Guidelines on agro-ecological intensification practices and implementation and management of biodegradable mulching

Website	FoodLAND-africa.eu
Twitter	@FoodLANDafrica
Facebook	FoodLANDafrica
LinkedIn	FoodLAND-africa

Table of Contents

SECTION 1 – Guidelines for Agro-Ecological Intensification 5
1. The concept of agroecology 6
1.1 Introduction 6
1.2 Principles of agroecology 6
1.3 The 10 elements of agroecology 7
2. Agroecological technologies and practices 10
2.1 Mulching 10
2.1.1 Introduction 10
2.1.2 Selection of Mulching material 11
2.1.3 Sources of Mulches 12
2.1.4 Application of Mulch 12
2.2 Mixed farming 13
2.3 Integrated pest management (IPM) 14
2.3.1 Introduction 14
2.3.2 Principles of IPM 15
2.3.3 Advantages and disadvantages of Integrated Pest Management 16
2.3.4 The push and pull technology 17
2.3.4 Pheromone trap 19
2.3.5 Use of organic pesticides 20
2.4 Inter-cropping 21
2.4.1 Introduction 21
2.4.2 Methods of inter-cropping 22
2.4.3 Rules to be followed in the selection of the inter-cropping crops 25
2.5 Use of manure and crop waste recycling 25
2.5.1 Introduction 25
2.5.2 Types of Manure 26
2.6 Crop rotation 36
2.6.1 Introduction 36
2.6.2 Principles of Crop Rotation 37
3. Application of agroecological practices in soil and water conversation 39
4. Application of agro-ecological practices in crop protection 41

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

Bibliography 43
SECTION 2 – Guidelines for Biodegradable Mulching 45
Introduction 45
Novamont biodegradable and compostable bioplastics 45
Mulch film made of biodegradable and compostable biopolymers 46
    Types of biodegradable mulch film 46
    Economic Implications 48
Guidelines on implementation and management of biodegradable mulching in field 50
    Preparation of the soil 50
    Laying out the film 51
    Crops setup: film perforation, crops transplant, irrigation and agricultural inputs 52
    Controlling weeds and duration of the film 53
    End of the crop cycle 53
    Biodegradable film storage 54
    Performance evaluation and management of biodegradable mulching in field 54
Customized guidelines for biodegradable mulching trial on tomatoes crops 59
    Cultivation of processing tomato 59
Characteristics and agronomical results from the use of biodegradable mulch film in processing tomatoes 60
    Field trials 60
    Tunisian Food Hub mulching trials on tomatoes. 61
Characteristics and agronomical results from the use of biodegradable mulch film in the horticultural crops 62
    Field trials 62
    Tanzanian Food Hub mulching trials on beans. 62
  How the biodegradable in soil mulch film will enhance production and nutritional performances in the countries of interest for the project. 63
    Conclusions 64

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

SECTION 1 – Guidelines for Agro-Ecological Intensification

List of contributors

No.	Name	Institution
1	Ms. Phiona Mwogeza	Makerere University
2	Prof. John Muyonga	FoodLAND Project, Makerere University
3	Dr. Richard Bukenya	
4	Mr. Yazidi Kalange	
5	Mr. Henry Nsereko	

Acknowledgement

The team that participated in the preparation of this training manual on Agro-Ecological Intensification (AEI) in Kamuli district, Uganda would like to acknowledge the European Union for providing the funds for implementing the Food and Local Agricultural and Nutrition Diversity (FoodLAND) Project. It is through this project that the team managed to contribute positively to the development to this manual which will be used for training extension staff and farmers on agroecological practices in Kamuli.

The team is equally grateful to institutions and individuals who contributed in one-way or the other towards the production of this training manual.

Acronyms

AE	Agroecology
AEI	Agro-Ecological Intensification
FoodLAND	Food and Local Agricultural and Nutrition Diversity
IPM	Integrated Pest Management
Q&A	Question and Answer
VEDCO	Volunteer Efforts for Development Concerns

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

1. The concept of agroecology

1.1 Introduction

Agriculture has turned out to be capital intensive. This is attributed to the various farming challenges, including loss of soil fertility due to over cropping, erosion, leaching; the unfavorable climatic patterns; high infestation of weeds and pests thus affecting the overall crop yields; among others. This has called for intensive use of inorganic fertilizers, irrigation water, pesticides, herbicides, thus resulting in an increase in overall production costs. As a result, various research initiatives are now working on solutions that not only enable sustainable food production but equally reduce the overall production costs for the farmer. Agroecology (AE) has been overly cited as the most viable solution to this growing issue.

Agroecology (AE) is the application of ecological concepts and principles to agriculture. AE maximizes the interactions of plants, animals, humans, and the environment while also protecting the social aspects of a sustainable and equitable food system. It is aimed at delivering food security and ecosystem health, while still promoting economic stability. AE approaches are location and situation specific, enhancing applicability and adoptability among the desired communities. AE farming methods include crop rotation, mulching, intercropping, use of cover crops, agro-forestry, integrating the landscape with agricultural areas, organic soil fertilization, and the use of natural insecticides. Some of the socio-economic benefits of AE include (i) Increase income, (ii) Maintain/create jobs, (iii) Saving on chemicals, (iv) Increase food security.

1.2 Principles of agroecology

Because AE involves the application of ecological concepts to agriculture, the design of an AE agricultural system is based on the following principles:

a) Increase of biomass recycling while improving nutrient availability and balancing nutrient flow. An enormous amount of biomass is produced year after year on an agricultural land (cow dung, corn stover, bean and coffee husk etc.). Farmers reuse this biomass to raise the soil's nutrient content. AE practices enable farmers to effectively utilize the biomass available to increase productivity.
b) Maintaining favorable soil conditions for plant growth, namely through regulating organic matter and increasing soil biotic activity. Organic matter assists favorable soil conditions for better plant growth.
c) Reducing losses due to flows of solar radiation, air, and water through managing microclimates, harvesting water, and managing soil through improved soil cover.
d) Species and genetic harvesting of the agroecosystem in time and space at the field and landscape levels. Selective breeding of plants leads to monocultures of genetically identical plants, which makes crops extremely susceptible to

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

widespread diseases. In contrast, species and genetic diversity helps plants adapt to changing environments.

e) Promoting essential ecological processes and services by increasing favorable biological interactions and synergy among agrobiodiversity components. An organism's interactions with its environment are fundamental to its survival and to the functioning of the ecosystem as a whole. Biological interactions are the effects organisms in a community have on one another. In the natural world, no organism exists in isolation, and thus every organism is connected to the environment and to other organisms.

1.3 The 10 elements of agroecology

The framework of the ten elements of AE is offered as a tool to aid in the building of various approaches for the transformation of agriculture and food systems. The 10 elements enable practitioners, extension, and other stakeholders to make better decisions in many circumstances at various levels and sizes.

a) Diversity - AE emphasizes the importance of diversity as a fundamental precondition and adaptive trait, particularly in the context of global change, whether it is diversity of species or ecological functions, or knowledge held by different actors within an agricultural system or diversity of activities and livelihood options within food systems. For example, in Busoga, most small-scale farmers integrate beans and maize in their gardens and rear a few livestock. The beans and maize can be a source of food for both humans and animals while livestock can provide animal manure and alternative source of income through the sale of animals and their products such as milk and eggs.

b) Co-creation and sharing of knowledge - A key factor influencing AE decision-making is the co-creation and sharing of knowledge, practices, science, and innovation. Agroecology can encourage trans-disciplinary engagement through the co-creation process, which can facilitate the blending of knowledge from various actors, such as traditional and indigenous knowledge on agricultural biodiversity and management experience for specific contexts held by men and women, practical knowledge of producers and traders related to markets, and global scientific knowledge and practices. For instance, adoption of readily available materials such as urine and ash for pest and disease management. This would be a great alternative to the very expensive inorganic fungicides and pesticides, thus promoting sustainable plant growth.

c) Synergies - AE entails designing diverse and synergistic systems that may include trees, animals, aquatic life, annual, perennial, and cover crops. It is crucial to purposefully use biological diversity and market linkages in redesigning agricultural and food systems to reap multiple concurrent benefits from component interactions. AE transitions should stress the value of collaboration, partnerships, and ethical leadership, including various actors at different stages, including multi-stakeholder partnerships. Mixed farming (integrating crop and

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

livestock production) enhances complementarities and synergies. Mixed farming can occur at the plot, farm, community or landscape level in either a spatial or temporal interaction. For instance, farmers often exchange resources like manure or straw between neighboring farms. Tomato farmers often rely on banana farmers for supply of dried banana leaves for use as mulch to control spread of soil fungal based diseases.

d) Efficiency - The goal of redesigning the food and agricultural systems with synergies in mind is to use resources more efficiently. Innovative agricultural and food production systems that aim to further increase productivity while maximizing the use of external inputs should be able to migrate from input-intensive systems to information and knowledge-based systems. Agroecological techniques primarily evaluate efficiency at the level of the entire farm or ecological network rather than at the level of a single component. For instance, farmers can reduce costs, use fewer external resources, and reduce the negative environmental impacts of external resources by enhancing biological processes and recycling nutrients, biomass, and water.

e) Recycling - Producers can boost profitability by utilizing fewer external resources while maintaining or increasing production, lowering costs and having a negative environmental impact. This is done by strengthening biological processes and recycling biomass, nutrients, and water.

f) Resilience - Enhanced sustainable agriculture and food systems depend on the resilience of individuals, communities, and ecosystems. By encouraging a diverse community of interconnected species, agro-ecological practices strive to work with the biological complexity of agricultural systems and enable the ecosystem to self-regulate in the face of pest and disease outbreaks. For instance, some agro-ecology practices such as community seed banking (store and manage seeds that aim to provide community members with seeds for future use) ensure that farmers have reliable access to affordable, diverse varieties of locally adapted seeds in a timely manner to ensure continued production amidst pandemics and other stresses.

g) Human and social values - AE should place a high emphasis on human and social values, including those related to gender and inter-generational equality, inclusion, and justice, as well as access to decent employment, all of which support the improved livelihoods dimension of SDGs. The goals and requirements of individuals who produce, distribute, and consume food should be at the center of food systems. AE supports and empowers women who are the major food producers and care givers to equitably access and control production resources such as land and financial services as well as fairly benefit from returns of agriculture production. This therefore contributes to increased productivity and equitable development at household and community level thereby reducing overall social vulnerability.

h) Culture and food traditions - When balanced, diverse, and culturally acceptable diets are encouraged, AE helps to ensure food security and nutrition while preserving the health of the ecosystem. Food and agriculture are important parts

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

of the human heritage; thus, they have a significant impact on how people behave. In order to promote the production and consumption of healthful foods, agroecology rebalances traditional and modern eating behaviors.

i) Responsive governance - Implementing sustainable food and agriculture practices requires effective governance structures at various scales, from local to global. For producers to transition their systems to AE practices and concepts, it is crucial to establish an inclusive, responsible, and transparent governance framework.

j) Circular and solidarity economy - Living within the limits of the earth is made easier by a circular and solidarity economy, which also provides a solid social framework for inclusive, sustainable development. AE prioritizes local markets and supports regional economic growth by reuniting farmers and consumers through a circular and solidarity economy.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

2. Agroecological technologies and practices

2.1 Mulching

2.1.1 Introduction

Mulching is the process of covering topsoil with plant material such as leaves, grass, twigs, crop residues, straw, etc. Mulch increases the activity of soil organisms like earthworms. They contribute to the formation of a soil structure with numerous smaller and bigger holes through which rainwater can easily infiltrate, minimizing surface runoff. As the mulch material decomposes, it enhances the organic matter content of the soil. Organic matter in the soil aids in the formation of a good soil with a stable crumb structure. As a result, mulching is critical in preventing soil erosion.

Some of the common farmer challenges that could be managed using mulching

- Excessive runoff and soil erosion during the rainy season
- Excessive weed growth for example in banana plantation
- Excessive soil water loss especially in the dry season Protecting the soil from wind and water erosion: Soil particles cannot be washed or blown away.

Advantages of mulches

- Protecting the soil from wind and water erosion: Soil particles cannot be washed or blown away.
- Improving the infiltration of rain and irrigation water by maintaining a good soil structure: no crust is formed; the pores are kept open.
- Keeping the soil moist by reducing evaporation: Plants need less irrigation or can use the available rain more efficiently in dry areas or seasons.
- Feeding and protecting soil organisms: Organic mulch material is an excellent food for soil organisms and provides suitable conditions for their growth.
- Suppressing weed growth: With a sufficient mulch layer, weeds will find it difficult to grow through it
- Preventing the soil from heating up too much: mulch provides shade to the soil and the retained moisture keeps it cool.
- Providing nutrients to the crops: While decomposing, organic mulch material continuously releases its nutrients, thus fertilizing the soil, and eventually forming the humus.

Note: In annual crops, covering the soil with dead plant material is an easy technique to manage weeds and protect the soil. This approach is adaptable to most existing cropping systems. However, it is critical to have appropriate plant material.

Challenges associated with mulches

- Some organisms can proliferate excessively in the damp and protected conditions of the mulch layer. Under a mulch layer, slugs and snails can multiply

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

rapidly. Ants and termites that cause crop damage may also find optimal living circumstances.

- When crop residues are utilized for mulching, there is an increased risk of pests and diseases persisting. Stem borers, for example, can live in the stalks of crops such as cotton, corn, and sugar cane. Plant material contaminated with viral or fungal diseases should not be used if the disease has the potential to spread to the following crop. Crop rotation is critical to mitigating these drawbacks.
- When carbon-rich materials such as straw or stalks are used for mulching, microbes may use nitrogen from the soil to decompose the material. As a result, nitrogen may be temporarily unavailable for plant growth.
- The availability of organic material is typically the primary constraint for mulching. Its production or collection usually requires labor and may conflict with crop production.

2.1.2 Selection of Mulching material

The type of material used for mulching has a significant impact on its effectiveness. Material that decomposes quickly will protect the soil for a limited time but will supply nutrients to the crops while degrading. Hardy materials degrade more slowly and thus cover the soil for a longer period. To accelerate the breakdown of the mulch material, organic manures such as animal dung can be sprinkled on top of it, increasing the nitrogen concentration. This increases nutrient release into the soil. Slowly decomposing mulch material (low nitrogen content, high C/N) will provide longer-term protection against soil erosion than swiftly decomposing material (Figure 1).

Figure 1: Mulching in vegetable garden

Note: Use the following demonstrates the practice of mulching https://youtu.be/_jViflR_epc

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

2.1.3 Sources of Mulches

- Weeds or cover crops e.g. pumpkin as cover crop in maize
- Crop residues such as maize stovers (Lusoga: *Ebidhumadhuma*), banana waste leaves (Lusoga: *ebyayi*)
- Grasses such as papyrus (Kitoogo – *Luganda dialect*)
- Pruning material from trees
- Cuttings from hedges
- Wastes from agricultural processing or from forestry such as wood shavings
- Biodegradable films (Figure 2a)

2.1.4 Application of Mulch

If feasible, apply the mulch before or at the start of the rainy season, when the soil is most fragile. If the mulch layer is not excessively thick, seeds or seedlings can be sown or planted directly in between the mulching material. On vegetable plots, apply mulch only after the young plants have become slightly hardier, as the results of decomposition from fresh mulch material may damage them. If mulch is put prior to sowing or planting, it should not be too thick so that seedlings can penetrate it. Mulch can also be put to existing crops; however, it is best done immediately after digging the soil. It can be applied between the rows, directly around single plants (especially for tree crops) or evenly spread on the field. During application of mulch, care should be taken not to cover the leaves of the plant as observed in Figure 2b.

FoodLAND has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

Figure 2: Comparison of mulching approaches (a) Beans mulched with biodegradable film (b) Mulch material covering bean leaves

2.2 Mixed farming

Mixed farming is when a farmer decides to combine two or more agricultural activities on the same farm. Mixed farming is a type of farming which involves both the growing of crops and the raising of livestock. In mixed farming, the land is used for growing food (crop production) and fodder crops and rearing livestock. The cultivation of crops alongside the rearing of animals for meat or eggs or milk defines mixed farming. For example, a mixed farm may grow cereal crops such as maize and also keep cattle, sheep, pigs or poultry. Often the dung from the cattle serves to fertilize the cereal crops.

Some of the common farmer challenges that could be managed using mixed farming

- Limited land available for different farm operation
- Declining soil fertility
- Lack of feed for animals
- Uncertainty surrounding the crop yields due to climate change

Advantages of mixed farming

- It enhances the productivity of the farm land
- Both farming enterprises complement each other.
- Farmers can keep their fields under continuous production.
- It enhances the productivity of the farmer also.
- Reduce dependency on external inputs and costs. Because the mixed farming system recycles much of its wastes, this reduces external inputs (like fertilizers

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

FOODLAND

and pesticides). This in turn reduce greenhouse gases emissions, whether directly or indirectly because less fossil fuels are required in the production and distribution of fertilizers and pesticides due to lower demand.

- It stabilizes the income of the farmer because the farmer is not depending solely on one activity. Should one activity fail (due to low price or pests or diseases), the farmer can still get income from the other activities.
- Increased biodiversity means less risks of pests and diseases outbreak in the farm. Outbreak usually occurs in monoculture where there is uniformity of species especially over a large area.

Drawbacks associated with mixed farming

- Because a mixed farming system consists of multiple activities running simultaneously, this makes the control, monitoring, and maintenance of the farm more difficult than a monoculture where only a single activity is run.
- Sometimes one activity may hinder the other activity. In a mixed farming system, animals may interfere with the crops as they are growing. Animals can feed on them and stampede them. this can still happen even when the animals are restricted, because they can always detach from their restricted zone whenever they find their way. Farm animals may feed on crops before harvest stage, thus resulting in loss of yield and reduction in market value.
- For the same reason above, the farmer needs to be knowledgeable (or an expert) in more than one area as compared to a monoculture farmer. A mixed farming farmer is running several activities at once, there may be management problem.
- It may become capital intensive as more resources are required for caring for your crops and raising your animals.

2.3 Integrated pest management (IPM)

2.3.1 Introduction

Integrated Pest Management (IPM) was developed in response to steadily increasing pesticide use, which led to crises in pest management (e.g., secondary pest outbreaks and pest resurgences following the emergence of pesticide resistance) and increasing awareness of the full costs of pesticide use to human health and the environment. IPM is the methodical evaluation of every pest management method already in use, followed by the incorporation of the most appropriate controls to prevent the spread of pest populations. It combines biological, chemical, physical, and crop-specific (cultural) management approaches to grow healthy crops while using less pesticides, decreasing or limiting the dangers that pesticides bring to human health and the environment, and achieving sustainable pest management.

IPM is a dynamic process that employs an ecological systems perspective and encourages the user or producer to explore and implement the complete range of optimal pest control alternatives currently available given economic, environmental, and social factors. IPM is highly grounded on ecology, aimed at sustaining ecosystem functions. It

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

supports the development of a wholesome crop while causing the least amount of harm to agro-ecosystems, and it supports organic pest management techniques.

Some of the common farmer challenges that could trigger the use of IPM

- Rampant pest and disease outbreak leading to yield losses
- High costs of pesticides and fungicides
- Invasion by perennial weeds that result into total losses
- Pests and weed persistence in fields

Examples of approaches used in IPM include; Crop rotation, Use of traps (e.g., pheromone traps, pull and push technology), use of organic pesticides, use of repellant plants (Napier grass, red pepper, American maly Gold, Chinese Chive among others among others).

2.3.2 Principles of IPM

Integrated pest management is based on eight principles (Figure 3) as discussed below:

(a) Principle 1: Prevention and Suppression - Prevention is adoption of measures to reduce the chance of occurrence of pest. Suppression is reducing the impact of the pests. Prevention and suppression can be done by applying the different techniques. It is a method of preventing the spreading of harmful organisms by hygiene measures (e.g., by regular cleansing of machinery and equipment). One of the methods of prevention and suppression is crop rotation where it would break the life cycle of the pests. Prevention and suppression also include use of adequate cultivation techniques (e.g., stale seedbed technique, sowing dates and densities, under-sowing, conservation tillage, pruning and direct sowing).

(b) Principle 2: Monitoring - Harmful organisms must be monitored by adequate methods and tools, wherever available. Monitoring can be done through observations, use of scientifically sound warning, forecasting and early diagnosis systems, advice from professionally qualified advisers, etc. Many countries like France, Denmark have adopted this monitoring and forecasting technique

(c) Principle 3: Decision making - Decision making is done based on the results of the monitoring IPM focuses on threshold-based intervention in most of the cases. Threshold is the defined pest density, or population level, which when exceeded, management should occur. However, threshold is difficult to define in most of the cases and in case of tolerant species, decision of intervention is based on the general observations. We should also be aware that specific crops, pest life cycle, climatic condition, etc., should be considered before making any kind of decisions.

Principle 4: Non-Chemical Methods - Non-chemical methods are prioritized over chemical methods if they can produce satisfactory results. As chemical methods are often not sustainable and creates more pest problems, non-chemical methods are always preferred at first hand as they are more sustainable with less biological and environmental hazards. Examples of non-chemical methods include soil-solarization or biological control. Use of live natural enemies is one

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

of the major non-chemicals (biological) intervention method. Other non-chemical methods include biological, physical and ecological methods.

(e) Principle 5: Pesticide Selection - IPM doesn't totally avoid the use of the pesticides. When the alternative methods are not properly used then the pesticides are used for pest control. The pesticides used however needs to be as specific as possible for the target. The pesticides shouldn't possess any threat to the health of human, non-target humans and environment.

(f) Principle 6: Reduced Pesticide Use - Reduced pesticides use refers to the reduction in the frequency and doses of the pesticides. This method needs to be supported by the other means of intervention. It helps in reducing the side effects of the pesticides

(g) Principle 7: Anti- resistant Strategies - IPM focuses on the anti-resistance activities as: - Unmanaged and haphazard use of the pesticides have created the problem of resistance and Pests have developed the resistance and the use of pesticides have less effect on them. This is also the major reason for the IPM. Anti-resistant strategies include use of combination of different pesticides that has different mode of action, applied in different time.

(h) Principle 8: Evaluation - Evaluation is the important aspect of the IPM program. Evaluation is done based on the records of the use of the pesticides, its effects and many more. Evaluation is necessary in studying the effectiveness of the plan protective measures and plan further.

Figure 3: The chorological flow of the principles of IPM

2.3.3 Advantages and disadvantages of Integrated Pest Management

Advantages of IPM

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

(a) Lower cost intervention: Traditionally, the use of the pesticides to control the pest invasion would account to lots of cost. Also, these pesticides need to be imported as well. The application of IPM would lessen the financial burden. Moreover, different techniques involved in IPM are more sustainable with long lasting benefits.
(b) Benefits to the environment: Use of the pesticides are often linked degradation of the environment causing some more additional problems. IPM is an eco-friendly approach and the effects on the environment is always considered before the application of any interventions. Less use of pesticides won't affect the fertility of soil.
(c) Minimizes residue hazards of pesticides: It is obvious that in an IPM schedule the use of pesticides will be considerably reduced, hence the pesticide residue hazards will also get automatically minimized.
(d) Anti-Resistance: The IPM model in itself is the anti-resistant mode for pest control. It discourages the use of chemicals and thus creates less cases of anti-resistance. Pesticides are used only when the other alternatives are not satisfying.
(e) Useful and best intervention for the general public: Assurance of safe, reliable and low-cost pest control. The pest control will not affect the crops. Moreover, it is safe and affordable for the general public as well.

Disadvantages of Integrated Pest Management

(a) More involvement in the technicalities of the method: IPM needs to be planned. IPM demands more attention and dedication. Requires expertise of various field. All those involved in the IPM need to be educated and trained which often requires much time.
(b) Time and energy consuming: Application of IPM takes time. Much time is needed in planning itself. As IPM strategies differs from region to region, a separate plan is required for each region. The expected results of intervention may take long time to be achieved.

2.3.4 The push and pull technology

Push–pull technology is an inter-cropping strategy for controlling agricultural pests by using repellent "push" plants and trap "pull" plants. For example, cereal crops like maize or sorghum are often infested by stem borers.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

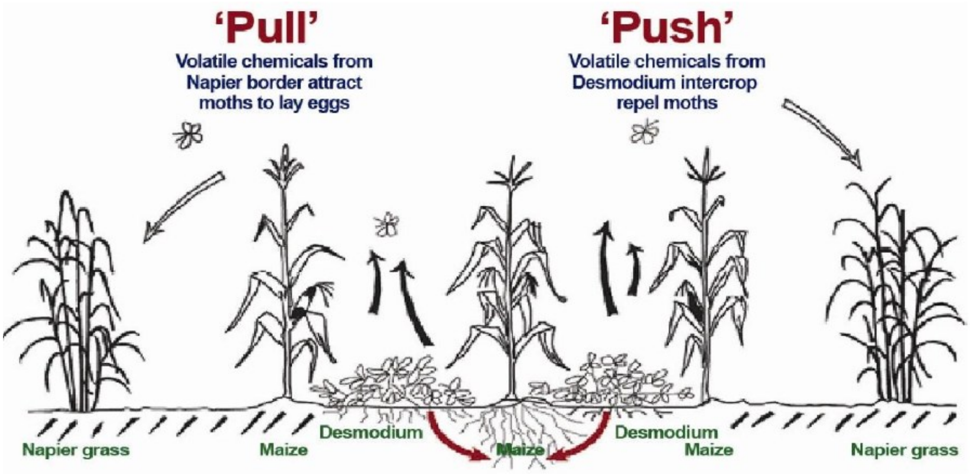

Figure 4: Demonstration of how the intercrop facilitates the push and pull mechanism

How it works for maize protection: Push-pull is a simple cropping strategy whereby farmers use Napier grass and desmodium legume (Silverleaf and Greenleaf desmodium) as intercrops (Figure 4, Figure 5). Desmodium is planted in between the rows of maize. It produces a smell or odor that stemborer moths do not like. The smell 'pushes' away the stemborer moths from the maize crop. Napier grass (*Pennisetum purpureum*) is planted around the maize crop as a trap plant. Napier grass is more attractive to stemborer moths than maize, and it 'pulls' the moths to lay their eggs on it. However, Napier grass does not allow stemborer larvae to grow and survive on it. When the eggs hatch and the small larvae bore into Napier grass stems, the plant produces a sticky substance like a glue that traps them, and they die. So, very few stemborer larvae survive, and the maize is saved because of the 'push-pull' strategy.

In addition, a ground cover of desmodium (*Desmodium uncinatum*, or Silverleaf), interplanted among the maize, reduces Striga weed. Research has shown that chemicals produced by the roots of desmodium are responsible for suppressing the Striga weed. Therefore, Striga does not grow where desmodium exists. As a legume, desmodium also fixes nitrogen in the soil and thus acts to enrich the soil.

Note: The following video shows demonstrates push pull technology. https://youtu.be/ZwChseDEe3E

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

Figure 5: Layout of the pull and push technology in maize production

2.3.4 Pheromone trap

A pheromone trap is a type of insect trap that uses pheromones to lure insects. Sex pheromones and aggregating pheromones are the most common types used. A pheromone-impregnated lure is encased in a conventional trap such as a bottle trap (Figure 6), Delta trap (Figure 7), water-pan trap, or funnel trap. Pheromone traps are used both to count insect populations by sampling, and to trap pests such as clothes moths to destroy them.

Pheromone traps use chemical signals (pheromones) emitted by females to attract a male (therefore pheromone traps only catch males of that species). Sorting through large numbers of insects can be extremely time consuming, and pheromone traps have the advantage of being much more specific than pitfall, sticky, or light traps, reducing the number of incidental insects caught.

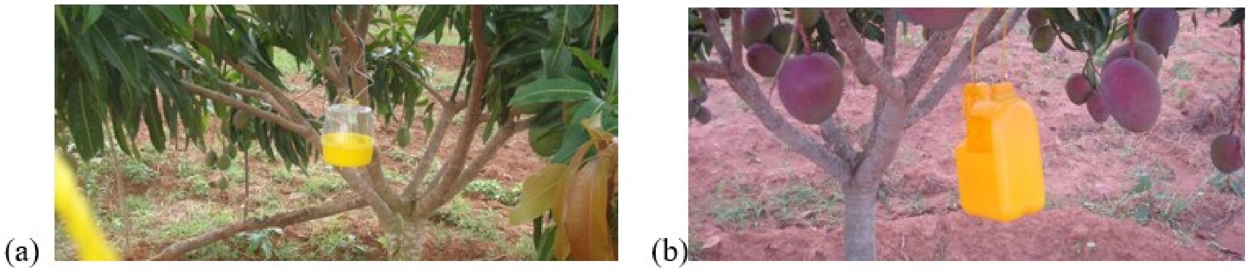

Figure 6: Bucket traps (a) Imported type (b) Locally made trap

Types of pheromone trap

The most used pheromone traps are the bucket traps and delta traps. Both trap types are suitable for use in a wide range of crops, easy to set up, and re-usable (except for the single-use delta traps)

(a) *Bucket traps*: Bucket traps consist of a lid containing the cage that holds the lure above a funnel leading to a holding bucket (Figure 6). The assembled trap is

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

suspended by a wire hanger. The target insect is attracted to the lure, falls through the funnel and into the bucket, where an insecticide-infused cube prevents escapes and minimizes damage (making it easier to confirm identification). They are relatively weather-proof and can hold more insects than delta traps.

(b) *Delta traps*: Delta traps are tri-folded to create a sheltered triangular area open at each end with a sticky side (Figure 7). They are available as single use, or with a replaceable sticky sheet.

Note: The following video shows the practice of use of pheromones for crop protection. https://youtu.be/rkyLWX5rweA

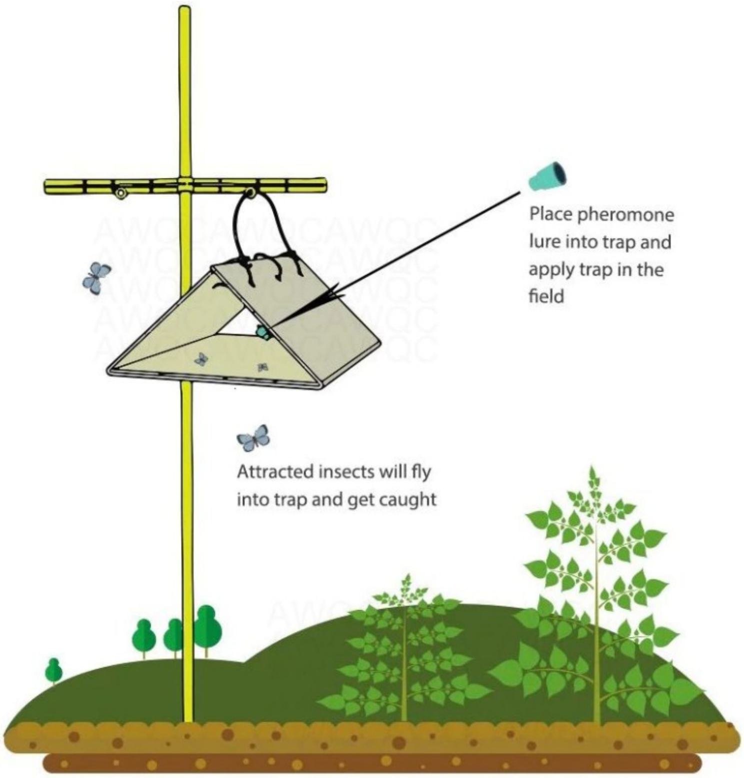

Figure 7: Arrangement of delta trap system

2.3.5 Use of organic pesticides

Organic pesticides are usually considered as those pesticides that come from natural sources. Some of the plants used in making pesticides are presented in Table *1*.

Table 1: Some of the plants used in making pesticides

No	English name	Scientific name	Lusoga Dialect	Luganda Dialect
1	Neem tree	*Azadirachta indica*	Nimu tri	
2	Fish bean	*Tephrosia vogelii*	Muluku	

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

3	Hot pepper	*Capsicum annuum*	Kamulali	
4	Pawpaw leaves	*Carica papaya*	Amakola gha mapapali	
5	Bitter leaf	*Vernonia amygdalina*	Olubirizi	Omululuza
6	Napier grass	*Pennisetum purpureum*	Ebigadha	Ebisagazi
7	American Malgold	*Tagetes erecta*	Mukazi muchafu	

Note: Use the following video demonstrates use of organic pesticides to protect crops https://youtu.be/g_Qoqu_qhjM

2.4 Inter-cropping

2.4.1 Introduction

Inter-cropping is the practice of growing two or more crops on the same plot of land at the same time. Inter-cropping, on the other hand, necessitates additional management to keep competition between inter-cropped species in check. When two or more crops are grown together, each must have enough space to maximize cooperation while minimizing competition. To accomplish this, four factors must be considered: (i) Spatial arrangement, (ii) Plant density, (iii) Maturity dates of the crops being grown, (iv) Plant architecture.

Some of the common farmer challenges that could trigger the use of inter-cropping

- Limited land available for different farm enterprises
- Declining soil fertility
- Uncertainty surrounding the crop yields due to climate change

Advantages of Inter-cropping

- It improves soil structure: Some crops have strong, deep roots. They can break up hard-pans and tap moisture and nutrients from deep in the soil. Others have many fine, shallow roots. They tap nutrients near the surface and bind the soil. They form many tiny holes so that air and water can get into the soil.
- It increases soil fertility: Legumes (such as groundnuts and beans) fix nitrogen in the soil. When their green parts and roots rot, this nitrogen can be used by other crops such as maize. The result is higher, more stable yields, without the need to apply expensive inorganic fertilizer.
- Inter-crops maintain the soil fertility as the nutrient uptake is made from both layers of soil
- Inter-cropping gives additional yield income/unit area than sole cropping. It produces different types of output: Growing a mix of grain, beans, vegetables and fodder means a more varied diet and more types of produce to sell.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

- It acts as an insurance against failure of crops in abnormal year. Inter-cropping can be the insurance that farmers need, especially when the region is vulnerable to weather extremes
- In some ways, inter-cropping takes the place of ploughing the soil: it helps aerate the soil, recycles nutrients, and helps control weeds, pests, and diseases.
- Reduction in soil runoff and controls weeds.
- Inter-crops provide shade and support to the other crop.
- Inter cropping system utilizes resources efficiently and their productivity is increased
- Better utilization of space available with the time dimensions.

Disadvantages of Inter-cropping

- Yield decreases as the crops differ in their competitive abilities. In inter-cropping, special attention must be paid to avoid competition between the crops for light, nutrients and water. This requires knowledge on arrangements, which promote growth of at least one of the crops.
- Management of an inter-crop having different cultural practices seems to be difficult task.
- If the crops aren't wisely chosen when inter-cropping, it may lead to soil exhaustion.
- Sometimes inter-crops work as alternate hosts for various pests and diseases.
- Differential maturity and sometimes harvesting may become difficult.
- It becomes difficult to control various pests and diseases.
- Inter-cropping is a labor-intensive practice.
- Allelopathic effect - This is a natural phenomenon describing the ability of certain plant species to produce compounds that affect the growth of other plants in their surroundings.
- Possibility of problems in carrying out intercultural operations.

2.4.2 Methods of inter-cropping

There are at least four basic spatial arrangements used in inter-cropping, and most practical systems are variations of these namely.

(a) *Row inter-cropping*: Growing two or more crops at the same time with at least one crop planted in rows (Figure 8). This can be beneficial in situations when using tall crops to reduce drought or heat stress of shorter crops, by providing shade and reducing wind speed.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

Figure 8: Row intercropping of maize and beans

(b) *Strip intercropping*: Growing two or more crops in strips broad enough to allow independent crop production with machines yet close enough for the crops to interact, such as intercropping beans and maize (Figure 9). Nitrogen-fixing bacteria are found in the roots of legumes. As a result, they compete for resources with non-legumes and, in some situations, supply nitrogen to adjacent plants.

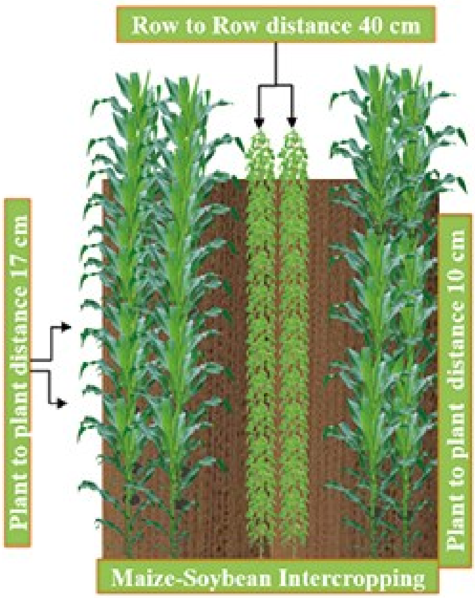

Figure 9: Strip inter-cropping of maize and soybean

(c) *Relay inter-cropping*: Planting a second crop into a standing crop at a time when the standing crop is at its reproductive stage but before harvesting (e.g., transplanting lettuce next to tomatoes plants) (Figure 10). The lettuce will use the space that is not yet occupied by the tomatoes and is harvested about the time the tomatoes are branching out to cover the width of the bed.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

Figure 10: Relay intercropping

(d) *Mixed inter-cropping*: Growing two or more crops simultaneously on the same piece of land with no distinct row arrangement (Figure 11). Some crops may also be sown as a border crop or as a trap crop at the hedges of the main crop to reduce pests. The pest, arriving in the field from the edges, encounter the trap crop (which is strongly preferred than the main crop) and stops. The trap crop may be sprayed with natural insecticide to control the pest before it moves to the main crop.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

Figure 11: Mixed inter-cropping within rows, where the component crops are planted simultaneously within the same row (corn with climbing bean)

2.4.3 Rules to be followed in the selection of the inter-cropping crops

Selecting crops with diverse growth habits, duration, root growth, taxonomical families, and so on should be done with caution. The following are some of the guiding principles for inter-cropping:

- Grow tall-growing crops along with bushy crops.
- Select shallow-rooted crops as inter-crops in the deep-rooted crop.
- Long-duration crops should be inter-cropped with short-duration crops.
- Grow slow-growing crops in vacant spaces of fast-growing crops.
- Selected main crops and inter-crops should show a very negligible allelopathic effect.
- Need to inter-crop non-legumes with legumes.
- Crops selected should be of different families to avoid various pests and diseases

2.5 Use of manure and crop waste recycling

2.5.1 Introduction

Manure is the decomposed form of dead plants and animals, which is applied to the soil to increase production. It is a natural form of fertilizer and is cost-effective. Human and animal excreta can also be used as manure. Manure is highly rich in organic matter and humus and thus improves soil fertility. Animal manure is rich in nitrogen, phosphorus, and potassium.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

Some of the common farmer challenges that could trigger the use of manure and crop waste recycling

- Infertile soils that result into very low yield
- High costs of fertilizers

Sources of manure

- Biodegradable materials like cattle dung, urine, slurry from biogas plants
- Waste products from human habitation such as human urine, night soil, sludge, sewage, domestic waste.
- Droppings of livestock such as goat and sheep
- Waste that is obtained from slaughterhouses such as bones, meat, horn and hoof meal, fish waste.
- By-products of agricultural industries.
- Waste material from crops.
- Weeds like water hyacinth

Advantages of Manure

- These are a good source of macronutrients.
- Improves soil fertility.
- Cost-effective in increasing yield
- Reduces soil erosion and leaching.
- Improves the physical properties of the soil and aerates the soil.
- Improves the water and nutrient holding capacity of the soil.
- Methane gas is evolved as the by-product of manure that can be used for cooking and heating purposes.
- The crops grown on the land treated with manure produces healthy crops.

2.5.2 Types of Manure

Manure can be grouped as farmyard manure, green manure and compost manure as discussed below.

Green Manure*:* Green manuring is the practice of growing a leguminous plant species for biomass production and incorporation into the soil (Figure 12). Green manure crops are grown in the field itself either as a pure crop, or as an inter-crop with the main crop, and buried in the same field. Green manures can also be grown as improved fallows, as seasonal green manures in rotation with other crops, or in strips between crops. Green manure increases the percentage of organic matter in the soil. Some of the crops that are used as green manure include: (i) Crotalaria (*Crotalaria ochroleuca*), (ii) Mucuna (*Mucuna pruriens var. utilis*), (iii) Lablab (*Dolichos lablab*), (iv) Canavalia (*Canavalia ensiformis*).

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

Figure 12: Incorporation of green manure into the soil

Advantages of Green Manure

(i) *Preventing erosion*: Green manure are also cover crops, as it covers soils, preventing it from exposure to harsh elements. Roots hold on to soil particles and hold them in place, while plant bodies shield the soil from extreme rains and the scorching sun, thereby preventing erosion.

(ii) *Prevention of leaching*: Green manure also minimizes the leaching of nutrients into the environment. It draws nutrients into their bodies and locks them until the crop is dug into the soil. The plants decompose and nutrients are slowly and gradually released into the soil, just in time for the next crop to utilize them for their growth.

(iii) *Providing nutrients and organic matter to the soil*: Using green manure results in increased levels of key plant nutrients. Leguminous green manure such as clover and vetch can grab nitrogen from the air and add it to the soil. Nitrogen, for example, is a key nutrient that promotes the healthy growth of the crops that will be planted after. Other green manure, such as buckwheat and lupin, enriches the soils with phosphorous. Lupin has been found to draw in and utilize 10 times more phosphorous than a common grain or wheat does. As such, phosphorous from the body of the lupin will be released to the subsequent crop if it is incorporated into the soil. Other green manure crops supply potassium, iron, calcium, and other trace minerals. High amounts of organic material, improved by green manures, ensure soil fertility is improved by bettering the soil's physical and biological properties.

(iv) *Suppressing weeds*: Green manure can suppress weeds by disrupting the growing patterns and cycle of weed plants. They also out-compete weeds for both water, nutrients, and space. Also, some species can release chemicals from their roots, which inhibit the growth of weeds and germination of seeds in the soil, in a process known as the allelopathic effect.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

(v) *Providing habitat for natural predators*: There are different ways of controlling pests, including boosting the number of their natural predators. Green manure crops can serve a home for predatory insects, such as ground and rove beetles. These two species of beetles are well known for being skilled hunters of pests and caterpillars. Blue flowers of Phacelia can also act as a home for hoverflies, which feed on aphids, a widespread and resistant pest to gardeners and farmers.

(vi) *Improving the soil's structure*: Green manure significantly improves the soil structure by adding organic matter into the soil. Such organic matter binds soil particles together and creates soil aggregates. The clusters of the improved larger particles allow for the formation of pores, which allows for proper soil aeration, nutrient distribution and water retention.

Disadvantages of Green Manure

(i) *Harboring slugs and snails*: A green manure crop may be the perfect opportunity for snails and slugs in which to breed. This means their numbers will increase and might ultimately affect some crops such as vegetables.

(ii) *It consumes time*: Farmers should wait up to a month after cutting back and rotating green manure crops before planting a new crop. This is because some crops are allelopathic (they naturally leave toxic substances in the soil that prevent new crops from germinating)

(iii) *Harboring pests and diseases*: Green manure crops may harbor pests and diseases in addition to slugs and snails. Such incidences may increase if the green manure crop is not kept free from diseases and pests. Applying phosphatic fertilizers to leguminous green manure crops increases yield for rapid Rhizobia growth while also boosting phosphorus levels in the next crop.

(iv) *Using moisture*: Green manure crops, like any other crop, use moisture. If moisture is scarce in a particular location, they will use available moisture that would otherwise have been conserved during fallow. If moisture is not a factor, the amount taken up by green manure crops is less than that used by mature crops.

(v) *Establishment costs:* There is a cost associated with growing green manure crops. It should not be more than the cost of growing other crops. It also should not outweigh the potential soil and nitrogen benefits. If it occurs, the farmer will be at a loss because they will be spending more time preparing the land than producing marketable crops.

Farmyard manure: Farmyard manure improves the soil structure and is used as a natural fertilizer in farming. It increases the soil capacity to hold more water and nutrients. It also increases the microbial activity of the soil to improve its mineral supply and the plant nutrients.

Factors affecting the composition of farmyard manure

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

(i) *Source of manure*: Composition of manures varies with kind of animal producing it. Poultry droppings is the richest followed by sheep manure for nutrient contents. Dung contains phosphate while urine contains nitrogen (N) and potassium oxide (K_2O). Amount of urine soaked in bedding material also decides the composition and vary with kind of animal.

(ii) *Food of the animal*: The richer the food in proteins, the richer will be the manure in 'N' which comes out in the dung and urine. The higher the quality of food the higher the quality of manure.

(iii) *Age and condition of the animal*: young animals need more proteins to build up their body; hence manure is poorer in N content than old animals. Manure of sick animal is richer than healthy animals.

(iv) *Function of the animals*: Milk cattle utilizes proteins for milk production; hence manure is poor in N, P & K content than draft purpose animals as they utilize more carbohydrates.

(v) *Nature & proportion of litter*: The composition of litter varies with the kind of straw and hence will affect the quality of manure. Bajra stalks are rich in N, P & K followed by wheat & maize.

(vi) *Preservation (method of storage)*: Under ordinary storage, there are losses of N. Potash get lost due to leaching when the manure is too moist. Should be stored in a leakproof roof and concrete floors to avoid leaching.

(vii) *Age of farmyard manure* - Well rotten manure has higher nutrient content.

(viii) *Type of animal used* - non-ruminants have a better quality of manure

Advantages of farmyard manure

- It usually has a high content of nitrogen and phosphorous
- It supplies a high amount of organic matter to the soil.
- It improves on the soil physical properties such as structure and hence increases the soil capacity to hold more water and nutrients.
- It also increases the microbial activity of the soil to improve its mineral supply and also the plant nutrients.

Disadvantages of farmyard manure

- It is difficult to collect enough animal dropping if the animals are scattered.
- Urine can only be collected when the floor is cemented and only if animals are kept indoors.
- Requires a lot of labor to collect the dung.
- Farmyard manure has a bad smell.

Compost manure: Compost is a mixture of organic matter, as from leaves and manure, that has decayed or has been digested by organisms, used to improve soil structure, and provide nutrients

Benefits of using compost

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

- Improves the soil structure, porosity, and density, thus creating a better plant root environment.
- Increases infiltration and permeability of heavy soils, thus reducing erosion and runoff.
- Improves water holding capacity, thus reducing water loss and leaching in sandy soils.
- Supplies a variety of macro and micronutrients. (However, amounts not known)
- May control or suppress certain soil-borne plant pathogens.
- Supplies significant quantities of organic matter.
- Supplies beneficial micro-organisms to soils and growing media.
- Improves and stabilizes soil pH.

Important considerations during composting

(a) Green stuff (high in nitrogen) to activate the heat process in your compost. Perfect heat-generating materials include young weeds (before they develop seeds); comfrey leaves; yarrow; chicken, rabbit, or pigeon manure; grass cuttings; etc. Other green items that compost well include fruit and vegetables; fruit and vegetable scraps; coffee grounds and tea leaves (including tea bags – remove the staple if you wish); vegetable plant remains; plants.

(b) Brown stuff (high in carbon) to serve as the "fiber" for your compost. Brown stuff includes dead plants and weeds (avoid weeds with seed); sawdust straw; old flowers (including dried floral displays, minus plastic/foam attachments); and hay.

(c) 'Other items that can be composted but you may not have thought of before: paper towels; paper bags; cotton clothing (torn up); eggshells; hair (human, dog, cat etc.) Use all these items in moderation.

(d) Air. It is possible to compost without air (anaerobically), but the process employs different bacteria, and an anaerobic compost pile will take on a sour smell like vinegar. It may also attract flies or take on a matted, slimy appearance. If you believe your compost pile needs more air, turn it, and try adding more dry or brown stuff to open up the structure. Turning a compost pile can be labor intensive and hard on the back. Some people use a shovel or pitchfork. There are also compost aerating tools that aim to make the process easier that are either of the "winged" type or "corkscrew" type.

(e) Water. Your pile should be about as damp as a sponge that has been wrung out. Depending on your climate, you can add water directly or rely on the moisture that comes in with "green" items. A lid on the compost bin will help to keep moisture in. If a pile gets too much water in it, it might not get enough air.

(f) Temperature. The temperature of the compost pile is very important and is an indication of the microbial activity of the decomposition process. The simplest way to track the temperature inside the heap is by feeling it with your hand. If it is warm or hot, everything is decomposing as it should, but if it is the same

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

temperature as the surrounding air, the microbial activity has slowed down and you need to add more materials that are high in nitrogen to the bin.

(g) Soil or starter compost. This is not strictly necessary, but a light sprinkling of garden soil or recently finished compost between layers can help to introduce the correct bacteria to start the compost cycle a little more quickly. If you are pulling weeds, the soil left on the roots may be sufficient to serve this purpose. Compost starters are available, but probably not necessary.

The process of heap compositing

(a) *Materials to put in a compost heap*

Nearly all organic materials can be used to make compost, but different items will take varying amounts of time to decompose, and some materials will attract pests and rodents while others will harbor harmful disease-causing organisms.

Different types of organic matter contain different proportions of carbon and nitrogen: (i) Fresh (green) materials decompose faster because they contain high levels of nitrogen and low levels of carbon. E.g., manure, food scraps, green lawn clippings and green leaves. (ii) Dry (brown) materials decompose slowly because they contain high levels of carbon and low levels of nitrogen e.g., straw, branches, stems, dried leaves, peels, bits of wood, bark dust or sawdust, papers, corn stalks, wood ash and eggshells.

Carbon provides both an energy source and the basic building block making up about 50 percent of the mass of microbial cells. Nitrogen is a crucial component of the proteins, nucleic acids, amino acids, enzymes, and co-enzymes necessary for cell growth and function.

(b) *How to build the compost heap*

- Start your compost heap on bare soil to allow beneficial organisms to colonize the composting materials.
- Make a base 30 cm high and 2 m wide with coarse materials such as twigs for good air circulation and drainage (any material that will note decompose can be used).
- Add a 10 cm layer of carbon-rich material such as maize stalks (chop bulk materials into at least 3 inches).
- Add a 10 cm layer of nitrogen-rich material such as fruit and vegetable scraps.
- Add 2 cm layer of animal manure or old compost to activate the compost heap and speed the process.
- Spread a layer of soil to mask odors and introduce microorganisms that will accelerate the composting process.
- Sprinkle ash and urine lightly onto these layers to accelerate the process of decomposition.
- Water the heap thus formed.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

- Repeat these layers except the first layer of coarse material, until the heap reaches 1 to 1.5 m high.
- Cover the heap to protect it against evaporation and heavy rain as this will wash away all the nutrients. Covering also helps retain moisture and heat. Sacking, grass thatch or banana leaves are suitable for this (Figure 13).

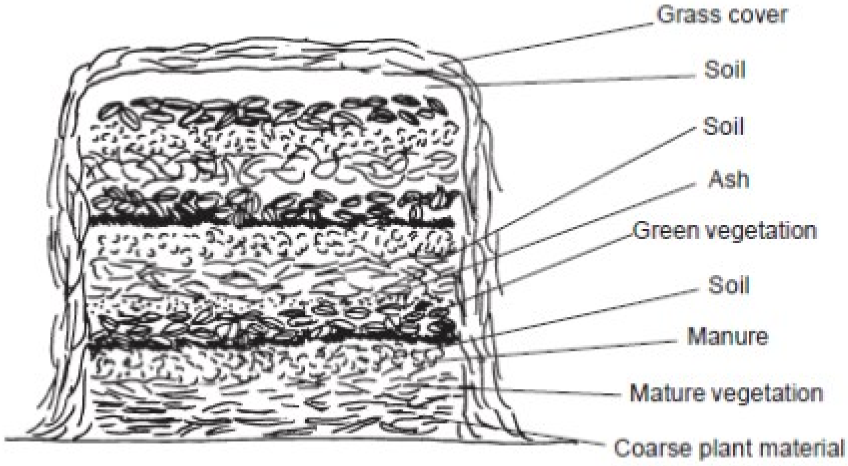

Figure 13: Structure of a compost heap

How to determine a suitable site for composting

- Distance and accessibility: A compost heap should be placed in an area where it is easy to carry the materials collected. Distance and access to the fields where the compost will be applied is also an important consideration.
- Water and shelter: Locate the heap where drainage is adequate, a shaded or sheltered area will help keep the pile from drying out. Ideally, the heap should also be located near a source of water. If you do not have a borehole close by, you should keep a container filled with water near to the heap.
- Vermin: Pests and vermin such as rats, snakes, termites, flies and mosquitoes may be attracted to the compost heap so it should not be placed too close to the home.

Maintenance of compost heap

- Maintain the desired moisture level - Dig a stick into the center of the compost heap and check if the stick is wet. A dry stick indicates that the heap is dry and requires watering.
- Turning to aerate the heap - More frequent turning will help if you need to speed up the process or if your compost pile has a strong odor
- Keep the pile at the proper temperature – Dig a stick into the center of the compost heap and check if the stick is warm. This indicates that decomposition is going on within the heap.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

Note: The following video shows how to make compost manure. https://youtu.be/WeB_Bf17VwU

Compost tea: Compost teas are liquid versions of the solid compost material. The term “compost tea” is used to define a wide range of aqueous solutions and/or suspensions made from different organic materials via a range of processes. Compost tea use as the sole or primary nutrient source may provide adequate nutrients to maintain plant growth and development, but that depend on application rate and frequency, strength (concentration) and crop species. Compost tea presents the best alternative liquid organic nutrient source for horticultural and agricultural use. Its origin in compost ensures that the product is sanitary and contains soluble constituents of the compost.

How to make compost tea: Compost teas were obtained by covering compost with water at a ratio between 1:5 to 1:8 (volume/volume). *Note: tap water should be dechlorinated by allowing it to sit for about 24 hours*. Put mature compost in the bag and place the bag in the bucket. Initially stir or gently massage the contents of the bag. The mixture is stirred once and allowed to ferment outdoors between 15° and 20° C for about 1 hour to 3 days. The longer the extraction period the great the potential for nutrients and microbes to be released into the water. After extraction, filter the liquid through cheesecloth, strainer, or a new nylon stocking (Figure 14). Apply the liquid immediately after preparation as a soil drench or as a foliar application. The liquid can also be further diluted with dechlorinated water as needed.

Note: The following video shows how to make compost tea https://youtu.be/bcQD0m9WfQE

FoodLAND has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

Figure 14: Production of compost tea

Fertilizer tea: Fertilizer teas or weed teas are made from plants. They are easy compared to compost tea as they don't require you to pick up a load of manure or use any of your precious compost. Many gardeners regularly use this technique to feed their plants and make use of their weeds at no cost. Weed tea can also benefit plants and soil by the microorganisms it contains, which assist in breaking down organic materials in the soil into plant food. Some choose to spray this tea onto the leaves of plants with the idea that it makes them stronger and more resistant to disease or pests.

Some of weeds and plants used for an extra nourishing fertilizer tea:

- Stinging nettle (kadhumbula) is high in nitrogen, calcium, iron, vitamins A, B, & C, phosphorus, potassium, boron, iron, zinc, selenium, and magnesium.
- Alfalfa is high in nitrogen, vitamin A, folic acid, potassium, calcium, and trace minerals.
- Horsetail is a deeply rooted weed that draws up minerals including potassium, silica, and iron from far below the soil.
- Willow is rich in growth hormones, making it especially good for getting young transplants off to a good start.
- Comfrey is rich in calcium, phosphorus, potassium, magnesium, vitamins A, B, & C, and trace minerals.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

 Stinging nettle (*Omwenyango* (Luganda dialect); *Lugenu* /kadhumbula (Lusoga dialect)	 Alfalfa (Olufafa;Lusoga dialect)
 Comfrey (Camfule; Lusoga dialect)	 Horsetail
 Willow	

How to make fertilizer tea: Weeds are chopped and placed into a bucket (Figure 15). When the container is about half full, fill it with water. Avoid using chlorinated water; rainwater is the best. Screen the top to keep mosquitoes out. Stir daily for 3 days to 3 weeks. Alternatively, pour it from one bucket into another to mix things up and keep it aerated. Strain off the liquid to use as a fertilizer or foliar spray. After you strain off the liquid, return the solids to your compost pile. It can be diluted or used full strength on established plants. Since plant leaves tend to absorb more nutrients more quickly than roots, foliar feeding is an efficient way to fertilize versus a soil drench.

Figure 15: Preparation of fertilizer tea

Note: The following video shows how to make fertiliser tea https://youtu.be/Ice330rsG38

2.6 Crop rotation

2.6.1 Introduction

It is a cropping practice that entails the successive planting of different types of crops in different regions of the field and at different seasons. It entails producing a variety of crops in the same region over the course of several growing seasons. The crop succession is meticulously planned to ensure that soil nutrients are maintained, pest populations are controlled, weeds are repressed, and soil health is built. Crop rotation is the process of changing crops over time and space. Rotation plans that are well-planned help soil fertility, healthy soils, weed and insect management, and disperse labor needs throughout time.

Some of the common farmer challenges that could trigger the use of crop rotation

- Infertile soils that result into very low yield
- High costs of fertilizers
- High prevalence of persistent pests, diseases and weeds

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

2.6.2 Principles of Crop Rotation

Crop rotation basically means rotating crops in a certain region such that no bed receives the same crop in consecutive seasons. The main objective is to maintain soil pH and nutrient levels stable so that each crop species may get the most out of the soil in each season.

There is no set crop rotation plan that all farmers must follow. The rotation duration might range from a single planting season to several years or even longer. Commodities in a field can be rotated based on a farmer's individual needs, soil type, climatic and environmental conditions, markets for diverse crops, and budget.

Some farmers, for example, may rotate two different crops, such as maize and soybeans, on a single field on alternate years. Others may pursue a more diverse approach, rotating five or six crops in a field over several years (Figure 16). The following are some basic crop rotation principles to assist you choose the correct crop to grow on the right soil at the right time.

a) *Crops belonging to the same natural order (family) should not follow one another*. Crops from the same family should not be grown in succession since they serve as alternate habitats for pests and illnesses. For example, avoid planting tomatoes, pepper, eggplant, or tobacco in the same row because they all belong to the same family (*Solanaceae)*, and hence share common pests. Also, avoid planting maize, millet, sorghum, barley successively as they share common weeds and pests. To help accomplish the goal, it is therefore recommended to follow such with crops from a different order and family, for instance following maize with soybean.

b) *The deep-rooted crop should be followed by a shallow-rooted crop and vice versa*. Crops having deep roots, such as carrot, should be followed by crops with shallow roots, such as wheat, rice, and maize. Cassava and other deep-rooted crops should be followed by shallow-rooted crops like okra. This guarantees that while the cassava feeds from the deep soil, the nutrients in the shallow soil are still available for the Okra to use when it is planted. This enables for the efficient and homogeneous utilization of soil nutrients.

c) *More exhaustive crops (e.g., cereals which take more nutrients from the soil and do not add anything to it) should be followed by restorative crops (e.g., legume crops which not only take nutrients from the soil but at the same time also add nutrients to the soil).* Because of their importance in soil fertility, legumes must be included in the rotation scheme. Most legumes incorporate nitrogen into the soil, which enriches it and minimizes need for fertilizers. As a result, the farmer's production costs are reduced. Plant legumes such as beans and soybean after non-leguminous or cereal crops such as maize. Legumes increase soil organic content and atmospheric nitrogen.

d) *Green manure preferably legume crops should be included in the rotation*. Green legumes serve as cover crops, and they also help prevent erosion while enriching the soil.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

e) *Long-duration crops should be followed by short-duration crops*.

f) *Broadleaved crops should be rotated by narrow-leaved crops*. This ensures that crops with different physiologies are alternated.

g) *Crops with taproot should be followed by crops with a fibrous root system*. This helps in the proper and uniform use of soil nutrients from different depths of the soil. For example, rotating maize with beans.

h) *Crops with minimum water requirements such as cowpeas and tomatoes should be grown in periods of water deficiency*.

i) *Crops that involve heavy irrigation and intensive labor such as rice should be grown after crops requiring less water and labor such as beans*.

j) *Crops such as vegetables susceptible to soil borne pathogens and parasitic weeds should be grown after tolerant crops*. Examples of crops that are susceptible to soil borne pathogens are; Tomatoes, tobacco, legumes, cucurbits, sweet potatoes and bananas. Crops that are affected by the parasitic weeds include cereal grains (e.g., sorghum and maize). For instance, tomato should be rotated with legumes like beans but not within the Solanaceae family (eggplant, chili, potato etc.) to reduce Fusarium wilt (*F. oxysporum*).

CROP ROTATION: a suggested plan.

	Year 1	Year 2
Plot A	Legumes - add well rotted manure	Brassicas - add compost and fertiliser
Plot B	Potatoes - add manure or compost, and fertiliser	Legumes - add well rotted manure
Plot C	Roots and Onions add fertiliser	Potatoes - add manure or compost, and fertiliser
Plot D	Brassicas - add compost and fertiliser	Roots and Onions add fertiliser
	Year 3	**Year 4**
Plot A	Roots and Onions add fertiliser	Potatoes - add manure or compost, and fertiliser
Plot B	Brassicas - add compost and fertiliser	Roots and Onions add fertiliser
Plot C	Legumes - add well rotted manure	Brassicas - add compost and fertiliser
Plot D	Potatoes - add manure or compost, and fertiliser	Legumes - add well rotted manure

Figure 16: A four-year crop rotation plan

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

3. Application of agroecological practices in soil and water conversation

Farmers have long recognized declining/poor harvests as their key issue. This has a fundamental connection to soil erosion, soil drying out, and soil fertility loss. Healthy soil is the foundation for profitable, productive, and environmentally sound agricultural systems. An integrated soil fertility management (ISFM) is encouraged as it entails integrated use of mineral fertilizers with organic matter. Other ISFM strategies include crop rotation, legume introduction, and crop-livestock integration systems.

Constraint	Approach	Examples
Soil erosion	Mulching	Material should be relatively dry to stay longer on the soil surface. These include the use of grasses, wood chips, wood fiber, straws, old hay
	Inter-cropping	Inter-cropping broad-leafed crops with cereals. The broad-leaved crops prevent direct interaction of soil erosion agents such as wind and running water with the soil surface. For example, integration of beans/cowpea/soybean with maize. Incorporation of trees in crops. The soils are protected from wind and water induced erosion. The adverse effects temperature and wind on soil fertility, soil flora and fauna are effects are ameliorated by agroforestry systems.
Soil fertility loss	Inter-cropping with agroforestry trees	Agroforestry trees, particularly leguminous trees, enrich soil through biological nitrogen fixation, addition of organic matter and recycling of nutrients.
	Application of manure	Animal manure applications can increase soil organic matter in medium / long term application periods. Consequently, manure contributes to reducing soil bulk density and compaction, as well as increasing soil aggregate stability, water infiltration and retention.
	Cover crops	Cover crops can also reduce nutrient losses from soil due to surface runoff. Leguminous cover crops fix nitrogen to soil.
	Crop rotation	Improve soil health by increasing biomass from different crops' root structures and increase biodiversity on the farm. Rotating with green manure and nitrogen fixing crops to the rotation schedule is therefore recommended.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

Soil water loss	Inter-cropping with agroforestry trees	Most important beneficial effect of the trees on the soil can include improvement of soil structure to reduce water loss through erosion and leaching
	Cover crops	Cover crops reduce the intensity of direct sun light to the soil, thus, reducing rate of water loss through evaporation
	Irrigation	Irrigation is to water crops by bringing in water from pipes, canals, sprinklers, or other man-made means, rather than relying on rainfall alone. Places that have sparse or seasonal rainfall could not sustain agriculture without irrigation. Irrigation can be done on all scales ranging from small, medium to large scale.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

4. Application of agro-ecological practices in crop protection

Crop protection is the combination of pest-resistance methods, tools, and products. Diseases, viruses, weeds, and insects are examples of these. They can all drastically reduce or even kill plants. Rather than dealing with the problem's consequences, it is preferable to control the situation by lowering the risks. Agro-ecological approaches to pest management for sustainable agriculture emphasizes the incorporation of ecological principles into pest management while ensuring high productivity and profitable harvests without causing harm to the environment.

Constraint	Approach	Examples
Weed manageme nt	Push and pull technology	The approach involves trapping stem borers on highly susceptible trap plants (the pull) and driving them away from the maize crop using repellent inter-crops (the push). For instance, in maize, Stem borers are attracted to Napier grass (*Pennisetum purpureum*), a trap plant (pull), and are repelled from the main cereal crop using a repellent legume intercrop (push), desmodium (*Desmodium spp*.).
	Cover crops	Cover crops may affect weeds at various points in their life cycle: (a) reducing the intensity and altering the quality of light reaching the soil surface; (b) acting as a physical barrier on the soil surface; (c) altering soil moisture and nutrient dynamics; (d) introducing allelochemicals; and (e) providing habitat for granivorous arthropods, mammals, and other weed seed consumers
Pest manageme nt	Push and pull technology	The approach involves trapping stem borers on highly susceptible trap plants (the pull) and driving them away from the maize crop using repellent intercrops (the push). For example, management of stem borer moth. The desmodium is planted in between the rows of maize produces a smell or odor that stem borer moths do not like. The stem borers are trapped by the Napier grass.
	Crop rotation	It breaks the pest cycles. If there is a break of several seasons or even several years when other crops (of a different crop family) are grown, the pest populations or disease incidence may be reduced and eventually disappear. For example, alternating maize with leguminous crops like maize breaks the life cycle for stem borer. Crop rotation replaces a crop that is susceptible to a serious pest with another crop that is not susceptible.
	Use of high-quality seed	The seed should germinate well, be disease-free and be of the variety the farmer wants to plant. Good pest management depends on healthy plants

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

	Timely planting	Late or staggered planting (plots of different ages) should be avoided. For instance, female moths (Fall army worm) have a favorite stage of maize to lay eggs on. If your field is one of the few late planted plots, all the female moths in a region will come to your plot, where she will lay her eggs

Area-wide management

For effective results, implement an integrated approach on an area-wide scale against the pests and diseases by combining cultural, biological, physical and (only as a last resort) synthetic pesticides.

Note - *It is advisable for farmers to use AE practices in combination for best results. However, farmers may also choose what practices to use based on their resources.*

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

Bibliography

Altieri, M. A. (2015). Agroecology, key concepts, principles, and practices. Third World Network (TWN)-SOCLA. Jutaprint. Penang. Malaysia.

Barrios, E., Gemmill-Herren, B., Bicksler, A., Siliprandi, E., Brathwaite, R., Moller, S., ... & Tittonell, P. (2020). The 10 Elements of Agroecology: enabling transitions towards sustainable agriculture and food systems through visual narratives. Ecosystems and People, 16(1), 230-247.

Constantine, J., Sibuga, K. P., Shitindi, M. J., & Hilberk, A. (2021). Awareness and Application of Existing Agroecological Practices by Small Holder Farmers in Mvomero and Masasi Districts-Tanzania. Journal of Agricultural Science, 13(1), 30 - 42

Envirothon (2019). Study guide – Agroecology. Retrieved from https://downloads.ctfassets.net/e09p19lzfrfe/65FcYX8OjlNm3JkFc2Zilc/ee54b825a8c8ec4ab6f69bbbddf0dc30/Agroecology-Guide_Final.pdf (Accessed on 10 November 2022)

Eudoxie, G., & Martin, M. (2019). Compost tea quality and fertility. In Organic fertilizers-history, production and applications. IntechOpen.

FAO and CABI. 2019. Community-Based Fall Armyworm (Spodoptera frugiperda) Monitoring, Early warning and Management, Training of Trainers Manual, First Edition. 112 pp. Licence: CC BY-NC-SA 3.0 IGO

FAO. (2018). The 10 Elements of Agroecology - Guiding the transition to sustainable food and agricultural systems. Rome.

FAO. (2019). Agricultural Extension Manual, by Khalid, S.M.N. & Sherzad, S. (eds). Apia.

FAO. (n.d). Pest and Pesticide Management. Retrieved from https://www.fao.org/pest-and-pesticide-management/ipm/integrated-pest-management/en/ (Accessed on 11 Novemebr 2022)

Gupta, V. P. (2020). Role of agroforestry in soil conservation and soil health management: A review. Journal of Pharmacognosy and Phytochemistry, 9(4S), 555-558.

http://www.push-pull.net/push_pull_works.htm

https://thebeatsheet.com.au/key-pests/monitoring-for-pests-and-beneficials/pheromone-traps/

https://www.greeninguganda.com/Products/Fruit-Fly-Traps

Liebman, M., Basche, A. D., Nguyen, H. T., & Weisberger, D. A. (2022). How can cover crops contribute to weed management? A modelling approach illustrated with rye (Secale cereale) and Amaranthus tuberculatus. Weed Research, 62(1), 1-11.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

Lithourgidis, A. S., Dordas, C. A., Damalas, C. A., & Vlachostergios, D. (2011). Annual intercrops: an alternative pathway for sustainable agriculture. Australian journal of crop science, 5(4), 396-410.

Pollard, S. & and du Toit, D. (n.d.). Principles of Soil and Water Conservation in Agroecology: What can we as farmers do? Retrieved from https://award.org.za/wp/wp-content/uploads/2019/10/AWARD-Brochure-Principles-of-Soil-Water-Conservation-in-Agroecology-20190930-v1.pdf (Accessed on 11 November 2022)

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

SECTION 2 – Guidelines for Biodegradable Mulching

Introduction

Mulching plastic systems can really help in the intensification of agriculture preserving soil condition while saving inputs, but the end-of-life management of traditional mulch films can be very difficult, they cannot be recycled and may leave plastic residues in soil if not properly removed. Furthermore the plastic mulch films removal at the end of the crop cycle is time consuming.

Plastic pollution (the so called “white pollution”) has a negative impact on soil. According to a recent report[1] every year 15,000 tons of microplastics are released in European soils, with an impact on crops growth with a progressive yield reduction up to 15%.

Within the FoodLAND project, to boost a sustainable intensification of agriculture through the introduction of combined agro-ecological practices, Novamont is developing biodegradable in soil mulch films according to EN17033 standard, so that they can be left in the soil without negative effects for the soil and environment while avoiding the production of agricultural plastic waste.

The main objective of this deliverable is to supply a customized guidelines for food hub operators reporting the best practices for a correct use of the biodegradable in soil mulch film under the specific crop and Food Hub requirements.

Novamont biodegradable and compostable bioplastics

Novamont designed a range of completely biodegradable and compostable thermoplastic materials to provide a low impact environmental solution and solve specific problems in different sectors, such as the separate collection of organic waste, packaging, catering, hygiene, agriculture and many other areas.

Novamont’s bioplastics are produced using renewable resources made from plant material such as starches from different crops (e.g. corn, other cereals and potatoes) and vegetable oils. Specifically biopolymers are obtained by a polymerization process consisting in two steps of reaction involving diacids and diols (monomers) and giving finally biopolyesters. Bio-polyesters are then worked throughout reactive extrusion involving biomasses, existing biopolymers and additives for producing bioplastics with the finalized functionalities for the application. Specific biopolymer grades have been developed for a range of agricultural applications including mulch film.

[1] Conventional and Biodegradable Plastics in Agriculture For the European Commission DG Environment. Project conducted under Framework Contract No ENV.B1/FRA/2018/0002 Lot 1 (https://ec.europa.eu/environment/system/files/2021-09/Agricultural%20Plastics%20Final%20Report.pdf)

FoodLAND has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

Novamont's bioplastics for mulch film are designed in compliance to the OK Biodegradable Soil and the European standard EN17033; these are standards that guarantees the complete biodegradability of biomaterial in soil at room temperature and with the absence of toxic effects in the soil and in the environment. In addition to this, EN17033 defines the specific mechanical and optical characteristics that a mulch films must have in order to be laid in a fully mechanized way and to efficiently control weeds. In addition, mulching film complies with the principles on biodegradation and environmental impact of International standards (European standard UNI EN 13432:2002, UNI EN 14995: 2007; American standard ASTM 6400:04).

Mulch film made of biodegradable and compostable biopolymers

By minimising the impact on the environment and saving time and resources in managing the end of life of mulched crops, mulch film made of biodegradable biopolymers provides an agronomically and environmentally efficient alternative to traditional mulch film. Such film has similar mechanical properties and usage characteristics to traditional plastic films. Properly the biodegradable film is laid and perforated with the same machinery used for traditional plastic film and as it can be laid very thin it provides excellent yields per kg of product. Thanks to the biopolymer capacity to biodegrade when incorporated into the soil, mulching film is converted into organic matter, water and carbon dioxide eliminating the production of plastic waste. So at the end of the crop, the film does not be removed or disposed, allowing significant reductions in labour costs, saving the time required for removal and disposal. Furthermore if traditional non-biodegradable plastic is not correctly removed and disposed, may leave plastic residues in the soil that can accumulate and generate soil pollution. The use of biodegradable mulch has been estimated to reduce overall greenhouse gas emissions: estimated savings are over 500 kg of CO_2 equivalent per hectare of mulch (considering coverage of the land with 6,000 m^2/ha of mulch)[2]. Moreover, biodegradable mulching practices reduce consumption of non-renewable energy resources by around 80% compared with traditional plastic film. This data was obtained considering the typical end-of-life scenario for plastic materials in Italy where 10% is recycled, 14% is incinerated and 78% is sent to landfill after use.

Types of biodegradable mulch film

Thanks to the versatile characteristics of Novamont biopolymer designed for agricultural applications, the related biodegradable mulch film can be used in different environmental conditions, for the cultivation of different species of plants and at different times of the

[2] Razza F., Farachi F., Degli Innocenti F., 2010, Assessing the environmental performance and eco-toxicity effects of biodegradable mulch film, pubblicato sui Proceeding della conferenza: LCA FOOD 2010 VII international Conference on life cycle assessment in the agri-food sector, Bari (Italy) September 22- 24 2010 – ProceedingsVolume 2 (378-383)

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

year. Materials are primarily chosen to suit climate, length of production cycle and growing conditions (in the open field or as a protected crop). Properly three biomaterials have been developed for different needs:

- Standard material for horticultural spring summer cycles
- Materials for long life crops (exceeding 6 months)
- organic farming material

Starting from these biomaterials related mulch film has been optimised for the specific required characteristics: shelf life in the field, colour, mechanisation, thickness and agronomic performance. The tuning of life in field is primarily related to film thickness; it is also possible to make films starting from 10 microns, according to the specific needs of the crop cycle: an average life from 2 to 6 months could be reached using 10 to 15 microns films; 20 microns-thick films can be used for crops with a cycle up to10 months and beyond 10 months a thickness up to 30- 40 microns is suggested. The typical range of properties relating to biodegradable mulching film with thickness from 12 to 18 μm is reported in the table below.

Table 2: Characteristics of mulching materials

Typical characteristics of mulching materials	Value	Method
Tensile strength (MPa)	20÷40	ISO 527-3
Elongation at break (%)	250÷500	ISO 527-3
Young modulus (MPa)	100÷300	ISO 527-3
Density (g/cm³)	from 1,23 to 1,29	ASTM D792
MFR (g/10')	from 3 to 7	ASTM D1238

Biodegradable in soil mulch films can be produced in different colour according expected soil conditions and agronomic effect on the crops. Most used mulch film colours are: black (weed control), white / black (double face, soil cooling film), green (soil heating film and PAR cut off).

At the moment the most versatile and used biodegradable mulch film is the black one at 15 microns. The data collected in the field during tests over the course of many years of experimentation showed for the black biodegradable mulch film:

- excellent performance in the field in controlling weeds and in terms of agronomic yield and product quality, comparable with traditional plastic films.
- excellent versatility for use and mechanisation: can be used with the same laying and laying-perforating machinery used for traditional plastics and at the same speed.
- excellent agronomic versatility and compatibility: biodegradable mulching film can be used in a wide range of crops in varying environmental and climatic conditions.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

Biodegradable black films have been tested on a wide range of crops, in different climatic areas over at least 20 years, both in experimental and in commercial fields.

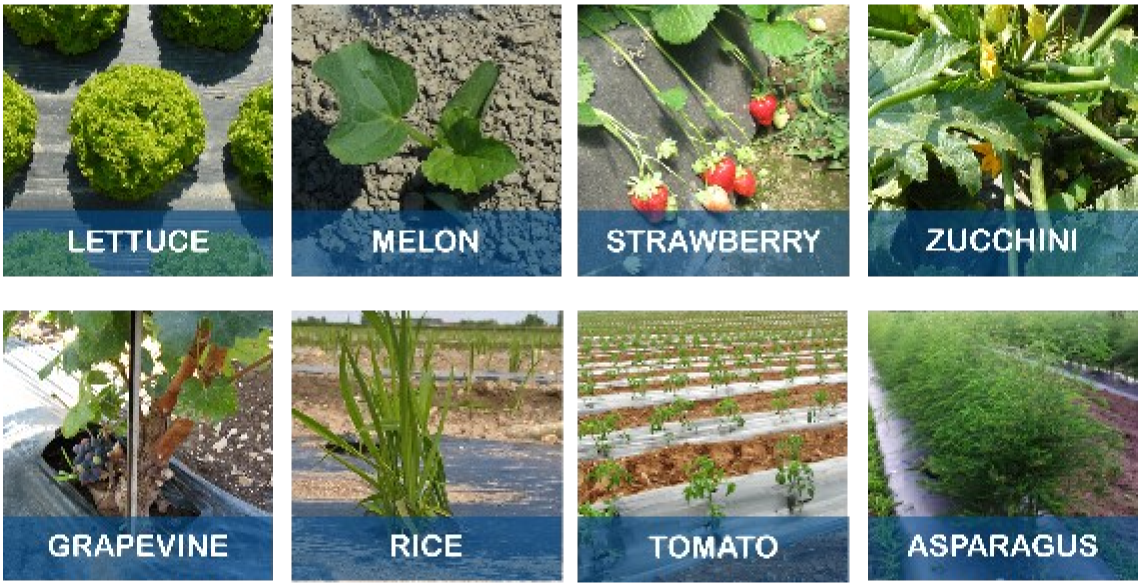

Figure 17: Main crops on which the biodegradable film has been tested

In the following table information about the wide applicability are reported.

Table 3: Mulch film applicability and characteristics

Cycle	Duration (months)	Crops	Thickness
SHORT CYCLE	1-3	lettuce	15µm (possible also 12 µm)
MEDIUM CYCLE	4-6	Zucchini, Pumpkin, Solanaceae (tomato, bell pepper, eggplant), Melon, Watermelon, Aromatics (Basil, Parsley,...), Potato, Cabbage, Corn, Industrial tomato, Green bean, Rice, Asparagus, propagating material	15µm
MEDIUM-LONG CYCLE	6-12	Strawberry, Onion, Garlic, Gherkin	from 15 to 18µm
LONG CYCLE	>12	Vine, Small fruit (blueberry, raspberry)	30-40 µm

Economic Implications

The market for biodegradable and compostable products in developing countries is being explored only recently, while the economic implications of the technology will be measured during the tests currently carried out at small-scale level in the target local

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

Food Hubs (Subtask 4.1.2) and through the validation process to be carried out at larger scale in the next period (ST 5.1.2).

What is the cost for the mulch?

Actually the cost for the production of the biodegradable and compostable material is approx. 2-3 times higher than the traditional plastic film in terms of kg of material.

However biodegradable mulch films, since do not need to be removed from the soil (and therefore they do not need to retrain good mechanical properties at the end of the crop cycle) are generally thinner than traditional non-biodegradable (LDPE) plastic films.

Together with this the difference in the price of raw materials in EU countries can be mitigated by other factors:

- Cost reduction in collection and disposal of non-biodegradable plastic mulch in terms of labour costs,
- Elimination of negative externalities related to plastic and microplastic pollution which could be formed if non-biodegradable plastic mulch are not properly removed at the end of the crop cycle,
- Elimination of externalities linked to soil erosion derived by top soil fraction that remains trapped in the removed non-biodegradable mulches and cannot be recuperated, as pointed out in the a recent EU Study (https://www.eunomia.co.uk/reports-tools/conventional-and-biodegradable-plastics-in-agriculture/).

Considering the early stage of the project we are not able to perform a precise calculation of the price of the product for the final user, given the different market conditions in the project countries.

In order to make the transition toward a biodegradable mulch film possible, the target in the project will be to promote these innovation primarily in crops where non-biodegradable plastic mulches are already used in the traditional agricultural method.

Will the mulch be produced locally or will it have to be imported?

As is the case in all countries where Novamont sell its agricultural products, the filming process can be performed locally, while biomaterials (the granules) are produced in Novamont plants in Italy. This will reduce the cost of the final product and promote the local industries to differentiate their production with innovative materials. Novamont grades of biomaterial can be filmed with traditional plastic film industrial machineries (blown film extrusion) just modifying and optimizing the production settings to the biodegradable materials characteristics, like speed and temperatures so the filming process can be easily transferred in different countries.

How practical will be its use for small scale farmers?

Mulch film is a product used in agriculture since a long time, both in family gardens and on large field extension.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The film can be laid on the ground manually, with small scale instruments such as manual mulching machine and finally with layers devices attached to agricultural machines of different sizes and powers. The use of biodegradable mulch films, eliminating the end of life operations (removal and disposal) helps the growers in the overall management of the crop, while reducing the labour time and costs.

Guidelines on implementation and management of biodegradable mulching in field.

In the Food Hubs selected for field tests biodegradable mulching practices are currently not in use.

This paragraph is intended to provide guidance to field operators and explain how to implement this technological innovation on the different cropping systems of interest. Here below a customized guidelines for the specific Food hub is provided, to describe a correct use and management of the biodegradable mulching in field operations.

Preparation of the soil

The methods used for working and preparing the soil (ploughing, milling, etc.) are largely the same as those used with traditional plastics for vegetable crops. However, in order to obtain the best results, both for controlling weeds and for the mechanical performance of the product, it is essential to prepare the soil correctly before laying out the biodegradable mulch film. The soil should be refined and prepared to ensure that stones and any crop residues, particularly harder items (e.g. corn or sorghum stalks, etc.), do not damage the film whilst it is being laid. Special care must be taken when laying mulch film over soil with a high percentage of rock fragments or stones, and if possible the surface must be prepared using a bed former machineries capable of burying the crop residues and rock fragments in the soil.

Figure 18: prepared soil for mulching operations

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

Laying correctly the film will guarantees its durability in the field. Biodegradable mulch film should not be laid immediately after surface application of manure (even if it is mature), in order to prevent the organic fertiliser from causing early biodegradation owing to its high micro-organism content. However, if fertilisation is conducted one or two months in advance, as usually occurs in normal farming practices, then the film will not be affected in any way.

Laying out the film

The laying out of biodegradable mulch film and the preparation of the soil are the most important operations to guarantee successful results in the field. The film can be laid manually (especially in case of small areas) or mechanically using the same machinery as for traditional plastic film and at similar speed and gear. In the case of mechanically laying it is essential to ensure the correct calibration of the mulch laying machine to ensure the biodegradable film is laid properly: the film tension must be reduced to a minimum to prevent it from being weakened during application, which could make it less effective. It is therefore advisable to adjust the brakes and clutch of the mulch laying machine so as to avoid applying excessive stress to the film during this operation.

Figure 19: Layed mulch film

In the case of **manually laying**, is more simple to avoid applying excessive stress to the film, but it is advisable don't step on layed mulch film and avoiding mechanical damages (breaks, punctures...) during the hilling the land around the film. It is also advisable to avoid using any rollers which pass over the film once it has been laid out in order to improve its adherence to the soil. Since it is very thin, biodegradable mulch film will stick to the ground perfectly after a few days.

Finally, care should be taken when using rollers for micro-perforations in the field (or to create perforations that allow irrigation waters to penetrate the soil more easily). If not adequately performed, these perforations may allow too much light to penetrate the film,

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

stimulating weed growth which could prematurely damage the film. In order to avoid the problems associated with the improper application of micro-perforations, perforated films are also available. However, if carried out carefully, the micro-perforation of laid film is well tolerated, especially for shorter crop cycles (e.g. spring-summer lettuce).

In particularly windy areas, it is advisable to anchor the mulch film to the ground with small quantities of soil (a shovelful is sufficient) every 2-3 metres on exposed areas. It is advisable to lay the film and transplant cuttings at the same time (normally mulch machine provides laying and transplanting), or to minimise the time between these operations. This will make it possible to take full advantage of biodegradable mulch film.

Crops setup: film perforation, crops transplant, irrigation and agricultural inputs

Perforation is generally carried out when the film is laid and is therefore completely mechanised. It is conducted using the same machines and procedures used for traditional plastics, bearing in mind that biodegradable film is more elastic. Ideally the systems used should perforate the film when it is already positioned on the ground. For manual perforation, equipment should not be used that could produce holes with irregular edges (e.g. cut tin cans) because these cuts can damage the film prematurely. One of the best ways to make perforations is to use a knife to make a cut in a cross shape or in a T or Y shape. This technique reduces the amount of uncovered land around the transplanted cutting. Holes made using cylindrical implements (including hot cylinders) make it possible to create holes with "clean" edges suitable for biodegradable mulch film.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

Figure 20: Mulch film perforation

The use of biodegradable mulch film does not require any change in normal cultivation techniques. The biodegradable mulch film is compatible with the same irrigation systems used with traditional plastic mulch materials: drip irrigation, spray irrigation and surface irrigation (less commonly used with vegetable crops). The use of biodegradable mulch film does not lead to changes in the quantity of water used, capacity or irrigation intervals compared with traditional materials.

No research agencies, universities or end users have reported any damage or negative interactions between biodegradable mulch film and the use of fertilisers and agricultural inputs, at the same doses and periods used normally during cultivation with traditional plastic film.

Controlling weeds and duration of the film

Test results and data from the widespread use of black biodegradable mulch film in the field have shown it is as effective at controlling weeds as traditional materials of the same colour. However, particular attention should be paid to certain species of weeds: field tests have shown that major infestations of horsetail (Equisetum sp.) and sedge (Cyperus sp.) can damage biodegradable mulch film, which in any case also occurs with thinner varieties of traditional plastic materials. The duration of biodegradable mulch film in the field depends greatly on environmental factors (rain, thermal regimes, solar irradiation, etc.) and therefore it does not depend solely on the action of micro-organisms in the soil. Biodegradable mulch film with a thickness of 15 µm is used to grow a wide range of vegetable species with crop cycles of between 2 and 6 months: from lettuce or leaf crops transplanted in the spring or summer to solanaceae grown in the open field. For crops with a longer crop cycle e.g. the cultivation of strawberries with an annual cycle (or which remain in the field for between 9 and 12 months and which are transplanted in summer/autumn), biodegradable mulch film has shown good performance in typical conditions in Mediterranean areas (Spain and Italy), with thickness of 18- 20 µm. Biodegradable film maintains its mulching capacity for longer in autumnal crop cycles than in the spring or summer, owing to the reduced impact of temperature and solar irradiation, and due to the reduced activity of micro-organism populations in the soil. Finally, for crops for which the soil must be covered for periods of over a year, biodegradable film with a thickness of 40 µm and above is recommended. Applications include small fruits (raspberries) and new vine plantations.

End of the crop cycle

Biodegradable mulch film should not be removed or disposed of at the end of the crop cycle (an obligatory process for traditional plastic film); instead, it is worked into the soil. This operation provides biodegradable mulch film with the ideal environment to end its life cycle through the mineralising action of soil microorganisms, transforming it into water, carbon dioxide and biomass.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

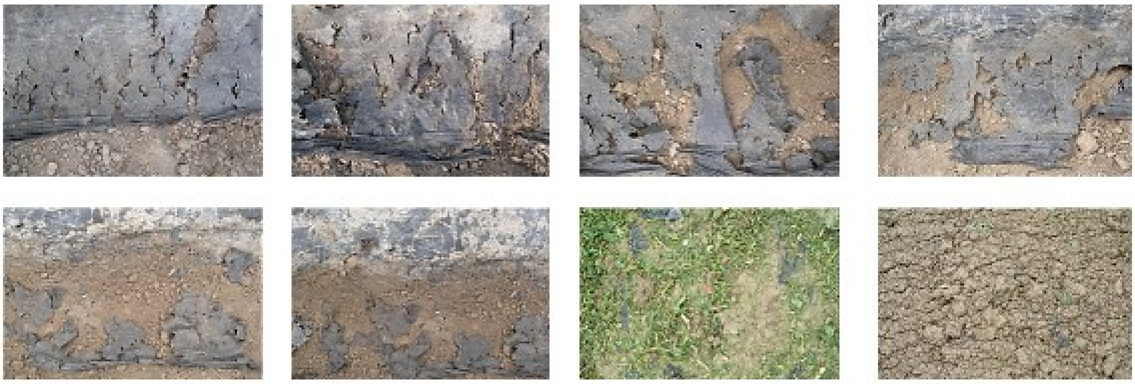

Figure 21: stages of mulch film biodegradation

Mulch film made of Novamont bioplastics which is left on the surface rather than being worked into the soil will take longer to biodegrade. A range of different operations can be used to work biodegradable mulch film into the soil depending on the type of soil and its state at the time of the operation. Soil conditions and environmental factors are therefore the fundamental elements in determining the biodegradation of the material. For example during the winter, with low soil temperatures, or in lands that remain saturated with water for long periods of time, the biodegradation processes will naturally take longer.

Biodegradable film storage

The processes used for storing biodegradable mulch film are different from those used for the storage of traditional plastics film. When not being used, rolls of biodegradable mulch film must always be stored inside the farm store in their original packaging, protected from water, light and sources of direct heat. If the rolls is not replaced in its original packaging after use, it is advisable to keep it upright to avoid flattening, deformation or breakage. Various tests have shown that when biodegradable mulch film is properly stored it can be used in subsequent seasons, with satisfactory performance and agronomic behaviour. Accidental breakages caused by improper storage of materials or damage during transport may have a negative impact on the life of the film in the field. If possible, any damaged parts of the film should be removed before use.

Performance evaluation and management of biodegradable mulching in field.

After following the best practices of biodegradable mulching film laying out, also the collection of field data is strongly suggested to carry out a comprehensive assessment of the mulching film performances and it allows to adapt the Novamont biomaterials to the specific regions and cropping system.

To facilitate monitoring and field assessment, a score evaluation has been defined for the different points of observation such as: Laying, film degradation in the exposed side, film degradation in the underground side, damages and tear resistance.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

In order to have a properly evaluation during field surveys on the mulch film, a simple numerical score system with values from 1 to 9 was chosen, according the following observations:

- Damages at laying: 1 = very high number of damages & hard to lay - 9 = no damages & easy laying
- Film degradation of the exposed side: 1 = 0% uncovered soil - 9 = 100% covered soil
- Film degradation of the underground side: 1 = film totally disappeared - 9 = film as new
- Damages (referring only to the exposed part of the sheet): any break, tear, hole, tear that appears on the sheet, reducing its functionality: 1 = very high number of damages - 9 = no damages
- Tear resistance of film exposed side: 1 = extremely fragile - 9 = very strong, elastic like new one

The collection of field digital photo is suggested to better prove the evaluation criteria used by Food Hub operators. Finally, during the trials would be useful also monitoring weather conditions whenever possible: temperature (minimum, average, maximum ° C), relative humidity (%), rainfall (mm), wind (m/s), soil temperature at 10 cm deep. Basically the designed plan for the mulch film assessment during the test could be summarized in the table below.

Table 4: Designed plan for the mulch film assessment during the test

Description	Survey modality	Timing for check
Degradation exposed side of film	SCORING (1-9)	Every 15 days
Degradation of the underground side of film	SCORING (1-9)	Every 15 days
Damages	SCORING (1-9)	Every 15 days
Tear resistance	SCORING (1-9)	Every 15 days
Laying damages	SCORING (1-9)	At beginning of test
Easy to lay	SCORING (1-9)	During laying
Weather conditions	Climatic station	Season of trials
Photographic survey		Every 15 days
Soil temperature	Temperature probe	daily

In order to help Food Hubs operators with the scoring assignment during the mulching test, an actual example of biodegradable mulch film assessment in field is reported following.

In the first period of observation (15 days from the laying) the biodegradable mulching film could appear as in the pictures below: film perfectly covers the soil (9), no lesions (9), film with a good tear resistance (9).

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

DEGRADATION: 9

LESIONS: 9

STRENGTH: 9

In a second check (30-45 days from the laying) the mulching film status could appear as in the following picture: due first lesions (7) the mulching film doesn't totally cover the soil (degradation 8) but the film tear resistance is not yet decresead.

DEGRADATION: 8

LESIONS: 7

STRENGTH: 9

Moving on with the crop cycle as well as the mulching aging (after 60-90 days), the lesions could affect more widely the film and the progressive loss of the film tear resistance could lead to a fully disintegration. In the pictures below are reported different stages of film degradation in order to help the scoring assignment and demonstrating the typical damages kind and loss of mulching functionalities on the weeds control.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

DEGRADATION: 7

LESIONS: 6

STRENGTH: 5

DEGRADATION: 8

LESIONS: 6

STRENGTH: 8

DEGRADATION: 6

LESIONS: 4

STRENGTH: 3

DEGRADATION: 6

LESIONS: 4

STRENGTH: 3

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

DEGRADATION: 7
LESIONS: 5
STRENGTH: 8

DEGRADATION: 6
LESIONS: 4
STRENGTH: 4

DEGRADATION: 5
LESIONS: 4
STRENGTH: 5

DEGRADATION: 4
LESIONS: 3
STRENGTH: 3

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

DEGRADATION: 3
LESIONS: 2
STRENGTH: 1

DEGRADATION: 1
LESIONS: 1
STRENGTH: 1

Customized guidelines for biodegradable mulching trial on tomatoes crops.

In the framework of FoodLAND project several mulching trials in the Tunisian Food Hub will be carried out under the leading of ISACM. Properly, the partner ISACM will implement a mulching trial on tomatoes, a crop on which Novamont has collected in the years a significant experience and a lot of agronomical data related to the best agricultural practices to use biodegradable mulch film.

Cultivation of processing tomato

Italy has a great technical and agronomical experience in the cultivation of processing tomatoes, representing one of the main world producers. Novamont has acquired a good experience in mulching processing tomatoes in over 20 years of trials and commercial fields in Spain and Italy. The region of Navarra (Spain), in a good example of implementing biodegradable mulch films: today 80% of mulch film used is in fact biodegradable,

Biodegradable mulch films can be used with success especially where the harvest is mechanical; conventional mulch films can hamper mechanical harvesting operations. On the opposite, biodegradable mulch films can solve this problem, since they do not interfere with this operation.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

There are several varieties, with either round or elongated fruit, intended for different uses: sauce, concentrates, canned diced and whole tomatoes. The method of harvesting also varies according to the intended use: for example, manual harvesting is preferred for whole canned tomatoes, while mechanised harvesting is preferred for sauces and concentrates. Transplanting is carried out from April in single or double rows with variable spacing, also depending on the type of fruit. While the varieties harvested manually in some areas are traditionally mulched with black film.

Characteristics and agronomical results from the use of biodegradable mulch film in processing tomatoes

For the cultivation of processing tomatoes intended for both manual and mechanical harvesting, it is recommended to use 15-micron thick black biodegradable film. This has proven to be effective in various field tests both for controlling weeds and for optimizing the agronomical result.

Field trials

Depending on the area of cultivation, processing tomatoes may or may not require mulching. Generally, however, mechanical harvesting cannot be done when non-biodegradable film is used. The use of biodegradable mulch film for tomato cultivation has shown several advantages from the agronomical point of view starting with an enhanced plant growth, especially evident in the first phenological stages (the so called “starter effect”). Mulched plants have a more rapid and uniform growth of the plant in the initial stages, due to an increase in temperature and soil humidity. Biodegradable mulch film has been used for over 15 years in the main tomato production areas in Europe: Italy, Spain and France. Around 2000 hectares of industrial tomatoes are cultivated in the Spanish region of Navarra, which are almost entirely mulched. Biodegradable film is used on about 80% of this surface area, in order to reduce the possibility to leave plastic residues in the soil. In Italy, biodegradable mulch film is used in the main areas where processing tomato is cultivated, predominantly in Southern Italy. (Apulia, Campania and Emilia Romagna regions). Field data have shown that the use of biodegradable mulch film provide the following benefits when compared to not mulched crops:

- Effective weed control during the crop cycle, without the need for extra weeding on the bed, which in the early growth stages can compromise the growth of young seedlings;
- Rapid growth of plants in the early cultivation stages;
- Improved plant root development;
- problem-free mechanical harvesting of the fruit and without the presence of mulch film fragments in the harvested product;

FoodLAND has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

Table 5: Field trial result about the use of biodegradable mulch films

Test	Total production (tonne/Ha)	Average weight of fruit (g)	Caliber (mm)
Test location: PUGLIA			
Black 15 µm	129,6	72	46
Bare soil	106,2	68	42

Test	Total production (tonne/Ha)	Soluble solid content (°Brix)	Waste (%)
Test location: EMILIA ROMAGNA			
Black 15 µm	101	5,10	1,7
Bare soil	95	4,95	2,9

Test	Total production (tonne/Ha)	Average weight of fruit (g)	Waste (tonne/Ha)
Test location: CAMPANIA			
Black 15 µm	138,5	68	10,2
Bare soil	130,7	71	12,5

Test	Total production (tonne/Ha)	Average weight of fruit (g)
Test location: SPAIN (Navarra)		
Black 15 µm	169,03	59,33
PE 15 µm	151,70	51,17

Tunisian Food Hub mulching trials on tomatoes.

In the framework of FoodLAND project several mulching trials in the Tunisian Food Hub will be carried out under the leading of ISACM. In detail, the partner ISACM will implement a mulching trial on tomato, for this purpose a customized template for data collection has been produced and sent to the project partner (Field Evaluation Diary).

The trials in Tunisia are characterized by similar spring/summer temperature compared to Southern Italy. Considering the need of a biodegradable mulch film with an affordable cost and considering the similar characteristics compared to Southern Italy a fully black biodegradable in soil mulch film was chose as mulching material.

Finally considering that the mulch film will be laid manually, the selected width was 1000 mm to allow manual handling. For the tomatoes crop a need of 90 days in soil resistance was required therefore the selected thickness is 15 micron.

Characteristics and agronomical results from the use of biodegradable mulch film in the horticultural crops

For the cultivation of the horticultural crops intended for both manual and mechanical harvesting, it is recommended to use 15-micron thick black biodegradable film. This has proven to be effective in various field tests both for controlling weeds and for optimizing the agronomical result.

Field trials

Depending on the area of cultivation, the horticultural crops may or may not require mulching. Generally, however, mechanical harvesting cannot be done when non-biodegradable film is used. The use of biodegradable mulch film for the horticultural cultivation has shown several advantages from the agronomical point of view starting with an enhanced plant growth, especially evident in the first phenological stages (the so called “starter effect”). Mulched plants have a more rapid and uniform growth of the plant in the initial stages, due to an increase in temperature and soil humidity. Field data have shown that the use of biodegradable mulch film provide the following benefits when compared to not mulched crops:

- Effective weed control during the crop cycle, without the need for extra weeding on the bed, which in the early growth stages can compromise the growth of young seedlings;
- Rapid growth of plants in the early cultivation stages;
- Improved plant root development;
- problem-free mechanical harvesting of the fruit and without the presence of mulch film fragments in the harvested product;

Tanzanian Food Hub mulching trials on beans.

In the framework of FoodLAND project several mulching trials in the Tanzanian Food Hub will be carried out under the leading of SUA. In detail, the partner SUA will implement a mulching trial on beans, for this purpose a customized template for data collection has been produced and sent to the project partner (Field Evaluation Diary).

The trials in Tanzania are characterized by similar summer temperature compared to Southern Italy. Considering the need of a biodegradable mulch film with an affordable cost and considering the similar characteristics compared to Southern Italy a fully black biodegradable in soil mulch film was chose as mulching material.

Finally considering that the mulch film will be laid manually, the selected width was 1000 mm to allow manual handling. For the beans crop a need of 110 - 150 days in soil resistance was required therefore the selected thickness is 15 micron.
Properly, the partner SUA will implement a mulching trial on beans. This crop usually may not require mulching, Novamont has collected interesting agronomical data related

FoodLAND has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

to the best agricultural practices on mulching of the green beans. Basically the use of mulching on beans crops could refer to the practices employed on the horticultural crops. Perforation is generally carried out when the film is laid. For manual perforation is suggest to make a small cut (1-2 cm) only on the seeding point. In case of climbing beans the use of supporting poles could be adopted, making a manual perforation of mulch film directly by the pole or making a small cut on film similar to the pole's diameter.

How the biodegradable in soil mulch film will enhance production and nutritional performances in the countries of interest for the project.

Considering the early stage of the project at the moment Novamont did not had the opportunity to collect production data related to the use of biodegradable in soil mulches in African countries, therefore project like FoodLAND help Novamont to expand the agronomical experience in different regions and on crops grown in different conditions.

Annexed to this Deliverable, a method and a data collection scheme, was provided to the project partner to collect productive and mulch performance information compared to cultivation on bare soils.

Here below is reported an estimation related to the potential increase in production for tomatoes and other horticultural crops such as beans (against bare soil condition):

Tomato under biodegradable mulch films vs bare soil:

- approx. 15-20% reduction in water consumption;
- improved production both in terms of quantity (increase in Gross Saleable Product from 10 to 30 %) and quality (fruits with more uniform colouring at harvest, with a greater number of red fruits and an increase in Brix of the juice (even if not statistically confirmed), fewer rotten and green fruits compared to non-mulched plants).

Beans under biodegradable mulch films vs bare soil::

Regarding beans we do not have precise data collected in our database. It will be therefore very important to see the agronomical results in terms of quantity and quality of the crop and water consumption. These two aspects are generally expected to be favourably impacted by the use of a biodegradable mulch film.

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

Conclusions

The Food and Agricultural Organization of the United Nations (FAO) forecasts that global food production will need to increase by 70% if the population reaches 9.1 billion by 2050.

The implementation of Sustainable Development Goal n°2 entails a shift to a more sustainable agriculture and food systems. In the near future it would be increasingly necessary to strengthen resilience to the effects of climate change while ensuring food security.

Mulching is a consolidated agronomic technique used to prevent weed growth, improving soil heal and fertility, while preserving soil moisture granting enhanced crop yields as well as precocity. Mulching has also some other positive environmental effects such as temperature regulation of soil and plant roots, minimum nutrient losses, cut down soil erosion and compactness, improving physical conditions of soil.

The application of traditionally, non-biodegradable plastic mulch film provides these benefits but entails also two main critical issues: (1) A proper disposal of the mulch films in waste management plants at the end of its life, resulting in higher cost for farmers and for the municipalities; (2) Environmental pollution due to accidental dispersion of non-biodegradable plastic fragments in the arable fields (white pollution).

Certified biodegradable in soil mulch films (according to EN 17033) offers an agronomically and environmentally efficient alternative to traditional plastic films, minimizing environmental impact and saving time and resources in managing the end-of-life of mulched crops.

Data collection regarding mulch film application performed in FoodLAND Food Hubs in African Countries and other areas that will be selected to evaluate climatic conditions not yet tested, will enable further developments of biodegradable materials for agricultural applications suitable also for North African countries.

This research activity will support the development of products that’s do not accumulate in soil that will allow their application in areas and regions where these solutions are not available or effective, potentially providing a small contribution to the achievement of the UN 2nd Sustainable Development Goal (End hunger, achieve food security and improved nutrition and promote sustainable agriculture).

FoodLAND has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

FOODLAND

Annex 1

Data Collection regarding biodegradable in soil mulch film performance and resistance								
Description	Survey modality	20 days	45 days	60 days	85 days	100 days	150 days	End cycle crop
Degradation exposed side of film	SCORING (1-9)	9	9	8	7	7	6	4
Degradation of the underground side of film	SCORING (1-9)	9	9	8	7	7	6	1
Damages	SCORING (1-9)	9	9	8	7	7	6	2
Tear resistance	SCORING (1-9)	9	9	8	7	7	6	1
Weather conditions & Notes (storms, rains..)	Climatic station & notes	dry, Tmax - Tmin	some days of rains Tmax - Tmin	short rains Tmax - Tmin	dry Tmax - Tmin	windy Tmax - Tmin	dry Tmax - Tmin	dry Tmax - Tmin
Photographic survey		✓ (global view, focus on plant, focus damages exposed side, focus damages underground side..)	✓ (global view, focus on plant, focus damages exposed side, focus damages underground side..)	✓ (global view, focus on plant, focus damages exposed side, focus damages underground side..)	✓ (global view, focus on plant, focus damages exposed side, focus damages underground side..)	✓ (global view, focus on plant, focus damages exposed side, focus damages underground side..)	✓ (global view, focus on plant, focus damages exposed side, focus damages underground side..)	✓ (global view, focus on plant, focus damages exposed side, focus damages underground side..)

Field map

mulched	bare soil	mulched
bare soil	mulched	bare soil
mulched	bare soil	mulched
mulched	mulched	mulched
bare soil	bare soil	bare soil
bare soil	bare soil	bare soil
mulched	mulched	mulched
mulched	mulched	mulched

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).

The views and opinions expressed in this document are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

FOODLAND

Data Collection regarding inputs and agricultural production								
Description	Survey modality	date	date	date	date	date	date	End cycle crop
Use of Fertilizers	Quantity and type							
Use of plant protection products	Quantity and type							
Soil management and tillage	description of management							
Irrigation	Quantity of water provided							
Rain	mm of rain in the period of cultivation							
soil characteristics	soil type and depth							
mulch film application	date							
Product Yield	t/ha							

FoodLAND has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (GA No 862802).