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# Constraints and levers to the use of compost and on-farm composting in the "Vallée de la Drôme et Diois"

Énora Chiri

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**Constraints and levers to the use of compost  
and on-farm composting in the “Vallée de la  
Drôme et Diois”**

Par : Enora CHIRI

**Soutenu à Rennes le 11 septembre 2023**

**Devant le jury composé de :**

Président : JAFFREZIC Anne

Maître de stage : BALANANT Tanguy

Enseignant référent : MENASSERI-AUBRY Safya

Autres membres du jury (Nom, Qualité)

DE GUARDIA Amaury

Chercheur – INRAE, OPAALE

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# Table of contents

Table of illustrations

List of tables

Table of appendices

List of abbreviations

1.	Introduction .....	1
1.1	Fertilisation and organic matter issues at national scale .....	1
1.2	Drôme and “Vallée de la Drôme et du Diois”: a region with diverse agricultural and geographical characteristics, leading to imbalance in the concentration, flow and valorisation of biomass .....	2
1.2.1	A diversity and spatial heterogeneity of agricultural systems in Drôme and in the “Vallée de la Drôme et Diois” .....	2
1.2.2	Biomass concentrations and flows are dependent on the organization of the agricultural sectors .....	2
1.2.3	The Drôme’s context exacerbates biomass issues .....	3
1.2.4	Composting as a solution to face environmental and economic issues and to manage biomass on the territory .....	3
1.3	Composting: a complex process determining compost quality .....	4
1.3.1	Definition and expected benefits of compost use on soil properties .....	4
1.3.2	The composting process .....	4
1.3.3	Compost quality: definition and indicators .....	5
1.4	Benefits and issues of on-farm composting .....	6
1.5	Aims, challenges and working way of the study .....	7
2.	Materials and Methods .....	8
2.1	Compost characterization and quality evaluation .....	8
2.1.1	Compost collection .....	8
2.1.2	Agronomic values and pathogens presence .....	8
2.1.3	Measures of dry matter .....	8
2.1.4	Analyses of compost stability .....	9
2.1.4.1	Extraction $\text{CaCl}_2$ of composts and dosing of ammonium, nitrite, and nitrate .....	9
2.1.4.2	Compost respiratory activity .....	9
2.1.5	Analyses of compost maturity .....	9
2.1.5.1	Germination index .....	9
2.1.5.2	Cress test .....	10
2.1.6	Compost innocuity: weed seed spontaneous germination .....	10
2.2	Qualitative study .....	10



2.2.1	Creation of the semi-structured interview .....	10
2.2.2	Choice of the sample .....	10
2.2.3	Transmission mode and transcription .....	11
2.3	Data treatment .....	11
3.	Results and discussion .....	11
3.1	Links between compost quality, process management and farmers' perceptions .....	12
3.1.1	Agronomical values content in composts: N, P, K and OMIS .....	12
3.1.2	Composts quality parameters .....	12
3.1.3	Links between compost indicators of quality and the different process management of windrows .....	12
3.1.4	Discussion .....	14
3.1.4.1	N, P, K and OMIS compared to farmers' perceptions: beliefs or reality .....	14
3.1.4.2	Links between composts' analyses and process management .....	14
3.2	Constraints and limits to the use of compost and to on-farm composting .....	15
3.2.1	Compost: a variable fertiliser used mostly by organic farms .....	15
3.2.2	Specific material is needed to on-farm composting and spread compost .....	17
3.2.3	The difficulty to manage moisture, in a territory with dry summer .....	17
3.2.4	An uncertain availability of raw matters in an agricultural diversified organic territory .....	18
3.2.5	A time and space-consuming practice .....	19
3.2.6	A costly practice but with a benefit/cost ratio often unknown .....	20
4.	Perspectives of the study .....	20
4.1	Farmers collectives: a solution to unite the needs, material, work and knowledge .....	21
4.2	Stakeholders close to farmers have an influence on changes and developments in farming practices .....	22
4.3	Advisors and researchers' aim is to develop knowledge about compost and composting .....	23
4.4	Political entities have the power to influence the development of practices on a larger scale .....	23
5.	Limits of the study .....	25
5.1	Compost collection .....	25
5.2	Compost analyses .....	25
5.3	Samples of surveyed farmers .....	25
6.	Conclusion .....	26

Bibliography

Sitography

Appendices





## Table of illustrations

Figure 1: Evolution of marketed inputs from 2010 and 2020 in France .....	1
Figure 2: Localisation of Drôme and map of the Drôme department with the VDD in purple ..	1
Figure 3: Distribution of poultry, cattle, goat and sheep manure production on the VDD territory, in tons per year .....	2
Figure 4: Topography of VDD and localisation of the main cities .....	2
Figure 5: Localisation of the main sites of green waste and distillery waste compared to the Drôme waterway and the main cities of the VDD .....	3
Figure 6: Scheme of the process of a theoretical composting process - the different steps of decomposition, the temperature evolution, the microorganisms acting – and the steps of the organic carbon and nitrogen transformation under aerobic and anaerobic conditions .....	4
Figure 7: Zoom of the particles environment in a compost pile, representing the structuring of water and air around compost particles .....	5
Figure 8: Tree structure with all the key elements used to write the semi-structured interview .....	10
Figure 9: PCA of the 11 composts quality analyses results and the process management .....	13



## List of tables

Table 1: Table of indicators commonly used to assess quality of a compost by taking into account its maturity, stability and innocuity .....	6
Table 2: Characteristics of composts collected and analysed .....	8
Table 3: Critical values of indicators, scores associated and their mean .....	11
Table 4: Agronomical values analysed and their perceptions by farmers .....	11
Table 5: Result and score per indicator, global score, and management of composting process .....	12
Table 6: List of the analysed compost with their characteristics and the main interventions during the process .....	12
Table 7: Links between global score of compost quality and process management .....	13
Table 8: Links between weed seed germination score and process management .....	13
Table 9: Links between cress test and germination index score and process management ..	14
Table 10: Links between respiration score and process management .....	14
Table 11: Profiles of the 23 farmers having answered to the semi-structured interview .....	15
Table 12: Management of soil fertility according to the main agricultural activities and the certification .....	15



## Table of appendices

Appendix I (1/2): Semi-structured interview

Appendix II: Map of localisation of compost collected, farmers interviewed and their main agricultural sectors

Appendix III (1/5): Farmers' answers to the interview, classified by thematic

Appendix IV: coefficient attributed to each species used for the germination index test and an example with the 9th compost

Appendix V: Regulations concerning on-farm composting, for each type and special features of farms



## List of abbreviations

<b>AM:</b> animal manure	<b>N:</b> nitrogen
<b>C:</b> carbon	<b>N<sub>min</sub>:</b> mineral nitrogen
<b>C<sub>org</sub>:</b> organic carbon	<b>N<sub>org</sub>:</b> organic nitrogen
<b>CCVD:</b> communauté de communes Val de Drôme	<b>N<sub>2</sub>:</b> dinitrogen
<b>CH<sub>4</sub>:</b> methane	<b>N<sub>2</sub>O:</b> nitrous oxide
<b>comcom:</b> communes' community	<b>NH<sub>4</sub><sup>+</sup>:</b> ammonium
<b>Conv.:</b> conventional farming	<b>N<sub>ox</sub>:</b> nitrogen oxide
<b>CO<sub>2</sub>:</b> carbon dioxide	<b>NO<sub>2</sub><sup>-</sup>:</b> nitrite
<b>CUMA:</b> coopérative d'utilisation de matériel Agricole	<b>NO<sub>3</sub><sup>-</sup>:</b> nitrate
<b>DM:</b> dry matter	<b>OF:</b> organic farming
<b>DW:</b> distillery waste	<b>OM:</b> organic matter
<b>Farm.:</b> farmer	<b>OMIS:</b> Organic Matter Index of Stability
<b>g:</b> gram	<b>P:</b> phosphorus
<b>GI:</b> germination index	<b>P<sub>2</sub>O<sub>5</sub>:</b> phosphorus pentoxide
<b>GWS:</b> green waste shred	<b>PAMP:</b> perfume, aromatic, medicinal plants
<b>h:</b> hour	<b>s:</b> second
<b>ha:</b> hectare	<b>SOM:</b> soil organic matter
<b>H<sub>2</sub>O:</b> water	<b>t:</b> ton
<b>H<sub>2</sub>S:</b> hydrogen sulphide	<b>TME:</b> trace mineral element
<b>K:</b> potassium	<b>UAA:</b> useful agricultural area
<b>kg:</b> kilogram	<b>VDD:</b> Vallée de la Drôme et Diois
<b>K<sub>2</sub>O:</b> potassium oxide	<b>3CPS:</b> communauté de communes du Crestois et Pays de Saillans
<b>MMD:</b> mix of animal manure and distillery waste	<b>(w(DM):v):</b> (weight(drymatter):volume)
<b>MMDG:</b> mix of animal manure, distillery waste and green waste shred	<b>(w:v):</b> (weight:volume)
<b>MMG:</b> mix of animal manure and green waste shred	<b>Ø:</b> diameter

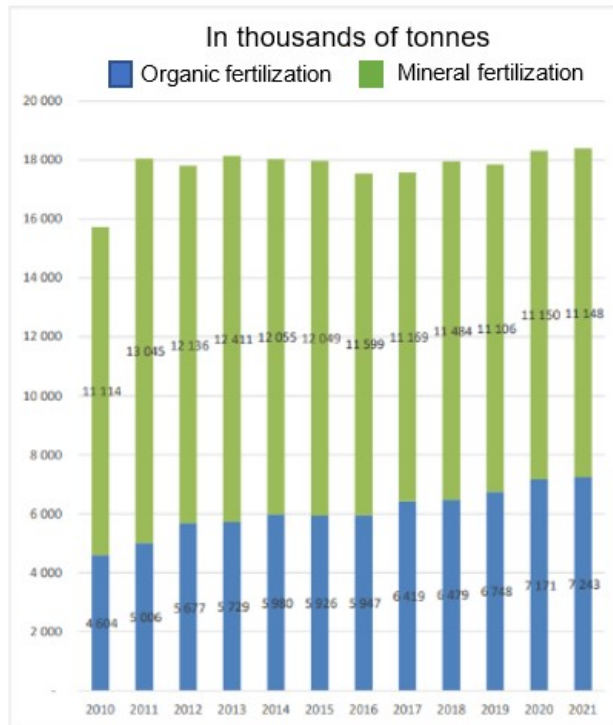


Figure 1: Evolution of marketed inputs from 2010 and 2020 in France (in thousands of tons) (ANPEA, 2021)

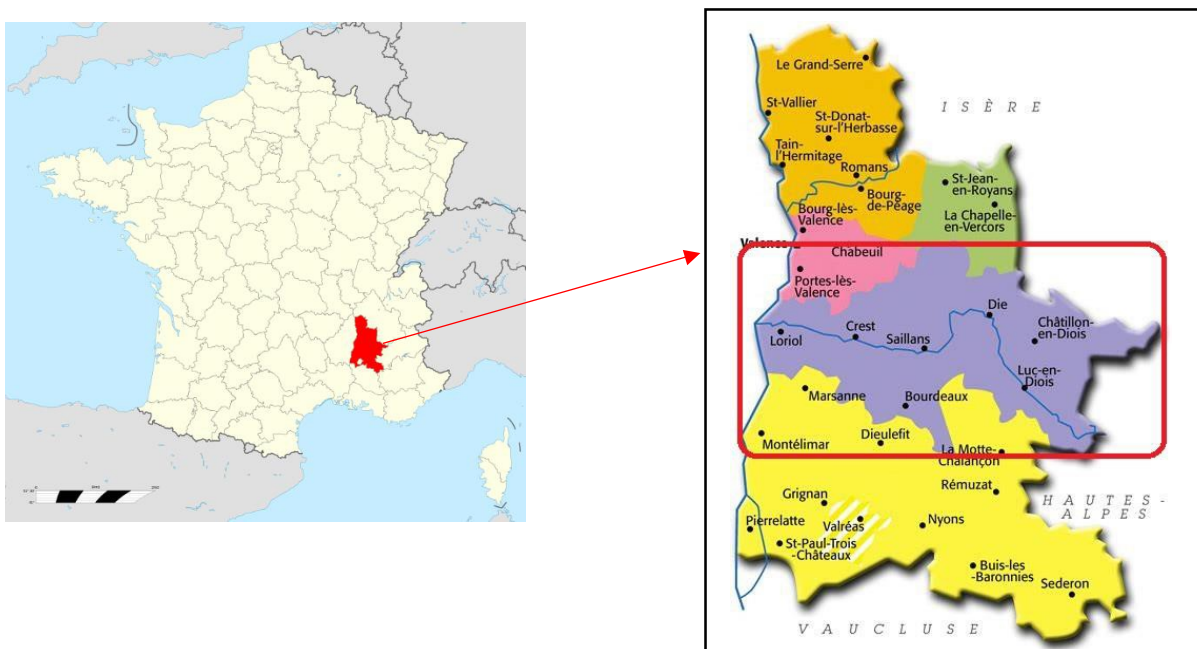


Figure 2: Localisation of Drôme and map of the Drôme department with the VDD in purple (Achard, 2023; Michel, 2023)



## 1. Introduction

### 1.1 Fertilisation and organic matter issues at national scale

Nowadays, agriculture faces major environmental and economic challenges. Because of years of intensive agriculture, soils have lost some of their potential functions and biodiversity (Tsiafouli and al., 2015; de Graaf and al., 2019). Among cultural practices singled out for criticism, intensive tillage is for example responsible of the decrease of microbial biomass, and other physical, chemical and biological soil characteristics (Liu and al., 2006). It also decreases soil organic carbon, especially by increasing carbon (C) mineralization (Guo and al., 2020). Another intensive cultural practice blamed is the use of mineral fertilisers. Indeed, their use is progressively leading to the decrease of humus quality and organic matter (OM) content because of soil acidity increase and because it does not contribute to soil organic carbon content improvement (Mensik and al., 2018). In addition to these agronomic constraints, mineral fertilisers are responsible of economic, environmental, and social issues (Foucaud-Scheunemann, 2021). For instance, mineral nitrogen (N) fertilisers production is very energy-consuming, and so their prices are dependent on energy one (Ahlgren and al., 2010), whereas phosphorus (P) and potassium (K) are becoming increasingly rare, thus leading to price rises. As a lot of countries are dependent on mineral N, P, K import, they are also dependent on price fluctuation. For example, the price of ammonitrate, a mineral fertiliser, increased more than 5-fold between May 2020 (€230/t) and March 2022 (€1,230/t), before falling back to €345 in April 2023 (Web-agri, 2023). On the other hand, their extraction and production lead to soil, water and atmospheric pollution, which directly impact biodiversity and human populations (Brahmi and al., 2014). At a larger scale, there is a raise of consciousness about their harmful use. One of the consequences which has been observed for eight years in France is the decrease of mineral fertilisers use, even if it is still predominant compared to organic ones (Figure 1).

To face these issues, it is necessary to change cropping systems and practices by better considering soil organic matter (SOM). Indeed, OM plays key roles in soils by affecting their physical, chemical, and biological properties (Gurmu, 2019):

- It improves soil structure by increasing aggregate stability and reducing bulk density.
- It improves soil water-holding capacity, which is partly due to the improvement of the physical characteristics listed above.
- It increases macro and micronutrients availability and cation exchange capacity.
- It enhances the abundance and activity of microflora such as mineralizing bacteria and mycorrhizal fungi. They are all contributors to main soil functions as nutrient mineralization, formation and stabilization of SOM.

Several agricultural practices have been shown to maintain or improve SOM: green manures, cover crops, reduced tillage, crop rotation, rotation with grassland or use of organic fertilisers and amendments (Viaene and al., 2016). This later practice includes a diversity of organic inputs, both as raw materials or processed products (ANPEA, 2021).

According to all the reports made below, a raise of consciousness of the impacts of mineral fertilisers and the benefit use of OM is observed. Even if mineral fertilisers are still more used than organic ones (1.5 times more in 2021, Figure 1), the use of organic fertilisers has been multiplied by 1.5 for ten years (Figure 1). Moreover, in France, in 2021, 13.4% of the country farms were engaged in organic agriculture and in ten years their number has more than doubled (Agence Bio, 2021). As it is forbidden to use mineral fertilisers for organic farming (Parlement Européen, 2018), the need for organic fertilisers is increasing too. This context is not an exception for any French department. In addition, territory organization, typology and other issues can amplify the need and the use of diverse OM by farmers, especially organic ones.

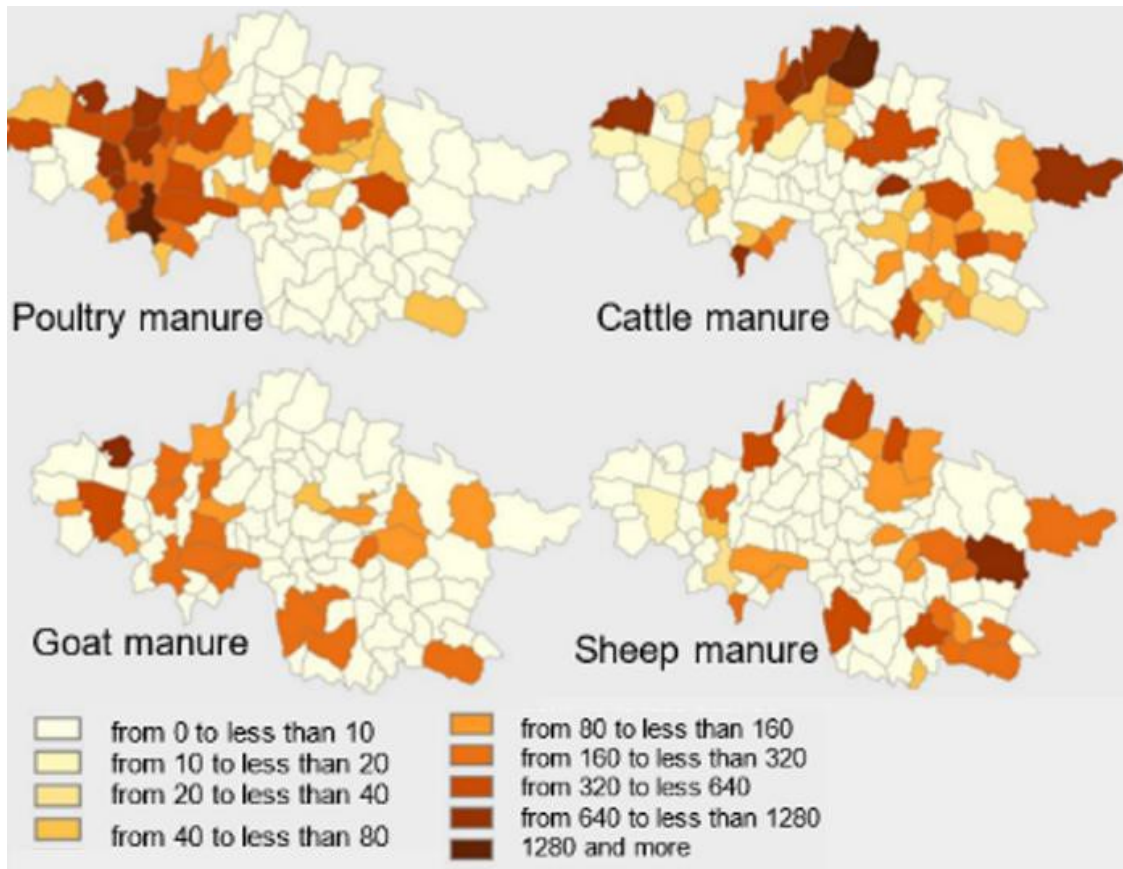


Figure 3: Distribution of poultry, cattle, goat and sheep manure production on the VDD territory, in tons per year (Gabriel, 2021)

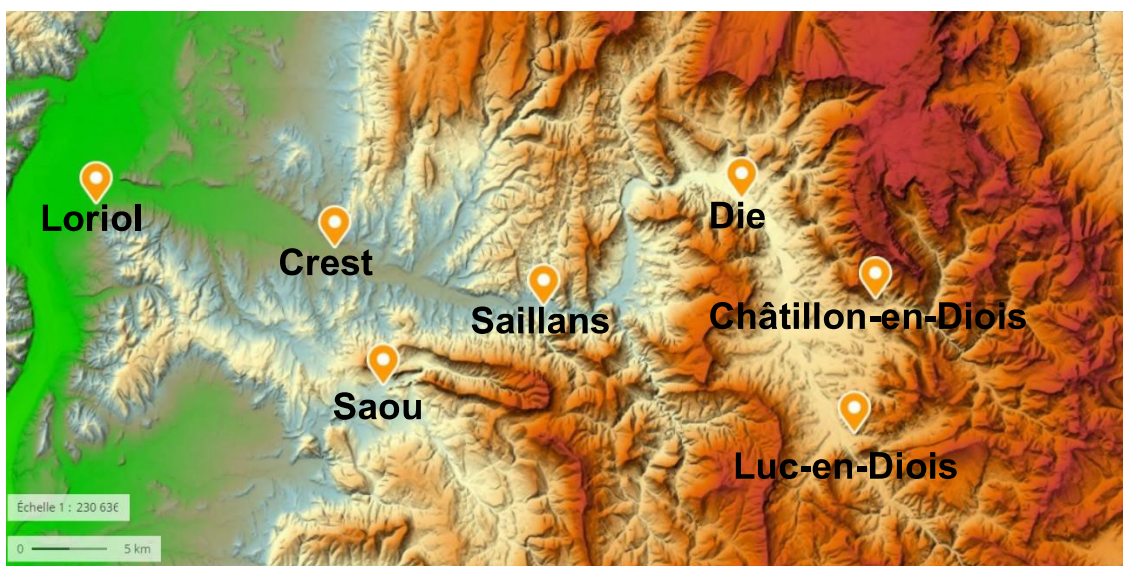


Figure 4: Topography of VDD and localisation of the main cities (Géoportail, 2023)

## 1.2 Drôme and “Vallée de la Drôme et du Diois”: a region with diverse agricultural and geographical characteristics, leading to imbalance in the concentration, flow and valorisation of biomass

### 1.2.1 A diversity and spatial heterogeneity of agricultural systems in Drôme and in the “Vallée de la Drôme et Diois”

The study takes place in the “Vallée de la Drôme et Diois” (VDD) (Drôme department, France, Figure 2). The Drôme department counted 5,250 farms in 2022 representing 194,000 hectares (ha) of useful agricultural surface (UAA). Agricultural productions are particularly diversified and include both plant production (arable crops, vegetable production, perfume, aromatic and medicinal plants (PAMP), winegrowing, fruit production and seed production) and livestock breeding (poultry, sheep, goats, and to a lesser extent, cattle and pigs). In addition, many crops constitute high value-added productions (e.g., lavender, garlic, seeds).

Within the VDD territory, the geographical repartition of crops is largely determined by the topographical and climatic conditions (Figure 3, 4):

- Arable crops, vegetables and fruit are mainly grown on plains, over large areas, where access to irrigation is easier. Winegrowing and PAMP production are mainly located on medium mountains, or on steep slope with no access to irrigation, insofar as these crops are known to handle difficult cropping systems.
- Poultry production tends to be found on the most easily accessible plains. Small ruminant breeding farms (goat and sheep) are scattered all over the territory, mainly in medium mountain areas. Cow production is prevalent in medium mountains in North and East of VDD.

Concentration of agricultural sectors in specific areas leads to similar fertilisation needs within a single zone and also to the concentration of the same agricultural by-products. In this case, each area of the territory has to deal with massive needs of a type of fertilisers and with an overflow of one by-product.

### 1.2.2 Biomass concentrations and flows are dependent on the organization of the agricultural sectors

In the case studied, the geographical organization of agriculture leads to spatial heterogeneity of co-products. As the different type of livestock breeding are concentrated in specific areas, described above, the manure production is spatially and quantitatively heterogeneous over the VDD territory (Figure 3). Cattle manure is concentrated in the North and East of the territory, small ruminants manure production is dispersed all over the VDD and poultry manure is mainly produced in the West. Nevertheless, poultry production is mainly indoor with no or low cropping lands, leading to excess manure on these farms, in contrast to ruminant breeding.

Arable crops, vegetables and fruit production by-products are concentrated on farms which means mostly in plain areas.

On the other hand, the winegrowing and PAMP sectors require raw products to be processed before sale (vinification and distillation respectively). Vinification mostly takes place in cooperatives, especially for the appellation “Clairette de Die”, located in a central position in relation to the vineyards. This way of functioning leads to concentration of by-products (grape pomace) in few places. In the same way, PAMP productions are mainly distilled after harvest, leading to by-products concentration at distillation sites (Figure 5). Concerning the distillery waste (DW), farmers have the choice to bring back this matter or not. On the contrary, winegrowers do not have the possibility to recover grape pomace, as these are sent to another department to be distilled ([Cabinet Isabelle Leduc, Inddigo, 2018](#)).

In addition to agricultural by-products, organic urban waste is an additional source of biomass to be recycled on the VDD territory. For instance, another biomass present in such territory

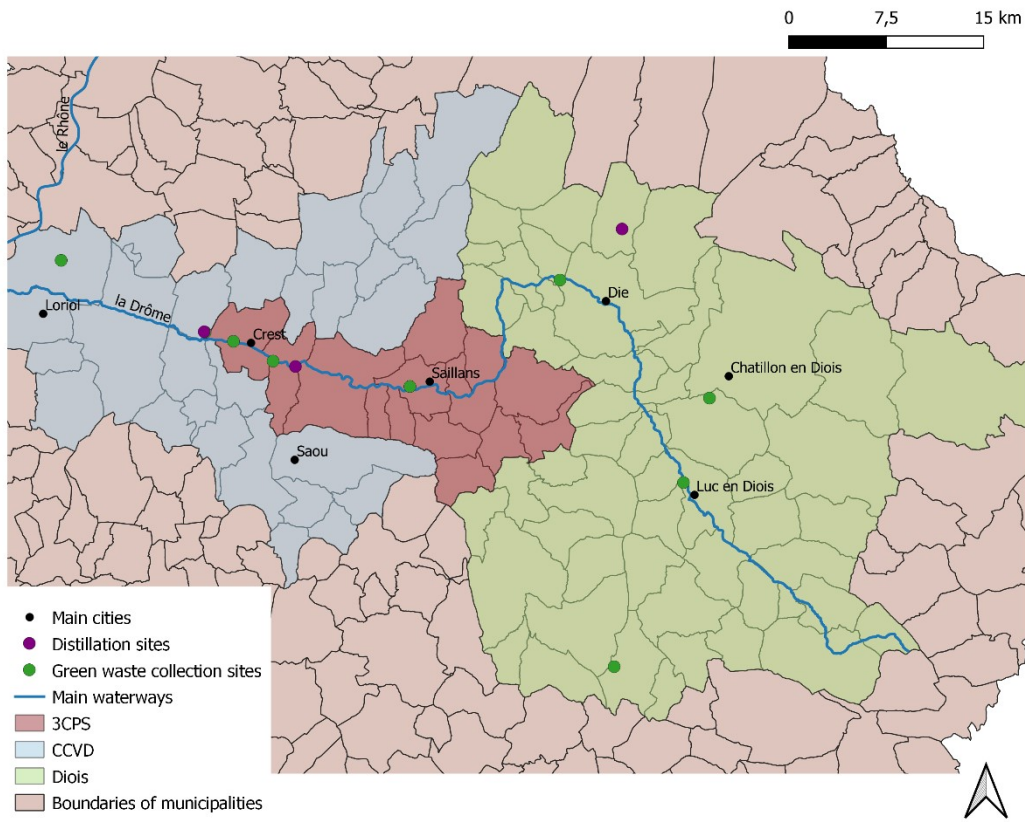


Figure 5: Localisation of the main sites of green waste and distillery waste compared to the Drôme waterway and the main cities of the VDD (Adapted from [Cabinet Isabelle Leduc, Inddigo, 2018](#); [Crestois et Pays de Saillans, communauté de communes, 2023](#); [Pays Diois, 2023](#); [Val de Drôme en Biovallée, 2023](#))

are yard trimmings. Indeed, landscapers and individuals have the obligation to bring their green waste in landfills instead of burning them (Légifrance, 2020). There are 2 or more landfills in each communes' communities (comcoms), and they are close to the main cities (Figure 5).

These reports lead to the conclusion that there is a geographical imbalance of biomass between plains and medium mountains and between urban and rural areas. The management of such flows can be difficult to handle. Indeed, this organization leads to overflows of biomass in the diverse areas of the VDD cited above, and deficits, mainly at the center of the territory. When a territory faces high concentration of biomasses, there are often exportations of the main ones and importations of biomasses which are in deficit. It is the example of the exchange of cattle manure from Savoy and straws from the Rhône plain, because each territory is in deficit in one of these biomasses (Gabriel, 2021).

When exchanges are not possible, areas with deficit in one or several biomasses have no choice than counting on fertilizer importation to fill the needs.

### 1.2.3 The Drôme's context exacerbates biomass issues

The national context about the rise of consciousness to use biomass for soils and to become less and less dependent on mineral fertilizer is all the truer in Drôme. First, organic farming is well represented in this department with 1,730 organic farms, so 33% of Drôme's farms are organic. It is the second department of France with the largest number of organic farms (Chambre d'agriculture Drôme, 2023). This context increases the OM needs. Then, this department under Mediterranean climate is more and more influenced by drought, and agriculture, mostly in the areas close to the Rhône, are submitted to water restrictions, earlier and stronger every year. Farmers have to adapt their practices to reduce their water consumption (Chambre d'agriculture Drôme, 2023), and one solution can be the OM input. Therefore, the pressure on the use of OM is becoming very important in Drôme.

### 1.2.4 Composting as a solution to face environmental and economic issues and to manage biomass on the territory

In light of these conclusions, biomass valorisation in agricultural sector is one of the keys to close local flows. Among the technics allowing biomass valorisation, composting appears to be a viable solution because it allows to recycle a diversity of agriculture by-products (straw, manure, etc.) or individual ones (yard trimmings, other organic wastes). Furthermore, it allows producing a valuable product for soil properties improvement (detailed below). In Drôme, a solution has already been implanted to facilitate the composting practice. Indeed, since 2001, a "Coopérative d'Utilisation du Matériel Agricole" (CUMA) has bought a windrow turner to develop on-farm composting. Today, it involves 200 farmers (Agriliens, 2018) and every farmer can access this service by joining. At the scale of comcoms, yard trimmings collected in landfills are shred and become green waste shred (GWS). Since 2017, farmers from "Communauté de communes Val de Drôme" (CCVD) can buy this matter to spread it and/or compost it (Val de Drôme en Biovallée, 2018). On the other hand, the association "Compost et moi!" was created by a group of farmers from VDD. The project was to build a composting platform in order to valorise agricultural by-products of several farmers of the territory (Cabinet Isabelle Leduc, Inddigo, 2018). The association does not exist anymore, but CCVD has been carrying out a similar project for a few years. Composting is more and more considered by farmers and public institutions to solve all the issues cited above. Indeed, solutions such as those already carried out have to be implemented to broaden this practice which has a specific process and properties.

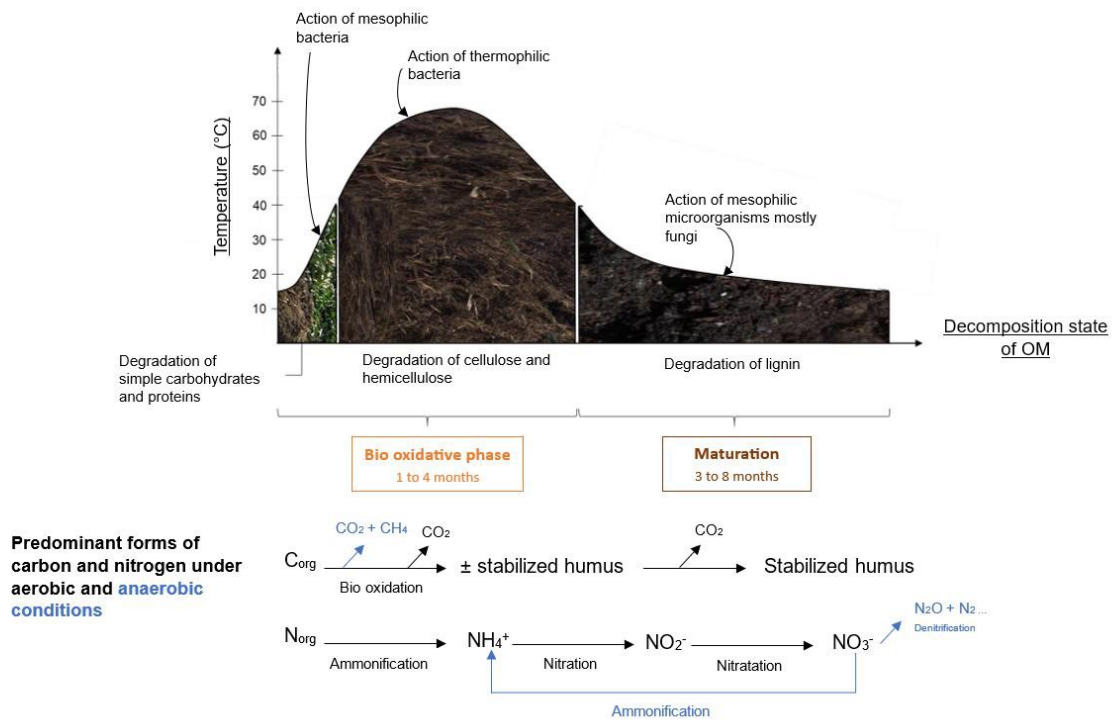


Figure 6: Scheme of the process of a theoretical composting process - the different steps of decomposition, the temperature evolution, the microorganisms acting – and the steps of the organic carbon and nitrogen transformation under aerobic and anaerobic conditions

### 1.3 Composting: a complex process determining compost quality

#### 1.3.1 Definition and expected benefits of compost use on soil properties

Composting is an aerobic biological decomposition and stabilization process of OM carried out by microorganisms under controlled conditions. Composting allows for the decomposition of several types of OMs, e.g., household kitchen scraps, crop residues, animal manures, GWS etc. From raw organic material, this process results in a stable and sanitized final products, spreadable on lands and known for its properties to improve soil characteristics : compost (Haug, 1993; Platt and al., 2014). Indeed, compost is considered as a valuable soil amendment which can be used to fertilize agricultural soil and improve its properties (Ko and al., 2008). Multiple benefits for the soil have been reported:

- Compost addition to soil has a positive impact on the yield of certain crop, it enhances the growth and productivity (Pane and al., 2014).
- The application of compost improves the available water content in soil, multiplied by 1.6 compare to no compost application, even if this effect is observed mostly at short-term (Weber and al., 2007). This is especially due to compost OM content which increases water holding capacity (Hargreaves and al., 2008).
- Compost addition to soil improves aggregate stability up to 41% in short-term (Annabi and al., 2011), which can decrease up to 66% soil runoff in short-term (Martinez-Blanco and al., 2013).
- Soil biodiversity (earthworms and microorganisms) can be enhanced by repeated application of compost (Steel and al., 2012; D'Hose and al., 2018).
- On the opposite, compost addition can decrease the quantity of parasitic nematodes (D'Hose and al., 2018).
- Compost application increases the availability of P, K and Mg at long-term. Their available contents are multiplied respectively by 2, 3 and 1.5 the first year of compost input (Weber and al., 2007).

#### 1.3.2 The composting process

Composting starts from a mix of OMs which each carries microorganisms, like mesophilic and thermophilic bacteria, actinomycetes and fungi, and which start their activity spontaneously and as soon as specific conditions of aeration, moisture and chemical ones are present (detailed below) (Noël and al., 2002; Ryckeboer and al., 2003). The speed of this process varies according to the matters to be composted (Francou, 2003) and to its management. It can be described in two phases (Pujol, 2012) (Figure 6):

First, during the bio-oxidative phase bacteria degrade simple bio elements like simple carbohydrates and proteins (Henry, Harrison, 1996). This degradation activity is characterized by carbon dioxide (CO<sub>2</sub>), water (H<sub>2</sub>O) and energy release which leads to a temperature increase, up to 40°C. This rise in temperature progressively inhibits the activity of mesophilic microflora, which cannot act above 40°C, giving way to thermophilic microbial communities. The latter are able to degrade more complex bio elements such as cellulose and hemicellulose. This degradation, which requires a lot of energy, leads to an increase in temperature mostly between 65 and 70°C (Van der Wurff and al., 2016). This stage, called "sanitation phase", is essential in composting because high temperatures, above 55°C, allow to kill pathogenic microorganisms and viable weed seeds (Bernal and al., 2009). At a temperature approaching 70°C, microorganisms cannot survive or be active during a long time. Their activity decreases, leading to a temperature drop (Bernal and al., 2009). During this phase, organic nitrogen (N<sub>org</sub>) is transformed in ammonium (NH<sub>4</sub><sup>+</sup>) by ammonification. Large quantities of H<sub>2</sub>O and CO<sub>2</sub> are released (Pujol, 2012), leading to important pile size decrease and compaction.

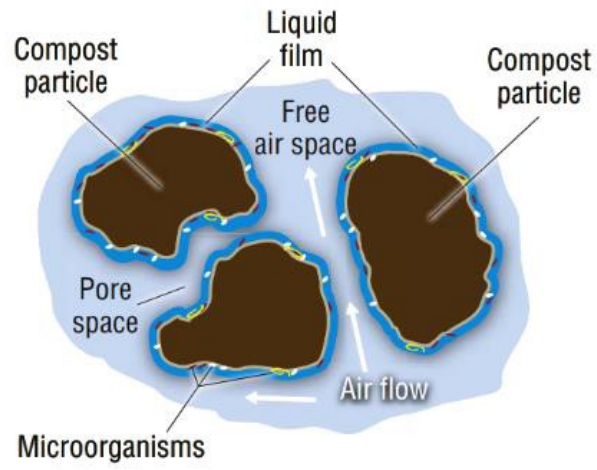


Figure 7: Zoom of the particles environment in a compost pile, representing the structuring of water and air around compost particles (Rynk, 2022)



During these phases, moisture and aeration are important for the process completion because they are necessary for microorganisms' activity. If the oxygen (O<sub>2</sub>) content is too low, the process could become anaerobic and lead to the production of greenhouse gases (methane (CH<sub>4</sub>), hydrogen sulphide (H<sub>2</sub>S), nitrogen oxide (N<sub>ox</sub>)). The optimum O<sub>2</sub> content is between 10% and 15% (De Bertoldi and al., 1988 ; Miller, 1993). Bacteria also needs water, they survive only in water films on the surface of bio elements (Van der Wurff and al., 2016). The optimum level of moisture content during this phase is between 60% and 70% (Gajalakshmi, Abbasi, 2008). The optimum O<sub>2</sub> content is found when there is enough space between compost particles which allow air flows. The optimum proportion of air-filled pores is between 35% and 50%. In the same way, if there is too much moisture, it fills the pore spaces and it reduces or prevent air flows (Figure 7). Above this limit, particles are too spaced, and it leads to temperature loss. If the porosity is less than 35%, particles are too close. Water and oxygen cannot circulate well and it leads to anaerobic conditions (Bernal and al., 2009). In addition to these parameters, the C/N ratio is a critical parameter to be respected. It is considered that the optimum C/N ratio is between 25 and 35 for a good degradation of OM. Under 25, microorganisms use labile carbon (C) by not transforming N into cellular compounds leading to N leaching or volatilization.

Above 35, the low availability of N in relation to C reduces the degradation speed (Van der Wurff and al., 2016).

- The second phase is the maturation one. As the temperature decreases, mesophilic microorganisms start again their activity to degrade more complex elements like lignin (Van der Wurff and al., 2016; Bernal and al., 2017). During this phase NH<sub>4</sub><sup>+</sup> is transformed into nitrite (NO<sub>2</sub><sup>-</sup>) then into nitrate (NO<sub>3</sub><sup>-</sup>) through nitrification by bacteria. Complex organic compounds are decomposed like lignin which leads to a stable humorous matter (Bernal and al., 2017). For the same reasons than in the first phase, if optimal conditions of moisture are not present, anaerobic transformations can occur and release CH<sub>4</sub> and/or nitrous oxide (N<sub>2</sub>O) and dinitrogen (N<sub>2</sub>) by denitrification (Van der Wurff and al., 2016). To avoid this, the optimum moisture content is between 45% and 50% during this phase (Bernal and al., 2017), and the optimum O<sub>2</sub> content is between 15% and 20% (De Bertoldi and al., 1988; Miller, 1993).

During composting, a number of operations are essential to ensure the process to run. First, watering the compost during the composting process ensures a sufficient level of moisture. It balances the water lost during composting through evaporation (particularly during the bio-oxidative phase) or through drying out due to weather conditions. In addition, turning compost piles is a mandatory step for composting. Its role is twofold: it homogenizes the material during the sanitization phase, thus sanitizing the entire material, but it also restructures the material as it becomes more compact (Gajalakshmi, Abbasi, 2008; Bernal, and al., 2009). This restructuring generally helps to re-stimulate the decomposition activity throughout composting. The intensity and frequency of these operations are highly variable, depending on the composting method, the materials being composted and the environmental conditions during the composting process. Composting management therefore requires both theoretical knowledge and experience (Rynk, 2022).

### 1.3.3 Compost quality: definition and indicators

As seen before, compost properties depend on the process management (length of decay, moisture and O<sub>2</sub> rate, etc.) as well as OMs composted. The wide variety of raw materials, composting techniques, and process management lead to a diversity of products with varying characteristics and quality.

**Table 1: Table of indicators commonly used to assess quality of a compost by taking into account its maturity, stability and innocuity**

Categories of quality assessment	Indicators	Positive points of the indicator	Limits of the indicator	Values	Sources
<b>Maturity</b>	Germination Index	Reliable indicator to assess compost phytotoxicity.	Phytotoxicity can be induced by high rate of salinity or TME.	Immature: <80% Mature: 80%-90% Very mature: >90%	(Buchanan and al., 2001)
	Cresson Test	Reliable indicator to assess compost phytotoxicity.	Phytotoxicity can be induced by high rate of salinity or TME.	Immature: <50% Mature: 50%-80% Very mature: >80%	(Fuchs, Weidmann, 2018)
	Texture	Simple indicator to know the decomposition stage.	Subjective.	Immature: very fibrous Mature: fibrous Very mature: crumbly	(Van der Wurff and al., 2016)
<b>Stability: physical indicators</b>	Odour	Simple indicator to know the decomposition stage	Subjective.	Immature: ammonia Mature: neutral Very mature: forest soil	(Van der Wurff and al., 2016; Bernal and al., 2017)
	NO <sub>3</sub> -N/N <sub>min</sub>	Illustrates well the progress of nitrification.	_____	Unstable: <0.2 Stable: 0.2-0.8 Very stable: >0.8	(Van der Wurff and al., 2016)
<b>Stability: chemical indicators</b>	C/N	Very used in compost analyses, assesses degradation.	Dependent on the C/N of the OMs before composting.	Unstable: >25 Stable: 12-25 Very stable: <12	(Bernal and al., 1998; Ko and al., 2008; Bernal, and al., 2009)
	CO <sub>2</sub> (mgCO <sub>2</sub> -C/gDM/d)	Assesses the microorganisms' activity.	Does not reflect the chemical progress of process.	Unstable: >8 Stable: 6-8 Very stable: <6	(Dimambro and al., 2015 ; Bernal and al., 2017)
<b>Innocuity</b>	Pathogens	Assesses if the sanitisation (temperature/length) has been successful.	_____	<i>Salmonella spp.</i> : absence in 25g BM Viable Helminth eggs: absence in 1.5g BM	(Chambre d'agriculture Occitanie, 2019)
	Weed germination	Assesses if the sanitisation (temperature/length) has been successful.	_____	Large number: >2 Noticeable Number: 0.5-2 Very low number: <0.5	(Vermont Agency of Natural Resources, 2015)
	Trace metal elements (TME)	Assesses if compost is spreadable without risk of polluting soils.	_____	Thresholds define for 9 TME by NF U44-051	(Chambre d'agriculture Occitanie, 2019)

The characterisation of compost quality is an important step in defining the potential impact of compost on the soil and the crop. For example, incomplete composting leads to a compost which can have negative impacts on seed germination and/or plant growth (Ko and al., 2008). Despite the lack of consensus on the definition of compost quality, the scientific community agrees on various parameters it should include, namely:

The **maturity** can be defined as the level of completeness of composting which means that the qualities obtained during maturation phase are taken into account (Bernal and al., 2009; Antil and al., 2014). One of the most important indicator to assess compost maturity is phytotoxicity because maturity is linked to plant growth potential (Iannotti and al., 1994; Epstein, 1997).

The **stability** of a compost is linked to a specific stage of decomposition which corresponds to the type of organic elements and their state during the process (Bernal and al., 2009; Antil and al., 2014).

**Agronomical values** correspond to fertilising values (contribution of mineral elements such as N, P, K, Ca, Mg, trace elements, etc.) and amending potential (contribution of organic matter).

The **innocuity** of a compost corresponds to the absence of harmful effects on spreading.

For all parameters (excepting agronomical values) several physical, chemical and biological indicators can be used (Wichuk, McCartney, 2010). The most widely used indicators, their advantages and limits are presented in Table 1. In addition, for maturity and stability assessment, it is generally accepted that two or more indicators should be determined per category (Ko and al., 2008; Antil and al., 2014; Alvarenga and al., 2016).

#### 1.4 Benefits and issues of on-farm composting

Compost has benefits on soil and can be used as an organic fertiliser or soil improver. But there are two types of compost. Industrial one can be bought like any other fertilisers or soil improvers. Industries compost from different sources - green waste, biowaste, residual household waste, waste sludge - and under very controlled conditions to fit standards. It is a viable solution for farmers to use this kind of compost because the process and the final product is controlled, and composts produced have normalized values. Despite this, it can be expensive because a lot of transport and handling is needed (Martel, 2009). Another type of compost is the on-farm produced one. Farmers compost according to what is produced on their farm and what is available around them (e.g., municipality can provide green waste, manure exchange, distillery by-products, etc.). For farmers, on-farm composting presents multiple advantages:

- It is less expensive than industrial compost because most of the time by-products are already on farms or raw matters are at low prices because they are considered as waste (e.g., GWS).
- Recycling by composting allows not to consider agricultural by-products as waste anymore, and rather seeing them as a precious resource to amend and fertilize soil (Pergola and al., 2018).
- It has been shown that composting on-farm is economically and technically viable and the production of a good-quality compost is more sustainable than buying organic fertilisers (Persiani and al., 2021).
- Compost is a way to replace chemical fertilisers and the key to ensure human and environmental health (Ayilara and al., 2020). Indeed, through life cycle assessment studies of production of several on-farm compost, the conclusion is that all the production cycle is environmentally sustainable (Pergola and al., 2018; Persiani and al., 2021).



However, on-farm composting presents certain limits. As composting is a controlled process where optimum conditions are needed, farmers have to monitor the process (Ko and al., 2008). Therefore, if farmers want to adopt this practice, they need:

- Equipment: an essential one is a compost turner but it can be expensive for only one farmer (Viaene and al., 2016). In France, this kind of costly equipment can be bought collectively through CUMA, but it means it has to be managed collectively as well, which is not always simple.
- Time: this practice is time consuming, mostly the monitoring of the process and turning. Farmers have to balance between composting and other farm's activities (Viaene and al., 2016; Cai and al., 2019). Moreover, there is often a shorter or longer time of composting because the length of feedstock decay does not correspond to the moment farmers want or have the right to spread (Viaene and al., 2016).
- Knowledge: farmers consider they lack experience and knowledge about on-farm composting (process, regulations, etc.). Moreover, some do not know how to assess compost quality ( Viaene and al., 2016; Paul and al., 2017; Cai and al., 2019).

Moreover, strict and complex regulations (Viaene and al., 2016) and the transport cost of raw matters (Paul and al., 2017) can prevent farmers to compost on-farm, especially nowadays with the increasing cost of oil.

On-farm composting has multiple advantages at different scale. Sometimes they are unknown, or they are ignored because the practice's constraints are more disturbing for the management of a farm.

### 1.5 Aims, challenges and operating mode of the study

Despite the fairly extensive knowledge about compost, the one about its production and use on farms remains poor. Thus, the main objective of the study is to characterize the use of compost and the scope of on-farm composting in VDD. It means that, on the one hand, the study aims to determine at which level the compost is used as an organic fertiliser or amendment in every sector of agriculture. On the other hand, it aims to characterize how many farmers actually do compost, their practices, their constraints, and the quality of their composts. Thanks to the information presented in the bibliographical work, it will be attempted to answer to the following questions:

- In a current context of increasing use and demand of organic fertiliser and amendment, what is the place of compost use in VDD? What are the main reasons of using it or not?
- Farmers sometimes choose to manage their by-products and/or to recycle other waste by composting them. It is a process with key stages, a specific management to obtain a spreadable final product. What is the quality of diverse composts produced on-farm and what conclusions can be made about the management of the process thanks to composts' analyses?
- Composting is a complex process which needs time, knowledge and material, but compost is also a beneficial fertiliser for soil; how many farmers compost, what are their motivations and how do they compost? What are their main constraints to compost and what levers can be considered to overcome them?

To answer these questions, FiBL France has launched a project aiming at better understanding and improving on-farm composting, and at improving knowledge on the effect of compost on soils under Mediterranean climate. The first part of this project, presented in this study, aims to report the current use of compost and the practice of on-farm composting. A survey was

Table 2: Characteristics of composts collected and analysed (o.f.: out of farm; f: farm)

Number of composts	Type of compost	Raw matters + origin
1	GWS	GWS (o.f.)
2	MMD	Goat manure (f) + DW (f)
3	GW	Crop residues (f)
4	GWS	GWS (o.f.)
5	AM	Sheep manure (f)
6	MMDG	Rabbit manure (f) + GWS (o.f.) + DW (f)
7	AM	Cattle manure (f)
8	DW	DW (f)
9	MMG	Sheep manure (f) + GWS (o.f.) + poultry droppings (f)
10	AM	Sheep manure (f)
11	GWS	GWS (o.f.)

carried out and 23 farmers from various agricultural sectors, composting on-farm or not, answered. 11 composts, from farmers who answered to the survey, were collected, and analysed to characterize their quality. From this data, links between compost analyses and farmers' answers have been made to identify the main constraints of these practices. Levers have then been proposed to face these later difficulties.

In the short term, the study will enable to reveal how farmers compost on farm and what limit this practice. In the long term, thanks to on-farm trials and the search for solutions to improve on-farm composting adapted to local context, awareness can be raised. The objective is to prove the need to use OM for soils, but also the need to have resilient agricultural systems to face environmental and economic challenges of the years to come.

## 2. Materials and Methods

### 2.1 Compost characterization and quality evaluation

The analyses described in this part have been chosen because they are the most common to assess compost quality and they are reliable (Table 1). Moreover, the importance of assessing each category of quality by at least two indicators has been considered in this study.

#### 2.1.1 Compost collection

11 samples of compost, considered as ready to spread by farmers, were collected in VDD farms from February to April 2023. Composts were produced from several raw matters alone (GWS n = 3, green waste (GW) n = 1, animal manure (AM) n = 3, DW n = 1) or as a mix of raw matters (mix of AM and GWS (MMG) n = 1, mix of AM and DW (MMD) n = 1, mix of AM, DW and GWS (MMDG) n = 1) (Table 2). The diversity of composts, raw materials and management are synthesized in Table 2. As soon as they have been collected, compost samples were stored at 4°C in unsealed plastic bags to avoid creating anoxic conditions. All the analyses presented below were carried out less than one week after compost collection.

#### 2.1.2 Agronomic values and pathogens presence

For each compost sample, sub-samples were sent to an external laboratory (SADEF, Aspach-le-Bas, France) for agronomical values and pathogens analyses. The shipping was done in a cool box at maximum 48 hours (h) after compost collection.

These analyses include:

- total N (Dumas method, NF EN 13654-2), P as P<sub>2</sub>O<sub>5</sub>, K as K<sub>2</sub>O, Calcium as CaO, Magnesium as MgO and Trace Mineral Elements (TME) (NF EN 16174).
- OMIS (Organic Matter Index of Stability):
- Organic C (C<sub>org</sub>): dry combustion (NF ISO 10694)
- C/N: calculation by C<sub>org</sub>/total N
- Presence of Salmonella and Helminth eggs (NF EN ISO 6579-1 and FD X33-040 respectively).

#### 2.1.3 Measures of dry matter

For each compost, 3 samples of fresh matter were weighed and oven-dried for 24h at 100°C. For each sample, the rate of dry matter (DM) was calculated with the formula:  $\frac{D_m - T}{F_m - T} \times 100$ , with D<sub>m</sub> the dry mass, F<sub>m</sub> the fresh mass, and T the container weight.





## 2.1.4 Analyses of compost stability

### 2.1.4.1 Extraction CaCl<sub>2</sub> of composts and dosing of ammonium, nitrite, and nitrate

This method is the one given with the reflectometer. For each compost, an extraction at 1:10 (w:v) in a solution of CaCl<sub>2</sub> (0,0125M) was done. After shaking for 1h at 200 turns/minute (Edmund Bühler SM-30) and filtration (VWR, size 185mm and particle retention 12-15µm), dosage of NH<sub>4</sub><sup>+</sup>, NO<sub>2</sub><sup>-</sup> and NO<sub>3</sub><sup>-</sup> were realised with a reflectometer (RQflex® 10, Merck). 3 repetitions were carried out for each compost sample.

The data obtained were converted and expressed in mgNH<sub>4</sub><sup>+</sup>-N/kgDM (same for NO<sub>2</sub><sup>-</sup> and NO<sub>3</sub><sup>-</sup>), following the formula:

$\frac{[NH_4^+]}{1000} \times \text{total volume} \div (\text{compost weight} \times 1000) \div \alpha \times \frac{\text{dilution coefficient}}{DM \times 100}$ , with  $\alpha$  the coefficient to convert NH<sub>4</sub><sup>+</sup> in NH<sub>4</sub><sup>+</sup>-N (1.2879), NO<sub>2</sub><sup>-</sup> in NO<sub>2</sub><sup>-</sup>-N (3.2844) and NO<sub>3</sub><sup>-</sup> in NO<sub>3</sub><sup>-</sup>-N (4.4266). Then, the NO<sub>3</sub><sup>-</sup>-N/N<sub>min</sub> ratio was finally calculated with mineral nitrogen (N<sub>min</sub>) the sum of NH<sub>4</sub><sup>+</sup>-N, NO<sub>2</sub><sup>-</sup>-N and NO<sub>3</sub><sup>-</sup>-N concentrations.

### 2.1.4.2 Compost respiratory activity

The method used was adapted from Benito and al., 2003. In brief, composts moisture were first restored to 57 ± 8%, by “hand-squeeze test” (Oshins, 2021) and incubated for 72h at room temperature. This preliminary step allows to overcome unsuitable moisture conditions which could lead to stability overestimation (Cooperband and al., 2003). After incubation, 100g of compost were placed in a pot and left overnight by taking care to prevent it from drying out. This step allows to stabilize it after the transfer between one container to another.

After this, respiration was measured with an infrared gas analyser (EGM-4, PPSsystems) for 180 seconds (s) for “active” composts and 300s for “less active” ones. For each pot, DM was measured with the same protocol described above. From the data, a linear regression coefficient was calculated, expressed in ppmCO<sub>2</sub>/s, and converted in mgCO<sub>2</sub>-C/gDM/d, following the formula:

$\frac{\text{measure} \left( \frac{\text{ppm}}{\text{s}} \right)}{\frac{DM (\%FM)}{1000}} \times 3.6643 \div 1.16 \times 10^{-5}$ , with 3.6643 coefficient to obtain mgCO<sub>2</sub>-C from mgCO<sub>2</sub>.

5 repetitions were done for each compost sample.

## 2.1.5 Analyses of compost maturity

### 2.1.5.1 Germination index

The method used was adapted from Yang and al., 2021. For each compost sample, an extraction on a dry weight basis at 1:10 (w (DM):v) in distilled water was done. This method was preferred to eliminate potential bias due to diverse compost moisture content (Luo and al., 2018). After shaking for 1.5h at 200 turns/minute (Edmund Bühler SM-30) and filtration (VWR, size 185mm and particle retention 12-15µm), 10 seeds of 3 species - radish (*Raphanus sativus*), Chinese cabbage (*Brassica rapa subsp. pekinensis*) and cress (*Lepidium sativum*) – were sown into Petri dish on a round filter (Rotilabo-Rundfilter Typ 11A). 5 millilitres of compost extract were added. The three species were chosen because they are regularly used to assess compost phytotoxicity and are considered to be the most sensitive to it (Young and al., 2016; Luo and al., 2018; Estrella-Gonzalez and al., 2020; Yang and al., 2021). 3 repetitions were carried out for each compost and each plant species. The same protocol was done with distilled water as control. All the dishes were then closed with Parafilm and put in darkness. After 72h, the number of germinated seeds was counted in each dish and the length of each root was measured. Then, the germination index (GI) was calculated as follow:

$$GI (\%) = \frac{\text{germinated seeds in compost filtrate}}{\text{germinated seeds in control}} \times \frac{\text{roots length in compost filtrate}}{\text{roots length in control}} \times 100$$

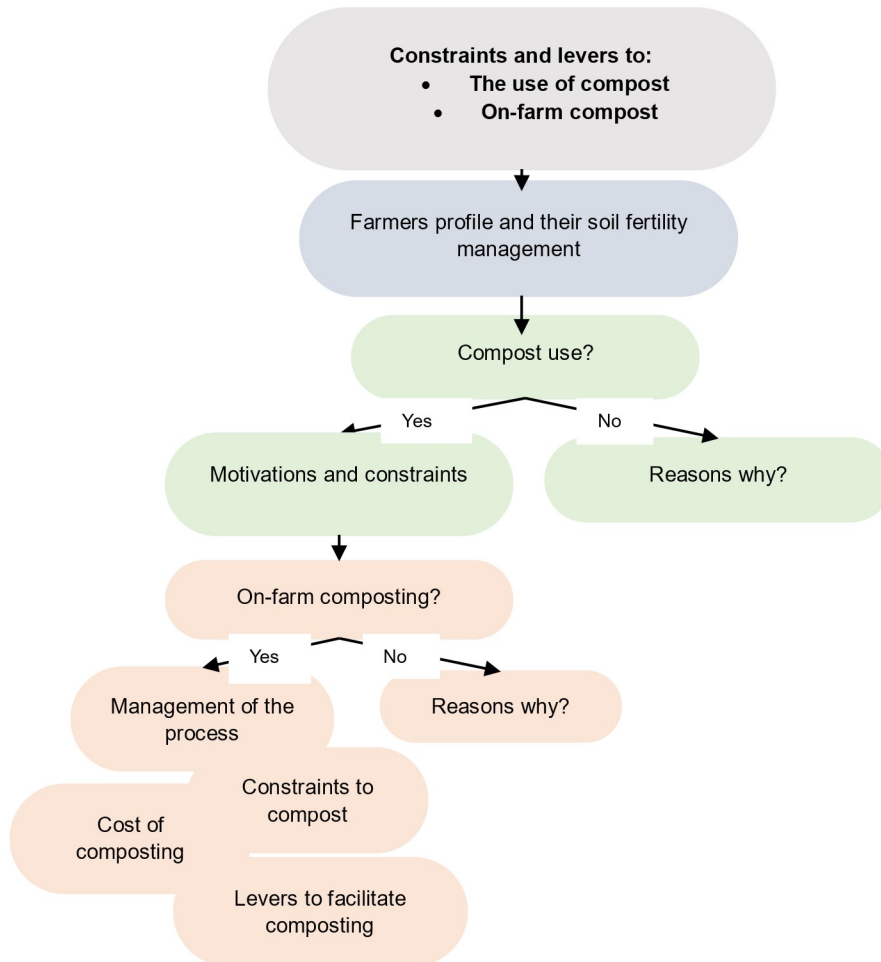


Figure 8: Tree structure with all the key elements used to write the semi-structured interview

### 2.1.5.2 Cress test

The method used for this test was established from [Fuchs, Weidmann, 2018](#). For each compost sample, moisture was adjusted to  $57 \pm 8\%$  according to “hand-squeeze test” and composts were incubated for 72h.  $50 \pm 1$  seeds of cress were seeded in pots ( $\emptyset$ : 6.5cm, height: 5cm) filled with compost. The same operation was done with breeding ground (Terreau horticole, Delbard) as a control. They were placed at room temperature under light (day-night 12h-12h) with a plastic film to allow homogeneous germination. For each compost sample, 5 repetitions were done. After 7 days, the mass of sprout of each pot was measured and compared to the control one.

### 2.1.6 Compost innocuity: weed seed spontaneous germination

The method used was adapted from [Vermont Agency of Natural Resources, 2015](#). A mix of compost and peat at 1:5 (compost:peat, v:v) was realised and put in a tray. Dilution of compost with peat allows reducing potential phytotoxicity which could lead to spontaneous seed germination underestimation. All the trays were placed at room temperature under light (day-night 12h-12h) with a plastic film to keep enough moisture for 3 weeks. Each week the number of germinated seeds was recorded and were then removed from the trays. At the end, the total number of viable weed seeds were calculated and expressed as total number of seeds per litter of compost. 3 repetitions were done for each compost.

## 2.2 Qualitative study

### 2.2.1 Creation of the semi-structured interview

Before creating the interviews, a bibliographical work was undertaken to understand the composting process and associated steps and practices which should be implemented. Readings about the context in VDD and the management of agricultural by-products and yard trimmings, especially about the local composting platform project, was done too.

As the issue lies in determining the constraints and levers relating to the use of compost and the practice of composting on-farm, several topics appeared essential to bring an answer. A tree structure was created (Figure 8) to visualize the key points needed to be addressed in the interviews to clear the issue. It has been divided into 4 sections, with the first one common to all the farmers interviewed. Then, three categories of farmers were established:

- They do not use compost.
- They use compost but do not compost on-farm.
- They use compost and compost on-farm.

The semi-structured interview was chosen because it allows to have as much details as farmers want to give us by asking them all the questions we want to ([Imbert, 2010](#)). It is pertinent in this case because the goal is to understand all factors which restrain the use of compost, the practice of composting on-farm and all the levers farmers are thinking about. The entire interview is presented in Appendix I.

### 2.2.2 Choice of the sample

Some criteria have orientated the choice of the sample:

- It was important to have a representative sample in terms of agricultural sectors present in the VDD and also to have a representative sample of their spatial heterogeneity.
- It was decided to have as many organic farmers as conventional ones, because different management of soil fertility could be observed, especially because organic farmers cannot use mineral fertiliser and could be more interested in producing or using compost.

Table 3: Critical values of indicators, scores associated and their mean

Category	Indicator	Critical value + score	Mean of scores
Maturity	Germination Index	<i>Immature</i> : <80% → <b>0</b> <i>Mature</i> : 80%-90% → <b>1</b> <i>Very mature</i> : >90% → <b>2</b>	<u>Immature</u> : the compost is still decomposing, and many phytotoxic elements are still present. <u>Mature</u> : the compost is practically mature, and a few phytotoxic compounds may still be present.
	Cress test	<i>Immature</i> : <50% → <b>0</b> <i>Mature</i> : 50%-80% → <b>1</b> <i>Very mature</i> : >80% → <b>2</b>	<u>Very mature</u> : the compost is mature and has no phytotoxic effects and may even encourage germination and plant growth.
Stability	NO <sub>3</sub> <sup>-</sup> -N/N <sub>min</sub>	<i>Unstable</i> : <0,2 → <b>0</b> <i>Stable</i> : 0,2-0,8 → <b>1</b> <i>Very stable</i> : >0,8 → <b>2</b>	<u>Unstable</u> : The compost is not yet ripe, and the micro-organisms are still working hard to break it down
	C/N	<i>Unstable</i> : >25 → <b>0</b> <i>Stable</i> : 12-25 → <b>1</b> <i>Very stable</i> : <12 → <b>2</b>	<u>Stable</u> : the compost is not quite ripe, and the micro-organisms are only moderately active in decomposing it.
	Respiration	<i>Unstable</i> : >8 → <b>0</b> <i>Stable</i> : 6-8 → <b>1</b> <i>Very stable</i> : <6 → <b>2</b>	<u>Very stable</u> : the compost is ripe and no longer decomposing.
Innocuity	Pathogens	<i>Presence</i> : <b>0</b> / <i>Absence</i> : <b>2</b>	0: There is a risk of contamination.  2: There is no risk of contamination.
	Weed seed germination	<i>Large number</i> : >2 → <b>0</b> <i>Noticeable number</i> : 0.5-2 → <b>1</b> <i>Low number</i> : <0.5 → <b>2</b>	
	TME	>thresholds: <b>0</b> / < thresholds: <b>2</b>	

Table 4: Agronomical values analysed and their perceptions by farmers

Compost	1	2	3	4	5	6	7	8	9	10	11
Type of compost	GWS	MMD	GW	GWS	AM	MMDG	AM	DW	MMG	AM	GWS
N (g/kg)	9,27	14,5	5,06	5,97	12,9	15,4	9,67	4,84	7,74	21	6,44
P <sub>2</sub> O <sub>5</sub> (g/kg)	3,48	7,4	4,82	2,46	8,13	14,9	3,31	2,61	3,52	10,3	2,78
K <sub>2</sub> O (g/kg)	5,67	10,1	5,25	3,41	28,3	11,2	8,2	4,71	6,72	29,9	2,71
OMIS (%)	62,8	81,5	77,3	64,3	59,5	78,7	80,7	69,7	75,7	58,2	78
Perceptions of farmers	OM input P and K input	OM input			OM input	Not much nitrogen OM input	P and K input	OM input	OM input	OM input	OM input

- It was important to have a fair ratio between compost user or not and between compost maker or not, to have as much diverse information as possible.

To contact farmers who could fit into these criteria, the list of farmers who take GWS from comcoms, the former list of the association “Compost et moi”, the FiBL network and the list of farmers struggling with irrigation have been rallied. Finally, 23 farmers have answered to the survey. A map synthetizing their localisation, their practice in terms of compost and their agricultural sectors is presented in Appendix II.

### 2.2.3 Transmission mode and transcription

All the interviews were conducted at farmers’ places and were recorded. Each of them, lasting between 15 minutes and one hour, was transcribed, first thanks to Word transcription tool, followed by one or several listening to correct the mis transcriptions.

## 2.3 Data treatment

Except the C/N ratio and the rate of TME, the agronomical values will be treated differently because conclusions about them depend on farmers aims in terms of fertilisation (such information was not asked during this study). For each indicator of maturity, stability and innocuity, the method of scoring was chosen to simplify and homogenise the understanding of composts’ quality. Indeed, according to the indicator, their critical values found into bibliography (Table 1), and their potential response curve (more is better, optimum, less is better), a score between 0 and 2 was attributed to each indicator (Schindelbeck and al., 2008; Obriot and al., 2016). 0 correspond to the worst quality (immature, unstable or phytotoxic compost) and 2 to the best quality (very mature, very stable, or not phytotoxic). All the indicators chosen, their critical values, the score associated and the meaning of each score are synthetized in Table 3. A global score was calculated by doing the sum of each indicator’s score. Understanding and conclusions about the 11 composts’ quality linked to process management are done by two methods. The first one is a statistical test, a PCA. Variables are expressed with the raw results and not the score. The second method is not statistical and is only based on the scoring. Concerning the agronomical values, N, P, K and OMIS have been chosen because they are the most widely used. Their values are compared to the farmers’ perceptions of their content in the composts.

All the answers to the questions of the survey (common to all the respondents) were gathered in several tables according to the different categories of practice (use of compost or not, on-farm composting or not, use of industrial compost), one table for farmers’ profile with their general fertilisation management and a last one with other useable information which resulted from other questions and discussions. Thanks to these tables, information were analysed by thematic method (Olivier de Sardan, 2008). Main topics which emerged from surveys were determined. All the answers (with the number of respondent) relating to each topic were grouped in a single document (Appendix III).

The results and discussions are divided into two parts because the 11 composts’ analyses allow to observe the diversity of composts produced on farms and to highlight constraints and issues when such a practice is done. The second part is here to approve, contradict, go further about the conclusions made in the first part.

## 3. Results and discussion

The results are organized in two parts. The first one discusses the links between the composts analyses and composting management and quality perception. The discussion is included in

**Table 5: Result and score per indicator, global score, and management of composting process (sd: standard deviation)**

	Stability			Maturity		Innocuity	Global score
	NO3-N/Nmin mean ± sd	C/N	Respiration mean ± sd (mgCO <sub>2</sub> -C/gDM/d)	GI mean ± sd (%)	Cress test mean ± sd (%)	Weed germination mean ± sd (nb of weed)	
<b>Results 1</b>	0,34 ± 0,25	19	36,75 ± 3,54	139,26 ± 37,66	54 ± 13	6 ± 5	
<b>Score 1</b>	1	1	0	2	1	0	5
<b>Results 2</b>	0,88 ± 0,02	11	3,38 ± 0,69	92,49 ± 17,02	63 ± 17	58 ± 11	
<b>Score 2</b>	2	2	2	2	1	0	9
<b>Results 3</b>	0,94 ± 0,01	10	0,45 ± 0,13	81,18 ± 6,91	70 ± 19	96 ± 11	
<b>Score 3</b>	2	2	2	1	1	0	8
<b>Results 4</b>	0,18 ± 0,03	22	5,33 ± 0,58	197,10 ± 22,05	67 ± 18	4 ± 6	
<b>Score 4</b>	0	1	2	2	1	0	6
<b>Results 5</b>	0,56 ± 0,01	14	29,60 ± 12,02	30,43 ± 5,73	0	0	
<b>Score 5</b>	1	1	0	0	0	2	4
<b>Results 6</b>	0,95 ± 0,01	9,4	3,47 ± 0,57	112,40 ± 13,22	55 ± 7	23 ± 16	
<b>Score 6</b>	2	2	2	2	1	0	9
<b>Results 7</b>	0,32 ± 0,03	13	3,48 ± 0,45	161,35 ± 19,69	92 ± 10	13 ± 5	
<b>Score 7</b>	1	1	2	2	2	0	8
<b>Results 8</b>	0,66 ± 0,05	13	11,36 ± 0,42	123,21 ± 39,34	52 ± 17	0	
<b>Score 8</b>	1	1	0	2	1	2	7
<b>Results 9</b>	0,66 ± 0,01	14	4,22 ± 0,55	114,95 ± 25,35	89 ± 5	6 ± 5	
<b>Score 9</b>	1	1	2	2	2	0	8
<b>Results 10</b>	0,92 ± 0,01	16	44,09 ± 6,40	84,11 ± 23,25	2 ± 5	0	
<b>Score 10</b>	2	1	0	1	0	2	6
<b>Results 11</b>	0,88 ± 0,02	14	1,43 ± 0,21	137,71 ± 14,48	52 ± 7	0	
<b>Score 11</b>	2	1	2	2	1	2	10

**Table 6: List of the analysed compost with their characteristics and the main interventions during the process (f: produced on farm; o.f.: produced out of farm; WT: windrow turner)**

Number of composts	Type of compost	Raw matters + origin	Composting time	Number of turnovers / material	Irrigation / Covering / None
1	GWS	GWS (o.f.)	2 months	2 / CUMA WT	None
2	MMD	Goat manure (f) + DW (f)	1 year	2 / CUMA WT	None
3	GW	Crop residues (f)	1 year	4 / CUMA WT	Covering
4	GWS	GWS (o.f.)	6 months	2 / CUMA WT	None
5	AM	Sheep manure (f)	2,5 months	1 / Fork	Covering
6	MMDG	Rabbit manure (f) + GWS (o.f.) + DW (f)	1 year	2 / CUMA WT	None
7	AM	Cattle manure (f)	8 months	1 / Spreader	None
8	DW	DW (f)	8 months	2 / CUMA WT	Irrigation
9	MMG	Sheep manure (f) + GWS (o.f.) + poultry droppings (f)	5 months	2 / CUMA WT	None
10	AM	Sheep manure (f)	5 months	2 / CUMA WT	None
11	GWS	GWS (o.f.)	2 years	1 / Backhoe loader	Irrigation

this part. The second one deals with the constraints enounced by interviewed farmers. This part is segmented by thematics for which results and discussion are dealt together.

### 3.1 Links between compost quality, process management and farmers' perceptions

#### 3.1.1 Agronomical values content in composts: N, P, K and OMIS

Table 4 synthetizes the main agronomical value, which are, in this study, the content of N, P, K and OMIS in composts, and the answers to the question "*What is the agronomic objective of using compost?*". 8 farmers out of the 11 answered that they use compost to bring OM to their soils. Concerning the real content of OMIS in each compost, there is a heterogeneity between them, from 58,2 to 81,5%. For farmers who answered "OM input", the OMIS content varies in the later range. So, there is a heterogeneity of values for the same answer.

Concerning the N, P, K values, the first result is that few farmers have an opinion about their content in the compost. Only 2 farmers (1 and 7) answered that compost bring P and K and 1 farmer answered that he thinks his compost does not contain enough N. For the later, his compost contains 15,4g/kg of N which is the third higher N content compared to the 11 composts. Compost 1 is composed by GWS only and contains 3.48g/kg of P<sub>2</sub>O<sub>5</sub> and 5.67g/kg of K<sub>2</sub>O. Compost 7 is composed by cattle manure and contains 3.31g/kg of P<sub>2</sub>O<sub>5</sub> and 8.2g/kg of K<sub>2</sub>O.

#### 3.1.2 Composts quality parameters

For each compost and indicator of quality, except for agronomical values, a score between 0 and 2 was attributed from the results of the analyses. Table 5 synthetizes the result and score associated for each indicator and also the global score for each compost. For all the composts, no targeted pathogens were detected (both Helminths and Salmonella) and the rates of all TME were lower than the regulatory thresholds. Because these results are identical for the 11 composts, they will not be used in the following results analyses.

In the first place, there is a heterogeneity of global scores for the 11 composts analysed, from 4 to 10 (the maximum reachable score is 12). Concerning NO<sub>3</sub>-N/N<sub>min</sub>, 1 compost out of 11 has a score of 0, 5 out of 11 have a 1-score and 5 out of 11 have a 2-score.

Composts have mostly a 1-score for C/N ratio (8 out of 11) whereas only 3 have a score of 2. As for C/N ratio, respiration rate is either very low with a score of 2 (7 composts out of 11) or very high with a score of 0 (4 composts out of 11). Concerning GI, a difference of sensitivity between the three species were observed, so a coefficient has been attributed to each of them according to this criterion (Appendix IV). The results are: 1 compost has a score of 0, 2 have a 1-score and 8 have a score of 2. Concerning cress test, 2 composts have a score of 0, 7 have a score of 1 and only 2 have a score of 2. Finally, weed seed germination number is very high with a score of 0 (7 composts) or equal to 0 with a score of 2 (4 composts).

#### 3.1.3 Links between the indicators of compost quality and the different process management of windrows

For each compost produced, the raw matters used and their origins, and the management of the composting process were given by the farmers (Table 6). For each compost, indicators' scores and global score assess the final product quality. As the process affects the quality, it is possible to find some links between both of them.

First, there is heterogeneity of compost management between farmers. Only 3 farmers out of 11 mix biomasses at the beginning of composting process whereas the other compost one biomass. The mean composting time is 8.8 months, and it varies from 2 to 24 months. 6 farmers stop the process to spread compost according to their calendar of fertilisation and their

Figure 9: PCA of the 11 composts quality analyses results and the process management

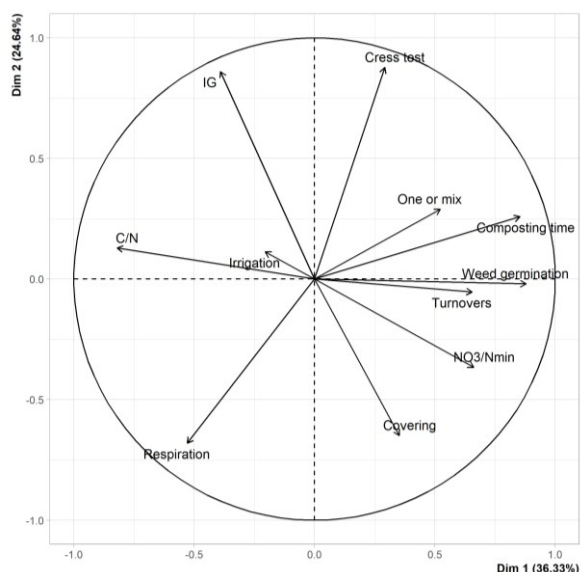


Table 7: Links between global score of compost quality and process management (in green: best scores related to process management; in orange: exceptions related to process management; in red: poor scores related to process management)

Compost	1	2	3	4	5	6	7	8	9	10	11
Type of compost	GWS	MMD	GW	GWS	AM	MMDG	AM	DW	MMG	AM	GWS
Global score	5	9	8	6	4	9	8	7	8	6	10
Turnover	2	2	4	2	1	2	1	2	2	2	1
Irrigation	No	No	No	No	No	No	No	Yes	No	No	Yes
Covering	No	No	Yes	No	Yes	No	No	No	No	No	No
Composting time (month)	2	12	12	6	2,5	12	8	8	5	5	24
1 or mix	1	Mix	1	1	1	Mix	1	1	Mix	1	1

Table 8: Links between weed seed germination score and process management (in green: process management related to the 2-scores of weed germination which are framed)

Compost	1	2	3	4	5	6	7	8	9	10	11
Type of compost	GWS	MMD	GW	GWS	AM	MMDG	AM	DW	MMG	AM	GWS
Weed germination	0	0	0	0	2	0	0	2	0	2	2
Turnover	2	2	4	2	1	2	1	2	2	2	1
Irrigation	No	No	No	No	No	No	No	Yes	No	No	Yes
Covering	No	No	Yes	No	Yes	No	No	No	No	No	No
Composting time (month)	2	12	12	6	2,5	12	8	8	5	5	24
1 or mix	1	Mix	1	1	1	Mix	1	1	Mix	1	1



free time. The others wait mainly to have a homogeneous product. The number of turnovers varies from 1 to 4, with a mean of 2. The main material used for compost turning is the CUMA windrow turner (used by 8 out of 11). Only 2 farmers out of 11 irrigate their compost and also only 2 out of 11 cover their windrow.

The first results analyse was done by a statistical test (Figure 9). It is possible to observe that some management factors are not well statistically represented, such as irrigation, one or mix and turnovers. Considering this information, a positive correlation between weed seed germination and composting time is observed. A hypothesis can be made about a possible positive correlation between the number of turnovers and weed germination. In the same way, a hypothesis can be made about a possible negative correlation between C/N ratio and turnovers. Then, composting time is well represented and is positively correlated to weed germination.

Considering that these later results do not take into account all the management indicators, other analyses are needed to understand if there are links between them and composts' quality or not. In this study, the mean quality is defined by obtaining the score of 1 for each indicator, so 6 for the global score. It can be noted that the highest scores (strictly above 6) are attributed to compost with specific process management compared to others. Indeed 3 modalities can be identified (Table 7, in green):

- The compost is made from a mix of organic matters (composts 2, 6, 9 with a score respectively of 9, 9, 8).
- The compost is covered (compost 3 with a score of 8).
- The compost is irrigated (composts 8, 11 with a score respectively of 7, 10).

There are 2 exceptions (Table 7, in orange):

- Compost 5 is covered but has a poor score (4).
- Compost 7 is not a mix, nor irrigated and covered but has a good score (8).

There are 4 composts with global scores under or equal to 6 and they have all one common point: their composting time is equal or inferior to six months (Table 7, in red) (composts 1, 4, 5, 10 with a score respectively of 5, 6, 4, 6), which is inferior to the mean of all the composts' (8.8 months  $\pm$  5.9).

There is heterogeneity of the global score according to the number of turnovers (Table 6). Indeed, for composts with one turnover, scores are 4, 8 and 10. For composts with two turnovers, scores are 5, 9, 6, 9, 7, 8, 6.

Global score can give a conclusion about compost quality, but it is also important to consider each indicator alone. This can give information about raw matters and composting management. For the 11 composts analysed, there are heterogeneities of scores between them for four indicators:

- Regarding the weed seed germination indicator, the score of 2 is attributed to four composts (5, 8, 10, 11) (Table 8). Among them, there are the two composts irrigated and the two animal manure composts. Compost 5, in addition to being a manure compost, is one of the covered composts. The other covered one has a score of 0.
- Regarding maturity parameters, cress test and GI can be considered together as they both allow to identify compost phytotoxicity. Composts 5 and 10 which are the only two animal manure compost (Table 9) both have a score of 0.
- Finally, regarding respiration parameter, the score of 0 is attributed to four composts which have a low composting time compared to the mean (composts 1, 5, 8, 10 which

Table 9: Links between cress test and germination index score and process management (in red: process management related to the 0-scores of both cress test and GI which are framed)

Compost	1	2	3	4	5	6	7	8	9	10	11
Type of compost	GWS	MMD	GW	GWS	AM	MMDG	AM	DW	MMG	AM	GWS
Cress test	1	1	1	1	0	1	2	1	2	0	2
GI	2	2	1	2	0	2	2	2	2	0	2
Turnover	2	2	4	2	1	2	1	2	2	2	1
Irrigation	No	No	No	No	No	No	No	Yes	No	No	Yes
Covering	No	No	Yes	No	Yes	No	No	No	No	No	No
Composting time (month)	2	12	12	6	2,5	12	8	8	5	5	24
1 or mix	1	Mix	1	1	1	Mix	1	1	Mix	1	1

Table 10: Links between respiration score and process management (in red: process management related to the 0-scores of respiration which are framed)

Compost	1	2	3	4	5	6	7	8	9	10	11
Type of compost	GWS	MMD	GW	GWS	AM	MMDG	AM	DW	MMG	AM	GWS
Respiration	0	2	2	2	0	2	2	0	2	0	2
Turnover	2	2	4	2	1	2	1	2	2	2	1
Irrigation	No	No	No	No	No	No	No	Yes	No	No	Yes
Covering	No	No	Yes	No	Yes	No	No	No	No	No	No
Composting time (month)	2	12	12	6	2,5	12	8	8	5	5	24
1 or mix	1	Mix	1	1	1	Mix	1	1	Mix	1	1

have composted respectively for 2, 2.5, 8, 5) (Table 10). There are 3 exceptions: composts 4, 7 and 9 also have composting time under the mean of the sample (respectively 6, 8 and 5) but a score of 2 is attributed for this indicator.

### 3.1.4 Discussion

#### 3.1.4.1 N, P, K and OMIS compared to farmers' perceptions: beliefs or realities

There is a high diversity of OMIS content in the 11 composts, which can be due to the composition of the raw matters but also to the management of the process. Nevertheless, farmers mainly consider that their composts bring OM to soils. According to the results, it is more a belief than a fact, which results probably from a known fact that compost is a soil improver because it contains OM.

Concerning the N content in composts, one farmer has mentioned it as too low. If it is compared to the N content of industrial organic fertilisers, indeed it is low. There is 1.5% of N in the analysed compost, whereas industrial organic fertilisers contain often more than 2/3% of N. Nevertheless, it is quite a high content for a compost.

The P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O content in composts can be compared to reference values. The values of the two elements for composts cited above fit into the P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O values found in literature for GWS compost (Joubert, 2012) and for cattle manure compost (Charbonnier, 2012).

Here the term perception can be used because none of the 16 farmers who compost on-farm send their compost to analyse it before spreading. Moreover, only 1 farmer follows-up the temperature with a probe. The others follow it up visually or by hand.

Two farmers answered the question by arguing that they use compost to bring a living matter to the soil (Farm.3) and to improve the soil structure (Farm.4). These two answers cannot be compared to reference as those above because they are impossible to quantify in such a study.

#### 3.1.4.2 Links between composts' analyses and process management

First, for the 11 composts, a heterogeneity of quality was observed. The analyses' results are very different from a compost to another. A diversity of raw matters and management was observed. As the biomasses composted and the process management are decisive to the final quality of a compost, their diversity leads to a heterogeneity of compost quality.

First, best scores are attributed to composts with specific management, which are moreover a minority compared to other composts. Indeed, it is often necessary during the composting to act on it by watering (Rynk, 2022). Compost needs optimal moisture to mature correctly because it allows microbial activity. Moreover, covering is used for several reasons: it allows to limit water evaporation and so keep moisture into windrows, it reduces nutrients leaching, and it allows to protect the windrow from external contaminations (e.g., weed seed) (Sun and al., 2018). Then, a mix of diverse raw matters is known to facilitate composting, especially for those with a high C/N ratio. For example, when green waste is mixed to "liquid" livestock manure, its moisture allows to bring enough water to compost green waste correctly, which is an uneasily degradable matter alone. It also allows to balance the C/N ratio (Chen and al., 2019). Another raw matter which is recommended to mix is DW because after distillation, so a long period under high temperature, microorganisms are lesser and less active into the matter (Greff and al., 2021).

In the case of the study, it is exactly this type of management which led to the best quality scores. Nevertheless, some exceptions were observed. First, compost 7 has a good score but there is no specific management. However, the raw matter composing is cattle manure. As it is a wet matter and has a C/N ratio between 20 and 30, the composting process is

Table 11: Profiles of the 23 farmers having answered the semi-structured interview (farms where composts were collected are framed / farms practicing on-farm composting are the 1 to the 16 / main agricultural activities are in bold)

Farmers	Settling year	Farm size (UAA)	Agricultural sector	OF/Conv.	Type of compost produced
1	2016	35ha	<b>Arable crops</b> Rabbit breeding	OF	GWS
2	2003	39ha	<b>Dairy goats</b> PAMP Arable crops	OF/Conv.	Goat manure + DW
3	2018	15ha	<b>Vegetable growing</b> PAMP	OF	Crop residues Mix of animal manure Cattle manure
4	2011	45ha	<b>Winegrowing</b> PAMP Fruit trees	OF	GWS
5	2018	19ha	<b>Vegetable growing</b> Sheep Arable crops	OF	Sheep manure
6	2010	34ha	<b>Arable crops</b> PAMP Winegrowing Rabbit breeding	OF	GWS + DW + rabbit manure
7	2019	90ha	<b>PAMP</b> Cattle Arable crops	OF	Cattle manure PAMP waste + cattle manure
8	1995	40ha	<b>Lavender</b>	Conv.	DW
9	2016	10ha	<b>Sheep</b> <b>Laying hens</b> Arable crops PAMP	OF	GWS + sheep manure + hens droppings
10	2011	120ha	<b>Sheep</b> <b>Arable crops</b>	OF	Sheep manure
11	1986	45ha	<b>Arable crops</b>	OF	GWS
12	1982	18ha	<b>Winegrowing</b> Arable crops	OF	Poultry manure
13	1995	80ha	<b>Dairy goats</b> Arable crops	Conv.	Goat manure
14	2017	2ha	<b>PAMP</b>	OF	Horse manure
15	2015	24ha	<b>Sheep</b> Arable crops	OF	Sheep manure
16	1995	100ha	<b>Arable crops</b> Poultry PAMP	Conv.	GWS
17	2001	68ha	<b>Arable crops</b>	Conv.	
18	1996	140ha	<b>Arable crops</b> PAMP	Conv.	
19	2003	34ha	<b>Winegrowing</b> Nut trees Arable crops	OF	
20	2004	40ha	<b>Arable crops</b> Poultry	Conv.	
21	2008	26ha	<b>Winegrowing</b>	Conv.	
22	1981	21ha	<b>Arable crops</b>	OF	
23	2020	3ha	<b>Vegetable growing</b>	OF	

Tableau 12: Management of soil fertility according to the main agricultural activities and the certification (farms using compost are in green; LB: livestock breeding, PP: plant production)

	Typology of farms				
		LB	PP	OF	Conv.
Number of farms using compost only	5	3	2	5	
Number of farms using compost and organic fertilisers	7	1	6	7	
Number of farms using compost and mineral fertilisers	2	1	1	2	
Number of farms using compost, fresh manure and organic fertilisers	2		2	1	1
Number of farms using only organic fertilisers	1		1	1	
Number of farms using only mineral fertilisers	1		1		1
Number of farms using organic and mineral fertilisers	1		1		1
Number of farms using fresh manure, organic and mineral fertilisers	1		1		1
Number of farms using fresh manure and organic fertilisers	1		1	1	
Number of farms not using fertiliser	2		2	1	1

facilitated (Devi and Khwairakpam, 2020). Then, compost 5 has a poor global score even if it is covered. This can be the consequence of a low composting time. Finally, compost 3 is covered but contains a lot of weed seed. This can be due to an insufficient temperature rise and/or a bad management of the covering (if the windrow is not covered during all the process, contamination can happen). As this compost has a good global score, the second hypothesis is more relevant.

Without such management processes, compost analyses have proven that compost quality is lower. Moreover, the poorest scores are attributed to composts with a low composting time. It is known that the couple of time and microbial activity leads to a good degradation and mature compost (Bernal and al., 2017). So, a low composting time coupled with no specific process management, lead to poor compost quality.

Concerning the number of turnovers, there are heterogeneity and no links between their numbers and the composts quality can be established. It explains why the link between them on the PCA is not significant. This conclusion can be explained by the fact that their frequency and the period when they are done are also important. If the windrow is aerated but is dry, there is low effect. Nevertheless, turning often is essential to a well-manage process and to reduce composting time (Reyes-Torres and al., 2018) (compost 11 was turned one time but stayed 24 months because it took time to be entirely degraded).

High phytotoxicity was observed only for animal manure composts (sheep manure only for both composts). It can be due to high salinity content of raw matter (Aslam and al., 2008). Unfortunately, this test was not conducted, and this hypothesis should be tested.

These conclusions show tendencies. A majority of farmers do not irrigate, cover and/or mix two or more biomasses in their compost. Moreover, a majority of windrow are turned by the CUMA turner, but the number of turnings is very random, as well as the composting time which is for a majority dependent of the farmers calendar and their fertilisation needs. Concerning compost quality perceptions, they are very uncertain. They are not based on facts because most of the farmers interrogated do not monitor the process and do not analyse the final compost. It may also be due to a lack of knowledge about the analyses needed to qualify the compost quality, how to read them, but also how to visually qualify a quality and a decomposition state.

These conclusions deducted from compost analyses are true for 11 composting farmers. To confirm or infirm them, the answers of the 23 surveyed farmers including the 11 where compost was collected are going to be analysed in the next part.

### 3.2 Constraints and limits to the use of compost and to on-farm composting

In this part, the results and discussion are going to focus on the answers of the 23 farmers surveyed.

#### 3.2.1 Compost: a variable fertiliser used mostly by organic farms

For each of the 23 farmers, questions about inputs (organic and/or mineral fertilisation) were asked.

Table 11 synthetizes the main agricultural activities and production system (organic or conventional), and the type of composts produced. The first result is that 16 farmers out of 23 use compost as soil improver, and moreover these composts are produced on-farm (Table 11). Table 12 synthetizes the links between fertilisation inputs and the typology of farms. Concerning the 16 farmers using compost, for 5 of them, it is the only input. 4 out of these 5 farmers gave a compost sample to be analysed and are part of the results described above. They are composts 2, 4, 5 and 9 with the scores of 9, 6, 4, 8 respectively. These 5 farms are about as many livestock breeders as plant producers. Nevertheless, farm 5 is a vegetable growing one mainly but has chosen to breed sheep to be autonomous in fertilisation.



Moreover, these 5 farms are all organic ones. Their motivations in using only compost are:

- To reach a fertilisation autonomy and to stop being dependent on industrial fertilisers (Farm.5 and 9).
- Organic fertilisers are too expensive (Farm.2 and 4).
- There is manure production, and it is sufficient to fertilise all the crops (Farm.15).

Concerning the others:

- 7 also use organic fertilizer. There are mainly plant producer and all organic farms.
- 2 use mineral fertilisers in addition to compost. One is a livestock breeder and the other is a plant producer. They are both conventional farms.
- 2 use both fresh manure and organic fertilisers in addition to compost. They are both plant producer mainly, even if they both also have a livestock breeding activity (which is less important). One is an organic farm and the other is a conventional one.

These 9 later farms do not use only compost and they were questioned about the reasons why. There are diverse reasons not to use only compost (some have one or more reasons):

- Availability of the resource: 3 farmers do not have sufficient compost available to ensure 100% of fertilisation. They must complete with organic fertilisers (because they are organic farmers).
- Crop system: 8 farmers add fertiliser (organic or mineral) because their composts are not sufficiently nitrogenous, especially for some specific crops (which are different for each farmer).
- Material: 4 farmers add fertilisers for plots which are unreachable for compost application. They can be preferred because they are easier to spread than compost.

For farmers who use compost, there are uncertainties in this practice. Compost produced on farm is non-standard (answered by 1 farmer) which is correlated with another answer given by 1 farmer that he does not know what he spreads (in terms of nutrients) with his compost. Moreover, none of the farmers who compost on-farm analyse their composts before spreading.

For the 7-non-compost-users, the use of compost as a soil improver generates uncertainties and constraints:

- 2 farmers produce high-value product (especially garlic, for consumption or seeds in VDD) which need specific input to reach specific yields. They think that compost is too unreliable, especially regarding the nutrients' availability, compared to organic or mineral fertiliser: *"in seed production, I am required to have a linear yield"* (Farm.18).
- 2 of them, who have composted on-farm in the past, do not use compost anymore. They stopped composting because they no longer have access to raw matters. Now, one uses no input at all whereas the other uses organic fertiliser.
- 2 farmers use fresh manure in addition to fertiliser. They do not compost it because they prefer spreading it directly to keep the "boost effect" and because they are not sure about the advantage of composting it: *"Composting will take me more time and money"* (Farm.20).
- The last one does not use compost because he prefers spreading GWS directly to not lose the value of the raw matter.

These results highlight a diversity of constraints related to the use of compost. Those who use only compost have different reasons to do so, autonomy research, economic and sufficient volume. Nevertheless, 2 of them compost on-farm and their composts quality remain poor. One practices because it is not expensive but the other does this to be autonomous in fertilisation.





This later case reports that even for farmers who relate at 100% on compost to fertilise and amend their soils, the process and the quality of compost is not considered as a priority. For farmers spread other fertilisers in addition of compost, one of the reasons is that they lack compost quantity. It can be due to a raw matter insufficiency. Some other farmers think that their compost is not sufficiently nitrogenous. Nevertheless, they do not analyse them, so this information is not based on real value but more about a feeling. They could be right about their beliefs because compost is not known for its nitrogen content. Otherwise, it could be interesting to compare the yield of a nitrogen-needed crop under organic fertiliser and compost, to know if it is necessary to spread organic fertiliser instead of compost. Another consequence of the absence of compost quality analyses is that compost is a non-standard product. This leads to special rules of spreading but also uncertainties about nutrients content and deliberation. It can be noticed that the reasons why farmers do not use compost are the constraints cited by farmers who use compost. It means that these issues are known by a majority of farmers, some dare or must use compost, but for some it prevents them to practice.

### 3.2.2 Specific material is needed to on-farm composting and spread compost

As it has been seen in part 3.1, on-farm composting requires some specific equipment. This requirement can lead to a dependency on material or can become a constraint.

3 farmers stated that this practice is too complicated if the farm is not well-equipped, at least with a bucket loader and a windrow turner. However, such equipment is expensive. Thus, most of the time, when it is possible, farmers' groups are created to share material. It is the case for 11 farmers out of the 16 who compost on-farm, who use a common windrow turner. They have signed up to a CUMA owning one (Agriliens, 2018). One person is responsible for turning every type of composts in Drôme and Ardèche, and he asks if farmers of the area he comes by are interested in having a turnover or not. This leads to a dependency on this material because farmers are dependent on the turner visit. 4 farmers mentioned this as an issue and 2 of them think about buying one to become independent and to turn compost when it is needed. This dependency affects composts' quality: *"The windrow turner is a bit complicated. It comes in the summer, but the manure is very dry, I don't know if there's a point in turning it over."* (Farm.15), *"This year we've had the windrow turner stopped, [...], I spread fresh manure on the rape and now I've got terrible barley regrowth in the rape."* (Farm.10).

Some other farms equip themselves with other material. Only 4 farmers out of the 16 who compost on-farm have tarpaulins and 3 out of the 16 irrigate the windrows. The fact that a minority of farmers uses these types of material results from constraints. There is a logistic issue. 2 farmers said that covering windrows is very complicated. Indeed, tarpaulins take time to be put on and pulled off and these actions have to be done before and after the turning. It is very time-consuming and as a windrow is more or less long, devices such as rewinder is needed (which is costly).

Similarly, the question of the use or availability of equipment was raised as a central issue by the farmers surveyed who do not use/make compost. When they were asked why they do not use/make compost, 4 of them replied that one of the main reasons is that they do not have the suitable material. It is about both the spreading, which requires specific material compared to those to spread mineral or organic fertiliser, and the on-farm composting, which requires important investments if a farmer starts from nothing.

### 3.2.3 The difficulty to manage moisture, in a territory with dry summer

Among the farmers who compost on-farm, 7 find their compost too dry, especially during summer. 6 out of the 7 cannot or do not want to irrigate windrows. In a department with several water restrictions especially in summer, farmers do not have access to water to irrigate their



crops, so, it is unthinkable to water their windrows: *“We have no water here. There’s nothing here that can be watered.”* (Farm.2). Through the interview, a difference between the volume of agricultural by-products according to the different farmers was highlighted. Indeed, farm. 8 obtains more than 1000t per year of DW compost, has a platform and irrigate, a better way of irrigation is even already in reflexion. On the contrary, farm. 13 obtains 300t per year of goat manure compost, on a plot edge, and said that it is unthinkable to water compost.

So, for a majority, the question of water is the heart of an uncomplete composting process, but also for a majority it is impossible to water compost (only 3 farmers out of the 16 farmers who compost on-farm irrigate their composts). and 4 use a tarpaulin (which is most of the time cited to avoid leaching more than keeping moisture). When the idea of covering to keep moisture is mentioned, some agree and say that they have already thought about it. Nevertheless, the first reason to use this equipment is to avoid leaching. However, only 4 out of the 16 farmers who compost on-farm use one, mostly because it is unaffordable.

It is interesting to report that farmers who have to compost a huge of compost implement more resources. It is becoming for them a real farm activity among the others. Nevertheless, a counterpart is needed to compensate the expenses.

### 3.2.4 An uncertain availability of raw matters in an agricultural diversified organic territory

The report that most of the farmers who compost on-farm use only one matter to compost has been raised in part 3.1. Moreover, knowing the VDD context about biomass, the hypothesis of a possible lack of biomass availability in certain area is confirmed by the interviewed farmers. They gave their opinion about the fluxes of biomass on the territory and at department/region scale. 4 farmers think that there is a biomass deficit in their area, one farmer thinks that biomass is gaining more and more in value at the territorial scale and 3 farmers think that these evolutions are due to the rising number of farms going to organic. The main biomass deficit according to farmers is in manure. 6 farmers said that it is complicated to find manure around them and throughout the department, mostly because those who have some tend to keep it. On the other hand, farmers who produce manure on their farms have many requests to buy manure: *“it’s a crazy thing, all the people who call me for manure.”* (Farm.15). This deficit forces farmers who really need manure to import it from other territories and at high prices. It is the case for one market gardening farm which buy cattle manure from Savoie. They are willing to pay it at a high price because for this type of production, fertilisation is an important expense.

This constraint is not only mentioned by farmers who compost on-farm. When farmers who do not use/make compost were asked the reasons why they do not make compost, 2 out of 7 said that a good compost is a mix of GWS and manure, but this later is unavailable around their farm, and they are not livestock breeder.

Several solutions to face this rarefaction of biomass in VDD were cited by farmers:

- For 3 winegrowers, grape pomace is a compostable matter which is lost. According to the winegrowers questioned, they all agree that cooperative must think about a local revalorisation of this by-product. Indeed, we could think of a similar operation than DW. For these later, farmers have the choice to bring them back on their farm or to leave them at the distillery place.
- 2 farmers discussed the fact that landscapers have the obligation to bring yard trimmings in landfills and to pay to do this. For these farmers, it could be simple for both that landscapers could leave their waste at the farmers’ places directly and for free.
- 1 farmer brought back shared household waste compost of a city nearby to spread it on his farm during a year. For him it was a good idea, because he knew that some households participating to this compost were buying his farm’s products.



Nevertheless, this was not really legal for organic farming and as the process was not controlled, the decomposition was random especially with some « compostable » products like coffee pods. This source of biomass should be taken into account and solutions to compost them efficiently should be found, especially because in France,

Finally, in addition to the rarefication of raw matters, their price (answered by one farmer) and their quality (answered by 2 farmers talking about the presence of plastic and weed seed in GWS) are considered as constraints. Moreover, the rarefaction of these matters can affect farmers. For instance, for farmer 12 engaged in a biodynamy label, it is forbidden to buy manure at more than 30 kilometers from the farm. Indeed, farms with this label are using compost as the main fertiliser (Demeter, 2023) so it could be difficult for farmers who are not livestock breeder in a territory with a decrease in manure availability.

### 3.2.5 A time and space-consuming practice

Regarding time dedicated to on-farm composting, it is a time-consuming practice for 3 farmers out of the 16 who compost. On the contrary, for livestock breeder, there is no loss of time because in any case, they would have to bring out the manure. Moreover, it is even a benefit to compost because it allows to reduce the volume of manure (answered by 1 farmer). On-farm composting is one more practice for a farmer among all his activities. So, it is often difficult to find time to take care of a practice often considered as minor (Viaene and al., 2016). For example, 3 farmers would like to do more follow-ups during composting and final analyses, but they lack time (answered by 3 farmers). This has consequences on the composts' quality because follow-ups could allow to adjust the process management. Moreover, the spread is also time-consuming (answered by 2 farmers). Surprisingly, the proportion of farmers who have highlighted the fact that composting is time-consuming remains poor in comparison to studies carried out in different context. On the one hand, this can be explained by the fact that few operations are carried out by farmers during composting (compost analysis results and composting practices) and that the most time-consuming operation (turning) is carried out by an external service provider. On the other hand, this can be due to the fact that farmers are at the beginning of what is possible to do. Indeed, this practice is for now coming after all the other agricultural practices. There are several reasons to this: they do not have time because the management of the farm is already time consuming, they do not have sufficient knowledge to compost correctly and simply and for now farmers practicing are a minority and except the CUMA, there are no working groups to improve the practices.

Regarding space dedicated to composting, generally speaking, windrows size is more or less important and so on-farm composting requires more or less place. Most of the time, farmers compost at the edge of a plot. Only 1 farmer out of the 16 who compost on-farm has a real platform. That means that a part of their UAA is committed to this practice. 7 farmers answered that the main constraint observed is that the space dedicated to composting must be accessible to lorries, turners and must comply with regulations: right distances between the composting area and waterways, housing, roads according to the type of farms (Chambre d'agriculture Occitanie, 2019). Considering these, the number of plots on which composting is feasible (both technically and in terms of regulation) is reduced. Thus, composting generally takes place on a permanent area from one year to the next. This leads to the degradation of the plots as well as soil pollution because of the accumulation of compost juice in soil. Moreover, it does not fit regulations (Appendix V), which are, according to 3 farmers, not adapted for on-farm-composting. Farmers are aware of these constraints but cannot do anything except building a compliant platform which is very expensive.



### 3.2.6 A costly practice but with a benefit/cost ratio often unknown

Regarding the cost-benefit ratio of on-farm composting, 5 out of the 16 who compost on-farm consider it as beneficial and 3 others answered that it allows not buying organic and/or mineral fertilisers. These answers are all based on perceptions and not on calculations and numbers. None of the farmers answering have done an economic analyse to calculate the real cost and benefits of the practice.

Concerning the 5 farmers considering the practice beneficial, 3 of them (farm. 2, 8, 13) compost only their agricultural by-products. The 2 others have different profile (farm. 3 and 11). Farmer 3 compost green waste from crop residues alone, the manure of a diversity of animal of the farm and finally cow manure coming from out of the farm. 200t of the latter raw matter is bought every year and it represents the main volume of compost. This year, the cost of such matter was 33€/t delivered, and each year the price increases. He is aware it is expensive, but as he is a vegetable grower, fertilisation and soil improvement are one of the most important expenses: “- *Int: Do you have any idea of the maximum price you'd be prepared to pay for this material? – Farm.: Expensive, very expensive, if you like, we have high value-added market garden production. [...] What's more, we're organic, so we don't have much choice.*” Farmer 11 compost GWS from CCVD, he pays €50/skip delivered. He finds it expensive but compared to organic fertiliser (€500/t delivered) and industrial compost (€25/t delivered), it is most beneficial.

When the cost of the practice is discussed, raw matters are at the heart of the answers. For the farmers who have free raw matters to compost, the question about the profitability is easily solved. For most of the others, the cost is the decision rule to buy one or another raw matter. Nevertheless, if the entire practice is considered (cost of oil spent to make compost, of material, time spent and final value of the compost), perceptions could change. For instance, if animal manure is considered, it has to be brought out of the building several times a year and it has to be moved to the composting location. These operations can take time and are also oil consuming. Moreover, according to the results and discussion above, some material such as tarpaulins are considered as too expensive, and its cost is the main limit for farmers buying one. But if we consider all the costs and the benefits it represents, compared to a practice without tarpaulin, it could be interesting and it could be a proof of the usefulness of some material. An economic analyse was done by [GAB44, 2015](#), to compare three modalities of cattle manure composting processes: without covering it, covering it with straws and covering it with a semi-breathing tarpaulin. The study quantifies the cost of the elements' loss by leaching, the cost of the type of cover and the working time. It concludes that the third modality, with a tarpaulin, is 5 times less expensive than the first one and 8 times less costly than the second one. This kind of calculations show the balance between all the factors which have to be taken into account to quantify the cost-benefit ratio. By taking into account all the actions and costs from the windrow making to the final compost, appropriate decision rules could be made by farmers.

## 4. Perspectives of the study

In the VDD current context, composting appears to be a solution to recycle agricultural by-products and other waste. Actions have already been set up by farmers and comcoms' actors. Nevertheless, according to the report made above, some factors hinder the well-functioning of on-farm composting and the use of compost. Levers must be found to overcome the two practices by organizing, facilitating, and promoting them at different scale.





#### 4.1 Farmers collectives: a solution to unite the needs, material, work and knowledge

Often, for changes in farming practices and new practices, farmers' groups are set up to facilitate the development and/or transfer of practices ([Ansaloni, Fouilleux, 2006](#)). As on-farm composting is becoming a topic in the farming world, levers could be found at farmers' collective scale.

As many composting farmers are already gathered in the CUMA owning the windrow turner, levers can be found into this group. For now, the windrow turner access is a major constraint for farmers. The first point at the CUMA scale is the necessity to improve its organization in order to ensure at least 2 turnovers at an optimal composting stage (when the temperature decreases in the pile). Multiple scenarios could be possible to overcome this problematic:

- Several turners could be bought and dispersed in several areas. It would not be only one person in charge of the turnovers, but each farmer would use the material when he needs it. One limit to this solution is that every farmer would have to know how to use it. Another one is that it represents an important investment, and the maintenance must be done by farmers.
- Other types of material could be bought to fit to all type and size of farms. According to these characteristics, they do not have to manage the same volumes of compost. Windrow turner is very efficient for long pile because it is very fast for such volumes. For smaller windrows, an alternative could be a rotor bucket (a bucket with a turning system) which is smaller than a turner, probably more adapted to small scale on-farm composting. In addition to the size of the windrow turner, additional equipment could be added. A turner with irrigation system or with a tarpaulin rewriter could be interesting for farmers for whom the logistic to turn, irrigate and cover windrows independently is too constraining.

Then, as logistic and some expensive material limit the practice of on-farm composting, it is possible to think about a collective practice. It could have several benefits:

- Instead of being alone to manage the process, several farmers are sharing the work. It is already done by a French association of farmers who collect, sort and recycle biomass ([Agriculteurs composteurs de France, 2023](#)). Naturally, if several farmers add their by-products to do one or multiple windrows, the volume will be higher. Nevertheless, according to the type of farm where the compost is done, regulations could limit the volume of compost. This type of practice also means that the process has to be managed by different persons and so, a precise organization between associated farmers has to be set up. Considering that there is more volume of compost to manage but that there is a collective functioning, the working time of each farmer has to be compared to a practice where a farmer composts alone on his farm.
- If farmers from different agricultural sectors join forces, it could allow to mix different biomasses to compost them. It would allow to have a better-quality compost. Nevertheless, the distribution of the final product has to be defined. Indeed, if a farmer brings manure and the other one GWS, there is a difference of value of raw matters. An arrangement about the volume of compost taken according to the value of raw matter could be considered. Here again an organization is necessary so as not to waste time and money whereas the goal of this practice is to save them.
- Material purchases would be decreased because the expenses would be divided by the number of associated farmers.

Finally, farmers network and meetings on farms should be developed because it allows to share practices, test new methods and discuss them. It is particularly used in farmers'



associations and it is also the principle of economic and environmental groups of interest ([Ministère de l'Agriculture et de la Souveraineté Alimentaire, 2014](#)). In addition to these official groups, farmers can organize themselves to discuss, with neighbours and with farmers from a farming sector. If this kind of group concerning compost and composting increases, it would allow to find simple levers to improve practices at farmers scale. Moreover, they would know what biomass is available around the farm and could discuss easily about exchanges.

Concerning the availability of raw matters, these kinds of collectives could also allow to source new biomasses. One of them is the green waste coming from the pruning of farm's trees. For now, this type of matters is burnt because there is too much volume to bring them into landfills or farmers lack of time and/or material to shred it and compost it. A shredder could be bought by several farmers, through CUMA principle, allowing GWS to be composted. First, a matter considered as a waste could be valorised and then, mixing several matters could be easier. Moreover, it would also allow to protect the absence of undesirable waste like plastic, which is the main constraints for farmers composting yard trimmings collected in landfills.

#### 4.2 Stakeholders close to farmers have an influence on changes and developments in farming practices

Farmers are at the heart of this practice and can play a role in the development of on-farm composting and compost use. Nevertheless, they cannot act alone. As cooperatives, comcoms are in relationship with farmers and also generate and manage waste, they have to work with them to help finding solutions.

One lever is to improve the recycling of agricultural by-products which is insufficient for some of them. For instance, cooperatives should work on grape pomace local valorisation. A system like that of DW could be implemented. Farmers should have the choice to bring back the grape pomace corresponding to the volume of grape they would bring. It could allow to mix it with other raw matters. One limit is the management of the grape pomace after the vinification. Indeed, most of the time in cooperatives, organic and conventional winegrowers vinify in the same cooperative. Currently, the pomace is mixed in one bucket to be sent to distillation. If farmers want to bring back the by-products, it is necessary to separate the pomace from organic winegrowing and from conventional one. If it is not the case, organic farmers would not be able to spread this matter. If some farmers do not want, two main solutions could be considered. The first one is still to bring the pomace to distillation. The second one is that cooperatives could compost it and sell the final product.

From January 1<sup>st</sup> of 2024, solutions need to be found to recycle household waste in a qualitative way. As the volume of recycled waste will increase, one of the possible recycling ways could be as a compost spreadable by farmers. Nevertheless, it has been already tried and there are limits. An increasing number of matters are considered as compostable, but their length of degradation is longer than for organic one (e.g., paper, cardboard) ([Francou, 2003](#)). If common composting bins are set up, their management must be monitored to produce a valuable final product. If not, it would not be spreadable by farmers. Therefore, one limit to this is the process management. It requires people to look after the composting, to turn the compost. Moreover, awareness of every citizen is essential to find in the bins only compostable matters. Finally, there is again the limit for organic farmers. Currently, the use of household compost, even if it is produced by an industry, is forbidden for this type of farming.



### 4.3 Advisors and researchers' aim is to develop knowledge about compost and composting

For now, there are increasing research about the effects of compost on soils but few about on-farm composting. This later should be more considered because all the benefits mentioned above. This study shows that some farmers do not compost on-farm because they do not have sufficient knowledge of the process and the benefits of the practice. It is the role of advisors. More trials should be done on farms to:

- Assess the effect of compost on different soils and under different climates, especially in the context of climate change.
- Find simple and reproducible solutions to on-farm composting: optimal watering, mix of biomass and degradation time, find and promote simple follow-ups during the process (temperature, pH or new indicators adapted to farmers).
- Facilitate the access to material: group purchase of tarpaulins launched by farmers' advisors, creation of new CUMA.

Then, farmers do not have precise knowledge of the quality and the fertilising value of their compost. This leads most of the time to random spreading and potential overfertilization in a territory facing OM deficiency. The main aim of using all the compost produced is that farmers do not have enough place to store their compost from one year to another. To avoid this, advisors and researchers should focus on the calculations of the inputs according to the different types of composts. One of the solutions could be to calculate fertilising and amendment theoretical values per tonne of compost according to the biomass composted and the composting management. Thanks to this, farmers could know the value of their compost and decide precisely the quantity of compost needed according to their crops.

Finally, it would lead to a better knowledge of the real raw matters volume needed considering the loss of weight during composting. If farmers reason out their needs, biomass would not be spoiled anymore. Moreover, this saved biomass would be available for other farmers nearby. More than reasoning in terms of biomass, this lever could allow to fertilise as close as possible to the needs of the crop and to limit soil and water pollution by appropriate fertilisation.

### 4.4 Political entities have the power to influence the development of practices on a larger scale

First, the quality of GWS provided by the VDD comcoms does not correspond to farmers' expectations. Farmers using GWS for composting were unsatisfied because of the abundance of plastic and the large size of pieces of wood. Therefore, solutions have to be implemented at different steps, from the collection to the final sorting before sending the GWS to farmers. The first one is to raise awareness of individuals. Landfills are organized by type of waste, but it happens often that the sorting is not well done by individuals. They have to be aware that there must not be plastic with green waste, especially because it is reused for agricultural purpose. Then, comcoms have to invest to better shred into small pieces and to sort the final products to obtain an optimal size particle (15mm according to (Reyes-Torres and al., 2018)). GWS is known to be difficult to compost: it is dry, and its C/N ratio is high. This type of compost needs high number of turnings and watering. This later depends on the irrigation possibility of the farms, but a solution could be that before sending GWS to farmers, comcoms water the matter. It would allow to "activate" the composting process.

Composting platforms are largely used by the compost-production industry. Nevertheless, project like the "Compost et moi!" association one is possible. The same project is now carried out by the CCVD. The goal is to build a platform where farmers could bring their by-products to compost them under controlled conditions and to obtain a normalized product. Moreover, yard trimmings collected in landfills would be composted in this platform. During the surveys,



the CCVD farmers were asked about the project. 6 farmers considered that transport between the farm and the platform is a constraint, and 5 farmers considered that the cost of the compost is another one. Concerning the advantages, 3 farmers answered the delegation of this practice and 1 said that it would allow to solve the regulations' issues. Moreover, 3 farmers expect a normalized product. They are mainly interested because it allows to delegate all the work done. Nevertheless, there are constraints such as transport because one platform in a 600 km<sup>2</sup> territory with 29 communes cannot be easily accessible to every farmer. Transport and cost are more or less the same problematic because transport is one of the main expenses in this kind of project. Some farmers surveyed thought about several platform in a territory to limit the transport. It could be possible, but such a project is very expensive. In addition, finding a location to compost agricultural products is difficult. On the one hand, it has to fit the regulations with such volumes. On the other hand, it has to be accepted by the inhabitants (societal expectations because of the odours mostly).

Building a common platform has constraints for farmers. To counter them, building several to be sufficiently close to each farmers interested could be interesting. It would allow to compost in one single location by fitting regulations, which is not the case when it is done directly on a plot. For now, platforms are very expensive and are affordable for a minority. One farmer surveyed who has built one, has said that he thinks about selling compost to offset this expense. It exists subsidies for agricultural equipment. One of them is for the renewal of agricultural equipment necessary for agroecological transition. For instance, farmers can ask for money for material aiming at reducing the loss during the spreading or during phytosanitary products sprays ([FranceAgriMer, 2020](#)). According to the context, with the implementation of subsidies in favour of agroecology, it is possible to think about some for composting. It could be for material such as windrow turner, but it also could be platforms subsidised by comcoms, departments, regions or even state. Nevertheless, most of the time, these subsidies concern only specific material for specific farm activities. It means that on-farm composting needs to be considered as a farming practice like any other.

Currently, there are decreases of livestock breeding in some areas. Concerning the Auvergne-Rhône-Alpes region, the number of cattle breeding decreased by 33% between 2010 and 2020 and the number of small ruminants and other herbivores breeding decreased by 35%. This decrease is essentially observed for small farms. The tendency is the grouping of small farms into larger ones. This leads to a deficit of manure in some areas of the territory, which forces farmers to import it. Other farmers have abandoned the idea to fertilize with manure because of these later reasons and are forced to use industrial fertilisers. One of the solutions to overcome this deficit is to ensure that the department and VDD remain a mixed crop and livestock breeding territory. To do this, there are multiple solutions:

- To support livestock breeding sectors by promoting their products and developing labels. Moreover, it is necessary to support the installation of young livestock breeders economically ([Ministère de l'Agriculture et de l'Alimentation, 2020](#)).
- It is necessary to promote and implement extensive way of breeding, because it is better for animal welfare and more environmental-friendly ([Poux and al., 2021](#)). There is a need to maintain livestock breeding to maintain manure production but the balance between animal welfare, environment and production of manure has to be taken into account.





## 5. Limits of the study

### 5.1 Compost collection

First, the sample is composed of 11 composts. Such a sample allows to assess the quality with at least two indicators for each parameter (maturity, stability, innocuity). Thus, it allows for a more detailed analysis of the quality of composts produced on-farms. Nevertheless, it is a quite small sample to do statistical analyses. It is possible to conclude about some indicators but for some others, a larger sample could have been necessary to conclude about the links between compost quality and management of the process by establishing correlations with statistical tests.

Moreover, for the 11 composts analysed, there are few samples for each category of raw matters composted. There are 3 GWS composts, 3 AM ones and only one sample for each other category. Therefore, comparisons between a same type of compost are quite impossible. It could have been interesting to have more compost samples and more repetitions of each type of compost found in VDD to compare their quality according to their management and their raw matters.

The composts' analyses were based on the spreading period most frequently encountered on farms in the territory. However, on some systems, compost is spread at different times (manure compost before straw cereals, amendment made in autumn). The analyses were based on a single sampling campaign compared to the different composting operations that can be carried out on farms over the course of a year. Moreover, for one farm, only one compost sample per farm was collected. In this study, the composting started in 2022 and finished in 2023. This sample is dependent of the climatic conditions during this period, the availability of the turner, the time farmers started to compost and so the time they needed it to spread. All of these conditions are variable every year and so as the compost quality is dependent of these parameters, there could be variations of quality from a compost to another for one farm.

### 5.2 Compost analyses

Some indicators have been chosen because they are commonly used to qualify compost quality. In the case of this study, a diversity of compost (characterized by a diversity of origin and volume or raw matters) was analysed. This can lead to a biased estimation of an indicator. For instance, the microorganisms' activity can be stopped by a high C/N ratio. So, during the respiration test, their activity and so the CO<sub>2</sub> rate, could have been underestimated. To avoid this bias, some tests are done by adding N.

Concerning the GI test, the three species were not so sensitive to compost phytotoxicity compared to the cress test. As the studies about this subject use several different species for the GI test, there is not one or more species known for their sensitivity and which could be part of a standard test. It could be necessary to test more species on different type of compost to see if there is a difference between the raw matters. If not, a standard test has to be implemented.

### 5.3 Samples of surveyed farmers

As one of the goals of the study is to characterize the use of compost in VDD in all the agricultural sectors represented in this territory, this was the first condition to the choice of the sample. Another choice was to have a fair balance between organic and conventional farmers. The first condition has been respected but not the second one. Indeed, there are more organic farmers surveyed than conventional ones. One reason to this is that organic farmers are more interested in composting. Moreover, two persons refused to answer to the semi-structured interview, and they are both conventional farmers. Nevertheless, as there is 1/3 of surveyed



who are conventional farmers, this bias cannot allow to conclude if conventional farmers really use less compost compared to organic farmers.

There is an inequality between the number of user or not of compost, coming from the fact that contact was easier with them. It could be a conclusion that there is more compost user. Nevertheless, it concerns the 23 farmers surveyed. Despite of this, it is important to consider that this result could be not representative of all the territory, even if there is a rise of organic farming and a rise of consciousness about organic matter.

## 6. Conclusion

In a context of increasing needs of OM to amend soils, compost appears to be an essential soil improver. Concerning the sample of the study, there is a majority of farmers who use compost. Nevertheless, for these later, they are mainly organic ones. The spread of compost is practiced, but it is important to mentioned that compost is not the only fertilizing and amending input. It is often used for some crops, which have no specific needs, whereas mineral and/or organic fertilisers are used for the high-value productions. The main reason is that compost is perceived as not enough nitrogenous, and the availability of the nutrients is not well-known.

Then, concerning on-farm composting, this practice leads to a heterogeneity of composts' quality. It does not exist one final type of compost, because of the raw matters at the beginning and the process management. Indeed, a link between a specific operation – irrigation, covering or mix of biomasses – and good quality compost have been established. Nevertheless, these management are done by a minority of farmers because they present constraints. Moreover, the turnover operation, which is one of the most important during the process, is done randomly because of the sharing of the windrow turner. These constraints have also been observed and developed during the interviews.

The main constraints for farmers who compost on-farm are the difficult management of the dry windrows, especially in summer, because a majority of farmers cannot irrigate them and some matters are basically very dry (e.g., GWS). Then, there is an availability decrease of biomasses, especially manure. This prevents farmers to mix them, whereas it leads to a better compost. A material dependency is observed, mainly with the turner, and for some more specific material as tarpaulin, it is mainly a cost and logistic issue which prevents farmers to use it. Finally, on-farm composting is time and space-consuming and perceive as an expensive practice. These results lead to the conclusion that it is still a practice which need improvement and knowledge, in order to facilitate the practice and also to introduce it as a real farm activity.

In a context of the increasing place of organic matter in the farming world, a practice such as on-farm composting and its limits have to be considered. To do this, many levers could be set up to overcome constraints highlighted in this study. A diversity of actors – from farmers themselves to political entity such as comcoms - have a role to play in order to develop and facilitate a promising practice.

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## Appendix I (1/2): Semi-structured interview

### 1. Personal details:

- Nom/First name:
- Location and name of the farm:
- Background of the farm :
- Education/professional background:
- Installation date:

### 2. Production system

- Production system (size, conventional/organic farming, number of workshop(s), number of people working on farm, commercialisation, *etc.*)?
- How is soil fertility managed at farm level (soil characterisation/soil analysis)?
- Do you add organic matter? If so, in what form(s)?

### 3. Do you use compost?

→ Yes

- What is the agronomic objective of using compost?
- What is the origin (industrial and/or produced on the farm)?
  - o Industrial
    - What type of product do you use (purchase, delivery, price)?
  - o Produced on farm
    - What are the objectives of composting as opposed to buying raw compost?
    - Do you sell some of the compost you produce?
- How much, how often and when do you use it?
- What proportion of fertilisation/amendment does this use represent?

### 4. If the compost is produced on farm

#### 4.1. Composting practices

- What inputs are treated? In what volume? Where do they come from?
- What is the composting period?
- Where is it composted (platform, field edge)? Exact position:
- Is the composting area fixed from one year to the next?
- How is the composting site organised (initial shredding, windrowing, initial mixing of inputs, height of windrows, initial moisture management, tarpaulins)?
- During composting, how do you control:
  - The composting process in general (monitoring, equipment, analysis)?
  - Moisture (decision rule, frequency, dose, type of irrigation)?
  - Number and frequency of turnarounds (decision rule, equipment)?
- When and by what means do you consider the process to be complete been carried out on the compost to be sampled?
- Are there any organic co-products on your farm that are not currently used? If so, which ones and why?

## Appendix I (2/2): Semi-structured interview

### **4.2. Overview of experiences, vision of composting**

- Is your management of the composting process and the compost obtained in line with the objectives you set? Do you think it complies with legislation?
- What is your perception of the cost/benefit ratio of this practice?
- What problems/constraints do you encounter with this practice?
- What ideas do you have to overcome these problems (collective approach/acceptable prices and km for external inputs)?
- What is your perception of compost at departmental level (supply, equipment, etc.)?
- What access do you have to composting resources (type of resources, time spent)?
- If compost wasn't produced on the farm, how much would you be prepared to invest in buying it?

### **4.3. Current need to develop this practice?**

- What do you need to develop this practice (equipment, training, end-of-field meetings, personalised support)?
- If knowledge is needed, what are the thematic priorities (covering, turning over, spreading, moisture management, temperature management)?

### **5. If the compost is not produced on the farm**

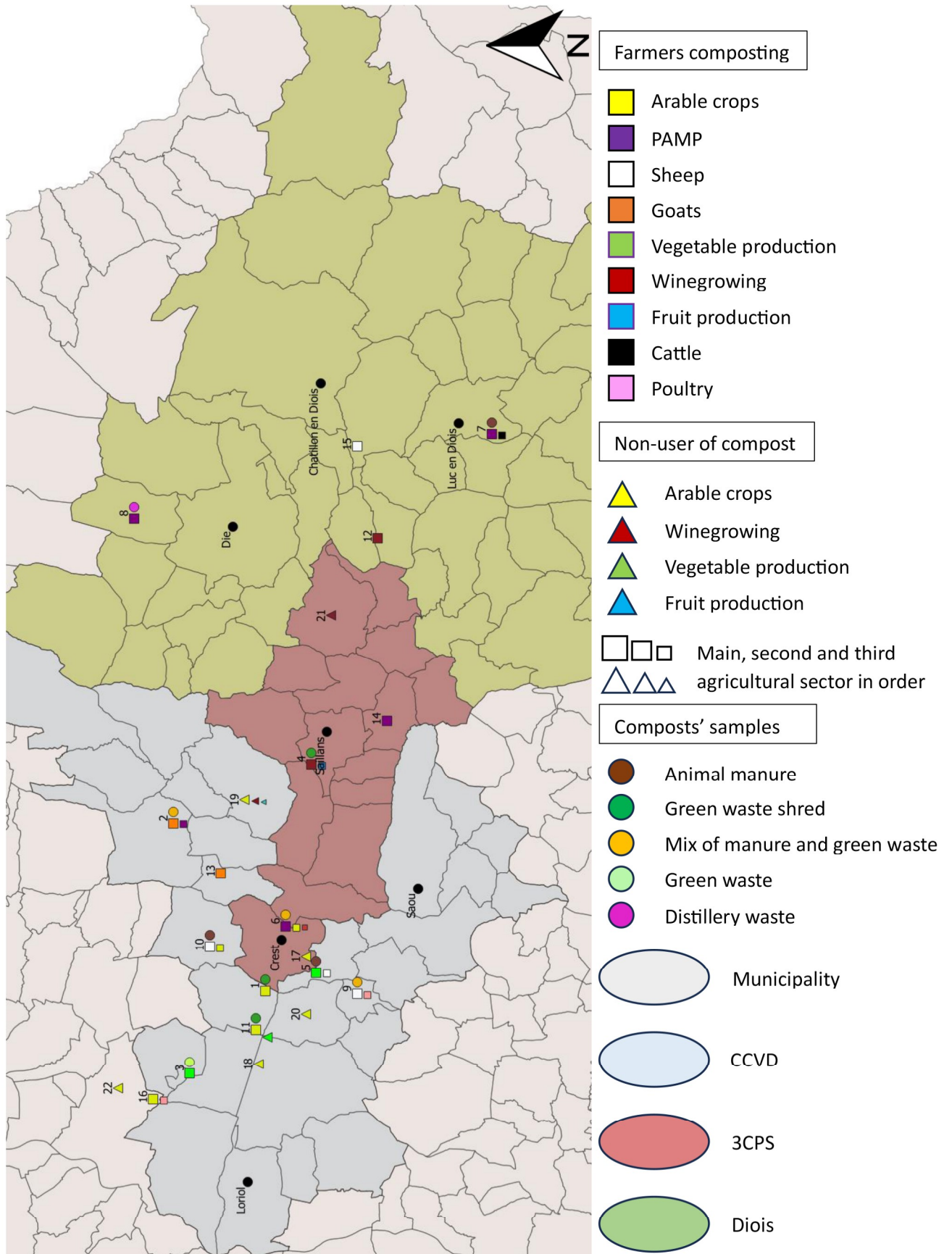
- Why not compost on the farm?
- Have you composted on your farm in the past? If so, why don't you do it anymore?
- Do you want to develop on-farm composting? Why or why not? What would you need to develop on-farm composting? (Equipment, training, end-of-field meetings, personalised support)
- Would you be interested in composting with several persons (on a farm/platform)? If so, what would be the conditions for you to join (price, delivery, etc.)?

→ No (no use of compost)

- For what reason(s)?
- Have you used compost in the past? If so, why not now?

**- In your opinion, what improvement(s) (technical, organisational, etc.) would encourage the development of the practice on local farms?**

Appendix II: Map of localisation of compost collected, farmers interviewed and their main agricultural sectors



## Appendix III (1/5): Farmers' answers to the interview, classified by thematic

Composting farmers

Non-user of compost/non-composting farmers

All farmers

### Issues/constraints of composting

- Compost is too dry, especially in summer **Farm.2, 6, 7, 10, 13, 15, 16**
- No constraints because it's good enough to have manure **Farm.10, 15**
  
- Regulations governing the composting area
  - Regulations are not adapted to composting zones **Farm.2, 6, 16**
  - Need a space that is accessible to lorries, turners and complies with regulations **Farm.1, 2,3, 6, 9, 13, 15**
  
- Issues about raw materials
  - The cost of raw materials can be a barrier to composting **Farm.1**
  - In biodynamic farming, 30km max to buy manure **Farm.12**
  - Too much plastic, large pieces of wood in communes GWS **Farm.11, 14**
  - Too many weed seeds in the GWS **Farm.1**
  
- Material
  - You need to be equipped otherwise it's too complicated to compost **Farm.1, 4, 6**
  - Being dependent on equipment **Farm.4, 9, 10, 15**
  
- Time spent
  - Time-consuming **Farm.4, 6, 11**
  - No time to follow up **Farm.3, 6, 11**
  
- Final product
  - Obtaining a non-standardised product **Farm.6**
  
- Process, technically speaking
  - Having to check temperature at key times **Farm.7**
  - Mulching can be time-consuming **Farm.7**
  - Water correctly **Farm.11**
  - When compost is not covered, too much nitrogen is lost **Farm.10**
  - Impossible to water at the same time as the turner **Farm.10**

### Perception of the cost/benefit ratio, taking time spent into account

- Perception of the cost of practice
  - Advantageous practice **Farm.2, 3, 8, 11, 13**
  - Turnaround has a cost, but it's not huge **Farm.10**
  - Ready to spend a lot of money on manure because of the importance of fertilisation in market gardening **Farm.3**
  - No need to buy fertiliser **Farm.4, 5, 7**
  
- Perception of time spent
  - No loss of time as manure has to be removed in all cases **Farm.2, 13**
  - Time-consuming to spread **Farm.6, 8**

## Appendix III (2/5): Farmers' answers to the interview, classified by thematic

- Perception of the value of compost
  - Longer-term contribution **Farm.1**
  - Waste is recycled, making a beautiful product **Farm.3**
- Investments
  - Building a platform has a cost **Farm.8**
  - If it's going to be a major workshop, it has to make money. **Farm.8**

### Remarks about composting

- Notes on raw materials and their composting
  - Compost with lavender/lavandin is too woody **Farm.2**
  - GW screened are complicated to bring up to temperature, the best is freshly ground fine. **Farm.1**
  - Lavender straws more expensive than GWS but compost better and faster **Farm.1**
  - Think you need to compost GWS and manure separately at the beginning, as GWS needs at least 6 months to decompose properly. **Farm.10**
  - Softwoods bring acid **Farm.16**
- Notes on irrigation/watering
  - Looking for a solution for good irrigation **Farm.8**
  - Think of making piles rather than windrows to optimise irrigation **Farm.8**
  - If the compost was covered it could do some good **Farm.10**
  - The logistics of tarpaulins are complicated **Farm.10, 16**
  - Putting up a tarpaulin and not watering is pointless. **Farm.11**
  - Is it possible to water the compost with the methanisation juice? **Farm.10**
  - No need to add water to the manure, it is already moist with urine **Farm.5**
  - Don't want to water the compost **Farm.13**
- Notes on the turner/returns
  - Think about buying a turner so you can turn it over when you need to **Farm.8, 15**
  - The turner comes the summer but is there any interest? **Farm.15**
  - If the turner goes through but you don't water it, it's no use **Farm.11**
- Composting structure
  - Demeter advised against concreting, which contradicts regulations **Farm.7**

### Remarks about spreading

- With DV compost, you don't know what you're spreading **Farm.16**
- Long to spread compost **Farm.6**
- The regulations are not adapted to the spreading periods **Farm.2, 6**

### Other remarks

- Autonomy in terms of fertilisation
  - Seeking self-sufficiency through composting **Farm.5, 7**
  - If we had more compost, we might do without organic fertiliser **Farm.6, 7**
  - Not enough compost for 100% fertilisation **Farm.13**



## Appendix III (3/5): Farmers' answers to the interview, classified by thematic

- Constraints of certain composts
  - Urban compost doesn't necessarily go organic and there are sometimes things that aren't really compostable. **Farm.5**
  - Not ready to use composted shred in market gardening because it contains too much carbon **Farm.5**
  - Preference for DV because it wants more humus than nitrogen **Farm.11**
- Good to have the windrow turner **Farm.2**
- It would be good to have more local raw materials **Farm.1**
- No purchase of poultry manure for the moment, but perhaps for N-rich inputs **Farm.3**
- One solution if no more manure, compost in plugs even if more expensive **Farm.12**
- You have to learn how to make good compost and that can be done by CUMA. **Farm.10**

### Remarks about compost quality

- Impact of the process on compost quality
  - Without rain, it doesn't compost enough, so it can be left in the heap for longer **Farm.16**
  - Composting is short because the soil mineralises very quickly **Farm.5**
  - The quality of the finished product depends on the initial moisture of the manure **Farm.10**
  - Since compost is not covered, loss of nitrogen **Farm.10**
- Finished product problems
  - Acidity of the finished product **Farm.16**
  - Compost does not contain much nitrogen **Farm.6**
  - Nitrogen hunger because compost has too much carbon **Farm.8**
  - Heterogeneity between the inside and outside of the heap **Farm.11**
  - Not mature enough **Farm.8**

### Reasons for not using/not composting

- Problems with raw materials
  - Not a livestock farmer so no effluent **Farm.17**
  - Not enough volume on farm **Farm.20**
  - Good mix is DV and manure but no manure around **Farm.19, 22**
  - DV with too much plastic **Farm.18**
- Equipment problems
  - No equipment **Farm.17, 18, 19, 20**
  - Not able to compost properly **Farm.20**
- Constraints on the use of compost
  - Shortage of compost **Farm.18**
  - Need for stable yields for seeds **Farm.18**
  - Need to have a spreading plan **Farm.19, 21**
  - Uncertainty over when elements can be released **Farm.17**

## Appendix III (4/5): Farmers' answers to the interview, classified by thematic

### Perception of compost/material flows at local/departamental level

#### - Overview of these flows and causes

- There is a shortage of OM **Farm.2, 5, 8, 21**
- There is a lot of export **Farm.2, 6**
- Manure comes from far away **Farm.3**
- Straw and manure exchange between Drôme and Savoie **Farm.5**
- Those who have material keep it **Farm.1, 2, 4, 8, 11, 17**
- MO increases in value **Farm.3**
- Increase in organic farming **Farm.8, 12, 18**
- Difficult to find manure, less and less livestock **Farm.2, 4, 8, 11, 12, 21**
- Many requests for manure when it is produced **Farm.13, 15**
- Not necessarily aware of who could trade **Farm.1**

#### - Exploring ways to recycle more materials

- Grape pomace go to distillery **Farm.4, 6, 12**
- Landscapers obliged to go to waste collection centres **Farm.3, 10**
- Not enough recycling of household waste **Farm.3**
- Ensure that the area remains a mixed farming and livestock farming area **Farm.5**

### Remarks about the composting platform

#### - Counterparties required if the platform goes ahead

- Ok for the platform only if agricultural materials **Farm.18**
- Ok for the platform but need to equip accordingly **Farm.19, 6**
- If platform, end product must be standardised **Farm.1, 6, 9**

#### - Corking

- Interesting but more for corking **Farm.3, 13, 20**
- Calculate transport + spreading VS corking **Farm.6**

#### - Advantages of the platform

- The advantage is to delegate management of the process **Farm.3, 4, 6**
- Avoid regulatory problems on **Farm.6**

#### - Platform constraints

- The main problem is transport **Farm.2, 3, 6, 10, 13, 20**
- Final cost will determine whether or not to join **Farm.2, 6, 11, 13, 21**
- By pooling, no traceability of materials **Farm.10**

#### - Collective

- Question as to whether it would not be better to create platforms with 2/3 farmers **Farm.2, 10, 20**
- Question as to whether it would not be better to create 3/4 platforms in the area to be close to everyone **Farm.6**
- We need to do something with municipal waste **Farm.5**
- Not interested if mixture of DV and manure **Farm.11**

## Appendix III (5/5): Farmers' answers to the interview, classified by thematic

### Levers

- Formalise the practice of composting, but it has a cost: retention basin, etc. **Farm.3, 6, 16**
- Screen and sell the compost **Farm.1**
- Irrigation or tarpaulin cover is a possibility **Farm.15, 16**
- Knowledge **Farm.9, 10, 15, 16**
- Co-composting, but are DV an interesting contribution? **Farm.10, 20**
- If compost conforms better, possibility of selling it **Farm.8, 16**

Appendix IV: coefficient attributed to each species used for the germination index test and an example with the 9th compost

	<b>Sensitivity</b>	<b>Coefficient</b>
<b>Radish</b>	Very sensitive	2
<b>Cress</b>	Sensitive	1.5
<b>Chinese cabbage</b>	Low sensitive	1

<b>Species</b>	Radish	Cress	Chinese cabbage
<b>Mean of GI per species</b>	116.75	164.77	171.61
<b>Calculation of the mean of the 3-species GI with coefficient</b>	$(2 \times 116.75 + 1.5 \times 164.77 + 1 \times 171.61) / 4.5$		
<b>Mean of the 3-species GI</b>	144.95		

Appendix V: Regulations concerning on-farm composting, for each type and special features of farms

Quantity of composted material	<3t/day, otherwise obligation to build a platform.
Distance between storage area and ...	Water areas: 35m
	Habitations: 200m
	Communication routes: 5m
Storage area	Compact manures that are not likely to leach can be stored or composted on a spreading plot after 2 months' storage under the
	Poultry manure that is not likely to leach can be stored or composted on a spreading plot without 2 months' storage under the animals.
	Poultry manure with a DM >65% must be covered with a semi-permeable tarpaulin.
	The return to the same site may not take place for a period of 3 years.
Storage period	Does not exceed 10 months (ICPE)/ 9 months (vulnerable area).
Organic	No obligation to compost.
	Effluent from organic livestock farms must be spread on land committed to organic farming.
	Organic matter does not have to come from organic production, but this is also recommended.
	From 1 July 2022, the following will be excluded from use on organic land livestock effluent from farms using slatted floors or full grids or from farms using cage system.

For every type of agricultural by-products

Only for livestock breeding effluents

	Diplôme : Ingénieur Spécialité : Horticulture Spécialisation / option : Agroecology Enseignant référent : MENASSERI-AUBRY Safya
Auteur(s) : CHIRI Enora Date de naissance* : 15/03/2000	Organisme d'accueil : FiBL France Adresse : Pôle Bio – Ecosite du Val de Drôme 150 Avenue du Judée 26400 Eurre
Nb pages : 26      Annexe(s) : 5	Maître de stage : BALANANT Tanguy
Année de soutenance : 2023	
Titre français : Contraintes et leviers à l'utilisation du compost et au composter à la ferme dans la Vallée de la Drôme et Diois Titre anglais : Constraints and levers to the use of compost and on-farm composting in the "Vallée de la Drôme et Diois"	
Résumé : Aujourd'hui, la prise de conscience du besoin en matière organique des sols et des effets des engrais minéraux est croissante dans le monde agricole. Ce contexte est amplifié dans la vallée de la Drôme. Il s'agit d'une zone agricole diversifiée avec une concentration spatiale des secteurs agricoles, entraînant des excédents et des déficits de sous-produits agricoles. La pression sur la matière organique est amplifiée par le nombre important d'exploitations biologiques et les restrictions d'eau dans la Drôme. Le compostage est une des voies de valorisation de la biomasse. Ce procédé permet d'obtenir un amendement stable et assaini qui présente de nombreux avantages pour le sol. Il permet de décomposer tous les types de biomasse (déchets verts, déjections animales, déchets de distillerie). Pendant le processus, le retournement et l'irrigation sont importants pour maintenir suffisamment d'O2 et d'humidité dans le tas. Les agriculteurs ont le choix entre l'achat de compost industriel et le compostage à la ferme. Cette dernière option et l'utilisation du compost sont étudiées ici : 11 analyses de la qualité du compost et 23 entretiens semi-directifs avec des agriculteurs ont été réalisés. La qualité du compost est hétérogène et est bonne en cas d'irrigation, de bâchage ou de co-compostage. Cette conclusion est liée aux contraintes rencontrées par les agriculteurs praticiens. Il s'agit de la disponibilité des matières premières, de la gestion du compost sec, du temps et de l'espace disponibles et du prix. Le compost est principalement utilisé par les agriculteurs biologiques et est perçu comme un engrais incertain. Pour surmonter ces limites, des leviers peuvent être mis en place à différents niveaux.	
Abstract: Today, a raise of awareness about the need of organic matter in soil and the effect of mineral fertiliser is increasing in the farming world. This context is amplified in the "Vallée de la Drôme". It is a diversified agricultural area with a spatial concentration of farming sectors, leading to overflows and deficit of agricultural by-products. In addition, yard trimmings are generated by particular. The pressure on the organic matter is amplified by the important number of organic farms and water restrictions in Drôme. One solution to recycle biomass is composting. This process leads to a stable, sanitized soil improver, with multiple advantages for soils. It allows to degrade any type of biomass (green waste, animal manure, distillery waste). During the process, turnovers and irrigation are important to maintain enough O2 and moisture content in the pile. Farmers have choice to buy industrial one or to compost on-farm. This later practice and the compost use are studied here. This was done by analysing 11 compost quality and doing 23 semi-structured farmers interviews. Compost quality is heterogenous and is good when irrigation, covering or mixing biomass are set up. This conclusion is linked to constraints that farmers face during the practice. These later are the availability of raw matters, the management of dry compost, the time and space available and the price. The compost is mostly used by organic farmers and considered as an uncertain fertiliser. To improve these practices, levers can be set up at different scale: from farmers collectives to political entity.	
Mots-clés : compostage à la ferme, qualité de compost, gestion de processus, biomasses, amendement organique	
Key words: on-farm composting, compost quality, process management, biomass, organic amendment	

