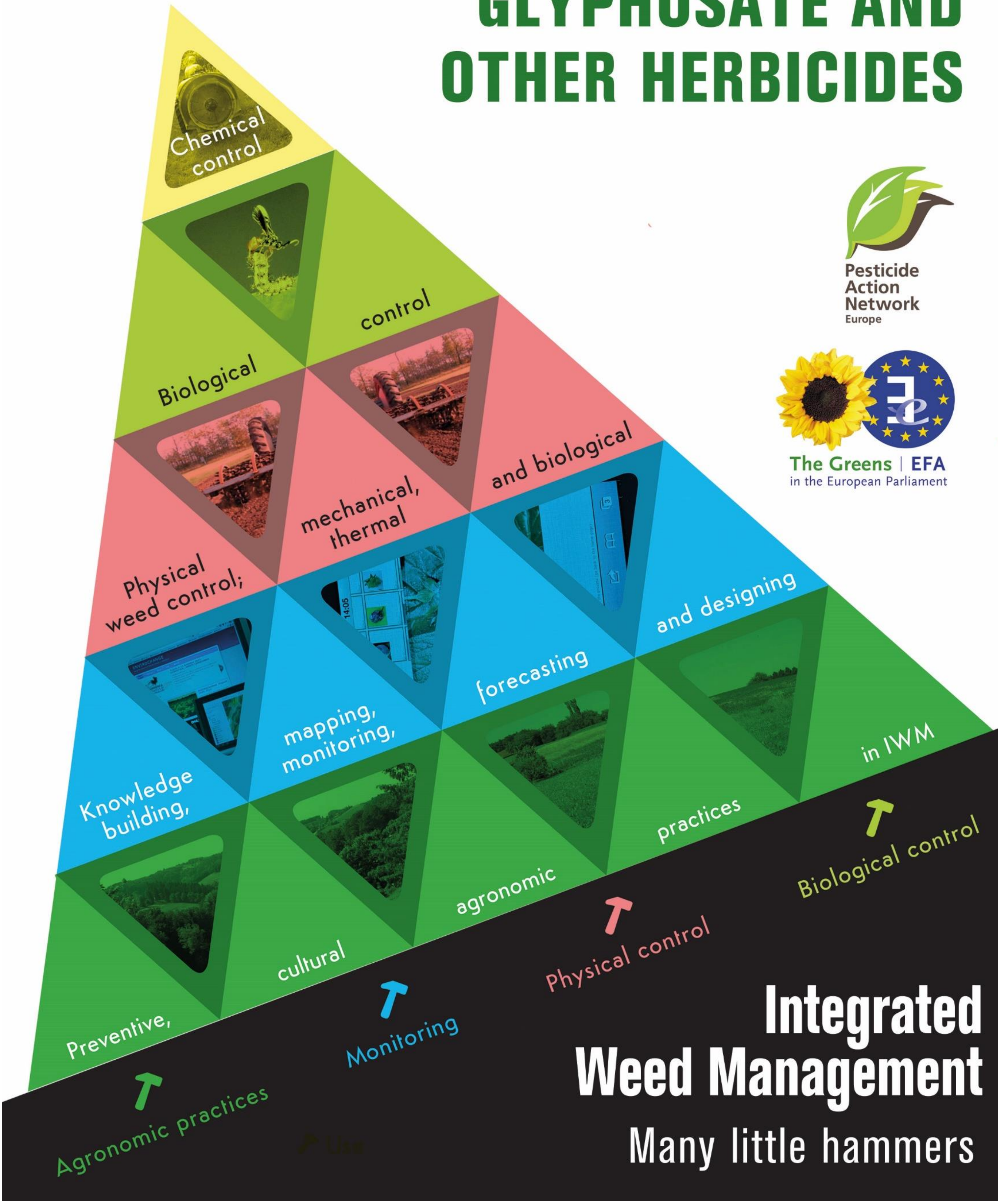
ALTERNATIVE METHODS IN WEED MANAGEMENT TO THE USE OF GLYPHOSATE AND OTHER HERBICIDES



Integrated Weed Management

Many little hammers

Pesticide Action Network Europe

The Greens | EFA in the European Parliament

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Pesticide Action Network Europe, 2017.

Rue de la Pacification 67, 1000 Brussels, Belgium

tel: +32 2 318 62 55 ; info@pan-europe.info; www.pan-europe.info

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1 Introduction

While the use of synthetic pesticides in agriculture might have helped to increase food production, this has not occurred without great costs to human health, the environment and natural resources. The 2017 UN report of the Special Rapporteur on the right to food highlights the adverse impact of pesticide use on human rights, human health (workers, their families, bystanders, residents and consumers) and the environment. The report also reveals that intensive agriculture based on pesticide use has not contributed to reduce world hunger, but rather it has helped to increase the consumption of food and food waste especially in industrialised countries[1].

Herbicides have been introduced in agriculture (and horticulture) mainly to combat weeds that compete with crops for nutrients and sunlight resulting in reduced crop yield and quality. Other common uses are to eradicate invasive plant species or undesirable plants for livestock farms, to assist the management of public areas, for aesthetic or practical reasons (e.g. sidewalks, pavements and railways) or for weed control in private gardens. In Europe, their use in farming has increased to replace mechanical ploughing, which has been reported to cause soil degradation and soil nutrient loss, particularly geographic zones with high rainfall and in intensive agriculture (Derpsch, 1998).

There is an overall erroneous perception that herbicides are safe for human health and have little impact on the environment. Based on this misconception, humans have developed agricultural practices and invested in technological development that completely depends on the use of pesticides and herbicides. Many farmers have abandoned more sustainable farming techniques altogether. As a result, every day tonnes of herbicides are released into open fields and their surroundings, which not only put human health at risk, but also interfere with the biological processes of nature and the ecosystem services it offers to combat weeds and other pests, naturally. Weeds become resistant, the soils get eroded and infertile, the crops susceptible to pathogens and diseases, and farmers feel obliged to use more pesticides to combat the new pests, and end up trapped in a "pesticide treadmill".

In a similar manner to other pesticides, herbicide active ingredients are biologically active compounds. They are designed to pass through membranes and diffuse into the interior of living cells to exert the desirable toxic action (Kearney & Kaufman, 1975). Because of their properties, when these substances are used on open fields they also affect other non-target plant species in the area and the surroundings, and through a cascade of ecological interactions end up affecting biodiversity. Furthermore, these same properties may allow them to interact with living cells of animal species, including humans, and result in toxicity. Herbicides can also be toxic

[1] United Nations, 2017. Report of the Special Rapporteur on the right to food.

to soil beneficial microorganisms (Grossbard & Davies, 1976) causing a decline in soil nutrients, fertility and defence systems. This has a direct impact on agriculture, where crops depend on the quality of the soil. Overall, the use of these chemicals has been so -*unnecessarily*- intensive that has caused a great impact not only on soil health and agricultural production, but also to human health, the environment and its ecosystems.

The present report aims to emphasise that we already have all the tools necessary to gradually start building a pesticide-free agricultural model and to show that weed control is possible using other means than harmful herbicides. There is an urgent need to develop technological methods of agriculture that do not depend on pesticide use. Using the popular glyphosate-based herbicides as a reference, the current analysis presents a wide variety of weed management approaches, where farmers work *together* - rather than *against* - nature.

By integrating the different available agricultural practices (e.g. preventive, agronomic and mechanical methods) with the broad knowledge we have acquired on the biological and ecological characteristics of herbs and plant crops, today farmers are capable of overcoming major agricultural challenges and manage weed growth successfully, maintaining a high agricultural yield, avoiding resistant species, protecting soil biodiversity and erosion, and reducing green-house emissions among others. This report presents and discusses the different alternative agricultural practices to herbicide use in weed control that when combined result in a sustainable weed management. Since glyphosate-based herbicides are non-selective and of broad spectrum, the alternative methods presented here can also substitute the use of different herbicide products.

This report also covers topics such as the use of glyphosate in the EU and globally, pesticide sales in the EU, and impacts of glyphosate on soil behaviour and environmental safety, as well as human health. Finally, it present a list of suggestions on the transition towards a pesticide-free weed management practices.

This work was carried out in parallel with the project "Filming farmers across European Union on alternatives to herbicides (with specific reference to glyphosate)", both being supported by The Greens/EFA of the EU.

2 Glyphosate

Glyphosate is the active ingredient of the world's (and EU's) most used herbicide-products, the most common of which is known with the trade name Roundup™, manufactured by Monsanto. Glyphosate became particularly popular globally in the 1990s with the development of Monsanto's soybean glyphosate-tolerant genetically modified (GM) crops (Roundup Ready) followed by GM maize and cotton roundup-resistant crops. However, its application is not limited to GM crops and is used in all areas of agriculture and weed management.

The herbicide potential of glyphosate (N- (phosphonomethyl) glycine) was discovered by Monsanto in 1971 and was registered as an herbicide (phytotoxicant) in 1974[2]. Glyphosate causes plant toxicity by blocking the action of an enzyme (5-enolpyruvylshikimate 3-phosphate or EPSP) with a key role in the synthesis of amino acids and other essential nutrients for the plant (through a cascade of reactions known as the shikimate pathway), resulting in plant starvation and eventually plant death (Holländer & Amrhein, 1980). This pathway is found in microorganisms (e.g. bacteria and fungi) and plants, but not in animals (Herrmann, 1995). In fact, glyphosate was patented in 2010 by Monsanto as an anti-microbial agent against certain pathogenic infections[3].

Monsanto however is not the only producer of glyphosate. Once its US patent expired in year 2000, other pesticide manufacturers started producing glyphosate-based herbicide products. According to the Glyphosate Task Force consortium of companies that produce glyphosate-based products, glyphosate is now marketed by more than 40 companies and over 300 herbicide products containing glyphosate are currently registered in Europe[4].

3 Uses of Glyphosate

Glyphosate is a broad spectrum, non-selective, systemic herbicide, crop desiccant and to a lower extent plant growth regulator[4]. Being non-selective, glyphosate-based herbicides (i.e. formulations containing glyphosate as active ingredient together with other chemicals) effectively kill or suppress all types of plants (including grasses, perennials, vines, shrubs and trees) and are typically applied on the foliage of the leaves or on the roots or on the soil to prevent weed growth. Glyphosate has been reported to be effective against more than 100 annual broadleaf weeds and grass species, and more than 60 perennial weed species (Dill et al., 2010). A representative summary of its uses in the European Union is given in Table 1.

In conventional agriculture, glyphosate-based herbicides are mostly applied before crops are sown to control weeds and their root systems, to facilitate crop growth. They are also used for no-tillage farming to prepare the land and avoid mechanical ploughing and as pre-emergent herbicides after sowing but before the crop shoots emerge, to prevent weeds from growing. If the crop has been rendered tolerant to glyphosate for example by GM technology, the herbicide can be used later, post-emergence of the crop (all plants and weeds but the resistant crop die). Glyphosate-based herbicides are also used in the rows between permanent crops like vines and the ground beneath orchard crops.

[2] Patent number US 3799758 A. N-phosphonomethyl-glycine phytotoxicant compositions.
[3] Patent number US 7771736 B2. Glyphosate formulations and their use for the inhibition of 5-enolpyruvylshikimate-3-phosphate synthase
[4] Glyphosate Task Force (industry consortium) website http://www.glyphosate.eu/history-glyphosate

Table 1 Sample of representative uses of Glyphosate registered in EU (EFSA Glyphosate peer-review, 2015)

Crops/plant species	Growth & Stage	Pests controlled	Application rate of product L/Ha (min-max)	Application rate of active ingredient kg/Ha (min-max)
All*	Pre-planting of crops	Emerged annual, perennial & biennial weeds	1-6	0.36-2.16
All*	Post-planting pre-emergence of crops	Emerged annual, perennial & biennial weeds	1-3	0.36-1.08
Cereals (pre-harvest) wheat, rye, triticale, barley, oats [a]	Crop maturity < 30 % grain moisture	Emerged annual, perennial & biennial weeds	2-6	0.72-2.16
Oilseeds (pre-harvest) rapeseed, mustard seed, linseed [b]	Crop maturity < 30 % grain moisture	Emerged annual, perennial & biennial weeds	2-6	0.72-2.16
Orchard crops, vines, including citrus, tree nuts & olive trees	Post emergence of weeds	Emerged annual, perennial & biennial weeds	2-8	0.72-2.88

*Crops including but not restricted to: root & tuber vegetables, bulb vegetables, stem vegetables, field vegetables (fruiting vegetables, brassica vegetables, leaf vegetables and fresh herbs, legume vegetables), pulses, oil seeds, potatoes, cereals, and sugar- & fodder beet; before planting fruit crops, ornamentals, trees, nursery plants etc

[a] Minimum pre-harvest interval (crops cannot be harvested before) = 7 days

[b] Minimum pre-harvest interval (crops cannot be harvested before) = 14 days

Another use of glyphosate-based herbicides is as crop desiccants to dry down the crops either before or after harvest. Application after harvest destroys the remaining crops to facilitate their removal, whereas pre-harvest application is carried out either to dry any green growth that may interfere with harvesting or in the case of cereals and other grain-crops, to accelerate the ripening process of the grains. The use of glyphosate as a pre-harvest desiccant has become a very common practice in today's agriculture, particularly in regions where humidity levels are higher. However, since this use leaves the highest amount of pesticide residues, some Member States have strict rules (Box 1[5]).

[5] DG SANTE official website https://ec.europa.eu/food/sites/food/files/plant/docs/pesticides_faq_glyphosate_20170719_final.pdf

Box 1. Glyphosate: Different desiccation practices along Member States

Glyphosate use practices vary across Member States. According to EU's Directorate General for Health and Food Safety DG SANTE some Member States have rules for **when glyphosate can be used** and some have rules on **how much can be used** for the different purposes. A Danish report made by the Danish Environment Protection Agency on the use of glyphosate explains:

"*The EU member states differ to some extent with regard to approval of specific applications of glyphosate use. In Denmark glyphosate products can be used for pre-harvest weed control and desiccation ("harvest aid") until 10 days before harvest. In Austria the use of glyphosate for desiccation ("harvest aid") in cereal crops was banned in 2013 while use for weed control is still permitted. In Germany, the use of glyphosate for harvest aid is not banned as such but is not considered good agricultural practice. Sweden is in the same is the situation: no glyphosate products approved for this particular use are available on the market*."

European Crop Protection Association (ECPA) adds: "*In several north western European countries glyphosate can be applied before crop harvest for weed control, to enhance ripening on non-determinate crops to reduce crop losses, and to help manage determinate crops in wet seasons. Different countries have different recommendations for crops but the common factor is that the bulk grain sample must have dried to a maximum of 30% moisture content. The climate in southern Europe is such that few weeds remain green at the time of harvest, and crops typically ripen fully, so pre-harvest use of glyphosate is not normally recommended*."

All the registered uses of glyphosate in the EU can be found in the glyphosate risk assessment peer review report of the European Food Safety Authority (EFSA, 2015) and a summary is given in Table 1. In the EU, the maximum amount of glyphosate that can be applied is 4.32 kg of active ingredient per ha (4.32 kg/ha) in any 12-month period, which corresponds, roughly, to 12 l of herbicide product (EFSA, 2015). This is one litre of undiluted product per month.

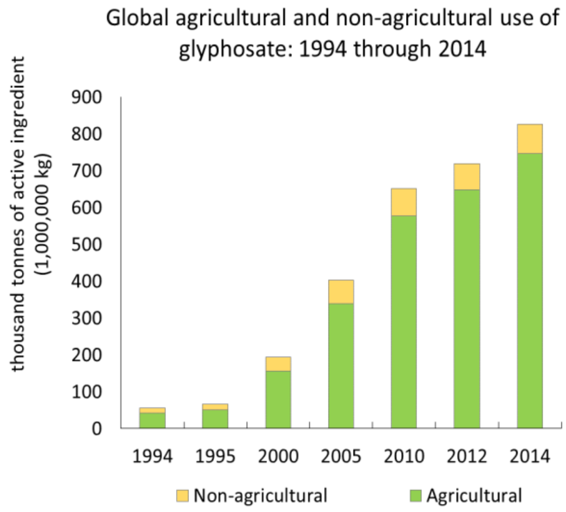


Figure 1. Global agricultural and non-agricultural uses of glyphosate (adapted from James, 2016).

On a global scale, about 50% of glyphosate products used in agriculture are used on genetically engineered crops, known as Genetically Modified crops or GM, that are specifically designed to be resistant to glyphosate (e.g. maize, cotton, soya beans, oilseed, sugar beet). In these cases, the use of glyphosate is inevitable. The European Union, however, has a strict regulation regarding the plantation of GM crops and 19 EU countries have sent demands to be excluded from the geographical scope of the GM applications already authorised or in the process of authorisation[6]. The Member States that cultivate GM plantations are the Czech Republic, Spain, Slovakia, Romania and Portugal[7] and in fact, the crop cultivated almost exclusively is Monsanto's glyphosate-tolerant GM maize – MON 810. Here we need to emphasize that the total area dedicated to GM crops in Europe is approximately 130,000 ha, which is just below 0.1% of EU agricultural land. Ninety percent (90%) of the land with GM crops (116,307 ha) is in Spain (James, 1996).

There are no official data on the overall amount of glyphosate used for agricultural or non-agricultural purposes across the EU. A publication in 2016, based on an analysis of U.S. and global official data or data from the industry gives an overall picture of the agricultural and non-agricultural use of glyphosate (Benbrook, 2016) presented in Figure 1. These data also reveal that global use of glyphosate has increased almost 15 times in the last 10 years.

[6] https://ec.europa.eu/food/plant/gmo/authorisation/cultivation/geographical_scope_en
[7] European Commission, Fact Sheet: Questions and Answers on EU's policies on GMOs (2015) http://europa.eu/rapid/press-release_MEMO-15-4778_en.htm

For Europe some of the data come from Member States. In Germany for example, glyphosate is applied in approximately 4.3 million ha of arable land (39% of total arable area) and a German study from the University of Gottingen estimated that application of glyphosate is between 3.6 to 4.6 thousand tonnes of active ingredient (Steinmann et al., 2012). In the UK, glyphosate-based herbicides were the ones used the most out of all herbicides accounting for almost 1,800 tonnes of active substance (Garthwaite et al., 2014).

4 Glyphosate and Herbicide Sales in EU

According to the global organisation Transparency Market Research, Europe held around 16.6% of the global glyphosate market in 2012[8] and according to its manufacturers glyphosate accounted for 25% of the global herbicide market in 2012[9].

The EU does not publish data on the use or sales of individual herbicides, making it difficult to find out how much glyphosate is being sold (or is being used) in EU countries. Nevertheless, the statistical office of the European Union, Eurostat, provides statistics for the sales of pesticides (expressed in weight of active ingredients) in Europe[10], of which the results for the EU Member States are presented below.

Figure 2 shows the summary of pesticide sales in the EU during 2011-2014 in thousands of tonnes (1,000,000 kg). Herbicides are the second most-sold pesticides in the EU (131.3 thousand tonnes of active ingredients), and in 2014 accounted for 33.1% of all pesticide sales (396.2 thousand tonnes of active ingredients in total).

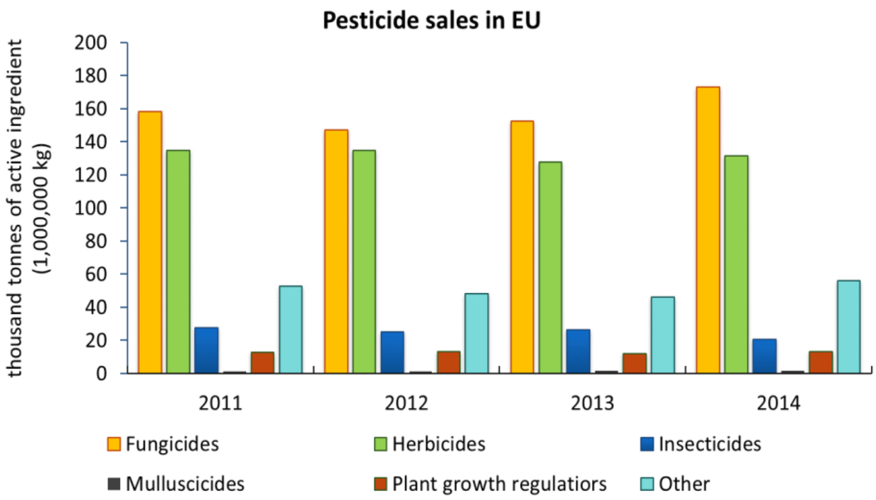


Figure 2 Pesticide sales in EU (2011-2014) by type expressed as thousand of tonnes of active ingredients (eurostat)

[8] https://www.transparencymarketresearch.com/glyphosate-market.html
[9] http://www.glyphosate.eu/glyphosate-basics/what-glyphosate
[10] http://ec.europa.eu/eurostat/statistics-explained/index.php/Pesticide_sales_statistics

However, by looking into the pesticide sales of each EU country, one can see that, in some countries, herbicides are in fact the pesticide products that are sold the most (Figure 3). For example, in 2014, herbicides came before fungicides and insecticides in the sales of 14 EU countries: Bulgaria, the Czech Republic, Denmark, Finland, Germany, Hungary, Ireland, Latvia, Lithuania, Poland, Romania, Slovakia, Sweden and the United Kingdom.

Finally, by focusing only on herbicide sales per country one can see that France, Germany, Spain, the UK and Poland are the countries with the highest herbicides sales (Figure 4). Together, these countries accounted for sales of 88.2 thousand tonnes of active ingredients in 2014, or 51% of the entire herbicide sales in the EU. Here, it is worth noting that Spain is also the country where most glyphosate-resistant GM crops are grown in EU and it's also the second EU country, after France, with the largest land area dedicated to agriculture in Europe (Eurostat). In general, herbicide sales did not change much during 2011-2014, with the exception of Denmark, where there was a clear reduction (Figure 4).

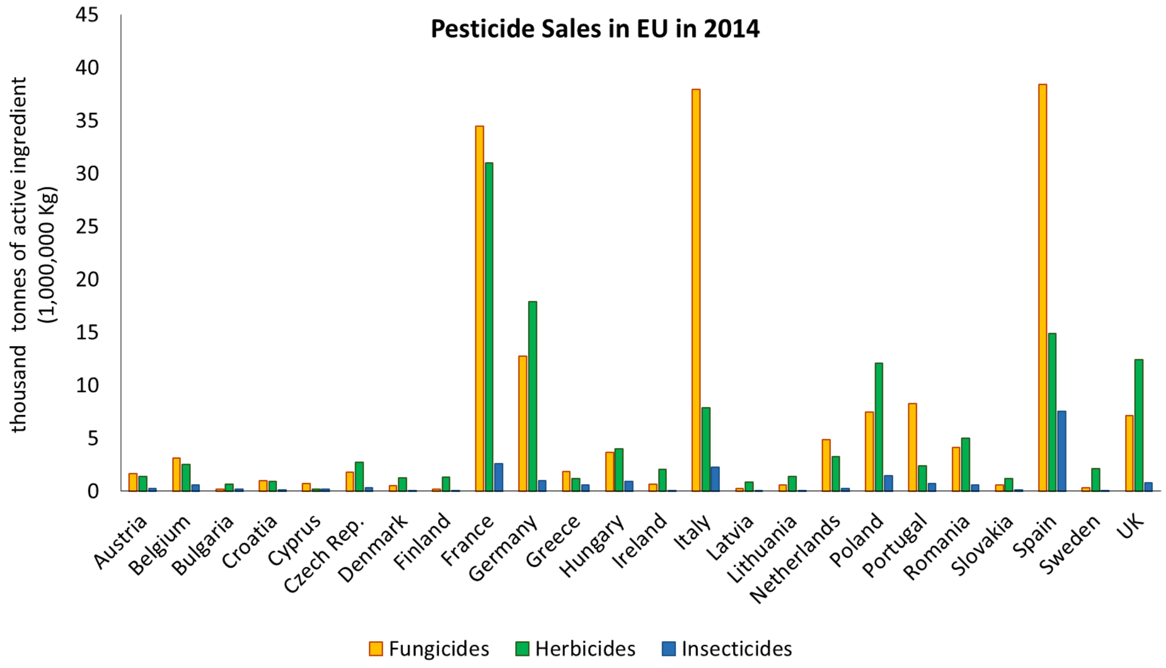


Figure 3 Sales of herbicides, fungicides and insecticides across EU countries in 2014 (Eurostat). Countries with sales below 1 million tonnes are excluded.

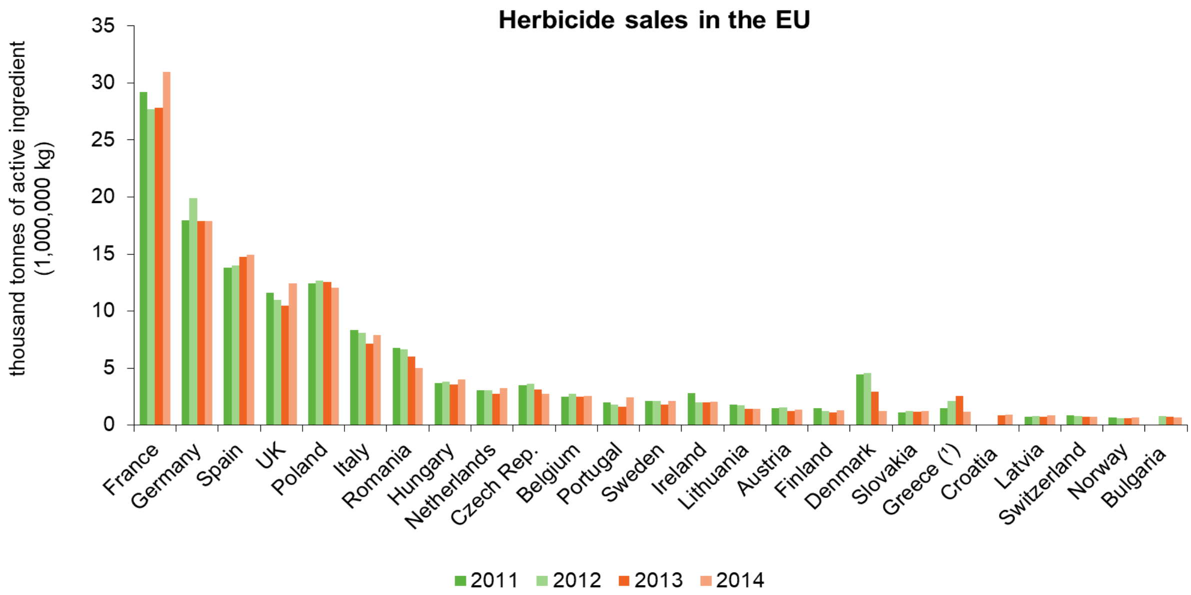


Figure 4 Sales of herbicides across EU countries in 2011-2014 (Eurostat)

5 Health concerns

By carrying out a search in the scientific literature one can see that exposure to glyphosate alone and to glyphosate-based herbicides has been associated with a wide range of adverse health effects in humans, laboratory animals, farm animals and wildlife (a summary on toxicity to glyphosate is given in Annex 1). What is probably of most concern to farmers is that certain clinical human studies have shown that workers who had previously used glyphosate had a higher incidence of non-Hodgkin lymphoma, a rare case of cancer, compared to those who had not used glyphosate (De Roos et al., 2003; Eriksson et al., 2008; McDuffie et al. 2001). In fact, in 2015, the International Agency for Research on Cancer (IARC), of the World Health Organization (WHO), after carrying out an assessment on the potential of glyphosate to cause cancer, classified it as “probably carcinogenic to humans” (IARC group of substances 2A) (IARC, 2016). Other studies from the scientific literature have reported a range of adverse effects in laboratory animals following exposure to glyphosate alone and glyphosate-based products: carcinogenic, genotoxic, reproductive, developmental, of endocrine disruption etc. (Annex 1). The glyphosate monograph of Pesticide Action Network International presents a big number of studies from the scientific literature that have reported adverse effects in humans, laboratory animals, the environment and its ecosystems.

Nevertheless, in Europe the European Food Safety Authority (EFSA)[11] and the European Chemicals Agency

[11] https://www.efsa.europa.eu/en/press/news/151112

(ECHA)[12] both concluded that glyphosate does not present any carcinogenic risk for humans and overall that its use poses no health risk for humans. Here, one should note that at the European Union level, European agencies carry out the toxicity assessment of pesticides on the individual active substances rather than the whole products. The final pesticide products that include the active substances and the different formulations are evaluated by the Member States through a much less rigorous assessment[13].

This discrepancy between the conclusions of the European Authorities and IARC brought reactions from the scientific community around the world, and a group of scientists published a Statement of Concern (Box 2). Further, the detection of glyphosate in food[14] and consumer products[15] as well as in people's urine (Conrad et al., 2017), has raised concerns in the general population about to how much glyphosate we are actually exposed to, and what are its potential health effects.

Box 2 Statement of Concern published in 2016 at the *Environmental Health* journal (Myers et al., 2016)

Statement of Concern directed to scientists, physicians, and regulatory officials around the world:

"(1) Glyphosate Based Herbicides (GBHs) are the most heavily applied herbicide in the world and usage continues to rise;

(2) Worldwide, GBHs often contaminate drinking water sources, precipitation, and air, especially in agricultural regions;

(3) The half-life of glyphosate in water and soil is longer than previously recognized;

(4) Glyphosate and its metabolites are widely present in the global soybean supply;

(5) Human exposures to GBHs are rising;

(6) Glyphosate is now authoritatively classified as a probable human carcinogen;

(7) Regulatory estimates of tolerable daily intakes for glyphosate in the United States and European Union are based on outdated science. We offer a series of recommendations related to the need for new investments in epidemiological studies, biomonitoring, and toxicology studies that draw on the principles of endocrinology to determine whether the effects of GBHs are due to endocrine disrupting activities."

[12] https://echa.europa.eu/-/glyphosate-not-classified-as-a-carcinogen-by-echa
[13] http://www.efsa.europa.eu/en/interactive_pages/pesticides_authorisation/PesticidesAuthorisation#pesticides
[14] https://www.slu.se/globalassets/ew/org/centrb/ckb/publikationer/dokumentation/p12-ramo.pdf
[15] https://www.rt.com/usa/319524-tampons-cotton-glyphosate-monsanto/

6 Impact on ecosystem services and agriculture

Herbicides are applied on open spaces and are inevitably transferred to all the different compartments of the environment (atmosphere, soil, surface waters and groundwater, sea). Depending on their application and biodegradation rate, these chemicals end up contaminating the environment (soil, water and living organisms) putting its ecosystems at risk (Carvalho, 2017).

Glyphosate works against all plant species, it can even kill large trees and may easily destroy habitats ranging from wild to semi-natural. No other herbicide is so non-selective. Hence, glyphosate and glyphosate-based herbicides have direct and indirect impact on the environment and its ecosystems. Direct effects include glyphosate being reported to cause harm in a wide range of environmental species (e.g. birds, fish, frogs, snails, insects, soil microbes, etc). Indirect effects include the unprecedented elimination of weeds, which in turn have an effect on agro-ecosystems (Watts et al., 2006). Farmland biodiversity and ecosystem functions such as natural pest control, pollination services and functional soil structures are increasingly jeopardised by today's nearly complete elimination of weeds and wild plants as well as due to species' intoxication by agrochemicals (Box 3). This impact on ecosystem services has a direct economic cost (Box 4). The ecological disturbance and disruption of ecosystem services in areas dedicated to conventional farming is one of the underlying causes of the difficulties conventional farmers are facing in returning to ecologically friendly agricultural systems (Schütte, 2003).

Glyphosate's toxic action on the plant also blocks its natural defence mechanism that responds to infections (Johal & Huber 2009). Glyphosate has been reported to alter soil microbial communities, for example to decrease the population of arbuscular mycorrhizal fungi, which facilitate nutrient uptake from the plant roots (Zaller et al., 2017). It is also toxic to beneficial soil bacteria, such as those of the *Bacillus* family (Yu et al., 2015) that have a key role in suppressing specific pathogenic fungi, as well as in making the soil minerals available to plants. Glyphosate has been reported to bind to the soil minerals (manganese, iron, etc.) blocking their bioavailability to the plants (Johal & Huber, 2009). Actually, glyphosate has been characterised to "*significantly increase the severity of various plants diseases, impair plant defence to pathogens and diseases, and immobilize soil and plant nutrients rendering them unavailable for plant use*"[16] (ibid.). Due to these effects and to increasing weed tolerance and resistance, farmers are obliged to use fungicides and additional herbicides on their crops, resulting in a much higher ecological impact.

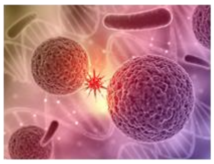
[16] Full review: Science in society 2012. Glyphosate Hazards to Crops, Soils, Animals, and Consumers. http://www.i-sis.org.uk/USDA_scientist_reveals_all.php

Box 3 Examples from the scientific literature on how glyphosate use affects ecosystem services

Ecosystem services and glyphosate

Earthworms: Also called "ecosystem engineers", they shred and redistribute organic material in soil, increase soil penetrability for roots through their movement, and consequently improve overall soil fertility. Glyphosate-based herbicides affect the reproduction of earthworms and cause a dramatic decline in their population[1].

Soil microbial communities: These form the basis of ecosystem services such as plant residues and litter decomposition, organic matter mineralization, carbon and nitrogen cycling among others[2]. Certain fungi and bacteria facilitate nutrient uptake in plant roots. Repeated applications of glyphosate alter the microbial community of certain soils[3] , increase soil pathogens[4] and plant nutrient uptake[5].



Pollinators: Honey bees, bumble bees, butterflies and other insects, play a key role in the pollination of the plants, and have a key role in the pollination of crops in agriculture to produce, seeds or fruits. Glyphosate being a broad spectrum herbicide, it reduces the number of flowering plants that are a food source for the pollinators but it may also impact honey bees following long-term exposure[6].

Plant defence: Plants have their own defence system to respond to infections by synthesizing and exerting specific substances to reach the site of infection (e.g. antimicrobial phytoalexins). Glyphosate acts on the pathway that many of these plant-defences are produced, making the crops more susceptible to pathogens and diseases[7].

[1]Gaupp-Berghausen et al., 2015; [2]Delgado-Baquerizo et al., 2016; [3]Lancaster et al., 2010; [4]Kremer and Means, 2009';[5]Zaller et al., 2014; [6]Herbert et al., 2014; [7]Johal and Huber, 2009.

Figure 5 Effects of long term use of glyphosate on crops[16]

Box 4 Economic costs of gradual loss in ecosystem services

The United Nations Environment Programme (UNEP) carried out a study in 2005 and found that 40% of the world's economy actually relies directly on ecosystem services (SCBD, 2010). Hence, it is of great concern that, according to the Millennium Ecosystem Assessment (2005) 60% of ecosystem services have deteriorated in the last 50 years. A study on the economics of ecosystems and biodiversity recently confirmed that the cost of inaction and the degradation of ecosystem services could account for up to 7% of world GDP (Gross domestic product) per year by 2050 (UNEP, 2008).

Box 5 Facts on soil contamination by glyphosate

Facts on soil contamination by glyphosate:

- Studies show that glyphosate and its degradation product aminomethylphosphonic acid (AMPA), which is also of toxicological concern, get quickly metabolised down to 50% by soil bacteria in silt/clay soil (9 and 32 days, respectively). Nevertheless, traces of glyphosate and AMPA can be detected 21 months after application (Simonsen et al., 2008).
- A recent study shows that glyphosate and AMPA are detected in 45% of European soil (300 samples from 10 European countries) (Silva et al., 2017). These substances are strongly (>90%) adsorbed to soil particles but are not necessarily immobilised in soil. On the contrary, they are transported together with the soil particles through atmoshpere and water, and can be taken up by living organisms or get deposited in rivers and lakes.
- Glyphosate may become easily mobile by water in soils high in phosphate. Phosphate in fertilizers reduces the adsorption of glyphosate to soil particles, increasing the amount of free glyphosate molecules in the soil, which can then be absorbed by the plant roots, metabolised by microorganisms or can leach into the groundwater (Munira et al., 2016).

7 Weed management methods without herbicides

Weed management is a big challenge in agriculture and in many cases a complex, controversial and expensive problem to resolve. The latter is evident by the sales of herbicides in EU, which accounts for 33% of all pesticide sales (Figure 2).

As we have seen, in order to protect soil fertility, ecosystem services as well as environmental and human health, there is a clear need to reduce and gradually overcome our dependency to herbicides and other such chemicals. The key is to invest in sustainable agricultural systems that, when practiced properly, not only stop contributing to the exhaustion and destruction of natural resources, but also prompt an ecologically viable agricultural production model.

This section shows that it is not necessary to be an organic farmer to reduce or even eliminate the use of herbicides in agriculture. Several methods of weed management already exist that farmers can adopt in combination to eventually withdraw altogether from pesticide use. Even complex issues, like the use of glyphosate in conservation tilling to avoid ploughing and "protect" the carbon-storage capacity of agricultural soils, can be resolved without herbicide use (TILMAN-ORG 2016).

Box 6 Herbicide-free conservation tillage

Conservation tillage: Reduced (shallow) tillage and green manure

Research and farming experience show that ploughing and many tillage practices are eroding the soils, resulting in poorer non-fertile soils with reduced carbon storage sinks. For this reason, many farmers may use glyphosate instead of tilling - and conveniently save several hours of labour work. Recent studies show that, in fact, reduced tillage (RT), such as shallow inversion ploughing (limited to 25 cm of soil depth) or non-inversion tillage (up to 10 or 25 cm), not only reduces weed density but also causes less disturbance to the soil in the long-term (has lower impact on soil communities, such as earthworms and mycorrhizal fungi) compared to deep tillage (over 25 cm soil depth). Therefore, when combined with other agronomic practices RT can be considered a good weed management technique that overcomes the need to use herbicides. For example, when reduced tilling is combined with the use of green manure to raise nitrogen levels, crop yields can be comparable, while soil fertility and carbon storage capacity is maintained (TILMAN-ORG, 2011-2014).

What is a weed? With no set scientific definition, it is often described as "a plant in the wrong place". In some agricultural systems in the EU, a farmer will pay significant sums to spray with wide spectrum herbicides, then pay again, often with publicly-funded subventions, to sow the same species of "weeds", for example wildflower strips that fulfil beneficial agro-ecological functions, attracting pollinators and natural predators of pest insects. Crop losses due to weeds depend on the type of crop, its growth stage, weed species, location, and farming systems applied. Weeds may directly reduce crop yield and quality, or increase harvest costs. Crops get mostly affected by weeds during their early growth stage, when the plants are young, vulnerable and highly dependent on nutrients, light, and water/moisture supply. If a crop has to compete with weeds at this stage, it may become weak and prone to pest and disease infections. Once the plant has grown, weed competition for nutrients and water is less of a problem. In these cases, weeds may cause a problem during harvesting and consequently reduce the crop yield (Barberi, 2003). Here, one should note that the concept of a 100% yield is a flawed one as there are so many variables that will prevent 100% "efficiency", especially climate and weather events, which can easily shift final results above or below 10% of the forecast.

But in any case, the solution is not to completely eradicate all weeds, as they also play a very important role in the conservation of soil and provide food for natural predators. According to a 20-year study in Denmark, about 80% out of a total of about 200 weeds growing in cultivated fields are too weak to compete with the crops and therefore do not affect the overall crop yield (Andreasen et al., 1996). It is only 20 % that may affect the yield significantly. "Weeds", if managed in certain manner, can have a beneficial role by providing biological diversity and supporting ecosystem services. For example, they offer a habitat for both beneficial biocontrol insects and mycorrhizal fungi: they cover bare soil after harvest keeping beneficial soil microorganism communities alive through their root exudates of sugars and proteins. Also, the pollen and nectar from certain weeds helps in maintaining the population of biocontrol insects and, which are very valuable for pest control.

Looking wider than just weed control in a more integrated approach, a key element is to obtain a balance between crop and non-crop vegetation to encourage an increase in natural enemies of crop pests. A successful weed management approach should take into consideration the biological and ecological characteristics of weeds and understand how their presence can be controlled by agricultural practices. In general, such measures aim at keeping the weed population at a level which does not result in an economic loss in cultivating the crop or in reducing the crop quality.

The first step in sustainable weed management is to integrate different methods to manage the weeds, each one adapted to the type of weed and type of crop and applied usually in combination, at specific times during the life cycle of the crop. This is the basis of Integrated Weed Management, where different management techniques (preventive, mechanical, biological and monitoring) are applied during the crops' different stages to achieve healthy, quality crops and good yields. The compilation of all the available techniques can be seen as a pyramid where each layer provides a list of methods ('many little hammers') that can be applied for weed management, where chemical control is used only as a last resort if all other methods have failed.

Figure 6 The Integrated Weed Management pyramid. Building from bottom to top

This report does not cover the option to use synthetic herbicides; natural herbicides are presented as a chemical weed management option. Nevertheless, the focus is given to the integration of all other methods.

The practices of weed management can be divided in four parts (the IWM pyramid; see Figure 6):

- Preventive and cultural agronomic practices (measures taken to reduce weed germination)
- Monitoring (observation and identification of weeds throughout the process)
- Physical control of weeds (mechanical, thermal)
- Biological control

Based on agricultural knowledge, these practices are now also possible in combination with various high-tech tools such as digital images for automated steering systems, e.g. used for steering hoes; GPS for electronic mapping of the position of the seeds; weeding devices etc. It must be noted that these are high-cost, high-technology machinery and tools that most small/medium farmers may not be able to afford, especially as farm debt is very high. This currently limits applicability for a great section of the farming community. Depending on the culture and set-up of farming operations, there may be options to share machinery between farms co-operating together, especially as machinery is often invented for one or a few specific crops in mind; this specialisation is important to consider in the shift between continuous year-on-year monocultures and diverse crop rotations.

It is useful to integrate several approaches in weed management because one method is not enough to control all weeds. This is because:

- some weeds are ephemeral or with shallow roots and so are easier to control than others;
- some weeds are annual and some perennial;
- some are spread by cultivation, others by wind;
- some are avoided by using grazing animals;
- some are very competitive against cover crops.

Figure 7 illustrates an example of an integrated weed management approach for vineyards.

Figure 7 Integrated Weed Management approach plan in vineyards

7.1 Preventive and "cultural control" agronomic practices

Prevention is better than cure: it is the most effective method for dealing with weeds. Once a weed has entered the field, and has grown and established itself, eradication is far more difficult and time-consuming; not only to successfully remove the weeds but also to prevent them from spreading further. Several preventive measures may be applied in parallel or at different times. The importance and effectiveness of the different methods depends to a large extent on the weed species and environmental or climatic conditions.

The term "cultural control" (or "cultural" agronomic practices) refers to any method used to maintain field conditions so that weeds are less likely to become established and/or increase in number, or to strengthen the crops and facilitate them in competing with the weeds. Some methods are very effective for a wide range of weeds and during different times of weed growth and therefore can be used throughout the crop's life-time. Cultural weed control includes non-chemical crop management practices ranging from variety selection to land preparation to harvest and postharvest processing.

On the other hand, before selecting which methods to use in weed management, one has to take into consideration that techniques involving machinery with fuel-powered combustion engines are based on unsustainable sources of energy and release carbon dioxide into the atmosphere, contributing therefore to global warming.

Farmers' tips to beginners for success:

1) start clean, stay clean – keep tools and machinery clean from dirt and plant residues that could carry pathogens or weed seeds

2) Prevention is always better than treatment – plan ahead to prevent the growth of weeds

3) One year's seeds will lead to seven years weed infestation – remove the weeds early, to stop them from spreading their seeds

7.1.1 Crop rotation and cover crops

The rotation of crops in a specified order in a field is one of the oldest and most effective agricultural control measures to regulate weed presence, as well as enriching the soil naturally with nutrients after it is depleted by producing crops, thanks to the nitrogen-fixing properties of leguminous crops included in the rotation. Crops are planted following a certain rotation cycle; nutrients they leave in the soil can be absorbed by the next crop. The underlying concept as regards weed control is that by changing the conditions in the field, one interrupts the growth and reproductive cycle of the weeds and this inhibits their growth and spread. In this way, crop rotation helps to avoid the build-up of pathogens and pests that often occurs in monocultures, and can also improve soil structure and fertility by alternating deep-rooted and shallow-rooted plants. Farmers may also include cover crops in the rotation under-sown with or immediately after the primary crop, as a preventive method. Cover crops do not usually provide a marketable yield but may be planted between two crops of interest (cost crops) to help in weed suppression, enrichment of soil with nutrients, reduced runoff of water or nutrients, etc. Overall the benefits of crop rotation are to promote pest-suppression, soil and water quality, nutrient cycling efficiency, and maintain good yield productivity (Snapp et al., 2005).

A traditional element of crop rotation, for example is to plant first legumes and/or brassica species that leave beneficial nutrients for the next crops. Legumes fix nitrogen, produce high quality but limited amounts of nitrogen (0.5-4 mg/ha), and enhance beneficial insect habitat. Brassica species in particular produce glucosinolate-containing residues (2-6 mg/ha) which help suppress plant-parasitic nematodes and soil-borne diseases (Snapp et al., 2005).

The selection of species to include in the rotations must take several factors into consideration: the marketing interest, the agricultural cycle of each crop, cycles of the main weeds to manage, and the pests and diseases to which the crops are susceptible.

7.1.2 Mixed cropping and undersowing

Mixed cropping, also known as polyculture, inter-cropping, under-sowing or co-cultivation, is a method that involves planting two or more plants simultaneously in the same field, so that the properties of one plant facilitate the growth of the other. Benefits of mixed cropping include a balanced input and output of nutrients in the soil, suppression of weed growth, suppression of insects and plant diseases and an increase in overall productivity. Suppression of weed growth can be done either physically by crowding out the unwanted species by covering all available bare soil, by encouraging many individuals of the crop plants and by using crop species that cover the soil with their leaves; or chemically whereby crop plant roots release into the soil chemicals that inhibit the growth of certain weed species (this is called allelopathy and it can also occur through mulching with some species). Mixed cropping can also be used in crop rotation (Hirst, 2017). For example, legume-maize mixtures can be used in inter-cropping as a home-grown, protein-rich forage, but also because of their positive agro-ecological impact on soil fertility due to the Nitrogen fixation by symbiotic rhizobia bacteria living in special organs in the roots of legumes (Nurk et al., 2017).

Undersowing is a mixed cropping practice, which involves seeding one or more crops at the same time as the main crop, but only the main crop is harvested; this leaves the secondary crops covering the soil, preventing weed establishment. In this case, apart from the benefits of mixed cropping (e.g. soil enrichment with nutrients) the under-sown crop suppresses weeds through natural competition and/or root exudation (allelopathy) and reduces or even eliminates the need for additional weed management. Many successful tests have been conducted with cereal crops (barley, wheat), maize and soya, using as under-crop legume plants (white clover, subterranean clover, fenugreek, etc) (Ramseier & Crismaru, 2014).

7.1.3 Selection of competitive/strong varieties

Competitive cultivars in agriculture are more tolerant to and therefore are affected less by the presence of weeds. The varieties may vary in their canopy structure and growth mode which gives them "weed-suppressing" ability (Andrew et al., 2017).

This is a potentially attractive option for weed control in comparison to other methods, because there are no additional costs. Such cultivars may be more capable of reducing the fitness of a weed species through competition for limited resources, may produce chemical exudates that reduce weed growth (allelopathy) and therefore reduce the economic burden of weeds by resulting yield loss. Competitive cultivars can reduce the reappearance of a weed species in the soil's seed bank and contribute to medium to long-term weed management strategies, reducing the pressure to use herbicides and improving the sustainability of cropping systems (Andrew et al., 2017).

7.1.4 False or Stale seed bed technique

This technique is a preventive method with the specific aim of reducing weed emergence in the next crop cycle and minimize overall soil disturbance. It involves preparing the seedbed several weeks before sowing by allowing weed seeds just below the surface to germinate and cover the bare soil surface. The emerged weeds are eradicated mechanically with a cultivator before sowing the crop of interest (preferably a competitive variety) (Hooks et al., 2014). At sowing time, the seed bank of weed species is already partially depleted and the emergence of these weeds is much reduced. Moist conditions are essential to encourage weed emergence. The small weeds which germinate are easy to manage and can be removed with a very shallow harrow or with a flame-weeder.

7.1.5 Mulching

Covering or mulching the soil with plant residues/wastes or synthetic mulches is one of the most popular management practices that reduce weed problems either by preventing altogether weed seed germination or by suppressing the growth of emerging seedlings. Mulch systems suppress weeds due to their physical impact by preventing weed seedlings growing by blocking or reducing solar radiation and by increasing the temperature range on the superficial layer of the soil. As well as soil temperature and light, mulches also affect the passage of water throughout the soil profile.

Mulches can be natural such as straw, sawdust, weeds, paper and plant residues or even synthetic. Mulching is used particularly for two reasons: to save water and prevent weeds emergence.

Organic mulches: These refer to mulches that derive from organic material (that decompose) rather than inorganic material (non-biodegradable). Organic mulches include bark wood chips, leaves, grass clips sawdust, hulls of plants, crop residues following harvest, as well as weeds removed from the field.

In addition to the above-mentioned effects on soil temperature and other soil properties, it is also possible to explore the allelopathic potential of certain species used in weed control.

The inhibitory effect of organic mulch on weeds may be due to both the physical effect of weed emergence suppression (the reduced passage of solar radiation and temperature range on the superficial soil layer) and the possible chemical effects arising from allelochemicals released by some crop residues that may contribute to emergence reduction (Oliveira Jr et al., 2014).

Organic mulches are only effective at stopping weeds from germinating. They are not effective at controlling established, especially perennial, weeds. Therefore, in order to be mulched, the ground must be completely free of established weeds before applying the mulch, including dormant perennial weeds.

Synthetic mulches: Plastic mulch is a standard practice used by many farmers to control weeds, increase crop yield, and shorten time to harvest. There are different weed control techniques and materials that could be used as synthetic mulches, and are explained below.

Two negative aspects of synthetic mulches come from the partial decomposition of the plastic particularly into micro-plastic fragments, as either this pollutes the soil, or it is transferred through the water system to the oceans where it contributes to ocean plastic; in both cases plastics are taken up by and may damage living organisms. It should be noted that biodegradable mulches can also contribute to these problems as degradation by soil microorganisms ceases during frozen or anaerobic waterlogged or underwater conditions.

Although mulching may be more effective in limiting evaporation and saving soil water in arid and semi-arid regions, it is problematic especially in wetter, colder climates, as the upper layers of the soil profile become waterlogged and so the nutrients in the soil accumulate at the very top of the soil profile; carbon sinking is also concentrated there rather than the organic carbon being spread throughout the upper horizons (Luo et al., 2010). In addition, waterlogged conditions are anaerobic, leading to prevalence of soil pathogens. These issues are also related to the problems encountered with no-till systems relying on glyphosate based herbicides (CATCH-C, 2014).

Soil solarisation (or solar heating) consists of covering (mulching, tarping) the soil with a transparent polyethylene sheet during the *hot* season, before crop plantation. It is used successfully in many countries to control or reduce soil borne plant pathogens, weeds, mites and other pests. Soil solarisation uses radiant heat from the sun, collected through the polyethylene sheet, to heat the soil to a temperature (40-55^oC) that controls soil the target pests.

The possible mechanisms of weed control by solarisation are (1) thermal killing of seeds, (2) thermal killing of seeds induced to germinate, (3) breaking seed dormancy and consequently killing the germinating seed, and (4) biological control through weakening or other mechanisms. The effect of solarisation is greater at top 5-10 cm layer than at lower layers. This explains the efficacy of solarisation on weed seed germination and seedling growth (Rubin et al., 2008).

The major effect of high soil temperature (up to 65^oC max) is the killing of the weed seedlings that germinate under the plastic. Solarisation has not been employed on a large scale in field crops but is used effectively in high-value vegetable crops. The plastic is removed prior to planting and must be disposed of—a problem all by itself—but solarisation is successful in nearly eliminating use of herbicides. Although it has the potential to improve weed management, the costs, compared to other methods, preclude its widespread adoption in crops other than the ones of high value (Zimdahl, 2013).

Today, solarisation is explored or implemented in more than 70 countries, and there are over 1,400 research papers documenting such studies, mostly from world's hot regions. The studies demonstrate the effectiveness of solarisation with vegetables, field crops, ornamentals, nurseries, and fruit trees against many pathogens, weeds, and soil arthropods, and in various cropping systems, including organic gardening and farming. The use of solarisation in existing orchards has been an important improvement and deviation from the standard pre-planting methods (Katan Jaavoc, 2013)

Plastic sheet colour. Black plastic film mulch is the weed management option of choice for many medium- to large-scale organic and conventional vegetable farms. The plastic cover is an opaque film that reduces germination of light-responsive weed seeds; it shades out and physically blocks the emergence of most weeds; and can enhance crop growth by conserving soil moisture, promoting soil warming, and speeding nutrient mineralisation from soil organic matter (Schonbeck, 2012).

Despite being one of the most used methods used in weed control, here we need to highlight some disadvantages, mainly because synthetic mulches:

- are manufactured from petroleum, a non-renewable resource.
- do not provide organic matter to feed the soil.
- do not provide as good a habitat for ground beetles, earthworms, and other beneficial species compared to organic mulches, which aid the throughflow and percolation of water.
- are not aerated, rainfall does not percolate, and require drip irrigation for moisture to reach to rhizosphere
- must be picked up and disposed at the end of the season.
- generate large volumes of plastic waste and plastic fibre (200–300 Kg/ha). These end up in the soil, rivers, the oceans and/or inside organisms including ourselves.

Despite these drawbacks, many farmers use these mulches because fit well into mechanised, medium- to large-scale production.

Woven black polypropylene mulches: This type of material provides a durable and effective barrier to weed growth. Often used in ornamental plantations, woven fabric mulches have found increasing use in commercial horticultural food crop production (especially berries and other high-value perennial crops) because of their particular properties (Schonbeck, 2012). These covers are:

- Permeable to air, water, and nutrients.
- Opaque and durable, giving effective weed suppression.
- Long-lasting, typically 8–12 years. Thus, they are considered more ecological comparing with other synthetic mulches as do not generate as much waste

The only disadvantage is that the material is heavy and expensive but the cost spreads out over years of use.

Biodegradable Plastic and Paper mulches: These mulches are the ecological alternative to the use of synthetic mulches, because they eliminate the need to gather and dispose the dirty plastic at the end of season (Ngouajio et al., 1991). The mulch is biodegradable, therefore no clean-up is required.

Degradable mulch has to degrade completely in the soil, be entirely composed of constituents derived from natural resources (bio-based), cannot contain synthetics such as petroleum-derived ingredients, and must completely biodegrade into carbon dioxide, water, and microbial biomass without forming harmful residues or by-products (Miles et al., 2013).

The disadvantage of these materials is the cost, as they are more expensive than regular plastic mulches. However, some farmers feel that the upfront costs are compensated by the end of the season since so much time and money is saved because the mulch requires no disposal.

7.2 Physical weed control

With the necessary preventive measures, weed density can be reduced, but this may not be enough to provide full protection during the early critical and "sensitive" period of the crop's life cycle, when the seeds have just sprouted and are especially liable to being out-competed by faster growing weed species. Therefore, mechanical methods remain an important part of weed management.

7.2.1 Mechanical weed control

The choice of mechanical weeding method depends in part on practical aspects such as the crop, the soil type, the price, the operating costs and labour requirements. On small areas or where sufficient work force is available, hand-weeding remains a possibility, particularly in high value crops; but on most farms, crops are grown on too large a scale, and labour is expensive and often of limited availability.

Mechanical weeders range from basic hand tools to sophisticated tractor-driven devices. Mechanical weed control may involve weeding the whole crop, or it may be limited to selective inter-row weeding. Mechanical weeders range from basic hand tools to sophisticated tractor-driven devices.

Some overall disadvantages of the use of mechanical weed control are:

- mechanical weeding can affect soil structure; especially with compaction in lower layers, there may be consequences for soil water infiltration

- mechanical weeding may increase soil erosion
- depending on the method, mechanical weeding may affect aeration in upper soil layers, potentially causing depletion of soil organic matter content

Mechanical inter-row weeder. Inter-row weeding takes place once the crop has emerged. In small farms, this can be done with the use of hand hoes, push hoes and other traditional hand weeding tools but in larger farms it is often seen as a last resort, due to the intense labour it requires.

Figure 8 Finger Weeder

There are many types of mechanical inter-row weeders (finger weeders, ploughshares, cover plates, etc) that are mounted on a main beam (e.g. tractor) and can be used for inter-row weeding, earthing-up and hoeing for weeds. Finger weeders (figure 8) consist of a turning steel disc with flexible polyurethane fingers, especially designed to control small and just emerging weeds. Mechanical inter-row weeding may be followed by hand weeding to deal with weeds left in the crop row that were missed by the inter-row weeder. Alternatively, some finger weeder discs mounted on springs can remove weeds both between and within the crop row. This is effective for bigger crop plants like cabbages. Leader prongs guide the fingers/brushes around the heads of the crop plants, once the obstacle is passed the mounted brushes spring back to continue weeding within the row.

Figure 9 Hand hoeing from a tractor

Alternatively, hand inter-row weeding may take place using mobile platforms (figure 9). Hand hoes, small knives, and fingers all have their place. The platforms are normally mounted on a tractor, allowing workers to sit or lie down on cushions or slung fabric, and provide protection from the sun, wind and rain.

Figure 10 Disk harrow

Harrows. Harrowing is used for smoothing the soil, and is also a traditional form of mechanical weed control for dealing with annual and small weeds, but it is ineffective against established deep-rooted weeds; therefore, it should be used in weed management together with preventive methods. In cereals, 'blind' harrowing before crop emergence may be carried out after seed drilling but before the crop seedlings emerge in order to kill the first flush of small emerging weeds. The most common types are spring-tine, disk, chain or drag harrows (Figure 10 & Figure 11). The aim is to give the crop an early advantage over the weeds to aid selectivity in subsequent harrowing operations.

Figure 11 Trailed chain harrow

Tractor hoes. Tractor hoes have 'A' or 'L' shaped fixed, vibrating or revolving plough shares that undercut weeds by passing through the soil at 2-4 cm depth (Figure 12). Soil structure is a critical factor as in rough clay soils, weeds may continue to grow in the lumps of soil lifted by the hoe. Tractor hoes work best in dry conditions as wet conditions after hoeing may stimulate weed regeneration. Hoeing is particularly effective against mature weeds.

Hoeing with harrows in the upper soil surface, between the crop rows, is a common practice often resulting in high weed control efficacy

Figure 12 Tractor hoes

A major disadvantage of hoeing is the relative low driving speed and the limitations of the fixed tool width resulting in low labour efficiency. Tractor hoes can only be used in crops that are planted with a relatively large distance between the rows. Another limitation of weed hoeing is the limited efficacy of weed control in the intra-row area. New technologies have been developed to automatically steer hoes close to crop rows using imaging and Global Navigation Satellite System (GNSS) technologies. These technologies have been applied in maize, sugar beet, soybean and several vegetable crops. Using digital image analysis, weeds are distinguished from the crop based on shape features and selectively removed.

Brush weeders. The brush weeder, or brush hoe, is primarily intended for inter-row weeding of vegetable crops such as carrots, onions and beetroot, although it has also been tested in cereals with very good results. When used in leafy vegetables there is a greater risk of crop damage.

As the name suggests, the weeding action comes from strong nylon brushes that rotate and brush the weeds onto the soil surface, pulling out the weeds with shallow ephemeral root systems or breaking and flattening more robust weeds. Thus, the advantage over the tractor hoe is that it can be used under more wet soil conditions as well. A second person, in addition to the tractor driver, or some form of self-steering mechanism is needed to ensure careful guidance of the brushes between the crop rows.

Figure 13 Brush weeder

Cover crop rolling is an advanced no-till technique. It involves flattening a high-biomass cover crop to produce a uniform mat of mulch. The crop of interest is then sowed through the mulch into the underlying soil. Attention should be given, because if the right kind of roller is not used on the right cover crop and at the right time, the rolling process itself will kill or partially kill the cover crop. As discussed above, care should be taken so that the mulch layer is not too thick, otherwise the underlying soil may become waterlogged and anaerobic in wetter climates.

Figure 14. Cover crop rolling

Rolling is useful for eradicating weeds before they set seed in stands of high-biomass cover crops. Uniform stands are important for uniform mulch thickness. In the right climatic conditions, this practice maximises the amount of organic matter that is deposited back in the soil by a cover crop. The mulch that is produced also has a positive effect as weed control, and improves moisture retention in more dry and arid climates and protects soil from rainfall impact and erosion.

For better results the farmer can use a roller-crimper (Figure 14). Crimping damages the cover crop even more, by snapping or breaking the stems rather than bending them, and so increases the likelihood it will stay down and die after rolling[17].

7.2.2 Thermal weed control.

Thermal weed control is used in pre-emergence or localised post-emergence of weeds, in combination with preventive methods, and as the name suggests, it eliminates the weeds by burning them.

Stubble burning is now almost banned because of the smoke and other hazards, but this traditional form of thermal weed control was frequently used to reduce the number of viable weed seeds returning to the soil after cereal harvest. Current methods of thermal weed control use a variety of energy sources to generate the heat needed to kill weed seeds and seedlings.

Flame weeding is probably the most popular methods of direct weed control after mechanical weeding. Weed burners or flamers are blowtorches adapted to deliver flames to ground level. They do not have to burn the plants to ash as long as the heat 'cooks' the leaves. Flamers work best on small weeds with high moisture content because the plant doesn't have the resources to regrow after the leaves are dead.

Figure 16. Flame Throwers

The main fuel used in the burners is liquefied petroleum gas (LPG), usually propane. Some concerns have been raised about using a finite resource as fossil fuels, however alternative fuels such as hydrogen can also be used (Bond et al., 2003). Costs of materials may also be an issue. Flame weeding can be faster than hand-weeding, but the cost of the machine is higher. Overall treating an area of 6-20 hectares would bring costs down to a reasonable level but for smaller areas it will depend on the cost of the crop.

Figure 15. Row Flamers

Flame weeders can be used for total vegetation control or for selective removal of unwanted plants, particularly during pre-emergence of crops. In weed management the use of

[17] http://blogs.cornell.edu/whatscroppingup/2016/09/29/on-farm-organic-no-till-planted-soybean-in-rolled-cover-crop-mulch/

pre-emergence flaming followed by post-emergence brush weeding or hoeing have been reported to give promising results (Hatcher & Melander, 2003). One disadvantage is the impact it may have on non-target organisms, which has not been fully investigated. But the soil temperature at 5 mm distance depth is raised by 4 °C and at 10 mm by 1.2 °C, and therefore the impact on deeper soil microorganisms is low (Bond et al., 2003).

Figure 17. Steaming- weed control

Steaming is traditionally used in glasshouses to sterilise the soil and control both weeds and diseases prior to crop establishment. However, now it is also used as an inter-row weed-management method during the crop growing cycle. Steam is applied under pressure beneath metal pans forced down onto freshly formed beds for periods of 3-8 minutes (figure 17). The steam raises the soil temperature to 70-100 °C killing most weed seeds to a depth of at least 10 cm. It is also possible to use jets of steam to kill emerged weeds (Bond et al., 2003).

Until recently most thermal weeders were based on gas powered burners. The best designs generally use 'liquid' rather than 'gas' phase burners as these are much less prone to pressure-drops and they incorporate a shroud or hood to retain heat and protect the flames from wind.

Steam has a number of advantages over flame weeders, in that steam is much more efficient at conducting heat, has better penetration into foliage, operates better in windy and wet conditions, is safer and some machines can be used to weed over plastic and even paper without causing damage (Schonbeck, 2012).

Steaming practices however, decrease the abundance of soil microorganisms and studies show that soil communities may recover but their structure may remain affected for at least 2 months following the steaming. This should be taken into account prior to the selection of this method (Roux-Michollet et al., 2008).

Steaming has been used successfully to eradicate the strong perennial weed *Cyperus esculentus* in vegetable fields in Switzerland, which could not be efficiently controlled with other methods, including herbicides (Keller et al., 2017).

Hot water. Hot water can be applied with specific machines that keep the water at a temperature over 80 degrees Celsius. Hot water is applied directly on the weeds of interest in the spot where they grow.

Productivity of this method is twice as much as manual removal, and the costs are only slightly higher. With hot-water treatment there is no need to transport roots away from the site and one avoids having holes in the grass sward. However, there is still some energy consumption, together with exhaust and noise emissions. A study carried out on hot water treatment of the common broad-leaved dock (*Rumex obtusifolius*) showed 80% success in eradicating the weeds and 1 year after treatment there was no evidence of lasting damage to the soil structure on the site, neither did the treatment stimulate the germination of any great number of dock seeds found in the soil (Latsch et al., 2017).

Despite not being widely used, there are a few more thermal methods of weed control, such as freezing, electric currents, irradiation, microwave radiation, and ultraviolet light, among others.

7.2.3 New and non-traditional methods

There are some promising new and non-traditional measures that could be used for controlling weeds in organic farming. New and non-traditional weed control methods such as, **infrared radiation (IR), lasers, microwave radiation, ultra-sonic weed control systems, real-time intelligent robotic weed control systems and electricity** could be used for weed control under field conditions. However, several of these methods are still under development or are used in small areas.

Finally, it can be concluded that successful and sustainable weed management systems are those that use integration among techniques rather than depending on a single method, in line with the "many small hammers" approach of integrated weed management. Further research is needed for new technologies and methods for weed control in sustainable agriculture.

7.3 Monitoring

Monitoring is the key procedure for successful weed management in sustainable agriculture. It starts with planning ahead before the crop is sowed and is carried out throughout the life cycle of the crop. During the preparation of the land and crop's growth cycle, monitoring helps the farmer to detect the weeds early, identify their type and location, and select what type of mechanical intervention is necessary, if at all, to remove them or prevent their growth and spread, based on knowledge and expertise. For example, perennial weeds are more vulnerable to control at the early bud stage or during fall when the plants begin to go dormant. Mechanical weeding at these stages will be effective. A balanced integration of preventive methods, mechanical methods and monitoring (many little hammers) is key to a successful weed management.

Through monitoring, the farmers also build up their knowledge in relation to the weeds they have to manage, the efficacy of the weed control methods they have applied (preventive and cultural, mechanical, biological, even chemical), the impact on the type of crop, and beneficial non-target species, etc. Then they can apply this knowledge in planning ahead for the next season or the next crop of interest.

7.4 Biological weed control and animal grazing

Biological control involves using living organisms, such as insects, nematodes, bacteria, or fungi to reduce weed populations. In weed management, biological control should be integrated with cultural practices such as tillage and crop rotation.

The mode of action of the biological control method depends on the selection of the organism. Fungi or insects that attack seeds can reduce the number of weed seeds stored in the soil, which in turn can reduce the size of future weed populations. This in turn lowers the effort needed to control the remaining emerging weeds. Some bacteria live on root surfaces and release toxins that stunt root growth. Many fungi infect roots and disrupt the water transport system, which reduces leaf growth. Beneficial insects and nematodes feed directly on the weed roots causing injury which allows bacteria and fungi to penetrate. Biological control methods have been successfully applied in some parts of the world, but not so much in Europe (Bond et al., 2003).

However, the application of biological weed control is dangerous, as it may introduce accidentally a tolerant 'invasive' species, and must be done very carefully. If not, the introduced species may spread beyond the targeted area and become a threat to other species, including other crops of interest.

Nevertheless, only a very small number out of the more than 100 organisms released for biocontrol of weeds worldwide have become pests. But it can happen and can have a major ecological and commercial impact (Zimdahl, 2013). For this reason, it is imperative that comprehensive ecological studies are carried out, and indeed enough research funding is provided for researching biological control methods as alternatives to synthetic chemical inputs.

To date, few weed species can be controlled effectively by weed species' specific pathogens, but there are good opportunities for classical biological control of weeds to be developed for Europe as well (Lundkvist & Verwijst, 2011).

Figure 18. Pig feeding on apples dropped during harvest

Figure 19. Sheeps graing in vineyards with a protective net

Animal grazing is another popular method for physical control of weeds, used in parallel with other methods in weed management. Cattle, goats, sheep and even horses can be used for weed management, considering of course that there is an availability of animals and that some adjustments on grazing time and area are necessary (Popay & Field 1996).

Pigs (hogs; Figure 18) are very good in controlling the growth of weeds and grass, and cleaning up dropped apples in orchards, and therefore are commonly used for vegetation control in organic orchard systems (Nunn et al., 2007).

“Sheep weeders” are becoming more popular in different parts of the world due to their low cost compared to manual labour and their ubiquity. Sheep grazing can be beneficial in vineyards not just for removing the weeds and machine-mowed grass and canopies, but also because sheep dung is a good fertiliser for the soil. Sheep should be controlled not to eat the ripe grapes, and one way to do this is protecting the vines with a net (Figure 19).

7.5 Natural herbicides

Natural herbicides are ingredients extracted directly from plants or animal as opposed to being produced synthetically. Being natural, they are biodegradable and leave no residues in the soil but they are not specifically targeting the weed, which means that they will affect other non-target species as well. Thus, natural herbicides have to be used only when and only when all other methods have failed as they are also considered chemical solutions in integrated pest management, albeit being natural chemicals.

Acetic acid, citric acid, clove oil and maize gluten meal all have great potential as non-synthetic herbicides for controlling weeds and are used in natural-herbicide products available on the market.

Other classes of natural herbicides are Cinmethylin, a natural herbicide produced by species of sage, which kills several annual grasses and suppresses some broad-leaved weed species; and the aqueous leachate of fresh leaves of *Eucalyptus globules* which significantly suppresses the establishment of vegetative propagules and early seedling growth of the weeds (Abouziena & Hagaag 2016).

Nevertheless, there is an urgent need for more research funding to accelerate the development and implementation of effective organic-compliant herbicides that are environmentally safe and that help the producer meet increasing consumer demand for organic products.

7.6 Case Study – perennial weed *Elytrigia repen*s (couch grass)

In cold northern European climates, the perennial weed *E. repens* poses a significant problem to farmers. How to control this perennial (especially) in organic farming, without making use of herbicides, while maintaining good soil conditions and trying to prevent it from re-surfacing? Ideally, by eradicating the perennials mechanically over the post-harvest period; however, this is incompatible with the use of cover crops to improve soil quality and prevent soil leaching over the same post-harvest period.

In the study by Melander et al. (2013), a new concept is presented comprising in "*the uprooting and immediate removal of vegetative propagules of E. repens located within the plough layer to allow for quick re-establishment of a plant cover*" concerning the issue of dealing with the perennial weed *E. repens* in the context of cold and wetter northern European climates (Melander, Nørremark, and Kristensen 2013).

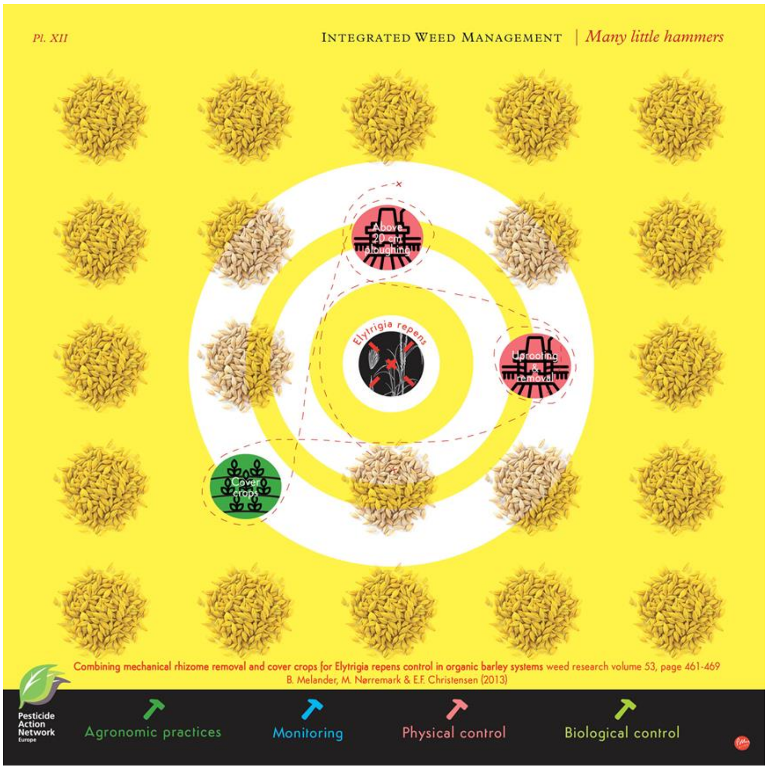


Figure 20 Integrated Weed Managment Approach for the weed *Elytrigia repens* (cough grass) in barley

The study provides a good example of a field experiment where weed growth in a barley crop was substantially reduced (by integrated weed management approach) through the use of conventional practices such as stubble cultivation, combined with varying rotary cultivation (one, two or four passes) and cover crops (none versus a rye-vetch-mustard mixture). The removal of *E. repens* rhizome, shoot growth and suppression was examined in two growing seasons.

"*Four passes with a modified rotary cultivator, where each pass was followed by rhizome removal, reduced* E. repens *shoot growth in barley by 84% and 97%. In general, the cover crop developed poorly and did not affect the barley or* E. repens*. Barley yield was only affected by treatments in the first season, where yield was negatively correlated with* E. repens *shoot biomass*".

While the authors commend the concept for having potential for the control of severe *E. repens* infestations, it must also be acknowledged that future research aiming at identifying more effective smother crops and less intensive methods of rhizome removal is still very much needed.

8 Economics of discontinuing glyphosate use

The pesticides industry and most farming organizations across the EU claim that a move away from glyphosate use will be catastrophic for the EU farming sector because there are no alternatives. The previous chapters describe that alternative practices to glyphosate use exist and provide a list of such methods. In this section we wish to look into the potential economic costs of an agricultural model without the use of glyphosate (mainly replaced with non-chemical means).

Apart from the supposed evidence brought on the table by the pesticide industry - the quality and impartiality of which are often open to question[18]- two recent scientific papers provide another insight on the costs of abandoning glyphosate:

- The first study carried out by the Julius Kühn Institute (Germany) on the 'Economic assessment of alternatives for glyphosate application in arable farming'[19] studied the technique of crop rotation in arable farming for winter wheat, winter oilseed rape, winter barley, maize and summer barley and different tillage systems (plough, no-plough). The report concluded that '*The economic advantages and disadvantages of substituting glyphosate by mechanical alternatives were strongly dependent on the treatment-area, the efficacy concerning yield expectations (in comparison to glyphosate use), the tillage system, the necessity of grain drying as well as further operational factors such as the availability of sufficient field work days and mechanical equipment'* (Kehlenbeck et al., 2016).
- The second study (Böcker et al., 2017) on 'Modelling the effect of a glyphosate ban on weed management in maize production'[20] develops a bio-economic model looking into replacing glyphosate for pre-sowing application with mechanical means, while replacing post-sowing uses of glyphosates with other herbicides. The report concludes: *'<u>We find that a glyphosate ban has only small income effects</u>. Our results show that selective herbicides are not used at higher levels, but glyphosate is substituted by mechanical practices leading to higher labour demand. Slight yield reduction due to less intensive pre- sowing strategies turns out as more profitable than maintaining current yield levels'.*

While none of the studies describe any catastrophic impact on EU agriculture, both studies argue that the shift to agronomic and physical means will increase the workload in the fields. The study from Julius Kühn institute is interesting as it estimates that the economic extra costs per hectare to German farmers for no longer

[18] PAN Europe is aware of the report of European Crop Protection Industry's report 'pesticides: with or without' as well as report from Oxford economics but as findings in these reports are based on two polemic reports made some years ago: the Anderson and the Humboldt report, and PAN Europe already showed the Humboldt report was made on incorrect assumptions: http://www.pan-europe.info/sites/pan-europe.info/files/public/resources/briefings/pan-europe-opinion-on-humboldt-report-2013.pdf

[19] https://ojs.openagrar.de/index.php/JKA/article/view/6179

[20] http://ageconsearch.umn.edu/record/261982/files/Boecker_109.pdf

applying glyphosate (and other herbicides) are:

- One mechanical weed treatment costs: 45.70 €/ha; and one tillage measure: 24.11 €/ha,
- Stubble and pre-sowing treatments: 0 to 37 €/ha, while
- Cost-intensive drying of the harvest to replace the practice of desiccation (in combination with a substituted stubble and/or pre-sowing treatment) on average will lead to additional costs of about 50 to 100 €/ha.

Dr Lorenzo Furlan (*Veneto Agricoltura*, Italy) recalls that the vast majority of herbicides can be replaced by mechanical means today, and that machinery has been developed even to allow for conservation agriculture[21]. This is not scientific "wishful thinking", it happens in reality: the fast-growing share of organic farming tells us that it is not impossible to live without glyphosate, as some argue, but will it always be too expensive? Also, according to Jesper Lund Larsen, health and environment officer at the Danish worker union *3F*, there are very good alternative methods and techniques making the difference of worker costs in the two systems (with or without herbicide use) relatively small[22].

In the economic calculation that the farmers have to do, it must not be forgotten that there are legal requirements, for farmers hiring workers using pesticides (access to showers, use of protection equipment); these costs should not be forgotten.

However, in the economic calculation that society has to do, one should not forget, although often excluded from any economic calculations, the health impacts of heavy use of pesticides on workers, bystanders and the pollution of water resources as well as damages to the environment.

Further, it is often said that a glyphosate- (or herbicide-) free agriculture will always mean investing in expensive machinery. However, while some farmers may choose to buy expensive, sophisticated machinery (particularly if it incorporates ICT features), other cheaper solutions are also feasible:

- The increasing interest in low-impact farming, especially of the organic kind, has resulted in many types of specific weeding equipment being available on the market. For instance, many orchard and grape producers are using small and very precise machines, often produced locally, while others have brought new tools but not necessarily new tractors.
- Many farmers operate machinery pools, which is a good way of spreading costs out, while others use contractors for specific tasks where the machinery would otherwise not be used that often. Flexible management is the key, and these farmers would not need to bear all the costs of buying new

[21] http://www.lifeagricare.eu/images/tecniche-innovative-AGRIcoltura.pdf
[22] A personal communication to PAN Europe in 2017.

machinery. Arguably, if the aim of policy is to accompany the transition towards a low input, sustainable agricultural model. One solution could be to give the role to public funding to bear the costs of that transition rather than leaving all the financial weight to the individual farmers as they are often under considerable financial pressure. The CAP already has provisions for the second pillar, but the Member States of the EU must first choose those options, co-finance them and then promote them to farmers.

- Some orchard farmers have introduced farm animals – mainly sheep – as a natural means of controlling weeds. This can be done by developing a new activity by the farmer or having a contract with another farmer raising sheep. Again, without the need to buy new machinery.

Over time, the transition towards lower-impact systems and less reliance on glyphosate could also become a multiplier for the local economy, engaging local enterprises, ensuring locally adjusted solutions at hand as leading to increasing value of local knowledge, and making farmers develop more mechanical skills. Concerning the approach to farming, it will be crucial for farmers not only in replacing glyphosate by using mechanical means or other less harmful herbicides as a last resort, but also to re-discover organic farming cycles and techniques, working with nature again, following the guidelines of the “many little hammers” approach (illustrated in Figure 6, Chapter 7) and in this way applying all aspects of the IWM as mentioned in Chapter 7, which over time will increase farmers' resilience while allowing for a decrease in expenditures for expensive inputs[23].

8.1 The Common Agricultural Policy on pesticide use reductions

Farm Advisory Services

As part of the latest CAP reform, Member States engaged in making sure that the Farm Advisory Services (FAS) have to be able to advise on Integrated Pest Management as from 2015, as called for in Article 55 of Regulation (EC) No 1107/2009 on plant protection products and Article 14 of Directive 2009/128/EC on the sustainable use of pesticides.

On the homepage of the department of the European Commission’s agriculture and rural development department, DG AGRI[24] it is stated that a FAS advisor should act as *a 'general practitioner', interlinking all different aspects of farming. He or She should explain to farmers not only the EU requirements but also their*

[23] http://www.pan-europe.info/sites/pan-europe.info/files/public/resources/briefings/innovation-and-resource-efficiency-1.pdf
[24] https://ec.europa.eu/agriculture/direct-support/cross-compliance/farm-advisory-system_en

objectives, and the underlying policies'. However, while the potential of the FAS is huge in the development of independent advice, the actual implementation remains very limited. Only a few Member States, like the United Kingdom[25], have made the FAS visible, by establishing an easy-to-find homepage. However, even the Member States who are providing some kind of advisory service, they are only focusing on how to apply pesticides 'better', rather than actually promoting agronomic and physical alternative solutions to the use of pesticides/herbicides.

In May 1958, during a meeting of weed scientists in Ghent, an international working group was set up to accelerate progress in solving problems caused by weeds, which created in turn the European Weed Research Society 1960. The Society promotes and co-ordinates scientific research into all aspects of weed science, including the establishment of the international Journal 'Weed Research' in 1961 endorsing issues of Weed Biology, Ecology and Vegetation Management[26,27].

Other scientific organisations[28] and stakeholders from the organic farming sector have also presented a list of alternatives to the use of herbicides in agriculture[29,30].

The European Innovative Partnership (EIP-AGRI) is financing work on alternatives to herbicides:

- Several focus groups studying topics of relevance such as 'Organic farming - Optimising arable yields'[31], 'Diseases and pests in viticulture'[32], 'IPM practices for soil-borne diseases suppression in vegetables and arable crops'[33].
- An Austrian project on 'Organic Dock Control', testing whether docks can be controlled with the help of native clearwing moths, instead of using herbicides[34]. Field tests have been done, and the results are now being spread through practical field tests in interested farms and through field workshops in Austria. Presentations are carried out in national and European workshops[35], and are available online[36].
- A French project studying 'Zero herbicides in Mediterranean perennial crops' (vineyards and orchards,

[25] https://www.gov.uk/government/groups/farming-advice-service
[26] http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1365-3180/issues
[27] European Weed Research Society http://www.ewrs.org
[28] Orgprint: http://orgprints.org/view/subjects/9weed.html
[29] IFOAM: http://farmknowledge.org/index.php/discussion-forum/weed-management
[30] Greenpeace: https://farmers2farmers.org
[31] https://ec.europa.eu/eip/agriculture/en/focus-groups/organic-farming-optimising-arable-yields
[32] https://ec.europa.eu/eip/agriculture/en/focus-groups/diseases-and-pests-viticulture
[33] https://ec.europa.eu/eip/agriculture/en/focus-groups/ipm-practices-soil-borne-diseases-suppression
[34] https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/field_event_attachments/20160420-21_ws-legnaro-2016_ogs_represented_final_25042016.pdf
[35] https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/field_event_attachments/20160420-21_pres02_organic_dock_control_patrick_hann.pdf
[36] http://www.melesbio.at/ampferglasfluegler/

a new context for weed management)[37] for a four years period is ending in 2018.

- An English project with the Farmer-Scientist Network of the Yorkshire Agricultural Society is carrying out a spring wheat trial over a two-year period intended to provide a response to the withdrawal of synthetic pesticides, looking at the extent to which various natural bio-controls used in the horticultural industry could be adapted for use within arable crops.

Finally, on a smaller level:

- For the past 6 years, PAN Europe has organised, together with the International Organisation for Biocontrol Control (IOBC), International Biocontrol Manufacturer Association (IBMA) and in some years also with Greenpeace Europe, an annual meeting, often hosted by the Greens/EFA, inviting researchers, farmers and companies to exchange information on experience in the uptake of alternatives to pesticides
- In the last years, testimonies have been collected from farmers explaining about their uptake of alternatives in vineyards and cereal crops[38].
- PAN Europe has, since a year ago, been organising annual farm visits to a French perennial farmer (grapes and apples) who has been applying integrated pest and weed management for some years and recently converted to organic farming. We have also organised a visit in Italy to a research station to show the uptake of alternatives in maize-growing.

While the FAS at EU level has failed to propose independent advice across the EU, one could hope that it will be able in the future to build on the interesting initiatives that have developed in its absence.

Examples of Rural Development Programs target biological and mechanical alternatives

The EU's Common Agricultural Policy allows – beyond general measures to encourage crop rotation – specific measures within the rural development program which can help farmers meet some of these costs. For instance, Member States like Belgium (Flanders), France and Luxembourg are already offering farmers financial compensation[39], within the current programming period 2014-2020, among other measures, for the uptake of mechanical weeding:

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[37] https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/field_event_attachments/20160420-21_pres06_zero_herbicides_in_mediterranean_perennial_crops_xavier_delpuech.pdf
[38] http://www.low-impact-farming.info
[39] The number of Member States adopting similar measures might have already increased

The Flemish rural development plan

The Flemish rural development plan[40] states: '*In Flemish agriculture and horticulture, most crops are kept free from weeds with the help of pesticides. However, it is possible to keep certain crops weed-free via mechanical weed control. The elimination of pesticides has an immediate positive effect on the quality of the soil, on the ground and surface water and on the biodiversity of the plot and of its surroundings. Mechanical weed control is eligible for support if it is applied on a plot of at least 0,5 hectares*'.

The plan offers farmers, as part of their agri-environmental scheme for the 2018 campaign, 260 euro/ha for the uptake of mechanical weeding to replace herbicide use[41].

The French Rural Development Programme

The French rural development programme is, among others, offering financial compensation for growers of cereal (around 87 euros/ha), protein crops (around 85 euros/ha), orchards (90 euros/ha) and grape growing (96 euros/ha) for training on and implementing herbicide use reductions[42].

An evaluation from 2015[43] indicates that the impact of this measure remains less efficient than expected, and that the level of reduction is not able to ensure the expected water quality.

The Rural Development Programme of Luxembourg

The Luxembourg government is offering co-financing machinery investment with 20%, while also offering specific agri-environmental support per hectare payments for among others wine, maize and potatoes[44].

To recapitulate, although the Julius Kühn Institute study on German cereals is not comparable to the financial costs and support for other crops in other countries, the CAP foresees support for agro-environmental measures to cover the additional costs for the transition period to adopt alternative approaches as well as investment support for the required mechanical tools. Therefore, the question as to why Member States haven't activated these measures to help farmers implement the transition away from dependence on glyphosate remains to be answered.

[40] http://lv.vlaanderen.be/sites/default/files/attachments/gr_201501_brochure_en_rdp_vrn_21x21_digi.pdf
[41] http://lv.vlaanderen.be/sites/default/files/attachments/fiche_subsidie_mechanische_onkruidbestrijding_versie_02102017.pdf
[42] http://aisne.gouv.fr/content/download/11052/67154/file/DDT02-201407-01-D-T-EU_PHYTO_04.pdf
[43] https://www.st-andrews.ac.uk/media/dept-of-geography-and-sustainable-development/pdf-s/DP%202015%2005%20Kuhfuss%20&%20Subervie.pdf
[44] http://www.ma.public.lu/actualites/communiques/2015/07/031/PDR14-20.pdf

Final remarks

As this report shows, by combining and integrating the different available farming methods (e.g. preventive, agronomic and mechanical methods) with the broad knowledge we have acquired on the biological and ecological characteristics of herbs and plant crops, today certain farmers are capable of overcoming major agricultural challenges and manage weed growth successfully, maintaining a high agricultural yield, avoiding resistant species, protecting soil biodiversity and erosion, and reducing green-house emissions among others.

There is no doubt that adopting an agricultural system that does not rely to the use of pesticide will be challenging but the long-term benefits will compensate all the initial struggles. Further research is still necessary on how to integrate the different levels of knowledge we have (using the many little hammers approach of Integrated Weed Management), and develop machinery and devices better geared at tackling specific weed control methods. Collecting success stories and research already available and distributing the knowledge on a wider audience, is a first step.

Many farmers already apply these systems, while the CAP already foresees support for agro-environmental measures to cover the additional costs of alternative approaches and investment support for the required mechanical tools. Decision-makers both at EU and Member State level must provide the initiative to help farmers who are willing to do this transition due to health and environmental concerns they may have or due to their willingness to work with nature rather than against it. A multilevel approach is required, where farmers, distributors, policy-makers, citizens and consumers are all informed on the negative impact of the use of herbicides and the available alternatives, and by adopting a long-term vision to work together to phase out the use of these harmful chemicals in agriculture.

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ANNEX 1

Summary on the toxicity of Glyphosate (PAN Europe)

Cancer/Carcinogenicity

IARC: The International Agency for Research on Cancer (IARC) of the World Health Organisation (WHO), classified glyphosate as a "probable human carcinogen", following a thorough analysis performed by 17 independent and world's leading experts from 11 countries using only publicly available studies[1]. This conclusion was reached based on "limited evidence of carcinogenicity in humans" and "sufficient evidence" in experimental animals. For humans, IARC took into account evidence from human cancer studies from 3 different countries where 2592 people (workers), in total, had developed Non-Hodgkin lymphoma (NHL; a rare case of cancer) following exposure to glyphosate-based herbicides and from a combined analysis (meta-analysis) of all NHL studies available. The conclusion on experimental animals was based on two experiments where mice had developed malignant tumours as a result of exposure to glyphosate alone, one revealing a rare case of cancer (kidney), which is extremely important in assessing human risk. Furthermore, the experts took into consideration the strong evidence of genotoxicity (DNA damage) and oxidative stress (tissue/cell damage) in humans and laboratory animals following exposure to glyphosate-pesticides and its metabolites.

EFSA peer review and Revised Assessment Report (RAR)[2] – BfR (German Health Authority) acting as a Rapporteur Member State for the European Commission: In fact, BfR having access to undisclosed industry studies found not two but five experimental studies were mice fed with glyphosate had developed malignant tumours. But it decided to dismiss the findings as non-significant. Ironically, it then dismissed the mechanistic data on genotoxicity and cell toxicity as non-relevant, because apparently, there were no evidence of carcinogenicity in experimental animals. Furthermore, all results on genotoxicity, cell toxicity or any toxicity in fact due to exposure to glyphosate products were all considered non-relevant because according to the EU rules risk assessment is done only on the active ingredient, despite the fact that people are exposed to the whole products. EFSA in its peer review approved the work of BfR. The analysis of the carcinogenicity potential of glyphosate by the European Authorities has received criticism by the scientific community[3,4,5,6].

Endocrine disruption: Glyphosate alone and glyphosate-based products alter the hormone metabolism in different mammalian cell lines[7,8]and have been reported to reduce the conversion of androgens to oestrogens (resulting in

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[2] Before the authorisation of an active substance, the applicant (pesticide industry) submits a dossier with all data requirements (chemical properties, toxicity, environmental fate etc.) to a Member State which acts as a Rapporteur (RMS) for the European Commission. RMS then evaluates the dossier and produces first the Draft Assessment Report (DAR) or the Revised Assessment Report (RAR) in case of re-authorisation.

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production of more male than female hormones), with formulations causing a stronger effect[9,10]. In experimental studies with mice, glyphosate-based products also alter the reproductive hormone metabolism and reduce fertility[11,12,13]. Despite the fact that endocrine disruption can cause serious health effects, very few studies have examined the capacity of glyphosate to alter the hormonal system[4]. Actually, EFSA has requested industry to evaluate the endocrine disruption potential of glyphosate and will publish its opinion in August 2017.

Toxicity of glyphosate on reproduction and development: In the RAR[A], there are already several incidences of developmental effects of glyphosate in mammals and in many cases below the recommended regulatory limits[14]. Experimental animals exposed to glyphosate have given birth to foetuses with increased heart malformations and abnormalities, absent kidneys, distorted ribs, lungs and skeleton, as well as embryonic deaths. These data were dismissed for unclear reasons that cannot be verified since the studies are not published. However, independent published scientific studies show that pups exposed to glyphosate-based products developed abnormal reproductive organs and had altered hormone levels and mating behaviour[15,16]. In a Danish farm, 38 live-borne one-day-old piglets had extraordinarily high percentages of abnormalities including serious cranial and skeletal malformations. By switching to non-GM and glyphosate-free feed the farmer instantly observed positive changes in the health of the sow herd[17].

Nervous system toxicity: Glyphosate and Glyphosate-based products affect the growth and development of nerve cells[18]. Glyphosate has been reported to disrupt the function of brain nerve signalling, brain cell organelles (mitochondria) and cause neuronal cell death all hallmarks of Parkinson disease[19,20,21]. Exposure to glyphosate products has been associated to ADD/ADHD, Parkinson disease and autism[22,23,24].

Plant Toxicity and effects on biodiversity: Glyphosate being a wide-spectrum herbicide, kills all plants and even large trees. No other herbicide is so non-selective. Significant reductions in plant biomass, flower and wild plants have been

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observed in green areas close to fields treated with glyphosate products[25]. This reduction in plant species causes in turn a reduction in terrestrial species that feed on them, including natural insect predators, amphibians, pollinators and birds, resulting in significant ecological impact and biodiversity loss[26,27,28].

Ecotoxicity: The ecotoxicity of glyphosate to aquatic and terrestrial organisms is already recognised in RAR and EFSA peer-review, reporting glyphosate toxicity with long-lasting effects. By using prediction models to estimate the environmental exposure and considering that mitigation measures are applied by the farmers, the European Authorities conclude that the risk for non-target organisms is low. But, studies have confirmed that these models often underestimate real environmental exposures, indicating that non-target organisms are at a much higher risk[29]. Nevertheless, glyphosate causes a wide range of adverse effects in non-target organisms.

Aquatic ecotoxicity: Glyphosate and glyphosate-based herbicides are toxic to microorganisms, and alter plankton and algae communities[30]. Adverse effects following exposure have been reported in insects[31], crustaceans[32], molluscs, amphibians[33] and fish[34] and effects include reproductive and developmental abnormalities, DNA damage, immune effects, oxidative stress, decreased capacity to cope with stress, altered feeding and mating behaviour that can threaten their survival. Glyphosate products are usually more toxic to fish than glyphosate alone[35].

Terrestrial ecotoxicity: Glyphosate has adverse effects on some earthworms and arthropods; and a number of beneficial insects useful in biological control, particularly predatory mites, carabid beetles and ladybugs[23,36]. It can also adversely affect other insects that play an important part in ecological balance such as wood louse and field spiders[24]. Glyphosate use may result in significant population losses of a number of terrestrial species, including birds through habitat and food supply destruction[33].

Anti-bacterial properties and toxicity implications: The anti-microbial activity of glyphosate is known since it was first licensed in 1970s[37]. It is also toxic to certain soil bacteria of the *Bacillus* and *Pseudomonas* families that have a key role in suppressing specific pathogenic fungi, as well as in making the soil minerals available to plants. Thus, glyphosate alters the microbial community of the soils, which has a direct impact on the health of the crops. Glyphosate also seems to bind to the soil minerals (Manganese, Iron, Copper and Zinc) and blocks their bioavailability to the plants. In fact, glyphosate

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has been characterised to "significantly increase the severity of various plants diseases, impair plant defence to pathogens and diseases, and immobilize soil and plant nutrients rendering them unavailable for plant use". Due to these effects and weed resistance farmers are obliged to use fungicides and additional herbicides on their crops[38].

Due to its antibacterial properties glyphosate has been reported to affect the gut microbiota of animals, killing the beneficial bacteria and leaving the pathogenic ones behind[39]. This has been linked to adverse effects in farm animals, which feed on glyphosate-treated soya and corn feed. Some studies suggest that this particular glyphosate action which affects the gut bacteria may have serious implications to humans [40].

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