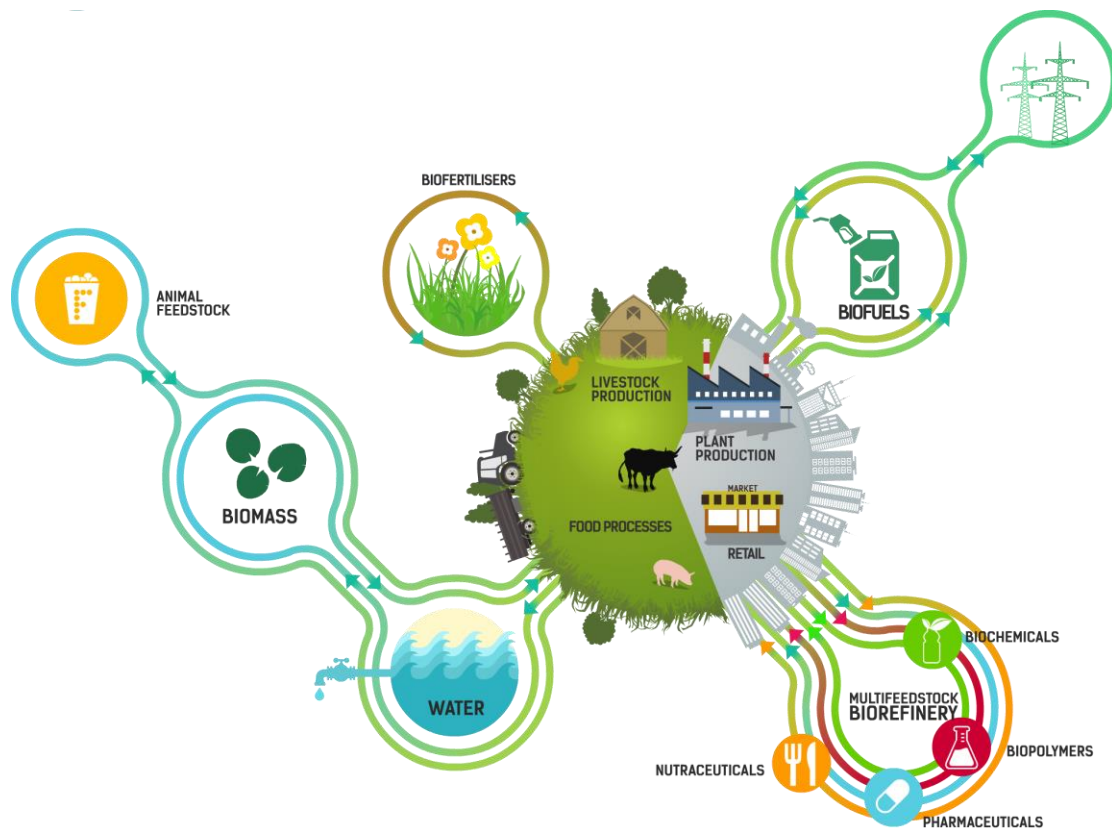


Practical guidelines for the use of agricultural wastes, co-products and by-products (D3.4)



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1. Introduction: why use AWCB

Europe is generating 1.3 billion tonnes of waste on an annual basis, of which 700 million tonnes are agricultural wastes. Agricultural and food wastes and under-utilised by-products and co-products that have enormous financial and environmental impacts, since they may pose a risk to the environment (eutrophication, gaseous losses of N, etc), contain toxic materials and be a risk to human health if poorly handled or controlled.

The Europe 2020 Strategy states measures to create a more resource efficient common agricultural policy (CAP), whilst the rural development programme in the 2014-2020 period and CAP itself focus on the challenges of climate change, food security, economic development of rural areas and sustainable natural resource management. Hence there is a growing recognition that waste management and resource depletion can be solved together, by utilising wastes as a resource, through sustainable valorization technologies.

In this context, AGROCYCLE is developing, demonstrating and validating novel processes, practices and products to achieve a 10% increase in the recycling and valorisation of agricultural wastes by 2020, maximising the AWCB use via the creation of new sustainable value chains. In particular, biofertilisers (BF) extracted from different waste streams have been evaluated for their potential in restoring soil organic Carbon and source of plant nutrients. The agronomic and environmental impacts of selected BFs have also been assessed on different crops.

2. Type of AWCB

Many of the organic materials produced by the agricultural industries can potentially be used as soil amendments, but there is still lack of knowledge on their agricultural value and environmental risks. In AGROCYCLE a large variety of the most important organic waste streams were characterized, in order to maximize their use as a soil amendment and close the nutrient and organic carbon loop. To this aim, the following types of AWCB were considered:

- Anaerobic digestate from cattle manure, activated by co-composting the solid fraction with different raw organic wastes;
- Poultry litter to produce biochar;
- Farm Yard manure;
- Olive waste compost;
- Semi-permeable-membrane-covered aerobic composting for agricultural wastes;
- Vegetable crop residue.

The effect of the different organic fertilizers has been studied in terms of crop performances and chemical soil fertility changing (e.g. soil mineral nitrogen availability, soil organic carbon and total nitrogen content).

3. Guidelines

In the Agrocycle framework, selected AWCBs have been tested through: *i*) processes of obtaining the biofertilizer, *ii*) field experiment, *iii*) relevance of the BF use at farm level in terms of utilization and opportunities.

These guidelines have been collected and structured in order to share the main results of this activity to a wide audience and their content will be made available in a Decision Support System (DSS) realized within the project.

For each AWCB/BF main information about feedstock availability has been reported to contextualize the relevance of their management at local and European/global level. Crucial aspects of AWCB processing are reported as well, whereas practical tips - as far as limitations - derived by the practical experience during the field experiments are discussed, to facilitate the information transfer to a wide stakeholder audience. Compliance with sustainable agriculture is finally reported, to motivate stakeholder in the utilization of the described AWCB/BFs in a context of obtaining cash production in a sustainable way.

The guidelines were structured on the basis of information previously categorized through a SWOT (Strength-Weakness-Opportunities-Threats) in order to address the reader on the weaknesses and strengths of the use of each specific material.

4. The activated anaerobic digestate from cattle manure

4.1. Background and description

Digestates are co-products from biogas plants for methane production and the volume of digestate is around 90-95% of the input raw materials (slurries, vegetable residues, etc). Germany produces the largest quantity of biogas in Europe (5067 kt_{oe} y⁻¹) followed by the UK (1765 kt_{oe} y⁻¹) and Italy (1096 kt_{oe} y⁻¹; Raboni and Urbini, 2014). Digestates from cattle manure can be used as soil amendments and fertilizers in agriculture. After the anaerobic treatment, the produced digestate can be further separated into a solid and a liquid fraction. Due to potential environmental risks, the liquid fraction, can be processed and recycled for biogas production, instead of a direct use in the field as biofertilizer. The solid digestate fraction contains from 60 to 80% of the organic matter and phosphorus, 20-25% of the nitrogen and 10-15% of the potassium compared to the original material (Møller et al., 2008). Besides the environmental factors (i.e., soil moisture and temperature), solid digestate decomposition rate in soil is a function of soil texture and microbial activity. Other properties of solid digestate such as phytotoxicity, viscosity and odour limit its direct application on agricultural soils (Abdullahi et al, 2008), and may pose environmental risks. Hence, digestate application may require pre-treatments to allow sustainable crop production (Hao et al., 2016).

Composting the digestate solid fraction can be a feasible way to improve the quality of this solid fraction, by reducing the odor emission, the concentration of volatile compounds, the moisture content and the potential phytotoxicity (Bustamante et al., 2012). However, direct composting of solid digestate has limitations since low C/N ratio and high pH are needed to increase the fertilizer value and allow its safe use as soil amendment (Torres-Climent et al., 2015). Therefore, further conditioning processes are required.

Activation process based on co-composting procedures is a strategy to foster the microbial activity by providing easily fermentable materials during the process, thus overcoming the above described limits of the solid fraction of digestates. Moreover, the obtained innovative biofertilizer after activation contributes to closing the cycle of wastes and co-products at local scale (i.e. periurban agricultural systems).

4.2. Recipe and method of preparation: the example in Agrocycle from CREA field trial, Italy

An activated anaerobic digestate (AD) can be obtained by co-composting the anaerobic digestate solid fraction with other raw organic wastes. In particular, in the CREA field trial the AD from cattle manure (80% of total dry weight, Fig.1a) was co-composted with (highly fermentable) organic vegetable wastes (10%, Fig. 1b) - such as aubergines, peppers, zucchini residues - and straws (10%) acting as bulking agent. The mixture was manually prepared in the experimental farm and

the composting process was carried out in static aerated piles (1.0 m high x 1.5 m base diameter, Fig. 1c) of about 300 kg each. The piles were set up on a concrete platform to avoid the loss of percolates. During composting, the pile moisture content was weekly checked and maintained between 40 and 70 °C. In order to allow aeration and temperature control, the piles were manually turned with a shovel once per week during the first three weeks of the entire six-week process.

The obtained activated AD was a stable material, with total N content of 2.5% (dry matter), C/N of 10, P content of 1.6 g kg⁻¹ and low heavy metal content (0.56, 8.26, 10.7, 2.71, 2.52 and 90.0 ppm for Cd, total Cr, Cu, Ni, Pb and Zn, respectively) compliant with Italian legislation (*DM 25 febbraio 2016*).



Figure 1. Activation process of anaerobic digestate (AD). a) AD solid fraction; b) vegetable waste collection to activate AD; c) straw and vegetable materials addition to the AD pile; d) final activated AD.

4.3. Utilization and Opportunities

Composting the digestate solid fraction of cattle slurry with vegetable residues and straws represents a feasible treatment to recycle these wastes, producing a biofertilizer that can be used in different agricultural sectors (such as crop production and land recovery), due to its adequate degree of stability and maturity. The use of a bulking agent (straw or pruning residues) can reduce N losses, which usually occur when manures are composted (Bustamante et al., 2012), and enhance microbial activity. Activated AD can be easily obtained with farm facilities and successfully applied as soil conditioner and/or fertilizer. Potential positive effects of activated AD include reclamation of degraded soils, increase in soil fertility, plant disease suppressiveness and carbon sequestration in the soil. Moreover, the use of AD can contribute to close the organic matter cycle from plant production to animal one and back to the field, reducing the use of external inputs (i.e. synthetic fertilizers and fossil fuels) and the associated negative effects.

4.4. Practical tips for on-farm production and storage, handling, distribution and soil application

The activated AD can be easily produced at farm scale depending on the availability of the raw materials in the farm/area. The stable product obtained by the co-composting process can be stored in the farm, if suitable devices for piles coverage and/or platform roof are available in order to avoid possible leaching losses. In such condition, activated AD can be stored for several months, taking into account that some changes of chemical properties (organic matter content, heavy metal concentration, etc) could occur, due to the unavoidable degradation process of the organic material.

The activated AD is a solid material easily movable. Due to the large volumes commonly distributed, some difficulties can occur in its handling. Mechanical shovels and tipper trailers should be used for its handling. Loading shovel and compost (or manure) spreader can be used for distribution. Due to its low C/N ratio, this material could rapidly mineralize nitrogen during its decomposition in the soil, depending on the climatic and pedological conditions: the higher the temperature the higher the mineralization rate, mostly in sandy soil. It is advisable to spread the activated AD in the early spring (warm climate, e.g. South of Italy) at least one week before crop transplanting. After spreading, superficial tillage (about 5-10 cm depth) may reduce fast mineralization of the material when high temperatures occur.

Results from long-term experiments suggest that the highest humification in the soil is achieved with relatively small doses of activated AD (about 10 t ha⁻¹) if repeated over time (every year, for more than 3 years). This implies the need to repeat the spreading at least on a mid-term period, ensuring the possibility to easily collect the material for more than one cropping cycle.

4.5. Limits and difficulties in AWCB/BF utilization and practical solutions

a) A critical point linked to activated AD use is the distance among the sites of the effluent production (livestock farm), the digestate production (biogas plant) and the fruit/vegetable farms, where the final product is applied to soil. This could be overcome by the promotion of mixed of animal/plant farming systems. Where not possible, since the fertilization potential of the activated AD depends on repeated soil application over time, the use of this biofertilizer is suggested for farms operating in the surroundings of biogas production plants.

b) Compared to mineral fertilizers, for which the nitrogen release dynamics are easily predictable, activated AD requires a higher farmer's expertise, to synchronize the mineralization rate with the plant growth. If not managed properly, there will be a risk of leaching of excess N. Therefore, application of AD is best combined with crops with high N demand, particularly in temperate climates. Best management practices that can be utilized to mitigate nutrient leaching, include adjustment of digestate nutrient supply to each crop demand, avoid application during wet periods, and sufficient time between digestate application and crop sowing.

c) Moreover, if the composting process is not well managed, the activated AD can have phytotoxic effects on the crops. To avoid these problems, it is advisable to strictly follow and complete all the phases of the composting process, in order to obtain a well-matured and high-quality product.

4.6. Compliance with sustainable agriculture (soil protection; nitrate leaching reduction risks; water eutrophication; synthetic input reduction)

The use of activated AD for fertilization purposes will reduce the risk of improper waste disposal (illegal land filling) and promote the recycling of organic materials, particularly at local level. Indeed, the major environmental concern with land application of untreated biogas digestates is the potential contamination of surface and ground waters with excess nitrogen and phosphorus, avoidable with the activation process. As a soil amendment, activated AD can contribute to soil carbon storage and to increase soil water retention ability. The activation process should facilitate the soil microbial activity, enhancing soil biodiversity and reducing the risk of plant pathogens. Moreover, as a fertilizer, it can be used in substitution of synthetic input, moving in the direction of reduced pollution strategies.

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5. Biochar from Poultry Litter

5.1. Background and description

Biochar is a charcoal like compound produced through the pyrolysis of organic materials. It differs from charcoal in that it is made from a wider range of feedstocks and is made with the intention of soil application, whereas charcoal is produced by the pyrolysis of wood, and is usually produced for burning for energy. Biochar has been increasingly promoted as a soil amendment in recent years due to its posited potential to simultaneously address multiple issues associated with sustainability including increasing yields, sequestering carbon in soil and providing biofuels (through the pyrolysis process) (e.g. Laird, 2008; Verheijen et al., 2010).

The biochar concept evolved from investigations of Terra preta soils present within the Amazon basin (Sombroek, 1966). These soils, named after the Portuguese for “Dark Earth”, are Anthrosols – human made soils - that were formed through the addition of charcoal like substances, and other waste materials, over a period of many years, potentially millennia (Neves et al., 2001). They have been shown to be significantly more fertile than the surrounding soils. Research has shown that the charcoal component functions to increase the cation exchange capacity of these soils compared to the surrounding soils. This increases the nutrient retention of these soils. Further, as these soils contain significantly more carbon than their surrounding soils, with carbon dating showing that the charcoal fraction has been retained in the soils for hundreds to thousands of years longer than soil organic matter in the surrounding soils (Neves et al., 2001). The concept of biochar developed based on arguments that adding charcoal/biochar to soils may function to increase crop yield while concurrently increasing soil carbon sequestration and mitigating climate change.

While many publications have supported the initial claims, confirming increased crop yields in some situations (Liu et al., 2012), and increased soil C sequestration potential (Woolfe et al., 2010), others have shown the gains to be far from certain in some scenarios and negative impacts have also been reported. These include reduced yield (Mukherjee and Lal, 2014) as well as albedo impacts (Verheijen et al., 2013), and accelerated turnover of soil organic matter (Zimmermann et al., 2011), each of which can reduce biochar’s climate change mitigation potential.

5.2. Recipe and method of preparation: the example in AgroCycle from HAU greenhouse trial

The Harper Adams University (HAU) greenhouse trial used biochar produced from poultry litter. The aim of the greenhouse trial was to investigate a hypothesised mechanism by which biochar achieves its yield impacts – nutrient availability from the biochar. This was done by comparing the yield impacts of biochar against the yield impacts of the poultry litter that the biochar was made from. For this reason, the characteristics of both the biochar and the poultry litter are included in Table 1.

Poultry litter was obtained from Ceredigion poultry farm, Wales, UK. The material was dried for 48 hours at 60°C in draught air oven. The dried material was shredded in domestic garden shredder down to granular material (dia ~ 1-4mm).

A total of 34.3 kg material was produced. Of this 17.1 kg was deployed in shallow, mesh-based trays in the base of pyrolysis plant carboniser vessel.

The material was charred in pyrolysis plant at 300°C for ~15mins then cooled. The carboniser vessel was quenched using CO₂ during cooling to reduce ashing. The material was removed after ~24 hours cooling at which point temperature reduced to ~15°C.

Table 1. Key characteristics of the biochar and feedstock

	% moisture	% carbon	% nitrogen	% phosphorous	% potassium	% ash
Biochar	1.9	36.1	1.9	5.2	2.7	64.8
Poultry Litter	4.5	67.0	5.2	2.3	1.8	33.3



The pyrolysis unit used to produce the biochar (based at The Institute of Biological, Environmental and Rural Sciences at Aberystwyth University, Wales, UK).

5.3. Utilization and Opportunities

Biochar can be utilized as a soil amendment either alone or following post treatment or mixing with other agricultural wastes. When used alone, biochar produced from manures rather than other agricultural wastes such as straws and residues has been shown to be most effective in increasing yields (Jeffery et al., 2017). This suggests that at least some of the nutrients present in the initial feedstock are available for plant uptake from the biochar.

Biochar is also proposed to be used as a carrier for other organic amendments to soil, such as compost (Schmidt et al., 2017). Evidence suggests that mixing biochar

in with compost substantially increases the nutrient concentration of the biochar due to nutrients binding to the surface of biochar particles as well as entering the pore space and leads to interaction effects where by yields can be increased by a greater margin than would be expected by the application of the compost or biochar alone (Joseph et al., 2017).

In addition to the above soil related applications, Schmidt, (2012) listed 55 applications that biochar can be utilized including as an additive in biogas plants, in animal feed, wastewater and contaminated soil treatments and textiles.

In terms of climate change mitigation, biochars produced by high temperature pyrolysis (>~500°C) are generally considered to be more recalcitrant (Crombie et al., 2013). However, the production of the biochar at higher temperatures mean that more C is lost from the initial feedstock compared to low temperature pyrolysis (Demirbas, 2004). The implications of the trade-offs between increased short term C loss and longer term C sequestration on biochar's climate change mitigation potential remains a topic of ongoing research. Carbon sequestration through increased soil C storage is not the only means by which biochar may aid climate change mitigation. A large body of evidence has shown that biochar can substantially reduce N₂O emissions from compost heaps (e.g. Li et al., 2017), and so potentially has a strong role to play in reducing the carbon footprint of agricultural (and municipal) compostable wastes.

5.4. Practical tips for on-farm production and storage, handling, distribution and soil application

Due to its current designation as a waste product, there remains no specific market for biochar for large-scale commercial application in Europe. However, as there are increasing amounts of biochar being produced and lobby groups working to change the legal status of biochar, it is possible that this will change in the future. In particular, if increased soil carbon sequestration becomes imbedded in carbon trading frameworks in the future, as has been posited, that is likely to drive the market demand for biochar forwards.

Biochar is a relatively stable compound. As such it can be stored, likely indefinitely, if kept under cool dark conditions. However, it is a flammable substance and can contain a lot of dust and fine particles, which can present a fire risk and potentially a dust explosion risk under some circumstances, as discussed in Section 5b. Therefore, it is recommended that it is always handled and applied to soil in damp form (i.e. after the addition of water) wherever possible to minimise dust generation, and that suitable protective clothing is worn when handling and applying biochar. Biochar should always be transported and distributed in sealed containers.

Incorporation into soil can be achieved through a number of means. It has commonly been broadcast and ploughed in to incorporate in some field experiments. In others, such as orchards and grassland experiments, it has been applied to the surface in a process referred to as "top dressing". Here it is hoped, that natural processes such as earthworm and other macro/meso faunal activity will incorporate the biochar into the soil over time. However, it is important to consider that biochar is very light, and floats in water, so is likely subject to wind and rain erosion. This would reduce the potential positive impacts of biochar due

to reducing its concentration here applied. And further, it may lead to negative off-site impacts if the biochar is translocated to different environments such as waterways. As such, in such areas that cannot be ploughed to incorporate the biochar, other methods such as disking, or the use of an air hammer, can reduce the loss of biochar to erosion.

5.5. Limits and difficulties of biochar utilisation and practical solutions

a) Biochar is a by-product of the pyrolysis process and so it is currently classed as a waste product of bio-energy production (Van Laer et al., 2015) and as such, its use is currently limited under the EU Waste Framework Directive (2006). This means that it is not permitted for wide scale commercial applications to soils within the EU. However, large amounts of biochar are now being produced, and this looks likely to increase as pyrolysis plants develop (Czajczyńska et al., 2017). Therefore, it is key that we increase our understanding of biochar impacts on soil to ensure that we can drive the formation of policy that best utilises the benefits of biochar while concurrently minimising the risks of any adverse impacts.

b) A critical point linked to biochar use in terms of sustainability is the distance between the production site of the feedstock, the pyrolysis site where the biochar is produced, and the distance to where the final product is applied to soil. This could be minimized by the uptake of small, on farm pyrolysis systems, but the development of such systems is still relatively scarce. Large, municipal scale pyrolysis plants are currently more common and so it is likely that agricultural wastes being used to produce biochar, which is then reapplied on farm, is likely to involve long distance journeys, reducing the sustainability of the pyrolysis platform.

c) Biochar particle size and dustiness results from a combination of pyrolysis temperature and the feedstock used. Biochars with small particle size and a high ash/dust content pose a particular a risk during handling, distribution and soil application as it is very light and so readily becomes airborne, particularly if there is any wind. Biochars are often highly alkali and so associated dust is liable to cause irritation to eyes and airways. Very small particles (PM 2.5) can be particularly dangerous if inhaled, although particles of this size are not expected from all biochars when produced such particles may be present in the soot associated with some biochars. Steps should be taken to minimise dust generation at all stages of biochar production and use.

d) Compared to mineral fertilizers, for which the yield effects are well known, biochar application to soil will require more expertise. It is key that biochar types are matched with the soil/crop/environmental combination in order to maximise positive impacts and to minimise the risk of negative impacts.

e) Due to evidence of negative interactions under certain biochar and environmental combinations a number of sustainability certificates have been proposed aimed at identifying biochars that have minimal risk of negative effects. These have been developed and promoted by actors such as the International Biochar Initiative. However, there remains no firm evidence that certified biochars will not lead to negative environmental impacts, including potentially decreased yields, under all circumstances, nor that biochars that do not achieve some of the required aspects for certification will always cause negative impacts if applied to soil. As such the value of such certification remains uncertain, but it is clear that they may need to be further developed in light of ongoing empirical evidence.

5.6. Compliance with sustainable agriculture (*soil protection; nitrate leaching reduction risks; water eutrophication; synthetic input reduction*)

The use of biochar from agricultural waste for soil amendment purposes will reduce the risk of improper waste disposal (illegal land filling) and promote the recycling of organic materials, particularly at local level. As a soil amendment, biochar from agricultural waste can contribute to soil carbon storage, increase soil water retention ability and boost crop yields when applied to poor soils. Moreover, further to its fertilizer potential, it can be used in substitution for lime due to its generally high liming capacity. As such, its use within an agricultural context has the potential to offset the use of agricultural lime and so potentially moderate the environmental impacts of lime production and distribution. The main environmental concern with land application of biochar from agricultural wastes is the potential contamination of surface and ground waters with either the ash or carbon fractions of biochar. Excess dust from inappropriate application strategies may also be an issue both environmentally and in terms of occupational health of end-users.

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6. Farm Yard Manure

6.1. Background and description

Manures are a waste product of the animal production industries. They can be split into three categories: 1) Liquid manure (slurry) - Housing system collection of all excreta in liquid form, the animals are kept on sloping solid floors that are regularly swept clear of any excreta. Some dilution can be expected from wash water and rain water; 2) Mixed manure - Housing systems producing solid and liquid manure streams, animals are kept on bedding material but liquids are drained from the bedding and collected elsewhere; 3) Solid manure (farm yard manure, FYM) - Housing types producing only solid manure, animals are kept on bedding material which is collected together with all excreta as FYM (Martinez and Burton, 2003).

While the nutrient and dry matter content of manures vary depending on livestock and housing facilities, these characteristics are more variable between manure fractions. The solid fraction of manure, such as FYM, contains a higher percent dry matter - as would be expected. Further to this FYM generally has a much higher proportion of organic nitrogen (N), whereas the liquid fraction generally has a much higher proportion of mineral N, particularly ammonium (NH_4^+) (e.g. Koelsch and Shapiro, 1997). These different characteristics mean that the manure fractions should be handled, stored and applied in different ways, and that their interactions with the soil environment will also differ. These guidelines focus on FYM - the solid fraction of manure. As well as containing manure it also often contains straw and other materials used as bedding for livestock.

FYM is nutrient rich, containing N, phosphorous (P) and potassium (K). It has a larger fraction of organic material compared to other agricultural wastes, such as slurries, representing a valuable source of fertilizer when used as a soil amendment. However, data on quantities of FYM produced and available are highly variable between studies. Estimates of annual FYM production in the UK vary from 33 million tonnes (Cherrier et al., 2014) to 83 million tonnes (Smith and Williams, 2016). This compares to an estimated 295 million tonnes produced within the EU 27 (Cherrier et al., 2014).

Knowledge regarding the use of FYM as a soil amendment to support and enhance crop yields has been well known for millennia. However, in recent times the development of alternative waste streams, such as digestate (anaerobic digestion (AD) by-product), means that in some areas there could be less FYM available for spreading to agricultural land. The demand for FYM as a feedstock is likely to increase due to changes in policy regulations. Meaning that subsidy payments for the generation of energy from AD requires a certain proportion of wastes to be included, as it has been introduced in the UK. Furthermore, Nitrate Vulnerable Zone (NVZ) Regulations in the UK limits the periods (close periods) when FYM can be spread to reduce the risk of water contamination.

6.2. FYM type and Characteristics: The Example in AgroCycle from HAU Field Trial

The HAU field trial used FYM from Knightley Eaves Farm, Ecceshall, Stafford. It was produced by indoors beef cattle (mix of heifers and steers), fed on grass, maize, barley and “Mix30 – high energy liquid feed”. The animals were kept on straw bedding. The manure was stored for less than a week prior to application in the field with a muck spreader. Total nitrogen level was 2.2%; available nitrogen was 0.6%.



FYM distribution in the field by muck spreader.

6.3. Utilization and Opportunities

Farm yard manure can be utilized in a number of ways. Historically, it has been used as a soil amendment where it returns nutrients to the soil as well as providing energy for the belowground system through the input of organic matter and potential improvement to soil structure and water retention. One tonne of fresh FYM can contain 1.2 kg N, 1.9 kg available phosphate, 7.2 kg potash, 2.4 kg sulphur and 1.8 kg magnesium (DEFRA, 2010).

In recent years alternative pathways have developed, such as the use of FYM as a feedstock for AD. FYM contains a high proportion of mineralisable C and so is readily digested through the AD process. However, it represents a material that had energy removed by the livestock that produced it and energy content can be reduced further by lengthy storage periods. The amount of biogas produced from FYM can be an order of magnitude lower than if the plant material used as animal feed were fed directly to the digester. Government financial incentives are being offered to promote the production of biogas through AD. The use of FYM as a feedstock for AD represents a potential new source of income for the livestock

sector at large and an attractive solution for livestock waste management during NVZ close periods. As the nutrients available from the FYM are most or completely carried through the AD process and into the resulting digestate, which can then be used as a soil amendment, the utilization of this pathway does not represent a violation of the circular economy principles – available nutrients can still be effectively recycled. Although, the positive effects of FYM application on soil biology may be reduced if the FYM is passed through an AD system and applied as digestate (WRAP, 2015).

The use of FYM can contribute to close the organic matter cycle, in keeping with circular economy principles, from plant production, through animals and back to the soil, thereby reducing the use of external inputs (i.e. synthetic fertilizers and fossil fuels) and the associated negative environmental impacts. Further, the return of FYM to soil, or through the AD system helps mitigate FYM as a waste issue and so adds value to this potential waste material.

6.4. Practical considerations for on-farm storage, handling, distribution and soil application

Whole FYM can often be readily stored at the farm-scale, it is also often produced at high rates and so large storage areas may be required. There are also several key considerations for the storage of FYM. While the N content of FYM is desirable for crop growth, it can have several undesirable impacts when FYM is stored.

During storage the amount of available N in FYM is reduced, from the region of 1.2 kg of N per Tonne down to 0.6 kg of N per Tonne (DEFRA, 2010). This N loss is caused by at least four different mechanisms; leaching, volatilisation, runoff and denitrification. The importance of each of these mechanisms is site and conditions specific.

Leaching and runoff are two water dependent mechanisms. Leaching can represent a loss pathway of more than 20% of available N when stored in FYM pits (Reddy et al., 2010). However, when stored on an impermeable surface, run off is more of an issue if the FYM is exposed to rainfall events. Both of these potential N loss pathways can be mitigated by using covered storage of FYM, on an impermeable surface. However, this is often not practical or possible and it can sometimes be necessary to construct temporary field heaps. In these instances it is advisable to construct such heaps on land with a low risk of run off – i.e. has an average slope of $<3^\circ$, does not have land drains, and is at least 50 meters from a watercourse, or conduit leading to a water course. If in a NVZ, there are strict guidelines that must be adhered to in order to prevent potential impacts on groundwater, through either leaching or run off. These are derived from the Nitrates Directive within the EU28 (Directive 91/676/EEC, 1991), which within the UK has been interpreted to produce the Guidance: Storing organic manures in NVZ (UK Gov, 2017).

Ammonia volatilisation is the loss of N as ammonia (NH_3). The amount of NH_3 which is lost through volatilization depends on a variety of factors; the ratio of $\text{NH}_3/\text{NH}_4^+$ (ammonium) in the manure, temperature, and the manure storage conditions. To reduce NH_3 loss, FYM should be covered while stored to reduce exposure to the air. Impermeable storage covers have been shown to reduce losses by up to 75% (Lupis et al., 2012). It should also be disturbed as little as possible, including during loading to the manure spreader. Finally, the addition of

other materials such as peat moss and biochar to manures can also reduce ammonia volatilisation (Janczak, et al., 2017; Dougherty et al., 2017)

To reduce NH_3 emissions from manure application it is key to incorporate that manure into soil as quickly as possible. Incorporation into the top 5 – 10 cm of surface-applied manure can reduce ammonia loss by 85-90% if undertaken within 1 hour of spreading due to reducing exposure of the FYM to the air (Lupis et al. 2012). While this may be difficult to achieve with some systems, such as when using no-till management, discing of the FYM into the soil surface can still help to moderate NH_3 emissions.

Denitrification is the conversion of nitrate to molecular nitrogen and as such represents a loss pathway of N from a plant available to plant unavailable form. This issue can be further exacerbated by nitrous oxide (N_2O) emissions, discussed further below (Section 5.a)

Spreading of FYM should only be undertaken with appropriate machinery that is in good working order. The precision of spreading and compliance with the planned application rates, as well as the uniformity of spreading, should be monitored at all times. Spread manures should be incorporated into the soil as soon as possible after spreading. The maximum allowable rate of FYM application to soil may be controlled in some areas, such as NVZ, and the appropriate legislation for the local environment should always be checked and followed before FYM applications are undertaken.

6.5. Limits and difficulties in FYM utilization and practical solutions

a) Manure storage and application can result in the emission of both methane (CH_4) and N_2O . These are powerful greenhouse gases with climate change impacts of approximately 30 and 300 times that of carbon dioxide (CO_2). As such, mitigation of these emissions can reduce the carbon footprint associated with livestock production.

- i. CH_4 is produced by microbes within the manure through an anaerobic process (i.e. requires the absence of oxygen). For this reason the separation of manure into solid and liquid fractions, with the solid fraction being composted (an aerobic process) can lead to CH_4 emissions being reduced by more than 40% (Amon et al., 2006; Loyon et al., 2016). The feeding of manures into AD systems also means that any CH_4 that is produced can be captured for energy production. The addition of biochar has been shown to reduce CH_4 emissions from stored FYM by up to 25% (Chen et al., 2017)
- ii. N_2O can be produced through nitrification and denitrification processes, as intermediate products or by-products. Addition of materials such as peat moss and biochar have been shown to have potential to greatly reduce N_2O emissions from stored manure by up to 80% (Wang et al., 2013).

b) FYM can be a possible source of pathogens (Hutchison et al., 2005). *E. coli* from manures can commonly survive on grass for 6 months (Avery et al., 2004).

As such the Food Standards Agency advise a 12-month interval between crop harvest and last direct manure application where growing fresh produce. The composting of manures has been shown to generate sufficient heat to inactivate enteric and other pathogens (Stanfield and Gale, 2003; Hutchison et al., 2005).

c) Compared to mineral fertilizers the rate of plant available N production through soil-based N dynamics are less predictable. Most of the N in FYM is in organic form, and therefore not plant available. The mineralisation of this organic N represents a slow release mechanism for N meaning that the plant available forms are generated over a much-extended period compared to synthetic N fertilizers. Nevertheless, FYM does contain mineral forms of N that can be readily leached and so application should still be avoided when soils are too wet, or when there is likely to be times of reduced plant N uptake.

6.6. Compliance with sustainable agriculture (*soil protection; building soil organic matter; synthetic input reduction*)

The use of FYM for fertilization purposes promotes the recycling of organic materials, particularly at local level, in line with the paradigm of the circular economy. The major environmental concerns with land application of FYM is the potential contamination of surface and ground waters with excess nitrogen and the emission of greenhouse gases during its storage and application. As a soil amendment, FYM can contribute to soil carbon storage and to increase soil water retention ability. If FYM is composted it reduces the risk of pathogen inoculation to the environment. Furthermore, due to its nitrogen and other nutrient content it can be used in substitution of synthetic input, thereby functioning to mitigate the environmental impacts associated with the production, distribution and use of synthetic fertilizers.

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7. Olive waste compost

7.1. Background and description

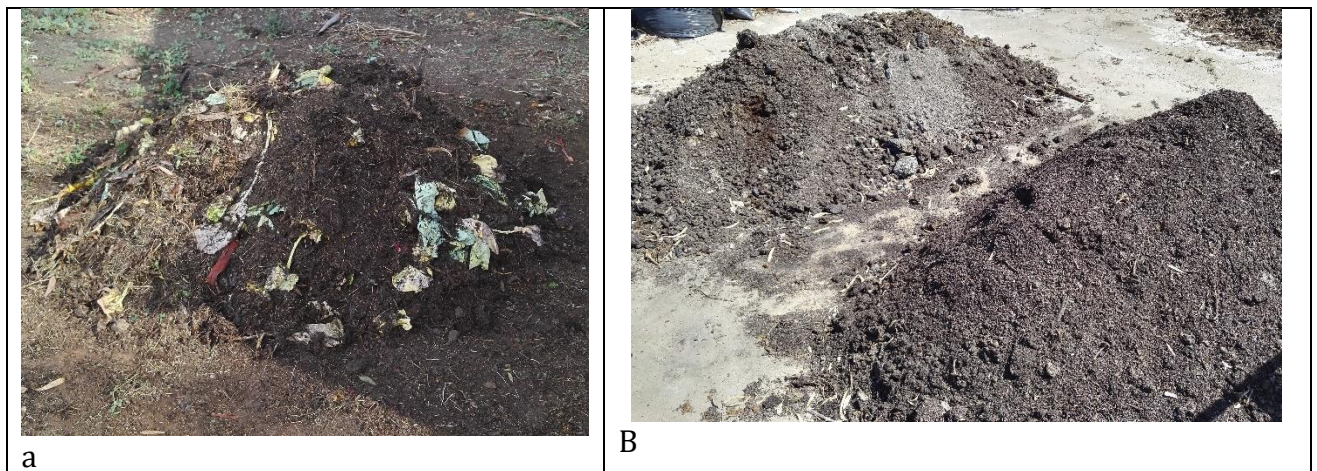
Olive oil farming is a significant aspect of land use in Mediterranean areas. Three quarters of the annual production in the world comes from European Union countries around the Mediterranean Sea. Mediterranean countries of the European community, led by Spain, produce 10 million tons per year, which is 75% of the world olive harvest. In these areas the olive mill wastes could represent an important environmental concern since they are generated in huge amounts in a short period of time (October-November) (Gómez-Muñoz et al., 2012). Their high content of phenols, lipids and organic acids can turn into phytotoxic activity and potentially impact land and water resources. At the same time, olive wastes contain valuable resources such as a large proportion of organic matter and a wide range of nutrients that could be recycled so that they can be used, after processing, in agriculture as soil amendments or fertilizers (Roig et al., 2006).

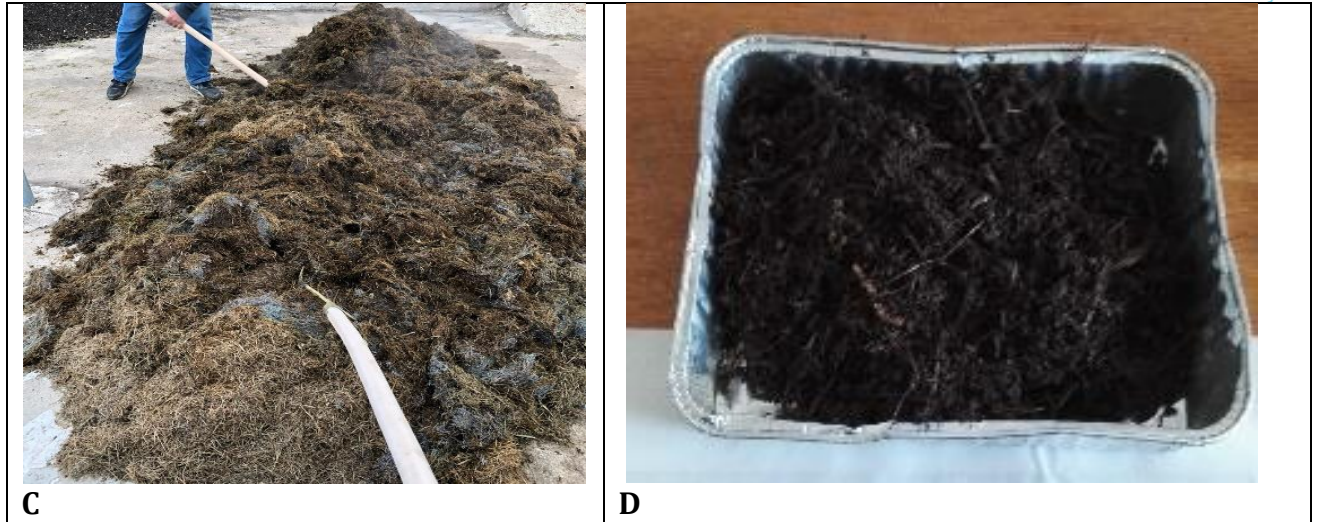
After the extraction of olive oil, by pressing, the solid fraction, called olive husk, which maintains a high level of humidity, is obtained as by-product along with an emulsion containing the olive oil and the remaining olive mill wastewater, separated by decantation. The olive mill wastewater constitutes the main pollutant fraction, representing a great environmental hazard when it is not properly managed. However, this fraction also contains valuable resources such as a high organic matter concentration (around 50 g/L) and nutrients, especially potassium, that could be converted as a potential fertiliser through several biotechnological transformation processes, such as microbiological treatments, composting and anaerobic digestion, mainly aimed at reducing the phytotoxicity (Roig et al., 2006). The wet olive husk can be valorised by drying it and performing a second extraction of oil with solvents. However, since it shows a high organic matter concentration (more than 90%) and nutrient richness, especially in potassium, it could be used in agriculture. The direct application to soil is not allowed under most of the national regulations of the producer countries. Composting is one of the main technologies for recycling the wet olive husk, transforming it into a fertiliser. Due to its semisolid consistence, it needs to be mixed with bulking agents before composting such as straws or pruning wastes. The final product shows a good degree of humification, a considerable amount of mineral nutrients and no phytotoxic effect, allowing sustainable crop production. The activation process based on co-composting procedures can be a strategy to foster the microbial activity by providing easily fermentable materials during the process. Moreover, the obtained innovative biofertilizer can contribute to close the cycle of wastes and co-products at local scale.

7.2. Recipe and method of preparation: the example in Agrocycle from CREA field trial

In the CREA field trial the olive compost (OC) was obtained by re-composting together two materials separately prepared. The first component (80% of the final product) was a powdery compost obtained by wet olive husk (80% of total dry weight) and olive pruning (20%) supplied by the Research Centre of Composting – CESCO – in Campania region (south of Italy). The Centre, in the framework of TIRSAV PLUS Life project, have designed and realized an innovative composting process which recycles both the solid fraction and olive mill wastewater by co-composting, producing a valuable product which can represent an important agronomic resource. The second material (around 20% of the final product) was obtained on farm from vegetable wastes - such as aubergines, peppers, zucchini residues - grass clippings and straws acting as bulking agent. The mixture was manually prepared in the experimental farm and the composting process was carried out in static aerated piles (1.0 m high x 1.5 m base diameter) of about 300 kg each. The piles were set up on a concrete platform to avoid the loss of percolates. During composting, the pile moisture content was weekly checked and maintained between 40 and 60%. In order to allow aeration and temperature control, the piles were manually turned with a shovel once per week during the first three weeks of the entire six-week process.

The obtained activated OC was a stable material, with total N content of 2.4% (dry matter), C/N of 18 (respect to 21 of the starting product), P content of 9.5 g kg⁻¹ and low heavy metal content (0.03, 0.1, 0.95, 0.06, 0.12 and 3.1 mg kg⁻¹ for Cd, Cr, Cu, Ni, Pb and Zn, respectively) and compliant with the Italian legislation (*DL n°75 – 29.04.2010, L.n°88 – 7.07.2009*).





Activation process of olive compost (OC). a) on farm compost preparation; b) starting materials: on-farm compost and olive compost supplied by CESCO; c) composting process; d) final product.

7.3. Utilization and Opportunities

Activating the compost from olive husk with an on-farm compost from vegetable residues represents a feasible treatment to recycle these wastes, producing a biofertilizer that can be used in different agricultural sectors, due to its adequate degree of stability and maturity. The co-composting can lead to a decrease in the C/N ratio compared to the starting material and to an enhancement of the microbial activity. The Activated OC can be easily obtained with farm facilities and successfully applied as soil conditioner and/or fertilizer. Potential positive effects of the activated OC include improving soil structure and stability of the soil aggregates and resistance to water erosion as its application increases the organic matter content in the soil, especially in soils most exposed to losses due to mineralization as in the Mediterranean areas. It also could improve the microbial activity and contributes to soil nutrient availability, plant disease suppressiveness and carbon sequestration. Moreover, the use of OC can contribute to close the organic matter cycle of the olive mill process back to the field, reducing the use of external inputs (i.e. synthetic fertilizers and fossil fuels) and the associated negative effects.

7.4. Practical tips for on-farm production and storage, handling, distribution and soil application

The activated OC can be easily produced at farm scale depending on the availability of the raw materials in the farm/area. The stable product obtained by the co-composting process can be stored in the farm, if suitable devices for piles coverage and/or platform roof are available in order to avoid possible leaching losses. In such condition, activated OC can be stored for several months, taking into account that some changes of chemical properties (organic matter content, heavy metal concentration, etc...) could occur, due to the unavoidable degradation process of the organic material.

The activated OC is a solid material easily movable. Due to the large volumes commonly distributed, some difficulties can occur in its handling. Mechanical shovels and tipper trailers should be used for its handling. Loading shovel and

compost (or manure) spreader can be used) for distribution. Due to its relatively high C/N ratio, this material could result in nitrogen immobilization in soil. It is advisable to spread the activated OC in autumn or in early spring, at least one month before crop transplanting. After spreading, superficial tillage (about 5-10 cm depth) is recommended. Results from long-term experiments suggest that the highest contribution to stable organic matter in the soil is achieved with relatively small doses of OC (about 10 t ha⁻¹) if repeated over time (every year, for more than 3 years).

7.5. Limits and difficulties in AWCB/BF utilization and practical solutions

Limits and difficulties in the OC utilization are similar to those reported for AD use (*cfr.* 4). These similarities are due to the activation process adopted in both the AWCB/BF reported in these guidelines.

a) A critical point linked to activated OC use is the distance among the raw material production site and the fruit/vegetable farms, where the final product is applied to soil. Since the fertilization potential of the activated OC depends on repeated soil application over time, the use of this biofertilizer is suggested for farms operating in the surroundings of OC production in Mediterranean areas, contributing to close the loop flow of these materials.

b) Compared to mineral fertilizers, for which the nitrogen release dynamics are easily predictable, activated OC requires a higher farmer's expertise, to synchronize the mineralization rate with the plant growth. If not managed properly, there will be a risk of N mining condition for crops, due to immobilization phenomena (up to four months), or leaching of excess N if the N release is not synchronized with the crop need. Best management practices that can mitigate these effects include adjustment of OC nutrient supply to each crop demand, avoid late application respect to crop sowing/transplanting. Integrating the OC with materials characterized by fast N release (e.g. fertigation) can be suggested in the first crop after OC distribution, to avoid N deficit in the first crop stages. Despite this, the application of OC is best combined with crops with the highest N demand in condition of high temperature and humidity (when the mineralization processes are favoured).

c) If the composting process is not well managed, the activated OC can have phytotoxic effects on the crops. To avoid these problems, it is advisable to check the quality of the starting materials and strictly follow and complete all the phases of the composting process, in order to obtain a well-matured and high-quality product.

7.6. Compliance with sustainable agriculture (*soil protection; nitrate leaching reduction risks; water eutrophication; synthetic input reduction*)

The recycling of the olive mill husk by composting represents a worthwhile strategy to avoid the potential environmental harm of olive mill waste disposal and could lead to increased soil fertility and functionality. The activation process

based on on-farm co-composting procedures can be a strategy to foster the microbial activity by providing easily fermentable materials during the process, contributing to close the cycle of wastes and co-products at local scale.

As soil amendment, the activated OC can contribute to soil carbon storage and to increase soil water retention ability. The activation process is expected to increase the soil microbial activity and soil biodiversity, and to reduce the risk of plant pathogens. Moreover, as a fertilizer, it can be used in substitution of synthetic input, moving in the direction of reduced pollution strategies.

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8. Semi-permeable-membrane-covered aerobic composting for agricultural wastes

8.1. Background and description

Human activity has led to increases of GHGs, especially CO₂, CH₄ and N₂O, which has made great contributions to global climate change. CH₄ emissions from livestock account for approximately 24 % (Moss et al., 2000) to 40 % (Hogan et al., 1991) of total human activity emissions, while livestock N₂O emissions account for about 44 % (Davidson, 2009) of total human activity emissions. Additionally, CH₄ emissions from livestock manure represent 6 % of total CH₄ emissions from human activity (Hogan et al., 1991; Moss et al., 2000), while those of N₂O account for 7 % of total human activity (Khalil and Rasmussen, 1992). Accordingly, proper disposal of livestock manure can effectively reduce GHGs emissions (Levis and Barlaz, 2011).

In China, the amount of livestock and poultry manure has reached 3.8 billion tons, but the manure utilization rate is less than 60 % (MOA, 2017). In addition, the lack of oxygen in traditional aerobic composting can lead to anaerobic conditions, thereby increasing GHGs emissions (Zeng et al., 2016).

Besides, previous studies have demonstrated that total nitrogen loss ranged from 40 % to 60 % of the initial nitrogen (Nigussie et al., 2017), while ammonia loss during composting ranges from 16 % to 76 % (Barrington et al., 2002) or 14 % to 53 % (Lim et al., 2017) of total nitrogen loss.

8.2. Recipe and method of preparation: the example in Tibetan Plateau, China

A membrane-covered, forced ventilation composting system (UTV AG, Baden-Baden, Germany) was used for this experiment. The critical feature of this composting system was that the membrane was constructed of Gore-Tex with ePTFE, which was waterproof and windproof, yet permeable to moisture (Mukhopadhyay and Midha, 2008). The Trench walls (figure b) were used for our experiments, and they measured 30 m in length and 8 m in width totally. The walls were 1.5 m in height and the compost pile itself measured 2 m in height.

Cattle manure from the farm was produced in the two months preceding this experiment. The bulking agent, which measured approximately 0.5–1 m in length, 0.1 m in width, and 0.02 m in height, was obtained from a wood manufacturer. The total volume of the batches used was about 110 m³, and the volume ratio of batches to dairy manure was about 1:1. Three representative repeatable samples were collected and analysed for physical and chemical indicators.



Activation process of membrane-covered compost. a) structural diagram of membrane-covered system (1. control system 2. PC 3. Rim weight 4. temperature sensor 5. oxygen sensor 6. cover handling device 7. aeration fan 8. Gore-Tex 9. aeration and leachate system 10. water trap 11. leachate collection); b) composting trough; c) fan and control system; d) mixing process with cattle manure and bulking agent; e) initial mixture; f) loading process; g) membrane sealing process; h) fermentation process

Oxygen was supplied to the compost pile using a combination of forced aeration and turning to maintain an aerobic state with an oxygen concentration $\geq 5\%$. A centrifugal fan with 1.5 kW of power and a ventilation capacity of 0–35 m³/min was used for aeration. This fan provided generally stable air flow at around 35 m³/min. Two ventilation pipes with a length of 27 m and an interval of 2.75 m were used to supply air. A controlled ventilation system was set to supply air to the compost pile automatically for one minute per five minutes during the first week, then one minute per three minutes during the second week. The oxygen supply lasted until the end of turning, which was started after the fourth week. After turning, the ventilation intervals were one minute per ten minutes until the aerobic degradation end. The compost pile was turned using a loader.

8.3. Utilization and Opportunities

Semi-permeable membrane-covered composting system has been widely applied worldwide (UTV AG, 2015; W. L. Gore Associates, 2010) because this system is efficient (W. L. Gore Associates, 2012), adaptable, energy-saving, easy to operate and environmentally friendly (UTV AG, 2015; W. L. Gore Associates, 2013).

Previous studies have shown that this type of compost technology had beneficial effects on odors, VOCs, dust and bioaerosols because the pore size of membrane was below 0.2 μm that macromolecular particles were controlled in the membrane (Schmidt et al., 2009; W. L. Gore Associates, 2013). Sun et al. and Ma et al. analysed NH₃ and CH₄ emissions by constructing a membrane-covered aerobic composting reactor in a laboratory and found that CH₄ emissions dropped by 40 % because the membrane promoted the formation of positive pressure, oxygen supply (Sun et al., 2016) and NH₃ emissions decreased by 20 %–30 % because the water film formed under the membrane could absorb ammonia gas and return it to the compost pile (Ma et al., 2017; Sun et al., 2016). A comprehensive performance assessment revealed that the membrane-covered composting system reduced emissions, composting time and energy consumption while producing a valuable product (González et al., 2016; Levis and Barlaz, 2011).

In recent years, the Chinese government has become increasingly demanding for the treatment of livestock and poultry manure and environmental protection during handling. The semi-permeable membrane-covered composting system could be a good choice for treatment of manure in China.

8.4. Practical tips for on-farm production and storage, handling, distribution and soil application

Membrane covered compost system can be used for treating of organic solids, such as manure, straw, sludge and so on. Generally, the raw materials can be divided into two parts: main materials and bulking agents. The main materials such as cattle manure should be stored in a sealed environment before being used for composting, and we generally recommend building a system near the farm. The bulking agent should be selected according to local situation, and long-distance transportation is not recommended.

In order to achieve good composting products, it is necessary to determine the material ratio and ventilation. The initial mixture should have a moisture content of 50%-60% and a C/N ratio of 25-30 (different from raw materials). The porosity is very important for this process, and the initial volumetric weight should be 0.6-0.8 kg/L. The aeration rate for membrane covered system should be at $0.2-0.4 \text{ L min}^{-1} \cdot \text{kg}^{-1} \cdot \text{vs}^{-1}$, the ventilation intervals were one minute per five minutes at the high temperature period and one minute per ten minutes at the cooling period.

The membrane selection and semi-membrane seal of compost pile play an important role in reduction results. Actually, the Gore-Tex with ePTFE, which is waterproof, windproof, and permeable to moisture, is a good choice. Bungee cords and bolts fixed to the wall can help to ensure system sealing.

The compost period usually last 6-8 weeks, the turning must happened after the 4th week.

8.5. Limits and difficulties in AWCB/BF utilization and practical solutions

The problem of system sealing cannot be completely solved, and some harmful gas will leak and escape when the film is removed. To avoid these problems, ventilation ducts and areas prone to gas leakage require further retrofit upgrades.

The cost of the membrane is high compared to conventional composting process. To avoid this problem, more membrane material should be used in this process, and depending on the deodorizing effect and cost performance, consumers should have the opportunity to make choices based on their needs.

8.6. Compliance with sustainable agriculture (soil protection; nitrate leaching reduction risks; water eutrophication; synthetic input reduction)

Treatment of manure and other organic solids with semi-membrane-covered compost will reduce greenhouse gas and odour emissions. Indeed, the semi-membrane has an effect on decreasing the total N loss. In addition, the membrane has a good thermal insulation effect, which ensures that the bacteria in the heap are more thoroughly eliminated. In this system, air enters via a pipeline located under the compost pile, which bypasses the membrane, and the air that is sent the compost system cannot leave the system immediately. Therefore, most of the air remains in the compost pile, which results in positive pressure within the composting system. This positive pressure under the membrane forces the oxygen to be evenly dispersed into the interspace of the compost, thereby increasing the degree of aerobic decomposition within the pile. Therefore, we can obtain higher quality compost products in a short time.

8.7. References

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9. Vegetable crop residues

9.1. Background and description

Vegetable crop production occupies about 2% of the total arable land in Europe. In contrast to its small share of cropping area, vegetable crop residues pose a significant threat to the environment, primarily due to a large amount of biomass, with a high N content at the time of harvesting. For instance, cabbage production leaves residues in the field between 40-60 tons FW ha⁻¹ and 100-200 kg N ha⁻¹ that is much higher compared to maize or wheat (Agneessens et al., 2014). Unlike other crops, most vegetable crops are harvested while at the reproductive stage when their N need is high, demanding high N application until harvest. Many vegetable crops are harvested in late autumn.

Given the high biomass, water content and low C:N, vegetable crop residues significantly contribute to nitrate leaching and greenhouse gas emissions (N₂O) that pollute water bodies and the earth's atmosphere, respectively. In order to minimize the negative environmental impacts of N, the EU sets standards in its water and N directives. To meet these standards, farmers should follow strict rules and recommendations in soil nutrient management, particularly in reducing the amount of nitrogen and phosphorus applied through organic and mineral fertilization. Working according to the requirements of these rules and regulation is costly (e.g., manure disposal costs) for farmers (Van Grinsven et al. 2015). In order to reduce the costs and implement the rules and regulations set by the EU, valorizing vegetable crop residues is essential.

In Belgium, especially in the northern part (Flanders), there is a very large problem of nutrient imbalances for N and P mainly due to excessive historical application of animal manures and to the nature of the current land use, still with very intensive livestock production and vegetable growing (Chaves et al., 2007). Because of the environmental risks with vegetable growing, notably the nitrate leaching following residue incorporation, we have investigated how vegetable crop residues can be managed to minimize this risk by both ***in-situ management techniques*** and by **removal of the crop residues** (Agneessens et al., 2015).

The in-situ management techniques aim to avoid the fast decomposition of the vegetable crop residues while leaving the residue in the field. These techniques include leaving the crop residue intact (without incorporation), co-incorporation of vegetable crop residues with other immobilizing materials, and growing catch crops. Valorizing techniques that require removal from the field include ensilaging, co-composting and anaerobic digestion (AD). Because AD is explained in section 1 of this guideline, the focus of this section of the guideline is on ensilaging and on-farm composting.

9.2. Recipe and method of preparation:

9.2.1. Co-silaging

For silaging, a plant material ideally should have a moisture content of 20%. However, most of the vegetable crop residues have a much higher moisture content. In this case, a dry residue (such as maize) can be added to obtain the right balance of C:N ratio and water content. We considered four different vegetable crop residues collected in autumn namely leek (*Allium porrum L.*), celery (*Apium graveolens var. Dulce*), cauliflower (*Brassica oleracea var. botrytis*) and white cabbage (*Brassica oleracea convar. capitata var. Alba*).

The vegetable crop residues were chopped by hand (5 cm × 5 cm) and mixed in a 1:1 volume ratio with maize straw (stems and leaves that were mechanically chopped (<1 cm) and put in silage buckets of 15 litres (Figure 1 and 2). The compressibility of the vegetable crop residue—maize straw mixtures was calculated as the volume of the mixture that could be compressed into the fixed volume of the silage buckets. We investigated the feasibility of ensiling pure leek residues without maize straw, which resulted in double the amount of sap and N losses compared to co-ensiling with 40% (v/v) maize straw (Figure 3). Ensiling was conducted for three months in the buckets that were closed airtight (oxygen-free) and with a reservoir to collect possible leachate from the silage (See picture 1).



Figure 1. Refined cauliflower residues and airtight silage buckets



Figure 2. Crop residues of celery and cauliflower ensilaged with maize residues



Figure 3. Crop residues of celery ensilaged without maize residues - Crop residues of cauliflower ensilaged without maize residues

9.2.2. on-farm composting

An ideal composting process needs a combination of N rich residues (vegetable crop residues) with C-rich bulking agents (e.g., straw, poplar bark, wood chips, heath biomass). Such combination optimizes the C:N ratio, decreases the moisture content and minimizes N losses during composting. Two combinations were tested as explained in Viaene et al. (2017) on a concrete pad in a windrow composting system.

The first combination consists of C rich wheat straw (1% v/v), maize straw (21% v/v), poplar bark (16% v/v) and wood chips (19% v/v), mixed with N rich cabbage residues (43% v/v) at the start of the composting process and with leek residues (43% v/v) after 10 days of the decomposition process. The second combination consists of leek residues (17% v/v) mixed with maize straw (28% v/v), wood bark (11% v/v) and either chopped heath biomass or strawberry substrate (44% v/v). Chopped heath biomass (i.e., biomass from heathland management) or spent strawberry substrate (i.e., growing medium at the end of the growing season of strawberry culture), were tested as an inexpensive alternative for wood chips (Viaene et al. 2017). These combinations resulted in the C:N ratio of 41 and 30 in the first and second combination, respectively.

The compost piles (12 m x 3 m x 1.5 m) were covered with a gas-permeable geotextile (TopTex) to allow air circulation while avoiding rainwater. The piles were turned 8-12 times using a compost turner (TG 301, Gujer Innotec AG, Switzerland) depending on the type of the compost to ensure aerobic conditions. Temperature and CO₂ were monitored using a Digital Thermometer GTH1150 and as Brigon CO₂ indicator, respectively as the average of four-point measurements along the length of the piles. When the temperature remained below <45°C, additional fresh leek residue was added to the piles to stimulate microbial activity and a subsequent increase in temperature. When the CO₂ concentration was high (>20%), the piles were turned frequently, and C rich bulking agents (poplar bark) was added on day 29.



Figure 4. Compost pile covered by permeable compost cloth and turning the compost pile

9.3. Utilization and Opportunities

Vegetable crop residues can be utilized in various ways in agriculture both by removing the residue after harvest and by leaving on the field. While leaving on the field contributes to nutrient cycling and organic matter buildup of the soil, additional management is required to reduce the associated greenhouse gas emissions and nitrate leaching to the groundwater.

There is a considerable valorization potential of vegetable crop residue that lies in their presence in a large amount, their high nutrient content, and the lack of competition with any other uses. After removal, the residues can be valorized as a stable compost, which is widely utilized as a slow release organic fertilizer. It can also be ensilaged and re-applied on the field when necessary or can be used as a feeding supplement for livestock. Anaerobic co-digestion of vegetable crop residue provides a sustainable renewable energy source that does not compete with arable crop and food production. Because of high moisture and organic carbon contents, vegetable crop residues are highly biodegradable in an anaerobic digester. Vegetable crop residues play significant roles here as readily available feedstock for co-digestion. The use of agricultural crop residues in Europe as a feedstock for biogas industry likely increases due to concerns regarding the sustainability energy crop production for biogas (Scarlat et al., 2018). Moreover, the value of these residues would increase following the growing interest in sustainable agriculture and shift towards the bio-economy.

9.4. Practical tips for on-farm production and storage, handling, distribution, and soil application

Ensilaging:

- The amount of soil collected with the residues must be kept to an absolute minimum to obtain good quality silage. Currently, only manual collection allows collecting residues that are clean enough.
- Two crucial factors for good quality silage are the freshness of the material and its fineness/hardness/compressibility. Only fresh crop residues that

are sufficiently fine (or refined) can be compressed to such an extent that good quality silage can be produced.

- The added C-rich material should have a sufficiently high dry matter content: the drier, the larger the fraction of crop residues that can be added.
- Large amounts of leek lead to large sap losses during the process.

Composting:

- If insufficient 'brown' materials such as wood chips are available, alternatives such as spent tomato and strawberry substrates can be used
- Leek residues which are removed from the field by definition can be used by vegetable farmers to supplement the composting pile, depending on its availability and availability of other vegetable residues

9.5. Limits and difficulties in AWCB/BF utilization and practical solutions

9.5.1. Feedstock availability:

For high-quality compost, a farmer needs the proper combination of brown (e.g., wood chips and straw) and green (more nitrogen-rich, e.g., vegetable crop residues) feedstock. Together they provide an optimum carbon-to-nitrogen ratio that the microorganisms need to break down the organic material. Some farms (e.g., farms in Flanders) are highly specialized and do often experience a shortage of C rich feedstock or at least do not have in the right balance. In these situations, biomass must be purchased from a third party. Alternatively, relatively easily available C-rich by-products, such as chopped heath biomass and spent growth media of strawberry can be used. Collaboration between farmers and stakeholders involving in landscape management could also help to get access to a variety of feedstocks that are excess at one partner while a shortage with another partner. Vegetable crop residues are only seasonally available. Ensiling could be a good technique to store the residue when available and to use it later when necessary for composting, direct field application or anaerobic digestion.

9.5.2. High costs to remove and transport the vegetable crop residues:

Removing the vegetable crop residue is challenging because of the high moisture content, wet soil conditions (especially in the humid climatic zones) and a large amount of soil that is often removed together with the crop residues. There is no easy, practical solution for the high moisture content of the crop residues. The farmer is advised to wait a relatively drier days for collection and removal of the crop residues and focus on other vegetable crop residues that have already been removed from the field (e.g., leek) to reduce the costs associated with the removal. If sufficient interest in recycling strategies can be generated, dedicated crop residue collectors could undoubtedly be developed. This will probably depend much also on the further evolutions in environmental legislation in the member states.

In case the soil conditions create a very difficult situation to remove and valorize the vegetable crop residues, immobilizing materials may be applied alternatively that reduce the adverse environmental effects, notably nitrate leaching and N₂O emissions. Co-incorporation of straw, green waste compost and sawdust reduced N leaching by 27%, 24% and 18%, respectively, compared to the incorporation of only cauliflower and reduce N₂O emission by 60%, 55% and 53%, respectively, compared to the incorporation of celery only.

An additional strategy in case of difficulty to remove and valorize the vegetable crop residue is that leaving vegetable crop residues without incorporating until the period when risks of N losses through leaching or denitrification are lower (e.g., towards the end of winter). The limitation here is that it may be difficult to do the incorporation by the end of winter because of the wet soil conditions. Also, pests and diseases may be more difficult to control with crop residue not incorporated immediately. Moreover, caution needs to be taken here, as the effect is crop specific. For example, leaving broccoli intact on the soil surface reduced nitrate leaching to 43% relative to incorporation, but no reduction in leaching was observed for leek residues.

9.5.3. Synchronization of nutrient availability and plant uptake

Even though silaging is a simple and low-cost strategy to enable long-term conservation and valorization of vegetable crop residues, it may cause temporary nutrient immobilization following its direct field application. To synchronize nutrient availability from the silage with the need of the crop, it is vital to consider enough time interval between field incorporation and crop sowing date, for example by applying in the autumn and or combining the silage with fast release mineral fertilizer.

9.6. Compliance with sustainable agriculture (*soil protection; nitrate leaching reduction risks; water eutrophication; synthetic input reduction*)

Co-ensilaging and on-farm composting of vegetable crop residues are promising tools for sustainable agriculture, particularly in reducing the nitrate leaching to the groundwater. Because of their large biomass and low market values, they have shown a great potential to be used as an organic fertilizer that reduces the use of synthetic fertilizers, and as a soil amendment that protects the soil degradation caused by water erosion, loss of organic carbon and loss of soil biodiversity.

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10. Conclusions

In the Agrocycle framework, a large variety of the most important organic waste streams has been characterized, to maximize their use as soil amendments in sustainable agriculture. The direct application of AWCBS to soil is often not allowed under most of the national regulations of the producer countries. Given the above, co-composting AD from cattle slurry at farm scale with other raw organic wastes is, as an example, a win-win strategy to recycle different wastes available at local level, reducing the risk of their improper disposal, and producing a biofertilizer which can be used in agriculture. Overall, the use of treated (mainly composted with farm facilities) organic wastes has the following advantages: i) contributes to close the organic matter cycle (e.g. for AD, OC, FYM, vegetable crop residues), ii) contributes to soil carbon storage, increase soil water retention ability and boost crop yields when used as soil amendments (e.g. for AD, OC, FYM, biochar), iii) reduces the use of external inputs (i.e., synthetic fertilizer) due to nitrogen and other nutrient valuable contents, and the associated negative environmental impacts, such as fossil fuels exploitation; contamination of surface and ground waters (as for biochar and FYM); emission of greenhouse gases (GHG) during storage and application (FYM). To obtain a well-matured and high-quality product, all the phases of the composting process must be completed. Considering the increasing demand for the treatment of livestock and poultry manure, semi-permeable membrane-covered composting system could be a good choice for AWCBS treatment in China. The use of the obtained biofertilizers (co-composted AD; re-composted OC, etc) is suggested for farms operating in the surroundings of the wastes production, contributing to close the loop flow of these materials at territorial scale (e.g. limiting GHG emission and costs due to transport; environmental and economic sustainability). Moreover, repeated soil applications over time require best management practices that can be used to mitigate nutrient leaching (e.g. adjustment of composted wastes nutrient supply to each crop demand, avoiding late application respect to crop sowing/transplanting). Finally, in the case of vegetable crop residues, their seasonal availability requires ensilaging, which could be a good technique to store them before use for composting, direct field application or anaerobic digestion.