ALTERNATIVES TO METHYL BROMIDE IN THE STRAWBERRY PRODUCTION SECTOR IN LEBANON: APPLICATION WITHIN AN INTEGRATED MANAGEMENT PROGRAM OF THE STRAWBERRY CROP
“If one way be better than another, that you may be sure is Nature’s way”

Aristotle
This manual has been produced along with the following five related fliers (in Arabic):
- Soil solarization;
- Soil fumigation with chemical alternatives to methyl bromide;
- Reasoned fertilization of the strawberry crop;
- Integrated management of strawberry pests;
- Integrated management of the strawberry crop.

Disclaimer
This manual and its related fliers, referred hereafter as documents, are a collective effort of many people in gathering and analyzing scientific knowledge. Although the authors have exerted the best efforts to express the information contained in these documents accurately, such information is for necessity, presented in a summarized and general way and remains for reference use only.

While guidance has been provided to farmers to adopt environment friendly agricultural practices like organic farming pest control methods and non chemical alternatives to methyl bromide (MeBr), chemical pest control methods are suggested only when non chemical methods fail to be applied. Farmers are encouraged to use chemicals reasonably and only when needed as indicated in the manual, and are urged to adopt non chemical pest control methods whenever possible.

Up to the publication date (December 2009), all MeBr alternatives indicated in these documents are officially adopted by the Montreal Protocol. Similarly, all mentioned pesticides are approved by relevant international bodies like the US EPA and are authorized in the European Union. If pesticides authorizations or the scientific knowledge on which these documents are based upon, change after the publication date, the project, its team, its basic partners namely the Lebanese Ministry of Environment (MoE), the United Nations Industrial Development Organization (UNIDO) and the United Nations Environment Program/Multilateral Fund for the Implementation of the Montreal Protocol (UNEP/MLF), and all its other collaborators who contributed to the production of these documents, will not be responsible for such change.

The decision to implement any farm management technique figuring in the produced documents including pesticides and alternatives to MeBr is situation and field specific. The responsibility for the above decision and all its resulting impacts rests exclusively with the individuals or entities choosing to use these documents as they know best the particularities and prevailing conditions in their fields.

The project, its team and its above mentioned partners and collaborators do not bear any liability or legal or financial dependence resulting from the use of, or reliance upon, any information, material or procedure described in these documents.

The views expressed in the produced documents are those of the project and do not necessarily reflect the official position of MoE, UNIDO, the UNEP/MLF or the other project collaborators.

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Forewords

The Republic of Lebanon represented by the Lebanese Ministry of Environment has been an active party in the protection of life on Earth through the conservation of the ozone layer in the troposphere since the accession of Lebanon to the Vienna Convention as per law No. 253, dated 22/7/1993. The Republic of Lebanon has ratified the Montreal Protocol in 1993 and has established in 1998, with the financial support of the Multilateral Fund of the Montreal Protocol (MLF) and in partnership with the United Nations Development Program (UNDP), the National Ozone Unit in order to coordinate the phase out activities of ozone depleting substances (ODS) in Lebanon. Between 1999 and 2001, the Ministry of Environment has executed the UNEP/MLF/MoE/UNDP demonstration project to study the methyl bromide (MeBr) alternatives that can be adopted in Lebanon. In 2002, the Ministry of Environment has launched in partnership with the United Nations Industrial Development Organization (UNIDO) and with the UNDP and with a grant from the MLF, two implementation projects for the phase out of MeBr from the strawberry, vegetables, cut flowers and tobacco sectors and for its replacement by ozone friendly alternatives. MeBr phase out has been implemented in parallel to the elimination by the National Ozone Unit, of ozone depleting substances from the industrial manufacturing sector. In September 2009, the Team of the Ministry of Environment has enhanced the sustainability all above ODS phase out actions though the decree No. 2604 which controls the imports and use of ozone depleting substances including MeBr. This manual is an essential output of the UNEP/MLF/MoE/UNIDO Methyl Bromide Alternatives Project for the Strawberry Sector. It is the fruit of a remarkable collaboration with various partners namely UNIDO, the Lebanese Agricultural Research Institute affiliated to the Lebanese Ministry of Agriculture and the faculties of agricultural sciences of the American University of Beirut and of the Lebanese University. It documents in detail the application protocols of the MeBr alternatives specific to the strawberry sector. It is also a guide for farmers to implement these alternatives as part of an integrated management program of the strawberry crop. This program extends beyond ozone layer protection and integrated pest management. It is a holistic eco-agricultural approach of crops that orients farmers towards sound and sustainable agricultural practices that improve yields, lower production costs and reduce the health and environmental impacts of crop production. This eco-agricultural approach will contribute to improving the healthiness of the strawberry crop in Lebanon and is in line with the Ministry’s strong conviction of the importance of supporting and complementing the role of its environmental partners like the Ministry of Agriculture.

H.E. Mr. Mohammad Naji Rahal

Minister of Environment
Working in 173 countries around the world, the United Nations Industrial Development Organization (UNIDO) is committed to promote sustainable industrial development in developing countries and economies in transition by providing technical integrated services in three priority areas namely trade capacity building; poverty reduction through productive activities; and energy and environment.

Given the role of methyl bromide (MeBr) in ozone layer depletion, UNIDO has collaborated since 2002 with the Lebanese Ministry of Environment (MoE), the Multilateral Fund of the Montreal Protocol (MLF) and various stakeholders from both the public and private sectors, for the elimination of MeBr use from the strawberry sector in Lebanon.

In 2009, the MLF/MoE/UNIDO Methyl Bromide Alternatives Project has successfully phased out 84 metric tons from this agricultural sector and ensured the sustainability of this action by contributing to the issuance of the decree 2604, dated 17/9/2009 controlling the use and imports of ozone depleting substances including MeBr. In parallel, the project has introduced sustainable ozone friendly MeBr alternatives to strawberry farmers.

The present manual is a very valuable tool for strawberry farmers in Lebanon. It describes in detail the application protocols of MeBr alternatives and guides farmers to apply these alternatives within an integrated crop management approach. The latter, which responds to UNIDO’s thematic priorities in food safety, orients farmers towards healthier, environment friendly and sustainable agricultural practices.

H.E. Mr. Khaled El Mekwad

UNIDO Representative
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The Faculty of Agricultural and Food Sciences (FAFS) at the American University of Beirut is committed, through higher agricultural education, teaching, research, and extension, to the sustainable improvement of agricultural practices applied by farmers in Lebanon and in the Middle East region. This commitment is based upon the application of modern technologies that allow for safer, environment friendly and healthier agricultural practices.

It is within this context that the FAFS has cooperated with the Ministry of Environment and UNIDO by availing its experts in plant pathology and soil science for the evaluation and optimization of alternatives to methyl bromide in strawberry production and for the preparation of the integrated crop management (ICM) section of the Manual issued by the project and covering the above subjects.

FAFS trusts that this Manual would be a very useful practical reference on methyl bromide alternatives in the strawberry sector in Lebanon and on integrated production and management of the strawberry crop, thus encouraging growers to continue their strawberry production business or even to expand their production activities on solid and safe grounds.

Professor Nahla Hwalla

Dean of the Faculty of Agricultural and Food Sciences
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The Faculty of Agricultural Engineering and Veterinary Medicine of the Lebanese University is committed to training its students, providing them with the newest technologies and sciences, and preparing them to work in the fields of agriculture, veterinary medicine, food processing, and environment. Thus, the Faculty Agricultural Engineering and Veterinary Medicine considers itself directly concerned with agricultural production and food safety within the respect of environmental standards. It is thus normal to have the Faculty participate, in various ways, in the “Methyl Bromide Alternatives Project for the Strawberry Sector». Through one of its professors and researchers, it has contributed in designing the irrigation networks of trial fields where methyl bromide alternatives have been tested, and in training the project team and many students on how to design and adjust the irrigation systems of farmers. The students have actually participated in applying the alternatives with the farmers in the fields.

Within the same context, the Faculty has contributed to the preparation of the project manual addressed to farmers and covering methyl bromide alternatives and integrated crop management in the strawberry sector.

Professor Tayssir Hamieh

Dean of the Faculty of Agricultural Engineering and Veterinary Medicine
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The growth of the world population at an alarming rate requires agricultural increase of productivity and reduction of waste, in order to satisfy food security and environment sustainability. The Lebanese Agricultural Research Institute (LARI) supports this policy, by supporting research activities in Integrated Pest Management (IPM). This strategy has been adopted to protect the environment by limiting the use of pesticides. Fumigation with methyl bromide, an effective answer for many past years, is now unusable because of environmental constraints, and other alternatives are being researched. Methyl bromide alternatives in the strawberry sector were proven effective, especially when associated to integrated crop management. The present work provides such a reference. It is the fruit of the collaboration of many partners in which LARI valuably contributed through compilation and coordination.

Eng. Michel Afram
President / Director General
Lebanese Agricultural Research Institute
About this manual

The present manual is a technical document covering the alternatives to methyl bromide (MeBr), an ozone depleting substance (pesticide), used in the strawberry production sector in Lebanon. In 2008, this sector covered 211 Ha and was exploited by around 175 farmers.

Several alternatives to MeBr covering soil solarization and chemical fumigation have been proposed. All are officially adopted by the Montreal Protocol relative to the control of ozone depleting substances.

Their choice has been based on their ozone friendliness, efficacy, ease of application, suitability to the agricultural infrastructure in Lebanon and cost effectiveness compared to methyl bromide. Chemical alternatives are suggested only when non chemical alternatives fail to be applied. On the other hand, the various MeBr alternatives have been tailored as per the different pest pressures and agricultural practices of the different strawberry cultivation regions in Lebanon. Accordingly, no alternative can be recommended to all situations and in all regions. Each is region and situation specific.

The application protocols of the different alternatives have been exposed in detail to allow farmers and agricultural extensionists to apply them in the most appropriate manner. For each MeBr alternative, the application protocol suggested was the one among the different existing protocols which suits the Lebanese context most. It has been adjusted by the project to the Lebanese context and optimized through rigorous experimental field trials conducted over five years.

All alternatives are to be applied with an eco-agricultural holistic approach, namely in the context on an integrated crop management (ICM) program. The latter is a more global concept in comparison to the Integrated Pest Management concept and focuses on the entire farm as a basic unit, on the central role of agro-ecosystems, on balanced nutrient cycles among others rather than on just pest management.

It is important to apply MeBr alternatives within the ICM context as the efficacy of these alternatives can be masked and coupled to poor yields when bad ICM practices are adopted such as the use of diseased plants, the occurrence of soil salinity as a result of excessive fertilizers use or the observation of disease outbreaks and pesticide resistance as a result of improper pest identification and excessive use of inappropriate pesticides. Not only does an ICM strategy allow the adequate assessment of the performance of MeBr alternatives, it also reinforces their efficacy, guarantees high yields, lowers production costs and contributes to reaching healthier, environment friendly and more sustainable agricultural practices.
The key aspects of ICM ranging from proper field selection to crop rotation, mulching, sanitation, use of resistant and certified cultivars, good water management, sound strawberry fertilization and proper pest and disease management have been exposed in details in the manual though they do not all directly or strongly relate to MeBr alternatives application.

Such detailed elaboration has been done for important environmental considerations on one hand, and in order to respond to the needs of most Lebanese strawberry farmers in this regard on the other. In the latter respect, most strawberry farmers in Lebanon especially those in the remote rural areas have been requesting such information from the project in order to master the strawberry production process and avoid improper agricultural practices which mask the efficacy of methyl bromide alternatives and lead to mediocre yields, high production costs apart from soil and ground water pollution.

With an approach similar to the one adopted for the selection and optimization of MeBr alternatives, all ICM recommendations have been formulated following a rigorous scientific and long term field evaluation by the project team of the ICM practices of a representative number of strawberry farmers operating in the main strawberry production regions in Lebanon.

Dr. Nada Sabra

National Project Manager
United Nations Industrial Development Organization
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## List of Acronyms

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<thead>
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<th>Acronym</th>
<th>Description</th>
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<tr>
<td>ICM</td>
<td>Integrated Crop Management</td>
</tr>
<tr>
<td>IPM</td>
<td>Integrated Pest Management</td>
</tr>
<tr>
<td>MeBr</td>
<td>Methyl Bromide</td>
</tr>
<tr>
<td>MeNa</td>
<td>Metam Sodium</td>
</tr>
<tr>
<td>MLF</td>
<td>Multilateral Fund for the Implementation of the Montreal Protocol</td>
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<tr>
<td>MoE</td>
<td>Lebanese Ministry of Environment</td>
</tr>
<tr>
<td>ODP</td>
<td>Ozone Depleting Potential</td>
</tr>
<tr>
<td>ODS</td>
<td>Ozone Depleting Substance</td>
</tr>
<tr>
<td>UNDP</td>
<td>United Nations Development Program</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environment Program</td>
</tr>
<tr>
<td>UNIDO</td>
<td>United Nations Industrial Development Organization</td>
</tr>
<tr>
<td>1,3D+Pic</td>
<td>1,3 Dichloropropene+Chloropicrin</td>
</tr>
</tbody>
</table>
Soil Solarization

Integrated Crop Management

Chemical Alternatives to Methyl Bromide
Environmental concerns of methyl bromide (MeBr)

Despite its fumigation efficacy, methyl bromide is to be phased out all over the planet given its contribution to ozone layer depletion and the subsequent risks it poses to health and life on Earth.
I. Environmental concerns of methyl bromide (MeBr)

1.1 What is methyl bromide?

Methyl Bromide (MeBr) is a hazardous colorless and odorless fumigation gas used for the control of fungi, bacteria, viruses, nematodes, insects and weeds.

Worldwide, MeBr is mainly used for soil fumigation. A moderate amount is used for the disinfection of durable commodities (grains, wood, dried fruits,…) and perishable ones (fresh fruits and vegetables, cut flowers,…) during storage or prior to export or import (quarantine and pre-shipment uses). A lesser amount is used to disinfect structures (food processing buildings, flour mills,…) or transport vehicles (ships, aircrafts, freight containers,…) [1,2].

In Lebanon, MeBr is mainly used as a pre-planting soil fumigant in the strawberry, vegetables, cut flowers and tobacco sectors.

1.2 Drawbacks of methyl bromide use

Although a very powerful fumigation agent, methyl bromide contributes to the depletion of 3-10% of the ozone layer located in the stratosphere [3]. This ozone depletion which is also caused by chlorine containing compounds especially the chlorofluorohydrocarbons (CFCs) (refer to annex 1) has led to the formation of large ozone holes over the poles, especially over the southern pole, and has resulted in an increased exposure of Earth to the UVB radiation (280-320 nm) of the sun.

Ninety percent of the ozone is present in the stratosphere at an altitude comprised between 15 and 35 km above sea level. Source of the photo: reference [4]
This radiation is unfortunately harmful to life and is associated with higher risks of:
- skin cancer;
- eye cataract;
- depression of the immune system;
- disruptions in the marine food chain;
- repressions in plant productivity;
- increased levels of toxic tropospheric ozone.

Besides the concerns related to ozone depletion, methyl bromide is a non-selective biocide which kills beneficial soil microorganisms and leads to soil sterility. It is also a highly hazardous and toxic compound. Direct exposure to it can cause a range of health effects in humans, including neurological symptoms such as headaches, nausea, muscle tremors and visual disturbance and even death in case of severe exposure.
The Montreal Protocol

Lebanon is committed to limit its consumption and imports of ozone depleting substances including MeBr as it has ratified the Montreal Protocol in 1993.
2. The Montreal protocol

The Montreal protocol is an international agreement designed to protect the Earth’s stratospheric ozone layer by controlling the production and consumption of ozone depleting substances (ODS) including MeBr. The Protocol was adopted in September 16, 1987. It came into force in January 1, 1989 and was ratified by Lebanon in 1993.

In 1997, Parties to the Montreal Protocol agreed on the following MeBr phase out schedules:

Table 1: Elimination schedules of MeBr for article 5* and non articles 5 countries [5]

<table>
<thead>
<tr>
<th>Non – Article 5 countries</th>
<th>Article 5 countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% reduction in 1999 (based on 1991 consumption levels)</td>
<td>Freeze of consumption in 2002 (based on the average 1995-1998 consumption levels)</td>
</tr>
<tr>
<td>50% reduction in 2001</td>
<td>20% reduction in 2005</td>
</tr>
<tr>
<td>70% reduction in 2003</td>
<td>Complete phase out in 2015</td>
</tr>
<tr>
<td>Complete phase out in 2005</td>
<td></td>
</tr>
</tbody>
</table>

*Developing countries whose annual consumption of ozone depleting substances falling under annex A of the Montreal Protocol (chlorofluorocarbons and halons) does not exceed 0.3 kg/capita. Lebanon is an article 5 country. Non-article 5 countries mainly comprise industrialized countries.

Both of these schedules have been set for the non critical uses of MeBr. Critical uses of MeBr are exempt from these controls.

Despite of these deadlines, many countries, have committed to phase out MeBr well in advance of the Montreal Protocol schedule. This is case of Lebanon which adopted a relatively short phase out schedule of 5 years starting 2002.

In 1998, the Government of Lebanon established the National Ozone Unit (NOU) within the Ministry of Environment (MoE) in order to coordinate all ODS phase out activities in the country, implement ODS elimination in the industrial sector, create and increase national awareness activities regarding ODS, monitor ODS usage, and
develop and enforce legislations to control ODS use and imports in the country. The activities of the NOU are executed by MoE, implemented by the United Nations Development Program (UNDP) and financed by the Multilateral Fund (MLF) for the implementation of the Montreal Protocol. The MLF has been established by the international community to help developing countries in phasing out ODS.
MeBr Alternatives Project for the Strawberry Sector in Lebanon

The present section highlights the goal and main objectives of the Methyl Bromide Alternatives Project for the Strawberry Sector in Lebanon.
3. MeBr Alternatives Project for the Strawberry Sector in Lebanon

The methyl bromide phase-out project for the strawberry sector in Lebanon responds to the ratification of the Montreal Protocol by the Government of Lebanon. Its main goal is the progressive elimination of 84 metric tons of MeBr use from the strawberry sector and their replacement by ozone-friendly alternatives.

The project is funded by the MLF, executed by MoE and implemented by the United Nations Industrial Development Organization (UNIDO).

It is carried out in parallel to a similar project implemented by the UNDP, executed by MoE, funded by the MLF and aiming to phase out of MeBr from the vegetables, cut flowers and tobacco sectors.

The duration of both UNIDO and UNDP MeBr Alternatives Projects was five years, starting from 2002. However, as a result of the security conditions observed in Lebanon in 2006, no MeBr could be phased out during that year and the activities of both projects have been extended until the end of 2008; with a rescheduling of the 2006 MeBr phase out targets (15 tons for the strawberry sector and 72.2 tons for the vegetables, cut flowers and tobacco sectors) over 2007 and 2008. The MeBr phase out schedules of the two projects is given in table 2 below:

Table 2: MeBr phase out schedule in Lebanon

<table>
<thead>
<tr>
<th>Year</th>
<th>MeBr metric tons phased out in the strawberry sector</th>
<th>MeBr metric tons phased out in the vegetable, cut flowers and tobacco sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>10.0</td>
<td>43.0</td>
</tr>
<tr>
<td>2003</td>
<td>16.8</td>
<td>60.0</td>
</tr>
<tr>
<td>2004</td>
<td>23.6</td>
<td>90.0</td>
</tr>
<tr>
<td>2005</td>
<td>18.5</td>
<td>60.0</td>
</tr>
<tr>
<td>2006</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Year</td>
<td>MeBr metric tons phased out in the strawberry sector</td>
<td>MeBr metric tons phased out in the vegetable, cut flowers and tobacco sectors</td>
</tr>
<tr>
<td>------</td>
<td>-----------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>2007</td>
<td>8.3</td>
<td>36.7</td>
</tr>
<tr>
<td>2008</td>
<td>6.6</td>
<td>35.5</td>
</tr>
<tr>
<td>All Years</td>
<td>84.0</td>
<td>310.2</td>
</tr>
</tbody>
</table>

To accomplish its goal, the MeBr Alternatives Project for the Strawberry Sector has set 3 main objectives:

1. Substitute MeBr by sustainable MeBr alternatives that are:
   a. Ozone friendly;
   b. Efficient;
   c. Cost effective compared to MeBr;
   d. Easy to apply;
2. Couple MeBr alternatives to an integrated crop management program (ICM);
3. Develop legislative tools to control MeBr use and imports.

The project shall conduct extensive capacity building activities in the form of awareness and training sessions at the level of farmers and bear part of the cost of the alternatives supplies in order to help farmers switch to MeBr alternatives.

*Discussing MeBr alternatives with farmers in the presence of Prof. Mohamed Besri from the MeBr Technical Options Committee of the Montreal Protocol. Photo taken by the project team.*
The Strawberry Crop

This section overviews the main aspects of the strawberry production sector in Lebanon including cultivation regions and surfaces, operating farmers, planting patterns and strawberry varieties.

Based on a field survey conducted by the project team, the data reported in this section applies for the 2007/2008 strawberry season.
4. The strawberry crop

4.1 The plant

The strawberry plant, *Fragaria sp.* is a low perennial herb belonging to the Rosaceae family and is native of temperate climates. The plant consists of a crown and a stem from which the roots grow downward. There are two basic types of strawberries planting systems:

- **Winter planting cultivars:** They are called June bearing strawberries or short day cultivars. They produce one crop per year. Plantings are made in mid to late fall for early spring fruit production.
- **Summer planting cultivars:** They are called ever bearing strawberries. They flower and set their fruits throughout the year as long as the weather is appropriate.

Strawberry plants will not produce flower buds when night time temperatures remain above 16°C. If daylight is shorter than 14 hours and temperatures are below 7.2 °C, the plant will be in a dormant state. More chilling increases vigor and decreases the number of flower branches whereas limited chilling results in low plant vigor.

During the rest period, strawberry tolerates freezing temperatures. Optimum temperature levels for the vegetative and reproductive phases are 10-15°C at night and 20-24°C during day time.

New strawberry plants, called daughter plants, develop along runners or stolons that grow from the axillary buds of the crown.

Optimal conditions for growing strawberries are in full sun, in a sandy loam soil with a soil pH of 7.0. The soil should be kept evenly moist and well drained.
4.2 Strawberry cultivation in Lebanon

Strawberry cultivation in Lebanon began in the early sixties and evolved during the late eighties to become a major horticultural crop. In 2008, Lebanon’s strawberry production has been estimated by the project to around 10,000 tons mainly domestically consumed, fresh or transformed. Exports are still limited and are mainly oriented towards the Arab gulf countries.

In 2001, strawberry farms covered an area of 200 Ha and were operated by 248 farmers. In the crop season 2007/2008, according to a survey conducted by the project team, strawberry area was still around to 200 Ha (211 Ha) but the number of farmers dropped to 175 (visit the data base web site of strawberry farmers in Lebanon: www.moe.gov.lb/geodatabase/mebr).

The main strawberry cultivation regions cover:

- the littoral mainly along southern Beirut and Akkar: it is characterized by winter fruit production under greenhouses or under plastic tunnels in the open fields;

- Kesserwan and Jbeil heights: are suitable for summer planting cultivars and are mainly dedicated to fruit production and to a lower...
extent, to plant production in the open field or under small tunnels;

- northern Bekaa: hosts the major Lebanese nurseries producing winter planting daughter plants in the open fields.

Fruit production is essentially done on raised beds. In the littorals, bed height is 20-30 cm and the average bed width ranges from 30-40 cm (top width) to 60-70 cm (base width). Usually, beds bear one drip irrigation line for two lines of plantation.

In Mount-Lebanon heights, bed height is 10-15 cm and the average bed width is 35-60 cm on the top and around 60 cm at the base. Beds contain two to four lines of plantation served by one to three drip irrigation lines.

In Bekaa nurseries, planting is done on a flat soil and irrigation is mainly practiced by flooding. Plants lines are usually 50 cm apart.

In the crop season 2007/2008, the main variety planted in Lebanon was Camarosa. Motto is planted to a much lower extent along with some newly introduced varieties in the costal areas and the Bekaa valley such as Ventana, Festival, Gadonga and Albium. Selva, Seascape and Whitney are essentially planted in the mountains.

In Lebanon, the strawberry soil borne pathogens are mainly fungi especially Rhizoctonia spp, Fusarium spp, Verticillium spp and Phytophtra spp. Nematodes are less encountered. Except in northern Bekaa and Jbeil heights, weeds are partially controlled by the plastic mulch that farmers use most of the season. Therefore, the key soil borne pathogens to be controlled by MeBr alternatives are fungi followed by weeds.
MeBr Alternatives Adopted by the Project

The MeBr alternatives adopted by the project are exposed in detail and their advantages and drawbacks highlighted.

They are situation and region specific and are all officially adopted by the Montreal Protocol. Their application methods have been tailored to the Lebanese agricultural infrastructure and to the Lebanese strawberry sector. Furthermore, they have been optimized by the project over several years. Besides these alternatives, the valuable experience of the project in soil steaming is exposed.
Soil solarization: principle, application method, advantages and drawbacks
5. MeBr Alternatives Adopted by the Project

5.1 Soil solarization

Introduction
Soil solarization is an environment friendly soil disinfection technique using solar energy to reduce the occurrence of many soil borne pathogens and weeds except those with deeply buried structures. It is one of the non chemical alternatives to MeBr that have been adopted by the Montreal Protocol [1,2]. It needs to be applied on a yearly basis and its efficiency is improved when coupled to crop rotation.

In Lebanon, soil solarization is mainly applied in northern Bekaa (Baalbeck, Hermel) and in Akkar valley in the north. In these regions, crop rotation is applied and soil exploitation is low to moderate. Agricultural lands are thus characterized by low to medium infestation levels. At the same time, they are relatively cheap compared to the more intensively exploited soils located along the coast at the south of Akkar or in Mount-Lebanon. Accordingly, farmers can afford solarizing their moderately infested soils over 6-8 weeks in northern Bekaa and in Akkar although soils will remain unexploited and thus non income generating during this relatively long period.

Application protocol
The application protocol is as follows:

1. All previous crop residues are removed from the land as remnants could be a source of contamination.
2. The soil is deeply ploughed (30-40 cm) and the proper quantity of fertilizers especially composted manure is added as per soil requirements. Composted manure contributes to temperature rise during the treatment and reduces the incidence of weeds in the soil.
3. The soil is flooded with water so that the soil moisture level is brought to 90%. Such flooding will activate soil pathogens and optimize their control during the treatment.
4. The soil is allowed to dry in the open air for few days so that its moisture content drops to 65% at 30 cm. The drying period varies from 4-5 days for light sandy soils and up to 7-10 days for heavy clayey soils.
5. The soil is tilled with a rotor tiller so that it is properly homogeneous and well aerated.

6. The drip irrigation system is installed to humidify the soil when needed and to keep its moisture level at a depth of 30 cm equal to 65% during the whole treatment period. For optimum soil coverage, the distance between two adjacent drip lines should not exceed 1 m.

7. Ditches are made at the four sides of the field.

8. The soil is covered with a thermal polyethylene sheet which allows a rise of 4°C to 5°C in soil temperature, in comparison with the use of regular polyethylene sheets. The plastic sheet needs to be fixed tightly over the soil to ensure optimum temperature and humidity conservation. For these reasons:
   a. The plastic roll should be unfolded very close to the surface of the soil and in the direction of...
the wind to avoid the formation of air pockets under the plastic sheet.

b. Once the plastic sheet is spread over the soil, the four extremities of the sheet are placed in the ditches and covered with soil from the inside. This will tighten the plastic sheet to the ground using a solarized soil.

c. Any perforations in the plastic sheet which may form during the treatment, due to animals crossing or other factors, need to be sealed off with a scotch tape.

9. Thermometers are fixed at a depth corresponding to the depth of the root zone (20-25 cm for strawberry) and daily readings are taken. The highest temperature is usually observed towards the sunset as the soil would have accumulated most of the solar energy by the end of the day.

10. Tensiometers are fixed at the same depth as the thermometers, and frequent readings are recorded. For an efficient soil solarization treatment, the soil moisture level should be kept above 65% at root depth. Consequently, the soil should be moistened whenever needed using the installed drip irrigation system.

11. The soil is left covered for 6 to 8 weeks. A rise in soil temperature at root depth above 45°C for at least 6 consecutive hours over several consecutive days (7-14 days) indicates that soil solarization is proceeding positively.

12. After a period of 6-8 weeks, the plastic sheet cover is removed while taking care to avoid soil recontamination by avoiding carrying non treated soil from uncovered areas to the treated soil.

Given the climate in Lebanon, and for optimum soil solarization results, it is highly recommended to start solarizing the soils starting mid-June or the beginning of July at the latest.
13. The soil is then ready for planting. Disease free transplants should be used. Similarly, farmers boots, equipment and other contaminated material should be avoided to prevent soil recontamination with inocula of pathogens.

**Advantages of soil solarization**
- Environment friendly and conserves many beneficiary soil micro-organisms;
- Cost effective compared to methyl bromide;
- Easy to apply.

**Drawbacks of soil solarization**
- Efficient on soils with low to medium infestation level only;
- Requires a relatively long application time and is not cost effective when land rental is expensive;
- Efficiency depends on climatic conditions.

Avoid burning or disposing of in nature agricultural plastic wastes such as solarization and fumigation sheets. Preserve the environment and gain profit by selling them to existing plastic recycling plants.
Soil fumigation with chemical alternatives to MeBr: MeNa and the mixture 1,3 Dichloropropene+Chloropicrin

The mode of action, application protocols, advantages and drawbacks of these soil fumigants are detailed in this section. The combination of soil solarization with chemical fumigation is also discussed.
5.2 Soil fumigation with chemical alternatives to MeBr

The chemical alternatives to MeBr adopted by the project are, as will be detailed in the following sections, the fumigants Metam Sodium and the mixture 1,3 Dichloropropene+Chloropicrin.

These fumigants are mainly applied in Beirut and the coastal areas of Mount-Lebanon (Choueifat, Jiyeh, Damour, Tabarja). To a lower extent, they are adopted in Batroun and in Kesrewan and Jbeil heights.

Compared to most soils in northern Bekaa and Akkar, the agricultural lands of the littoral located at the south of Akkar especially in Beirut and in Mount-Lebanon are very expensive and many farmers can not afford solarizing their soils and getting no revenue from them for nearly 2 months. In Kesrewan and Jbeil heights, soil solarization is limited as only summer planting varieties can be planted there and thus as soil is harvested and ready for treatment only by mid to late fall (end of October-mid November).

At the same time, in all above regions, crop rotation is either not adopted or improperly practiced (crop cycle: 1 year, rotation crops: tomatoes, cucumbers and egg plants mainly) given the high cost of lands and the limited revenue of suitable strawberry rotation crops such as cereals, leafy vegetables and legumes.

On the other hand, soils in Beirut and Mount-Lebanon are heavily exploited and thus heavily infected by strawberry pathogens. Even if applied, soil solarization alone does not produce satisfactory results especially that the climate is moderate in these regions. Soil fumigation with chemical alternatives to MeBr is indispensable and better if combined with soil solarization whenever possible.

5.2.1. Soil Fumigation with Metam Sodium (MeNa)

Introduction
MeNa is a pre-planting soil fumigant which is effective against several soil borne pathogens such as fungi (Fusarium sp.; Verticillium sp.; Phytophtora sp.; Rhizoctonia sp…), nematodes, soil insects, and weeds. [1,2].
When diluted in water, it is decomposed to give a gas called methyl isothiocyanate (MITC) which disperses in the soil and disinfects it. The Lebanese commercial form of MeNa exists at a concentration of 510g/l.
MeNa is a soil fumigant which treats soil pathogens efficiently while causing a limited environmental impact. In fact, the MITC gas produced from MeNa has the same structure and mode of action as some natural biofumigation by-products of the Brassicacea family (ex. some species of rapeseed, radish, cabbage and mustard).

**Application Protocol**
In Lebanon, MeNa is applied by drip irrigation. In order to ensure optimum soil disinfection results, factors other than MeNa itself should be taken into consideration. A thorough ploughing and tilling of the soil is needed to secure an even distribution of the product in it. Also, an adequate watering is needed to activate MeNa uniformly in the soil. Other parameters should be considered as well such as the proper design of the irrigation system, soil temperature, soil nature, and the life cycles of soil borne pathogens.

**Preparatory steps**
Before applying MeNa, several preparatory steps should be followed:
1. All remaining crop wastes from previous seasons are removed;
2. The soil is deeply tilled (30-40 cm) and the proper dose of fertilizers added. A minimum period of 3 weeks should be observed between the application of natural organic fertilizers such as manure and the application of MeNa in order to avoid MeNa's adsorption on those fertilizers and a consequent drop in product efficacy.
3. The soil is flooded with water.
4. The soil is allowed to dry a little bit in the open air for few days. The drying period varies from 4-5 days for light sandy soils to 7-10 days for heavy clayey soils.
5. The soil is tilled with a rotor tiller so that the soil is properly homogeneous, aerated and with a moisture content of 65% at 30cm prior to treatment.
6. The drip irrigation system is installed on either a flat soil or on raised beds. In either case, the number and length of the drip lines should respect the dimension of the water pipe feeding these drip lines.

If MeNa is to applied on a flat soil, the maximum distance between every two irrigation lines should be 40 cm. Photo taken by the project team.
the drippers should not be clogged and should be opened when needed with the suitable acidic solutions such as nitric acid (refer to annex 2).

a. Design of the irrigation system for flat soil applications: It is recommended to apply MeNa on a flat soil and to raise strawberry beds once the fumigation is over as the plastic sheet would be tightly stuck on the soil, a fact which ensures good penetration of MeNa in the soil and thus optimal fumigation results. A maximum distance of 40 cm should be observed between every two drip irrigation lines (25-30 cm is better) to ensure good dispersion or coverage of the active ingredient in the soil.

b. Design of the irrigation system for raised bed applications: For raised bed crops like strawberry, the application of MeNa on raised beds is more practical than flat soil application although it leads to less adequate product distribution in the soil. To overcome inadequate product distribution in the soil the plastic sheet should stick to the soil on both sides of the bed (observation of proper soil moisture levels of 65% at root depth prior to fumigation would be of great help). In addition, irrigation lines should be placed in the alleys in case these need to be planted. Finally, once the treatment is over, it is imperative to work the beds with a fork at 10 cm in order to ensure their proper aeration.

7. Following the installation of the irrigation system, ditches are made at the four sides of the field.

8. The soil is covered with a polyethylene sheet. Virtually Impermeable Films are recommended as they reduce losses of the fumigant across the film and allow better results with lower pesticide doses. The plastic sheet needs to be fixed tightly or hermetically over the soil to ensure optimum temperature and humidity conservation in the soil.

In raised bed application of chemical fumigants, the irrigation lines should be fixed at the center of the beds. Photo taken by the project team.

In raised bed chemical fumigation, the plastic sheet should be as tight as possible on each side of the bed to allow best fumigation results. Photo taken by the project team.
Remarks:
• It is preferable that steps 5-8 above are achieved in one day to conserve soil moisture at the optimal level.
• Four to five days before the application of MeNa and until the soil is fumigated, the soil should be well irrigated with a moisture level of 60-65% at a depth of 30 cm.

Injection of MeNa in the soil
It is recommended to have MeNa applied by soil fumigation professionals. On the treatment day, the application steps of MeNa are as follows:

1. The soil is irrigated for few minutes to moisten the soil and build pressure in the irrigation system.
2. MeNa is applied at a dilution rate of 5%-8% (the rate should not drop below 4% as MeNa is very unstable in dilute solutions) and a dosage of 150 liters/1,000 m² using a stainless steel positive displacement injection pump. The latter discharges a fixed amount of MeNa in the irrigation pipe at regular intervals.
3. At the above dilution rate, the duration of the application time should not exceed 10-15 minutes per 1000m². The treatment dosage can be lowered to 100-120 liters/1,000 m² if the operation is coupled to soil solarization.
4. After MeNa is applied, the soil is irrigated for a time corresponding to three times the application time. This will ensure the migration of the MeNa and its by-products to the desired root depth (around 25 cm) and rinse the irrigation system as well.

Waiting period
1. Following MeNa application, the plastic should remain on the soil for 21 days to optimize treatment efficacy and minimize post-planting phytotoxicity due to MeNa residues in the soil.
2. No water should be added to the soil during the waiting period.
3. After 21 days, the plastic sheet can be removed while taking care to avoid soil recontamination caused by carrying non treated soil from uncovered areas to the treated soil.

If planting is delayed when the waiting period is over, it is recommended to keep the soil covered with the plastic sheets until it is planted in order to minimize soil re-infestation by crossing people and animals or by wind carrying weed seeds.
Preventing post-planting phytotoxicity by MeNa residues in the soil

After the plastic sheet is removed, and in order to minimize the risks of post-planting phyto-toxicity by MeNa residues in the soil,

1. The soil should be irrigated for 1-2 hours/day over 2-3 consecutive days to remove all residues of MeNa from the soil and the irrigation system (the final volume of applied water depends on soil type).

2. The soil is left for aeration for 2-3 additional days. Aeration should be improved manually by working the soil with a fork at a shallow depth (max. 10 cm).

3. A germination test using lettuce seeds needs to be conducted to be sure that the soil is free from product residues. Seeds should germinate in three days in the absence of MeNa residues in the soil.

4. The soil is ready for planting. Infested farmers’ boots and equipment and other contaminated material should be avoided to prevent soil recontamination. Similarly, disease free plants should be used.

Recommendations and considerations

- The temperature at the depth of 10 cm should be between 10°C and 25°C, as temperatures less than 10°C slow down the dispersion of the fumigation gas inside the soil.
- MeNa is classified as a class II moderately hazardous fumigant. It causes skin allergy to humans, medium hazards for mammals and birds and severe hazards to the water ecosystem. It is corrosive and produces a harmful gas when mixed with water or acids.

Advantages of MeNa

- Targets main soil borne strawberry pathogens namely fungi;
- Highly efficient in moderately infested soils;
- Gives very good results when combined to crop rotation & soil solarization;
- Moderately hazardous with a limited impact on humans & the environment;
- Cost effective compared to MeBr.

Drawbacks of MeNa

- Is moderately effective in soils with high pest pressures. Its moderate effect on weeds and limited effect on nematodes are however improved when
doses higher than those specified previously are adopted;
• Has a relatively limited dispersion coefficient in soils, a fact that requires
  that irrigation lines on flat soil be placed at a maximum distance of 40 cm
  from each other.

5.2.2 Soil fumigation with the mixture 1,3 Dichloropropene+Chloropicrin (1,3D+Pic)

Introduction
The mixture 1,3 Dichloropropene+Chloropicrin (1,3D+Pic) is a pre-planting soil
fumigant with high action on soil borne fungi and nematodes and a lower action on
weeds [1,2].
1. The Dichloropropene component is very powerful on nematodes and
   some fungi and has a secondary effect on weeds;
2. The Chloropicrin component is highly volatile and has a high action on
   fungi and a lower action on weeds.
In Lebanon, the commercial formulation of 1,3D+Pic is composed of around 72%
(w/v) of Dichloropropene and 43% (w/v) of Chloropicrin.

Application Protocol
In Lebanon, 1,3D+Pic is applied by drip irrigation. In order to ensure optimum soil
disinfection results, factors other than 1,3D+Pic itself should be considered such as
good soil preparation, suitable design of the drip irrigation system, soil temperature,
soil nature, and the life cycles of the soil borne pathogens among others.

Preparatory steps
Before applying 1,3D+Pic, several preparations should be taken. The preparatory
steps adopted are the same as those adopted prior to MeNa application except
that, when placing the irrigation system on a flat soil, a maximum distance of 70
cm should be observed between every two drip irrigation lines to ensure good
dispersion or coverage of the active ingredient in the soil.

Injection of 1,3D+Pic in the soil
As for MeNa, it is recommended to have 1,3D+Pic applied by soil fumigation
professionals. On the treatment day, the application steps of 1,3D+Pic are as follows:
1. Water is applied for few minutes at a rate of 7-10 m³/1,000m² to moisten the
   soil and build pressure in the irrigation system.
2. 1,3D+Pic is applied at a dilution rate of 2‰-3‰ and a dosage of 40-50 kg/1,000m²
   using a stainless steel positive displacement injection pump. The application
time should be comprised between 45min and 60min per 1,000 m². The lower
application rate (40 kg/1,000 m$^2$) is used for light or moderately infected soils. The treatment dosage can be lowered to 35 kg/1,000 m$^2$ if the operation is coupled to soil solarization.

3. After 1,3D+Pic is applied, the soil should be irrigated for 30 minutes at a rate of 5-10 liters/m$^2$. This will push the product to root depth (25-30 cm) and will rinse the irrigation system as well.

**Waiting period**

1. Following 1,3D+Pic application, the plastic sheet should remain on the soil for a minimum of 15 days (a period of 21 days is better) to optimize treatment efficacy and minimize post-planting phytotoxicity due 1,3D+Pic residues in the soil.

2. No water should be added to the soil during the waiting period.

3. After 15-21 days, the plastic sheet is removed while taking care to avoid soil recontamination by carrying non treated soil from uncovered areas to the treated soil.

**Preventing post-planting phytotoxicity by 1,3D+Pic residues in the soil**

The steps indicated previously to avoid post-planting phytotoxicity by MeNa residues in the soil (steps 1-4, p. 35) prevent post-planting phytotoxicity by 1,3D+Pic residues in the soil as well and should therefore be adopted. It is worth noting that the manual aeration of the top soil with a fork (part of step 2) and the germination test with lettuce seeds (step 3) are obligatory after soil fumigation with MeNa while they are recommended after its fumigation with 1,3D+Pic.

**Recommendations and considerations**

- The temperature at the depth of 10 cm should be between 10°C and 25°C as temperatures less than 10°C slow down the dispersion of the fumigation gas inside the soil;
Both active ingredients of 1,3D+Pic namely Dichloropropene and Chloropicrin are classified as High Hazard fumigants;

1,3D+Pic is highly toxic to humans and can lead to death;

Due to its content of 1,3 Dichloropropene, 1,3D+Pic is highly phytotoxic and moderately toxic to fish;

1,3D+Pic poses a risk of ground water pollution due to the relative mobility of Dichloropropene in soils;

1,3D+Pic is corrosive and is not compatible with other products and should therefore be applied alone;

Given its environmental profile, 1,3D+Pic should be limited to highly infested soils and avoided in cases of shallow water tables and springs proximity.

Advantages of 1,3D+Pic

- Recommended for highly infested soils and especially efficient on nematodes and fungi;
- Diffuses in soils widely and relatively rapidly by virtue of its high gas partition coefficient and consequently allows up to 70 cm of distance between the drip irrigation lines when fumigation is done on a flat soil;
- Has a relatively short application time compared to other fumigants such as MeNa.

Drawbacks of 1,3D+Pic

- Has a limited efficacy on weeds;
- Is a highly hazardous organochlorine fumigant and poses risks of ground water pollution due to the relative mobility of dichloropropene in soils;
- Is highly toxic to humans and can lead to death.
Summary of the application protocols of MeNa and 1,3D+Pic
5.3 Combination of soil solarization with chemical fumigation

Reduced doses of MeNa or 1,3D+Pic can be adopted when chemical fumigation is coupled to soil solarization. MeNa doses can be reduced to 100-120 liters/1000m² (instead of 150 liter/1000m²) and 1,3D+Pic doses can be lowered to 35 kg/1000m² (instead of 45 kg/1000m²) provided soil solarization is applied under suitable climatic conditions for 4-6 weeks.

The combined treatment reinforces the efficacy of soil solarization and should be applied on a flat soil.

After installing the drip irrigation system, the soil is covered with plastic sheets and injected with the fumigants. Injection can be done immediately after soil coverage or with a delay of 7-10 days.

No water should be added during the application time of the fumigants (21 days for MeNa and 15 days for 1,3D+Pic). It can be added later on if needed.

At the end of the treatment (4-6 weeks), the plastic sheets are removed and the irrigation system rinsed as previously described for the chemical fumigants. Post-planting precautions should be adopted as done following the application of MeNa or 1,3D+Pic.
Project experience in soil steaming
5.4 Project experience in soil steaming

Soil steaming is a soil disinfection technique based on the injection of steam in the soil. In general, a soil temperature of 70°C should be observed for 30 minutes at a soil depth equivalent to the root zone depth in order to free the soil from plant pathogenic fungi, nematodes, bacteria, insects and weeds. The temperature of 70°C for 30 minutes excludes viruses which need a thermal inactivation point between 85°C and 100°C [1,2].

Soil steaming is a very powerful soil disinfection technique. Its efficiency is equal and in some cases superior to that of MeBr. Unlike MeBr, it has the main advantage of being relatively environment friendly as it is based on just steam and without any chemicals added [1,2].

Different soil steaming techniques exist namely passive or sheet steaming, positive pressure steaming & negative pressure steaming.

In the first two techniques, steam is applied on the soil and the latter is covered with a heat resistant plastic sheet (sheet steaming) or with a rigid aluminum plate (positive pressure steaming). Steam penetration in the soil is more efficient and more rapid in the positive pressure technique due to the rigidity of the steaming plates. In negative pressure steaming, steam is applied on top of the soil and the latter is covered with heat resistant sheets. Rapid steam penetration in the soil is assured by powerful vacuum pumps connected to perforated pipes embedded in the soil below the root zone and which rapidly
suck the steam from the top of the soil to the desired soil depth. Negative pressure steaming is more expensive and more difficult to apply than sheet or positive pressure steaming.

In Lebanon, sheet steaming has been tested by the project on an experimental basis while positive pressure steaming has been applied as a MeBr alternative on a limited scale in the main strawberry production regions.

The choice of soil steaming has been decided by UNIDO and MoE following the former MLF/MoE/UNDP Demonstration Project on MeBr Alternatives (1998-2001) based on the proven efficiency of this technology, its non-chemical nature and the readiness of strawberry farmers to adopt it. Unfortunately, no soil steaming could be tested by the demonstration project.

The practical application of positive soil steaming technology by the MLF/MoE/UNIDO MeBr Alternatives Project for the Strawberry Sector revealed that this technology is limited by various technical and cost limitations: high fuel consumption (around 775 liters/1000 m²), high and constant increases in fuel prices, long application time (around 11 hours/1000 m²), field access difficulties (mainly in mountains and in narrow roads), high labor requirements and thus high labor cost, difficult and expensive transport conditions of the steam generator and its accessories, tractor dependence and high rental costs of tractors, need for water treatment prior to use in the steam generator and thus higher operational costs, water and fuel replenishment difficulties, work delays due to labor limitations, difficult payment facilities for farmers, and eventual machine breakdown delays among other limitations.

While the practical experience of soil steaming revealed that the high fuel consumption and the long application time are inherent of the steaming technology itself, many of the remaining above limitations are specific to the Lebanese agricultural infrastructure and could not be easily and accurately foreseen before the implementation of the project especially that soil steaming could not be tested by the former UNDP demonstration project.

Given the above mentioned technical and cost limitations, soil steaming has been abandoned by the project and substituted by the alternatives described in the previous sections namely soil solarization and chemical fumigation (MeNa and 1,3D+Pic) as they are more practical, cost effective and more sustainable alternatives compared to soil steaming.
MeBr Alternatives and Integrated Crop Management (ICM)

The importance of implementing MeBr alternatives in the context of an Integrated Crop Management (ICM) strategy is discussed. The major aspects of ICM including sound strawberry fertilization, proper pest and disease management, crop rotation and adequate water management are exposed.

The present section has been prepared following the field assessment by the project team of the ICM practices of a representative number of strawberry farmers working in the major strawberry production regions in Lebanon. Accordingly, this section allows the improvement of several inadequate ICM practices observed by the project team in many strawberry farms.
6. MeBr Alternatives and Integrated Crop Management (ICM)

Integrated Crop Management (ICM) is an environmentally sensitive and economically viable production system or process which uses the latest available techniques to produce high quality food in an efficient manner [9].

**Sustainable Agriculture**

ICM is a more global concept than the Integrated Pest Management concept as the latter is basically concerned with pest control. ICM is an integral component of Integrated Farming Systems or Integrated Production which focuses on the entire farm as a basic unit, on the central role of agro-ecosystems, on balanced nutrient cycles, and on the welfare of all species including those in animal husbandry [9].

The preservation and improvement of soil fertility and of a diversified environment are of prime importance. Biological, technical and chemical methods are balanced carefully taking into account the protection of the environment, profitability and social requirements [9].

*Source of photo: [9]*
Importance of Integrated Crop Management in the context of the project

ICM reinforces the efficacy of MeBr alternatives, guarantees high yields, lowers production costs and contributes to reaching healthier, environment friendly and more sustainable agricultural practices.
6.1 Importance of ICM in the context of the project

No soil disinfection method including soil fumigation with MeBr itself can be really evaluated if it is associated to bad crop management practices. The real performance of MeBr alternatives can be masked and coupled to poor yields when inappropriate ICM practices are adopted such as the use of diseased plants, the contamination of freshly treated fields with infected soil or irrigation water, the occurrence of soil salinity as a result of excessive fertilizers use or the observation of disease outbreaks and pesticide resistance as a result of improper pest identification and excessive use of inappropriate pesticides.

All methyl bromide alternatives should therefore be coupled to an integrated crop management program in order to:

- Adequately assess the performance of MeBr alternatives;
- Reinforce the efficacy of MeBr alternatives;
- Guarantee high yields;
- Lower production costs;
- Reach healthier, environment friendly and sustainable agricultural practices.

The sections below will detail the most important ICM practices in relation to the application of MeBr alternatives in the strawberry sector and will guide farmers towards better yields and more environmental friendly and sustainable production practices. Besides being based on relevant references (mainly references 10, 11, 12, 13, 14, 15, 2, besides references 1, 9, 16, 17 and others), the preparation of these sections comes after a rigorous field monitoring of the ICM practices of a representative number of strawberry farmers operating in the major strawberry producing regions in the country.
Factors affecting the integrated management of the strawberry crop: Basic considerations

The basic components of the integrated management of the strawberry crop are covered in this section namely proper field selection, crop rotation, adequate soil preparation, mulching, the use of certified and resistant cultivars, sound water management and sanitation.
6.2 Factors affecting the Integrated Management of the Strawberry Crop

6.2.1. Basic considerations

6.2.1.1 Field selection
Soils with good soil history, and which are neither saline nor infested need to be selected.

6.2.1.2 Crop rotation
Planting a given field with the same crop year after year depletes the soil from the nutrients required by this particular crop, thus increasing the fertilization requirements. On the other hand, the field becomes more prone to the build up of soil pathogens and the risk of having these develop a resistance to pesticides increases.

These problems can be reduced by adopting crop rotation which is a traditional agricultural practice in which a given field is planted with a variety of crops and where no crop is planted in the same place each year.

The observed diversity and spatial rotation of crops breaks the cycle of the strawberry diseases and thus, limits the spread of the pathogens.

For best results in managing the soil borne strawberry pathogens, crop rotation needs to be applied over a cycle of 3 years or more.
Also, the selected rotation crops should belong to families that are different from that of strawberry. These include cereals (wheat, barley, ...) mostly cultivated in the Bekaa or leafy vegetables (lettuce, radish, cabbage, rocket, mint, ...) and leguminous plants (green beans, green peas, etc.) frequently planted in Akkar.

Crops belonging to the Brassicacea family such as cabbage or radish are very recommended before strawberry cultivation as they release natural bio-pesticides upon fermentation in the soil.

Crops having common diseases with strawberry such as tomatoes or cucumbers are to be avoided.

In the more intensively exploited soils where soil pathogens levels are higher as in Beirut and Mount-Lebanon, crop rotation should be envisaged to reduce pesticide dependence. Pertinent rotation crops with an acceptable financial revenue like broccoli need to be envisaged.
Besides its contribution to lowering soil pathogens levels, crop rotation:
- Contributes to the conservation of the soil nutrient balance;
- Improves soil structure and reduces fertilization requirements and costs;
- Conserves soil beneficial microorganisms and contributes to preserving the integrity or equilibrium of the soil;
- Provides additional strawberry weed control because some crops are very competitive with weeds;
- Contributes to reaching a sustainable agriculture.

Despite its advantages, the contribution of crop rotation to reducing MeBr use and even totally phasing it out is limited to the fields with low to medium pest pressure only. In addition, crop rotation does not control soil borne pathogens with wide host ranges.

Nevertheless, because of its numerous advantages, crop rotation reinforces the efficacy of MeBr alternatives. In Bekaa and Akkar areas, farmers combine it to soil solarization to get better soil disinfection results. Crop rotation is thus recommended in combination with all MeBr alternatives and with all agricultural practices.

In Lebanon, as soil solarization, crop rotation is mainly practiced in rural areas such as Bekaa plain or Akkar valleys where the lands are relatively cheap and farmers can have wide areas to practice crop rotation and can afford planting suitable rotation crops despite their low revenue.

6.2.1.3 Soil Preparation
Good soil preparation is one of the essential keys for the development of long-term high yielding strawberry production.
- Prior to planting, and after removing residues of previous crops and adding, when needed composted manure and fertilizers, the soil should be flooded to activate soil pathogens and weeds.
- Next, once the moisture content drops to 65% at root depth, it needs to rotor tilled in order to become a homogenous aerated structure allowing optimal soil disinfection results.
- Strawberry beds are finally raised with an appropriate slope when applicable. **The higher the beds, the better the water drainage is.** The main bed type used in Lebanon is 30 cm height, includes two rows of plants with one or two irrigation drip lines running between them.
- Ditches should be installed to control water flooding during high rainy seasons.
6.2.1.4 Use of Certified and Resistant Cultivars

Strawberry plant certification programs guarantee that transplants obtained from them are free from known plant-borne pathogens. Generally no more than three years elapse between screen house propagation (Meristem Plants) and availability to growers (Certified Plants). The choice of varieties could be done on the aptitude of these varieties to be resistant to pathogens among other considerations. We should not forget that a cultivar that is resistant to a particular disease in the area in which it originated may be susceptible or may express a lower level of resistance in other areas. Thus, we can not rely totally on resistant varieties coming from foreign regions to the Lebanese conditions.

6.2.1.5 Planting and spacing

Adopt proper planting practices:
- Choose the adequate planting time depending on the variety used. Hot weather is to be avoided.
- When planting, make sure to cover the roots and only half of the crown. Do not bend the roots horizontally.
- Respect proper spacing between the plants (20-25 cm).
- Avoid planting other crops within strawberry beds as this can increase soil humidity, create shade, rise the incidence of diseases and reduce strawberry yields.

6.2.1.6 Mulching

Mulching consists of covering the planting bed with plastic cover for many purposes. This operation reduces fruit decay problems by limiting plant contact with soil and irrigation water and helps in regulating plant growth and fruit production.
Black colored mulch, which is the most used in Lebanon, controls weed growth although it might cause fruit burn in high altitude areas.

6.2.1.7 Irrigation Water Management
An adequate management of irrigation water is important for a successful strawberry production. It involves controlling water quality and quantity and ensuring a homogeneous distribution of water in the field.

6.2.1.7.1 Controlling water quality
- Avoid using saline water (and saline soils) as this leads to reduced yields (table 3). Strawberry plants can tolerate a salt concentration up to 1 mS/cm = mmho/cm in soil saturation paste. If the irrigation water is saline, it is recommended to adopt artificial or rain leaching to improve the situation (the average leaching requirement is 30 cm of non saline water to remove 90% of salts).

**Table 3:** Influence of water salinity (ECw) and soil salinity (Ecs) on the yield of strawberry crops (fragaria, sp.),[18].

<table>
<thead>
<tr>
<th>ECw (mS/cm)</th>
<th>Ecs (mS/cm)</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.7</td>
<td>100%</td>
</tr>
<tr>
<td>1.3</td>
<td>0.9</td>
<td>90%</td>
</tr>
<tr>
<td>1.8</td>
<td>1.2</td>
<td>75%</td>
</tr>
<tr>
<td>2.5</td>
<td>1.7</td>
<td>50%</td>
</tr>
<tr>
<td>4.0</td>
<td>2.7</td>
<td>0%</td>
</tr>
</tbody>
</table>

- Avoid water coming from open canals as such water can be a potential source of pathogens.
- Maintain regularly the irrigation system as shown in annex 2.
### 6.2.1.7.2 Controlling water quantity

Over irrigation or excess moisture increases the risks of diseases. Therefore, it is recommended to:

- Dig drainage ditches to avoid water flooding;
- Use drip irrigation systems rather than flooding irrigation and when applicable plastic mulch to reduce plant contact with water. This will also reduce water consumption;
- Use tensiometers to verify that no excess water is applied and to know when to start and when to end watering.

### 6.2.1.7.3 Ensuring a homogenous water distribution within the irrigation system

This contributes to having uniform plant growth and yield in the 4 corners of the field. This is also essential to ensure both efficient and uniform pre-planting soil disinfection especially when chemical fumigants are applied via the drip irrigation system.

To ensure a homogeneous water distribution in an irrigation block (part of the open field or greenhouse unit watered with one pipe), drip irrigation should be adopted rather than flooding irrigation. In addition, the drip irrigation system needs to be properly designed. In this regard, farmers must follow the following guidelines:

1. Record the following information per irrigation block:
   - The length of the drip irrigation line (L in m);
   - The number of drip irrigation lines (N);
   - The distance between the drippers on the drip line (d in m);
   - The flow rate of each dripper (f dripper in L/h).
2. Verify that the length of your drip lines are within an acceptable range as given by tables 4 and 5 below:

**Table 4:** Maximum recommended length of irrigation tape

<table>
<thead>
<tr>
<th>Internal Diameter (mm)</th>
<th>Dripper spacing (cm)</th>
<th>Operating pressure (bar)</th>
<th>Flow per linear meter (L/hr)</th>
<th>Flow variation (%)</th>
<th>Maximum length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>10</td>
<td>0.55</td>
<td>1.14</td>
<td>10</td>
<td>81</td>
</tr>
<tr>
<td>16</td>
<td>10</td>
<td>0.55</td>
<td>1.35</td>
<td>10</td>
<td>78</td>
</tr>
<tr>
<td>17</td>
<td>10</td>
<td>0.55</td>
<td>1.30</td>
<td>10</td>
<td>60</td>
</tr>
</tbody>
</table>

*Recommended operating pressure is 0.55 bar (8PSI).*

**Common wall thickness: 6 mil (0.15 mm)-8 mil (0.20 mm)**

**Table 5:** Maximum recommended length (m) of GR drip lines

<table>
<thead>
<tr>
<th>Dripper spacing (cm)</th>
<th>Pipe Diameter 16 mm</th>
<th>Pipe Diameter 20 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dripper Flow rate 2 L/h</td>
<td>Dripper Flow rate 4 L/h</td>
</tr>
<tr>
<td>20</td>
<td>40</td>
<td>28</td>
</tr>
<tr>
<td>30</td>
<td>53</td>
<td>35</td>
</tr>
<tr>
<td>40</td>
<td>63</td>
<td>43</td>
</tr>
</tbody>
</table>

3. Calculate the number of emitters ($n$) per drip irrigation line ($n = L / d$)

4. Calculate the flow rate per drip irrigation line ($f_{\text{line}} = f_{\text{dripper}} \times n$)

5. Calculate the flow rate of the irrigation block $F_{\text{block}}$ in (L/h) that is the flow rate of all drip irrigation lines ($N$) watering the soil simultaneously, according to the following equation: $F_{\text{block}}$ (L/h) = ($f_{\text{line}} \times N$)

6. Note the diameter of the pipe supporting the drip lines and determine the maximum flow rate it can deliver (L/h) by using table 6 on the next page:
Table 6: Maximum recommended flow of the irrigation pipe (\( F_{pipe} \)) based on pipe diameter (water velocity < 1.5 m/sec) [17]

<table>
<thead>
<tr>
<th>Internal diameter</th>
<th>Maximum Flow rate*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inch</td>
<td>mm</td>
</tr>
<tr>
<td>5/8</td>
<td>16</td>
</tr>
<tr>
<td>½</td>
<td>20</td>
</tr>
<tr>
<td>¾</td>
<td>25</td>
</tr>
<tr>
<td>1</td>
<td>32</td>
</tr>
<tr>
<td>1¼</td>
<td>40</td>
</tr>
<tr>
<td>1½</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>63</td>
</tr>
<tr>
<td>2½</td>
<td>75</td>
</tr>
<tr>
<td>3</td>
<td>90</td>
</tr>
</tbody>
</table>

*Although possible, operation at higher flow rates is not advisable and can be in some cases dangerous as it can lead to the disconnection of the whole irrigation system.

7. Decide on the adequacy of your irrigation system.
   - In principle, the flow rate delivered by the pipe (\( F_{pipe} \)) should be greater or at least equal to that of the block (\( F_{pipe} \geq F_{block} \)) in order to ensure that the distribution of water and chemicals is homogeneous and done at the proper rate;
   - If \( F_{pipe} < F_{block} \), your irrigation system is not adequate. To improve it and thus guarantee adequate irrigation and chemigation procedures, two solutions are possible:
     - Enlarge the diameter of the pipe in order to have \( F_{pipe} \geq F_{block} \);
     - Divide the irrigation block into smaller parts by using separation valves and irrigate and chemigate each part alone.
6.2.1.8 Sanitation

Follow good sanitation practices to reduce the possibility of introducing diseases, insects and weed problems in the treated soil via contaminated transplants, soil, field equipments or irrigation water. Therefore, it is crucial to:

- Remove residues of previous crops from the soil as they constitute a potential source of soil pathogens. Crop residues may be naturally degraded or **composted** and reused at a later stage as soil conditioners. If manure is to be applied, it is crucial to use composted manure to maximize nutrient release from it and avoid the spread of pathogens and most importantly weed seeds in the soil.
- Rinse agricultural equipment and shoes with hot water or disinfection agents.
- Use disease free transplants.
- Irrigate with clean non infected water.

**Compost** is the end product resulting from the degradation of organic matter by microorganisms. Besides allowing waste reduction, compost contributes to reaching better yields as it increases water retention in the soil, improves soil aeration and is a source of nutrients. When mixed with manure, it becomes an excellent soil fertilizer. Interestingly, compost may protect against some soil borne pests and may thus allow operation at lower MeBr dosages. Refer to annex 3 to learn how to compost your crop residues and your manure.
Factors affecting the integrated management of the strawberry crop: Proper Fertilization

Strawberry fertilization is discussed in depth given its impact on crop healthiness and yield, production cost and soil and ground water pollution. Guidance is given to farmers on how to collect representative soil samples from the field, on how to interpret soil analysis results and on how to fertilize their soils both prior and after planting. Nutrient excess and nutrient deficiency symptoms are also discussed and illustrated with photos.

All recommendations presented in this section are based on field observations, on soil analyses and on the evaluation by the project team of the soil fertilization practices of a representative number of strawberry farmers operating in the main strawberry production regions in Lebanon.
6.2.2 Proper Fertilization
Proper soil fertilization is a basic issue in ICM and one of the essential requirements of good crop yields. Nutrient deficiencies can lead to fruit deformation besides stunted plants. Over fertilization results in soil salinity which makes the plants more susceptible to diseases, leads to limited growth and reduced yields, rises production costs and increases the risks of soil and ground water pollution.

6.2.2.1 Basic nutritional requirements of strawberry plants
Strawberry is a typical rosette plant. Its root system is mainly located in the upper 20cm soil layer.

The nutrient removal per 100Kg of fruits is as follows: (N=0.8-1Kg); (P_2O_5 = 0.3-0.4Kg) and (K_2O = 1-1.2Kg) with nutrient ratio of (2.5:1:3.5). The total uptakes of nutrients range between: (N=225-275 Kg/ha); (P_2O_5 = 125-175 Kg/ha) and (K_2O = 375-425 Kg/ha).

Special attention should be given to the following points:
• 60-80% of the root system is at 0-10cm depth;
• The strawberry plant prefers medium to light textured soils;
• It is sensitive to soil and water salinity;
• It is susceptible to iron deficiency (chlorosis of the upper leaves);
• Floral bud differentiation usually occurs early and it is largely affected by the nutrient reserves of the plant;
• Maximum nutrient absorption is during flowering stage;
• Avoid the use of fertilizers which contain Na (e.g. Sodium Nitrate), or Cl (e.g. Potassium Chloride) or compound fertilizers containing KCl;
• Fe and other micronutrients are applied by foliar spray or via irrigation water (fertigation) preferably as chelated sources.

6.2.2.2 Evaluation of pre-planting soil fertility
Any fertilization program needs to be based on a pre-planting soil analysis. Farmers are therefore advised to collect a composite soil sample from several points in the
greenhouse or the field at a depth of 0-25 cm and send it for analysis at a reputable laboratory as described below.

6.2.2.2.1 Soil Sampling

In order to decide on the proper soil fertilization program, soil sampling and subsequent analysis should be done prior to soil fertilization.

To take a representative soil sample, farmers should:

1- Divide the field to plots having uniform soil texture characteristics.

2- In a given uniform plot:
   a- Scrape away surface litter.
   b- Obtain a small portion of soil by making a boring that is 25 cm deep by using an auger or a soil sampling tube. If a spade is used, farmers should dig a V-shaped hole to sample depth; then as illustrated in the first photo of this section, cut a thin slice of soil from one side of the hole, in a vertical way starting from the bottom of the hole to the soil surface level.
   c- Take a small portion of soil from 10 to 15 locations (never less than 7 locations) to account for soil variations.
   d- Mix the collected sub-samples to form one representative soil sample.
   e- On the sample bag, mark the farmer’s name and address, the sample number and location and the date.

3- Keep a record of the sampling areas, analysis results and recommendations for future use.

6.2.2.2.2 Soil analysis and interpretation of soil analysis results

Soil samples should be analyzed in a reputable laboratory using internationally approved analytical methods.

The following table gives information about the suitable methods for the analysis of Lebanese soils and about the interpretation of such analysis.
Table 7: Guidelines for analyzing Lebanese soils and for interpreting the analysis results [16]

<table>
<thead>
<tr>
<th>Level mg/kg (ppm)</th>
<th>Method</th>
<th>V. Low</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>V. High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrate–N (NO₃⁻)</td>
<td>Water Colotimeter</td>
<td>0-15</td>
<td>15-30</td>
<td>30-60</td>
<td>60-100</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Calcium (Ca)*</td>
<td>1N NH₄OAC</td>
<td>0-500</td>
<td>500-1500</td>
<td>1500-3000</td>
<td>3000-5000</td>
<td>&gt;5000</td>
</tr>
<tr>
<td>Potassium</td>
<td>1N NH₄OAC</td>
<td>0-100</td>
<td>100-200</td>
<td>200-400</td>
<td>400-800</td>
<td>&gt;800</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>1N NH₄OAC</td>
<td>0-100</td>
<td>100-200</td>
<td>200-300</td>
<td>300-700</td>
<td>&gt;700</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>1N NaHCO₃-Olsen</td>
<td>0-12</td>
<td>12-25</td>
<td>25-40</td>
<td>40-70</td>
<td>&gt;70</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>1N - DTPA</td>
<td>0-2</td>
<td>2-4</td>
<td>4-8</td>
<td>8-15</td>
<td>&gt;15</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>1N - DTPA</td>
<td>0-1</td>
<td>1-4</td>
<td>4-8</td>
<td>8-15</td>
<td>&gt;15</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>1N - DTPA</td>
<td>0-0.8</td>
<td>0.8-2</td>
<td>2-5</td>
<td>5-10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>1N- DTPA</td>
<td>0-0.2</td>
<td>0.2-0.5</td>
<td>0.5-1</td>
<td>1-5</td>
<td>&gt;5</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>Hot Water</td>
<td>0-0.5</td>
<td>0.5-1</td>
<td>1-2</td>
<td>2-4</td>
<td>&gt;5</td>
</tr>
</tbody>
</table>

*The calcareous soils exchangeable Ca values could be 50-100% higher than the above values*

From the results of soil analysis, farmers will learn about the levels of available nutrients for the strawberry crop and can predict the fertilizer requirements.
6.2.2.3 Strawberry Fertilization Guidelines

6.2.2.3.1 Pre-planting guidelines
Following the collection of a representative soil sample (prior to fertilization) and its analysis in a suitable soil laboratory, strawberry growers in Lebanon need to:

1. Apply composted good quality manure (free from weeds and diseases) at a rate of about 0.5 ton/1000 m² and mix it well in top soil during land preparation stage.
2. Prior to planting, apply (NPK) fertilizers and mix them well with the top soil according to the results of soil analysis as explained in the following table:

Table 8: Proposed application rate of fertilizers to the soil prior to planting*

<table>
<thead>
<tr>
<th>Nutrient Level (given by Soil Analysis)</th>
<th>N (Kg/1000 m²)</th>
<th>P₂O₅ (Kg/1000 m²)</th>
<th>K₂O (Kg/1000 m²)</th>
<th>MgO (Kg/1000 m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>15</td>
<td>15</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>Medium</td>
<td>10</td>
<td>10</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>High</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Very high</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

* Refer to annex 4 to relate the above application rates to the commonly marketed formulation of fertilizers

**Important remark:** If soil analysis was not conducted as recommended earlier, then the following general guideline is given to farmers at the pre-planting stage: application of 0.5 tons/du of well decomposed and composted manure which is free from weed seeds and diseases in addition to 10Kg/1,000m² N; 10Kg/1,000m² P₂O₅ and 15Kg/1,000m² K₂O before planting.

6.2.2.3.2 Post-planting guidelines
During the season, farmers are advised to fertigate (apply soluble fertilizer with irrigation water through the irrigation system) according to the following program (density = 10,000 plants/du).
### Table 9: Post-planting strawberry fertilization schedule per plant growth stage

<table>
<thead>
<tr>
<th>Growth Stage</th>
<th>Fertilizer</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vegetative Stage</strong></td>
<td>20-20-20+TE or similar grade</td>
<td>3Kg/1,000m²; every 15 days</td>
</tr>
<tr>
<td></td>
<td>Iron chelate: Fe-EDDHA (6-7% Fe)</td>
<td>300 g/1,000m² over the totality of the stage</td>
</tr>
<tr>
<td><strong>Flowering Stage</strong></td>
<td>15-30-15+TE or similar grade</td>
<td>4Kg/1,000m²; every 15 days</td>
</tr>
<tr>
<td></td>
<td>Iron Chelate: Fe-EDDHA (6-7% Fe)</td>
<td>500 g/1,000m² over the totality of the stage</td>
</tr>
<tr>
<td><strong>Harvest Stage</strong></td>
<td>15-15-30+TE or similar grade</td>
<td>4Kg/1,000m²; every 15 days</td>
</tr>
<tr>
<td></td>
<td>Iron Chelate: Fe-EDDHA (6-7% Fe)</td>
<td>300 g/1,000m² over the totality of the stage</td>
</tr>
</tbody>
</table>

**Notes:**
- Use the above program as a guideline. Observe your crop and adjust as needed.
- Spray foliar fertilizers containing micronutrients if needed. The total quantities of the total fertilizers to be used during a season are about 20 Kg/1,000m² (vegetative stage); 25 Kg/1,000m² (flowering stage) and 25 Kg/1,000m² (fruited/fruiting stage) and chelated Fe ≈ 1 Kg/1,000m².
- Use of acidic soluble fertilizers gives better results because it makes the pH of the soil solution slightly acidic and helps nutrient uptake.
- Soil and water salinity levels should be low.
- Use fertilizer grades that are free of chloride (Cl⁻) and have a low salinity index (refer to annex 5 for the salinity indexes of fertilizers).
6.2.2.4 Visual Deficiency Symptoms

Every essential nutrient plays a specific role in plant physiological processes which are interrupted by the nutrients absence or low level in the growth medium. The main visual deficiency symptoms that could be observed in Lebanon are the following:

**Nitrogen (N):** The green color of the leaves fades, then turns yellow and in severe deficiency the color becomes red starting from older leaves. The growth becomes stunted and yield is markedly reduced. Source of the photo: [11]

**Potassium (K):** Yellowing the leaf margins followed by spots on the plants blades of young leaves and the margins tend to bend upwards. The interior part of the leaves becomes dark green and finally leaf early-shedding takes place. Source of the photo: [11]

**Magnesium (Mg):** Starts appearing on older leaves, by the formation of interveinal discoloration. Premature leaf shedding takes place. Source of the photo: [11]

**Phosphorus (P):** Decreased plant size, with brown reddish coloring of elder (lower) leaves. Source of the photo: [11]

**Calcium (Ca):** Reduction in plants growth rate accompanied by deformation and yellowing, browning and death of the tips of young leaves followed by death of root tips. Black spots appear on stolons also. Source of the photos: [19] for the photo on the left and [11] for the photo on the right.

**Iron (Fe):** The color of the upper leaves becomes yellow, while the veins net remains green. Photo taken by the project team.
6.2.2.5 Nutrient excess symptoms

Excessive application of fertilizers leads to soil salinity and to a subsequent decrease in plant growth and yield. Plants grown on saline soils have leaves showing brown burnt edges and such burning starts from the tip of the leaves downwards.

Farmers are therefore advised to select non saline soils and to avoid applying excessive doses of fertilizers.
Factors affecting the integrated management of the strawberry crop: Adequate Pest Management

The present section covers the identification and treatment of the major strawberry pests and diseases in Lebanon. These represent the pathogens that have been most commonly encountered by the project team during its field visits to strawberry farms.

Both soil borne and aerial strawberry pathogens are tackled besides weeds. Pathogens are first described along with the factors favoring their proliferation and the symptoms they leave on plants. The appropriate pest management methods covering organic farming based control measures besides conventional ones are then exposed.
6.2.3 Adequate pest management

Proper pathogen identification is a key issue for adequate disease & pest management.

The sections below describe the main diseases and insect pests encountered in strawberry fields in Lebanon and provide the basic guidelines for their adequate management. Both organic farming and rational chemical control methods of pests and diseases will be suggested.

Organic farming control methods

are not widespread among Lebanese strawberry farmers yet but are gaining more interest with time. The organic farming control methods suggested in the following sections are to be adopted whenever possible and whenever they are available in Lebanon. In order for such methods to give satisfactory results, the whole concept of organic farming should be respected. For example, natural predators can not control a given pest if chemical pesticides are applied in the farm or in nearby farms.

Until organic farming becomes more widespread in Lebanon, it is important that farmers adopt sound ICM practices that aim at using the least amounts and safest possible types of chemical pesticides and fertilizers.

Before using any chemical, farmers should read carefully the notices attached to their products. Farmers should be aware of the impact of these products on the crop, environment, consumers and operators themselves.

Hereafter are the most important considerations that should be adopted for the good use of pesticides:

- Be aware of the toxicity of pesticides on humans, predators and the environment (Annex 6 & 7) and use efficient pesticides having the least eco-toxicological impact;
- Avoid over using pesticides and be aware that pesticides are used to lower pest populations below the economical damage threshold and not to totally eradicate them;
- Respect the waiting period before harvest;
- Alternate the use of active ingredients to avoid building-up pest resistance to pesticides. Some chemicals like sulfur or copper sulfate lead to low pest resistance;
- Use selective pesticides to increase the efficacy of the product and to protect the predators;
Use pesticides at the correct time. Applying pesticides after the proliferation of pests does not lead to noticeable control results. This is primordial for the efficacy of the treatment (Annex 8);

- Respect the delay between the consecutive treatments;
- Never mix chemicals unless they are compatible;
- Control how and when to spray pesticides by using calibrated sprayers in suitable weather conditions such as moderate temperature and low wind speed;
- Use the adequate personal protective equipments when manipulating pesticides;
- Keep your pesticides in adequate security conditions by storing them away from the sunlight and fire hazards in a well aerated room;
- Get rid of the packing materials as suggested by relevant authorities. Do not incinerate them or discharge rinsing water in water resources.

6.2.3.1 Soil borne pathogens and pests

Soil borne diseases are caused by pathogens that are transmitted by infected transplants, contaminated soil, or by splashing water. The major means of managing these diseases are: pre-planting soil disinfection as discussed in section 5 above and adequate ICM practices including crop rotation, limiting over fertilization, adequate irrigation water management, annual planting and the use of certified transplants. To a lower extent, post-planting chemigation may be administered with caution in case there is a real need for it.
6.2.3.1.1 Phytophthora Crown rot

**Causal organism:** *Phytophthora* spp. (mainly *Phytophthora cactorum* and *Phytophthora megasperma*)

**Epidemiology:** The disease is favored by wet soil conditions, while symptoms are enhanced by water stress [10]. Crown rot may appear anytime during the season.

**Symptoms:** are first observed as plant stunted growth or small and wilted young leaves. Wilting spreads to the rest of the plant and some leaves may turn reddish. Affected plants collapse either entirely or one side only, depending on the part of the crown involved. Intense brown discoloration and eventual disintegration of the vascular tissue of the crown are characteristic of the disease. The same *Phytophthora* species also attack roots, causing brown root rot.

Organic farming control: Soil solarization in the warmer areas for 30-40 days of hot weather and the use of certified transplants, tolerant or resistant varieties, good soil drainage and clean non-infested irrigation water provide adequate control of the disease.

Reasoned Chemical Control: Prior to planting, chemical fumigants especially 1,3D+Pic control the disease. Soil solarization coupled with MeNa gives satisfactory results too. The systemic fosetyl-aluminum and/or metalaxyl-M [13] may be applied as a preplanting dip or as a foliar spray two to three weeks after planting. Postplanting ground or drip applications of Metalaxyl-M or phosphorous acid are advisable when susceptible cultivars are used.
6.2.3.1.2 Phytophthora Red Stele

**Causal organism:** *Phytophthora fragariae*

**Epidemiology:** The optimum period for growth and infection by this fungus is in winter, when the moisture is high and the temperature is cool. Plants show typical symptoms within 10 days [11]. Affected plants become stunted and older leaves die and dry up.

**Symptoms:** Infected strawberry roots will appear gray, while the new roots of a healthy plant are yellowish white. The disease is characterized by rotting of young roots and a red discoloration of the stele (central core); this discoloration may extend into the crown in highly susceptible plants [10].

**Control:** Same as for the Phytophtora crown rot. Disease incidence and severity can be minimized by planting strawberries on raised beds in well-drained soils, using certified transplants, and by soil disinfection before planting.

6.2.3.1.3 Anthracnose

**Causal organism:** *Colletotrichum acutatum*

**Epidemiology:** This pathogen can survive in the soil for at least 9 months without a host plant. Disease inoculum may originate from a contaminated soil carried by field equipment or may be blown in by wind from nearby weed hosts of this disease.

**Symptoms:** Affected plants may wilt and collapse. Dark brown lesions occur on the stems, petioles and runners and under humid warm conditions these lesions show abundance of salmon colored spore masses. Infections of the crown area lead to wilting and complete death of the plant. If the crown is sliced open, the internal tissue is firm and cinnamon brown while it is soft in Phytophtora lesions. Fruits get infected especially in periods of warm rainy weather and show small sunken oval or round brown spots [14] that expand to cover a large area of the fruit surface. Decayed tissues are firm and dry.
Organic farming control: Since high soil fertility favors anthracnose, over fertilization is to be avoided. Soil solarization, drip irrigation, sanitation and adapted resistant cultivars are used to limit the effects of this disease.

Reasoned Chemical Control: The disease can be managed by soil fumigation. Chemical treatments include dipping transplants for 5 minutes just before planting in a solution of azoxystrobin, and later on the use of foliar fungicides such as manebe, thiram, azoxystrobin or cyprodinil + fludioxonil [12, 13] when the disease is present and conditions are favorable for its development. Two consecutive spray applications will be enough to control the disease.

6.2.3.1.4 Verticillium Wilt

Causal organism: *Verticillium dahliae*

Epidemiology: Once established in the soil, it is extremely difficult to eradicate. The fungus sclerotia may remain alive in the soil for 25 years or longer and have a wide host range. Cool and overcast days interspersed with warm and bright days [11] are most conducive to disease development. Once inside the root, the fungus invades the water-conducting tissues.
**Symptoms:** Symptoms appear first on the leaves. Older leaves turn brown along the margins and between the veins, may develop an off-green color, or may wilt. Leaves dry up as the disease progresses and the entire plant dies. Wilt symptoms vary with the susceptibility of the cultivar and cannot be easily differentiated from those of the Crown rot, winter or water stress injury. A laboratory culture is necessary for positive identification [20].

**Control:** The spread of the disease from a contaminated planting stock is an increasing concern, making control of this disease at the nursery stage crucial. This disease is not usually a problem when the soil has been fumigated. Soil solarization is effective in controlling also *Verticillium*. Effectiveness of solarization can be increased following the application of metam sodium or after incorporating the residues of a cruciferous crop in the soil. Crop rotations with broccoli or other cruciferous crops are effective to reduce *Verticillium* in the soil, and it is important to avoid crops susceptible to this pathogen such as tomatoes and potatoes.

### 6.2.3.1.5 Fusarium Wilt

**Causal organism:** *Fusarium oxysporum* f. sp. *fragariae*.

**Epidemiology:** Rhizoctonia spp. proliferates in humid or poorly drained soils. Cool weather conditions favor root infections while warmer climates favor crown and petiole infections.

**Symptoms:** Infected leaves wilt and die rapidly. Chlorosis rather than wilting may occur under cold conditions [11]. A reddish brown discoloration appears on crown tissues. Lower crown tissues may decay extensively as the disease advances. White masses of conidia may be produced on infected plant parts.

**Organic farming control:** Fusarium and other root rot complex pathogens (*Rhizoctonia* spp., *Phytophthora* spp.,...) are controlled by soil solarization and the use of resistant varieties. Effectiveness of solarization can be increased after incorporating residues of a cruciferous crop in the soil. Crop rotation, well-drained soil and compost application aid in the control of this disease.
**Reasoned Chemical control:** Soil fumigation by 1,3D+Pic. MeNa coupled to soil solarization gives acceptable results too.

**6.2.3.1.6 Rhizoctonia Root Rot closely related to the Black Root Rot Complex**

**Causal organism:** *Rhizoctonia fragariae* or *Rhizoctonia solani*. In Lebanon, besides causing the Rhizoctonia root rot, Rhizoctonia spp. were found to be the main causal agents of the black root rot complex in which a complex interaction of fungi, nematodes and poor soil conditions favor the disease.

**Epidemiology:** Rhizoctonia spp. proliferates in humid or poorly drained soils. Cool weather conditions favor root infections while warmer climates favor crown and petiole infections.

**Symptoms:** Symptoms of this disease include purple coloring, curling up of the underside of leaves and collapsing of the plant in the early part of the fruiting period. The petiole, or the part connecting the leaf to the stem, turns brown and the crowns are killed along with some of the smaller roots [11]. Feeder rootlets become water soaked in appearance and disintegrate. The loss of rootlets results in a serious stunting of the shoots and consequently in yield reduction. Symptoms of this disease could be confused with those of boron deficiency or the stem nematode *Aphelenchoids fragariae* [14].

[Image: Root Rot symptoms: Reddish brown lesions are formed on young roots. Feeder rootlets become water soaked in appearance and disintegrate. Source of the photo: [11]]

**Organic farming control:** Includes soil solarization especially when coupled to crop rotation, the use of clean transplants and planting on well drained soils [15].

**Reasoned Chemical Control:** soil fumigation followed by the introduction of the biocontrol *Trichoderma harzianum* is effective in controlling Rhizoctonia root rot.
6.2.3.1.7 White grub

Causal organism: *Phyllophaga* sp.

**Epidemiology:** Larva of *Phyllophaga* sp. beetles normally feed on perennial grasses [10] and attack strawberries. Adults emerge in May-June and are active by night for about two weeks after emerging. Eggs are laid on the soil and the larvae feed on plant roots for two years before pupating. Mature larvae are C-shaped. Damage results from white grubs destroying root hairs and chewing bark and cortex from larger roots.

**Symptoms:** Injured plants decline slowly.

**Organic farming control:** The milky-spore bacteria *Bacillus popillae* and *Bacillus lentimorbus* are important enemies of white grubs. The beneficial nematodes *Steinernema carpocapsae* and *Heterorhabditus bacteriophora* are also effective. These biological agents are currently commercially produced outside Lebanon in countries like the USA, and could be available in Lebanon upon request.

**Reasoned Chemical control:** Soil fumigation practiced for the control of soil borne diseases and nematodes is effective also on white grubs.

6.2.3.2 Pathogens and pests affecting the aerial parts of strawberry plants

6.2.3.2.1 Powdery Mildew (PM)

Causal organism: *Sphaerotheca macularis*

**Epidemiology:** It tends to be more serious in the coastal areas where humidity is higher, although disease development is inhibited by rainy and wet conditions. The disease affects leaves, flowers and fruits.

**Symptoms:** PM symptoms show an upward curling of leaf edges which is the first symptom seen [10]. Reddish blotches appear on the lower and upper surfaces of infected
leaves. Patches of a white, powdery fungus mycelium may appear on the undersides of the leaves or on fruits [11]. Infected flowers are covered with a white powdery mycelium and become deformed or killed.

**Organic farming Control:** Sulfur is the most common control agent in both conventional and organic farms. Commercial formulations of *Bacillus pumilis* and *Ampelomyces quisquali* are used on strawberries for PM control. Avoid favoring high humidity conditions, such as close spacing of plants or shade.

**Reasoned Chemical control:** For the proper management of PM, fungicides must be applied at the first sign of the disease or about one month after planting and again 3 weeks later on. Additional treatments can be applied at the beginning of the bloom. Several fungicides are effective such as penconazole, azoxystrobin [13], micronized sulfur or insecticidal soap sprays [12].

6.2.3.2 Gray Mold

**Causal organism:** *Botrytis cinerea*

**Epidemiology:** the disease thrives during prolonged rainy and cloudy periods. Wind, splashing water and human activity spread the conidia, depositing them on blossoms, stems, young fruits and leaves. Infections are most common in the well protected areas of the plant, where the humidity is high and air movement is poor. Heavy applications of nitrogen fertilizers, resulting in thick foliage shade, create ideal conditions for the development of gray mold rot. Pickers handling infected berries can spread the infection to healthy berries [23].
**Symptoms:** Botrytis attacks blossoms leading to blossom blight [10] especially when wet weather prevails during bloom. Affected flower parts turn brown and die. The fungus is constantly present throughout the growing season. It infests fruits causing their decay.

![Gray Mold attacks flowers which turn brown and die. Source of the photo: [12].](image1)

![Gray Mold fruit infections appear as soft, light brown, rapidly enlarging spots. The berry soon dries out, turns darker brown, and becomes covered with a gray, dusty powder. Source of the photo: [12].](image2)

**Organic farming control:** Drip irrigation under plastic mulch and bed designs that improve air circulation, reduce the development of gray mold. Management of gray mold is also done by the reduction of inoculum level that is the removal of dead leaves and fruits. Fruits should be frequently harvested early in the day and refrigerated promptly to control Botrytis fruit rot.

**Reasoned Chemical control:** Application of protective fungicides is practiced during bloom periods when damp weather is expected. Fungicides such as thiram, cyprodinil + fludioxonil, mepanipyrim and pyrimethanil [13] are effective in controlling the disease.

### 6.2.3.2.3 Aphids

**Causal organism:** *Myzus persicae*, *Chaetosiphon fragaefolii* and *Aphis gossypii* are the most common aphids species.

**Epidemiology:** Aphids on strawberry are soft bodied insects less than 2mm long. Their reproduction is favored by moderate temperatures and high humidity. In coastal areas, aphids populations increase rapidly in March and April and decline in May and June when the weather becomes hot and dry. Aphids secrete honey dew [14] which is not harmful to the plant but makes its fruits sticky and thus unsalable. Aphids
MeBr Alternatives and Integrated Crop Management (ICM) rarely cause serious damage in strawberry fields. However, they transmit viruses that can cause significant economic losses and are of major concerns in nurseries.

**Organic farming control:** In strawberry fruit production fields, aphids are not usually treated unless spring weather is very conducive for their development. Avoid the use of excess nitrogen fertilizers on strawberry plants because such plants are favorable for a rapid increase of aphid populations. Weekly checks for increases in aphid populations are necessary. An insecticidal soap spray or paraffinic oil (Stylet oil) will help to reduce aphids numbers with minimal damage to beneficial insects.

**Reasoned Chemical control:** In strawberry nurseries, treatments are applied to prevent virus spread. Chemical control is applied in strawberry fruit production when aphid numbers are increasing to reach an average of 10 or more per leaf on a random sample of 10 leaves per dunum. Deltamethrin, pirimicarb [13] and thiamethoxam [12] are commonly used against aphids in strawberry production.

### 6.2.3.2.4. Mites

- **Two Spotted Spider Mites**

**Causal organism:** *Tetranychus urticae*

**Epidemiology:** The two-spotted spider mite is a serious pest of Lebanese strawberries farms. Spider mites outbreak is favored by hot and dry weather. Dust that accumulates on the spider mite’s webbing creates an ideal shelter for the mites and their eggs. These little dust “tents” discourage predators and prevent the miticide from reaching the mites and their offsprings.

Honey dew produced by aphids makes both fruit and leaves sticky and promotes the growth of a black sooty mold of limited harm to the plant. Source of the photo: [12].

Two spotted spider mites females are around 0.5mm long. They are pale green and marked with a dark blotch on each side. With their spherical eggs, they mainly live in the underside of the leaves. They appear as tiny moving dots when seen without magnification. Source of the photo: [19].
**Symptoms:** Two spotted spider mite damage to strawberries appears as stippling, scarring, and bronzing of the leaves and calyx. Eggs are laid on the undersides of the leaves. Fruits on infested plants are small and fruit production stops.

**Organic farming control:** Cultural practices that favor vigorous plants can minimize damage from spider mites [24]. Insecticidal soaps, rosemary oil or organic stylet oil, neem-based products and sulfur are acceptable miticides in organic production. *Amblyseius californicus* and *Phytoseiulus persimilis* are effective predators against mites [14]. *Phytoseiulus* is released at a ratio of 1/10 on primary infested plants. The use of mites free nursery stock is recommended. In case of doubt, transplants should be treated in hot water at 38°C for 30 minutes before planting.

**Reasoned Chemical control:** Miticides are applied when about 5-10% of the leaflets possess one or more spider mites. To control mites in general, clofentizine can be applied on eggs and abamectin on adults. To avoid build up of pesticides resistance, other miticides such as befenazate or etoxazole [12] can be used.

- **Cyclamen mites**

**Causal organism:** *Phytonemus pallidus*

**Epidemiology:** Cyclamen mites represent an important threat to strawberry crops in Lebanon. They are very small and not visible without a magnifying glass. The immature stages of cyclamen mites are translucent while the mature adults are pink and shiny. Cyclamen mites can easily be spread between strawberry fields by pickers, bees, and equipment.
Symptoms: Leaves become stunted and crinkled resulting in a compact mass of leaves [10]. Fruits on infested plants are small and fruit production stops. As in the case of two spotted spider mites, a bronzing of leaves and calyx is observed.

Control: All control measures recommended for the two spotted spider mites infections are applicable to control cyclamen mites.

6.2.3.2.5. Thrips

Causal organism: *Frankliniella occidentalis*. Adults of this insect are generally yellowish-brown to straw colored.

Epidemiology: Thrips exist on many crops. They begin feeding on strawberry when the flowers open and the weather is warm. Insects are frequently found feeding under the calyx, on flowers or around the seed pits in early fruits sets [14]. However, they do not cause significant damage unless numbers get very large. Feeding by a large number of thrips may cause blossoms to fall off or fruits to remain small and hard.
**Control:** Treatment with insecticides such as deltamethrine or spinosad [13] is possible when populations exceed 10 thrips per blossom [24]. Thrips feed on spider mite eggs; any damage they cause is compensated by their benefit in helping keep mites controlled.

### 6.2.3.3 Nematodes

**Causal organisms:** In Lebanon, these mainly comprise the root nematodes Meloidogyne spp. and Pratylenchus

**Epidemiology:** Nematodes are microscopic roundworms found in water, soils, decaying organic matter, plants and animals. In Lebanon, their occurrence is relatively low compared to that of the soil borne fungi or the aerial diseases and pests that have been discussed in the previous sections. They are favored by high moisture levels in soils and their activity is further increased when the weather is hot.

**Symptoms:**
- Root nematodes: Root knot nematodes (*Meloidogyne* spp) cause the formation of swellings known as galls or knots near the root tips along with excessive branching around and above the location of the galls [10]. Stunted growth, plant wilting and decreased yield (reduction down to 50%) may be observed too.

- Root-lesion nematodes (*Pratylenchus* spp.) cause lesions on roots and can be associated with the black root rot complex discussed in section 6.2.3.1.6 above.

**Organic farming control:** soil solarization can lower nematodes populations below damaging levels when applied appropriately and in suitable weather conditions. Cultural practices including crop rotation, proper field selection, sanitation and the use of disease free transplants [24] lower the incidence of the disease as well.

**Reasoned Chemical control:** prior to planting, soil fumigation with 1,3D, 1,3D+Pic or metam sodium control the disease. The efficacy of the chemical treatment is increased when coupled to soil solarization and suitable cultural practices such as crop rotation.
6.2.3.4 Weeds Management

Based on life cycles, weeds within strawberry fields can be classified as annuals (summer or winter), biennials or perennials. Annual weeds usually pose the biggest problems.

For Lebanese strawberry producers and particularly in the coastal areas, the most serious species are: *Amaranthus* spp. (Pigweed), *Chenopodium album* (Common lambsquarters), *Malva* spp. (Little mallow), *Melilotus* spp. (Sweet clover), *Lactuca serriola* (Prickly lettuce), *Senecio vulgaris* (Common groundsel), *Sonchus oleraceous* (annual sowthistle), *Capsella bursa pastoris* (Shepherd’s purse), *Convolvulus arvensis* (field bindweed).

The most serious grasses are *Cynodon dactylon* (Bermuda grass), *Poa annua* (Bluegrass), *Hordeum* spp. (Wild barley), *Lolium* spp. (ryegrass), *Setaria* spp. (Foxtails).

Scouting and proper weed identification is the foundation of any integrated weed management.

The most effective strawberry weed management program includes the following four components:

1. **Preventive**: Clean farm equipment between fields; weeds kept in ditches, field edges under control, soil fumigation or soil solarization;
2. **Cultural**: Sanitation, crop rotation and when applicable, mulching;
3. **Mechanical**: Tillage, hand weeding, hoeing and mowing;
4. **Chemical [12,13]**: Strawberry herbicides are applied either:
   a. **Pre-planting**: chemical alternatives to MeBr can be used;
   b. **Or Pre- emergence**: (after planting but before weeds emerge);
   c. **Or Post- emergence**: (after planting and after weeds emerge):
      - quinalofop-p-ethyl or phenmedipharm or pelargonic acid can be used.
Annexes, References and Useful Web Links
Annex 1 [25]

Ozone depleting substances

<table>
<thead>
<tr>
<th>Halogen Source Gas</th>
<th>Lifetime (Years)</th>
<th>Ozone Depletion Potential (ODP)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chlorine</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CFC-12</td>
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</tr>
<tr>
<td>CFC-113</td>
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</tr>
<tr>
<td>CFC-11</td>
<td>45</td>
<td>1</td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>26</td>
<td>1.1</td>
</tr>
<tr>
<td>HCFCS</td>
<td>1-26</td>
<td>0.001-0.52</td>
</tr>
<tr>
<td><strong>Bromine</strong></td>
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<td></td>
</tr>
<tr>
<td>Halons (Halon-1301)</td>
<td>65</td>
<td>10</td>
</tr>
<tr>
<td>Methyl Bromide</td>
<td>0.7</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Major sources of ozone depleting substances

<table>
<thead>
<tr>
<th>Sector/Industry</th>
<th>Ozone Depleting Substances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigeration</td>
<td>R-12 (Domestic Refrigerators)</td>
</tr>
<tr>
<td></td>
<td>R-12 (Industrial Refrigerators)</td>
</tr>
<tr>
<td></td>
<td>R-502 (Chillers)</td>
</tr>
<tr>
<td></td>
<td>R-12 (Air Conditioners)</td>
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<tr>
<td>Aerosols</td>
<td>R-11, R-12 (Propellants)</td>
</tr>
<tr>
<td>Foams</td>
<td>R-11 (Blowing Agents)</td>
</tr>
<tr>
<td>Halons</td>
<td>H-1301 (Fire Extinguishers)</td>
</tr>
<tr>
<td>Soil Fumigation</td>
<td>Methyl Bromide</td>
</tr>
<tr>
<td>Chemicals</td>
<td>Carbon Tetrachloride (Industrial Processing)</td>
</tr>
</tbody>
</table>
Annex 2: Recommendations for the use and maintenance of drip irrigation system [26]

<table>
<thead>
<tr>
<th>Water Source</th>
<th>Type of waste</th>
<th>Preventive actions</th>
<th>Curative actions</th>
</tr>
</thead>
</table>
| **Open Reservoir** | - Vegetation (debris+algae)  
- Sand + silt  
- Calcium Carbonate + iron  | - sand filter  
- screen or disc filter                          | - periodic flushing of filters  
- replacement of internal parts of screen filter  
- periodic injection of Nitric acid solution $\text{HNO}_3$ ($d = 1.33$)  
2 to 5 liters / m$^3$ of water under all crops |
| **Open Channel** | - Solid waste (Vegetation debris + algae)  
- Sand + silt  
- Calcium Carbonate + Iron  | - Hydro cyclone filter  
- sand filter  
- screen or disc filter                              |                                                                                  |
| **Well** | Sand + silt  
Calcium Carbonate + Iron  | Screen or disc filter                    |                                                                                  |
| **All cases** | | - Install pressure gauges, one before filter another one after the filter  
- Control both gauges periodically                      |                                                                                  |
Annex 3: Composting crop residues and manure [27, 28, 29, 30]

I. How to compost crop residues?
Crop residues can be composted aerobically using the bin or pile method or treated anaerobically in an underground pit. While both processes lead to the same result, the aerobic process is faster and thus recommended.

**Bin composting method:** compared to the pile method, the bin composting method has the advantage of containing the wastes in a bin and thus avoiding their dispersion by animals. The basic steps of the bin composting method are as follows:

1. Reduce the size of crop residues to 5-7 cm using a shredder.

2. Build a composting bin. The ideal bin would be a 1mx1m aerated wooden bin made up of wooden sticks 5-10 cm apart and having a mobile door. Alternatively, a bin made of a metallic net can also be used.

3. Place the bin in a suitable place: away from direct sun light, protected from rain and in such a way that wind does not orient odors towards farmer’s house or hut. In the winter, cover the top of the bin with a plastic sheet.

4. Fill in your bin with wastes:
   a. Types of wastes
      i. Ideally, crop residues should be equally divided on volume basis between wet nitrogen rich wastes (residues of fruits and vegetable crops) and dry carbon rich wastes (residues of wheat or barley crops, wood branches, dry leaves).
      ii. If the above mixture is not available, use what ever crop residues you have knowing that too much wet wastes leads to bad odor generation and too much dry wastes slows down the composting process.
      iii. In all cases, add about 5% of manure to accelerate the process.
   b. Filling procedure
      i. If you have a big quantity of wastes, fill the bin and cover the top wastes with a thin layer (handful) of soil. Soil addition limits the production of bad odors, reduces the attraction of insects and is a
source of micro-organisms. The composting process can start.

ii. Otherwise, you need to fill the bin progressively. In this case, start by putting a 10 cm layer of dry wastes, followed by a 10 cm layer of wet wastes followed by a handful of soil.

5. Monitor the moisture content: The optimum moisture level of wastes should be between 40% and 60% or 50% on average. Add water whenever needed. However, avoid putting excess water. Treat excess dryness by adding water or wet wastes and treat excess moisture by adding dry wastes.

6. Control pathogens in your wastes: when the bin is full, do not turn your pile until its temperature reaches 65°C and stays on that level for 3 days or reaches 70°C and stays on that level for 1 day (24 hours). Having the wastes at around 65°C 3 days or 70°C for 1 day kills many pathogens and weed seeds in your compost. Right after pathogen control, the wastes start turning into a dark mass and it becomes difficult to discriminate the individual types of wastes originally added. Also, their volume decreases due to the degradation of the organic matter into CO₂ and H₂O and to their progressive transformation into compost.

7. Transfer your pile from one place to another:
   a. If you have a limited production of raw wastes, move your pile from one location to another one few meters away from the first one with a fork.
   b. If you have a continuous production raw wastes, transfer the pile to a new bin and use the first one to receive new wastes.

Compost moisture content can be determined using soil moisture meters. Alternatively, conduct the simple squeeze test: take a handful of wastes and squeeze it. If few drops (2-3) of liquid are released, the moisture level is around 50% and is thus acceptable.

This transferring operation mixes the pile and aerates it supplying the needed oxygen for the degrading microorganisms. It also dissipates excess heat build up and allows working at the optimal composting temperature which is 45°C-60°C.

8. Monitor the maturation phase: The active composting phase has ended and the maturation phase which extends over 2-3 months has started. During the maturation phase:
   a. Stop adding new wastes to the transferred wastes that are being composted.
   b. Moisten the wastes with water from time to time in a way to keep the moisture level of the wastes around 50%.
   c. Aerate your pile on a regular basis:
      i. In case you have a limited production of wastes, aeration can be done by turning the pile with a fork every time the pile temperature exceeds 65°C.
ii. In case you have a continuous production of raw wastes, aeration can be done by transferring the piles from one bin to another each time the first bin is full.

9. After the maturation phase, verify that your compost is ready for use. If it is:
   a. It is a homogeneous mass having a dark brown to black color;
   b. Its volume is around 1/3 the volume of wastes originally added;
   c. Its odor is the odor of the soil after the first rain;
   d. Its temperature does not increase after turning the pile and remains equal to ambient temperature.

10. Screen your compost.

11. Use your compost in the soil at the rate of 1 - 2 tones/Ha.

12. Repeat the composting operation with new wastes and inoculate them with manure and with compost including the rejects of the screening operation (rich in microorganisms) at a rate of 5% for each.

**Pile composting method**
All steps of the bin composting method apply except that the waste pile is not contained in a bin.
For the composting process to work, the pile should be about 2.5m wide and 1.5 m high. Once the pile is built and heat treated, its transfer from one bin to another is replaced by transferring the pile with a fork to a new location few meters away from the location of the original pile. Transfer your pile every time its temperature exceeds 65° C.
II. How to compost a manure?

1. Pile your manure in a pile which is about 2.5 m wide and 1.5 m high.

2. If needed, add water to it so that its moisture level ranges between 40% and 60%.

3. Control pathogens by avoiding turning the pile before its temperature reaches 65°C and stays on that level for 3 days or reaches 70°C and stays on that level for 24 hours.

4. Once the heat treatment phase is over, turn it on regular basis (every 10 days on average) until its temperature reaches ambient temperature. During this process, moisten the pile whenever needed.

5. Your manure is now composted & ready for use.

Manure pile. Photo taken by the project team.
Annex 4: Analysis of Common Fertilizers Material

<table>
<thead>
<tr>
<th>Material</th>
<th>Analysis</th>
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<tbody>
<tr>
<td><strong>N Fertilizers</strong></td>
<td></td>
</tr>
<tr>
<td>Ammonium Nitrate - NH₄NO₃</td>
<td>33 % N</td>
</tr>
<tr>
<td>Ammonium Sulfate - (NH₄)₂SO₄</td>
<td>21 % N</td>
</tr>
<tr>
<td>Urea - CO(NH₂)₂</td>
<td>46 % N</td>
</tr>
<tr>
<td><strong>P Fertilizers</strong></td>
<td></td>
</tr>
<tr>
<td>Triple Super Phosphate (TSP)</td>
<td>48 % P₂O₅</td>
</tr>
<tr>
<td>Single Super Phosphate (SSP)</td>
<td>17 % P₂O₅</td>
</tr>
<tr>
<td><strong>K Fertilizers</strong></td>
<td></td>
</tr>
<tr>
<td>Potassium Sulfate - K₂SO₄</td>
<td>50 % K₂O</td>
</tr>
<tr>
<td><strong>N &amp; P Fertilizers</strong></td>
<td></td>
</tr>
<tr>
<td>Mono Ammonium Phosphate (MAP)</td>
<td>11%N + 52 % P₂O₅</td>
</tr>
<tr>
<td>Diammonium Phosphate (DAP)</td>
<td>11% N + 46 % P₂O₅</td>
</tr>
<tr>
<td><strong>N &amp; K Fertilizers</strong></td>
<td></td>
</tr>
<tr>
<td>Potassium Nitrate – KNO₃</td>
<td>13 % N +46 % K₂O</td>
</tr>
</tbody>
</table>
Annex 5: Salt Index for common fertilizer materials [31]

<table>
<thead>
<tr>
<th>Material</th>
<th>Analysis*</th>
<th>Salt index, relative to NaNO₃</th>
<th>Partial salt index**</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N sources</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH₃</td>
<td>82.2</td>
<td>47.1</td>
<td>0.572</td>
</tr>
<tr>
<td>NH₄NO₃</td>
<td>35.0</td>
<td>104.1</td>
<td>3.059</td>
</tr>
<tr>
<td>(NH₄)₂SO₄</td>
<td>21.2</td>
<td>88.3</td>
<td>3.252</td>
</tr>
<tr>
<td>NH₄H₂PO₄ – MAP</td>
<td>11.0</td>
<td></td>
<td>2.453</td>
</tr>
<tr>
<td>(NH₄)₂HPO₄ – DAP</td>
<td>18.0</td>
<td></td>
<td>1.614</td>
</tr>
<tr>
<td>UREA</td>
<td>46.0</td>
<td>74.4</td>
<td>1.618</td>
</tr>
<tr>
<td>UAN</td>
<td>28.0</td>
<td>63</td>
<td>2.250</td>
</tr>
<tr>
<td>UAN</td>
<td>32.0</td>
<td>71.1</td>
<td>2.221</td>
</tr>
<tr>
<td>NaNO₃</td>
<td>16.5</td>
<td>100</td>
<td>6.080</td>
</tr>
<tr>
<td>KNO₃</td>
<td>13.8</td>
<td></td>
<td>5.336</td>
</tr>
<tr>
<td><strong>K Sources</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KCl</td>
<td>60.0</td>
<td>116.1</td>
<td>1.936</td>
</tr>
<tr>
<td>KNO₃</td>
<td>50.0</td>
<td>69.5</td>
<td>1.219</td>
</tr>
<tr>
<td>K₂SO₄</td>
<td>54.0</td>
<td>42.6</td>
<td>0.852</td>
</tr>
<tr>
<td>Sul-Po-Mag</td>
<td>22.0</td>
<td>43.4</td>
<td>1.971</td>
</tr>
<tr>
<td>K₂S₂O₃</td>
<td>25.0</td>
<td>68.0</td>
<td>2.720</td>
</tr>
<tr>
<td>KH₂PO₄</td>
<td>34.6</td>
<td>8.4</td>
<td>0.097</td>
</tr>
<tr>
<td><strong>S Sources</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(NH₄)₂S₂O₃</td>
<td>26.0</td>
<td>90.4</td>
<td>7.533</td>
</tr>
<tr>
<td>(NH₄)₂S</td>
<td>40.0</td>
<td>59.2</td>
<td>2.960</td>
</tr>
<tr>
<td>CaSO₄.2H₂O</td>
<td>17.0</td>
<td>8.2</td>
<td>0.247</td>
</tr>
<tr>
<td>MgSO₄.7H₂O</td>
<td>14.0</td>
<td>44.0</td>
<td>2.687</td>
</tr>
<tr>
<td><strong>Organic Sources</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manure salts</td>
<td>20.0</td>
<td>112.7</td>
<td>4.636</td>
</tr>
<tr>
<td>Manure salts</td>
<td>30.0</td>
<td>91.9</td>
<td>3.067</td>
</tr>
</tbody>
</table>

* % N in N carriers, % P₂O₅ in P carriers, and % K₂O in K carriers.

** The salt index of a mixed fertilizer is the sum of the partial salt index per unit (20 lbs) of nutrients times the unit due to each source in the mixture.

Remark: To evaluate the salt index of a given fertilizer, refer to column 3 of the above table. Salt indexes are to be compared to that of NaNO₃ which has the highest salt index (100).
Annex 6: Determination of WHO hazard classification based on acute LD50 (rat) of formulated product (mg/kg) [32]

<table>
<thead>
<tr>
<th>WHO Hazard class</th>
<th>Information to appear on label</th>
<th>Acute LD50 (rat) of formulation (mg/kg)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hazard Statement</td>
<td>Band Color</td>
</tr>
<tr>
<td>Ia Extremely hazardous</td>
<td>VERY TOXIC</td>
<td>PMS Red 199C</td>
</tr>
<tr>
<td>Ib Highly hazardous</td>
<td>TOXIC</td>
<td>PMS Red 199C</td>
</tr>
<tr>
<td>II Moderately hazardous</td>
<td>HARMFUL</td>
<td>PMS Yellow C</td>
</tr>
<tr>
<td>III Slightly hazardous</td>
<td>CAUTION</td>
<td>PMS Blue 293C</td>
</tr>
</tbody>
</table>

* Products unlikely to present a hazard in normal use

Lethal Dose 50 (LD 50): the dose of a substance (in milligrams per Kg body weight) that kills 50 % of the test animals in a standard assay.
Annex 7: Relative toxicities of some insecticides on honey bees and natural enemies [12]

<table>
<thead>
<tr>
<th>Common name</th>
<th>Mode of action</th>
<th>Selectivity (affected groups)</th>
<th>Predatory mites</th>
<th>General predators</th>
<th>Honey bees</th>
<th>Duration of impact to natural enemies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abamectin</td>
<td>6</td>
<td>moderate (mites, leafminers)</td>
<td>M</td>
<td>L</td>
<td>II</td>
<td>Long to predatory mites and affected insects</td>
</tr>
<tr>
<td>Bacillus thuringiensis ssp. aizawai</td>
<td>11.B1</td>
<td>narrow (caterpillars)</td>
<td>L</td>
<td>L</td>
<td>IV</td>
<td>short</td>
</tr>
<tr>
<td>Bifenazate</td>
<td>25</td>
<td>narrow (spider mites)</td>
<td>L</td>
<td>L</td>
<td>III</td>
<td>short</td>
</tr>
<tr>
<td>Etoxazole</td>
<td>10C</td>
<td>narrow (mites)</td>
<td>—</td>
<td>—</td>
<td>IV</td>
<td>short</td>
</tr>
<tr>
<td>Insecticidal soap</td>
<td>—</td>
<td>broad (exposed insects, mites)</td>
<td>M</td>
<td>M</td>
<td>IV</td>
<td>short to none</td>
</tr>
<tr>
<td>Paraffinic oil (JMS Stylet Oil)</td>
<td>—</td>
<td>broad (exposed insects, mites)</td>
<td>L</td>
<td>L</td>
<td>III</td>
<td>short to none</td>
</tr>
<tr>
<td>Petroleum oil</td>
<td>—</td>
<td>broad (exposed insects, mites)</td>
<td>L^2</td>
<td>L</td>
<td>III</td>
<td>short to none</td>
</tr>
<tr>
<td>Pyrethrin</td>
<td>3</td>
<td>broad (insects)</td>
<td>—</td>
<td>M</td>
<td>III</td>
<td>short</td>
</tr>
<tr>
<td>Rosemary oil</td>
<td>—</td>
<td>broad (exposed insects, mites)</td>
<td>L</td>
<td>L</td>
<td>IV</td>
<td>—</td>
</tr>
<tr>
<td>Spinosad</td>
<td>5</td>
<td>narrow (caterpillars, thrips, whiteflies, fruit flies, leafminers)</td>
<td>L</td>
<td>M^8</td>
<td>III</td>
<td>short to moderate</td>
</tr>
<tr>
<td>Thiamethoxam</td>
<td>4A</td>
<td>narrow (sucking insects)</td>
<td>—</td>
<td>—</td>
<td>I</td>
<td>moderate</td>
</tr>
</tbody>
</table>

H = high    M = moderate    L = low    — = no information

1 Rotate chemicals with a different mode-of-action group number, and do not use products with the same mode-of-action group number more than twice per season to help prevent the development of resistance. For additional information, see their Web site at http://www.irac-online.org

2 Selectivity: Broad means it affects most groups of insects and mites; narrow means it affects only a few specific groups.
Generally, toxicities are to *Phytoseiulus persimilis*.

Toxicities are averages of reported effects and should be used only as a general guide. Actual toxicity of a specific chemical depends on the species of the predator or parasite, environmental conditions, and application rate.

Ratings are as follows: I-Do not apply to blooming plants; II-Apply only during late evening; III-Apply only during late evening, night, or early morning; and IV-Apply at any time with reasonable safety to bees.

Duration: Short means hours to days; moderate means days to two weeks; and long means many weeks or months.

Not hazardous to bees when applied at least 4 weeks before bloom.

Toxic against some natural enemies (predatory thrips, syrphid fly and lacewing larvae, beetles) when sprayed and up to 5-7 days after, especially for syrphid fly larvae.
Annex 8: Treatment Timing

<table>
<thead>
<tr>
<th>Pathogens/Disease</th>
<th>Pre-plant fumigation</th>
<th>Clean nursery stock</th>
<th>At planting</th>
<th>Pre-harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dips or water washing</td>
<td>Before overhead irrigation</td>
</tr>
<tr>
<td>Anthracnose&lt;sup&gt;3&lt;/sup&gt;</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
</tr>
<tr>
<td>Botrytis fruit rot&lt;sup&gt;3&lt;/sup&gt;</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>+</td>
</tr>
<tr>
<td>Powdery Mildew&lt;sup&gt;3&lt;/sup&gt;</td>
<td>---</td>
<td>+++</td>
<td>---</td>
<td>+++</td>
</tr>
<tr>
<td>Phytophthora crown rot&lt;sup&gt;4&lt;/sup&gt;</td>
<td>+++</td>
<td>+</td>
<td>---</td>
<td>++</td>
</tr>
<tr>
<td>Phytophthora Red stele&lt;sup&gt;4&lt;/sup&gt;</td>
<td>++</td>
<td>++</td>
<td>---</td>
<td>+</td>
</tr>
<tr>
<td>Verticillium wilt&lt;sup&gt;*&lt;/sup&gt;</td>
<td>+++</td>
<td>++</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>White grubs</td>
<td>+++</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Thrips</td>
<td>---</td>
<td>+++</td>
<td>---</td>
<td>+</td>
</tr>
<tr>
<td>Mites</td>
<td>---</td>
<td>+++</td>
<td>---</td>
<td>+</td>
</tr>
<tr>
<td>Aphids</td>
<td>---</td>
<td>+++</td>
<td>---</td>
<td>+</td>
</tr>
</tbody>
</table>

Note: Not all indicated timings may be necessary for disease control.

*: Data taken from the reference [12]

Rating: +++ = most effective, ++ = moderately effective, + = least effective, and — = ineffective.

1. Preharvest treatments include applications of fungicides before heavy fog, dews, or rain.
2. Preplant fumigation includes soil solarization and chemical alternatives to MeBr.
3. Integrated programs required for management including rotation of fungicides of different classes.
4. In-season, foliar treatments include phosphite or fosetyl-aluminum products or soil applications.
References


Useful web links

- Methyl Bromide Alternatives Project for the Strawberry Sector in Lebanon:
  www.moe.gov.lb/mebr/strawberry
- Ministry of Environment, Lebanon:
  www.moe.gov.lb
- Ministry of Agriculture, Lebanon:
  www.agriculture.gov.lb
- Lebanese Agriculture Research Institute:
  www.lari.gov.lb
- United Nations Industrial Development Organization:
  www.unido.org
- United Nations Environment Program (UNEP), Ozone Secretariat:
  http://ozone.unep.org
- The Multilateral Fund for the Implementation of the Montreal Protocol:
  www.multilateralfund.org
- University of California, Division of Agriculture and Natural Resources, UC IPM
  online Statewide Integrated Pest Management Program:
  http://www.ipm.ucdavis.edu
- Ontario Ministry of Agriculture and Rural Affairs, Integrated Pest Management Program:
- United States Environmental Protection Agency (US EPA), Regulating Pesticides Home:
  http://www.epa.gov/pesticides/regulating/index.htm
- European Union, EUROPA pesticides data base
- Purdue University’s National Pesticide Information Retrieval System:
  http://ppis.ceris.purdue.edu/
- Association for Lebanese Organic Agriculture:
  http://www.aloalebanon.org/home.php
- United Nations Food and Agriculture Organization, Organic Agriculture Home:
- European Union, EUROPA Organic Farming Home:
  http://ec.europa.eu/agriculture/organic/home_en
- United States Environmental Protection Agency (US EPA), Organic Farming web page:
  http://www.epa.gov/oecaagct/torg.html
- United States Department of Agriculture, National Organic Program:
  http://www.ams.usda.gov/AMSv1.0/nop
- Ontario Ministry of Agriculture and Food & Rural Affairs, Organic farming web page:
Chemical Alternatives to Methyl Bromide
Integrated Crop Management
Soil Solarization

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Web page: www.moe.gov.lb/mebr/strawberry

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