OPTIONS FOR NON-CHEMICAL WEED CONTROL IN GREECE: A LITERATURE STUDY

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April 1997

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ACKNOWLEDGMENT

This literature survey started longer than a year ago and was being planned to be finished within 3 months. Having next to my studies a job and the frequently hopeless search in the Greek literature resulted in only finishing this report after a year.

In order to verify the state of affairs, I contacted companies, institutes, growers from Greece and research-workers from The Netherlands, Ireland, Pakistan and China. It was not so easy to meet Dr. Baluch from Pakistan who from a research position in an institute had been transferred to the Ministry of Agriculture. I had also a difficult time when I wanted to contact a company of plastics in Krete. One person sent me to the other and I had to call for about a month until I found my information. Actually I had to pretend to be a grower wanting to purchase plastic sheets for his greenhouses! The most difficult situation I encountered was when I had to wait for promised help. Looking every day in the mail for papers sent from Greece also led to big disappointments and in some cases I was not able to go as thoroughly as I wanted to do it in this research. However all this year I had a very stimulating time. I was feeling the satisfaction of conquering the knowledge every time I was keeping searching and writing.

First I want to thank my supervisor Ir. Henk Naber for his patience with me and with my report and for allowing me to work on a topic that I suggested. For his guidance in this work and the facilities he provided me at the Department of Theoretical Production Ecology. I was all the time allowed to enter his office and ask him everything I needed and search in his bookcase.

Specially thanks to Dr. Ir. Wybo van der Zweep. I met him unexpectedly and he provided me with a lot of literature to start. As "master of languages" he has read and corrected some grammatical mistakes in this report.

Further I want to thank the Greek growers for their interviews, my friends Maria Pentaskoufi and Theodoras Vrachnakis

for sending me a lot of information after calling and contacting the proper persons in Greece.

2-1-1997

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CONTENTS

1 SUMMARY

In chapter 3 meteorological data (average temperatures and total rainfall in different locations) are given from Greece. Statistical data related to the agricultural area by main category (wooded area, arable land, permanent grassland, permanent crops) are also given. Harvested areas and production of important crops, fresh vegetables and fruits cultivated in Greece are further given in this chapter. At the end a Figure is given with the holdings by size of classes in EU countries.

Some recent non-chemical weed control methods are discussed in Chapter 4. In paragraph 4.1 is given very briefly the preventive measures referred to sanitation of the farm and some cropping practices. *Orobanche* spp. and their control on the basis of cropping practices is discussed in more detail. Mechanical efforts of weed control in order to reduce or total avoid the use of herbicides are given in paragraph 4.2.

Soil Solarization is a physical weed control method that is extensively discussed in paragraph 4.3. Research efforts in outdoor conditions and in greenhouses in different countries with similar climatic conditions as in Greece are given in order to see the possibilities of a further application of this method under Greek conditions. The advantages/disadvantages for the grower, crops, weeds and environment as well as the costs are discussed in sub-paragraphs 4.3.1.4-4.3.1.6. An other physical method called mulching is very briefly discussed in paragraph 4.3.2. Plastic soil covers and natural remainders are mentioned as the two possible mulching techniques.

Some studies on allelopathy as a possible future biological weed control method are mentioned in paragraph 4.4.1. Out of the many research efforts of scientists worldwide to investigate allelopathic effects some studies are mentioned that have been

carried out in Greece or studies related to important crops or weeds of the Greek agriculture. Possibly combination of crop rotation and allelopathy or the use of cover crops with allelopathic potentials are also mentioned very briefly.

Biological selective and non-selective methods are discussed in paragraphs 4.4.2 and 4.4.3 respectively. Biological control of some important weeds in Greece like *Orobanche* spp., *Chenopodium album* and *Convolvulus arvensis* are more extensively discussed. More emphasis is given to recent research studies as well as to research efforts from Greek scientists. In paragraph 4.4.4 positive and negative aspects of biological weed control are discussed.

In the discussion (chapter 5) options for farming systems without herbicides are discussed.

2 INTRODUCTION

The struggle of mankind against biotic and abiotic factors reducing agricultural production has been a permanent one since the moment he converted from food collector to grower. Weeds, insects, fungi, bacteria, viruses and nematodes are limiting biotic factors influencing growth and quality of plants. Nowadays series of plant protection methods are available and applied by the growers to control factors detrimental to the crops. In this way the best possible economic yield from cultivated crops can be obtained.

The discovery of modern pesticides created a revolution in the field of plant protection in crop management. Harmful organisms, destroying a crop within a short time, could now be exterminated. A small quantity of pesticide, not so expensive in relation to good results, was able to save crops and to realize an optimal production. Herbicides* are used specifically for the control of weeds.

Definition of the Concept Weed

Many weed scientists have been concerned with finding a definition for the weeds. According to Rademacher (1948) it is useful and necessary to review from time to time then current definitions and adapt their contents to the constantly changing developments. For practical reasons I limit myself to a definition based upon the one accepted by the European Weed Research Society (EWRS) created in 1975 in Mainz and reworded by W. v.d. Zweep (1997, personal communication) in the following way: *Weeds are plants, undesirable to the person responsible for the management of a specific locality at a specific moment.* However, not all unwanted vegetation has a weed character. For

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*In this report the term "herbicide" is used to mean the modern chemical herbicides.

example when crop plants are removed because they have diseases or because the planting density should become smaller. These plants are unwanted but they are not weeds. Also Milona (1993) mentioned that weeds are higher plants that for a period of time and at a specific place cause losses to the growth of some cultivated plants. It is known that without these limitations (time, place) is may be possible that the same plants at another time constitute a beneficial flora (for example in relation to producing food for grazing animals or bees). They may also contribute to the ecosystem balance, have aesthetic functions, are of pharmacological use or even in gastronomy (Milona, 1993).

Harmfulness of Weeds

The harmfulness of weeds in agriculture is not only limited to competition for light, water, space and nutrients, resulting in a loss of production. Allelopathy, parasitism, transfer of diseases and plagues, hindrance during harvest and quality losses of the products play an important role (Hoogerkamp and Naber, 1994). The economic damage can be detrimental and this can explain the intensive attempts, through the ages, to control weeds.

Weed Control

Weed control can be carried out in many different ways. Through the ages various mechanical, cultural, biological and chemical methods have been developed to control weeds. Up to now (and certainly globally speaking) hand-work takes an important role. The biggest change was realized by the large scale introduction of herbicides.

Sodium chloride (kitchen salt) as a general killer may be the oldest herbicide. In the Bible (The Book of Judges 9:45) is mentioned that after the destruction of an hostile city salt was spread to make the soil unfertile. Publications from the 19th century mention the use of salt as a selective weed killer against moss and *Cuscuta* in clover and lucerne (Kolbe, 1983). In the second half of the 19th century selective chemical weed control was realised with fertilizers, acids and metal salts like sulphuric acid, iron sulphate and copper nitrate, mainly in cereals. Other chemicals used were sodium chlorate, borates and arsenic products. Since the beginning of the 20th century calcium cyanamide and kainite were used, especially in cereals.

The first organic chemical herbicide, DNOC, dates from about 1930. After the second world war a strong development took place with the arrival of the synthetic growth substances MCPA and 2,4-D for weed control in cereals and pasture land. About the middle of the years seventies one or more herbicides were available almost for every crop. Since then many of these products were withdrawn from the market or were replaced by other products that were less poisonous and less harmful to the environment.

Before the second world war, the inorganic products were based upon contact action (etching); the second generation of herbicides were active by interfering with respiration and germination and later with photosynthesis. The youngest generation of herbicides often have a more specific activity, for instance hindering biosynthesis of aminoacids, carotenes and lipids and the interference with nitrate metabolism (Naber, 1993). These products are extremely effective in small amounts, less harmful to man and the ecosystem as the older products. Also the new substances couple to a large extent biological activity on weeds with selectivity in crops.

Herbicides do their work "perfectly". They are relatively inexpensive, easy to use and to be procured in the market. It is not accidental that the world sales only for herbicides amounted 44% of the pesticides in 1991 (Fig. 1). Seventy five per cent of sales arose from agrochemical use in six crop areas, as shown in Table 1. However, penetration of these markets by biological pesticides (bio-pesticides) has been limited to date (0,45%) and is dominated by bio-insecticides (Table 2).

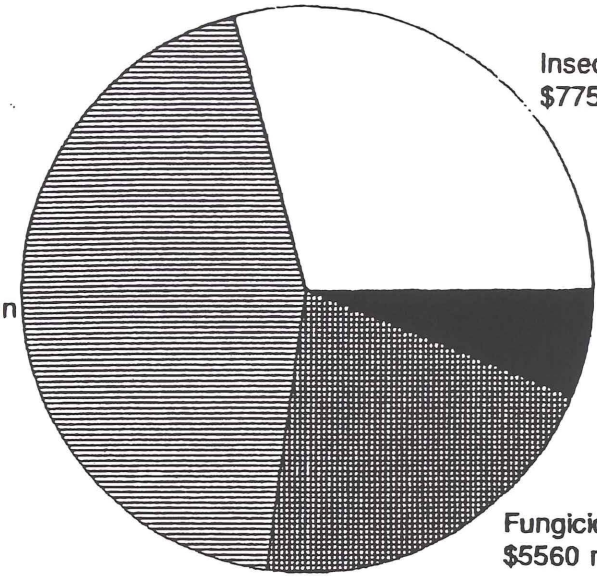

FIGURE 1: Global agrochemical sales in 1991 (end-user value given in millions of US dollars at 1991 level), (Powell & Jutsum, 1993).

TABLE 1: Global sales of herbicides for use on the world's major crops (end-user value given in millions of US dollars at 1991 level), (Powell & Jutsum, 1993).

Crop	US$ million	percentage of sector
Small-grain cereals	2300	19
Maize	1856	16
Soya	1580	13
Fruit, Vegetables, vines	1720	14
Rice	980	8
Cotton	540	5
Total		75%

TABLE 2: Sales of pesticides and bio-pesticides (Powell & Jutsum, 1993).

Product	Market size (US$ million) 1985	1991
Insecticides	4970	7635
Bio-insecticides	31	120
Fungicides	2800	5560
Bio-fungicides	< 1	< 1
Herbicides	**7000**	**11905**
Bio-herbicides	**< 1**	**< 1**

Weeds may develop resistance to herbicides. That can create a chain of reactions: new herbicides or mixtures of herbicides are needed to control the tolerant weeds etc.. Increasing use of chemical control methods is in itself a very potent factor leading to changes in the weed flora; sometimes it has resulted in an increase in the importance of some weeds. In the application of herbicides it was considered to be necessary that the plants have some uniformity. Creation and cultivation of adjusted varieties is frequently considered to be a key factor in pest control in all areas of the world, in all climates and on all soils; not needing a check of the specifications in each individual area. The fact of uniformity disturbs the environment with tragic ecological consequences in relation to the balance in the trophical chain.

It did not take so much time until mankind became aware of the negative effects of herbicides to user, consumer, wild life and environment. The disappearing of animal species, water pollution, persistence of herbicides in various ways, carcinogenic effects, genetic consequences, the residue problems in the crop and other abnormal phenomena appeared very soon.

The awareness of the consequences of chemical control resulted in a lot of discussions, man wondered if there were other, alternative solutions for pest control. As a result a new approach was developed in pest control management. Moreover, in 1992, the governments represented in the United Nations decided that Integrated Pest Management* (IPM) should be the standard in crop protection (UNCED, 1992).

In relation to the status of weed control worldwide, alternatives to chemical methods presently are only occasionally used to manage weeds. The most important reason for this is the availability of cheap and effective herbicides for almost every weed problem. In fact, this may be a disincentive for developing alternative pest control methods such as microbial pesticides in the agricultural market dominated by chemicals. Nevertheless, non-chemical weed control methods have been quite successful.

In Greece, non-chemical weed control is still in a preliminary stage. The particularity of the Greek agriculture related to, the big variety of crops, weeds, and cultural practices makes weed problems in Greece exceptionally complicated (Giannopolitis, 1995). Research currently conducted in Greece related to non-chemical control is mostly emphasizing on: a) Using soil solarization as a method for weed control. b) Utilizing indigenous fungi for biological weed control and c) Studying the allelopathic potential of plant species (Giannopolitis, personal communication).

The aim of this literature study is to collect information and discuss the possibilities of applying non-chemical weed control methods in countries with a mediterranean-climate and more specifically in Greek agriculture. This report deals in detail with the most recent non-chemical weed control methods like soil solarization, techniques based on allelopathy and biological weed control (bio-pesticides).

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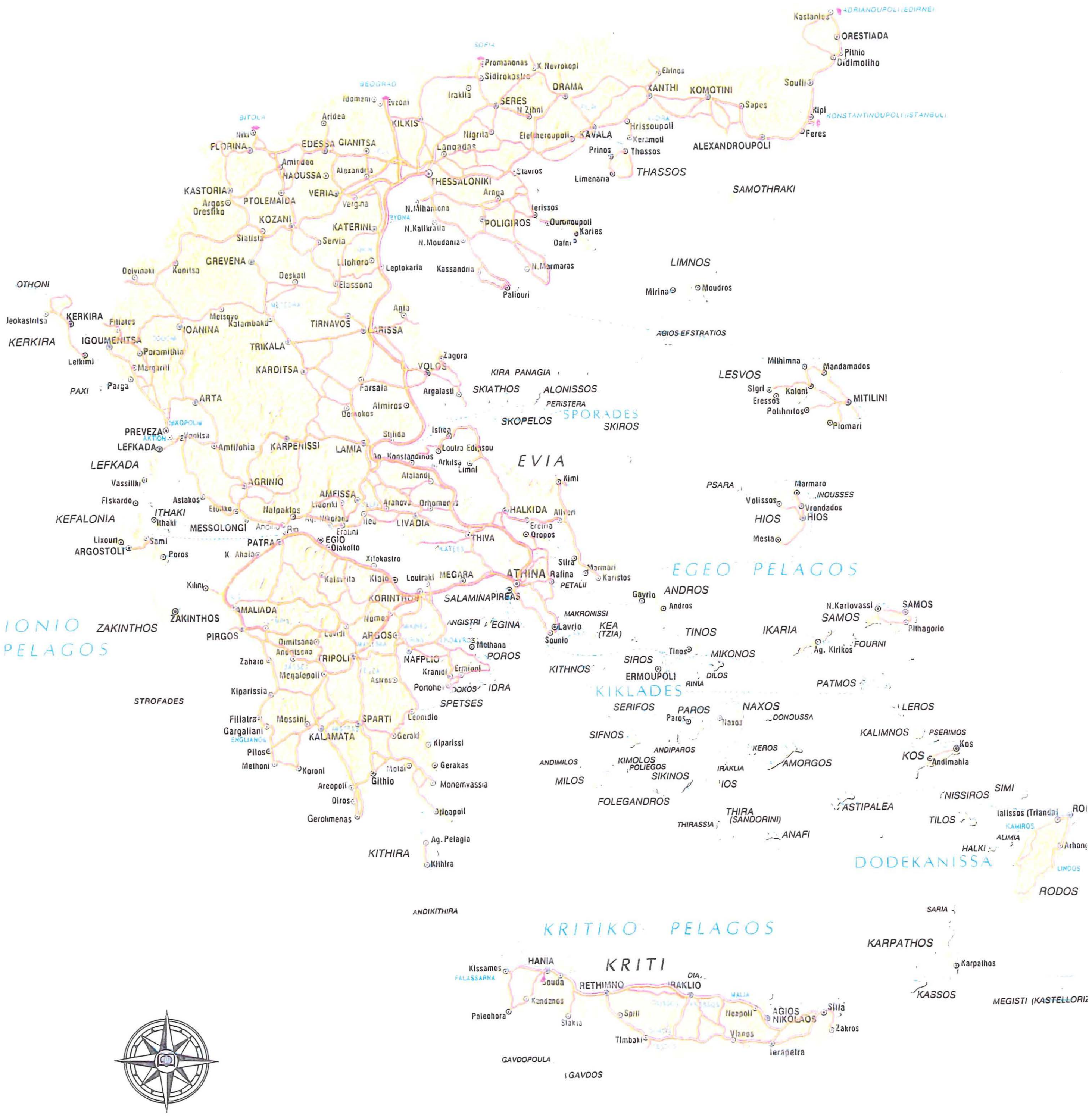
*The term Integrated Pest Management is used to mean any combination of methods of pest control in order to minimize the negative effects of pests on the crops and to come to the most ecologically acceptable method of pest control.

But other non-chemical weed control methods are also discussed. To support the discussion and determine the perspectives research data are collected from Greece or in countries with similar climatic, soil conditions and the same weeds and crops.

Having always in mind a sustainable way of farming with respect to nature, I will try to consider the problem holistic: Where do we go? What can we do? Where to start? Which methods can be applied under the Greek reality? How important is support of the government on research efforts? Is introduction of IPM more achievable? How important is to change the way of pest management and at the same time change the mentality of growers and consumers? How important is governmental contribution and support on this point? Last but not least with this report I will try to contribute to the struggle against weeds in agriculture and to help nature-friendly growers in their efforts to adopt cultural practices in an ecologically way.



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MAP OF GREECE

3 BASIC INFORMATION

3.1 The Mediterranean Climate

The Mediterranean climate is a subtropical-type moderate temperature climate, characterized by warm dry summers and mild wet winters. A hot dry season between May to September has an average temperature of 26^0C, while a cool moderate wet winter has an average temperature of 8^0C. The annual average precipitation of the area is 600 mm/year.

3.2 Main Crops of the Mediterranean Region

The most commonly grown crops in the Mediterranean region are: dates, olives, citrus fruits, avocados, grapes, cereals, maize, sugar cane, potatoes, sugar beets, brassicas, cotton, tobacco and various fruit and vegetable crops.

3.3 Statistical Data from Greece

TABLE 3.1: Average temperature (^0C) of decades at different locations in Greece in the year 1988 (Eurostat, 1990).

	Temperature (^0C)					
	Decades (AV)				Year	
Location	1-9	10-18	19-27	28-36	1988	AV
Thessaloniki	7,6	18,1	24,9	8,9	14,9	14,5
Alexandroupoli	7,3	16,6	23,9	8,6	14,1	14,0
Larissa	7,1	18,4	25,4	8,1	14,7	14,6
Arta	10,7	19,2	25,4	12,7	17,0	17,1
Aliartos	10,0	19,7	26,5	12,6	17,2	17,2
Andravida	10,5	18,8	24,8	13,1	16,8	16,3
Kalamata	10,5	18,9	24,7	13,5	16,9	16,8
Iraklio	12,5	20,3	25,4	15,3	18,4	18,1

TABLE 3.2: Total rainfall (mm) of decades at different locations in Greece in the year 1988 (Eurostat, 1990).

	Rainfall (mm)					
	Decades (AV)				Year	
Location	1-9	10-18	19-27	28-36	1988	AV
Thessaloniki	134	46	51	141	372	525
Alexandroupoli	166	129	18	164	477	558
Larissa	132	47	10	224	413	431
Arta	275	26	32	322	655	1002
Aliartos	132	47	10	283	472	559
Andravida	398	29	5	395	827	847
Kalamata	330	44	81	402	857	828
Iraklio	175	38	10	198	421	477

TABLE 3.3: Total and agricultural area (1000 ha) of Greece by main category (Eurostat, 1996).

	1987	1989	1991	1993	1995
Total area	13196	13196	13196	13196	13196
Wooded area[1]	5755	2951	2940	2940	2940
Utilized agric. area[2]	5765	5212	5187	5163	5163[4]
Arable land[3]	2925	2358	2329	2297	2250[5]
Permanent grassland	1789	1789	1789	1789	1789[5]
Land under permanent crops	1051	1065	1067	1077	1077[4]

[1] Actual forests dominated by trees or shrubs capable of producing wood or other forest products. Also areas which are not themselves productive but necessary for production. It is not included orchards, gardens, parks and other areas with ornamental plants.
[2] The total area used for crop production (Arable land including temporary grassing and fallow and green manure, permanent grassland, land under permanent crops e.g. fruit and grapes, crops under glass and other utilized agricultural areas).
[3] Land worked regularly, generally under a system of crop rotation, which includes fallow land.
[4] 1993
[5] 1994

TABLE 3.4: Arable land (1000 ha) of Greece by category in 1994 (Eurostat, 1996).

	Area (1000 ha)
Cereals total	1322
Dried pulses	20
Vegetables & strawberries	120
Ornamental plants	1
Fallow	476
Rest[6]	311
Total arable land	2250

[6]Root crops, industrial crops (oilseed, textile crops, tobacco, aromatic and medicinal plants, chicory, sugar cane), fodder (lucerne, green maize and cereals for silage or green fodder, grassing in rotation), seeds.

TABLE 3.5: Greenhouse area (ha) in Greece (FAO, 1988).

	Area (ha)
Glass houses	100
Plastic tunnels	3000

TABLE 3.6: Harvested area (1000 ha) of important crops (Eurostat, 1996).

	Harvested area (1000 ha)				
Crop	1987	1989	1991	1993	1995
Wheat and spelt	891	916	1011	912	825
Barley	240	231	171	167	133
Grain maize	262	224	231	198	160
Sunflower seeds	97	25	14	18	22
Soya beans	2	8	4	0	0
Beans	22	22	19	17	15
Potatoes	55	56	45	40	41
Sugar beets	179	174	165	180	174

TABLE 3.7: Production (1000 t) of important crops (Eurostat, 1996).

	Production (1000 t)				
Crop	1987	1989	1991	1993	1995
Wheat and spelt	2314	2763	3138	1970	2096
Barley	545	614	468	440	374
Grain maize	2383	2221	2321	1728	1520
Sunflower seeds	140	54	15	19	30
Soya beans	4	23	11	1	0
Beans	33	35	34	28	30
Potatoes	948	1172	987	1006	972
Sugar beets	2025	3435	2571	2719	2600

TABLE 3.8: Harvested area (1000 ha) of important fresh vegetables (Eurostat, 1996).

	Harvested area (1000 ha)				
Vegetable	1987	1989	1991	1993	1994
Cauliflower	3	4	3	3	3
Lettuce	3	4	3	4	4
Tomatoes	39	43	39	33	32
Melons	10	9	7	8	8
Onions	11	11	10	10	10
Green peas	3	2	2	2	2

TABLE 3.9: Production (1000 t) of important fresh vegetables (Eurostat, 1996).

	Production (1000 t)				
Vegetable	1987	1989	1991	1993	1994
Cauliflower	61	68	57	67	65
Lettuce	63	62	65	70	76
Tomatoes	1689	2052	1840	1813	1961
Melons	149	137	153	177	160
Onions	180	170	191	188	185
Green peas	13	11	11	10	9

TABLE 3.10: Main area of important fruits (Eurostat, 1996).

	Area (1000 ha)				
Fruit	1987	1989	1991	1993	1994
Oranges	35	37	39	38	38[7]
Grapes	169	164	143	136	137
Olives	669	684	809	713	703
Apples	17	17	19	16	16[7]
Pears	6	7	13	8	8[7]
Cherries	7	7	9	9	9[8]

[7] 1992
[8] 1991

TABLE 3.11: Harvested production of important fruit (Eurostat, 1996).

	Production (1000 t)				
Fruit	1987	1989	1991	1993	1994
Oranges	485	944	809	879	875
Grapes	1371	1619	1404	1323	1260
Olives	1372	1647	1853	1370	1772
Apples	302	312	186	331	329
Pears	121	115	66	78	76
Cherries	41	42	23	39	42

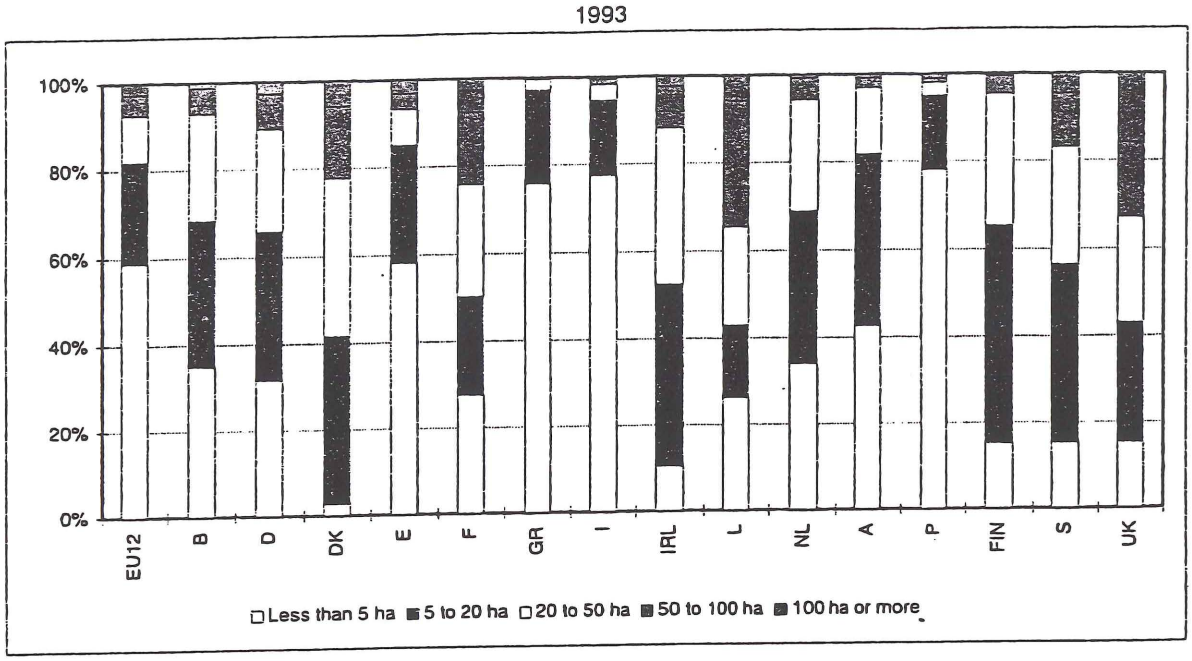

Figure 3.1: Holdings by size of classes in E.U. countries in 1993 (Eurostat, 1996).

4 NON-CHEMICAL WEED CONTROL METHODS

There are two strategies in weed management: eradication and containment. With eradication all effort is focused on the elimination of the weeds (Kropff, 1996). In the most cases this strategy can not be realized because of the high costs of the eradication process. With containment the weed population is kept at a level which is acceptable for the grower (Naber, lecture notes).

4.1 PREVENTION OF WEED OCCURRENCE

4.1.1 Hygienic Measures

Prevention of infestation of weeds in a field can be a very efficient weed control method. Knowledge of the components of the cultivated land prior to cultivation is a valuable guide as to what to expect in the sense of common weed problems. Expert knowledge of the timing of germination and the depth from which emergence can occur may be useful in planning the cropping sequence in order to avoid that competition during the early stages of crop growth and to decide how to cultivate crops in particular situations. As more information is obtained of the populations of viable weed seeds in the soil and their behaviour, it will be possible to use this information in the long-term planning of control measures.

For a good success it is also necessary to know the ways in which weeds are spreading. The wind, birds, animals, farm machinery, hand tools, manure and organic mulch contribute to weed spreading. For example, animal-food containing weed-seeds must be avoided; farm machinery and hand tools have to be cleaned carefully before they are moved to other fields and contribute to weed spreading. It is impossible to take any measurement against wind and birds.

A particularly important aspect of hygiene is the use of clean seed for sowing. In The Netherlands it has been shown that the spread of troublesome weeds like *Avena fatua* in cereals or *Cyperus esculentus* in gladiolus can be prevented when the crop seeded or planted is absolutely weed free. Seed cleaning techniques contribute to the reduction of weed propagules spreading with the planting material. For example, because of seed cleaning techniques in advanced agriculture, *Agrostemma githago* and *Lolium temulentum* have disappeared from the breadwheat.

4.1.2 Cropping Practices

Cropping practices assist the crops to compete better with the weed vegetation.

Timing of Sowing

Delayed sowing has been a traditional practice followed by farmers in the Mediterranean basin in order to reduce *Orobanche* infestation in cool-season food legumes. A good method to "catch" weeds is preparing a stale seedbed (false seedbed). The soil is ready for sowing but the grower is waiting for some days until the weeds are emerged. Sowing of the crop seeds takes place after weed control of the seedbed.

Depth of Sowing

Early and deeper sowing is another cultural practice against *Orobanche*. In the USSR, sowing of sun flower seeds at 10-20 cm reduced the infection from *O. cumara*, because the root system of the host plant was planted at a lower level than the level of the largest infection by the parasite (Kott, 1969).

Fallow Period

A fallow period has two functions: maintenance of soil fertility and weed control. Active weed control during a fallow period was started at the beginning of the 20th century in the form of land tillage. During the period that the land lays fallow, the soil is grazed by sheep or goats and a reduction of weeds can be realized. This form of fallow has been later replaced by cultivation of clover and lucerne often in combination with grass.

Crop Rotation

Alternation of crops is called crop rotation that can have weak and strong weed suppression characteristics. For example Johnson grass (*Sorghum halepense*) as a predominant weed in continuous maize (*Zea mays*) can be controlled by rotating maize and cotton (*Gossypium hirsutum*).

Krishnamurty and Rao (1976) mentioned that the rotation sorghum-tobacco or maize-tobacco is more effective against *Orobanche* than the alternation lay fallow-tobacco. Malykhin (1974) found that when spring cereals were cultivated for two years long and subsequently sun flowers were planted the infection of sun flowers by *Orobanche* was reduced to half. Crop rotation of tomatoes with *Linum usitatissimum* L. (flax) or tomatoes with sweet pepper controls *O. ramosa* to 95% and 80% respectively (Kotula-Syka, 1986).

In studies at ICARDA (Syria) in search of legume species that could better resist *Orobanche*, susceptible cool-season legumes in rotation led to the identification of large inter- and intraspecific variations in the susceptibility of several annual forage legumes (Linke *et al.*, 1993). *Lathyrus ochrus* and *Vicia villosa* ssp. dasycarpa were nearly free of parasite infection, whereas several varieties of *V. narbonensis* L. and *V. sativa* L. showed low susceptibility. All these could be used to replace faba bean, lentil or peas and yet retain the legume component in the rotation.

In areas with 350-600 mm precipitation per year *O. crenata* can be controlled in three-course crop rotations with a sequence of cool season cereals, cool season legumes, and summer crops (e.g. wheat/faba bean/sesame or barley/lentil/melon) (Keatinge *et al.*, 1985), but two-course rotations (e.g. barley/lentil or lentil/fallow) were as well found to control *O. crenata* (ICARDA, 1987).

Trap Crops

Cultivation of *Sinapis alba* and *Linum usitatissimum* L. before the transplantation of tobacco and tomato contributed considerably to the decrease of infection by *Orobanche* (Abu-Irmaileh, 1984; Aleksiev, 1966). These two "trap" crops (false hosts) stimulate the germination of the parasite seed, but cannot be infected. Thus the germinated seed dies, reducing the seed bank (Saxena *et al.*, 1994) needing only 4-6 weeks to reduce the parasitism. Species of the genus of *Pennisetum* and *Setaria* as well as *Medicago, Zea mays, Trifolium repens, Brassica oleraceae* v. gongyloides, *Sinapis alba, Capsicum annuum, Ricinus communis* and sesame have been used for the same purpose against *O. ramosa*. For *O. cernua* has been used *Capsicum annuum* and for *O. crenata* *Linum usitatissimum* (Kasasian, 1971). Eleftherochorinos and Lolas (1993) mentioned that flax, sorghum, and *Trigonella* have been used for the same purpose against *Orobanche*.

The results of a study on the reduction of the *O. crenata* seed bank showed that the highest reduction in the seed bank occurred after woolly-pod vetch (*Vicia villosa* ssp. dasycarpa Ten.), acting as a "trap" crop. The maximum reduction within one season reached 20-30% (Linke *et al.*, 1991). A field experiment conducted by Al-Menoufi (1991) in the Nile Delta of Egypt over 5 years showed that it was possible to minimise *O. crenata* infestation if faba bean was grown after three to four successive crops of berseem (*Trifolium alexandrinum* L.). The *Orobanche* infestation in faba bean was 8,3% and 1,0%, respectively when faba bean followed 3 and 4 crops of berseem. This compared with an infestation of 68,7% when beans were grown continuously. The author attributed this reduction in infestation to a reduced seed bank because of berseem acting as a "trap" crop.

An other similar method is the incorporation in the soil of sun flower remainders after harvest. The method was applied for a period of three years and showed a positive influence on germination of *Orobanche*. The germinated plants died because of the absence of plant hosts (Barcinskii, 1940). This method gave better results when organic substances were added. It is already known that poor soils have a positive influence on the growth of broomrape.

4.1.3 Discussion

As prevention of weeds may be a very effective and low cost method of weed control, it requires knowledge of weed-flora and weed-habits, as well as a continuous application of hygienic measures by the growers. Use of clean seeds does not depend always from the growers, still use of home-grown seeds should be avoided. It is very important when growers buy from trustful suppliers. The total costs of more expensive but clean seeds are much lower than those of later weed control in the form of labour, time and herbicides.

An objection against hand or hand-tool weeding in relation to the crop is that removing the shoots of the weed may cause mechanical damage to the root system of the host plants (Parker and Wilson, 1986) especially in the case of parasitic weeds. Two other objections are the high labour costs and the time required for hand or hand-tool weeding. In extensive farming, and there where the labour is cheap, hand weeding is still achievable.

Delay of sowing to escape the germination period of some weeds, as well as the preparation of a stale seedbed reduce the duration of crop growth. It can also reduce the yield of the crop, but this is not always the case; hence a suitable compromise has to be made between weed damage and yield. It is important to estimate the level in reduction of the yield, the size of weed damage by not delayed sowing and the costs of weed control.

Grazed by sheep and goats of land laying fallow can contribute to the import of new weed seeds through organic manure.

Krishnamurty and Rao (1976) and Malykhin (1974) mentioned that crop rotation including "trap" plants and not host crops to

Orobanche is very effective to the control of this parasite but it takes several years until full control.

Therefore, based on all the above issues, it is reasonable to state that a weed problem should be analyzed not only at the crop rotation level, but also for the whole cultivation program. Such a program must consider the analysis of the weed problems at the following levels:

a) at a specific field/parcel
b) on the farm - holding as a whole
c) in relation to the other farms in the area
d) in relation to the future of yield in production, and considering the potential commercial traffic.

It is important to manage "weed-problems" in practice and in research in view of an ecological way of thinking.

4.2 MECHANICAL METHODS

Some centuries ago transition from broad-cast sowing to sowing in rows created more possibilities for mechanical weed control. Hand-hoeing, implements pulled by ox and horses and subsequently (just after the Second World War) replaced by tractor-fastened tools allowed soil cultivation in between the plant rows.

Greece is a country with many sloping and impassable cultivated terrains (olive groves), often making mechanical weed control almost impossible. In sloping areas portable grass/shrub cutter-machines can be used in the control of perennial weeds like *Rubus fruticosus*.

There are two types of mechanical weed control (Paspatis, 1995): a) Ploughing of the soil and burial of the weeds and b) Cutting of the weeds. Ploughing is an effective method for the control of annual weeds. Bell *et al.* (1990), concluded that the weed *Solanum elaeagnifolium* can be eradicated completely by practicing soil cultivation every month for three periods long. In Bulgaria *Orobanche ramosa* and *Orobanche muteli* on tobacco were reduced significantly after deep ploughing (45-50 cm) taking place in autumn (Aleksiev, 1967).

Weeds with underground shoots or rhizomes like the perennials *Convolvulus* sp., *Cirsium arvense*, *Elymus repens*, *Cynodon dactylon*, *Sorghum halepense* and *Cyperus* sp. are able to regenerate and thus the effectiveness of ploughing is decreased. In this case repeated cuttings of the aboveground plant parts with grass-cutters will stimulate the depletion of the reserves of these weeds. But when repeated cuttings are followed by burials then the underground plant parts will be exhausted because of deficiency of carbohydrates after continuous regenerations (Paspatis, 1995). In Greek agriculture, *Cirsium arvense* is another perennial weed that can be eradicated by repeated soil tillage in the spring and summer. Four to six weeks after emergence of the first shoots, soil cultivation starts and is continued 1 to 2 times until the underground buds are exhausted (Giannopolitis, 1994). Small annual weeds can be controlled by strongly damaging their weed root system by ploughing. With this objective are used: cultivators, blades, rotators, ridge making devices etc.

Cutting weeds is used on tall weeds and has the objective to limit weed plant competition for light, water and nutritious elements and to hinder seed production. With this method the growers try to exhaust the weeds. Apical dominance is disturbed and secondary buds develop. The resources in the underground parts are all consumed and through cutting they can not be replaced. Perennial weeds can be controlled when they are cut between the complete developing of the foliage and the forming of the first flowers (late spring). A first cut of the top part of the weed and a second later of the lower part (when the secondary buds are developed) gives the best results. This method is inefficient for weeds producing seeds near the soil surface like *Taraxacum* sp., *Rumex*, *Cynodon dactylon* etc. (Paspatis, 1995).

In Greece row-crops like cotton and maize (both 500,000 ha), sugar beet and industrial tomatoes, mechanical methods play an additional role. Within the rows commonly chemical weed control is practiced and between the rows in all cases mechanical control. The machines that are used are (Efthimiadis, Agricultural University Athens, personal communication): a) soil tillage machines in spring crops in order to avoid soil compression. b) Mechanical cultivators like rotary hoes, cutter blades and rotary harrows in winter crops in order to avoid too intense loosening of the soil. c) Disc harrows. These machines are used on all soil types and in all cultivated counties of Greece against all weeds mainly in cotton and maize.

Especially the type of use of the land has large influence on the weed vegetation. Arable cropping favours annual and certain perennial weeds. The frequency and timing of the cultivations plays a large role in determining which species become prevalent. Intensive cultivation as practised in vegetable growing, however, discourages perennials and favours mainly those annuals (like *Urtica urens* and *Senecio vulgaris*) which are able to mature and reproduce very quickly. In grassland competition from the established sward acts against species depending upon reproduction by seed, but species able to propagate vegetatively may benefit from the absence of soil disturbance. The weed flora of grassland is influenced by the height at which the sward is maintained; in this aspect lawns present an extreme case and here weeds are either rosette species such as *Bellis* spp. or prostrate or creeping plants like *Trifolium* spp.

Traditionally the mould-board plough has been accepted as the main means of producing a clean seed-bed into which a cereal crop can be sown. This has also been one of the main methods of keeping perennial grass weeds in check. Good quality ploughing, where the furrow slide is completely inverted and where coulters are correctly set to bury weeds and avoid the growth of weeds between the furrow seams, will give good control of many weed species.

Trials have shown that in absence of a serious weed problem ploughing to a depth of 10 to 20 cm can be adequate but it should be accepted that as to the control of perennial weeds this will have little effect. As a general rule seed-bed cultivations in cereals should be kept to the minimum required for creating a suitable depth of tilth into which the cereal crop can be sown. Deep cultivation should be avoided since this will tend to drag weed debris (*Avena* spp., *Alopecurus myosuroides)*, particularly grass stolons and rhizomes, to the surface. In addition to leading to loss of moisture, superfluous cultivations tend to make the soil excessively loose with the result that the cereal seed will be drilled too deep.

Experiments on cereals (Weide *et al.*, 1994) showed that the usual treatments with herbicides could be replaced by harrowing three times between the rows. The first time, harrowing caused small loss of the plants, and up to 10 percent of the plants was covered completely. This was compensated by extra shoot formation of the remaining plants. There was some harvest reduction because of the extra tracks of the tractors. The result of mechanical control in cereals depends on the time of sowing, the first possibility to harrow in spring and the weed flora present. Early sowing and a late start of harrowing make it difficult to control weeds mechanically (like *Matricaria* spp. and *Alopecurus myosuroides* germinating in autumn).

In maize, sown at 6 cm depth, harrowing took place between the emergence of the plants and the two-leaf stage. The result could be improved by hoeing soil into the crop rows. This strategy was also effective against difficult weeds like *Echinochloa crus-galli* and resistant annual weeds (Weide *et al.*, 1994).

According to Weide *et al.* (1994), is not necessary to make ridges immediately after planting potatoes on clay soils. Rows can be made until the potato plants emerge, but it is better to make the rows just before emergence to avoid any damage to the plants. An extra treatment can be done by removing the upper part of the ridge by harrowing, after which the soil is placed back to the ridge with a hoe. This treatment cannot be done on heavy soils, because stolons can be damaged.

Peas and field beans are sensitive to harrowing. Hoeing, which is necessary to improve the result, can only be done if the distance between the rows is large enough. For peas this means a distance of 50 cm between the rows, resulting in an average of production loss of 3,5 percent. Hoeing is practised in dwarf french beans, but is impossible to be done three days before emergence until the first leaf stage, because then the tops of the shoots will break easily (Weide *et al.*, 1994).

In Greek fruit orchards chemical weed control is applied in the rows and leads to 40-50% of total weed control obtained (Vasiliadis, 1988). Mechanical control takes place with soil tillage machines. The weeds are killed satisfactory and the good soil aeration has a positive effect on the microflora. Repeated grass cuttings is also a usual practice that happens mainly with ROTAVATOR machines (Vasiliadis, 1988).

4.2.1 Discussion

The success of the mechanical weed control depends on the situation where it can be practiced. Manual and mechanical weed control have been and still are applied to a great extend and it even seems that the maximum use of mechanical techniques has not yet been reached. Row-grown crops still seem to offer more possibilities for mechanical control.

Vasiliadis (1988) mentioned that in fruit crops repeated soil cultivations damage the soil texture, endanger the crop root system, create mechanical injuries to the top of the fruit trees and reduce the organic matter content of the soil. Another very important aspect is the acceleration of soil erosion in sloping areas and the loss of soil moisture. Leaving or depositing repeatedly grass cuttings on the soil have also many negative effects like weed-tree competition, increasing the risk of frost damage and of diseases (Vasiliadis, 1988).

The use of energy and the pollution by the machines are two environmental aspects that must be taken in account in systems where the objective is to come to sustainable plant farming. When mechanical control is compared with chemical methods the demand of more labour is not in favour of mechanical applications.

4.3 PHYSICAL METHODS

4.3.1 Soil Solarization

4.3.1.1 Introduction

More than fifty years ago, Grooshevoy (1939) obtained effective control of soil pathogenic organisms by trapping solar energy under cold frames subjected to direct sunlight prior to planting. In 1976 this non-chemical method of soil disinfection in areas with intense sunshine, called soil solarization (SS) was further developed by Katan and his associates in the Valley of Jordan river. Scientists from Japan mentioned that similar efforts have been made in their country too, independent of those in Israel. The method has been proven in more than 40 countries and it is applied mostly in Israel, USA, Italy, Japan and Greece (Kalomira, 1995). In Greece 5-10% of the growers apply the method of SS (Giannopolitis, personal communication).

Soil solarization is a method of solar heating of soil by covering wet soil during the hot season with sheets of transparent polyethylene (PE) in order to increase soil temperature to levels lethal to soil-borne pests, diseases and weeds. Besides temperature effect, a shift in microbial population and changes in chemical and gas composition level because of PE mulch are considered to be involved in disease control (Sauerborn and Saxena, 1987). Although the primary focus was to control plant diseases, from the beginning the method also has had significant uses for weed control. Experiments have been carried out in naturally infested soils, in several countries, to evaluate the effectiveness of SS in disease control under field conditions. Control of soil-born diseases through solar heating of the soil was reported to range between 65-95% (Katan, 1981).

Direct killing of weed seeds in soil by lethal soil temperature built up under transparent PE is the main mechanism of reducing weed seed population and weed emergence. Annual and perennial weeds belonging to genus like *Amaranthus*, *Anagallis*, *Avena*, *Chenopodium*, *Digitaria*, *Fumaria*, *Lactuca*, *Phalaris*, *Poa*, *Portulaca* and *Xanthium* are effectively controlled by solarization (Katan, 1981). Winter annuals like, *Poa annua* and *Phalaris brachystachys* are susceptible to SS because of their low temperature requirement for germination (Clyde, 1991). A list with weeds partially or completely controlled through SS as well as the weeds that are not controlled by SS is given on APPENDIX II.

Second to steaming, SS is considered as the most effective non-chemical method of soil disinfection. The measure should be applied in areas where climatic, soil and economical conditions are favourable for its application. In addition, pre-plant solarization film may be left in place, after plant emergence, as a post-plant mulch.

In Greece during the summer period climatic conditions appear to be extremely favourable for application of the method, provided certain requirements such as the availability of irrigation water and land during the solarized period are met. In Greece vegetable cultivation in plastic houses is an important agricultural business. Soil solarization has opened new research fields and has given promise in solving also weed problems (Tjamos, 1991). Other terms which are used for SS are *Solar Heating*, *Solar pasteurization*, *polyethylene or plastic mulching of soil*. In this report the term Soil Solarization (SS) is used.

4.3.1.2 Soil Solarization in Outdoor Conditions

In the field, solarization has been best adapted to control weeds for autumn seeded crops such as onions, garlic, carrots, broccoli and other *Brassica* crops and lettuce. Other crops that have been evaluated include broad beans, potatoes, transplanted strawberries, orchard trees, and vineyards.

Three species of *Orobanche* have been reported to be controlled by solarization: *O. aegyptiaca* in carrot (Jacobsohn *et al.*, 1980), *O.ramosa* L. in eggplant (Braun *et al.*, 1987) and *O. aegyptiaca* and *O. crenata* in faba bean (*Vicia faba* L.) and lentil (*Lens culinaris* Medic.) (Sauerborn & Saxena, 1987). In these studies the parasite infestations were reduced by 90-100%. Accordingly, experiments were conducted by Sauerborn *et al.*, (1989) in Northern Syria (characterized by a typical Mediterranean climate) to examine the effect of solarization during the summer on the control of naturally infested fields with a mixed population of broomrape species *O. aegyptiaca* and *O. crenata* and other weeds in crops of faba bean and lentil. For daily maximum temperature the difference between PE-covered and uncovered soil was 8-15^{0}C in the years 1985-88. The mean maximum temperature of soil covered for 40 days in 1985/86 was 51^{0}C at 5 cm depth (Table 4.1). Temperatures above 40^{0}C lasted for around 13 h a day at 5 cm depth, 14 h at 10 cm depth, and 8 h at 15 cm depth (Sauerborn *et al.*, 1989).

TABLE 4.1: Mean maximum temperature(^{0}C) of PE-covered and uncovered soil in Northern Syria in July and August 1985/86 at several depths (Sauerborn *et al.*, 1989).

	Soil depth (cm)					
	PE-covered			Uncovered		
Time (days)	5	10	15	5	10	15
10	49,0	43,7	37,6	35,1	30,5	29,6
20	51,1	45,6	39,4	36,5	31,2	30,1
40	50,8	46,0	40,0	36,5	31,0	29,7

In 12 counties of Greece solarization experiments were carried out (Fig. 4.1). Maximum soil temperatures of some of these counties are shown in Table 4.2.

FIGURE 4.1: Map of Greece showing 12 counties where solarization or commercial applications were carried out. Counties: 1 to 4, Crete; 5, Argolis; 6, Attiki; 7, Fthiotis; 8, Magnesia; 9, Trikala; 10, Arta; 11, Preveza; 12, Kastoria (Tjamos, 1991).

The timing and duration of solarization both determine the magnitude of control of broomrape and other weeds. Solarization for 10 days in hot weather and 50 days in milder weather may be of help to precondition the broomrape seeds for germination and breaking the dormancy of some of the weed seeds so that more infestation with parasites and weeds can occur in these crops in comparison to untreated check. However, when the solarized period was 40 days, the broomrape infestation decreased very considerably (Table 4.3). In the Sudan Braun *et al.* (1987) observed also a stimulation of germination with *O. ramosa* infestation in eggplant following a short 10-day period of solarization.

TABLE 4.2: Maximum soil temperatures in solarized and uncovered fields recorded in various areas of Greece (Tjamos, 1991).

		County, month and year of temperature recording (in °C)			
Treatment	soil depth (cm)	Attiki July '82	Argolis July-Aug. '83	Magnesia July-Aug. '84	Trikala Sept. '87
Solarization	10	-	52-57 (m 55)	52-57 (m 55)	48-50 (m 49)
	15	51-53 (m 52)	-	-	-
	20	-	40-50 (m 48)	43-50 (m 46)	-
	30	-	-	-	41-43 (m 42)
Uncovered	15	39-41 (m 40)	-	-	-
(control)	20	-	30-40 (m 37)	33-36 (m 34)	-

Note: m, mean maximum temperatures recorded for a 10- to 15-d period; Attiki and Magnesia, olive groves; Argolis, globe artichoke fields; Trikala, tomatoes, application in closed plastic house.

A 50-day treatment in fields heavily infested by *Orobanche* spp. did not provide full control but the dry weight of *Orobanche* was reduced by 71 and 87%, respectively, occuring in faba bean and lentil crop (Table 4.3). In the same area evaluation of viability of *Orobanche* seed buried in soil indicated a complete kill of seed to a depth of 5 cm following solarization. Seeds buried deeper (10 to 15 cm) were destroyed up to 99% (Table 4.4).

Some other major weeds that were found in these experiments were: *Phalaris brachystachys*, *Sinapis arvensis* and *Sorghum halepense*. Solarization reduced dry weight of weeds, particularly when the period of solarization exceeded 10 days in the hot season. *Phalaris brachystachys* was 100% controlled by SS for 20 days or more (Sauerborn *et al.*, 1989).

TABLE 4.3: Effect of duration of SS on broomrape infestation (number/m², dry weight g/m²) in faba bean and lentil in Northern Syria, 1985-1988 (Sauerborn *et al.*, 1989).

	Broomrape			
	Faba bean		Lentil	
Days solarized	no./m²	g/m²	no./m²	g/m²
1985/86				
0	33	57	94	57
10	56	87	141	69
20	16	45	26	35
40	3	8	1	2
s.e.±	8,5	14,7	18,1	5,9
1986/87				
0	2	4	9	10
50 pre*	7	16	28	27
s.e.±	0,4	1,6	6,4	3,6
1987/88				
0	115	152	61	33
20	57	122	32	37
30	33	65	25	35
40	26	57	22	29
50	13	41	4	4
s.e.±	14,4	18,6	11,4	10,9

**50 pre is the treatment where solarization was done in September and October for 50 days immediately before sowing.*

An other experiment was carried out in the Jordan Valley by Abu-Irmaileh (1991). He showed that six weeks SS reduced weed development, weed growth and improved crop yield in naturally infested fields that were cultivated with Squash and tomatoes. Horowitz *et al.* (1983) reported that solarization with clear PE for two to four weeks gave good weed control, which was still appreciable after one year. Abu-Irmaileh (1991) found that in field conditions, the growth of most weed species was suppressed by solarization but not completely eliminated (Table 4.5). In the same experiments, *Orobanche aegyptiaca*, *Anagallis arvensis*, *Avena sterilis*, *Senecio vernalis*, *Sinapis alba* L. and *Sinapis arvensis* L. were completely controlled by SS, while *Convolvulus arvensis* L. *Crepis aspera*, *Melilotus indicus*, *Senecio vernalis* and *Vicia narbonensis* were not suppressed by SS.

TABLE 4.4: Effect of SS on the *Orobanche* seed bank (number of seeds/kg soil), viability of seed and the number of *Orobanche* shoots/m^2 in Northern Syria (Linke *et al.*, 1991).

	No. of *Orobanche* seeds per kg soil	Seed viability* (%)	No. of emerged *Orobanche* shoots/m^2
Control	198	86,8	60,5
Solariz.	191	1,0	3,5
s.e.±	17	1,0	11,3

**Up to 15 cm soil depth.*

TABLE 4.5: Effect of SS on weed dry weight (wdwt) and crop yield in Jordan, 1987-88 (Abu-Irmaileh *et al.*, 1991).

	Squash		Tomato	
	wdwt (g/m^2)	yield (tons/ha)	wdwt (g/m^2)	yield (tons/ha)
Sol	175	26	267	22
Control	329	0,5	1202	1
s.e.±	26,9	6,2	94,3	6,5

Preliminary experiments in Attiki, Greece, have shown that weed control in lettuce following use of SS continued for 5 months after the removal of PE sheets (Vizantinopoulos, 1990). The weeds controlled were: *Urtica urens*, *Amaranthus* spp., *Portulaca oleracea*, *Setaria viridis* and *Chenopodium album*. Most annual crops are sensitive to weed competition during the first 2 months.

Other experiments (Vizantinopoulos and Katranis, 1993) in central Greece on silty clay soil were conducted for controlling annual weeds in maize and soybean. Pre-emergence herbicides leave phytotoxic residues for following crops such as wheat, sugar beet or cotton and should be avoided. Three or 4 weeks of SS gave better weed control than pre-emergence herbicides and effectively controlled volunteer wheat (*Triticum aestivum*), *Portulaca oleracea*, *Digitaria sanguinalis*, *Solanum nigrum*, *Amaranthus* spp. and other weeds (Tables 4.6 & 4.7). At 7,5 cm depth it was generally 7-9^{0}C warmer than in uncovered soil. The solarized plots remained free of weeds for at least 4 months after removal of the plastic. That long lasting effect confirmed previous results (Vizantinopoulos, 1990) and supported those of Horowitz *et al*. (1983). The maximum soil temperatures recorded were lower than those reported elsewhere in Greece under similar air temperatures, which ranged up to 53^{0}C (Tjamos, 1983; Vizantinopoulos, 1990). This was presumably because of the silty-clay soil type of the experimental area which heats up less than some other soils (Mahrer *et al*., 1984). In other experiments in Southern Greece carried out on light soil under similar air temperatures, maximum temperatures of PE covered soils reached 55^{0}C (Vizantinopoulos, 1990). However, the critical factor for killing seeds in wet soil is not only the maximum temperature reached, but the cumulative total of hours above certain temperature level (temperature sum). For some weed or crop seeds tested in the laboratory like *Phalaris paradoxa* L., *Bromus japonicus* L., *Avena byzantina* L. (cv. Kassandra), *Helianthus annuus* L. the temperature*time product for killing about 90% of seeds in wet soils was 40^{0}C*50 h, 45^{0}C*24 h or 50^{0}C*12 h (Vizantinopoulos, unpublished data).

TABLE 4.6: Effect of SS and herbicide treatments on weed control and yield of maize in Greece (Vizantinopoulos and Katranis, 1993).

Treatment	Rate (Kg a.i./ha)	Weeds/m^2	Plot yield (g)
Pendimethalin+atrazin	1,2+0,8	5,3	1290
Acetochlor+atrazine	1,8+1,2	14,6	1015
SS+acetochlor+atrazin	0,9+0,6	2,5	1632
SS (0,015 mm)	_	2,4	1493
SS (0,030 mm)	_	1,9	1745
Control (weeded)	_	1,3	1393
Control (unweeded)	_	33,9	755
SED (18 d.f.)			133

TABLE 4.7: Effect of SS and herbicide treatments on weed control and yield of soybean in Greece (Vizantinopoulos and Katranis, 1993).

Treatment	Rate (Kg a.i./ha)	Weeds/m^2	Plot yield (g)
Imazaquin+metolachlor	0,112+1,5	5,0	345
Metribuzin+alachlor	0,375+1,98	9,8	280
SS+imazaq.+metolach.	0,056+0,75	0,8	643
SS (0,015 mm)	_	0,8	525
SS (0,030 mm)	_	1,0	513
Control (weeded)	_	1,0	323
Control (unweeded)	_	27,4	262
SED (18 d.f.)			44

Vizantinopoulos and Katranis (1993) showed in experiments with maize and soybean that during the period of solarization the temperature*time product was higher than required. The minimal temperature required for weed killing that Vizantinopoulos (personal communication) mentioned was $40^{0}C*50$ h. The temperatures were recorded at a depth of 7,5 cm. Higher maximum temperatures would presumably have been attained nearer to the soil surface, as found in some other studies (Horowitz *et al.*, 1983; Rubin and Benjamin, 1983 & 1984).

According to the authors of the above mentioned experiments with maize and soybean the degree of weed control was similar with PE thicknesses of 0,015-0,030 mm, a finding of practical value as the thicker sheets are more expensive. However in Table 4.6 the difference in crop yield are not explained.

Experiments in eggplants and carrots where the soil before planting was covered with plastic have shown an important reduction of *O. aegyptiaca* and the same time a very satisfactory growth and production of the crops (Jacobsohn *et al.*, 1980; Katan *et al.*, 1979). Due to *Orobanche* control by SS 20% increase in yield of bean (Abdel-Rachim, *et al.*, 1988) was reported and a yield of 78 ton/ha of carrot from the solarized plot, while the non-solarized plot did not yield at all (Jacobsohn, *et al.*, 1980). Control of weeds alone due to solarization increased the yield of onion by 100-125% (Katan, *et al.*, 1980).

Yield increase with solarization in maize crop ranged from 7-20%. The phenomenon of increased growth is commonly found in fumigated and heated soils (Courter *et al.*, 1964; Takatori *et al.*, 1964; Ratan, 1974; Chen and Katan, 1980) and is not only due to the control of weeds. Control of soil-borne diseases and other factors, such as increased release of macro- and micro-nutrients, release of plant growth regulators and the development of mycorrhizae have all been suggested (Takatori *et al.*, 1964; Ratan, 1974; Chen and Katan, 1980). Increased yield in solarized plots would make the method of SS extra atractive for application.

4.3.1.3 Soil Solarization in Greenhouses

The efficacy of SS has been shown better in greenhouses than in open fields. More disease problems, higher costs in outdoor conditions and extension of the method to cooler areas are some of the reasons that make SS more important in greenhouses. In greenhouses or in the more temperate to tropical regions, solarization can be used before planting of the spring-planted crops such as tomatoes, peppers, squash, and cucurbits. Last years many efforts have been made in greenhouses in Greece to apply solarization in order to replace methyl bromide or the physical but very expensive method of steaming.

Experiments in greenhouses in Athens, on solarization showed a spectacular reducion of dormant *Amaranthus retroflexus* seeds that were added to the soil (Paspatis *et al.*, 1995). Other experiments on the effectiveness of solarization on the natural population of *Amaranthus viridis*, *Urtica* sp., *Stellaria* sp., etc. during the winter following solarization showed significant reduction of germinated seeds and especially those of *A. viridis* (Paspatis *et al.*, 1995).

A laboratory study (Ikonomou *et al.*, 1995) showed that dormant seeds of *Bromus rigidus* and *Sinapis alba* were not more viable when the soil was covered with plastic for 15 days and temperature varied between 35-45^{0}C.

In APPENDIX III a vegetable grower is presenting information on how the preparation of the soil is taking place in her own greenhouse and what are the results of the application of SS on weed control.

4.3.1.4 Advantages

Soil solarization has potential advantages over other soil disinfection methods, especially in greenhouse-grown crops. A major advantage is the safety to the user and the environment as it is a non-chemical method. This advantage is of special interest in those countries, where the arsenal of chemicals available is restricted for vegetable crops.

Soil solarization is less harmful to the soil flora and fauna than steaming or fumigation. It does not require extra energy. There is no release of big amounts of manganese or other toxic products. The soil does not reinfect soon because no bio-gap is created (Dawson *et al.*, 1965; Newhall, 1955) as happens in case of steaming or chemical disinfection. The temperatures reached by SS are much lower than those obtained by steaming. In this way all the negative consequences of high temperature on biological factors and on the physical and chemical soil properties are avoided.

Indirectly biological control of weeds and other pathogens can be achieved by SS (Katan, 1981), because it is considered as a selective method to soil micro-organisms. Changes in the soil micro-fauna act positively on saprophytic micro-organisms that work antagonistically on soil pathogens and weed seeds; and not to phytopathogens that demand more specific conditions for growth. High soil humidity for a long time secures better conditions for the growth of antagonistic soil micro-organisms. Also the partially anaerobic conditions under the PE seem to have influence on biological control by SS. Bacteria of the genera *Pseudomonas* that are beneficial to the plant root system multiply quickly after SS application. The percentage of Gram positive bacteria that have antibiotic abilities *in vitro* has been found to be many times higher after SS.

Commonly control of dormant weed seeds does not occur with herbicides, but is has been observed after SS. Seeds located at a depth where the prevailing conditions are not favourable for germination will remain dormant (secondary dormancy), but viable until these conditions change. Under SS, the temperature-increase in deep layers is probably not high enough to be lethal, but it might be sufficient to break secondary dormancy and force germination. Thus during their emergence, the seedlings will be killed by the high temperature of the hot upper layer (Rubin and Benjamin, 1984). Rubin (personal communication) found in several cases that solarization breaks dormancy, he supposed that this is due to temperature fluctuations, resulting in increase in infestation of weed species which have hard seeds (e.g. *Malva*, *Melilotus*, etc.). *Convolvulus arvensis* which propagates vegetatively, will be controlled if the majority of rhizomes or stolons are in the affected depth (0-10 cm). The vegetative propagules at a lower depth will generally be only slightly affected and they may emerge later. This happened with *Cyperus rotondus* as well as with *Sorghum halepense*. However, *S. halepense* seedlings emerging from seeds, are easily controlled by solarization. It is not known what is the response of seeds of *C. arvensis*, however it is found that *Convolvulus pentapetaloides* (an annual weed, not-existent in Greece), is not adequately controlled by solarization (Rubin, personal communication, whole paragraph).

Improved crop growth response and higher concentration of the chemical elements P, K, Ca, etc. in the soil are very often observed after application of SS. The increases in the yield of crops can largely result from the control of parasitic and other weeds. However, the contribution of other factors associated with the solarization treatment to the improvement of yield of crops cannot be excluded. In field experiments heavily infested with *O. crenata* mean seed yield of food legumes is increased by 315% and of straw by 105%. Harvest indexes were also positively affected and increased from 19 to 31% (Table 4.8). Stapleton & DeVay (1986) have reported increased nitrogen mineralization of the order of 27-177 kg/ha and improved availability of other mineral nutrients in the soil following solarization. Chen & Katan (1980) observed improved crop growth after solarization even when no major soil pathogens or pests had to be controlled and they attributed the improvement to enhanced soil fertility.

After SS, control of pests and improved plant growth are not only observed in the year of application but also in the second and third year. In experiments in Northern Syria in crops of faba bean and lentil (Sauerborn et al., 1989), decrease of weed infestation by about 75% was observed in the second year when solarization was done for 40 days in 1985/86 season and by 42% in the third year. The long duration of the effectiveness of the method is not mentioned for any other soil disinfection method.

This is because SS reduces the density of infestation of pathogens in soil and at the same time useful antagonists that delay the reinfection of the soil, are not killed; on the contrary they profit (Kalomira, 1995).

TABLE 4.8: Effect of solarization on seed and straw yield and harvest index (HI) of three food legumes on fields infested with *O. crenata* in Northern Syria. (Linke *et al.*, 1991).

	Without solarization			With solarization		
Crop	Seed yield (kg/ha)	Straw yield (kg/ha)	HI (%)	Seed yield (kg/ha)	Straw yield (kg/ha)	HI (%)
Faba bean	359	1601	19	1546	3189	33
Lentil	229	1493	12	1240	3561	26
Pea	648	1391	29	1239	2167	36
Average	337	1511	19	1393	3102	31

Soil solarization is a simple method accessible to growers and appropriate for developed and developing countries. For small fields, the covering can be carried out by hand and in large fields the soil can be covered by specific machines that have been developed to reduce the costs of application (Hetzroni *et al.*, 1983). It can be applied in big agricultural fields where other methods are not effective (e.g. to parasitic weeds) or when herbicides are not wanted. A big advantage is the possibility to apply SS in already planted fields like in vineyards and arboriculture while it can act as an alternative to control weeds resistant to herbicides or in cases where selective herbicides do not exist.

At last but not at least, SS is a proper method to control weeds according to the principles and philosophy of ecological agriculture.

4.3.1.5 Disadvantages

The method of SS can be applied only in warm areas. Heavy clay soils are not proper for SS. Light sandy soil is much more suitable. Dark coloured soils are also preferable as they absorb more radiation than light coloured soils. An irrigation system is required to wet the soil before SS can start. The soil must be kept wet during the SS period to improve heat conduction for an efficient killing of pests, diseases and weeds in deeper soil layers and increase thermal sensitivity of these soil organisms. Small differences in soil humidity can lead to big differences in conduction of heat to greater depth. Mahrer *et al.* (1984) developed a model showing that soil temperature is influenced by different soil moisture regimes in mulched sandy and clay soils. They determined a decrease of the temperatures with decreasing water content of the PE covered soil. Soil moisture content of at least 50% water holding capacity creates favourable conditions for killing weed seeds (Vizantinopoulos, unpublished data). Yaduraju and Shukla (1995) showed in New Delhi that solarizing wet soils gave a higher level of weed control in gladiolus (80% in July) compared with the dry soil (70%). In these experiments the maximum temperatures at 5 cm deep were 38^0C in July and 33^0C in August.

While controlling soilborne pests and pathogens by SS it might be possible reducing also the population of useful soil microbes. The effectiveness of SS is not satisfactory on a big number of other harmful pathogens.

Land should be free of crops for about one or two months at the time of SS. It must not be forgotten that one third of the cultivated land in Greece is leased (rented) and thus the method becomes too expensive and does not enable the farmers to practice this technique without sacrificing their land/crop.

The effectiveness of SS is increased by prolongation of the application of the method. But for other reasons (eg. leasing of the land) this is not always possible.

Egley (1983) reported that solarization did not eliminate primary dormant weed seeds from the germination zone. The intense temperatures probably killed many nondormant seeds and seedlings prior to emergence.

An ecological question to commercial uses of plastic mulches for SS is the disposal of the plastic film when it is not appropriate any more for use. Plastic film is usually removed from the field by burning, physical removal, and removal and storage of plastic. Long-term degradable film requires many years to degrade. It builds up in the field and interferes with future planting operations. Plastic film-residue left over in the soil may clog harvesting machinery. Also, plastic cannot be safely burned because it tends to produce toxic smoke. Environmental protection laws have made burning difficult or impossible in many areas. The third alternative would be to collect the film into piles, load it on trucks and then dispose it. However, many landfills no longer permit dumping of agricultural plastics. Storing the used plastic is an alternative to disposal where space is available and farmers cannot justify the use of valuable farm land for this purpose.

One method of handling plastic removal and disposal is to have a plastic film which will degrade after harvesting. Biodegradability has been found to be an inferior method because most polymeric materials are resistant to bacterial attack. The chemical groups required for biodegradability frequently cause a significant reduction in the desired properties on the plastic materials (Eggings *et al.*, 1971, Potts *et al.*, 1973). Starch-based films containing sufficient starch to improve their biodegradability have inferior physical properties, before or after soil contact, and their rate of degradability is difficult to predict (Otey and Westhoff, 1984). Photodegradation of PE involves a photo-oxidizing action on the polymer chain. The main difficulty lies in getting it to occur after a suitable and predictable lapse of time (De Carsalade, 1986). The plastic can discompose too early, too late, or unevenly.

Recycling is technically possible, but past efforts have not been economically viable (Stevens *et al.*, 1991). Efforts should be directed towards educational anti-litter programmes and the establishment of plastic recycling centres instead of spending them on developing photodegradable and biodegradable resins.

4.3.1.6 Costs

The costs of application of SS in outdoor conditions or in greenhouses depend mainly on the value of PE and labour costs. The value of PE depends on the thickness of PE: more expensive when thicker. The costs of soil covering depend on the method of application, for example by hand or by specific machines (Hetzroni *et al.*, 1983). In Greece 0,030 mm PE sheets cost about US$850/ha or US$550/ha, when using 0,015 mm plastic sheets (Vizantinopoulos, 1990). An efficient film-laying machinery can reduce the application costs (Hetzroni *et al.*, 1983).

Tjamos *et al.*, (1989) obtained a significant reduction in labour costs by eliminating the attachment of the plastic sheets to the soil in covered plastic tunnels. UV-absorbing polyethylene has the advantage of being more resistant to degradation under intense sunshine. That makes it possible to reduce the thickness of the plastic sheets, especially for use inside greenhouses (greenhouses reduce the UV radiation reaching the PE sheets and protect from uncomfortable climatic conditions like wind).

A new PE (type 101) of 0,005 mm is developed in Greece by a private company. It can be used in greenhouses as well as for outdoor conditions. Seventy five kg of the plastic are required for one hectare. The cost is about US$510/ha (Kikrilis, Crete Plastics, personal communication). These prices are much lower than those of fumigants like methyl bromide.

A hypothetical economic analysis should be made by the growers. An example is given in Table 4.9. The total benefits from solarization must be compared with the total conventional treatment costs. If the crops are non-pesticide treated, the same hypothetical analysis can be used but then grown-organically without solarization (instead of conventional) against grown-organically with solarization. Since "produced without pesticides" ("organic") food is currently selling for a premium depending upon yield of the crop, a reduced yield is possible with a net income still higher (low population of pests but still with reduced yield) or lower (major reduction in yield due to heavy pest pressure).

TABLE 4.9: Hypothetical economic analysis for a conventional and a solarized grown crop.

Inputs	Conventional	Solarized
Land preparation		
(pre-plant)	....*	....
Soil insect control	....	0
Soil pathogen control	....	0
Weed control (chem.)	....	0
Weed control (hand)	....	....
Plastic sheeting	0	....
Total variable costs	....	....
Fixed costs (land,		
Equipment, etc.)	....	....
Yield	....	....
Price	....	....
Gross income	....	....
Net "	....	....

**Every empty space (....) must be filled-in by the grower with the costs made.*

4.3.2 Mulching

Black Polyethylene

Soil covering techniques can be applied in arboriculture (young trees), vine yards and strawberries. Black Polyethylene plastic (BPE) is used on the ridges and small-grain straw in the furrows in almost all strawberries grown for the fresh fruit market (Photo 4.1). Straw is only used in strawberries grown for processing. After harvest straw can be grazed by sheep. In Greece this method is applied by 30% of the strawberry growers. Plastic mulching provides excellent long term control.

Higher yields, early fruit maturity and better quality were given by covering the soil of the tree lines in width 2 m with BPE in W. Navel Orange orchards on the island Crete, Greece, during the winter months (Protopapadakis, 1989). It favoured the fruit set and the June drop was diminished, so that the significant effect on yield was obtained with greater number of fruits corresponding to their smaller weight. The skin thickness was generally decreased resulting in a better quality. This was probably related to the more even supply of water during the growth of the fruits.

Paper and ground cloth (anti-rooting cloth) are good possibilities to control weeds in horticulture. In this report however, these methods will not be discussed.

Natural Remainders

Mulching with natural remainders like cut grass, straw and sawdust makes it possible, to hinder weed germination, restrain loss of soil moisture and gradually improve the fertilization/compost without negative effects, (Dessilas, 1993).

When straw is used for mulching, volunteer cereal plants germinated from seeds present in straw are a problem. They have to be controlled otherwise competition will occur and picking will be difficult (Naber, 1987).

Photo 4.1: Application of black polyethylene in strawberries in Peloponnese, Greece.

4.3.3 Discussion

The effectiveness of SS for control of different soil inhabiting pathogens has been proven in various countries in the world with sunny climates. Research is still going on in different directions, improving application methods, materials and mechanisms so that SS will contribute more to crop protection.

In Greece the mean maximum air temperatures in summer range from 35-38^{0}C. SS with transparent polyethylene sheets may be the best weed control method in profitable crops such as maize and soybean planted as second season crops. Its use would reduce the risks of environmental contamination and phytotoxicity due to persistence as it happens from the use of pre-emergence herbicides in summer crops. The effect of solarization on the weed flora and the lethal effect on dormant weed seeds in the soil would be expected to result in a progressive reduction of the weed population after repeated annual treatment (Rubin and Benjamin, 1984; Vizantinopoulos, 1990).

The temperature in soils covered by PE in 0-10 cm is mostly higher than 45°C and some times even higher than 50°C. Under Greek conditions the required lethal temperature*time values are obtained in light soils within 10-15 days (Vizantinopoulos, 1990). Moreover weed control continues for longer than 2 months after removal of PE sheets. This is a very important point if it is taken in account that the most critical period concerning competition of weeds is the first period of growth of the crops.

In greenhouses, SS is without doubt the solution, where application of herbicides, methyl bromide, dazomet etc. is not allowed. In plastic tunnels of Northern Greece solarization has shown success and to an even greater extent on Crete, where PE covered soil reaches higher temperatures. SS is also applied in other areas of Greece e.g. Peloponnese, region of Preveza, Samos island etc. (Vizantinipoulos, Personal communication). Concerning the Krete island, the extent of SS application has as followed (Vizantinopoulos, personal communication):

Region	**Extent of greenhouses (ha)**	**% application**
Chania	120	50
Iraklio-Rethymno	350	20
Ierapetra	1100	10

Increase of SS application in open fields is possible in Greece in vegetable cultivations such as lettuce, carrots, cabbage, eggplants. It results in high yields and application of PE can be manually or with specific machines that are already developed in Greece. In vineyards and arboriculture because of no damage to the root system the technique of high temperatures will form a new scientific approach to weed control; it harmonizes with the principles and philosophy of ecological agriculture.

Weeds sensitive to soil solarization are the annual winter weeds. Perennials like *Cyperus* spp. and *Convolvulus arvensis* and spring weeds are more tolerant. Rubin and Benjamin (1983) reported that also leguminous weeds show good tolerance to solar heating. The increased emergence of some species following solarization might be due to accelerated weathering of the seed coat by the moist heat and therefore a reduction in the seed coat-imposed dormancy. The combination of solarization with the application of bio-control agents may be a promising concept. Bio-control agents added to SS treated soil may extend the period of control (Garibaldi and Gullino, 1991).

The solarization technique is simple and easy to use by farmers but it has not been used at large scale until now because of the high cost. However, its immediate application appears to be more promising in nursery areas and in high value crops, such as vegetable growing and floriculture (Yaduraju, 1993).

Under the limitations of its applicability, SS is a safe and effective method of pest control that may reduce the necessity of chemical applications on soils. With the possible phase-out of methyl bromide due to its ozone-depleting potential, interest may increase in SS as a viable soil-disinfection alternative for medium- to high-value crops in sunny climates. In spite of negative aspects of SS, at this moment it is an additional weapon against soil disorders and if is used correctly can be beneficial in many cultivations.

Because SS is a relative new method it is preferable to analyze the soil in order to detect possible negative effects to soil, crops, flora and fauna of that area, especially in areas where SS is applied every year.

Mulching with black polyethylene showed good control of the weeds and in some cases increased yield was observed but the environmental problem of the plastic remainders (BPE and PE) are again a source of pollution, unless recycling programmes can be started. Natural remainders like cut grass and sawdust seem to be better than straw as straw can be a source of new weed seeds (volunteer weed) interfering with competition and harvesting.

4.4 BIOLOGICAL METHODS

4.4.1 Allelopathy

Allelopathy in weed science refers to any process involving secondary metabolites produced by plants (chemical interference), that influence the growth and development of neighbouring plants. Research areas include the study of the biological functions of secondary metabolites, their significance and importance in biological control of growth either individually or synergistically and their application to needs of weed science. Another possible interference mechanism is competition for light, moisture, and nutrient resources. The complicated nature of interference among plants makes it difficult to separate the two mechanisms and it is generally unknown the relative importance of competition and allelopathy as mechanisms of plant interference.

Research on allelopathic effects of different plants on weeds has been very limited. Up to now the main plant species that have shown to posses allelopathic properties are graminaceous and legumes plants. Residues of wheat, barley, rye and oat were very effective in reducing weed population in several vegetable crops (Putnam and Defrank, 1983). Rye (*Secale cereale* L.) and its residues have been shown to provide 90% suppression of a variety of agroecosystem weeds (Barnes and Putnam, 1983; Putnam, 1985). Rye reduces the ground biomass of several weeds including redroot (*Amaranthus retroflexus* L.) (Shilling *et al.*, 1985). Aqueous extracts of wheat inhibited the germination of velvetleaf (*Abutilon theophrasti*) (Steinsiek *et al.*, 1982). Dhimo *et al.* (1995) have considered possible antagonistic effects in allelopathic relations of the winter cereals *Hordeum distichum* L., and the weeds *Avena sterilis* L., *Phalaris minor* Retz. and *Sinapis arvensis* L. in field experiments. The 3 weeds had no influence on the yield of *H.*

distichum. On the contrary the growth and total biomass of the weeds were reduced significantly. According to the authors, control of the above mentioned weeds can be obtained without herbicides but with selection of genotypes with a high antagonistic effect in allelopathic relations.

Lehle *et al*. (1983) evaluated the allelopathic potential of white lupine (*Lupinus albus* L. var. Hope) with cotton, soybeans and 6 weed species (*Digitaria sanguinalis*, *Sorghum halepense*, *Xanthium pensylvanicum*, *Sida spinosa*, *Amaranthus hybridus*, *Ipomoea hederacea*). Cotton emergence was significantly reduced at all concentrations of incorporated lupine herbage with a 53% reduction at the highest concentration (i.e. 8000 ppm). *Digitaria sanguinalis* emergence on the other hand was stimulated up to 31%. (500 ppm concentration incorporated lupine). Emergence of the remaining species was unaffected by lupine incorporation, regardless of concentration rates. Lehle *et al*., mentioned that Hackworth (1973) in his research indicated that germination and growth of soybean, cotton, sorghum, *Amaranthus hybridus*, *Ipomoea hederacea*, *Digitaria sanguinalis* and *Xanthium pensylvanicum* was inhibited by incorporated white lupine (var. Hope) at rates much lower than those required in the study of Lehle *et al*.. Kalbourtzi (1989) found that root extracts of white lupine (*Lupinus albus* L.) and maize postponed the growth of *Chenopodium album* and *Amaranthus retroflexus*. The allelopathic potential of white lupine may differ between species and variations in the inhibitory potential of white lupine varies between years (Lehle *et al*., 1983). The toxicity of *Lupinus albus* and *Zea mays* to weed growth is also reported by Dzubenko and Petrenko (1971).

Experiments conducted in Greece (Ikonomou, 1995) have shown clearly reduced growth of *Chenopodium album* in vivo after applying root irrigation with wash off of *Helianthus annuus* roots. Significant reduction of the dry weight of *Triticum aestivum* was also obtained, while *Hordeum sativum* did not show significant growth reductions. Ikonomou (1995) supposed that there is a critical concentration of the extract of *H. annuus*: Where higher extract concentrations were used, higher effects on germination and growth of test plants were observed. On the other hand when the extract concentrations were lower, the germination and growth was higher. However Ikonomou did not determine exactly the required critical extract concentration of *H. annuus*. In the same study Ikonomou showed leaf extracts of *H. annuus* to have higher reductions in growth of test plants than root extracts.

About 526 cultivars of cucumber were examined for the possible production of phytotoxins that might provide control of weeds in that crop (Putnam and Duke, 1974). Under field conditions, two cucumber accessions were very effective in suppressing barnyard grass (*Echinochloa crus-galli* Beauv.) but less weed suppression occurred under heavy rainfall indicating the dilution of allelochemics (Lockerman and Putnam, 1979). Fresh and dry weights of soybean plants were reduced by diluted fresh rhizome extracts of *Sorghum halepense* used for irrigation (Lolas and Coble, 1982). Gonzalez *et al.* (1993) mentioned after conducted screening experiments that *Capsicum annuum* could have a potential activity against weed growth. The inhibitory compounds occurring in pepper plants are a group of toxic phenols inhibiting seed germination and plant growth.

Swain and Bhan (1993) found allelopathic effects of dry herbage powders of ragweed (*Parthenium hysterophorus* L.) and castor bean (*Ricinus communis* L.). The germination of the weeds chicory (*Cichorium intybus* L.) and medicago (*Medicago denticulata* L.) in pots was strongly reduced by quantities that did not or only slightly reduce the germination of wheat and chickpea. These differences in germination were more extreme in petri-dish experiments. The effects in the pot experiment were less, probably because of biodegradability of toxic substances. In most cases boiled extracts showed better effect than fresh extracts.

Hanwen (1996) in his study on the allelopathic effect of *Lolium perenne* L. on *Calystegia sepium* L. showed that exudates of germinating roots of *L. perenne* significantly inhibited the germination of *C. sepium*, comparable to the inhibitory effect on germination of lettuce. The release of allelochemicals by shoot residues in the same study showed that shoot exudates were more effective than root exudates, but it is important to mention that lettuce was more sensitive than *C. sepium*. Dead mulch (0,12 gr/cm^2) led to an significant inhibition of growth and germination of seeds of both *C. sepium* and lettuce.

Crop rotation may be combined with allelopathy when plants are used that release secondary metabolites in the soil which have phytotoxic effects on the present or on the weeds of the following crop (Paspatis, 1995). In India, native sunflower (*Helianthus annuus* L.) and 13 commercial cultivars were surveyed for allelopathic weed suppression using a sunflower-oat-sunflower rotation. Results showed that sunflower in the rotation suppressed weed populations (Leather, 1983).

Germination and growth of weed species could in some cases be affected by germination of some cover crops that demonstrated to have allelopathic effects with the grown weed species. Hoffman *et al*. (1996) used species as cover crops that are known to have allelopathic potentials. When sorghum was used, it showed 50% reduction of the weed *Setaria viridis* 2, 4 and 6 days after planting. But the weeds *Abutilon theophrasti*, *Amaranthus hybridus* and *Digitaria sanguinalis* were not affected by germination with sorghum. In the same study germinating sorghum reduced radicle length of *A. theophrasti*, *A. hybridus* and *S. viridis* but not *D. sanguinalis*. Shoot length of *A. hydridus* was also reduced. White sweetclover (*Melilotus alba* Desr. var. *annua*) used as cover crop in the same study reduced *A. theophrasti* radicle length by 23%. Reduction in radicle and shoot length may occur due to competition for nutrients and light.

4.4.2 Selective Biological Methods

4.4.2.1 Introduction

Selective biological weed control is focused on separate plant species where selectively attacking organisms are released. The method has been used successfully to control several major weeds in various countries since the mid-1800s (Charudattan, 1988). Worldwide, projects have been conducted to control many weed species using a large number of introduced or native organisms. The majority of the projects have been in Australia, Hawaii, USA, Canada, South Africa, ex-USSR, China and New Zealand. Several weeds have been or are presently under investigation as possible candidates for biological control.

There are two strategies based on this application method:

a) Inoculative application where the organisms (agents) are applied once and they multiply further by themselves. In most cases insects are used as agents but also nematodes and fungi are used for that purpose. With inoculative application is tried to control introduced weeds with attacking organisms from the same area as where the weeds come from. This method is attractive because the agents are continuously active, but they are very sensitive for disturbances occuring in the system. Their success is the best in extensive areas and especially at places where the introduction of plant species takes place in the form of monoculture.

b) Inundative application where the organism is introduced more than once and reaches densities that are not possible in nature. The way of application implies that the agents can easily reproduce and be set on the weeds. Because of that reason it is preferable to use pathogenic fungi as agents above insects (Scheepens and Kempenaar, 1994).

4.4.2.2 Use of Insects to Harm Weed Populations

The classic example of a successful biological control of a weed is the control of the cactus *Opuntia* by *Cactoblastis cactorum* in Australia. *Opuntia* species are native in America. During the 19th century they were introduced in Australia by immigrants. In 1925 about 25 million ha grassland was heavily occupied by *Opuntia* and the half of this area was completely impenetrable for man and animals (Pieterse and van Zon, 1982). The costs of mechanical or chemical control were higher than the value of the land. The march against *Opuntia* led to the insect *Cactoblastis cactorum* introduced from Argentina. Nowadays *Opuntia* as plague has practically disappeared from the land.

In 1944 in California the weed *Hypericum perforatum* had occupied about one million ha of pasture land. Control with beetles imported from Australia led to a strong reduction of the weed and ten years later was not counted any more to the harmful weeds of the area (Pieterse and van Zon, 1982).

4.4.2.3 Use of Fungi to Harm Weed Populations

The use of fungi for the control of the weeds is a more recently introduced method than the application of insects. Since the 1970s many research projects are in progress. Because native pathogens are not enough effective, it is tried to increase their effectiveness by using unnaturally high concentrations of the pathogen. Such an application can be compared with a herbicide application because of the specificity of the pathogen to the weed and because they are applied periodically. The mycoherbicide approach may be defined as the use of a plant pathogenic, endemic fungus in an inundative strategy to reduce the population density of a weed at a specific locality (Templeton *et al.*, 1979; Charudattan, 1991). The mycoherbicide approach to control weeds has received much attention in recent years both in research and practice. Low toxicity to man and absence of toxic residues, specificity on the target weed and proven method of application, are the big advantages of mycoherbicides.

On a world-wide scale three mycoherbicides are now available on a commercial basis and five on a non-commercial basis (Table 4.10).

TABLE 4.10: Pathogenic fungi that are applied as mycoherbicide (Scheepens and Kempenaar, 1994).

Pathogen (Mycoherbicide)	Weed	Culture	Country
Application on commercial basis*:			
Colletotrichum gloeosporioides (COLLEGO)	Aeschynomene virginica	arable	USA
Colletotrichum gloeosporioides (BIOMAL)	Malva pusilla	arable	Canada
Phytophthora palmivora (DEVINE)	Morrenia odorata	citrus	USA
Application on non-commercial basis:			
Acremonium diospyri	Diospyrus virginiana	pasture land	USA
Colletotrichum gloeosporioides	Clidemia hirta	forestry	USA
Colletotrichum gloeosporioides (LUBOA 2)	Cuscuta spp.	arable	China
Colletotrichum gloeosporioides	Hypericum perforatum	pasture land	Canada
Fusarium oxysporum (PRODUCT F)	Orobanche spp.	arable	ex-USSR

*see also APPENDIX IV

Some remarks to Table 4.10 are: a) DEVINE has commercially the disadvantage that the fungus stays active for many years in the soil.(Kenney, 1986). b) COLLEGO and BIOMAL are active on weeds of relatively local importance. c) Efforts are being made in USA to re-register COLLEGO in an attempt to put the product on the market by 1997 (Anonymous, 1996).

In Europe only one mycoherbicide has been registered. This mycoherbicide is developed for the control of *Prunus serotina* Erhr. in Dutch forests by the fungus *Chondrostereum purpureum* Pers. ex Fr. (De Jong *et al.*, 1990). Commercially interesting and in an advanced developing stage by companies are the fungi *Colletotrichum coccodes* against *Abutilon theophrasti* (Wymore and Watson, 1989), *Puccinia canaliculata* against *Cyperus esculentus* (Phatak *et al.*, 1983) and *Colletotrichum orbiculare* against *Xanthium spinosum* (Auld *et al.*, 1990). For these cases the effect of the pathogens has not been always satisfactory. Reasons can be the variations in sensitivity of the weed in the problem areas, or variations in environmental circumstances in space and time.

Theoretically there are many reasons for success of commercial mycoherbicides in agriculture: the constant high activity that can be reached in practise, the crops are not damaged, they can be applied in a total packet of control and growing conditions, the pathogenic fungi are relatively cheap to reproduce and the formulation is easy to make, also the price is acceptable.

4.4.2.4 Biological Control of Specific Weeds

***Orobanche* spp.**

Mycoherbicide PRODUCT F on the basis of *Fusarium oxysporum* f. sp. *orthoceras* was developed in the former Soviet Union and used especially against *Orobanche aegyptiaca* in tomato, melon and cabbage. The effectiveness of the fungus depends on the temperature and soil moisture. As best temperatures were mentioned 15-20^{0}C and at 60-80% relative humidity (Khalimov, 1970). Recent studies under controlled environmental conditions at the University of Hohenheim revealed the potential use of *F. oxysporum* f. sp. *orthoceras* to control *O. cumana* in sunflower (Mosaddegh-Manschadi, 1991) (Table 4.11). Bedi and Donchev (1991) have tested an isolate of *F. oxysporum* f. sp. *orthoceras* on *O. cumana* in Bulgaria which gave 90% control of the parasite on sunflower when incorporated in the soil before planting in the field. An isolate of the fungus *Ulocladium atrum* Preuss has also been found to be effective in infesting *O. crenata*, provided the ambient temperature was around 20^{0}C and the relative humidity between 50% and 80% (Linke *et al.*, 1992). However the field performance and practical use of these methods require more study.

TABLE 4.11: Effectiveness of the fungus *Fusarium oxysporum* f. sp. *orthoceras* against the phytoparasite *O. cumana* on sunflower (Sauerborn *et al.*, 1994).

	No. of *Orobanche* per pot[1]		
	Emerged	Underground shoots	Tubercle
Control[2]	11,3(100%)	10,9(100%)	11,4(100%)
F. oxysporum sp. *orthoceras*[3]	0,5(4,4%)	6,1(56%)	0,4(3,5%)

[1]*Evaluation was made after three months.*
[2]*Control consisted of the host sunflower and 150 mg Orobanche seeds.*
[3]*Fusarium was propagated on PDA and incorporated in the soil before planting at a rate of 5*10[8] spores.*

The only insect which selectively and effectively damages Orobanche spp. is *Phytomyza orobanchia* Kalterbach. Larvae mine in the stem and feed on seeds. It is native to the mediterranean region, the main area of *Orobanche* infestation. This insect was used for the control of *Orobanche* in the years seventy in Eastern Europe and Former Soviet Union in cabbage, sun flowers, tomato and water melons (Bronshtein, 1968; Sushchinskii, 1969;), (APPENDIX V) and in Egypt in *Vicia faba* ((Hammad *et al.*, 1967). Five hundred to thousand nymphs per ha were enough to reduce *Orobanche* for more than 90% into 3-5 years (Antonets *et al.*, 1970; Bronshtein, 1968; Kapralov, 1974). In Syria it was found to reduce the *O. crenata* by 30% under natural conditions (Linke *et al.*, 1990). A big disadvantage of *Phytomyza* as biocontrol agent is that this insect is parasitized by other insects. The proportion of parasitized fly larvae can reach 90% (Klyueva and Pamukchi, 1978). Because of this hyperparasitism on *Phytomyza* its effectiveness as an antagonist of *Orobanche* is greatly reduced. The utilization of *Phytomyza* as a biological control of *Orobanche* will only succeed if it is possible to promote *Phytomyza* directly

(Sauerborn, 1993). That means mass-rearing of the fly, free of parasites. (Sauerborn, 1993).

Chenopodium album

Ascochyta caulina (P. karst.) is a plant pathogenic fungus. Scheepens (1979) suggested that pycnidiospores of *A. caulina* could be used as a mycoherbicide to control *Chenopodium album*. Kempenaar (1995) showed that applications of *A. caulina* to the soil, young and flowering plants, can control *Chen. album* without damaging the cultivated crops.

In greenhouses, pre-emergence applications of *A. caulina* to the soil on *Chen. album* in *Beta vulgaris*, *Zea mais*, *Triticum aestivum* and *Pisum sativum* resulted in disease development on *Chen. album*. Approximately 10^9 to 10^{10} spores/m^2 were required for 50% mortality of emerged *Chen. album*. The plants that survived infection were considerably retarded in growth and less competitive than healthy plants. Increase of the soil moisture content from 15% to 18% had positive effect on disease incidence. The proportion of seeds that emerged was not influenced by soil moisture content, soil type or spore density. Sandy soils gave better results than clay and commercial types of peat (sand > clay > peat). Disease incidence and mortality were not or hardly influenced by spore application method and sowing depth. Spores maintained their effectivity in the soil for a period of at least two weeks but after almost 20 days the maximum results were visible. Here it should be mentioned that effectiveness of application of *A. caulina* to the soil seemed to depend little on environmental conditions, but soil treatment has yet to be proved under field conditions.

Field applications of *A. caulina* on *Chen. album* in maize and sugar beet crops resulted in necrosis of *Chen. album* plants. One week after application appeared the first necrotic symptoms. In the second and third week some plants died. The maximum mortality was reached three weeks after application of the mycoherbicide. *Chen. album* plants that survived infection had a reduced size. In maize, but not in sugar beet, yield reduction by competition

of *Chen. album* was already prevented at incomplete levels of control. This indicated that incomplete levels of control of *Chen. album* can be accepted more easily in a tall crop.
Field applications of *A. caulina* to flowering *Chen. album* plants in maize and sugar beet showed flower-necrosis. A disadvantage was that high levels of control could only be achieved when the environmental conditions were favourable for infection, i.e. high relative humidity and rain showers. About 3 weeks after spore application and 85% relative humidity complete necrosis of flowers and mortality of all plants was observed. Effectiveness was also dependent on the growth stage of *Chen. album*. Application early in the season showed better results.

Ease of control considers biological, technical and economical aspects such as production of the mycoherbicide, application technology, ability to use the mycoherbicide over a broad range of conditions, and compatibility of the mycoherbicide with other cultural measurements (Kempenaar, 1995). Spraying of *Chen. album* with a suspension of pycnidiospores of *A. caulina* and a non-lethal dosage of a herbicide can result in additive and synergistic effects (Kempenaar, unpublished data). But no satisfactory levels of control of *Chen. album* can be mentioned. They are considered to result from an additional stress of *A. caulina* by the herbicide (Scheepens, 1987; Sharon *et al.*, 1992).

Fungicides can reduce effectiveness of mycoherbicides According Kempenaar (1995) fungicides must be applied after the control of *Chen. album* has been achieved. *A. caulina* must be applied early in the growth season. When applied later in the season, as the control of flowering plants, the effectiveness may be hampered by fungicide treatments.

Susceptible crops known so far are *Spinacia oleracea* f.sp. Martine and *Chenopodium quinoa*. Not all spinach varieties are susceptible to *A. caulina*. Kempenaar (1995) tested "Martine" and "Amsterdams Reuzeblad". In Table 4.12 is showed the susceptibility of various plants and their cultivars.

The risk of dispersal to another field after application of *A. caulina* is not expected to be large (Kempenaar, 1995). The risk of persistence in soil cannot be assessed yet because data on survival of the fungus in the soil are not available. Resistance development has not yet been reported. However, a lesson from the past is that every weed problem strategy creates its own new weed problems, and thus the risk of resistance development should not be underestimated (Kempenaar, 1995).

Kempenaar (1995) after extended research has concluded that there is promise in the use of *A. caulina* as a mycoherbicide against *Chen. album*. Application of *A. caulina* to the soil and the young plants seems to fit in current weed problem strategies in arable and vegetable crops. At the moment mycoherbicide for the control of *Chen. album* is in an advanced stage of development by the company Giba-Geigy Agro.

TABLE 4.12: Average proportion of necrotic leaf area of juvenile plants of various plant taxons, assessed one week after application of *Ascochyta caulina* spores. Standard errors are in parentheses (Kempenaar, 1995).

plant taxon[1]	Cultivar	Severity of leaf necrosis
Chenopodium album		0,30 (0,11)
Chen. ficifolium		0,35 (0,12)
Chen. quinoa	Elsevier	0,24 (0,10)
	Wilde type	0,06 (0,05)
Chen. glaucum		0,11 (0,11)
Chen. polyspermum		0,02 (0,02)[2]
Chen. rubrum		0[2]
Atriplex prostrata		0,35 (0,12)
A. patula		0,27 (0,11)
Spinacia oleracea	Martine	0,02 (0,02)
	Amsterdams reuzeblad	0
Beta vulgaris		
(ssp. *vulgaris*)	Carla	0
	Lucy	0
	Univers	0
	Kyros	0
	Egyptishe platte ronde	0
Corispernum		
marschallii	Brazil	0
Zea mays	Mandigo	0
Pisum sativum	Eminent	0
Triticum aestivum	Arminda	0
Brassica oleacerea		
ssp. *capitata*	Bartolo	0

[1]The first 17 taxons are from genera of the plant family of Chenopodiaceae.
[2]Chlorosis on leaves.

***Convolvulus arvensis* L.**

A variety of organisms (mainly insects and fungal pathogens) parasitizing on leaves, stems, roots or seeds seem to be promising candidates for bio-control agents and provide a good outlook for success in controlling *Convolvulus arvensis* L.. So far attempts of biological control of the weed have been very limited and confined to the use of insects only (Giannopolitis and Chrysayi, 1986). Species of arthropods which have been suggested as possible candidate-agents for bio-control are summarized in Table 4.13. Host specificity and control potential are the basic requirements for a species to be regarded as a promising bio-control agent.

TABLE 4.13: Arthropods suggested as promising agents for bio-control of *Conv. arvensis*.

Parasitized organ	Parasitizing species
Leaves	*Aceria malherbae* Nuzzaci (Acarina: Eriophyidae). Source: Italy, Greece.
	Bedellia somnulentella Zell.[1] (Lepidoptera: Lyonetiidae). Source: Egypt.
	Cassida indicola Duvivier (Coleoptera: Chrysomelidae). Source: India.
	Chelimorpha cassidae F. (Coleoptera: Chrysomelidae). Source: Long Island (USA).
	Galeruca rufa Germar[2] (Coleoptera: Chrysomelidae). Source: Southern Italy, France.
	Onebala lambrostoma Zell.[3] Source: Pakistan.
	Tyta luctuosa Schiff. (Lepidoptera: Noctuidae). Source: Italy.
Flowers-seeds	*Alcidodes fabricii* F.[4] (Coleoptera: Curculionidae). Source: Pakistan.
	Alcidodes chaudoiri Cherv. (Coleoptera: Curculionidae). Source: Samarkand, Leninabad (USSR).
	Eublemma baccalix Swinh.[4] (Lepidoptera: Noctuidae). Source: Pakistan.
	Spermophagus sericeus Geoffroy (Coleoptera: Bruchidae). Source: Iraq, Italy, Portugal, Spain, USA.
Stems-roots	*Melanagromyza convolvuli* Spencer[3] (Diptera: Agromyzidae). Source: Pakistan.
	Metriona tuberculate F.[5] (Coleoptera: Chrysomelidae). Source: North Of Mexico (USA).
	Noctuelia floralis Hb. (Lepidoptera: Pyralidae). Source: Pakistan.
	Sharpia bella Faust[3] Source: Pakistan.

[1]Minor pest of sweet potato. In Egypt was considered to be an important bio-control agent (research was carried in 1976). In California showed to be not suitable as bio-agent (research was carried in 1984).
[2]Feeds only on species in the genera *Convolvulus* and *Calystegia*, well synchronised with its food-plant.
[3]Not either polyphagous or injurious to the closely related and economically important plant genus *Ipomoea* (sweet potato, ornamental morning glories).
[4]Seed and flower feeders are unlikely to harm sweet potatoes which is vegetatively propagated.
[5]Pest of sweet potato and bindweed (*Conv. arvensis*).

A form of classical biological control was attempted in Canada (Julien, 1982). Three Chrysomelidae, viz. *Chelymorpha cassidea* (F.). *Chirida guttata* (Olivier) and *Metriona purpurata* (Boheman), which are native in Saskatchewan were released in Alberta in an attempt to enlarge their range. The insects finally did not establish in Alberta. A form of inundative biological control was successfully tried in Long Island, USA (Selleck, 1979). The easily reared Argus tortoise Beetle (*Chelymorpha cassidea*) naturally feeding on *Calystegia sepium* was transferred in fields heavily infested with *Conv. arvensis*. Control of the weed was excellent.

Rosenthal and Buckingham (1982) conducted extensive surveys in western Mediterranean Europe and collected 139 species of phytophagous arthropods feeding on *Conv. arvensis* and its close relatives *Calystegia sepium*, *Conv. althaeoides* and some *Ipomoea* spp.. Of these species, 71% are external leaf feeders, 4% are leaf miners, 17% feed on flowers, seeds or seed capsules and 8% feed on or in stems and roots. Most species have been eliminated from consideration as biological control agents because they are polyphagous, pests or able to complete their development on sweet potato. Noteworthy was the search for natural enemies of *Conv. arvensis* that has been conducted in Pakistan in the past years. Due to lack of money research for natural enemies of *Conv. arvensis* is stopped at the moment in Pakistan (Ashraf, Institute of Biological Control, Rawalpindi, Pakistan, personal communication).

Aceria malherbae was imported from Greece to the USA and released in 1989 in Texas, as a potential biological control agent for *Conv. arvensis*. Two years later 76% of the crowns were infested and the mites had moved 9,6 m from the plot. Mites overwintered on rhizomes 0,1-6,0 cm beneath the soil surface (Bold and Sobhian, 1993). This represents the first successful establishment of an introduced arthropod for biological control of a crop weed in the USA. The mite is now being released on field bindweed in more places in the USA (Bold and Sobhian, 1993). The suitability of *Aceria malherbae* in South Africa is also studied and a permission for the release of this arthropod is granted since 1994 (Craemer, 1995).

Chrysomelids could not be considered as promising biological control agents for the weed in areas where sweet potato and other *Ipomoea* spp. are of economic importance. However where damage to these plants is not as important as control of the weed, the beetles could be of great value in suppressing the weed. The fact that *Chelymorpha cassidea* feeds only on plants of Convolvulaceae makes it a potential candidate for the control of *Convolvulus* spp. and morning glory (*Ipomoea* spp.) in areas and crops where insecticides are not used during periods of larval and adult feeding. In crops like rye, zucchini (*Cucurbita pepo*), maize, grapes, pine, yew, Euonymus and Ajuga, when there is infestation with *Conv. arvensis*, biological control can be realized with insects that feed also on sweet potatoes. *Tyta luctuosa* limits its possibilities to be used as a biological control agent because of larval predation by *Solenopsis invicta*.

The status of the use of fungal pathogens in the biological control of *Conv. arvensis* is quite behind, although several fungal pathogens have been described since long ago. Main difficulty is considered to isolate fungus agents which do not attack the sweet potato. Fungi that have been reported as pathogens of *Conv. arvensis* are classified according to the type of disease that they cause and given in Table 4.14. Of the above fungi only *Erysiphe convolvuli*, *Pucinia convolvuli* and *Septoria convolvuli* have been reported as pathogens of *C. arvensis* in Greece (Pantidou, 1973). The first two have also been found on *Calystegia sepium* and the third on *Calystegia silvatica* Chois (Pantidou, 1973). All pathogens in Table 4.15 seem to have good host-specificity, as none of them has so far been reported on sweet potato, the most important crop of the Convolvulaceae family (Giannopolitis and Chrysayi, 1986). Nevertheless, host-specificity should be carefully checked before any of these pathogens is used for control of the weed.

TABLE 4.14: Fungal pathogens reported on *Conv. arvensis* (Giannopolitis and Chrysayi, 1986)

Disease	Pathogen
Leaf spotting	*Ascochyta convolvuli* Fautr.
	Cladosporium sphaerospermum Penzig
	Phyllosticta calystegiae Sacc.
	Septoria calystegiae West.
	Septoria convolvuli Desm.
	Septoria convolvulina Speg.
	Septoria longispora Bondarzew
	Septoria septulata Beach
	Septoria obesispora Oud.
	Sphaerella adusta Niessl.
	Stagonospora calystegiae (West.) Grove
Powdery mildew	*Erysiphe communis* Duby
	Erysiphe convolvuli Lev.
	Erysiphe polygoni DC.
	Oidium erysiphoides Fr.
Rust	*Puccinia convolvuli* (Pers.) Cast.
Smut	*Ustilago capsularum* Fr.

In Greece priority has been given to the study of leaf spot fungi as most promising bio-control agents, for the following reasons (Giannopolitis and Chrysayi, 1986): a) They infect *Conv. arvensis* at a more critical growth stage. b) They grow and sporulate *in vitro*, while the powdery mildew fungi, as obligate parasites, do not. c) They can be more efficiently manipulated as inundative bio-control agents.

Giannopolitis and Chrysayi (1989) demonstrated sufficient pathogenicity and host specificity to be regarded as promising bio-control agents with two species of the genus *Septoria* Sacc. and one of the form-genus *Phoma* sacc. isolated from naturally infected *Conv. arvensis* L. in Greece. One inoculation was applied to *Conv. arvensis* seedlings of two growth stages (2-3 leaves and

25-30 cm high) under growth chamber conditions and to *Conv. arvensis* stands growing naturally in sprinkle-irrigated maize in humid and hot conditions. Inoculum was also applied in sprinkle-irrigated potatoes under humid and warm conditions, and in an infested vineyard that was not irrigated and the conditions were extremely dry and hot. Inoculation that took place at about the beginning of flowering, resulted to establishment of all three pathogens. The two *Septoria* species caused large necrotic lesions on leaves and severe (60-90%) defoliation of plants on artificially inoculated *Conv. arvensis*. The *Phoma* species caused a rapid necrosis of the shoot apices (Table 4.15). In the preliminary field experiments, pathogen establishment and disease development was achieved in the moist conditions of irrigated maize and potatoes, but not in the dry conditions of a vineyard.

TABLE 4.15: Disease development following artificial inoculation of *Conv. arvensis* seedlings with conidial suspensions of three fungi (Giannopolitis and Chrysayi, 1989).

Fungal isolate	Disease severity (0-4)* Days after inoculation 2	6	13
Sept1	0	1	4
Sept2	0	1	4
Phoma	1	2	2

**0: 1-5% severity, 1: 6-25%, 2: 26-50%, 3: 51-75%, 4: 76-100%.*

Of twelve plant species examined, only two close relatives of *Conv. arvensis*, the two weeds *Conv. althaeoides* L. and *Calystegia sepium* demonstrated mild susceptibility to these fungi but suffered not from damage (Table 4.16). Two other species of the Convolvulaceae family, *Ipomoea purpurea* and *Dichondra mircrantha* were not infected by any of the three fungi. The same was observed with one weed species (*Bilderdykia convolvulus*) and seven plant species of various families.

TABLE 4.16: Host specificity of the three fungi. Disease severity was scored 14 days after inoculation (Giannopolitis and Chrysayi, 1989).

Plant species	Disease severity (0-4)*		
	Sept1	Sept2	Phoma
Conv. arvensis L.	4	3	4
Conv. althaeoides L.	1	1	2
Calystegia sepium (L.) R.Br.	1	1	2
Ipomoea purpurea Roth	0	0	0
Dichondra micrantha Urban	0	0	0
Bilderdykia convolvulus (L.) Dumort	0	0	0
Apium graveolens L. ("Apio Lieno Blanco No.11")	0	0	0
Phaseolus vulgaris L. ("Pyrgetos")	0	0	0
Pisum sativum L. ("Kephalinia")	0	0	0
Lycopersicon esculentum Miller ("Earlypak No. 7")	0	0	0
Triticum turgitum durum L. ("Mexicali 81")	0	0	0
Triticum aestivum L. ("Generoso E")	0	0	0

**0: 1-5% severity, 1: 6-25%, 2: 26-50%, 3: 51-75%, 4: 76-100%.*

Other fungi that have been indentified as bio-agents for *Conv. arvensis* are *Phomopsis convolvulus* and *Phoma proboscis*. *P. convolvulus* is found to cause leaf spots and anthracnose lesions on *Conv. arvensis* in Quebec (Ormeno-Nunez *et al.*, 1988). Seedlings were killed after spray inoculation with 109 conidia/m^2 of the fungus. In controlled environments excellent control of the weed (95% reduction in foliage biomass and up to 55% mortality) was achieved when a continuous of minimum 18 h of dew was given. A high relative humidity (95 to 100%) during the humid periods favoured infection compared to lower relative humidity (80 to 85%). Pycnidia and conidia were produced on diseased plants indicating that sub-optimal moisture conditions represent a possible constraint that may reduce the weed control efficacy of *P. convolvulus* on *Conv. arvensis* (Morin *et al.*, 1990).

Controlled environmental studies have been conducted to elucidate some of the conditions for optimum disease development of *Phoma proboscis* on *Conv. arvensis*. High levels of disease occurred on plants that received at least 12 h of dew (spore concentration 107 spores/ml) and tested at different temperatures. Fresh weight reduction in shoots and roots correlated well with disease ratings (Heiny and Templeton, 1991).

4.4.3 Non-Selective Biological Methods

Non-selective methods focus on control of complete vegetations (Wapshere *et al.*, 1989). The use of taller plants with big and spreaded leaves to compete weeds, ground-cover plants and grazing by animals are some strategies of this category.

In ecological management of olive groves the soil can be protected by cover crops. They have a multi-functional role and contribute substantially to a rational and effective ecological management (Kabourakis, 1996). In olive groves the functions of the cover crops are the prevention and suppression management of harmful plant species ("weeds") through competition (Kabourakis, 1996). Other benefits are: fertilisation of the soil and the nutrition of the olive trees, better absorption of rainfall and water conservation, offering shelter and food to beneficial insects and parasites of the olive enemies, improvement of the soil structure and prevention of soil erosion (Kabourakis, 1996). According to Kabourakis (1996), the cover crops technique in olive groves can be carried out in a frame of five-year crop rotation plan which will include legume and graminae plants. The selection of species for the crop rotation must be based on the soil type, the climatic conditions of the area and the nitrogen requirements. Species and local varieties used in the traditional agriculture of an area are valuable as these are perfectly adapted to the regional agroclimatic conditions (Kabourakis, 1996).

Protopapadakis and Giannitsaros (1992) used the legume *Medicago polymorpha* L. in citrus orchards and found that it established well and supressed spring weeds. *Medicago* covered the soil from December to April. In this period there is no competition for water (period of rainfall). Extra effects that the researchers mentioned were the positive influence on the soil structure, the water filtration and storage, binding of N_2, reduction of the nutritious elements, higher yields, weed control without disturbance of the eco-system. Giannopolitis (1992) mentioned that dense-small vegetation with weak competitive abilities in the orchards and grapes and strong allelopathic action against the weeds must be the main characteristics of the cover crops.

Oxalis cernua is the most common winter vegetation in Citrus orchards in Crete. It forms a plant carpet which has sufficient advantages for the citriculture (reduce "water spot" without nutritive competition). Maintaining *Oxalis* in the citrus orchards showed a higher percentage of juice and did not show qualitative differences with other non-tilled treatments (plastic covers) (Protopapadakis, 1989).

Oxalis pes-caprae grows abundantly on a wide range of soil types. It is a species very often found in vineyards, citrus orchards and olive groves. In case of olive groves *Oxalis* impedes the hand-picking of olives from the ground. Also its leaves and stems, which are picked together with olives, increase the acidity of the olive oil. Moreover many cases of animal poisoning have been reported, especially of sheep fed on *Oxalis*.

Oxalis pes-caprae can not be considered as a serious weed problem in vineyards in Greece, although it can utilize the fertilizers applied in the winter (Paspatis, 1987). On the other hand because it germinates in the winter it can protect the soil from erosion (vegetative reproduction with tubers) and cover the soil in a level that no other weeds can germinate (soft weed) (Giannopolitis, personal communication).

Orobanche spp. has been found parasitizing on *O. pes-caprae*; so the possibility to use *Orobanche* in order to control *Oxalis* had been considered. Experiments were carried out for that purpose but the risk that broomrape may infest sensitive crops and cause unpredictable damages formed the potential disadvantage to leave the efforts of using *Orobanche* spp. to control *Oxalis* (Giannopolitis, personal communication).

Brassica green manure crops have shown potential for controlling several common potato pests including weeds. Research was done (Boydston and Hang, 1995) to evaluate weed suppression in potato following fall-planted green manure crop of rapeseed

(*Brassica napus*) during a two-year study. Rapeseeds were sown in March 1992 and 1993 on a loamy sand soil, in Washington. Rapeseeds were just beginning to flower when incorporated. Rapeseed reduced weed density 85 and 73% in 1992 (dominant weed: *Chenopodium album*, other weeds: *Amaranthus retroflexus*, annual grasses) and 1993 (dominant weed: *Amaranthus retroflexus*) respectively and reduced weed biomass 96 and 50% in 1992 and 1993 respectively, in following potato crops compared to potato after fallow (Table 4.17). Potato following rapeseed yielded 17% more total tuber weight than potato following fallow in 1993. The amount of tubers grading was similar between potato following rapeseed or fallow.

TABLE 4.17: Total mid-season weed density above the potato and final weed biomass in potato following fallow, rapeseed in 1992 and 1993 near Prosser, Washington[a] (Boydston and Hang, 1995).

	1992				1993			
	Weed density		Weed biomass		Weed density		Weed biomass	
Green manure treatment	No herbicide	Herbicide treated[b]	No herbicide	Herbicide treated	No herbicide	Herbicide treated	No herbicide	Herbicide treated
	no./100m^2		g/m^2		no./100m^2		g/m^2	
None (fallow)	61a	1a	386a	0a	62a	0a	529a	1a
Rapeseed	9b	0a	14b	0a	17b	0a	263b	0a

[a]Data averaged across methods of incorporation. Means within a column followed by the same letter are not different at P=0.05 according to LSD test.
[b]Herbicide treated received pendimethalin and metribuzin at 1 and 0.5 kg/ha, respectively.

Grazing of sheep is a method used quite often to control weeds in perennial strawberry cultures in Northern Greece. Sheep enter the fields just after the last picking of berries (late in spring). Selective grazing of the existing weeds (sheep do not touch strawberry plants) prevents the production of weed seeds, thus reduces the chances of a weed build-up (Giannopolitis, 1987). Furthermore, coupling the system with a proper crop rotation (not replanting strawberries in the same field), also improves consistency in weed control. Dessilas (1993) mentioned that grazing of weeds by sheep in olive groves has also some additional advantages like recycling of manure and utilization of animal food. An other example comes from cotton cultures where grazing by geese can also be combined with meat production (Paspatis, 1995).

Nuoffer (1993) concluded after 3 years of research that the selective grazing of goats can reduce weeds in herbicide-free farming systems. In his experiments with field beans, potatoes, summerwheat and rye he showed that field beans and potatoes were not fed on by goats (because of the amount of secondary plant contents), as long as the goats had as feeding source the present weeds. The grazing behaviour of the goats was basically dependent on the availability and palatability of the feeding plants. Summer wheat and rye were always grazed by goats, but could tolerate and compensate the injury or yield depression when grassed in early stages of growth. Interesting was also the observation that *Cirsium arvense* was better controlled by lactating goats when grazing on potato and oat fields.

4.4.4 Discussion

Agroecosystems differ widely in climatic, edaphic, biotic and cultural characteristics. Such variations affect the biological interactions between crops, weeds and the connected microbial and insect populations. Moreover, with human activities aimed at maximizing economic returns, agroecosystems undergo constant changes in dynamics of weeds and crops. These changes affect the choice of which pathogens and insects can be used as weed control agents, and also partially explain why biological control only in few cases has led to a permanent solution of the weed problem.

Host-specificity and efficacy are the two primary concerns affecting decisions on the choice of pathogens as bio-control agents. Before a pathogen can be given serious consideration as a candidate, it must be determined to be safe in its host range and it must be capable of providing a satisfactory level of weed control (Charudattan, 1988). The control should be rapid depending on the weed and crop situation. It should be easy to use. This is not only in regard to application tools and techniques but also in the ability to use the agent over a fairly broad range of environmental conditions. For example, a mycoherbicide agent that has very stringent requirements for infection and disease development is likely to fail sooner than one that is less stringent. Likewise a mycoherbicide that needs special tools and radical shifts from the existing agronomic and pest control practices is less likely to be accepted than one that can be integrated with existing equipment and practices. Any additional cost, due to unusual tools or added steps in management practices, may discourage mycoherbicide use.

It is noteworthy that the two registered mycoherbicides, COLLEGO and DEVINE, provide high levels of control, act speedily and are easy to use (Charudattan 1985, TeBeest and Templeton, 1985). These two mycoherbicides provide typically ≥85% control of their respective weed targets. Usually control is obtained within 4 to 6 weeks, and both can easily be applied with conventional equipment. Although both are sensitive to certain fungicides and other pesticides, it is possible to integrate their use with ongoing pest management schedules (Smith, 1986). It is therefore noteworthy that COLLEGO and DEVINE satisfy the three aspects, viz. amount, speed, and ease, and their success may have been due to these facts.

Because mycoherbicides are comparable to chemical herbicides in their application and weed control methodologies, it may be that the public expectation of mycoherbicide efficacy is already conditioned by the experience with herbicides. Herbicides are already known for their cost-efficiency, effectiveness, ease of application, speed of control, and predictability of results. A demand for a comparable type of efficacy for mycoherbicides would mean that only a limited number of pathogens can be capable of providing weed kill. As the public becomes more educated about mycoherbicides, weed control objectives may change from complete weed kill to weed suppression.

Greenhouse studies have limitations. Greenhouse-grown weeds tend to be more susceptible and therefore may overestimate pathogenicity (Charudattan, 1988). Only field performance under appropriate conditions should be taken as the final determination of efficacy of mycoherbicides. Weed and crop phenologies are also important factors. Crop phenology effects the periods of suitable time available for weed control. The suitable time for infection and weed control must coincide with proper growth stages of the crop. For example, if crop growth and cultural practices are not suitable for aerial or tractor-based spraying of mycoherbicides, other application methods or alternative weed control methods may be necessary.

Due to the extensive and deep rooting system of *Conv. arvensis*, management of the weed is very difficult and costly. Biological control methods, if developed, could therefore contribute to more efficient and economical management systems applicable to large acreage. A weak point in attempting biological control of the weed is that most organisms do not utilize roots of *Conv. arvensis* as a food source (Rosenthal and Buckingham, 1982). The weed reproduces by sending up new shoots from a deep and extensive underground root system consisting of a tap root (0,5-3 m deep) and many cordlike and fleshy rhizomes permeate soil in all directions.

Rosenthal *et al.* (1983) concluded that it will not be easy to find adequately host-specific biological control agents that may be used against *Conv. arvensis* in California or any other area of North America. They were led to this conclusion from the fact that some American sweet potato varieties and native North American morning glories are susceptible to be attacked by organisms associated with *Conv. arvensis*.

Control of *Conv. arvensis* in Greece in crops like vegetables is at present very difficult due to lack of selective herbicides with satisfactory effectiveness against the weed (Giannopolitis and Chrysayi, 1986). Vegetable growers are thus obliged to fallow infested fields, in order to be able to use non-selective herbicides, as well as other cultural methods (rotation with field crops) with considerable loss of income in areas of intensive vegetable growing. It seems, therefore, that any effort towards biological control of *Conv. arvensis* in such crops is justified.

In vegetable cropping systems particularly in Europe, the place of origin of *Conv. arvensis*, inundative biological control looks more rational than classical biological control (Giannopolitis and Chrysayi, 1986). Plant pathogens, whose manipulation as bio-control agents is usually easier than that of insects, should then be given more consideration than they have received up to now.

The results from the research conducted by Giannopolitis and Chrysayi (1989) indicate that the leaf spot fungi *Septoria* and *Phoma* may have a potential as mycoherbicides and merit further investigation. More field experiments must be conducted. Precise determination of the required environmental conditions should precede. Research must be continued to reduce duration of dew period requirement for the fungi that have potential to be used as bioherbicides. In Greece further research for establishment of the agents that are mentioned on the Tables 4.13 and 4.14 must be carried out.

Mycoherbicides generally have a requirement for dew or high humidity for satisfactory results. COLLEGO and DEVINE are both used in irrigated agriculture and this is also part of the reason for their success. BIOMAL is used in situations where rainfall events are likely and can be confidently predicted in the mid-west wheat growing region of Canada. A moisture requirement has hampered the development of several potential mycoherbicides in dry land agriculture in temperate regions.

From the research conducted in The Netherlands by Kempenaar (1995) it is concluded that application of *A. caulina* spores to *Chen. album* in some crops can have a large impact on the development of the weed. The amount of necrosis that could be induced largely depended on the length of duration of wetness after treatment. When *A. caulina* is considered for use as a postemergence mycoherbicide as presented, it is obvious that the results will depend on weather conditions (Kempenaar *et al.*, 1996). To improve efficacy under less optimal conditions, formulation, strain selection, repeated application, and mixed application with an other stress factor may be considered (Kempenaar, 1995).

Chen. album is a spring weed that in Greece emerges from April to May. This period of the year is not suitable for infestation with *A. caulina*. During the April's nights the plants are practically wet. Applications at nightfall should be the most appropriate. In May the humidity is decreasing and the chances for success are less. Thus, a great deal of research effort must be placed on the development of formulations to overcome this dew requirement.

A lot of *Ascochyta* species have been found in Greece but not *A. caulina* and also no other Ascochytas that attack *Chenopodium* species (Laskaris, Benakion Phytopathological Institute, personal communication). Inundative applications are needed and introduction of a new fungus may present a lot of dangers for attaching crops.

An other barrier for biological control by insects or fungi is that some weeds are closely related to crops, so that a biocontrol agent would have to be highly host specific to avoid damage to the crop. An example already mentioned is that of morning glories and field bindweed that are closely related to sweet potato.

Summarizing we conclude that the major factors in successful biological control is the introduction of a good enemy agent which should possess the following qualities (Bhan and Singh, 1993):

1. Host specificity
2. Ability to kill the weed or prevent its reproduction.
3. Good adaptation to the weed host and the environmental conditions in which weed is infesting.

Research efforts to control weeds with the method of allelopathy have been limited up to now and they do not go further than the laboratory or the experimental field area. Efforts should be concentrated to limited plant species with allelopathic potentials and continuous research must lead the feasibility studies onto practical approaches. The method still sounds promising but it is still far from introduction in practice.

When cover crops, known to have allelopathic potentials, are used to suppress weeds the soil fertility must be managed during the growth period. Competition for nutrients is a common interference mechanism that must not be eliminated as a possible source of weed suppression. Biomass reduction should occur due to both competition and allelopathic effects.

In the agricultural production sector of Greece, the use of higher plants to control weeds is less applied because of competition with crops. Cover plants in winter months reduce heat radiation from the soil increasing the chances of cold damage as well as creating a fire hazard after frost (Protopapadakis, 1989). Keeping *Oxalis* in winter and maintaining the ground in a clean cultivated state during the remainder of the year is a good alternative for non-frost areas. In intercropping systems must be taken care for competition with the crop especially in dry zones where the soil moisture is the limit factor (Dessilas, 1993).

Selective grazing by goats, sheep and geese can be used to reduce weeds in eco-farming. But this needs precisely worked-out instructions to have few or no damages by grazing and mechanical damage by treating the crop plants. This is difficult especially when culture and weed plants are close together in the scale of preference, and the available amount of weeds is small. A difficulty is that a shepherd is needed or a fence is required to isolate the field from the other fields where grazing is not allowed.

It is essential to concentrate effort and resources of biological control onto a limited number of projects where there is real potential for success. Further it is important to examine the weaknesses of biological control and to look at ways in which these weaknesses can be overcome. Projects based on the feasibility of practical approaches to solve the weaknesses will book the best results.

Biological methods must provide a satisfactorily high level of weed control. However, proper educational efforts and considering the fact that even herbicides do not always provide complete control, the public may be convinced to accept less than complete or total weed kill.

Theoretically speaking, biological control is the most attractive way for the control of weeds. This technique is save to the environment. When a balance is reached between weed and the biological control mechanism the effect is often lasting and the costs are low. Biological agents may provide more economical control of some weeds and control others that are difficult to manage by conventional methods. However the practice is not so simple due to the requirement of specificity of the agent to the weed species.

Limiting factors are also the long list of procedures for developing a bioherbicide, requiring extensive investments and multidisciplinary efforts. Labour-intensive and costly methods of inoculum production may be impractical from a commercial prospective specially in developing countries.

5 GENERAL DISCUSSION

The particularity of Greek agriculture is related to the big variety of crops, weeds, and cultural practices. This makes the weed problems in Greece exceptionally complicated. For a successful weed control it is necessary to use adapted methods and practices, needing for further development continuous and detailed improvements under the Greek conditions.

Research currently conducted in Greece related to non-chemical control is mostly emphasizing soil solarization, the use of indigenous fungi for biological weed control and the study of the allelopathic potential of plant species.

The major questions "where do we go" and "what can we do" must keep growers and researchers continuously awake. The growers must be assured of the sustainability of their growing conditions. A strategic plan supported by the government should be agreed on to remove the gaps in the knowledge, by a) organizing seminars and courses for the growers, b) promoting weed research and c) study and analysis of the weed problems of every region and crop separately.

Next to proper educational efforts starting from the knowledge of the weed flora and the weed habits, also is needed being aware of the fact that even herbicides do not always provide complete control and that the effectiveness of the non-chemical methods is often mild too. The growers should perhaps be convinced that complete or total weed kill is not always required.

Because mycoherbicides are comparable to herbicides in their application and weed control methodologies, it may be that the public expectation of mycoherbicide efficacy is already conditioned by the experience with herbicides. Herbicides are already known for their cost-efficiency, effectiveness, ease of application, speed of control, and predictability of results. A demand for a comparable type of efficacy for mycoherbicides would mean that only a limited number of pathogens can be capable of providing weed control. As the public becomes more educated about mycoherbicides weed control objectives may change from complete weed kill to weed suppression.

Laboratory research does not directly lead to practice ready applications and controlled environmental studies only do not allow to make further conclusions. Research results cannot always straight away be into governmental policy. The conclusions coming from conducted research must be analyzed as to their applicability in the field and the inclusion in official recommendations. It is essential to concentrate efforts and resources onto a limited number of projects in areas having a real potential for success. Investments on extensive research for bioherbicides and cooperation with other countries where recently biological methods have been more studied are two important keys of progress.

Research efforts to control weeds with the method of allelopathy have been limited up to now and they do not go further than the laboratory or the experimental field area. Efforts should be concentrated on a limited number of plant species having allelopathic potentials. Continuous research should lead feasibility studies to practical approaches. The method is still far removed from introduction into practice.

Every region and crop must be studied separately. Estimating the level in reduction of the potential yield, the size of the weed-damage and the costs of weed control, a weed control plan for the region/crop must help the growers. A weed problem should be analyzed for the whole cultivation program. Such a program must consider the analysis of the weed problems at a specific field/area on the farm - holding as a whole, in relation to the other farms in the area, in relation to the future of yield in production and considering the potential commercial traffic. It is important to address the field and research weed problems based on an ecological thinking, before any major decisions are enforced during the development/application of the plan.

The best step in a herbicide-free farming system could be an Integrated Weed Management* (IWM). This is not easy as sometimes many different weed control methods must be combined in order to achieve good weed control. IWM has been more applied in strawberries than in any other crop in Greece. IWM is currently practised by a number of growers. We saw already the application of black plastic soil covers in strawberries providing long term weed control and in citrus improving the yield. The use of bioherbicides could be also included in IWM schedules. Local conditions may make the use of certain techniques impossible. For example sloping and impassable cultivated terrains often make mechanical weed control almost impossible or in fruit orchards where damaging the soil texture can endanger the crop root system or reduce the organic matter content of the soil. Soil erosion in sloping areas could be an other barrier for mechanical control. Row-grown crops seem to offer more possibilities for mechanical control.

In an IWM system precisely worked-out instructions to avoid crop damages are required for example when weeds are controlled by grazing with goats. Other important point in IWM is that the growers are able to make good economic analysis.

For the Mediterranean region, from the preventive measures mentioned in this report special conclusion cannot be made yet. In intensive cultivations using of clean seed for sowing is already achieved.

The most promising new method of weed control that should be stimulated more in Greece is soil solarization. It could be an alternative solution to the possible phase-out of methyl bromide. In Greece during the summer period climatic conditions

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Integrated Weed Management is used to mean any combination of methods of weed control in order to minimize the negative effects of weeds on the crops and to come to the most ecologically acceptable method of weed control.

appear to be favourable for this method and the certain requirements such as irrigation water and land are met too. Under Greek conditions the required lethal temperature*time is achieved in greenhouses and outdoor. In vineyards and arboriculture SS can be applied without damaging the root system.

Thinking that vegetable cultivations in plastic tunnels is an important agricultural business and that many greenhouses are empty during the hottest period of the year, SS could be a good mild weed control method. The most serious disadvantage we see in outdoor conditions is that one third of the land is leased. To practice SS the land should be free of crops for about two months. The method then becomes too expensive and does not enable the farmers to practice SS without to sacrifice their land/crop.

Governmental efforts should be directed towards the disposal of plastic films by educational anti-litter programmes and investments on plastic recycling centres.

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APPENDIX I

LATIN NAME, PROPOSED GREEK COMMON NAME AND COMMON NAME IN ENGLISH (U.S.A.) FOR WEEDS OF GREECE. LETTERS E, Δ, AND Π INDICATE THAT THE SPECIES IS ANNUAL, BIENNIAL AND PERENNIAL RESPECTIVELY (Damanakis *et al.*, 1983).

α/α No	Λατινικό όνομα Latin name		Ελληνικό κοινό όνομα Greek common name	Κοινό όνομα στ' αγγλικά Common name in English
1	*Abutilon theophrasti*	Ε	αγριομπαμπακιά	velvetleaf
2	*Acanthus spinosus*	Π	απούρανος	—
3	*Adonis aestivalis*	Ε	άδωνης	summer pheasant's-eye
4	*Aegilops* spp.	Ε	αγριόσταρο	goatgrass
5	*Agrostemma githago*	Ε	γόγγολη	corn cockle
6	*Agrostis* spp.	—	άγρωστη	bentgrass
7	*Ailanthus altissima*	Π	βρωμόδεντρο	tree-of-heaven
8	*Alcea rosea*	Π	δεντρομολόχα	—
9	*Alisma plantago-aquatica*	Π	πεντάνευρο νερού	common waterplantain
10	*Alkanna tinctoria*	Π	βαφόριζα	—
11	*Allium roseum*	Π	αγριοκρέμμυδο	—
12	*Alopecurus myosuroides*	Ε	αλεπονουρά	—
13	*Amaranthus albus*	Ε	άσπρο βλήτο	tumble pigweed
14	*Amaranthus blitoides*	Ε	πλαγιαστό βλήτο	prostrate pigweed
15	*Amaranthus deflexus*	Π	πολυετές βλήτο	—
16	*Amaranthus hybridus*	Ε	καλλιεργούμενο βλήτο	smooth pigweed
17	*Amaranthus retroflexus*	Ε	τραχύ βλήτο	redroot pigweed
18	*Amaranthus viridis*	Ε	λεπτό βλήτο	slender amaranth
19	*Ammi majus*	Ε	ασπροκέφαλος	greater ammi
20	*Anagallis arvensis*	Ε	αναγαλλίδα	scarlet pimpernel
21	*Anchusa* spp.	—	αγχούζα	bugloss
22	*Anthemis* spp.	Ε	ανθεμίδα	—
23	*Apera spica-venti*	Ε	ανεμόχορτο	windgrass
24	*Arum creticum*	Π	κρητική δρακοντιά	—
25	*Arum italicum*	Π	κοινή δρακοντιά	—
26	*Arum maculatum*	Π	στικτή δρακοντιά	—
27	*Arundo donax*	Π	καλάμι	giant reed
28	*Asparagus* spp.	Π	αγριοσπαράγγι	—
29	*Asphodelus aestivus*	Π	ασφόδελος	—
30	*Aster squamatus*	Ε/Π	αστέρας	—
31	*Avena barbata*	Ε	μικρή αγριοβρώμη	slender oat
32	*Avena sterilis*	Ε	μεγάλη αγριοβρώμη	winter wild oat
33	*Bellardia trixago*	Ε	μπελλάρντια	—
34	*Bellis* spp.	—	μπέλλα	daisy
35	*Bifora* spp.	Ε	μπιφόρα	—
36	*Bilderdykia convolvulus*	Ε	αναρριχώμενο πολύγονο	wild buckwheat
37	*Briza maxima*	Ε	μεγάλο σκουλαρίκι	quakinggrass
38	*Briza minor*	Ε	μικρό σκουλαρίκι	little quakinggrass
39	*Bromus* spp.	—	βρόμος	brome
40	*Buglossoides arvensis*	Ε/Π	λιθόσπερμο	corn gromwell
41	*Bunias erucago*	Ε	βουνιάδα	—
42	*Butomus umbellatus*	Π	βούτομο	flowering rush
43	*Calamagrostis* spp.	Π	καλαμάγρωστη	—
44	*Calendula arvensis*	Ε	καλεντούλα	field calendula
45	*Calystegia sepium*	Π	μεγάλη περιπλοκάδα	hedge bindweed
46	*Capparis ovata*	Π	κάππαρη	—
47	*Capsella bursa-pastoris*	Ε	καψέλλα	shepherd spurse
48	*Cardamine* spp.	Ε	καρδαμίνα	bittercress
49	*Cardaria draba*	Π	βρωμολάχανο	hoary cress

α/α No	Λατινικό όνομα Latin name		Ελληνικό κοινό όνομα Greek common name	Κοινό όνομα σε' αγγλικά Common name in English
50	*Carex* spp.	Π	ξιφάρα	sedge
51	*Centaurea cyanus*	Ε	κενταύρια	cornflower
52	*Cerastium arvense*	Ε	κεράστιο	field chickweed
53	*Cerinthe* spp.	—	κερίνθη	—
54	*Chamomilla recutita*	Ε	χαμομήλι	wild chamomile
55	*Chenopodium album*	Ε	λουβουδιά	common lambsquarters
56	*Chenopodium vulvaria*	Ε	βρωμολουβουδιά	stinking goosefoot
57	*Chondrilla juncea*	Δ/Π	χονδρίλλα	rush skeletonweed
58	*Chrozophora tinctoria*	Ε	χρωζοφόρα	officinel croton
59	*Chrysanthemum coronarium*	Ε	μαργαρίτα	—
60	*Chrysanthemum segetum*	Ε	αγριομαργαρίτα	corn marigold
61	*Cichorium intybus*	Π	ραδίκι	wild chicory
62	*Cirsium arvense*	Π	κίρσιο	Canada thistle
63	*Cnicus benedictus*	Ε	καλάγκαθο	blessed thistle
64	*Conium maculatum*	Π	κώνειο	poison hemlock
65	*Consolida regalis*	Ε	καπουτσίνος	larkspur
66	*Convolvulus arvensis*	Π	περιπλοκάδα	field bindweed
67	*Conyza* spp.	Ε	κόνυζα	—
68	*Crepis* spp.	—	πικραλίδα	hawksbeard
69	*Cuscuta* spp.	Ε	κουσκούτα	dodder
70	*Cynodon dactylon*	Π	αγριάδα	bermudagrass
71	*Cynosurus echinatus*	Ε	κυνόσουρος	rough dogtailgrass
72	*Cyperus esculentus*	Π	κίτρινη κύπερη	yellow nutsedge
73	*Cyperus rotundus*	Π	πορφυρή κύπερη	purple nutsedge
74	*Dactylis glomerata*	Π	δακτυλίδα	orchardgrass
75	*Dasypyrum villosum*	Ε	τριχοκρίθαρο	—
76	*Datura stramonium*	Ε	τάτουλας	jimsonweed
77	*Daucus carota*	Ε/Δ	αγριοκαρώτο	wild carrot
78	*Desmazeria rigida*	Ε	σκληροπόα	—
79	*Digitaria sanguinalis*	Ε	αιματόχορτο	large crabgrass
80	*Dittrichia graveolens*	Ε	μικρή ακονυζιά	—
81	*Dittrichia viscosa*	Π	μεγάλη ακονυζιά	—
82	*Dracunculus vulgaris*	Π	φιδόχορτο	—
83	*Ecballium elaterium*	Π	πικραγγουριά	—
84	*Echinochloa crus-galli*	Ε	μουχρίτσα	barnyardgrass
85	*Echium* spp.	—	βοϊδόγλωσσα	—
86	*Elymus repens*	Π	έλυμος	quackgrass
87	*Epilobium* spp.	Π	επιλόβιο	willow weed
88	*Equisetum arvense*	Π	αλογοουρά	field horsetail
89	*Erodium cicutarium*	Ε/Π	βελονίδα	redstem filaree
90	*Erophila verna*	Ε	ερωφίλη	whitlowwort
91	*Eruca vesicaria*	Ε	ρόκα	garden rocket
92	*Eryngium amethystinum*	Π	παπαδίτσα	—
93	*Eryngium campestre*	Π	φιδάγκαθο	field eryngo
94	*Eryngium creticum*	Π	σφαλάγκαθο	—
95	*Erysimum graecum*	Δ/Π	σκυλόβρουβα	—
96	*Euphorbia characias*	Π	φλώμος	—
97	*Euphorbia dendroides*	Π	δενδροφλώμος	—
98	*Euphorbia helioscopia*	Ε	μεγάλη γαλατσίδα	sun spurge

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99	*Euphorbia peplus*	Ε	μικρή γαλατσίδα	petty spurge
100	*Ferula communis*	Π	άρθηκας	—
101	*Festuca* spp.	Π	φέστουκα	fescue
102	*Filago* spp.	Ε	φιλάγκο	cudweed
103	*Foeniculum vulgare*	Π	μάραθο	common fennel
104	*Fumaria* spp.	Ε	καπνόχορτο	fumitory
105	*Galium aparine*	Ε	μεγαλόκαρπη κολλητσίδα	catchweed/bedstraw
106	*Galium spurium*	Ε	μικρόκαρπη κολλητσίδα	—
107	*Galium tricornutum*	Ε	κυρτόκαρπη κολλητσίδα	—
108	*Genista acanthoclada*	Π	αφάνα	—
109	*Geranium* spp.	—	γεράνι	geranium
110	*Gladiolus illyricus*	Π	μικρή μαχαιρίδα	—
111	*Gladiolus italicus*	Π	μεγάλη μαχαιρίδα	—
112	*Glycyrrhiza glabra*	Π	γλυκόρριζα	
113	*Hedera helix*	Π	κισσός	English ivy
114	*Helianthus tuberosus*	Π	κολοκάσι	Jerusalem artichoke
115	*Heliotropium europaeum*	Ε	κοινό ηλιοτρόπιο	common heliotrope
116	*Heliotropium dolosum*	Ε	μακρόκαρπο ηλιοτρόπιο	—
117	*Heliotropium hirsutissimum*	Ε	τριχωτό ηλιοτρόπιο	—
118	*Herniaria* spp.	Ε	ερνιάρια	—
119	*Hibiscus trionum*	Ε	αγριοϊβίσκος	Venice mallow
120	*Hippocrepis* spp.	—	ιπποκρεπίδα	—
121	*Hirschfeldia incana*	Ε/Π	βρούβα	shortpod mustard
122	*Holcus lanatus*	Π	τριχωτός ολκός	velvetgrass
123	*Holcus mollis*	Ε	μαλακός ολκός	German velvetgrass
124	*Hordeum bulbosum*	Π	βολβοκρίθαρο	—
125	*Hordeum murinum*	Ε	αγριοκρίθαρο	wall barley
126	*Hyoscyamus* spp.	—	γέροντας	henbane
127	*Hyparrhenia hirta*	Π	υπαρένια	common thatchinnggrass
128	*Hypecoum imberbe*	Π	υπήκοο	—
129	*Hypericum perforatum*	Π	βάλσαμο	St. Johnswort
130	*Hypericum triquetrifolium*	Π	αγούδουρας	—
131	*Imperata cylindrica*	Π	δεματόχορτο	cogongrass
132	*Juncus* spp.	—	βούρλο	rush
133	*Knautia* spp.	—	κουφολάχανο	scabious
134	*Lactuca serriola*	Ε	αγριομάρουλο	prickly lettuce
135	*Lagurus ovatus*	Ε	γατάκι	—
136	*Lamium amplexicaule*	Ε	δωδεκάνθι	henbit
137	*Lamium bifidum*	Ε	δίλοβο λάμιο	—
138	*Lamium purpureum*	Ε	πορφυρό λάμιο	red deadnettle
139	*Lathyrus aphaca*	Ε	κοινό αγριολαθούρι	yellow vetchling
140	*Lathyrus nissolia*	Ε	μακρόφυλλο αγριολαθούρι	grass-vetchling
141	*Lavatera cretica*	Ε/Δ	λαβατέρα	—
142	*Legousia speculum-veneris*	Ε	αγριογιούλι	common Venus's lookingglass
143	*Lemna minor*	Π	νεροφακή	common duckweed
144	*Leontice leontopetalum*	Π	φούσκα	—
145	*Lolium multiflorum*	Ε	πολύανθη ήρα	Italian ryegrass
146	*Lolium perenne*	Π	πολυετής ήρα	perennial ryegrass

α/α No	Λατινικό όνομα Latin name		Ελληνικό κοινό όνομα Greek common name	Κοινό όνομα στ' αγγλικά Common name in English
147	*Lolium rigidum*	Ε	λεπτή ήρα	Swiss ryegrass
148	*Lolium temulentum*	Ε	μεθυστική ήρα	darnel
149	*Lophochloa cristata*	Ε	λοφοχλόα	—
150	*Lupinus* spp.	Ε	λούπινο	lupine
151	*Lythrum* spp.	—	λύθρο	—
152	*Malva* spp.	—	μολόχα	mallow
153	*Medicago* spp.	—	μηδική	burclover
154	*Melica ciliata*	Π	μελίκα	ciliated melickgrass
155	*Melilotus* spp.	—	μελίλωτος	sweetclover
156	*Mentha* spp.	Π	μέντα	mint
157	*Mercurialis annua*	Ε	σκαρολάχανο	annual mercury
158	*Milium vernale*	Ε	μίλιο	—
159	*Muscari neglectum*	Π	βορβός	grapehyacinth
160	*Myagrum perfoliatum*	Ε	μύαγρο	muskweed
161	*Myriophyllum* spp.	Π	μυριόφυλλο	—
162	*Najas* spp.	Ε	ναϊάδα	naiad
163	*Nasturtium officinale*	Π	νεροκάρδαμο	watercress
164	*Neslia paniculata*	Ε	νέσλια	ball mustard
165	*Nigella arvensis*	Ε	μαυροκούκι	field fennelflower
166	*Oenanthe* spp.	—	οινάνθη	—
167	*Onobrychis aequidentata*	Ε	ισοδοντωτή ονοβρυχίδα	—
168	*Onobrychis caput-galli*	Ε	κοινή ονοβρυχίδα	—
169	*Ononis* spp.	—	ανωνίδα	restharrow
170	*Onopordum* spp.	Δ	γαϊδουράγκαθο	—
171	*Opuntia ficus-indica*	Π	φραγκοσυκιά	—
172	*Orlaya kochii*	Ε	ορλάγια	—
173	*Orobanche* spp.	Ε	οροβάγχη	broomrape
174	*Oxalis pes-caprae*	Π	οξαλίδα	Bermuda buttercup
175	*Pallenis spinosa*	Ε/Δ	καρφόχορτο	—
176	*Panicum repens*	Π	πάνικο	torpedograss
177	*Papaver dubium*	Ε	μακρόκαρπη παπαρούνα	field poppy
178	*Papaver rhoeas*	Ε	κοινή παπαρούνα	corn poppy
179	*Parietaria diffusa*	Π	περδικούλι	pellitory
180	*Paspalum paspalodes*	Π	νεραγριάδα	knotgrass
181	*Phalaris brachystachys*	Ε	κοντή φάλαρη	short-spiked canarygrass
182	*Phalaris coerulescens*	Π	βολβοφάλαρη	—
183	*Phalaris minor*	Ε	μικρόκαρπη φάλαρη	littleseed canarygrass
184	*Phalaris paradoxa*	Ε	παράδοξη φάλαρη	hood canarygrass
185	*Phlomis fruticosa*	Π	ασφάκα	—
186	*Phragmites australis*	Π	νεροκάλαμο	common reed
187	*Physalis* spp.	—	φυσαλίδα	groundcherry
188	*Phytolacca americana*	Π	αγριοσταφίδα	common pokeweed
189	*Picnomon acarna*	Ε	πίκνομο	—
190	*Piptatherum miliaceum*	Π	γρήλαρη	smilograss
191	*Plantago* spp.	—	πεντάνευρο	plantain
192	*Poa annua*	Ε	κοινή πόα	annual bluegrass
193	*Poa bulbosa*	Π	βολβοπόα	bulbous bluegrass
194	*Poa trivialis*	Π	τραχεία λειβαδοπόα	roughstalk bluegrass

α/α No	Λατινικό όνομα Latin name		Ελληνικό κοινό όνομα Greek common name	Κοινό όνομα στ' αγγλικά Common name in English
195	*Poa pratensis*	Π	λεία λειβαδοπόα	Kentucky bluegrass
196	*Polygonum aviculare*	Ε	πολυκόμπι	prostrate knotweed
197	*Polygonum hydropiper*	Ε	νεροπιπεριά	marshpepper smartweed
198	*Polygonum lapathifolium*	Ε	λαπάτσα	pale smartweed
199	*Polygonum persicaria*	Ε	αγριοπιπεριά	ladysthumb
200	*Portulaca oleracea*	Ε	αντράκλα	common purslane
201	*Potamogeton* spp.	Π	ποταμόχορτο	pondweed
202	*Potentilla reptans*	Π	ποτεντίλλα	creeping cinquefoil
203	*Prunella* spp.	—	βουτυρόχορτο	—
204	*Psoralea bituminosa*	Π	καλοσύκι	psoralea
205	*Pteridium aquilinum*	Π	φτέρη	bracken
206	*Pulicaria dysenterica*	Π	σκυλόχορτο	—
207	*Ranunculus* spp.	—	ρανούγκουλος	buttercup
208	*Raphanus raphanistrum*	Ε/Δ	ραπανίδα	wild radish
209	*Rapistrum rugosum*	Ε	ράπιστρο	—
210	*Reseda alba*	Π	άσπρη ρεζεντά	white mignonette
211	*Reseda lutea*	Π	κίτρινη ρεζεντά	yellow mignonette
212	*Rorippa* spp.	—	ρορίππα	fieldcress
213	*Rubus* spp.	Π	βάτος	—
214	*Rumex acetosa*	Ε	ξινολάπαθο	sorrel
215	*Rumex acetosella*	Ε	ξινάκι	red sorrel
216	*Rumex crispus*	Π	λάπαθο	curly dock
217	*Rumex obtusifolius*	Π	μεγάλο λάπαθο	broadleaf dock
218	*Ruta chalepensis*	Π	απήγανος	—
219	*Saccharum ravennae*	Π	καλαμίδι	—
220	*Salsola kali*	Ε	αλμυρίδι	Russian thistle
221	*Salvinia natans*	Ε	σαλβίνια	floating salvinia
222	*Sambucus ebulus*	Π	βουζιά	dwarf elder
223	*Sarcopoterium spinosum*	Π	αστοιβή	—
224	*Scabiosa* spp.	—	σκαβιόζα	—
225	*Scandix australis*	Ε	σκαντζίκι	—
226	*Scandix pecten-veneris*	Ε	μυρώνι	shepherds-needle
227	*Scirpus* spp.	—	σκίρπος	bulrush
228	*Scolymus hispanicus*	Δ/Π	ασκόλυμπρος	—
229	*Scrophularia peregrina*	Ε	σκροφουλάρια	figwort
230	*Senecio vulgaris*	Ε	μαρτιάκος	common groundsel
231	*Setaria pumila*	Ε	κίτρινη σετάρια	yellow foxtail
232	*Setaria verticillata*	Ε	σπονδυλωτή σετάρια	bristly foxtail
233	*Setaria viridis*	Ε	πράσινη σετάρια	green foxtail
234	*Sherardia arvensis*	Ε	προβατόχορτο	field madder
235	*Silene vulgaris*	Π	βοϊδοκράτης	bladder campion
236	*Silybum marianum*	Ε/Δ	κουφάγκαθο	milk thistle
237	*Sinapis alba*	Ε	ήμερο σινάπι	white mustard
238	*Sinapis arvensis*	Ε	άγριο σινάπι	wild mustard
239	*Sisymbrium* spp.	—	σισύμπριο	—
240	*Smilax aspera*	Π	αρκουδόβατος	—
241	*Solanum nigrum*	Ε	στύφνος	black nightshade
242	*Solanum elaeagnifolium*	Π	σολανό	silverleaf nightshade

α/α No	Λατινικό όνομα Latin name		Ελληνικό κοινό όνομα Greek common name	Κοινό όνομα στ' αγγλικά Common name in English
243	*Sonchus arvensis*	Π	πολυετής ζωχός	perennial sowthistle
244	*Sonchus asper*	Ε	τραχύς ζωχός	spiny sowthistle
245	*Sonchus oleraceus*	Ε	ζωχός	annual sowthistle
246	*Sorghum halepense*	Π	βέλιουρας	johnsongrass
247	*Spartium junceum*	Π	σπάρτο	Spanish broom
248	*Spergula* spp.	Ε	σπεργούλα	spurry
249	*Spergularia* spp.	—	σπεργουλάρια	sandspurry
250	*Stellaria* spp.	Ε	στελλάρια	—
251	*Stipa* spp.	—	στίπα	—
252	*Tamus communis*	Π	αβρονιά	—
253	*Taraxacum* spp.	Π	αγριοράδικο	dandelion
254	*Thlaspi* spp.	Ε	θλάσπι	pennycress
255	*Thymus capitatus*	Π	θυμάρι	thyme
256	*Tordylium apulum*	Ε	καυκαλίθρα	—
257	*Torilis* spp.	Ε	τοριλίδα	hedgeparsley
258	*Tragopogon* spp.	Π	τραγοπώγονας	salsify
259	*Tribulus terrestris*	Ε	τριβόλι	puncturevine
260	*Trifolium* spp.	—	αγριοτρίφυλλο	clover
261	*Trigonella* spp.	Ε	τριγωνέλλα	—
262	*Tussilago farfara*	Π	χαμολεύκα	coltsfoot
263	*Typha* spp.	Π	ψαθί	cattail
264	*Urtica dioica*	Π	πολυετής τσουκνίδα	stinging nettle
265	*Urtica pilulifera*	Ε	μεγάλη τσουκνίδα	—
266	*Urtica urens*	Ε	μικρή τσουκνίδα	burning nettle
267	*Vaccaria pyramidata*	Ε	βακκάρια	cow cockle
268	*Verbascum* spp.	—	βερμπάσκο	mullein
269	*Veronica* spp.	Ε	βερόνικα	speedwell
270	*Vicia* spp.	Ε	αγριόβικος	vetch
271	*Viola arvensis*	Ε	κοινός αγριοπανσές	field violet
272	*Viola tricolor*	Ε	ποικιλόχρ. αγριοπανσές	wild violet
273	*Vulpia myuros*	Ε	μεγάλη βούλπια	rattail fescue
274	*Vulpia ciliata*	Ε	μικρή βούλπια	—
275	*Xanthium spinosum*	Ε	ασπράγκαθο	spiny cocklebur
276	*Xanthium strumarium*	Ε	αγριομελιτζάνα	heartleaf cocklebur

APPENDIX II

WEEDS PARTIALLY OR COMPLETELY CONTROLLED BY SOIL SOLARIZATION.

Abutilon theophrasti	S*-MS*	SAW*
Amaranthus sp.	S	SAW
A. viridis	S	SAW
A. retroflexus	S-MR	SAW
Anagallis arvensis	S	AW*
Avena sterilis	S-MS	WAW*
Bromus rigidus	S	WAW
Capsella bursa pastoris	S	WAW
Chenopodium album	S	SAW
Convolvulus arvensis	S-MS	PW*
Cynodon dactylon	S-MS	PW
Digitaria sp.	S	AW
D. sanguinalis	S-MS	SAW
Echinochloa colonum	S	SAW
E. crus-galli	S	SAW
Erodium sp.	S	WAW
Fumaria spp	S	WAW
Heliotropium sp.	S	AW
Lactuca scariola	S	WAW
Lamium amplexicaule	S	WAW
Malva parviflora	S-MS	SAW
Mercurialis annua	S	AW
Orobanche ramosa	S	SAW
Orobanche aegyptiaca	S	SAW
Orobanche crenata	S	SAW
Phalaris brachystachys	S	WAW
Phalaris minor	S	AW
Poa annua	S	WAW
Poa sp.	S	AW
Portulaca oleracea	S-MS	SAW
Raphanus raphanistrum	S	WAW/BW*
Senecio vulgaris	S	WAW
Setaria viridis	S	SAW
Sinapis arvensis, Sinapis alba	S	AW

Solanum nigrum	S-MR	SAW
Sonchus oleraceus	S	WAW
Sorghum halepense	MS	PW
Spergula arvensis		AW
Stellaria sp.	S	WAW
Tribulus terrestris	S	SAW
Triticum aestivum (volunteer)		
Urtica urens	S	WAW
Xanthium spinosum	S	SAW

*AW = annual weed
PW = perennial weed
BW = biennial weed
SAW = summer annual weed
WAW = winter annual weed
S = sensitive to SS
MS = Moderately sensitive = normally controlled, but may remain because of large seeds that may be deep in soil.

WEEDS NOT CONTROLLED BY SOLARIZATION

Amaranthus spp.		PW
Conyza canadensis	MR*	SAW
Convolvulus arvensis	MR-R*	PW
Crepis aspera	R	-
Cyperus sp., *C. rotundus*, *C. esculentus*	R	PW
Melilotus sp. *M. indica*	R	-
M. sulcatus	R	SAW
Malva sp.	MR	AW
Vicia narbonensis	R	AW

*MR = Moderately resistant
R = Resistant, poorly controlled

APPENDIX III

APPLICATION OF SOIL SOLARIZATION IN PATRA (Pelloponissos, Greece) (Interview, oral information from the grower Maria Pentaskoufi*)

SS is applied in greenhouse cultivated with vegetables in Patra every 2 years. The first year SS is applied, the second year sorghum is planted as green fertilizer and weed suppresser. SS starts about the 10th of July until end of August. Begin of July the crops are uprooted. All plant residuals are removed as well as the irrigation system. The soil is prepared by tilling to form a fine-texture seedbed starting early July. The soil is sprinkle-irrigated, ploughed, levelled, then furrowed at appropriate distances to suit the crops in the trial. The furrows are irrigated prior to the solarization treatments. Soil preparation is necessary to avoid that the plastic has no good contact with the soil. After some days the soil is covered with PE of 0,020 mm. The windows and doors of the greenhouse are shut. In this green house, curtains or other shadow materials are not present so that the developed temperatures are very high (higher than 45^{0}C even when the weather is cloudy. After the solarization period is terminated, plastic sheets are removed carefully and crops are planted with minimal soil disturbance.

The success of the method is confirmed from the fact that at the moment handweeding is not even necessary to apply.

*Maria Pentaskoufi, Ethnikis Antistaseos 3 26500 Paralia Patron Patra Greece, has studied plant production at the Higher Agricultural School (TEI) of Crete. She carried out her thesis research at AB-DLO, Wageningen, The Netherlands in 1992.

APPENDIX IV

PATHOGENIC FUNGI APPLIED AS MYCOHERBICIDE (Anonymous, 1993)

Colletotrichum gloeosporioides (Penz.) Penz. & Sacc. f. sp. aeschynomene

Trade name and Manufacturer: COLLEGO® - Ecogen

Formulation: The active ingredient of COLLEGO® is living spores of the fungus Colletotrichum gloeosporioides f. sp. aeschynomene. COLLEGO® is a two-component product. Component A consists of a water soluble spore rehydrating agent and Component B is a wettable powder formulation of living fungal spores of C. gloeosporioides f. sp. aeschynomene.

Bioherbicide Use: COLLEGO® is a selective postemergent mycoherbicide for the control of northern jointvetch (Aeschynomene virginica (L.) B.S.P.) in rice and soybean. COLLEGO® should be applied to emerged northern jointvetch plants that are from 20 to 60 cm tall and have not reached the bloom stage. Rice fields should be flooded before application. Soybean fields should be irrigated just prior to application. Free moisture or relative humidities above 80% and air temperatures of approximately 26°C for at least 12 hours are necessary for development of the highest degree of infection.

Application Methods: For best results, apply by aerial application with fixed-wing or helicopter aircraft and use a spray volume of at least 93 litres per hectare.

Mode of Action: C. gloeosporioides f. sp. aeschynomene is an anthracnose disease that forms lesions on the above ground parts of northern jointvetch. Lesions occur principally on the stems and once the stems are girdled, plant parts above the girdle collapse and die. Death of the plant may not occur for 4 to 5 weeks after COLLEGO® is applied.

Toxicological Properties: No known hazards to humans or to the environment are attributable to COLLEGO®. Non-toxic to mallard duck, bobwhite quail, bluegill fish, channel catfish, crayfish, and earthworm.

Acute oral (Rat) - LD_{50} 5000 mg/kg body weight; acute dermal (rabbit) - LD_{50} 721,000 mg/kg body weight; primary dermal irritation (rabbit) - no dermal irritation; primary eye irritation (rabbit) - no ocular irritation; toxin potential/intraperitoneal (mouse) - no pharmacotoxic effects at 50 ml/kg body weight; lysed and whole spores dermal sensitization (guinea pig) - not a dermal sensitizer; acute inhalation (rat) - LC_{50} 41.2 mg spores/l; infectivity (mouse) - viable spores noninfective in either depressed or nondepressed animals.

Source of Information: Ecogen Inc., 2005 Cabot Blvd. West, Langhorne, PA 19047-1810 U.S.A.

Colletotrichum gloeosporioides (Penz.) Penz. & Sacc. f. sp. malvae

Trade name and Manufacturer: BIOMAL® - Philom Bios Mfg. Inc.

Formulation: The BIOMAL® formulation is a wettable powder consisting solely of living Colletotrichum gloeosporioides f.sp. malvae spores.

Bioherbicide use: BIOMAL® is a post-emergent mycoherbicide for the specific control of round-leaved mallow (Malva pusilla) in field crops. BIOMAL® can be applied to actively growing round-leaved mallow plants anytime after the two-leaf stage and preferable before the weeds are 15 cm tall. Although BIOMAL® is effective when applied at any stage of weed growth, control occurs at a slower rate in older, more mature plants. The most effective stage of application is at an early seedling stage.

Application methods: BIOMAL® may be applied with any conventional field sprayer calibrated to supply at least 10 to 15 gallons/acre (100 to 150 litres/hectare) of water. The suspension should be agitated constantly during spraying to ensure that the spores stay in uniform suspension. The suspension should be applied within 3 hours of preparation. Successful spore germination and infection require a period of high humidity for approximately 18 to 24 hours after application. These conditions usually occur on overcast, humid days; during late afternoon or early evening; or when rain is imminent. Rainfall during or immediately after application facilitates spore germination. If available, sprinkler irrigation can be used to create more humid conditions after application.

Mode of action: Infection of round-leaved mallow by BIOMAL® results in typical anthracnose disease symptoms. Lesions will form on the leaves, petioles, and stems of infected plants within two to four weeks after BIOMAL® application. As the disease progresses, the stems are girdled by lesions which results in plant mortality. Later germinating round-leaved mallow plants are infected by diseased plants and are also controlled within two to four weeks after emergence.

Toxicological properties: The commercial BIOMAL® formulation did not have any adverse toxicological or infectivity effects on laboratory rats (intraperitoneal, oral, pulmonary, dermal), rabbits (ocular), birds (mallard ducklings, bobwhite quail chicks), or honey bees. No significant changes occurred in any of the parameters measured. However, a hypersensitivity study with guinea pigs indicated the potential for BIOMAL® to have allergenic effects. Therefore, appropriate cautionary statements are included on the label.

Source of Information: Philom Bios Inc., 318-111 Research Drive, Saskatoon, SK, Canada S7N 3R2.

Phytophthora palmivora (Butl.) Butl. MWV Pathotype

Trade name and Manufacturer: DeVine®- Chemical and Agricultural Products Division, Abbott Laboratories.

Formulation: DeVine® is a submerged fermentation product containing chlamydospores of the fungus Phytophthora palmivora MWV Pathotype. The liquid formulation is available in one pint containers which must be kept refrigerated (2 to 8°C) until use.

Bioherbicide Use: DeVine® is a mycoherbicide for control of Morrenia odorata, strangler or milkweed vine, in citrus groves. This fungus will initiate a root infection in milkweed vine plants that kills the vine in two to ten weeks following application, depending on the size and maturity of the vine. The surface of the soil must be wet at the time of application.

Application Methods: DeVine® may be applied in any type of citrus grove from May through September after the weed has germinated or is actively growing. Apply DeVine® with a herbicide boom sprayer to achieve uniform coverage of the soil under the tree canopy. Use at least 124 litres of spray water per treated hectare.

Mode of Action: P. palmivora infection of milkweed vine shows typical Phytophthora rot symptoms. Dying plants are girdled at the soil line and up to an inch above it. The infection, initially occurring at the soil line, progresses until it encompasses all plant roots. Infected plant roots slough the cortex, leaving only the stele when the plant is pulled from the soil. The root rot induces leaf wilt, the leaves wither and eventually fall from the plant. The fungus can be consistently isolated from the diseased plant roots.

Toxicological Properties: A chlamydospore preparation of P. palmivora MWV Pathotype (P.p.) caused no clinical signs of toxicity or infectivity in the laboratory rat (oral and intratracheal) or domestic rabbit (ocular and dermal). There were no hematologic or blood chemical changes attributable to P.p. administration. Body weight change, feed consumption, and rectal temperature were not influenced by the fungus. Moreover, animal behavior was normal throughout each of the experiments. Mycotoxins were not detected in either chlamydospore or the spent broth preparations. A series of dermal applications of the organism followed by a single challenge did not produce hypersensitivity in the guinea pig. These findings indicate that P.p. is not a mammalian pathogen and presents no imminent hazard upon human exposure.

Source of Information: Chemical and Agricultural Products Division, Abbott Laboratories, North Chicago, IL 60064.

APPENDIX V

SOME WEEDS CONTROLLED BY BIOLOGICAL METHODS* (Charudattan and DeLoach, 1988)

A. Skeletonweed, *Chondrilla juncea*

Skeletonweed, of Mediterranean origin, was introduced into Australia where it became a serious weed in cereal crops and rangelands. After considerable research, a rust fungus from the Mediterranean region, *Puccinia chondrillina*, was introduced into Australia. Following inoculative releases, this classical biological agent spread rapidly, created epidemics, and in the process infected, stressed, and killed the most common and susceptible biotype of the weed. After the successful establishment of the pathogen, the weed density in cereal crops decreased to less than 10 plants per m^2 from the level of about 200 plants per m^2 that existed before rust introduction. Equally spectacular control was also obtained in pastures.

The rust was introduced from Europe into the USA to control a biotype of the weed in western rangelands where, unlike in Australia, it was only partially successful. Under these conditions of less than expected efficacy, the rust has been used along with a chemical herbicide, picloram (4-amino-3,5,6-trichloro-2-pyridine-carboxylic acid), and insect biocontrol agents, *Cystiphora schmidti* (a gall-forming midge) and *Aceria chondrillinae* (a gall forming mite) in an integrated weed management program to maximize its benefits.

B. Blackberry, *Rubus* spp.

Between 1952 and 1973, blackberry, especially *Rubus constrictus*, posed problems in rangelands in Chile and required control. Introduction from Europe of a host-specific pathotype of the blackberry rust, *Phragmidium violaceum*, resulted in satisfactory weed control. The rust-infected plants became less

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*They are mentioned only the weeds that exist in Greece.

competitive and reduced in size compared with rust-free plants. In Australia, the same rust was either accidentally introduced, or unofficially introduced by ranchers, and giving very good control of blackberry, *Rubus fruticosus*, in some areas.

C. Nutsedges, *Cyperus rotundus* and *C. esculentus*

Research in cotton fields in Mississippi from 1972 to 1980 resulted in the only technically workable method to date using an insect to control weeds in cultivated crops. The weeds are purple nutsedge, *C. rotundus*, rated as the world's worst weed, and the yellow nutsedge, *C. esculentus*, rated as the sixteenth worst. Both are pests of corn, cotton, vegetable crops, and citrus in the USA, and are of cosmopolitan distribution. Both reproduce by underground tubers as well as seeds and are very difficult to control. The introduced purple nutsedge has no beneficial value but the seed and the tubers of the native yellow nutsedge serve as wildlife food. Searchers for natural enemies have been in India, Pakistan, the USA, and the Philippines. However, no insect has yet been found that provides satisfactory control under natural conditions; the most damaging are several species of moths in the genus Bactra (Tortricidae) and some weevils, all of which feed on the underground stems and damage the bulbs and the tubers.

Control was achieved by making inundative releases of neonate larvae of *Bactra verutana* in the field. Started 3 weeks after planting, 3 weekly releases of 5 to 10 larvae per nutsedge plant suppressed purple nutsedge by 50% for 6 to 7 weeks after the last release, while 4 to 5 weekly release suppressed nutsedge growth by 62 to 68%. All of these rates allowed a production of seed cotton equal to that in plots with no nutsedge. The yield of cotton in untreated plots was only 38% of that in treated plots in one year and 70% in another year. Damage caused to nutsedge was increased by 15 to 75% by coating the larvae with herbicides before release.

Although satisfactory control was achieved in the field, the cost of rearing and releasing so many *Bactra* larvae was considerably more than the cost of herbicide treatments. Commercial development would require large facilities and an extremely rapid distribution system since the duration of the egg stage would be only 3 days. The method would be useful in high value crops, in crops that would be damaged by the herbicides, or in situations where herbicides were not wanted for other reasons.

A rust fungus, *Puccinia canaliculata*, native to North America was successfully manipulated through augmentation strategy to control yellow nutsedge in experimental plots. Epidemics were created by releasing uredospores of the rust over crops. The rust can be integrated with other pest management programs.

D. Johnsongrass, *Sorghum halepense*

Johnsongrass is considered to be the world's sixth worst weed. The main problem for biocontrol is its close taxonomic relationship to grain sorghum, *Sorghum bicolor*. Southwestern Asia is the site of origin of the genus *Sorghum* and of *S. halepense*.

Several natural enemies of Johnsongrass have been found in Israel and neighbouring countries. In Pakistan three species have possible value for control. One insect from Israel, the pyralid *Metacrambus carectellus*, was particularly promising because its larvae fed only in the rhizomes. Since the beneficial species of *Sorghum* do not have rhizomes, they should not be damaged, and in fact they are not damaged in fields of Israel. However, larvae fed in the stems of cultivated sorghum in laboratory tests which has discouraged further research. The great losses caused by Johnsongrass would justify further testing of this and other potential agents.

In the USA three pathogens are under study for control of Johnsongrass: *Sphacelotheca cruenta*, *Pseudomonas syringae* and *Helminthosporium* spp. *Sphacelotheca cruenta* substantially reduced seed production and plant size but did not kill the plants. *Sphacelotheca holci* (possibly a physiologic race of *S. Cruenta*) is less pathogenic to cultivated sorghum, and in greenhouse tests reduced tillering by 50%. They were also found significant reductions in plant height, aboveground biomass, and lateral rhizome expansion in *S. holci*-infected Johnsongrass compared to healthy controls. Another fungus, *Bipolaris sorghicola*, of worldwide distribution, killed 88% of the plants after 8 days and 100% after 25 days in field tests in North Carolina. Although *B.*

Sorghicola also attacks cultivated sorghum, it could probably be used safely to control Johnsongrass whether sorghum is not planted in adjacent fields.

E. Cocklebur, *Xanthium* spp.

Cocklebur is thought to be native in the USA and Eurasia. It is the same plant tribe, Heliantheae, as sunflower.

Several insects and a pathogen have been introduced into Australia from the USA; the insects have given little control but the pathogen *Puccinia xanthii* exerts partial control and is spreading. A stem-boring cerambycid beetle from India, *Nupserhavexator*, is giving minimal control in Australia; it attacked sunflower during testing in India, but has not noticeably damaged sunflower in Australia. Other insects have been found in Argentina, and two of these, a stem borer, *Emphytoecia versicolor*, and a mordelid seed beetle, are being tested. Additional exploration is needed for natural enemies in Eurasia and South America. In Mississippi, the naturally occurring fungus, *Alternaria helianthi*, controlled cocklebur in greenhouse tests. This fungus probably could be used safely as a bioherbicide if production costs were not too high and if consistent infection could be obtained in the field.

F. Sorrell and Dock, *Rumex* spp.

Surveys for natural enemies have been made in several countries, but until now no control agents have been released. In Switzerland, the pathogen *Uromyces rumicis* is under study for possible biological control. Several insects attack *R. Obtusifolius* in Japan, including a native chrysomelid leaf beetle, *Gastrophysa atrocyanea*, that is being considered for control. In Pakistan, 26 species of insects attack *Rumex* spp. Two leaf-feeding chrysomelid beetles, *Altica himensis* and *Mantura lutea*, and a stem-feeding weevil, *Perapion* sp.nr. *Curtirostre*, were specific to *Rumex*; some other insects were found that attacked only *Rumex* and *Polygonum*.

Personnel of the Biological Control of Weed Laboratory, USDA-ARS, in Rome have identified more than 200 species of insects and 50 pathogens that attack *R. crispus* in the Mediterranean area. Of nine species of insects tested from the

Western Mediterranean, *Bembecia (=Pyropteron) chrysidiforme* and *Chamaesphecia doryliformis* (Lepidoptera: Sesiidae) were considered the best candidates for introduction in Australia. Also, a weevil from Morocco, *Lixus cribricollis*, damaged *Rumex* and *Emex* was recommended as candidate to control *Rumex crispus* in Australia. *Pyropteron chrysidiforme* also was studied in quarantine in Stoneville, Mississippi.

G. Velvetleaf, *Abutilon theophrasti*

In Pakistan 39 species of insects attacked *Abutilon* spp., but only 2 appeared to the genus. *Hexomyza abutilonicaulis*, a stem-gall-forming agromyzid fly, was promising for biocontrol but did not become established when released in Mississippi, probably because it could not survive the cold winters. The flower and the fruit feeding weevil, *Acallopestus maculithorax*, was also promising but needs more testing. Several microorganisms that may have potential use in an augmentation program have been found in the USA.

H. Pigweed, *Amaranthus* spp.

In Pakistan, 22 species of insects were found on *Amaranthus*. One species, the weevil *Hypolixus truncatulus*, appeared promising for biological control, but it attacked all species of *Amaranthus* tested. Therefore, its use would necessitate an evaluation of damage caused to non-weedy species of *Amaranthus* and the possible future development of some species as crops (*Amaranthus* is one of the most valuable plants for wildlife food and some species are under consideration for grain production and as a leafy vegetable crop).

I. Hoary cress, *Cardaria draba*

In Poland, after surveying the insects that attack Cruciferae, it was proposed that *C. draba* would be a good candidate for biological control. The most promising control agents were an eriophyiid mite, *Aceria draba*, that attacks the flowers and the two weevils, *Ceutorhynchus turbatus* and *C. parvilus*.

J. Dodder, *Cuscuta* spp.

Two species of weevils, *Smicronyx roridus* and *S. Rufovittatus*, and a fly, *Melanagromyza cuscutae*, all from Pakistan, were liberated in Barbados in 1967 and 1971 for the control of *cuscuta americana* and *C. indecora*, but none of these insects became established. In the ex-USSR, three native organisms are being evaluated, the agromyzid flies, *M. cuscutae* and *Phytomyza orobanchia*, and a fungus, *Alternaria cuscutacidae*. The fungus is effective in several areas, and the fly produces some control in spite of being attacked by parasites.

K. Broomrape *Orobanche* spp.

A native seed-feeding agromyzid fly, *Phytomyza orobanchia*, used in the ex-USSR and ex-Yugoslavia, has achieved up to 95% destruction of seeds.

APPENDIX VI

ORAL INTERVIEWS FROM GREEK GROWERS

Area: Gianitsa
Crop: Asparagus
Areal: 4 ha
Weed control practices: To prepare the beds soil tillage is carried out. In the period of harvest Gramoxone (Paraquat).

Area: Seres
Crop: Roses
Areal: 0,4 ha greenhouse
Weed control practices: In the rows directed application of herbicides (Gramoxone). Between the rows soil tillage and herbicides. Five times a year spraying with herbicides and twice a year soil tillage. He is planning to start growing in plastic bags in order to avoid soil diseases and weeds.

Area: North Greece
Crop: Roses
Areal: 1 ha greenhouse
Weed control practices: Handweeding. This grower was against directed application of herbicides (Gramoxone). He was believing that exposure to Gramoxone may damage the green young parts of the plants.

Area: Thessaloniki
Crop: Cut flowers (greenhouse), Asparagus
Areal: 0,6 ha greenhouse, 3,5 ha open field.
Weed control practices: In the greenhouses the grower applies at the moment methyl bromide but he is going to replace it very soon by steaming. For the weeds that are going to grow later on he will apply handweeding or herbicides. In the open fields soil tillage before planting, later on herbicides and hoeweeding.

Area: Larissa
Crop: Apple orchard
Areal: 3,5 ha
Weed control practices: 50% herbicides in the row. 50% grasscutters (near the trees).

Area: Attiki
Crop: Gerberas
Areal: 1 ha greenhouse
Weed control practices: At the moment 100% methyl-bromide. In the future he will grow in pots, Grodan or use of sterilized soil.

Area: Chalkidiki
Crop: Gerberas
Areal: 2 ha greenhouse
Weed control practices: 100% methyl-bromide. In the future he will apply steaming.

Area: North Greece
Crop: Fruit orchard (peaches, peers)
Areal: 4 ha peaches, 0,5 ha peer
Weed control practices: herbicides in the row. Between the rows use of grasscutters.

Area: North Greece
Crop: Asparagus
Areal: 4 ha
Weed control practices: This grower uses 100% herbicides. He is against soil tillage because the created dust from the soil tillage covers the plants and damage due to freezing is increasing

Area: Larissa
Crop: Hazelnuts
Areal: 1 ha
Weed control practices: Twice a year soil tillage. From April to August every 20 days application of herbicides.

Area: Gianitsa
Crop: Asparagus
Areal: 0,9 ha
Weed control practices: 50% soil tillage and 50% hoeweeding and application of herbicides. Hoeweeding is done in the row before earthing-up. Between the rows soil tillage. After earthing-up only application of herbicides.

Area: Thessalonoki
Crop: Indoor-plants
Areal: 0,4 ha greenhouse
Weed control practices: Only handweeding. In this nursery the weeds were not a problem because they were using sterilized soil.

Area: North Greece
Crop: Fruit orchard (peaches, cherries), grapes and maize
Areal: 3 ha fruits and 1 ha maize
Weed control practices: 100% grass cutters and hoeweeding in the fruit orchard and grapes. Herbicides in maize.

Area: Katerini
Crop: Tobacco
Areal: 1,5 ha (2/3 leased).
Weed control practices: First ploughing after soil tillage and 4 days before planting application of herbicides. After planting soil tillage (60%) and handweeding (40%). Handweeding is applied against *Cyperus esculentus* when herbicides are not sufficient effective. Every 2 years crop rotation with wheat against *Orobanche* and *Cyperus*.

Area: Magnisia
Crop: Wheat (planting in row)
Areal: 30 ha (12 leased)
Weed control practices: 100% herbicides. Once in five years crop rotation with legumes.

Area: Amfissa
Crop: Olive grove
Areal: 1 ha
Weed control practices: None.

Area: Kriti (Ierapetra)
Crop: Roses, vegetables
Areal: 0,3350 ha greenhouse (roses), 0,4 ha greenhouse (vegetables)
Weed control practice: Three times a year application of herbicides and handweeding. In vegetables 100% handweeding. The culture is organic.

Area: North Greece
Crop: Gerberas and various other cutflowers
Areal: 0,55 ha greenhouse, 1,5 ha outdoor conditions
Weed control practice: Chemical control. Handweeding is applied for *Convolvulus arvensis*. He uses methyl-bromide for soil disinfection. Soil solarization requires a lot of time until positive effects are reached, while methyl-bromide only 15 days.

Area: Pelloponissos (Patra)
Crop: Roses
Areal: 0,2 ha
Weed control practice: 100% handweeding. At the moment he has drop irrigation system and before he was using black plastic as soil cover. Outside and around the greenhouse ploughing.

Area: Agrinio
Crop: Roses
Areal: 0,7 ha
Weed control practice: 4-5 times a year chemical control (Gramoxone). Also handweeding.