contribute to this phenomenon.

Biodiversity

Biodiversity performs a variety of ecological services beyond the production of food, including recycling of nutrients, regulation of microclimate and local hydrological processes, suppression of undesirable organisms and detoxification of noxious chemicals (Altieri, 1999).
In agrosystems, such as an olive orchard, biodiversity leads to secure crop protection and soil fertility. Enhancing it will result in a more environmentally compatible agrosystem but also, the pest management in this agrosystem will require less input of energy and resources than conventional pest management (Brown, 1999). It is relevant to assess this category for the improvement of the prototypes and the comparison of the types of olive groves.

Energy use

The depletion of energetic resources is considered as an impact category (Haas *et al.*, 2000). This category is defined as the burden of the agricultural activity on the primary energy (Audsley *et al.*, 1996).

Groundwater depletion

Since 1984, an extensive network of pumping stations has been installed that has allowed the conversion of what used to be dry cultivation of vines and olive trees to drip irrigated cultivation. The consequences have been a dramatic drop in the groundwater level as much as 30 m in some wells (Acreman, 2000), and the drying-up of springs, which formerly sustained havens for flowers, insects, birds and small mammals in the surrounding hills and wetland.

Erosion

The erosion of agricultural soil is unwanted for several reasons. First of all, erosion leads to the loss of fertile topsoil. It can also damage the crops. Furthermore, erosion by wind or water can cause environmental burden since minerals, organic matter, residues of pesticides and sometimes heavy metals in the topsoil are transported to surface water or nearby nature reserves. Many factors determine the potential erosion; for example, the crop management factor and the slope gradient. Therefore it is interesting to compare the environmental burden due to erosion by different management types and structures of the olive groves.

STEP 2: CLASSIFICATION

The purpose of classification is to organise and possibly combine the Life Cycle Inventory (LCI) results into impact categories. For LCI items that contribute to only one impact category, the procedure is a straightforward assignment. But, for LCI items that contribute to two or more different impact categories, a rule must be established. There are two ways of assigning LCI results to multiple impact categories (ISO, 1998):

⇒ **Allocate** a representative portion of the LCI results to the impact categories to which they contribute. This is typically allowed in cases when the effects are dependent on each other.

⇒ **Assign** all LCI results to all impact categories to which they contribute. This is typically allowed when the effects are independent of each other.

For this study, the first method will be applied. The problem of allocation is not valid for Biodiversity, Groundwater depletion, Energy use, Erosion and Global Warming, but for Acidification and Eutrophication. Then, allocation has been calculated on fate factor basis, as:

Table 5: Allocation of Ammonia (NH_3) and nitrogen oxide (NO_2).

Emission gas	Eutrophication	Acidification
NH_3	33%	67%
NO_2	39%	61%

STEP 3: CHARACTERIZATION

Impact characterization uses science-based conversion factors, called characterization factors, to convert and combine the LCI results into representative indicators of impacts to ecological health. Characterization factors are also commonly referred to as equivalency factors. Characterization provides a way to directly compare the LCI results within each impact category. In other words, characterization factors translate different inputs into directly comparable impact indicator.

Impact indicators are typically characterized using the following equation (ISO, 1998):

INVENTORY DATA X CHARACTERIZATION FACTOR = IMPACT INDICATOR

STEP 4: NORMALIZATION

Normalization is an LCA tool used to express impact indicator data in a way that can be compared among impact categories. This procedure normalizes the indicator results by dividing by a selected reference value (EPA, 2001). For this study, the surface unit (ha) will be used as it is the most relevant for the impact categories. But, it is still possible to convert it to product weight (t) by dividing it by the yield (t/ha). This later unit is particularly appropriate for consumer-oriented analysis.

STEP 5: GROUPING

A hierarchy is created with the intention of sorting the impact categories in order of sustainability issues that are the most relevant, ranking from short term/local to long term/global impacts. Grouping assigns impact categories into one or more sets to better facilitate the interpretation of the results. Since agricultural sustainability is defined by production over time, guaranteeing that food and labour are supplied to the community; products and business are provided to the economy and bio-physical context is preserved, three aspects of systems can be outlined: Space, Time and Dimension (Herdt and Steiner, 1995).

Dimensions are three, physical/biological, economic and social, and constitute the three marks corresponding to each impact category (Table 6). As sustainability depends also on Time (short term, medium term, long term) and Space (field, region, globe), the marks are set in the matrix, considering the field or farm's impacts as the most threatening to a sustainable activity. In order to grade, the marks are added and sorted from the smallest to the highest. When it is possible, impact categories are attributed to the corresponding dimension. One compartment (global, short-term risk) is not marked because of its non-significance in this study.

Table 6: Grading of the impact categories :

		SPACE		
TIME	Term	FIELD	REGION	GLOBE
	SHORT (<15 years)	1 B(e), RS(b), R_2(e), R_1(e).	4 B (b), R_1(s).	
	MEDIUM (15-30 years)	2 E_1(b), RS(e), R_1(b).	5 E_1(b), E_2(b), R_2(s).	7 R_2(b), E_3(s).
	LONG (>30 years)	3 E_2,(b), RS(s).	6 E_1(e), E_2,(e), E_3(b).	8 B (b), E_3(e).

Dimensions:
(e)= economic
(s)= social
(b)= physical/biological

Abbreviations:
E_1= Eutrophication
E_2= Acidification
E_3= Global warming
R_1= Groundwater depletion
R_2= Energy use
RS= Erosion
B= Biodiversity

Table 7: Sorting the impact categories :

Abbreviation	**Impact categories**	Calculation	Total	**Rank**	Group
RS	Erosion	1(b)+ 2(e)+ 3(s)	6	1	Resource use
R_1	Groundwater depletion	1(e)+ 2(b)+ 4(s)	7	2	
R_2	Energy use	1(e)+ 5(s)+ 7(b)	13	3	
B	Biodiversity	1(e)+ 4(b)+ 8(b)	13	4	Biodiversity
E_1	Eutrophication	2(b)+ 5(b)+ 6(e)	13	5	Emissions
E_2	Acidification	3(b)+ 5(b)+ 6(e)	14	6	
E_3	Global warming	6(b)+ 7(s)+ 8(e)	21	7	

STEP 6: WEIGHTING

a. Erosion	Loss of soil per hectare (t/ ha).
b. Groundwater depletion	Sustainability of water use Index (grade/ ha).
c. Energy use	Non-renewable energy reported to the functional unit (MJ/kg olives).
d. Biodiversity	Biodiversity index (BI) (grade/ ha).
e. Eutrophication	Eutrophication potential (EP) (g NO_3-equiv/ ha).
f. Acidification	Acidification potential (AP) (SO_2-eq/ ha).
g. Global warming	Global warming potential (GWP) (CO_2-equiv/ ha).

4.3.4. QUANTIFICATION OF THE ENVIRONMENTAL IMPACTS

A. Erosion

The erosion indicator is based on the widely accepted model, USLE (Universal Soil Loss Equation) established by Wishmeier and Smith (1965). This formula is used to predict long-term average soil losses. The USLE computes the soil loss as a product of six major factors and is given by:

$$A = R \times K \times L \times S \times C \times P$$

A= estimated soil loss (t/ha/year)

R= Rainfall factor
K= Soil susceptibility to erosion
L = Slope length factor
S = Slope gradient factor
C = Crop management factor
P = Erosion control factor

Rainfall erosivity factor (R)

The rainfall erosivity factor (R) is expressed as:

$$R = 1/100 \times E \times I_{30}$$

Where E is the total kinetic energy (t/ha/cm) of the rainfall, I_{30} is the maximum rainfall of 30 minutes duration of a storm (cm/h), and E is given by:

$$E = 210{,}3 + 89 \times \log_{10} I_i$$

Where I_i is the intensity of rainfall (cm/h) in a given duration of time i.

Such values of rainfall are impossible to obtain, unless there is a precise measurement during several years at the farm site, so a linear regression correlating intensity of rainfall and average annual rainfall, will be used as follows (El Swaify *et al.*, 1985):

$$R = 38{,}5 + 0{,}35\ p$$

Where p is the annual rainfall in millimetres (mm), the value of annual rainfall is 529.5 mm, average from 1955 to 1997, (national meteorological service, 1998), leading to a rainfall erosivity factor of 223.825 MJxmm/(haxh).

Soil susceptibility to erosion factor (K)

The soil erosion factor (K) is expressed as (Wishmeier and Smith, 1978):

$$K\ (\text{tonsx h/(MJxmm)}) =$$

$$(2.1 \times 10^{-6})(12-OM)(N1 \times N2)^{1.14} + 0.0325(S-2) + 0.025(P-3)$$

Where OM = per cent organic matter, N1 = per cent silt + per cent fine sand, N2 = per cent silt + per cent fine sand + per cent sand (Annex 1), S = soil structure code and P = permeability class of the soil.

Data from soil analysis from the Messara valley olive orchard organic matter content (from Kabourakis, 1993):

- Organic (spreading of manure plus cover crop during winter) organic matter: 1%.
- Conventional (no manure without sown cover crop during winter): 0.7%.

Table 8: Structure code of soils (USDA, 2000).

SOIL STRUCTURE CODE	DESCRIPTION
1	Very fine granular
2	Fine granular
3	Medium coarse granular
4	Block, platy or massive

Table 9: Permeability class of the soils (USDA, 2000).

PERMEABILITY CLASS	DESCRIPTION
1	Rapid
2	Moderate to rapid
3	Moderate
4	Slow to moderate
5	Slow
6	Very slow

Slope-length/slope-gradient factor (LS)

The LS factor is given by:

$$LS = (l/22.13)^{m(0.043\,x^2 + 0.3\,x + 0.43)/6.613}$$

Where l is the slope length in metres, x is the slope gradient in percentage and m is an exponent whose value depends on the slope steepness as given below:

Table 10: Relation between the exponent m and the slope (USDA, 2000).

SLOPE %	<1	1-3	3-5	>5
m	0.2	0.3	0.4	0.5

Crop and cropping management factor (C)

The crop and cropping management factor (C) is the ratio of soil loss under given conditions to soil loss from cultivated fallow for identical condition of soil, slope and rainfall. This factor ranges from 0 to 1.

There is no data concerning the olive orchard and its management but values from different fruit orchards and their management practices (i.e. tillage and cover cropping) calculated by USDA (2000) in United States are available variable with date:

Table 11: Wishmeier and Smith calculation of C-factor (Wishmeier and Smith, 1978):

	ORGANIC *(40% cover, trees excluded)*	*CONVENTIONAL* *(5% cover, trees excluded)*
HILLY	0.14	0.42
PLAIN	0.14	0.42

<u>Conservation practice factor (P)</u>

The conservation practice factor (P) is the ratio of soil loss with specified conservation practices (contour tillage, strip cropping, terracing) to that with up and down the slope cultivation. This factor ranges from 0 to 1 and is equal to 1 if there is no conservation practice. The calculation for this factor includes the effects of: contouring, strip cropping and terraces and the equations are:

$$P = Pc \times Ps$$

Or,

$$P = Pt$$

(If terraces are present)

Where, Pc= contouring factor, Ps= strip cropping factor and Pt= terraces factor.

Table 12: P-factor for different slopes and management practices (USDA, 2000):

	CONSERVATION PRACTICE FACTOR P		
	Contouring factor Pc	Strip cropping factor Ps	Graded terraces Pt
HILLY (20%)	0.7	0.7	0.17
PLAIN (5%)	0.55	0.55	0.1

The conventional hilly grove has a terrace, that is why the conservation practice value is low (0.17) compared to the organic where strip cropping and contouring is done only (PcxPs).

Table 13: Calculation of P-factor (USDA, 2000):

	ORGANIC (strip cropping and contouring)	*CONVENTIONAL (Contouring only)*
HILLY	0.49	0.17 (terraces)
PLAIN	0.3	0.55

<u>B. Groundwater depletion</u>

Knowing that almost all the olive orchards in this region are now drip irrigated and that irrigation in Crete is the major water use (82%) (Angelakis *et al.,* 1996). The amount of water used every year especially for olive tree irrigation is calculated, assuming that this irrigation water is only taken from the groundwater, it is possible to calculate an index of wateruse sustainability:

SUSTAINABLE WATERUSE INDEX =

$$1 - \frac{\text{CONTRIBUTION OF AGRICULTURE TO WATER USE (\%)} \times \text{IDEAL EXTRACTION } (m^3/\text{year})}{\text{AMOUNT OF WATER USED } (m^3/\text{ha}/\text{year}) \times \text{TOTAL IRRIGATED AGRICULTURAL AREA (ha)}}$$

Where the ‘ideal extraction rate’ represents the extraction rate for a recharge rate of the aquifer equals to 0, it is calculated by the inputs of water minus River and Groundwater flow.

The closer to 1 this index is, the worse the contribution to depleting watertable is.

C. Energy use

The assessment of this category is the ratio of non-renewable energy (fossil fuel, fertilizer ores and sequestered energy in materials), to the functional unit. A comparison of the different systems will then be possible.

D. Biodiversity

The assessment of this category is particularly difficult with state data (field measurements and inventory of plant, insect and animal species). Indeed, those data should be collected all around the year to be conformed to the reality of the evaluating biodiversity within the agrosystem.

The data that will be measures are the following (IERE, 2001 and author):

PRESSURE ON FLORA

- Method, frequency and timing of weed control (mowing, grazing or herbicides).
- Cover crop management: use of cover crop and span of the covering (enrichment of soil in nitrogen, beneficial for soil flora).

PRESSURE ON FAUNA

- Presence of natural and semi-natural features (scrubs, woodland, dry-stone walls, ponds),
- Degree of floral pressure
- Severe pest problem during the past five years (indicator of natural predator imbalance)
- Use of pesticides (type, quantity and timing).
- Distribution: size of naturally managed/average field size.
- Connectivity: percentage of adjacency to other natural land.
- Cover crop management: use of cover crop (food for mammals and birds).

Those indicators are weighted quantitatively on the basis of the questionnaires' answers and the visit in the field. The indexes are:

Table 14: Indexes used for the biodiversity assessment :

Detrimental	Neutral	Beneficial
-1	0	1

Then an average mark is calculated for both pressures estimations in order to estimate the impact of management and conservation practices on biodiversity.

E. Eutrophication potential

Method:

There are different approaches to quantify the eutrophication potential of the agricultural activity (Jensen *et al*. 1992, Heijungs *et al*. 1992 and Finnveden *et al*. 1992). For this study, the method of Jensen *et al.* will be used. In this method, emission of nitrogen to air and water and emission of phosphorous to water are treated separately and then aggregated. The impact indicator is called "biomass production". All emissions of nitrogen, to both air and water, and phosphorous to water are assumed to contribute only once to the same impact.

Emissions of nitrate (NO_3), ammonia (NH_3) and nitrogen oxides (NO_x as NO_2), from production and use of inputs are taken into account for the calculation of aquatic eutrophication potential, but also for acidification and gobal warming potentials. The formula used is taken from Heijungs *et al*. (1992) as:

$$\text{EMISSION} = f(\text{ACTIVITY, EMISSION FACTOR})$$

and,

$$\text{IMPACT} = \text{EMISSION x CLASSIFICATION FACTOR}$$

Eutrophying emissions from the production of fertilizers, and burning of pruning residues:

- NH_3 (from N fertilizer production and manure storage)
- NO_2 (from mineral fertilizers and burning of pruning residues)
- P (from P-fertilizer production)

Eutrophying emissions from the use of fertilizers are:

- NO_3 and PO_4 (from leaching and run off),
- NH_3 (from deposition on the aquatic environment after fertilizer volatilization)
- NO_2 (emission from fertilizer use and deposition on aquatic environment).

Eutrophication emission factors:

The emission factors from the production of mineral and organic fertilizers and use of fuel are taken from the literature available on eutrophying substances.

Table 15: Emission factor for eutrophication potential:

Activity		Agent	Emission factor	Reference
N-Fertilizer production	Process related emission	NO_2	1.58×10^{-3} kg/kg N	Biewinga & Van der Bijl (1996)
		NH_3	3.72×10^{-3} kg/kg N	Biewinga & Van der Bijl (1996)
	Energy related emission	NO_2	8.1×10^{-3} kg/kg N	France and Thompson (1993)
P-Fertilizer production	Process related emission	NO_2	1.53×10^{-3} kg/kg P	Hoogenkamp (1992)
		P	4×10^{-3} kg/kg P	Bøckman *et al*. (1990)
	Energy related emission	NO_2	2.28×10^{-3} kg/kg P	France & Thompson (1993)
Manure production	Stable and storage emission	NH_3	0.1 kg/kg N	RIVM-EDGAR (1995)
Burning of pruning residues		NO_2	$5.6\ 10^{-3}$ kg/kg FW	IPCC (1996)
Fuel use		NO_2	1.24 kg/ GJfossil	Frischnecht et al. (1994)

The emission factors for the use of mineral and organic fertilizers responsible for eutrophication from the field should comply with a model of leaching (NO_3) and volatilization (NH3) of those inputs. Brentrup *et al*. (2000) developed a methodology to estimate on-field nitrogen emissions as an input to LCA studies. In their model, volatilization assessment for organic manure is based on the type of manure applied (dry matter content and NH_4-N content) and on four important and easy to get parameters:

- ➔ Average air temperature
- ➔ Infiltration rate (low, medium and high)
- ➔ Precipitation or incorporation after application
- ➔ Time between application and incorporation

For this study, the type of manure applied is from sheep and goat, its dry matter content is 30%, N content of 9.1 kg/t and NH_4-N content of 30% of total N (Barker *et al*., 2002). The average air temperature during application is 20-25 °C (meteorological agency). The infiltration rate is low to medium following the classification of Horlacher and Marschner (1990) because the soil is not heavily compacted but the manure applied is solid. The practice of manure application is asked to the farmers during the interview like the occurrence of rain after the application.

Ammonia volatilization due to mineral fertilizer application is usually lower compared to manure (Isermann, 1990). However, dependent on the ammonium and urea content of a mineral fertilizer, the climatic conditions and soil properties, considerable ammonia volatilization can also take place when applying mineral fertilizers. The ECETOC (1994) proposed a method to estimate these emissions taking into account the different soil properties throughout Europe and the different NH_3 volatilization risk dependent on the fertilizer type (see table 16). Crete and Greece are classified in the first group corresponding to the highest volatilization sensitivity because of the calcareous soils and a pH higher than 7 (basic).

Table 16: Emission factor related with fertilizer type (ECETOC, 1994):

FERTILIZER TYPE	EMISSION FACTOR (% NH_3-N loss of total applied mineral N)
Urea	20
Ammonium nitrate, Calcium Ammonium Nitrate, NP, NK, NPK	3
Ammonium phosphate	5
Ammonium Sulphate	15
Urea Ammonium Nitrate solution	8

Information about the type of mineral fertilizer is asked to the farmers during the interview in order to assess which emission factor of the ammonia volatilization suits to the calculation of the eutrophication impact of mineral nitrogen application.

Nitrate (NO_3) leaching and run off assessment method developed by Brentrup *et al.* (2000) is used here to estimate eutrophication potential. The most important parameters determining the nitrate-leaching rate are:

- ➔ **NITROGEN BALANCE** (kg N/ha/y)
- ➔ **FIELD CAPACITY** in the effective rooting zone (FC_{RZE})(mm)
- ➔ **DRAINAGE WATER RATE** (mm/y)

The nitrogen balance is the difference between nitrogen input and nitrogen output, as follow:

N-BALANCE (farmgate)
=
[N INPUT]
(Mineral/organic N fertilizer + biological N fixation + atmospheric N deposition)
-
[N OUTPUT]
(N exportation + volatilization (NH_3 emission) + denitrification (NO_2) emission).

This equation follows the nitrogen cycle represented as:

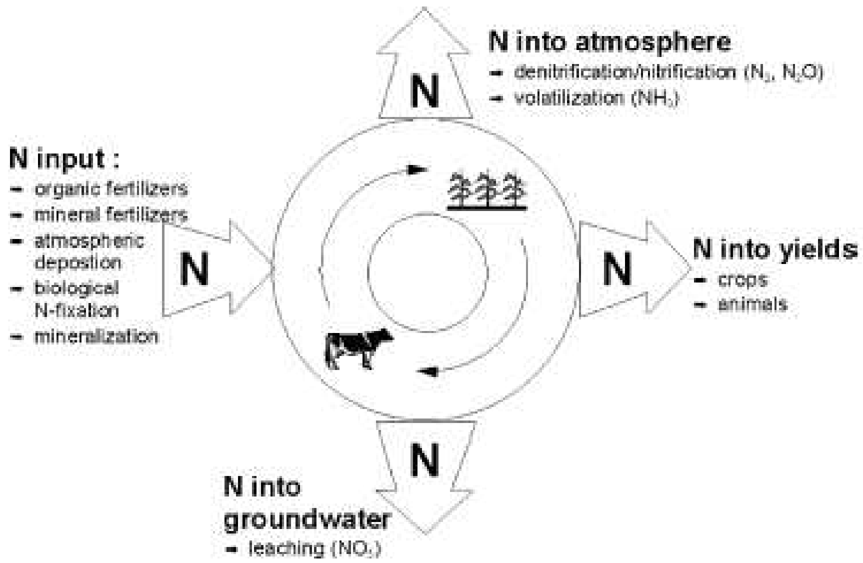

Fig.7: Nitrogen cycle on farm (adopted from ECETOC, 1988).

Exportation of nitrogen from the field is accounted only for the nitrogen content of the crop (olives), that is to say only 0,85% per mass (Climato, 1990). The residues'nitrogen is normally returned to the soil as leaves and branches are burned or chopped and spreaded on the ground. The losses of nitrogen during the combustion is negligible compared to the other figures of the formula and are not included in the exportation, but will be analysed for global warming potential.

The biological N-fixation of the leguminous cover crop, usually vetch, is 78 kg/ha (Papastylianou and Danso, 1991). The atmospheric N-deposition is estimated to be 3.8 kg/ha in Greece (Umweltbundesamt, 1997). Volatilization of nitrogen is calculated with the emission factor (3.72×10^{-3} kg NH_3/kg N) and denitrification is assessed using its emission factor (1.58×10^{-3} kg NO_2/kg N) (Biewinga & Van der Bijl, 1996).

The field capacity in the effective rooting zone (FC_{RZE}) describes the capacity of the soil to adsorb water within that part of soil in which the roots are able to take up water. The FC_{RZE} can be calculated by multiplying the available field capacity (FCa) by the effective rooting zone (RZe). The available field capacity, as well as the effective rooting zone, strongly depends on the soil texture and tables give the correlation. Hence, to calculate the field capacity in the effective rooting, only information about soil texture is needed.

For the Sandy loam soils of the olive groves in the Messara Valley (result from soil analysis), the Fca is 22 mm*dm^{-1} and the RZe is as high as 20 dm (adapting for trees), leading to a FC_{RZE} of 440 mm.

The precipitation rate (Wprecip) and its distribution through the year, as Liebscher and Keller (1992) mainly determine the rate of drainage water (Wdrain):

$$W_{drain}\,(mm) = 0.86 \times W_{precip\text{-}year}\,(mm) - 11.6 \times (W_{precip\text{-}summer} / W_{precip\text{-}winter}) - 241.4$$

The constant values (0.86, 11.6, 241.4) come from the model developed by Liebscher and Keller (Liebscher and Keller, 1992).

The annual precipitation is, on average between 1955 and 1997, 529.5 mm. The rain in winter (from December to March) is 306 mm and 3.1 mm in summer (from June to September), on average between 1955 and 1997 (National meteorological service, 1998). The rate of drainage water is calculated and its value is: 213.85 mm

Therefore, the leaching of nitrate is given by the formula:

$$\text{Leached } NO_3\text{-N (kg N/ha/y)} = \text{Nitrogen balance (kg N/ha/y)} \times W_{drain}\,(mm) / FC_{RZE}\,(mm)$$

The eutrophication potential due to PO_4 emission will be estimate from the study of Sonneveld (1993), the emission factor being 0.1 kg PO_4-P/kgP.

Classification factors:

Huijbregst and Seppälä (2001), improved the model of classification factors made by Heijungs *et al.* (1992), for aquatic eutrophication, by including fate factors of anthropogenic emissions to air and soil:

$$AEP_{s,i,e} = AFF_{s,i,e} \times AEF_s$$

Where the Aquatic Eutrophication Potential (AEP) is the characterisation factor for aquatic eutrophication of compounds emitted in region i to compartment e (kg PO_4^{3-}eq./kg). The Aquatic Fate Factor (AFF) is the fate factor represents the fraction of compounds emitted in region i to compartment e that is transported to the aquatic environment. Whereas, the Aquatic Effect Factor (AEF) represents the potential biomass production of phytoplankton per mass unit of compounds relative to PO_4^{3-} (kg PO_4^{3-} -eq/kg).

The fate factors, effect factors and potential aquatic eutrophication are given for Europe in the table below (Huijbregst and Seppälä, 2001)

Table 17: Fate and effect factors for eutrophication (Huijbregst and Seppälä, 2001)

EUTROPHYING SUBSTANCES	AFF	AEF	AEP kg PO_4^{3-}eq./kg
NO_3	0.23	0.42	0.1
P	0.03	3.06	0.09
PO_4	1	1	1
NH_3	0.33	0.35	0.11
NO_2	0.39	0.13	0.05

F. Acidification

Method:

Emissions contributing to acidification potential are overlapping those of eutrophication potential. For ammonia (NH_3) and nitrogen oxides (NO_2), that causes both eutrophication and acidification, their acidification fate factor (Ac.F.F) is obtained as the remaining of their aquatic fate factor (A.F.F). In order to avoid double counting of these gas potential effects on acidification. The calculation of the acidification impact category is done the same way as the two others emission related impact category (i.e. eutrophication and global warming potential).

Acidification emission factors:

The gas responsible and their sources of emission, potentially leading to acidification are:

1) Production of fertilizers and burning of pruning residues:

- ✦ NH_3 (from N fertilizer production and manure storage)
- ✦ NO_2 (from mineral fertilizers and burning of pruning residues)
- ✦ SO_2 (from mineral fertilizers production)

2) Use of fertilizers:

- ✦ NH_3 (from fertilizer volatilization)
- ✦ NO_2 (from fertilizer use to the air).

Table 18: Emission factor for the acidification potential:

<table>
<tr><th colspan="2">Activity</th><th>Agent</th><th>Emission factor</th><th>Reference</th></tr>
<tr><td rowspan="4">N-Fertilizer production</td><td rowspan="2">Process related emission</td><td>NO_2</td><td>1.58×10^{-3} kg/kg N</td><td>Biewinga and Van der Bijl (1996)</td></tr>
<tr><td>NH_3</td><td>3.72×10^{-3} kg/kg N</td><td>Biewinga and Van der Bijl (1996)</td></tr>
<tr><td rowspan="2">Energy related emission</td><td>NO_2</td><td>8.1×10^{-3} kg/kg N</td><td rowspan="2">France and Thompson (1993)</td></tr>
<tr><td>SO_2</td><td>1.13×10^{-2} kg/kg N</td></tr>
<tr><td rowspan="3">P-Fertilizer production</td><td>Process related emission</td><td>NO_2</td><td>1.53×10^{-3} kg/kg P</td><td>Hoogenkamp (1992)</td></tr>
<tr><td rowspan="2">Energy related emission</td><td>NO_2</td><td>2.28×10^{-3} kg/kg P</td><td rowspan="2">France and Thompson (1993)</td></tr>
<tr><td>SO_2</td><td>3.18×10^{-3} kg/kg P</td></tr>
<tr><td>Manure production</td><td>Stable and storage emission</td><td>NH_3</td><td>0.1 kg/kg N</td><td>RIVM-EDGAR (1995)</td></tr>
<tr><td colspan="2">Burning of pruning residues</td><td>NO_2</td><td>$5.6\ 10^{-3}$ kg/kg FW</td><td>IPCC (1997)</td></tr>
<tr><td colspan="2" rowspan="2">Fuel use</td><td>NO_2</td><td>1.24 kg/GJfossil</td><td rowspan="2">Frischknecht et al. (1994)</td></tr>
<tr><td>SO_2</td><td>0.153 kg/GJfossil</td></tr>
</table>

The calculation of ammonia (NH_3) emission factor from field use of fertilizer is based on the same methodology developed for eutrophication emission assessment. Volatilization after manure or fertilizer application contributes to eutrophication, as the ammonia is partially deposited on aquatic ecosystem, and to acidification. The fate factor for this emission is calculated from the aquatic fate factor and multiplied by the classification factor in order to allocate the contribution of the emission to each impact category.

Classification factors:

Acidification fate factors for ammonia (NH_3) and nitrogen oxides (NO_2), are calculated as:

$$Ac.F.F = 1 - A.F.F$$

Giving these values for the classification factors of the emissions contributing to acidification:

Table 19: Fate and effect factors for acidification (Huijbregst and Seppälä, 2001; and author):

ACIDIFYING SUBSTANCES	AFF	AcFF	AcEF	AcP kg SO_2 eq./kg
SO_2	0	1	1	1
NH_3	0.33	0.67	0.7	0.462
NO_2	0.39	0.61	1.88	1.147

Acidification effect factor (AcEF) is measured in kg SO_2 equivalent/kg (Heijungs *et al*., 1992). The acidification potential (AcP) has the same unit since the aquatic fate factor (AFF) and the acidification fate factor represent a fraction of compound that is emitted from a certain region to a compartment, either water or air.

G. Global warming

Method:

Global warming potential is characterised using the IPCC Global Warming Potentials (IPCC, 1996), which expresses all emissions in CO_2 equivalent for all the greenhouse gases. The methodology used here is the same as the one used for characterizing eutrophication impact. Sources of emissions from production and use of inputs are listed, an emission factor is attributed to each source and classification factors (found in the literature) serve the aggregation of the different sources.

Emission factor:

The gas responsible and their sources of emission, potentially leading to global warming are:

- CO_2 (from tractor use and burning of pruning residues)
- CH_4 (from stable and burning of pruning residues)
- N_2O (from field denitrification, mineral fertilizer and burning of pruning residues)

Table 20: Emission factors, taken from the literature, related to global warming potential:

Activity		Agent	Emission factor	Reference
N-Fertilizer production	Process related emission	N_2O	2.7×10^{-2} kg/kgN	Kroeze and Bogdanov (1997)
	Energy related emission	CO_2	2.5 kg/kg N	France and Thompson (1993)
		N_2O	3.78×10^{-5} kg/kg N	France and Thompson (1993)
P-Fertilizer production	Energy related emission	CO_2	0.705 kg/kg P	IPCC (1997)
		N_2O	1.06×10^{-5} kg/kg P	IPCC (1997)
Manure production	Stable emission	CH_4	1×10^{-3} kg/kg manure	Corinnair (1996) and Barker *et al*. (2002)
Fuel use		CO_2	85.2 kg/GJfossil	Eurostat (1991) and Frischnecht et al. (1994)
Burning of pruning residues		CO_2	$3\ 10^{-2}$ kg/kg FW	IPCC (1997)
		CH_4	$3.24\ 10^{-3}$ kg/kg FW	
		N_2O	$1.8\ 10^{-4}$ kg/kg FW	
Nitrogen use (denitrification)		N_2O	0.0125 kg/kgN	Bouwman (1995)

FW= Fresh Weight

The methodology for estimating greenhouse gas emissions from burning of agricultural products is based on:

1) total carbon released, which is a function of the amount (kg of fresh weight burned, FW), efficiency of biomass burned or fraction oxidised, taken as 90% (IPCC, 1997), the carbon content of the wood, taken as 38,8% of dry matter weight (IPCC, 1997 and Kabourakis, comm. Pers.), nitrogen content in the branch, varying from 0.25% in the big branch to 1.215% of dry weight in the small branches and leaves(Bouat, 1969) and the total dry matter of wood 60% of fresh weight (FW) (Bouat, 1969); and

2) The application of emission ratios and conversion factors to full molecular weight; for exemple, this ratio is equal to 16/12 for CH_4, as the molecular mass (M) of CH_4 is 16 g/mol (12+4*1) and MC= 12 g/mol.

- Calculation of the proportion of carbon released:

CARBON RELEASED = Average dry matter of the crop residues (%) x Fraction oxidised (%) x Carbon content (dry matter) (%).

- Calculation of the emissions (examples):

CH_4 emissions = Carbon released x emission ratio x 16/12 (conversion to real weight)
N_2O emissions = Carbon released x N/C ratio x emission ratio x 44/28.

Classification factors:

For a 100 years reference, the equivalencies are given by IPCC (1997):

CO_2= 1kg CO_2-eq,
CH4= 21 kg CO_2-eq,
N_2O= 270 kg CO_2-eq.

5. RESULTS, DISCUSSION AND RECOMMENDATIONS

5.1. RESULTS AND DISCUSSION

5.1.1. ENERGY EFFICIENCY STUDY

The outcome of the study on energy efficiency, done with the data gathered from the four farms of the project, is presented in this section. An average of energy inputs and outputs has been calculated for hilly and plain since the management is comparable and values close. First, the distribution of inputs is presented, in order to get an insight into the different direct, indirect and capital energies used by the two types of farmers. Then, efficiencies of organic and conventional are compared.

5.1.1.1. INPUT ANALYSIS

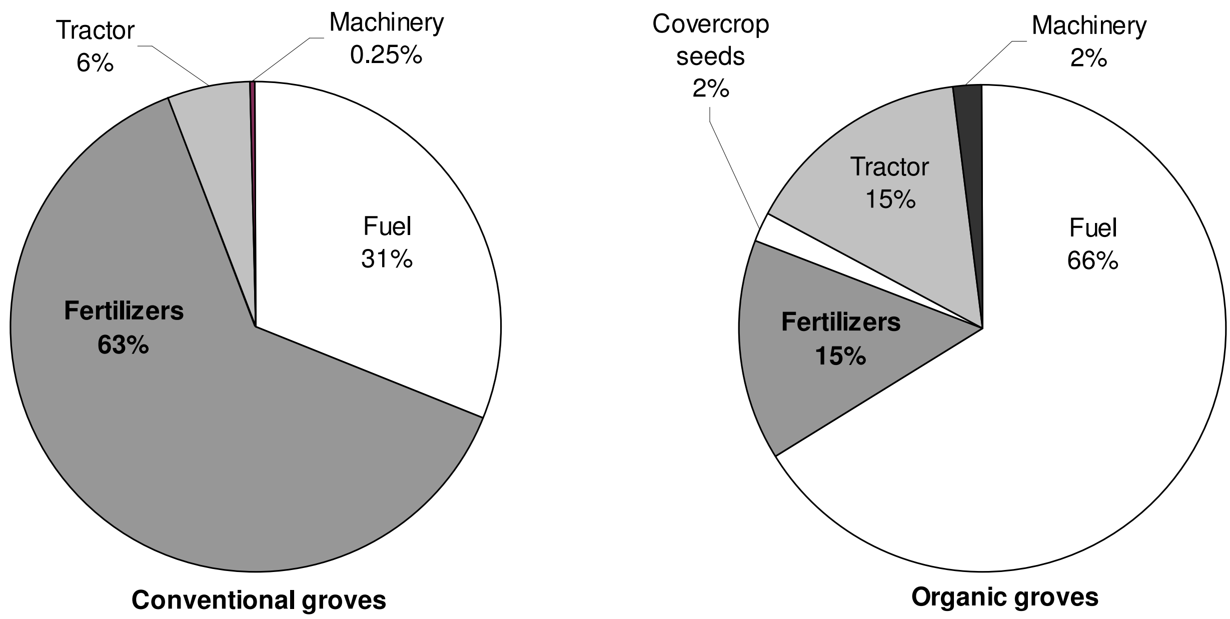

Fig.8: Distribution of energy inputs for Organic and Conventional groves.

The figure above shows the main differences in the use of energy between organic and conventional cultural practices. Overall energy use is lower in organic production (1157 MJ/ha for the organic groves compared to 3153 MJ/ha). Direct energy use in organic groves represents two thirds of the overall energy use, whereas it represents only one third for the conventional production.

Indirect energy is the main energy input in the conventional groves with 63% from the fertilizers embodied energy, compared to 15% in the organic production. This latter has been calculated from the estimation of the non-renewable energy requirements to produce manure.

It is noticeable to observe that machinery use is, proportionally, greater in organic production. This is mainly due to the fact that more mechanical cultural practices are needed in the organic groves. In deed, sowing and ploughing under (incorporating) the cover crops requires special machinery.

5.1.1.2. GROVES'EFFICIENCY

The figure below shows energy efficiencies of the two types of groves studied and details of the output and input levels.

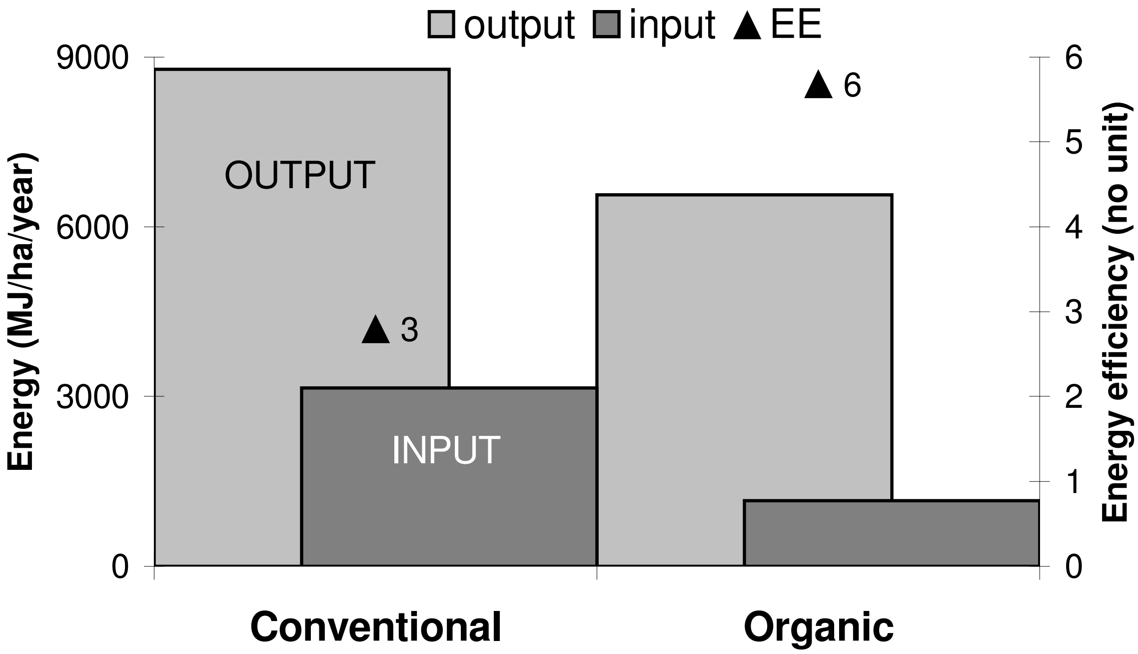

Fig.9: Energy efficiencies of Organic and Conventional olive groves, triangles represent the energy efficiency (EE).

Energy efficiencies of both hilly and plain groves are slightly different but an average has been calculated in order to compare organic practices with conventional ones. The most striking point on this graph is the fact that organic groves are two times more energy efficient than conventional groves. The level of energy inputs used in organic production can explain this result. In deed, almost two times more inputs are used in conventional production compared to organic production, but the output, energy content of the crop (olives), is only 1.33 times higher than organic production.

By having a closer look at the inputs used in the production of olives, chemical fertilizers contribute for a great extend at increasing the indirect energetic input of the conventional grove, this explains why the efficiency of the conventional production is so low. Also, the use of direct energy (fuel) is more important (absolute value) in conventional groves than in organic groves, contributing to a decrease in energy efficiency of the agrosystem. Indeed, spraying and tilling are done more systematically and more frequently in conventional cultural practices than for organic ones.

The differences between plain and hilly groves are not presented here in the graph, they are not neglected but in order to simplify the comparison, they are not included. The most relevant difference between hilly and plain groves'energy input is the amount of capital energy (mainly tractor) used. Since the slope can be important in the hills, the power of the tractor is higher, resulting in a higher energy content, typically around 200 MJ/ha/year for the hilly groves, compared to 145 MJ/ha/year in the plain groves.

5.1.2. LIFE CYCLE ANALYSIS

5.1.2.1. IMPACT CATEGORIES ASSESSMENT

In this section the seven chosen impact categories (soil loss, groundwater depletion, energy use, biodiversity loss, eutrophication, acidification and global warming) are analyzed in details. Each impact is presented with a figure or a table describing, for each type of grove (conventional and organic; hilly and plain), the fate of the emissions (air, water and soil), and calculations for the other impact categories on a surface unit basis (ha).

Soil loss

Table 21: Results of the erosion potential impact assessment:

		Hill		Plain	
DATA	UNITS	Conventional	Organic	Conventional	Organic
Soil susceptibility (K)	**tonsx h (MJxmm)**	**0.82**	**0.83**	**0.73**	**0.72**
Slope-length (LS)	**no unit**	**6.28**	**6.28**	**1.09**	**1.12**
Rainfall (R)	**MJxmm (haxh)**	**223.83**	**223.83**	**223.83**	**223.83**
Crop management (C)	**no unit**	**0.42**	**0.14**	**0.42**	**0.14**
Erosion control (P)	**no unit**	**0.17**	**0.49**	**0.5**	**0.3**
Annual soil loss	**tons/ha/y**	**82.5**	**79.7**	**37.5**	**7.6**
Average	**tons/ha/y**	**81.1**		**22.5**	

First, it is noticeable that hilly groves are potentially more eroded than the plain ones. Also, the organic plain grove is far less sensitive to erosion, this result is mainly due to the crop management factor that is lower than the conventional one. The sowing of cover crop in between the olive tree rows is leading to a good improvement in the erosion potential, following the USLE calculations.

Secondly, the difference between hilly conventional and organic groves is not well marked because the conventional orchard analyzed in the study is maintaining a terraces system that contributes greatly to lower the erosion control factor (P). Whereas the hilly organic grove is as much potentially eroded simply with the help of the cover cropping contributing to lower the crop management factor (C).

Groundwater depletion:

Table 22: Results of the groundwater depletion potential:

		Hill		Plain	
DATA	UNITS	Conventional	Organic	Conventional	Organic
Volume of water	**(Ml/ha/y)**	**1200**	**400**	**800**	**750**
Groundwater depletion index	**no unit**	**0.72**	**0.16**	**0.58**	**0.55**

The calculation of the groundwater depletion index is explain in the paragraph 4.3.4, part B. The equation used depends on a sustainable water extraction rate calculated following the recommendations set by Acreman et al. (2000), using the numerical model AQUA 3D for the Messara basin aquifers. From the result obtained, it seems that the organic orchards are using less irrigation water than the conventional ones, contributing then to a lower extent to the groundwater depletion potential. This difference is even more important for the hilly groves. Since there is no standards concerning the amount of water that should be used to irrigate the olive fields, there is a large heterogeneity in the results obtained from the interviews. the farmer takes the decision of the amount of water applied in the grove based on his experience and local knowledge.

Energy use:

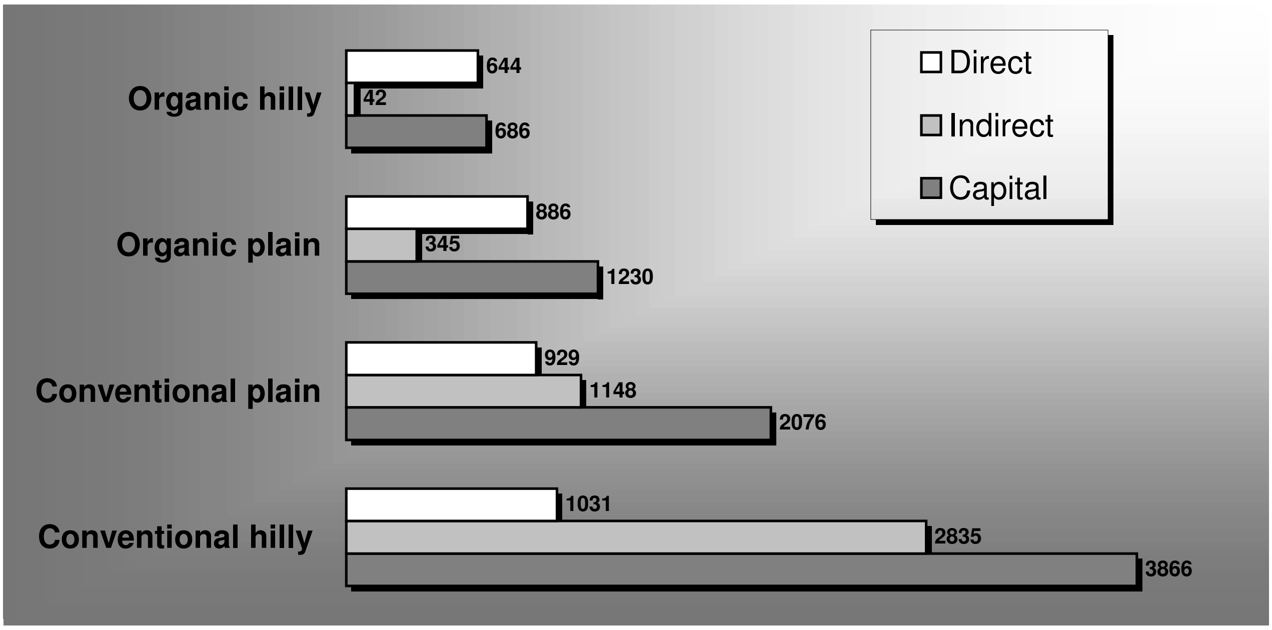

Fig.10: Components of the energy depletion potential (results are expressed in MJ).

This impact category is marked by a clear difference between organic and conventional systems of farming. In deed, the total amount of energy from any source (direct, indirect and capital) is greater in conventional groves than in organic groves. The consumption of energy is the highest for the conventional hilly grove; whereas it is the lowest in the case of the organic hilly. This difference is certainly due to the fact that the hilly conventional farmer is willing to intensify his production on this hilly but terraced grove. On the contrary, the hilly organic farmer is adopting more traditional methods of production, this latter point is visible on the figure by looking at the very low use of indirect energy.

Biodiversity loss:

Table 23: Results of the biodiversity loss potential:

Pressure	Criteria	Conventional hilly	Conventional plain	Organic plain	Organic hilly
Flora	**Covercrop management**	**0**	**0**	**1**	**1**
	Weed control	**-0.5**	**0**	**0.5**	**0.5**
Fauna	**Degree of pressure on flora**	**-0.25**	**0**	**0.75**	**0.75**
	Pesticide use	**-0.5**	**-0.5**	**0**	**0**
	Severe pest problems	**-1**	**0**	**0**	**0**
	Distribution and Connectivity	**0.5**	**0.5**	**0.5**	**1**
	Natural features	**1**	**0**	**0**	**1**
	Covercrop management	**0**	**0**	**1**	**1**
Biodiversity index (no unit)		**-0.04**	**0**	**0.38**	**0.63**

The assessment of the farming systems' contribution to biodiversity loss shows a clear difference between organic and conventional ways of farming. This difference is mainly due to the consideration of the cover cropping as beneficial to the soil flora and fauna but also to the aerial and terrestrial fauna since the cover crop supplies them with food and habitat. There are also management methods that are considered as detrimental to biodiversity such as the weed control and the use of pesticide, which are directly linked with the potential loss of flora and fauna. The happening of a pest problem during the past 5 years is an indicator of the auto-regulation ability of the agrosystem, this happened in the conventional hilly grove only (which is also the most intensified of all). Finally, it is noticed that the presence of natural features and their connectivity does not depend on the type of grove (organic or conventional).

Eutrophication:

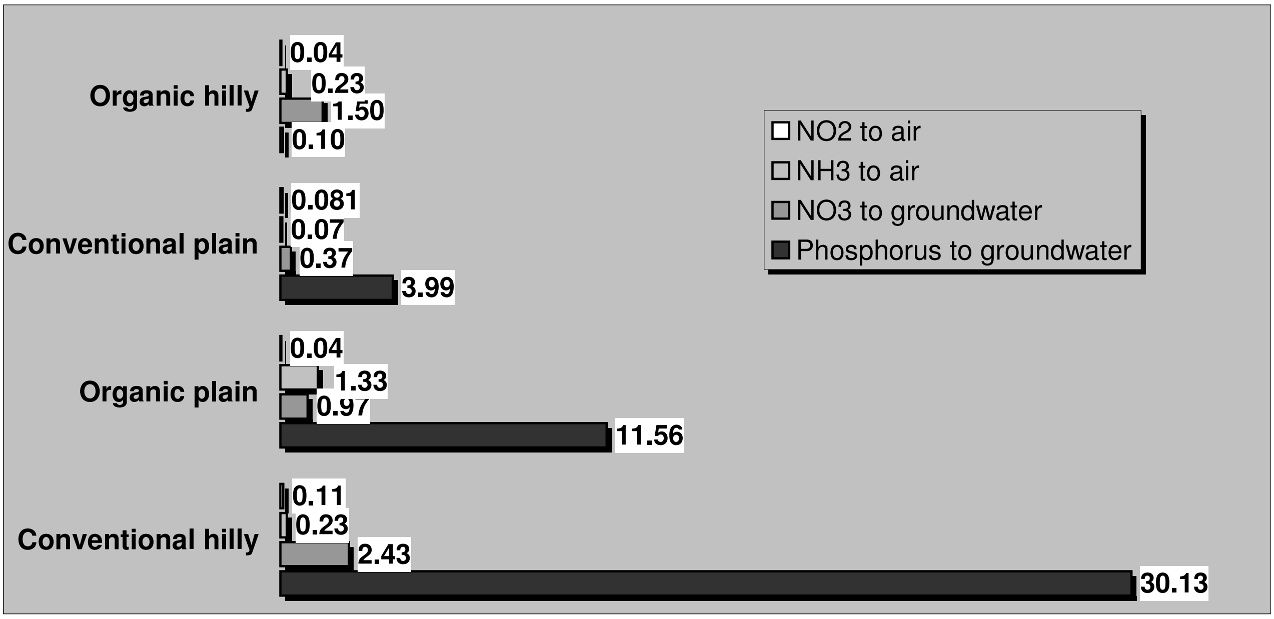

Fig.11: Components of the eutrophication potential (results are expressed in kg PO_4 eq./ha).

The figure above shows potential contribution and its components of the different farm types to the aquatic eutrophication. The grove types are ordered from the one that contributes the less to the one that contributes the most to the eutrophication. The plain organic orchard is more polluting the aquatic environment than the plain conventional one. This result is due to the fact that the farmer applies a very large quantity of manure (5 t/ha/y) in his field. Compared with the hilly organic grove, this amount of manure is multiplied by ten.

It is interesting to notice that the main component leading to eutrophication is the phosphorous applied. Especially in the hilly conventional grove, the amount of phosphorous that is potentially leached to the groundwater has a tremendous impact. It is not only the amount of chemical phosphorous used that lead to such impact, but most of all the classification factor of the phosphorous potentially leached that contribute to such an important eutrophication.

The other components (nitrogen dioxide NO_2, ammonia NH_3 and nitrate NO_3) are of less importance to the potential eutrophication impact. Except for the hilly organic grove, these components are not the main contributors to this impact. The emission of phosphorous to air is not presented in the figure above because its contribution to aquatic eutrophication is negligible, the values are even smaller than those of the eutrophication potential of the nitrogen oxide (NO_2) to air.

Acidification:

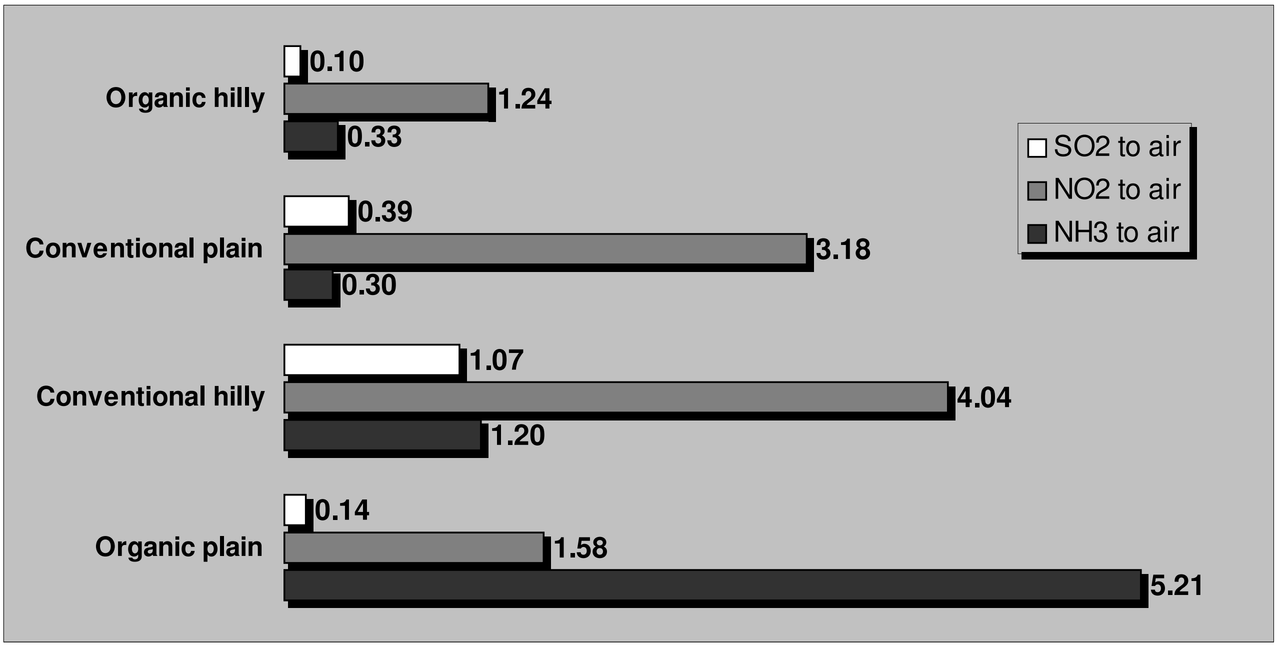

Fig.12: Components of the acidification potential (results are expressed in kg SO_2 eq./ha).

Although the level of contribution to acidification is barely the same between the plain organic (6.93 kg SO_2 eq.) and the hilly conventional (6.31 kg SO_2 eq), the contribution to acidification by ammonia (NH_3) is very high for the plain organic olive grove. Volatilization of the NH3 during the application of the large quantity of manure is the cause of such quantity of ammonia emission to the air. The main emission causing acidification for the conventional groves is the nitrogen dioxide (NO_2) coming from fuel use and burning of pruning residues.

Global warming:

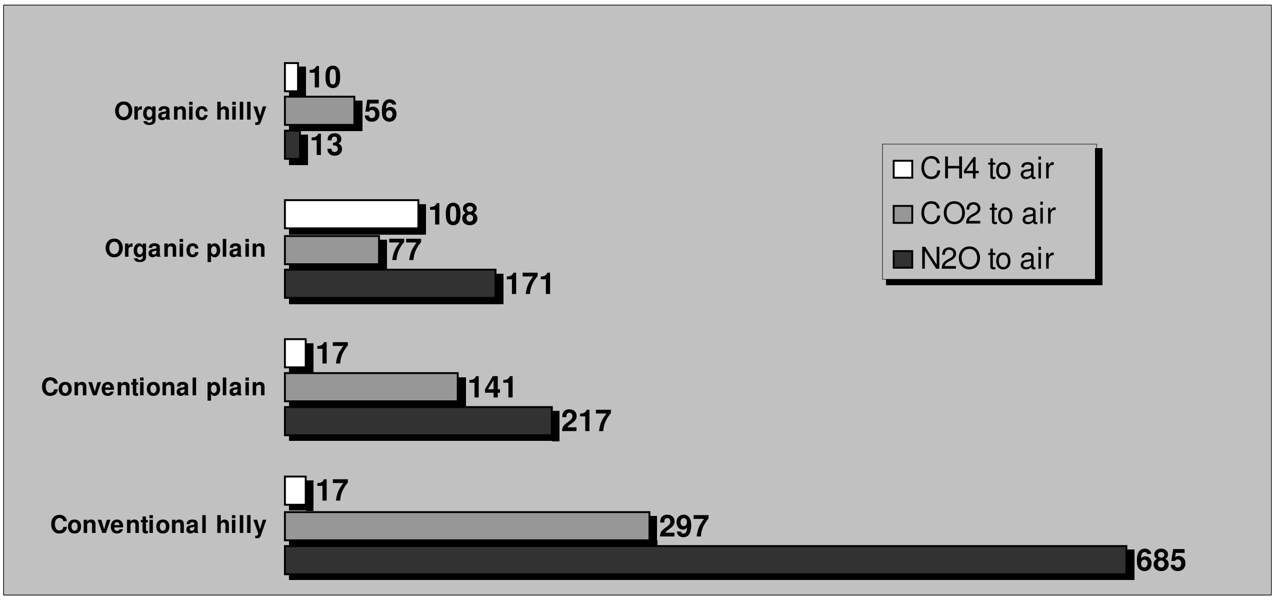

Fig.13: Components of the global warming potential (results are expressed in kg CO_2 eq./ha).

The graph above is very similar to the one representing the energy use. This is mainly because a great part of the contribution to global warming can be attributed to the use of fuel and chemical fertilizers causing nitrous oxide (N_2O) emissions. Carbon dioxide (CO_2) emission comes from the use of fuel and the burning of pruning residues.

5.1.2.2. *Life cycle stages analysis*

Only the emission related impact categories (eutrophication, acidification and global warming) and the energy use are dealt with in this section, the other impacts have strictly on-field created environmental effects (erosion, groundwater depletion and biodiversity loss). The stages considered in usual LCA are presented below (figure 14). For this study, the farm gate is the end limit to the analysis.

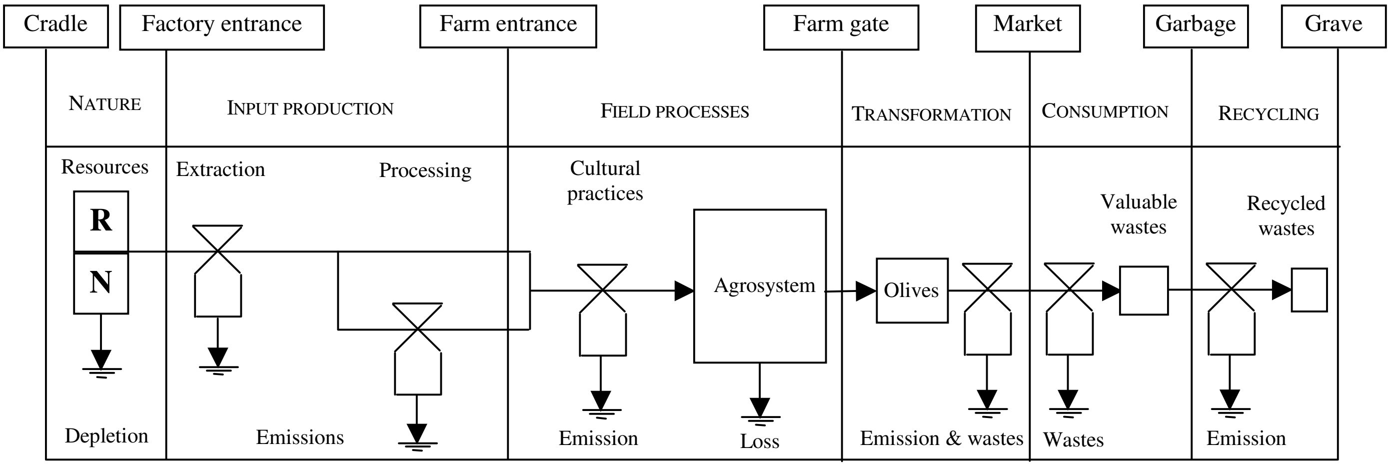

Fig.14: Scheme of production stages (from the cradle to the grave). R= renewable resources and N= non-renewable resources.

Considering this separation between the input production and the field processes, the figure below (figure 15) shows the distribution of the impact categories overlapping the two stages.

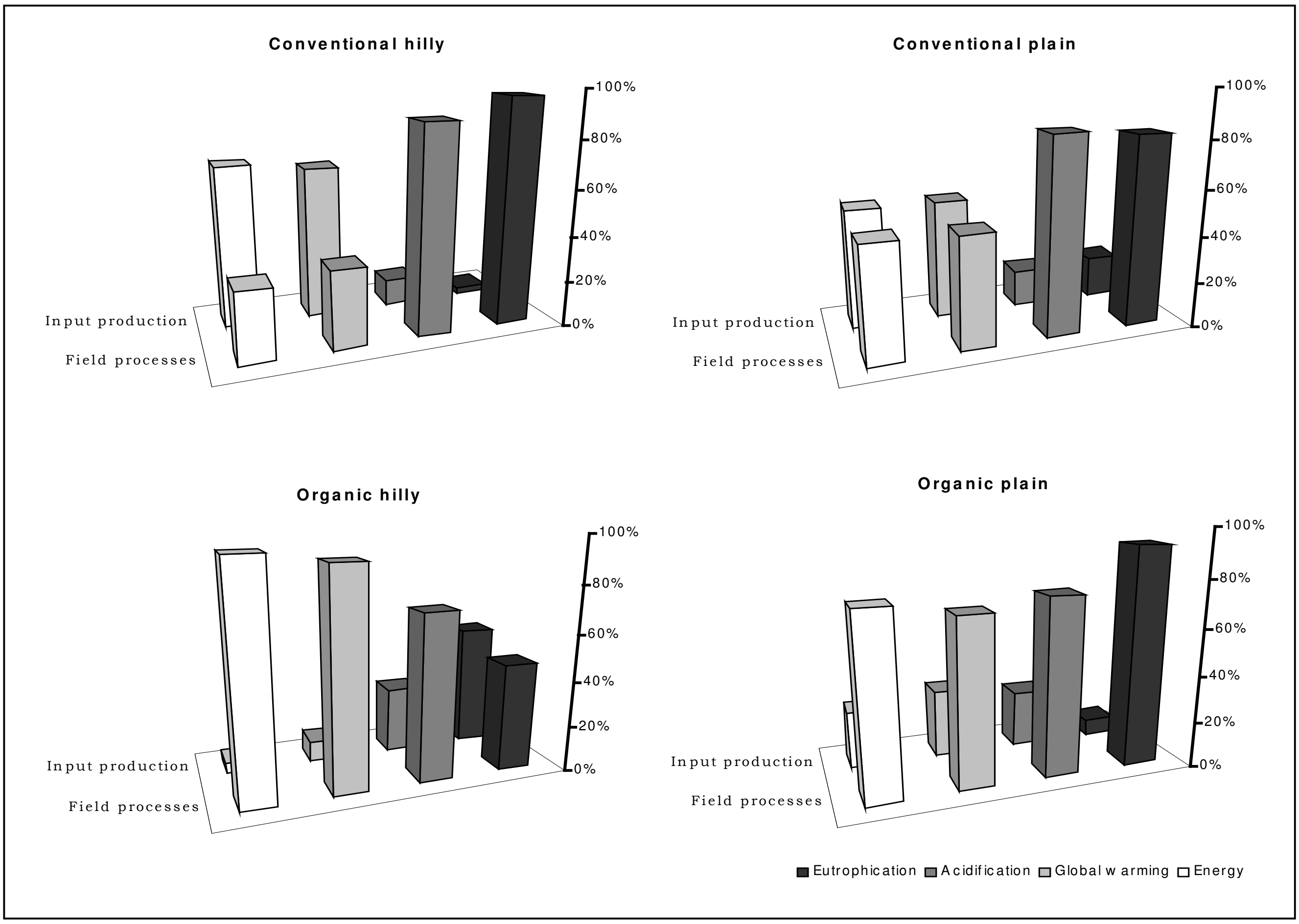

Fig.15: Stages analysis of the relative emission and energy use impact categories.

On the figure 15 (previous page), the relative contributions of the energy and emission related impact categories are split between the production of inputs and the field processes themselves. From this figure it is noticeable that the main energy used and the main contribution to global warming take place during the input production for the conventional production systems, whereas those impacts are lower and more present during the field processes stages in the organic production systems.

It is also remarkable that the energy use and the global warming potential are following the same patterns for the four groves analyzed. The distribution of those impacts among the two stages (input production and field processes) are really similar. It is clear that the comparison between plain and hilly groves regarding energy use and global warming potential is a flattening of the differences between input production and field processes. This is due to the different approach between conventional and organic farming practices, in deed, on the hills for example, the organic farmers have to spend more energy on-field but the conventional ones rely more on inputs such as chemical fertilizers.

Finally, the eutrophication and acidification impact categories are evenly distributed among the different types of groves. In deed, those emissions are field-related impacts, this is the reason why they are much more important in the field processes stage. The organic hilly grove production system seems to contribute highly to eutrophication during the input production stage, but the values are very low (around 1 kg PO_4 eq./ha/year) for both stages (input production and field processes).

5.1.2.3. CATEGORY COMPARISON PER SURFACE UNIT (HA)

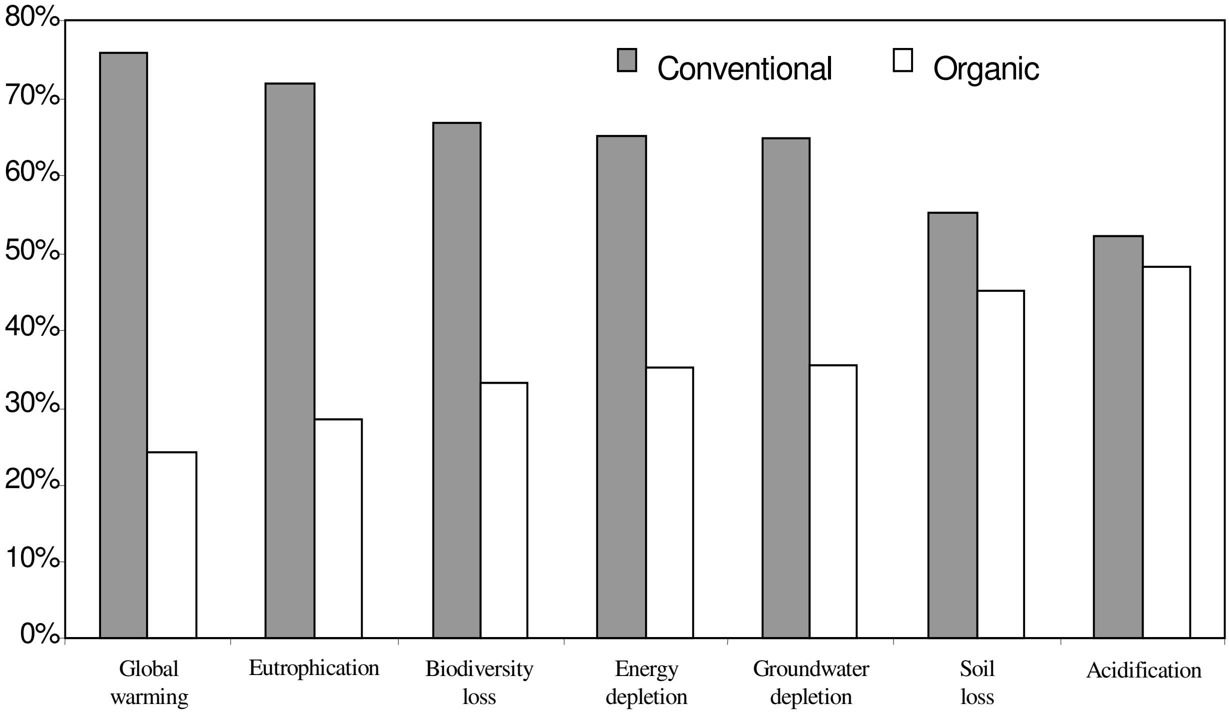

Fig.16: Relative proximity of the environmental impacts related to the two types of groves.

The figure above shows the different impact categories ranked in order of relative proximity between the organic and conventional olive groves (Annex 3). In order to obtain comparable and normalized results, the average impact of hilly and plain groves is calculated, then the potential contributions related to organic and conventional are divided by the sum of both kind of grove. The Y-axis represents the percentage of contribution for each type of grove (conventional and organic).

From the analysis of the figure, it is possible to compare, relatively, the proximity of organic and conventional farming practices leading to environmental impacts. The wide range of the results obtained from each impact category does not allow a practical representation and a good comparison on one single figure, that is why it has been chosen to make a relative comparison of the environmental impacts between organic and conventional production.

The interesting outcome of the figure is the ranking of the impact categories following their relative importance for both types of groves. It is clear from the ranking order that there are two kinds of environmental impacts, for the interest of the study, those that are really different between organic and conventional production and those that are more or less equivalent for both production types. Global warming, eutrophication, biodiversity loss, energy depletion and groundwater depletion are much lower with the organic practices; but, soil loss (through erosion) and potential acidification contribution (through emission of acidifying compounds) are quite the same in both farm types.

5.1.2.4. CATEGORY COMPARISON PER PRODUCTION UNIT (TON OF OLIVES)

Although the calculation of environmental impacts related to the output (olives) (Annex 4), from the area to the mass of useful product is possible by dividing them by the yield, some impacts categories are loosing their significance. As an example, the erosion potential related to the product mass has not a real meaning, since soil loss depend more on the management practice than on the surface productivity.

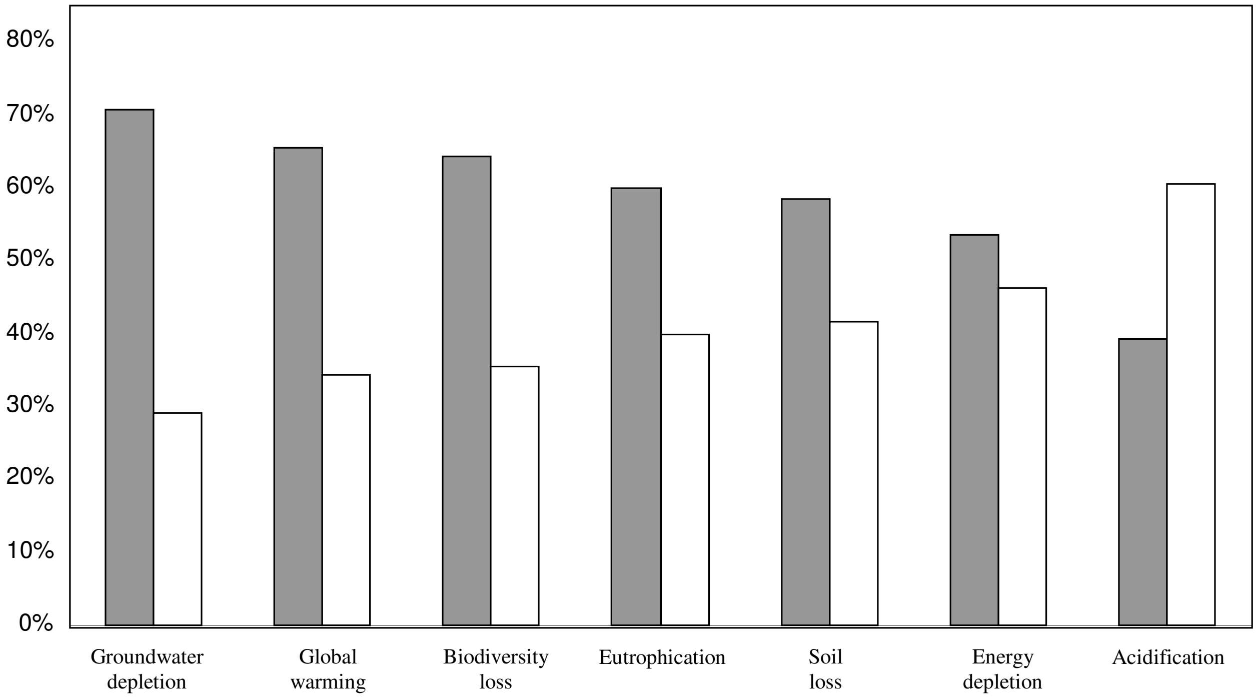

Fig.17: Relative proximity of the environmental impacts related to the two types of groves.

The most striking point on the figure above compared to the one related to the surface unit is that acidification potential of the organic groves is now above the one of the conventional when the results are divided by the yield to obtain a comparison on a per ton basis. This can be explain by the fact that the two types of groves are contributing, more or less, at the same extent to acidification but when dividing them by the yield (kg/ha), knowing that conventional yield are higher than the organic one, then the result is changed to the opposite.

Nevertheless, by analyzing the figure and the relative proximity, or the efficacy of organic farming practice to lower some impact, global warming potential, biodiversity loss, groundwater depletion and, at a lower extent eutrophication seem to be really improved by the organic cultivation methods. On the contrary, soil loss and energy depletion are really close between organic and conventional groves, that is to say that to produce the same amount of olives, olive growers use almost the same amount of non-renewable energy and the olive groves loose almost the same amount of soil, in organic field as well as in the conventional ones.

Concerning the differences between hilly and plain groves, the result shows that organic hilly groves are on average contributing less to the environmental impact, except for erosion, than the organic plain. For conventional groves, it is noticed that plain groves contribute less than hilly groves. Meaning that hilly conventional fields are less potentially harmful to the environment than the organic hilly grove which is contributing less to impact categories among all the groves tested.

5.1.2.5. CULTURAL PRACTICES COMPARISON

The results obtained from the relative comparison between organic and conventional contribution to environmental impacts are linked with the production processes involved (Annex 5). The cultural practices leading to a decrease in environmental harmfulness are explained below.

COVER CROPPING

Cover cropping is a cultural practice leading to several ecological and agro-environmental benefits. It aims at creating a sustainable soil fertility (physically, chemically and biologically), increasing biodiversity (both spatially and temporally) with minimum external inputs (machine labour, fertilizers and biocides) (Kabourakis, 1993). It includes the integration of weed and erosion control and minimizes soil tillage, and saves fossil energy by using nitrogen fixing cover crops instead of synthetic nitrogen fertilizers.

From the results obtained in this study, it is possible to underline the effectiveness of this cultural practice in lowering some of the ecological impacts. **Eutrophication** is lowered in the organic groves, partly because no chemical (highly soluble) fertilizers are use, but also because cover cropping increases soil organic matter content leading to a better retention of the nutrients and then, to less leaching of nutrients to aquatic environment. **Biodiversity** loss is lowered since cover crop provides food and shelter to animals and avoids the use of herbicides. Cover cropping contributes, indirectly, to lower **energy depletion**. Indeed, cover-cropping lowers input requirements (fuel for mechanical work and other fertilizers), and no weeding has to be carried out with a soil cover in the grove. This cultural practice contributes to diminishing soil loss, but is not the essential point in the reduction of **erosion**; also erosion control infrastructures are important in the attempt of fighting erosion.

USE OF MANURE

Using manure in the olive grove is a worthy way to valuate the output of sheep and goat keeping. But, could also be the cause of indirect problem, such as overgrazing and direct on-field ecological impact such as volatilization. In deed, manure use in the grove, if not directly incorporated, has a tendency to volatilize causing eutrophication and acidification.

The 'non use of fertilizer', in organic groves, lowers the overall emissions: less leaching and no N_2O (during N fertilizer production) and CO_2 (during P fertilizers production) are noticeable (see annex 5), those emissions are responsible for the contribution to **global warming** potential. The high solubility of chemical fertilizers leads to serious problems of nutrification for aquatic environment causing **eutrophication**.

CHOPPING OF PRUNING RESIDUES

Burning of pruning residues account for the three emissions category: **acidification, eutrophication and global warming**; especially for the latter, since considerable amount of CO_2, CH_4 and N_2O are emitted during the burning of pruning residues. Chopping the pruning residues and incorporate them to the ground is also a valuable way of increasing soil organic matter content. The increase in soil organic matter is important for the soil quality of the grove, leading to lower erosion risks and better soil capacity for moisture and nutrient retention. Those two characteristics are needed to avoid **groundwater depletion** and **eutrophication** potential problems.

5.1.2.6. OVERALL COMPARISON PER SURFACE UNIT (HA)

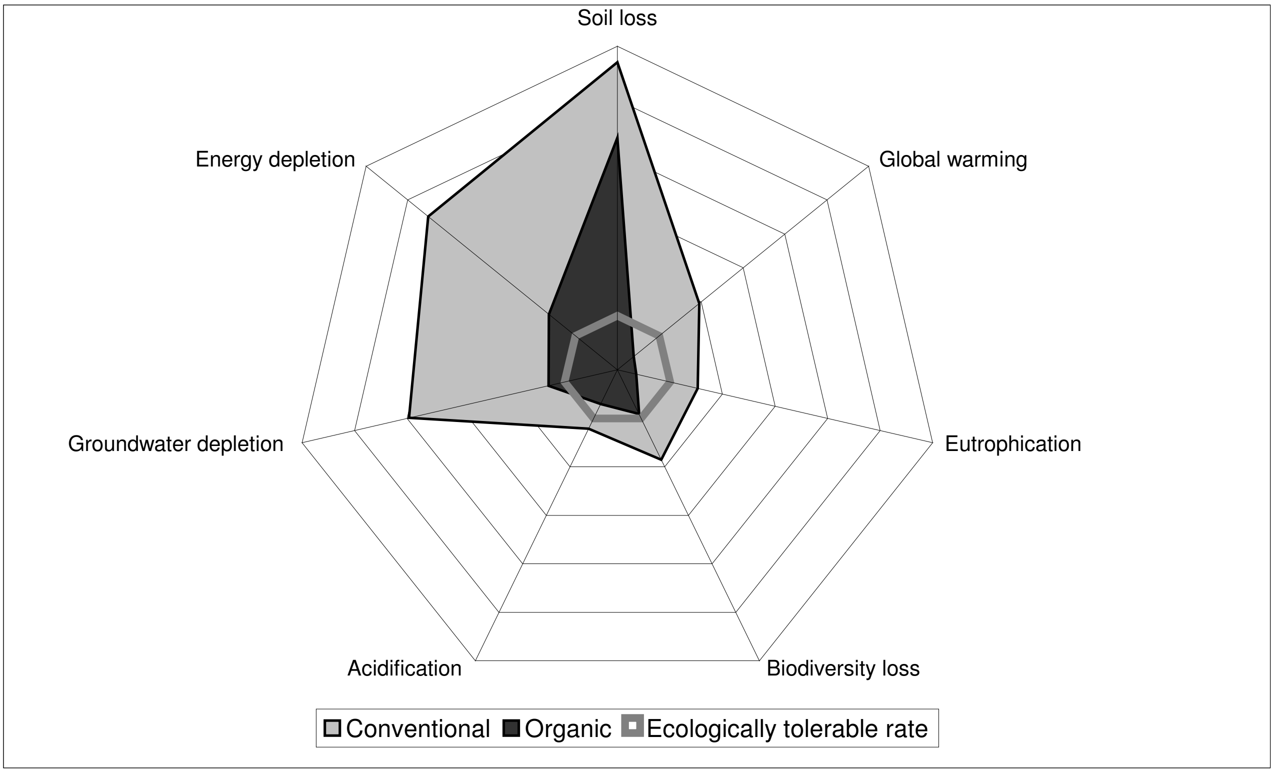

Fig.18: Comparison of conventional versus organic olive farming and their sustainability limits, per surface unit.

On the radial graph above, potential environmental impacts for organic and conventional groves are represented. They are divided by an ecologically tolerable rate (see table 24), which is the critical limit for each impact category that could be bared by the environment, in relation to this agricultural activity.

Table 24: Ecologically tolerable rate chosen for this study:

	Unit (per year)	*Ecologically tolerable rate (per unit and per year)*	*Reference*
Global warming	kg CO2 eq./ha	400	IPCC (1996)
Eutrophication	kg PO4 eq./ha	13	estimation
Biodiversity loss	between –1 and +1	0.55	estimation
Energy depletion	MJ/MJ olive	0.1	Kabourakis (1993)
Groundwater depletion	between 0 and +1	0.5	estimation
Soil loss	tons/ha	6.72	Webster (2001)
Acidification	kg SO2 eq./ha	4	IPCC (1996)

From the analysis of the radial graph it is possible to distinguish three kinds of potential impacts:

1. The resource depletion categories (energy and groundwater) are both exceeding the tolerable rate, meaning that the energy efficiency of the groves should be improved and that the amount of irrigation water used by farm reported to the total agricultural area, exceed the aquifers recharge rate. Soil loss could be included here since it is the greatest of all environmental threats and because it can be also considered as a resource depletion category.

2. Global warming, eutrophication and biodiversity loss can be grouped together. Indeed, there is for those three, real improvements by the organic practices. For global warming, this difference is due to the production and use of synthetic fertilizer and the combustion of pruning residues; for eutrophication, leaching of nutrients in the conventional grove is mainly involved; cover crop and weed/pest management in organic production are responsible for the lower resulting potential impact.
3. Acidification potential in organic grove is above the one of the conventional groves making this third group a weak point in the organic production process. Although the difference is small and the difference with the critical limit is also small, attention should be paid to this impact.

5.1.2.7. *OVERALL COMPARISON PER PRODUCTION UNIT (TON OF OLIVES)*

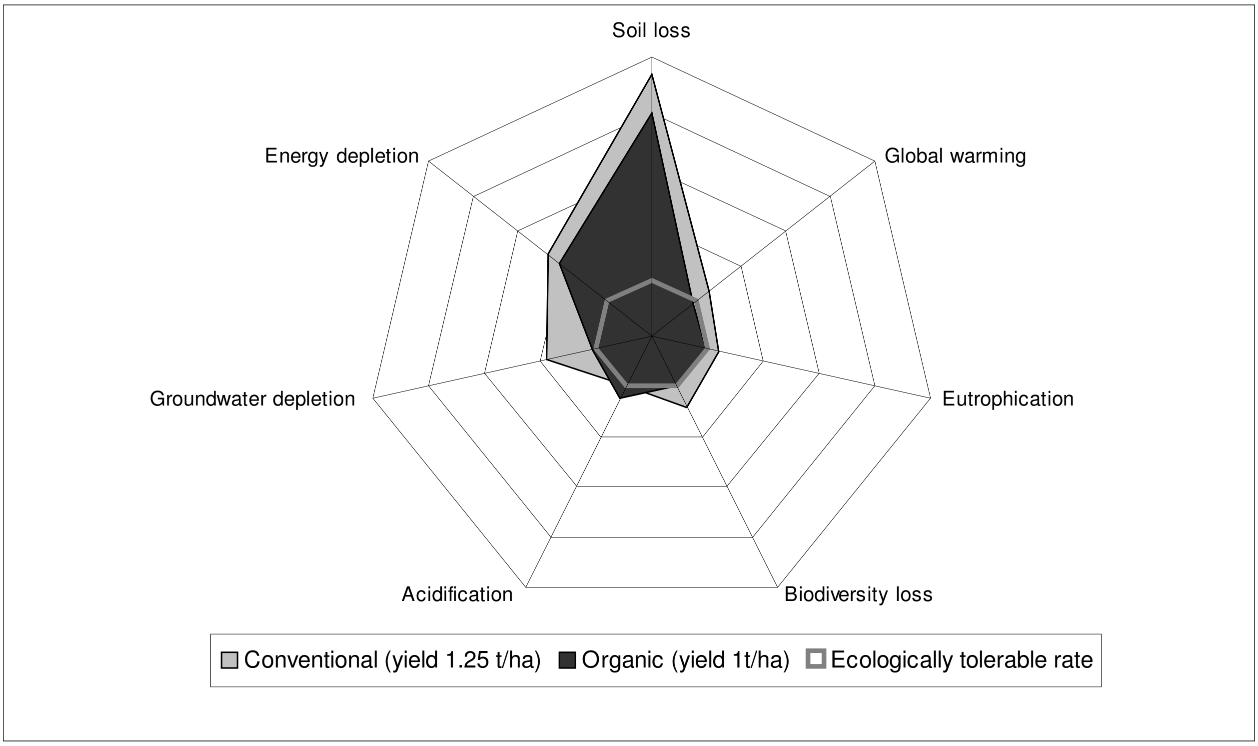

Fig.19: Comparison of conventional versus organic olive farming and their sustainability limits, per production unit (t).

The shape of the impact categories on this spider web or radial representation does look really much like the one comparing environmental impacts of organic and conventional groves but on a surface basis. The order of importance of the environmental burdens did not change. Verifying that the resource depletion categories: groundwater, energy and erosion (as soil can be considered as a resource at the farm level) are ranked as the most damaging categories and the most important issues in olive production in the Messara Valley.

Acidification potential is somehow higher for the organic groves when compared on a product basis, but the difference is very small and it is only slightly over the ecologically tolerable rate. Nevertheless, improvement of the emission of acidifying compounds should be done, especially when using manure that is sensitive to volatilization. Otherwise, it is verified that organic production contributes to a lower extent to biodiversity loss, eutrophication and global warming. Indeed, on a per surface comparison and on a per mass of product comparison, those impacts harmfulness is lowered by the specific use of ecological farming practices.

5.1.3. QUANTIFICATION OF MATERIALS AND ENERGY FLOWS

5.1.3.1. MATERIAL FLOWS

From the flowcharts of materials inputs and outputs of both organic and conventional olive groves (see Annex 7 and 8), the comparison between these two types of farms is made easier. The main difference comes from the cultural practices. In conventional olive groves, the use of materials is mainly concentrated on tillage and fertilizers'use. Whereas in organic cultivation, the material flows are much more split between sowing the cover-crop, tillage, incorporation of green manure and compost, manure spreading and finally chopping of pruning residues.

Due to the burning of pruning residues, emissions from conventional groves are five-fold compared with organic groves where pruning residues are chopped and incorporated to the ground. Similarly, the use of chemical fertilizers leads to a tremendous output of greenhouse gases in the former groves while in the latter this output is nearly seven times less. On the other hand, manure production in organic groves contributes to potential acidification due to volatilization of ammonia (NH_3) whereas there are no acidifying compounds in the conventional fertilizer production.

5.1.3.2. ENERGY FLOWS

The main difference in energy flows in the two grove types can be noticed in tillage practice. Indeed, tillage carried out for weeding and contour tillage uses almost twice as much energy in the conventional groves than the organic ones. Again, conventional groves spend four times more energy in order to produce and use artificial fertilizers while the organic groves only use energy in the spreading of the manure. The reason why energy use for irrigation purposes has not been taken into account in this analysis was explained in detail in section 4.3.1.

5.1.4. RELATIONSHIP BETWEEN ENERGY EFFICIENCY AND ENVIRONMENTAL IMPACTS

Based on the outputs of this study, a clear link exists between global warming potential impact category and the energy efficiency (ratio of the output from the system to the non-renewable energies needed to produce it). Greenhouse gases are mainly emitted during the fertilizer production phase and by using fuel for the different cultural practices. Only the burning of pruning residue, which does not require relevant non-renewable energy inputs, contributes to global warming without being directly related to energy efficiency.

Regarding the other impact categories, it is not possible to establish a correlation between the energy efficiency of the system and the level of potential impacts. Eutrophication seems to be driven by the nitrogen use efficiency; a misuse of fertilizers (volatilization) and the practice of burning pruning residues cause acidification potential. Biodiversity loss index increases because of cultural practices such as pesticide use and elimination of soil vegetal cover. Soil loss is lowered by covering the grove soil and by the maintenance of terraces. Groundwater depletion is due to poor water management.

5.2. RECOMMENDATIONS

This study proceeded from the incentive of clarifying the agricultural processes and choices leading to high energy efficiency and to low environmental impacts in and from the olive groves. This objective has been attained, but the results and their interpretations are submitted to critics because of the little number of farms analyzed and the impossibility of doing a sensitivity analysis. Nevertheless, deeper insight in the farm as a whole allows drawing of conclusion and therefore recommendations to olive farming activity.

5.2.1. ENERGY USE

Increase the energy efficiency at the farm level could reconcile the often-conflicting economic and environmental objectives of a more sustainable agriculture. Energy efficiency description should be considered by farmers and advisors as a management tool, enabling them to analyze the effects of new production systems and to optimize these systems for their specific farm situation.

In practice, there are production methods that should be promoted in order to diminish the expenses of non-renewable energy inputs of the olive grove. Cultural practice such as systematic tillage for weeding should be avoided, as long as weed control can be done by means of cover cropping.

5.2.2. MATERIAL USE

The use of chemical fertilizers is responsible for a tremendous decrease in the energy efficiency, and should be rationalized or avoided as it is the case in organic production. Also, the use of fuel is the cause of a high amount of greenhouse gases and, similarly to the recommendation concerning energy efficiency, should be diminished.

From the calculation of the water use sustainability index, it is advisable to decrease the amount of water use for irrigation in both types of groves, since their water use index is above the tolerable limit. Considering the risk of the aquifer depletion and its possible salinization and considering the fact that olive tree is particularly resistant to draught, reducing the amount used is a necessity and a possible evolution toward a sustainable use of water.

5.2.3. AGRICULTURAL PRACTICES

Two agricultural practices should be recommended for the olive production in order to increase energy efficiency and reduce environmental impacts. First, cover cropping between the tree rows is recommended to increase soil fertility and avoid mechanical weeding, increasing, therefore, the energy efficiency. Second, chopping of pruning residues, instead of burning them, and their incorporation is highly advisable since it contributes to soil organic matter content increase and avoid emissions due to the combustion of wood.

5.2.4. INFRASTRUCTURE

The grove infrastructure is constituted of all the features contributing to the spatial pattern of the grove. In this study, the presence of natural features, meaning patches of natural vegetation, and terraces have been estimated as relevant factors contributing to biodiversity for the former and erosion control for the latter. The presence of these natural features is not the main factor contributing to biodiversity, but their connectivity with other natural areas is the most influencing factor. Terraces maintenance in hilly groves should be practiced since it takes an important role in the erosion control, cover-cropping being the major factor diminishing the soil loss when comparing organic and conventional potential erosion.

CONCLUSION

In this study, olive grove management in the Messara Valley has been measured by the use of Life Cycle Analysis. This concept provided a powerful method for analyzing the total set of variables characterizing farmers' management. For both the energy efficiency and the environmental impact assessment, a life-cycle approach, from the cradle to the farmgate, has been applied to both organic and conventional production processes, considering the activity of the system as a distribution of resources, wastes and products along the whole life span process of olive for olive oil production.

With regards to the analysis of agro-environmental management, an interesting finding was that there is a positive correlation between energy efficiency and the reduction of global warming contribution. Although this study was not meant to analyze socio-economic influences of the grove management, the more labor hours were needed, the higher the energy efficiency was. In other words, energy efficiency can be used as an indicator towards improvement of sustainability.

Concerning the environmental impacts, the Life Cycle Analysis enables to show the differences between organic and conventional production systems, highlighting the cultural practices and the use of resources leading to rationalized environmental burdens. The results show also that resource depletion, especially soil loss, groundwater and non-renewable energy, constitutes a problem as these resources depletion rate is above the critical limit for the conventional systems as well as for the organic ones.

Attention should be paid to two cultivation methods. Cover-cropping between the tree rows leading to increased soil fertility, water and nutrients' retention and avoidance of mechanical weeding, increases the energy efficiency. Chopping and incorporating pruning residues, instead of burning them, contributes to soil organic matter content and helps avoiding emissions due to wood combustion. Mainly organic farmers perform these cultural practices, but these should be promoted to a broader population and at a larger scale.

Improvements could be done on the emission of acidifying compounds at the farm level. Indeed, when comparing this impact on a per unit of product (ton), the contribution of the organic farming practices to the acidification potential is higher than the one of the conventional groves. The emission of acidifying compounds by volatilization during manure production and spreading seems to be the cause.

The comparison between organic and conventional agro-environmental management in production of olives for olive oil permitted to get deeper insight in the ecologically sound production processes involved, without intending to advertise more the organic products. Although only four farms were investigated in this study, positive environmental and energy trends in favor of this kind of holistic assessment for farm management, encouraging further and wider research.

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Table of Annexes

Input	Conventional hilly	Organic hilly	Conventional plain	Organic plain
Tractor power hp	64	65	45	45
Number of hours	6	3	6.25	6
N fertilizer kg/ha.y	63	0	19.2	0
P fertilizer kg/ha.y	63	0	9.7	0
K fertilizer kg/ha.y	63	0	9.7	0
Manure kg/ha.y	0	300	0	5000
Covercrop seed kg/ha.y	0	150	0	150
Machinery number	1	3	1	3
Water volume Ml/ha.y	1200	400	800	750
Pruning residues burned kg/ha.y	250	50	250	50
Output olive kg/ha.y	1000	1250	1500	600
Other information				
Age of trees	15	30	21	6
Variety	koroneiki	koroneiki	koroneiki	koroneiki
Density (tree/ha)	210	125	225	219
Variety of covercrop	-	vetch, barley, fava beans	-	vetch
Sowing	0	1	0	1
Grazing period	february	no	no	march/april
Severe pest problem	yes olive fly	no	no	no
Slope %	20	20	5	5
Length m	80	80	60	80
Labour hours/ha.y	168	228	280	192
Selling price euro/kg	2.5	3	2.35	-
Subsidies euro/kg	1	1	1.17	1
Soil properties				
Silt (%)	30	30	45	31
Fine sand (%)	45	46	30	41
Sand (%)	53	54	40	49
Clay (%)	17	16	15	18
organic matter (%)	0.7	1	0.7	1
soil structure code	2	2	2	2
permeability index	3	3	3	3
N input	66.80	84.53	23.00	68.80
N balance	52.63	32.75	8.52	27.76
P input	63.00	1.46	9.70	24.38
P balance	62.00	0.21	8.20	23.78

Data needed for the study.

PROCESSES	DATA	UNIT	Conventional hilly	Organic hilly	Conventional plain	Organic plain
Gross energy of product	Functional unit	MJ/ha.y	6922	8875	10650	4260
Non-renewable direct energy	Fuel	MJ/ha.y	1031	644	929	885.6
Non-renewable indirect energy	Fertilizers	MJ/ha.y	2835	19	1148	322
	Covercrop seeds	MJ/ha.y	0	22.5	0	22.5
Non-renewable capital energy	Tractor	MJ/ha.y	201.6	204.6	145.8	145.8
	Machinery	MJ/ha.y	8	24	8	24
Output/Input ratio		**MJ/MJ**	**2**	**10**	**5**	**3**

Energy efficiency results ordered by activity.

	Organic plain	**Organic hilly**	Average Organic	**Convent. hilly**	**Convent. plain**	Average conventional
CULTURAL PRACTICES	MJ					
Tillage	308	250	279	620	541	581
Sowing	453	240	149			
Incorporating	357	235	279			
Fertilization	44	61	450	3455	1689	2572
TOTAL	1161	787	**1157**	4076	2230	**3153**

Comparison of the energy spent for the cultural practices.

CRITERIA	PROCESSES	DATA	UNITS per ha	Conv. hilly	Organic hilly	Conv. plain	Organic plain	CALCULATION
Global warming	CO_2 to air	Fuel use	kg CO_2 equivalent	88	55	79	75	Emission = f (activity, emission factor); Impact = emissions x classification factor (Pluimers et al., 2000).
		P-fertilizer prod.		44	0	7	0	
		N-fertilizer prod.		158	0	48	0	
		Pruning res. burning		7,5	1,5	7,5	1,5	
	CH_4 to air	manure production	kg CO_2 equivalent	0	7	0	105	
		Pruning res. burning		17	3,4	17	3,4	
	N_2O to air	N-fertilizer prod.	kg CO_2 equivalent	460	0	140	0	
		P-fertilizer prod.		0,18	0	0,19	0	
		Denitrification		212,63	10,13	64,8	168,75	
		Pruning res. burning		12,15	2,43	12,15	2,43	
Total global warming contribution			**kg CO_2 eq.**	**999**	**79**	**376**	**357**	
Eutrophication	NO_3 to water	N leaching	kg PO_4 eq.	2,43	0,55	0,37	0,97	
	P to water	P leaching	kg PO_4 eq.	30,13	0,10	3,99	11,56	
	P to air	P-fertilizer prod.	kg PO_4 eq.	0,023	0	0,003	0	
	NO_2 to air	N-fertilizer prod.	kg PO_4 equivalent	0,030	0	0,009	0	
		P-fertilizer prod.		0,012	0	0,002	0	
		Pruning res. burning		0,07	0,014	0,07	0,014	
	NH_3 to air	Volatilization	kg PO_4 equivalent	0,21	0,2	0,063	0,78	
		N-fertilizer use		0,026	0	0,008	0	
		Stable		0	0,033	0	0,55	
Total contribution to eutrophication			**kg PO_4 eq.**	**32,93**	**0,90**	**4,52**	**13,88**	
Acidification	SO_2 to air	Fuel use	kg SO_2 equivalent	0,16	0,10	0,14	0,14	
		N-fertilizer use		0,71	0	0,22	0	
		P-fertilizer use		0,20	0	0,03	0	
	NH_3 to air	Volatilization	kg SO_2 equivalent	0,87	0,2	0,27	3,11	
		N-fertilizer use		0,33	0	0,033	0	
		Stable		0	0,13	0	2,1021	
	NO_2 to air	N-fertilizer use	kg SO_2 equivalent	0,69	0	0,21	0	
		P-fertilizer use		0,275	0	0,042	0	
		Pruning res. burning		1,61	0,32	1,61	0,32	
		Fuel use		1,47	0,92	1,32	1,26	
Total acidification contribution			**kg SO_2 eq.**	**6,31**	**1,34**	**2,27**	**6,61**	
Biodiversity	Biodiversity loss	Pressure on flora	Cover	0	1	0	1	IERE (Schenck et al., 2000) and Haas et al. (2001).
			Weeding	-0,5	0,5	0	0,5	
		Pressure on fauna	Press. flora	-0,25	0,75	0	0,75	
			Pesticide use	-0,5	0	-0,5	0	
			Pest prob.	-1	0	0	0	
			Dist./Conn.	0,5	1	0,5	0,5	
			Nat. feat.	1	1	0	0	
			Cover	0	1	0	1	
Biodiversity loss index			**no unit**	**1,04**	**0,38**	**1**	**0,63**	
Erosion	Soil loss	Soil susc. (K)	tonsx h/ (MJxmm)	0,82	0,83	0,73	0,72	Wischmeier and Smith (1965) formula: Soil loss = K*L*S*R*C*P.
		Slope-length (LS)	no unit	6,28	6,28	1,09	1,12	
		Rainfall (R)	MJxmm/ (haxh)	223,83	223,83	223,83	223,83	
		Crop manag. (C)	no unit	0,42	0,14	0,42	0,14	
		Erosion control (P)	no unit	0,17	0,49	0,5	0,3	
Annual soil loss			**tonnes**	**82,5**	**79,7**	**37,5**	**7,6**	

Results of environmental impacts ordered by category per surface unit (ha).

CRITERIA	PROCESSES	DATA	UNITS per tonne olive	Conv. hilly	Organic hilly	Conv. plain	Organic plain	CALCULATION
Global warming	CO_2 to air	Fuel use	kg CO_2 equivalent	88	69	119	45	Emission = f (activity, emission factor); Impact = emissions x classification factor (Pluimers et al., 2000).
		P-fertilizer prod.		44	0	10	0	
		N-fertilizer prod.		158	0	72	0	
		Pruning res. burning		7.5	1.875	11.25	0.9	
	CH_4 to air	Manure production	kg CO_2 equivalent	0	8.75	0	63	
		Pruning res. burning		17	4.3	26	2.0	
	N_2O to air	N-fertilizer prod.	kg CO_2 equivalent	460	0	210	0	
		P-fertilizer prod.		0.18	0	0.28	0	
		Denitrification		212.63	12.66	97.2	101.25	
		Pruning res. burning		12.15	3.0375	18.225	1.458	
Total global warming contribution			**kg CO_2 eq.**	**999**	**99**	**564**	**214**	
Eutrophication	NO_3 to water	N leaching	kg PO_4 eq.	2.43	0.69	0.56	0.58	
	P to water	P leaching	kg PO_4 eq.	30.13	0.13	5.98	6.93	
	P to air	P-fertilizer prod.	kg PO_4 eq.	0.023	0	0.005	0	
	NO_2 to air	N-fertilizer prod.	kg PO_4 equivalent	0.030	0	0.014	0	
		P-fertilizer prod.		0.012	0	0.003	0	
		Pruning res. burning		0.07	0.0175	0.105	0.0084	
	NH_3 to air	Volatilization	kg PO_4 equivalent	0.21	0.25	0.095	0.468	
		N-fertilizer use		0.026	0	0.012	0	
		Stable		0	0.04125	0	0.33	
Total contribution to eutrophication			**kg PO_4 eq.**	**32.93**	**1.13**	**6.77**	**8.33**	
Acidification	SO_2 to air	Fuel use	kg SO_2 equivalent	0.16	0.12	0.21	0.08	
		N-fertilizer use		0.71	0	0.33	0	
		P-fertilizer use		0.20	0	0.05	0	
	NH_3 to air	Volatilization	kg SO_2 equivalent	0.87	0.25	0.40	1.866	
		N-fertilizer use		0.33	0	0.049	0	
		Stable		0	0.16	0	1.26126	
	NO_2 to air	N-fertilizer use	kg SO_2 equivalent	0.69	0	0.32	0	
		P-fertilizer use		0.275	0	0.064	0	
		Pruning res. burning		1.61	0.40	2.41	0.19	
		Fuel use		1.47	1.14	1.98	0.76	
Total acidification contribution			**kg SO_2 eq.**	**6.31**	**1.68**	**3.40**	**3.96**	
Biodiversity	Biodiversity loss	Pressure on flora	Cover	0	1.25	0	0.6	IERE (Schenck et al., 2000) and Haas et al. (2001).
			Weeding	-0.5	0.625	0	0.3	
		Pressure on fauna	Press. flora	-0.25	0.9375	0	0.45	
			Pesticide use	-0.5	0	-0.75	0	
			Pest prob.	-1	0	0	0	
			Dist./Conn.	0.5	1.25	0.75	0.3	
			Nat. feat.	1	1.25	0	0	
			Cover	0	1.25	0	0.6	
Biodiversity loss index			**no unit**	**1.04**	**0.47**	**2**	**0.38**	
Erosion	Soil loss	Soil susc. (K)	tonsx h/ (MJxmm)	0.82	1.03	1.09	0.43	Wischmeier and Smith (1965) formula: Soil loss = K*L*S*R*C*P.
		Slope-length (LS)	no unit	6.28	7.85	1.64	0.67	
		Rainfall (R)	MJxmm/ (haxh)	223.83	279.78	335.74	134.30	
		Crop manag. (C)	no unit	0.42	0.175	0.63	0.084	
		Erosion control (P)	no unit	0.17	0.6125	0.75	0.18	
Annual soil loss			**tonnes**	**82.5**	**99.7**	**56.2**	**4.5**	
Primary energy depletion			**MJ/MJ**	**0.59**	**0.13**	**0.31**	**0.20**	CLM (1996).
Groundwater depletion			**no unit**	**0.72**	**0.19**	**0.87**	**0.33**	Acreman (2000).

Results of environmental impacts ordered by category per functional unit (t).

		Production			Use of Materials							Cultural practices				Infrastructure		
		N fertilizer prod.	P fertilizer prod.	Manure prod.	N fertilizer use	P fertilizer use	Volat.	Denit.	N leaching	P leaching	Fuel use	Pruning res. burning	Weed manag.	Pest manag.	Cover	Dist./ Conn.	Nat. feat.	Terrace
Global warming	Conv. hilly	617.4	44.6	0				212.6			88	36.7						
	Organic hilly	0	0	7				10			55	7.3						
	Conv. plain	188	7	0				64.8			79	36.7						
	Organic plain	0	0	105				168.8			75.5	7.3						
	ORGANIC	**0**	**0**	**56**				**89.4**			**65.2**	**7.3**						
	CONVENT.	**402.8**	**25.8**	**0**				**138.7**			**83.5**	**36.7**						
Eutrophication	Conv. Hilly	0.05	0.03	0	0.03		0.21		2.43	30		0.07						
	Organic hilly	0	0	0.03	0		0.20		0.55	0.10		0.01						
	Conv. Plain	0.01	0.01	0	0.01		0.06		0.37	3.99		0.07						
	Organic plain	0	0	0.55	0		0.78		1	11.6		0.01						
	ORGANIC	**0**	**0**	**0.3**	**0**		**0.5**		**0.8**	**5.8**		**0.01**						
	CONVENT.	**0.03**	**0.02**	**0**	**0.02**		**0.14**		**1.4**	**17**		**0.07**						
Acidification	Conv. Hilly			0	1.73	0.48	0.87				3.09	1.61						
	Organic hilly			0.13	0	0	0.20				2	0.32						
	Conv. Plain			0	0.46	0.07	0.27				2.78	1.61						
	Organic plain			2.10	0	0	3.11				2.65	0.32						
	ORGANIC			**1.11**	**0**	**0**	**1.66**				**2.29**	**0.32**						
	CONVENT.			**0**	**1.10**	**0.27**	**0.57**				**2.94**	**1.61**						
Biodiversity	Conv. Hilly												1.5	1.5	2	0.5	0	
	Organic hilly												0.5	0	0	0	0	
	Conv. Plain												0	0.5	2	0.5	1	
	Organic plain												0.5	0	2	0.5	1	
	ORGANIC												**0.5**	**0**	**0**	**0.25**	**0.5**	
	CONVENT.												**0.75**	**1**	**2**	**0.5**	**0.5**	
Erosion	Conv. hilly														0.25			0.1
	Organic hilly														0.1			0.2
	Conv. plain														0.25			0.01
	Organic plain														0.1			0.01
	ORGANIC														**0.1**			**0.105**
	CONVENT.														**0.25**			**0.055**

Results of environmental impacts ordered by cultural practice.

Questionnaire for the energy efficiency assessment and the environmental impacts of the conventional hilly olive groves.

Foreword : This questionnaire aims at retrieving data of the olive farm's activities in order to assess its energy efficiency and its environmental impacts; the results of the investigation is not addressed to official organisms but will be used as a university study.

- The person answering those questions is supposed to be the olive farm responsible.
- The time needed for the questionnaire is foreseen of 1 to 2 hours.
- The farm is visited with the farmer in order to see the erosion control practices, mechanical devices and the type of irrigators.
- Measurement of the slope for the hilly groves is done.
- Samples of irrigation water (0.5 l) from the pipe and soil sample (500 g) are taken from the fields.

General information:

What is the size of the olive field (ha)?

0.3

How many trees per hectares are planted?

210

How old are they?

15 years

What is the variety(ies) grown?

Koroneiki

What is the average production per hectare and per year (t/ha.year)?

0.35

Are you sowing cover crops and what kind?

No

What is the amount of seeds sown (kg/ha)?

-

Did you have "severe" pest problem during the last 5 years?

Yes, with the olive fly.

Fuel use:

How many hours of tractor is needed per year (hours/year)? **2**

What is the power of the tractor (s) you are using (kW or horse power (1 horse power = 0.735 kW)? **48**

Could you estimate the percentage of use of the tractor for the following activities (%):

Tillage: **100**
Fertilization: **-**
Spraying of pesticide or herbicide: **-**
Harvesting: **-**

Fertilizer use:

What is the composition of fertilizer (N-P-K)?

15-15-15

What is the amount of fertilizer applied in the olive field (kg/ha.year)?

420

Weed control:

Is there a grazing period in the grove?

Yes

Are you mowing the weeds?

No

When are these practices done?

Grazing is done in winter after pruning.

Water use:

Are you irrigating the olive field?

Yes

How often?

5 times a year.

What is the amount of water used per year and per hectare (m^3/ha.year)?

1200

Subsidiary question:

What is the selling price of your olive oil (euros/kg)?

2.5

Do you receive subsidies from the European union and how much (euros/kg olive oil)?

1

Could you estimate the number of hours worked in the farm (number hours/ year)?

168

Questionnaire for the energy efficiency assessment and the environmental impacts of the organic hilly olive groves.

Foreword: This questionnaire aims at retrieving data of the olive farm's activities in order to assess its energy efficiency and its environmental impacts; the results of the investigation is not addressed to official organisms but will be used as a university study.

- The person answering those questions is supposed to be the olive farm responsible.
- The time needed for the questionnaire is foreseen of 1 to 2 hours.
- The farm is visited with the farmer in order to see the erosion control practices, mechanical devices and the type of irrigators.
- Measurement of the slope for the hilly groves is done.
- Samples of soil (500 g) are taken from the fields.

General information:

What is the size of the olive field (ha)?

3

How many trees per hectares are planted?

125

How old are they?

25 years

What is the variety(ies) grown?

Koroneiki.

What is the average production per hectare and per year (t/ha.year)? **1.2**

Are you sowing cover crops and what kind?

Yes: Vetch, barley, fava bean.

What is the amount of seeds sown (kg/ha)?

150

Did you have "severe" pest problem during the last 5 years? **No**

Fuel use:

How many hours of tractor is needed per year (hours/year)? **8**

What is the power of the tractor (s) you are using (kW or horsepower, 1 horsepower = 0.735 kW)? **48**

Could you estimate the percentage of use of the tractor for the following activities (%):

Tillage and sowing the cover crop: **30**

Incorporating the cover crop: **30**

Spraying of organic pesticide: **0**

Spreading the compost: **10**

Wood chipping: **30**

Fertilizer use:

Do you use manure and what type?

Yes: goat and sheep manure.

What is the amount of manure applied in the olive field (kg/ha.year)? **300**

Do you use oil mill waste?

No

What is the amount of seeds for green manure used (kg/ha/year)? **150**

Other organic fertilizers?

No

Weed control:

Is there a grazing period in the grove?

No

Are you mowing the weeds?

No

Water use:

Are you irrigating the olive field?

Yes

How often?

3 to 4 times during the 2 summer months.

What is the amount of water used per year and per hectare (m3/ha.year)? **400**

Subsidiary question:

What is the selling price of your olive oil (euros/kg)? **From 2.5 to 3.2**

Do you receive subsidies from the European union and how much (euros/kg olive oil)?

1

Could you estimate the number of working hours in the farm (number hours/ year)?

228

Questionnaire for the energy efficiency assessment and the environmental impacts of the conventional plain olive groves.

Foreword : This questionnaire aims at retrieving data of the olive farm's activities in order to assess its energy efficiency and its environmental impacts; the results of the investigation is not addressed to official organisms but will be used as a university study.

- The person answering those questions is supposed to be the olive farm responsible.
- The time needed for the questionnaire is foreseen of 1 to 2 hours.
- The farm is visited with the farmer in order to see the erosion control practices, mechanical devices and the type of irrigators.
- Measurement of the slope for the hilly groves is done.
- Samples of soil (500 g) are taken from the fields.

General information:

What is the size of the olive field (ha)?

0.8

How many trees per hectares are planted?

225

How old are they?

21 years

What is the variety(ies) grown?

Koroneiki

What is the average production per hectare and per year (t/ha.year)?

1.5

Are you sowing cover crops and what kind?

No

What is the amount of seeds sown (kg/ha)?

-

Did you have "severe" pest problem during the last 5 years?

No

Fuel use:

How many hours of tractor is needed per year (hours/year)? **5**

What is the power of the tractor (s) you are using (kW or horse power (1 horse power = 0.735 kW)? **33**

Could you estimate the percentage of use of the tractor for the following activities (%):

Tillage: **100**
Fertilization: **-**
Spraying of pesticide or herbicide: **-**
Harvesting: **-**

Fertilizer use:

What is the composition of fertilizer (N-P-K)?

16-8-8

What is the amount of fertilizer applied in the olive field (kg/ha.year)?

120

Weed control:

Is there a grazing period in the grove?

No

Are you mowing the weeds?

No

When are these practices done?

-

Water use:

Are you irrigating the olive field?

Yes

How often?

Once every 15 days during the summer months.

What is the amount of water used per year and per hectare (m^3/ha.year)?

800

Subsidiary question:

What is the selling price of your olive oil (euros/kg)?

2.35

Do you receive subsidies from the European union and how much (euros/kg olive oil)?

1.1

Could you estimate the number of hours worked in the farm (number hours/ year)?

280

Questionnaire for the energy efficiency assessment and the environmental impacts of the organic plain olive groves.

Foreword: This questionnaire aims at retrieving data of the olive farm's activities in order to assess its energy efficiency and its environmental impacts; the results of the investigation is not addressed to official organisms but will be used as a university study.

- The person answering those questions is supposed to be the olive farm responsible.
- The time needed for the questionnaire is foreseen of 1 to 2 hours.
- The farm is visited with the farmer in order to see the erosion control practices, mechanical devices and the type of irrigators.
- Measurement of the slope for the hilly groves is done.
- Samples of soil (500 g) are taken from the fields.

General information:

What is the size of the olive field (ha)?

0.3

How many trees per hectares are planted?

220

How old are they?

7 years

What is the variety(ies) grown?

Koroneiki.

What is the average production per hectare and per year (t/ha.year)? **0.6**

Are you sowing cover crops and what kind?

Yes: Vetch.

What is the amount of seeds sown (kg/ha)?

150

Did you have "severe" pest problem during the last 5 years? **No**

Fuel use:

How many hours of tractor is needed per year (hours/year)? **6**

What is the power of the tractor (s) you are using (kW or horsepower, 1 horsepower = 0.735 kW)? **33**

Could you estimate the percentage of use of the tractor for the following activities (%):

Tillage and sowing the cover crop: **33**

Incorporating the cover crop: **33**

Spraying of organic pesticide: **0**

Spreading the compost: **33**

Wood chipping: **0**

Fertilizer use:

Do you use manure and what type?

Yes: goat and sheep manure.

What is the amount of manure applied in the olive field (kg/ha.year)? **3000**

Do you use oil mill waste?

No

What is the amount of seeds for green manure used (kg/ha/year)? **150**

Other organic fertilizers?

No

Weed control:

Is there a grazing period in the grove?

No

Are you mowing the weeds?

Yes

Water use:

Are you irrigating the olive field?

Yes

How often?

10 times during the 2 summer months.

What is the amount of water used per year and per hectare (m3/ha.year)? **750**

Subsidiary question:

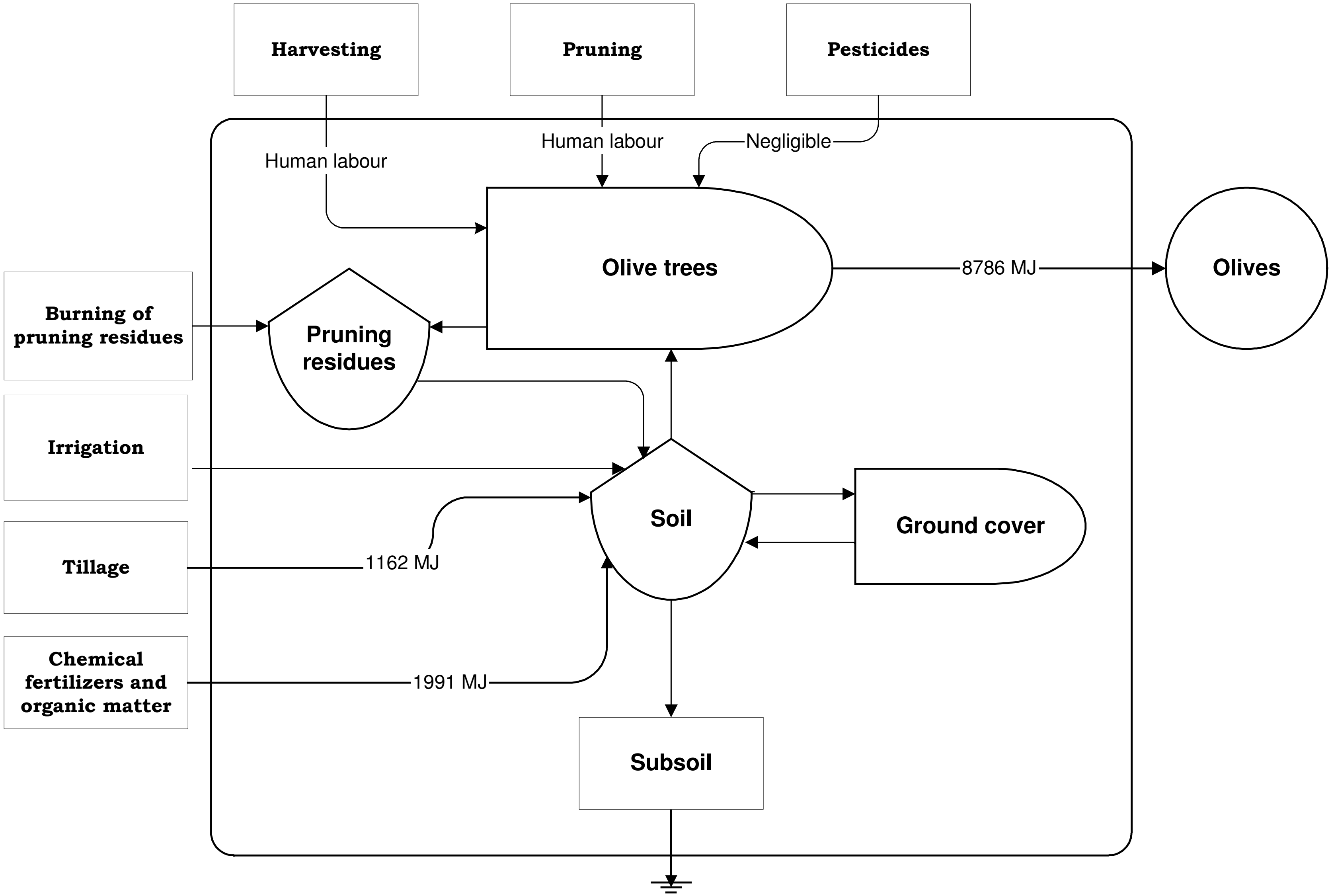
What is the selling price of your olive oil (euros/kg)? **No answer.**

Do you receive subsidies from the European union and how much (euros/kg olive oil)?

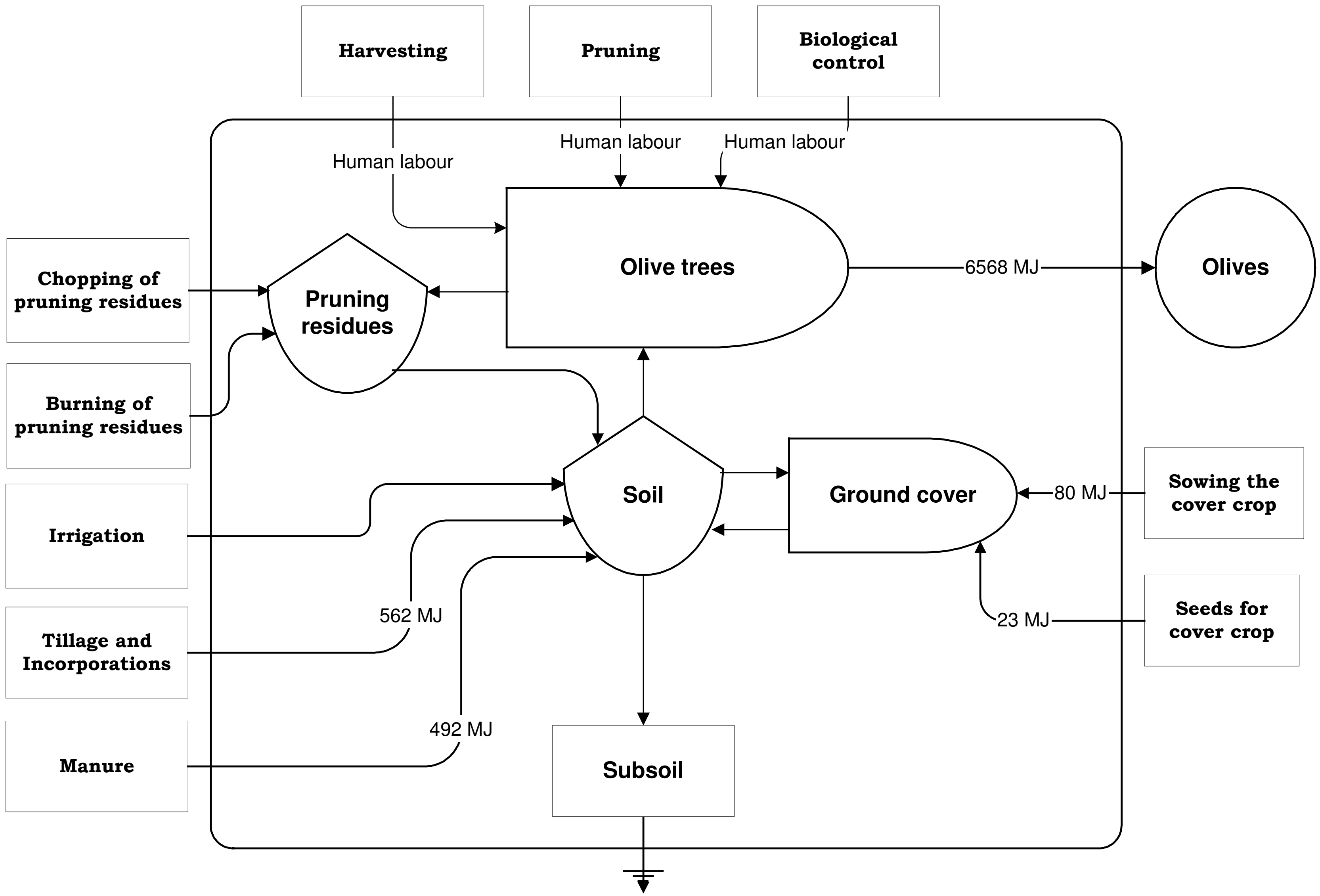
1

Could you estimate the number of working hours in the farm (number hours/ year)?

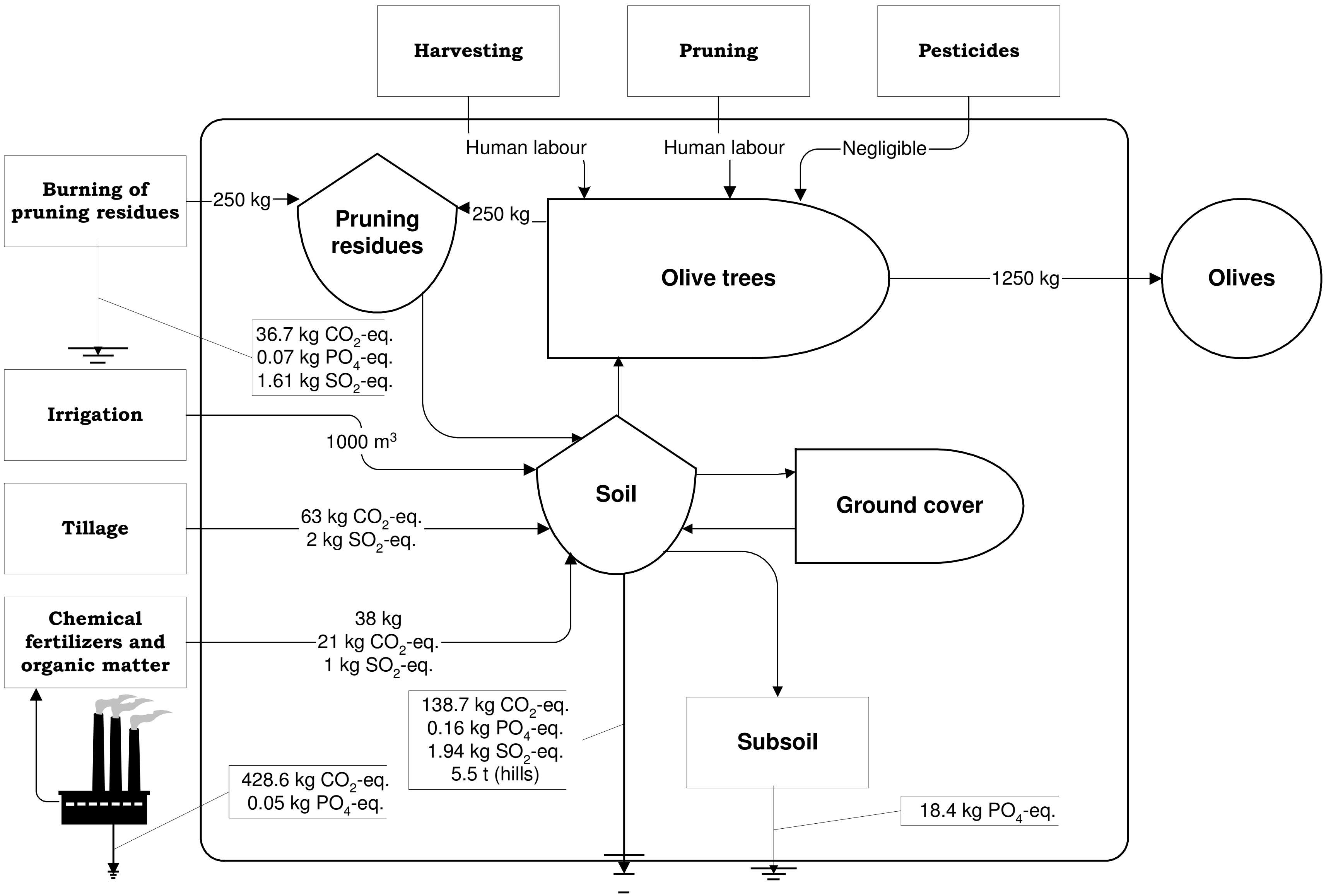
192



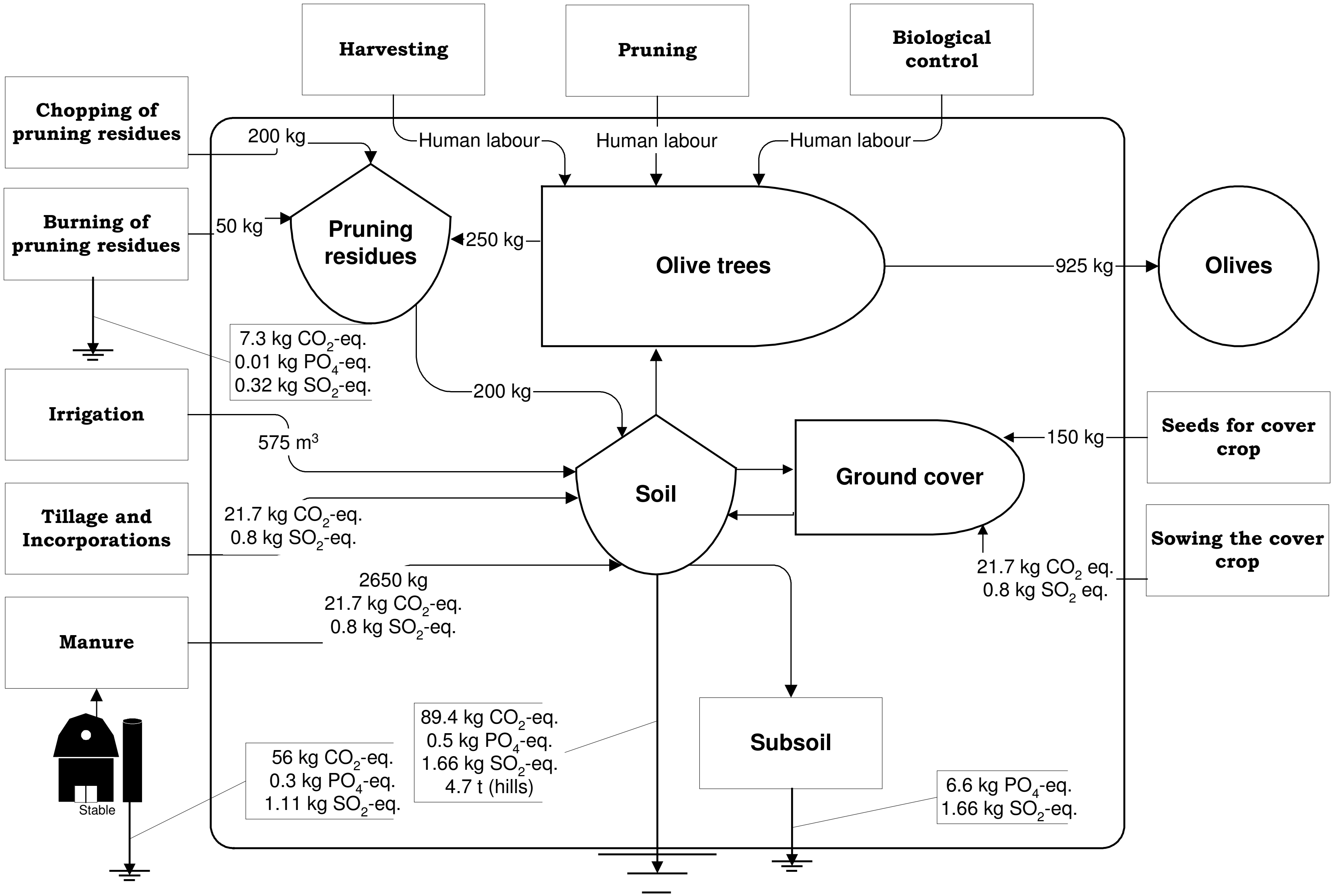
Energy flows in the conventional groves.



Energy flows in the organic groves.



Material flows in the conventional groves.



Material flows in the organic groves.

Table of Appendices

COUNCIL REGULATION (EEC) N° 2092/91 (24 June 1991)
on organic production of agricultural products.

1. Regulation (EEC) No 2092/91(4) concerns the principles for, and specific inspection measures covering, organic production of livestock, unprocessed livestock products and products intended for human consumption containing ingredients of animal origin;

2. **Demand** for organically produced agricultural products **is rising** and consumers are increasingly attracted by such products;

3. Livestock production allows that range of products to be extended and permits the development on agricultural holdings practicing organic farming of complementary activities accounting for a major share of income;

4. This Regulation harmonizes rules of production, labeling and inspection for the most relevant livestock species;

5. Moreover, livestock production is fundamental to the organization of agricultural production on organic-production holdings in so far as it provides the necessary organic matter and nutrients for cultivated land and accordingly contributes towards soil improvement and the development of sustainable agriculture;

6. In order to avoid environmental **pollution**, in particular of natural resources such as the **soil and water**, organic production of livestock must in principle provide for a close relationship between such production and the land, suitable multiannual rotation systems and the feeding of livestock with organic-farming crop products produced on the holding itself;

7. In order to **prevent pollution of water** by nitrogenous compounds, organic-production livestock holdings should have appropriate storage capacity and plans for the spreading of solid and liquid livestock effluents;

8. Pastoral stockfarming carried out in accordance with the rules of organic farming is an activity particularly suited to the maintenance and exploitation of the potential of abandoned areas;

9. A wide **biological diversity** should be encouraged and the choice of breeds should take account of their capacity to adopt to local conditions;

10. **Genetically modified organisms** (GMOs) and products derived therefrom are not compatible with the organic production method; in order to maintain consumer confidence in organic production, genetically modified organisms, parts thereof and products derived therefrom should not be used in products labelled as from organic production;

11. Consumers should be given guarantees that the products have been produced in accordance with this Regulation; as far as technically possible, this should be based on the **traceability** of products;

24. (From 12 to 23, Livestock keeping regulations) the indications in the **labelling**, advertising material or commercial documents which are considered by the consumer as a reference to the organic production method are reserved by Regulation (EEC) No 2092/91 for products produced in accordance with that regulation

26.Certain indications are generally considered by the consumer as a reference to the organic production method;

27.However, it is necessary to provide a transitional period in order to permit trade-mark holders to adapt their production to the requirements of organic farming, provided that such a transitional period is available only to trade marks bearing the aforementioned indications where application for registration was made before the publication of Regulation (EEC) No 2092/91 and that the consumer is informed appropriately of the fact that the products are not produced according to the organic production method,

Rules of production

ARTICLE 6

The organic production method implies that for the production of **products** referred to in Article 1(1)(a) **other than seeds and vegetative propagating material**:

1. At least the requirements of Annex I and, where appropriate, the detailed rules relating thereto, must be satisfied;
2. Only products composed of substances mentioned in Annex I or listed in Annex II may be used as plant protection products, fertilizers, soil conditioners;
3. Only seed or vegetative propagating material produced by the organic production method referred to in paragraph 2 is used;
4. Genetically modified organisms (GMO) and/or any product derived from such organisms must not be used, with the exception of veterinary medicinal products.

The organic production method implies that for **seeds and vegetative reproductive material**, the mother plant in the case of seeds and the parent plant(s) in the case of vegetative propagating material have been produced:

1. Without the use of genetically modified organisms and/or any products derived from such organisms, and
2. In accordance with subparagraphs 1. and 2. of paragraph I for at least one generation or, in the case of perennial crops, two growing seasons.

Inspection system

Article 9

1. Member States shall set up an inspection system operated by one or more designated inspection authorities and/or by approved private bodies to which the operators producing, preparing or importing from third countries products as referred to in Article 1 shall be subject.
2. Member States shall adopt the measures necessary to ensure that an operator who complies with the provisions of this Regulation and pays his contribution to inspection expenses has access to the inspection system.
3. The inspection system shall comprise at least the application of the precautionary and inspection measures specified in Annex III.
4. For the application of the inspection system operated by private bodies, Member States shall designate an authority responsible for the approval and supervision of such bodies.
5. For the approval of a private inspection body, the following shall be taken into account:
   a) The standard inspection procedure to be followed, containing a detailed description of the inspection measures and precautions which the body undertakes to impose on operators subject to its inspection;
   b) The penalties which the body intends to apply where irregularities and/or infringements are found;
   c) The availability of appropriate resources in the form of qualified staff, administrative and technical facilities, inspection experience and reliability;
   d) The objectivity of the inspection body vis-à-vis the operators subject to its inspection.
6. After an inspection body has been approved, the competent authority shall:
   a) Ensure that the inspections carried out by the inspection body are objective;
   b) Verify the effectiveness of its inspections;
   c) Take cognizance of any irregularities and/or infringements found and penalties applied;
   d) Withdraw approval of the inspection body where it fails to satisfy the requirements referred to in (a) and (b) or no longer fulfils the criteria indicated in paragraph 5 or fails to satisfy the requirements laid down in paragraphs 7, 8, 9 and 11.

   The inspection authority and the approved inspection bodies referred to in paragraph 1 shall:
   a) Ensure that at least the inspection measures and precautions specified in Annex III are applied to undertakings subject to their inspection;
   b) not disclose information and data they obtain in their inspection activity to persons other than the person responsible for the undertaking concerned and the competent public authorities.
7. Approved inspection bodies shall:
   1) Give the competent authority, for inspection purposes, access to their offices and facilities, together with any information and assistance deemed necessary by the competent authority for the fulfilment of its obligations pursuant to this Regulation;
   2) Send to the competent authority of the Member State by 31 January each year a list of operators subject to their inspection on 31 December of the previous year and present to the said authority a concise annual report.

ANNEX I

PRINCIPLES OF ORGANIC PRODUCTION AT FARM LEVEL

PLANTS AND PLANT PRODUCTS

The principles set out in this Annex must normally have been applied on the parcels during a conversion period of at least two years before sowing or, in the case of perennial crops other than grassland, at least **three years** before the first harvest of products as referred to in Article 1.

The reduction in the conversion period must take account of all the following points:
- The parcels were already converted or were undergoing conversion to organic farming,
- The degradation of the plant protection product concerned must result in an insignificant level of residue in the soil and, where the latter is a perennial crop, in the crop,
- The Member State concerned must notify the other Member States of its decision concerning the obligation of treatment and also the level of the reduction decided for the conversion period,
- Products of the harvest following treatment may not be sold bearing an indication referring to organic production.

The fertility and the biological activity of the soil must be maintained or increased, in the first instance, by:

A. **Cultivation of legumes, green manures or deep-rooting plants** in an appropriate multi-annual rotation programme;

B. **Incorporation of livestock manure** from organic livestock production in accordance with the provisions and within the restrictions of part B, point 7.1, of this Annex;

C. **Incorporation of other organic material**, composted or not, from holdings producing according to the rules of this Regulation.

Pests, diseases and weeds shall be controlled by a combination of the following measures:

A. Choice of appropriate species and **varieties**,

B. Appropriate **rotation** programme,

C. Mechanical **cultivation procedures**,

D. **Protection** of natural enemies of pests through provisions favourable to them (e.g. hedges, nesting sites, release of predators),

E. **Flame weeding**.

ANNEX II

A. Fertilizers and soil conditioners

General conditions:
- Use only in accordance with provisions of Annex I,
- Use only in accordance with the provisions of the legislation on placing on the market and use of the products concerned applicable in general agriculture in the Member State where the product is used.

Name	Description, compositional requirements, conditions for use
Farmyard manure	Product comprising a mixture of animal excrements and vegetable matter (animal bedding) Indication of animal species Coming from extensive husbandry and only in the sense of Article 6 (5) of Council Regulation (EEC) No 2328/91 (OJ No L 218, 6.8.1991).
Dried farmyard manure and dehydrated poultry manure	Indication of animal species Coming from extensive husbandry and only in the sense of Article 6 (5) of Council Regulation (EEC) No 2328/91
Composted animal excrements	Need recognized by the inspection body or inspection authority Indication of animal species Factory farming origin forbidden
Liquid animal excrements (slurry, urine, etc.)	Use after controlled fermentation and/or appropriate dilution Indication of animal species Factory farming origin forbidden
Composted or fermented household waste	Product obtained from source separated household waste, which has been submitted to composting or to anaerobic fermentation for biogas production Only vegetable and animal household waste Only when produced in a closed and monitored collection system, accepted by the Member State Maximum concentrations in mg/kg of dry matter: cadmium: 0,7; copper: 70; nickel: 25; lead: 45; zinc: 200; mercury: 0,4; chromium (total): 70; chromium (VI): 0 (*)
Peat	Use limited to horticulture (market gardening, floriculture, arboriculture, nursery)
Guano	Need recognized by the inspection body or inspection authority
Composted or fermented mixture of vegetable matter	Product obtained from mixtures of vegetable matter, which have been submitted to composting or to anaerobic fermentation for biogas production
Seaweed's and seaweed products	As far as directly obtained by: 1. Physical processes including dehydration, freezing and grinding 2. Extraction with water or aqueous acid and/or alkaline solution; 3. Fermentation.
Sawdust and wood chips	Wood not chemically treated after felling
Composted bark	Wood not chemically treated after felling
Wood Ash	From wood not chemically treated after felling
Soft ground rock phosphate	Product as specified by Council Directive 76/116/EEC (OJ No L 24, 30.1.1976,p. 21). Cadmium content less than or equal to 90 mg/kg of P_20_5
Aluminium calcium phosphate	Product as specified by Directive 76/116/EEC. Cadmium content less than or equal to 90 mg/kg of P_20_5 Use limited to basic soils (pH > 7,5)
Crude potassium salt	Need recognized by inspection body or inspection authority

(For instance: kainit, sylvinite, etc.)	
Potassium sulphate, possibly containing magnesium salt.	Product obtained from crude potassium salt by a physical extraction process, and containing possibly also magnesium salts.
Stillage and stillage extract	Ammonium stillage excluded.
Magnesium and calcium carbonate of natural origin	Only of natural origin Need recognized by the inspection body or inspection authority
Calcium chloride solution	Foliar treatment of apple trees, after identification of deficit of calcium Need recognized by inspection body or inspection authority
Calcium sulphate (gypsum)	Product as specified by Directive 76/116/EEC. Only of natural origin

B. PLANT PROTECTION

General conditions :

- Use in accordance with provisions of Annex I,
- Only in accordance with the specific provisions of the plant protection product legislation applicable within the Member State where the product is used (where relevant (*)).

I. Substances of crop or animal origin

Name	Description, compositional requirements, condition for use
Azadirachtin extracted from *Azadirachta indica* (Neem tree)	Insecticide Need recognised by the inspection body or inspection authority
(*) Beeswax	Pruning agent
Gelatine	Insecticide
(*) Hydrolysed proteins	Attractant only in authorized applications in combination with other appropriate products of this Annex II, part B
Lecithin	Fungicide
Extract from *Nicotiana tabacum*	Insecticide Only against aphids in subtropical fruit trees (e.g. oranges, lemons) and tropical crops (e.g. bananas) used only at the start of the tropical crops.
Plant pils (e.g. mint oil, pine oil, caraway oil)	Insecticide, acaricide, fungicide and sprout inhibitor
Pyrethrins extracted from Chrysanthemum cinerariaefolium	Insecticide Need recognised by the inspection body or inspection authority.
Quassia extracted from Quassia amara	Insecticide, repellent
Rotenone extracted from *Derris spp.* and *Lonchocarpus spp.* and *Terphrosia spp.*	Insecticide need to be recognized by the inspecton body or inspection authority

(*) In certain Member States the products marked with (*) are not considered as plant protection products and are not subject to the provisions of the plant protection legislation.

II. Microorganisms used for biological pest control

Name	Description, compositional requirements, condition for use
Microorganisms (bacteria, viruses and fungi) e.g. *Bacillus thuringiensis*, Granulose virus etc.	Only products not genetically modified in the meaning of Directive 90/220/EEC (OJ No L 117, 8.5.1990, P.15)

III. Substances to be used in traps and/or dispensers

General conditions:

- The traps and/or dispensers must prevent the penetration of the substances in the environment and prevent contact of the substances with the crops under cultivation.
- The traps must be collected after use and disposed of safely

Name	Description, compositional requirements, condition for use
(*) Diammonium phosphate	Attractant only in traps
Metaldehyde	Molluscicide only in traps containing a repellent to higher animal species
Pheromones	Attractant; sexual behaviour disrupter Only in traps and dispensers
Pyrethroids (only deltamethrin or lambdacyhalothrin)	Insecticide only in traps with specific attractants only against ***Batrocera oleae*** and *Ceratitis capitata* need to be recognized by the inspecton body or inspection authority

(*) In certain Member States the products marked with (*) are not considered as plant protection products and are not subject to the provisions of the plant protection legislation.

IV. Other substances from traditional use in organic farming

Name	Description, compositional requirements, condition for use
Copper in the form of copper hydroxide, copper oxichloride, (tribasic) copper sulphate, copper oxide	Fungicide need to be recognized by the inspecton body or inspection authority
(*) Ethylene	Degreening bananas
Fatty acid potassium salt (soft soap)	Insecticide
(*) Potassium alum (Kalinite)	Preventions of ripening bananas
Lime sulphur (Calcium polysulphide)	Fungicide, insecticide, acaricide
Paraffin oils	Insecticide, acaricide
Mineral oils	Insecticide, fungicide Only in fruit trees, vine, **olive trees** and tropical crops.
Potassium permanganate	Fungicide, bactericide only in fruit trees olive trees and vines
(*) Quarz sand	Repellent
Sulphur	Fungicide, acaricide, repellent

(*) In certain Member States the products marked with (*) are not considered as plant protection products and are not subject to the provisions of the plant protection legislation.

Standardization series of Life Cycle Analysis by ISO (International Standards Organization)

Goal and scope (ISO 14040)

- Definition of the objectives of the study
- Choice of the functional unit
- Delimitation of the system boundaries
- Data quality requirements
- Cut-off rules

Life Cycle Inventory Analysis (ISO 14041)

- The system : construction of the life cycle tree
- Data collection
- Use of data
- Application of cut-off rules, taking into account of co-products
- Computation of the inventory
- Identification of the contribution of flows to the different life cycle stages, and identification of the most represented stages

Impacts assessment (ISO 14042)

- Selection of impacts categories
- Determination of the flows that are taken into account for the impact assessment
- Determination of their contribution to the impacts
- Computation of the impacts
- Identification of the main flows contributing to the impacts

Interpretation of results (ISO 14043)

- Identification of the strong and the weak points of the studied cases
- Meeting the goals set during the first stage
- Validation of the solution if necessary by the way of :
    - Additional data collection
    - Sensitivity analysis, scenarios
    - Detail of the applications and boundaries of the study leading to other possible studies