Compost quality indicators

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1. Introduction

Compost can be very diverse in quality and characteristics related to the variety in feedstock composition and management of the composting process. This report gives an overview of a number of different compost quality indicators, describes how they are measured and explains how the indicators are interlinked. Furthermore, this report includes information on what indicators are most interesting for specific cases (intended use, specific input materials, etc.) and for matching compost with a certain use.

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2. Basic standard analyses

This section lists the standard analyses that are generally useful for compost quality assessment. In addition, the information gathered by these measurements can also serve for matching compost with a specific use (more details included below).

Visual screening

A visual screening can already give a first quick idea about the compost quality. Elements to check are:

- Temperature: Mature and stable compost has a moderate temperature in accordance to the outside air temperature. If the compost feels hot, it indicates that it still generates heat due to decomposition and transformation process (linked to but different from the 'self-heating test', see section on 'Compost stability').
- Color: Compost color should vary between middle and dark brown. Darkness also depends on moisture content. Black compost often indicates too high temperatures during composting, leading to combustion. However, home-made compost involving worms and other bigger organisms can also be black.
- Odor: a mature compost should smells like a forest soil.
    - Ammonia smell in an ongoing process indicates excessive N losses due to volatilization as a result of a feedstock mixture with a too low C:N ratio and or a too low moisture status)
    - H_2S smell (rotten eggs) indicates anaerobic circumstances which are to be prevented for composting
- Impurities: The presence of plastic, glass, metal, etc. in the feedstock (e.g. municipal waste) can affect compost quality negatively. This can be observed directly or after sieving (e.g. 2 mm mesh, described below).
- Non-degraded plant material: Non-degraded plant material in the compost (e.g., blades of grass, little branches, etcetera) indicates that the composting process is still ongoing or that it is halted due to suboptimal circumstances. This can be observed directly or after sieving (e.g. 2 mm mesh).
- Particle size: Particle size can be judged visually, but compost can also be sieved to determine different fractions (see further, EN 15428: Soil improvers and growing media - Determination of particle size distribution).
- Structure: A crumbly structure is desired, indicative for particle aggregation due to microbial activity. Unfavorable composting conditions may result in a dusty appearance.
- Moisture content: Compost moisture content can be estimated with the squeeze ball test. To have a good moisture content, you should be able to squeeze the compost into a ball in your hand without water dripping out.

Moisture content

Composts with high moisture content (above 60 %) are usually clumpy and difficult to spread. Composts with a too low moisture content (below 40 %) might be dusty. The squeeze ball test is performed for a general judgement of the moisture content. To have a good moisture content, you should be able to squeeze the compost into a ball in your hand without water dripping out.

The moisture content is expressed on fresh matter basis. Mostly, instead of moisture content, dry matter content is reported[1]. Organic matter and elemental contents are determined on dry matter basis. The analytical results on dry matter basis are used for compost quality comparison. For dosing compost accounting for composition, nutrients or organic matter content should be expressed on a fresh matter basis.

To determine the moisture content, compost samples are dried at 103°C until constant weight is achieved. Weight loss equals moisture loss, based on which moisture content or dry matter content of the compost is calculated. The procedure is described in EN13040 Soil improvers and growing media – Sample preparation for chemical and physical tests, determination of dry matter content, moisture content and laboratory compacted bulk density.

Bulk density

Bulk density depends on both porosity and moisture content. It is an interesting parameter to know if you want to convert a volume unit of fresh material into a weight unit. Furthermore, composts with a high or low (dusty) bulk density might be more difficult to spread. They have lower porosity and or a higher percentage of water filled pore space. Composts with low bulk density can suffer from excessive pore space and low water retention, important for compost use in growing media (see further).

The laboratory compacted bulk density is measured on fresh compost. Minimum 4 L compost should be sieved over a 20 mm mesh, placed on a cylinder of 1000 mL with a ring on top. When the cylinder is full, the sieve is removed and a plunger (650 g) is placed on the compost for 180 s. After this, the plunger and ring are removed and the cylinder is weighed. The bulk density is calculated from the difference in weight with an empty cylinder divided by the volume of the cylinder. This is repeated three times to have an average wet bulk density. The method is described in EN13040 Soil improvers and growing media – Sample preparation for chemical and physical tests, determination of dry matter content, moisture content and laboratory compacted bulk density. The wet bulk density is highly dependent upon the moisture content, in contrast to the dry bulk density. The latter can be determined by drying (103°C to constant mass) and weighing the sample in a fixed volume according to EN13041 Soil improvers and growing media -

[1] The water content should be maximal 50% and the dry matter content minimal 50% on fresh weight base according to the Federal laws in Belgium. However, when the organic matter content is min. 18% on fresh weight, the dry matter content can be 40%.

Determination of physical properties - Dry bulk density, air volume, water volume, shrinkage value and total pore space.

Organic matter or carbon content

The organic matter or carbon content of compost is of major importance if you want to use the compost to enhance soil organic matter content[2]. Low organic matter values in compost can result from mineral soil (low in organic matter) being mixed into the compost, either from feedstocks or by turning on bare ground. The use of purely organic waste streams results in a high level of organic matter in the stabilized compost product. On the other hand, a high level of organic matter can be an indicator of an unfinished composting process or unstable compost (see further on compost stability indicators). This organic matter will be partly respired via microbial decomposition after application.

The analysis comprises the determination of residual ashes and provides an estimate of the content of non-volatile, inorganic components present in the sample. If no inorganic substances are volatilized, the difference between the dry and residual ash content gives an estimate of the content of organic substances. Through the use of a fixed conversion factor (e.g. 0,58 (Van Bemmelen, 1890)), the organic matter content is converted into organic carbon content. The procedure is described in detail in EN 13039: Soil improvers and growing media - Determination of organic matter content and ash. Alternatively, the organic carbon content can be determined directly by dry combustion followed by CO_2 measurement (with correction for the inorganic carbon content), described in ISO 10694 and EN 15936.

Major and secondary nutrients

Major and secondary nutrient content of compost is important to estimate the fertilizer value and to know how much of the compost is preferably or can be (legally) applied. Repeated applications of compost rich in certain elements can be useful to overcome an imbalance of the nutrient status of the soil. The compost nutrient content can be used to match a certain need, e.g., a high K content for K depleted soil, a high Ca content to ameliorate the soil physical status, etc. (more information in the section on matchmaking below). On the other hand, care should be taken with repeated application of compost with high contents of certain elements, e.g., a soil highly enriched with K due to repeated compost applications might restrict Mg uptake by plants. Compost application strategy should be based on both soil nutrient status and in accordance to crops nutrients export.

Total K, Ca, Mg, Na, P, S, Mn, Fe, B, Mo, Co and Se content in the compost can be determined on a dried and grinded sample after destruction of the sample in strong acids,

[2] According to Belgian laws, composts should have an organic matter content of at least 16% on fresh weight.

e.g. *aqua regia*. After destruction, element concentrations can be measured by ICP-OES (EN 13650: Soil improvers and growing media – Digestion of aqua regia soluble elements).

Total N content can be determined according to three different methods:

- Dumas method: EN 13654-2 Soil improvers and growing media – Determination of nitrogen – Part 2: Dumas methode
- Combustion method: EN 16168 Sludge, treated biowaste and soil – Determination of total nitrogen using dry combustion method
- Modified Kjeldahl or Kjeldahl + mineral N: EN 13654-1 Soil improvers and growing media – Determination of nitrogen – Part 1: Modified Kjeldahl method

pH

The pH of compost is typically between 6 and 9.5[3], with the lower values for plant based composts and higher values for manure based compost. A too low pH can indicate immature compost (see section on Compost maturity). The compost pH should match the specific application, e.g. low pH composts should be used for acid-loving plants as rhododendron and blueberry.

To determine the pH, 20 mL fresh compost is mixed with 100 mL water in a plastic cup. The suspension should be mixed and the pH is measured afterwards in the aqueous solution. The procedure is described in EN 13037 Soil improvers and growing media – Determination of pH.

Electrical conductivity (EC)

The electrical conductivity (EC) is used to evaluate the total salt content of the compost. A high salt content (> 1500 µS/cm) can induce salt stress, especially when compost is used in growing media.

To determine the EC, 50 mL fresh compost and 250 mL water is placed in an Erlenmeyer of 500 mL. The suspension should shake 1 hour with an agitator and filtered afterwards. The EC is measured in the water extract. More details are described in EN 13038 Soil improvers and growing media – Determination of electrical conductivity.

Available nitrate and ammonium content

Mineral N (NO_3^--N and NH_4^+-N) is the N directly available for the plant (in contrast to the total N content). In a well matured compost there is little or no NH_4^+-N (< 0.4 g/kg), a predominance of NO_3^--N and thus a NO_3^--N/NH_4^+-N ratio > 1 (see section Compost maturity). The mineral N is determined in the water extract (see EC), EN 13652 Soil improvers and growing media – Extraction of water soluble nutrients and elements.

[3] The pH should be between 6.5 and 9.5 according to Belgian standards

Cation exchange capacity

The cation exchange capacity (CEC) is the amount of electrostatic negatively charged binding sites for cations that can be exchanged to the soil solution. Negatively charged binding places are available on both organic matter and clay minerals present in compost. It can be an important indicator of compost quality since application of compost with high CEC on soils can increase the soil fertility by increased cation binding and exchange.

Both the potential (at fixed pH) and the actual (at *in situ* pH) CEC can be measured. There are several methods available for both indicators, e.g. cobaltihexamine or $BaCl_2$ for the actual CEC and the ammonium acetate method for the potential CEC. For the latter, the CEC binding places are occupied by ammonium by rinsing the compost thoroughly with ammonium acetate at pH 7. The electrostatically bound ammonium is then determined after exchange with K^+ from KCl.[4]

In addition to the total cation exchange capacity, the specific occupation of this CEC by cations can be analyzed. These exchangeable cation contents are lower than the total cation contents and are more in line with the so-called plant available elements (see section on Availability of nutrients).

Compost stability

Definition and importance

"Compost stability" typically refers to microbial activity and can be defined by the respiration or transformation of various chemical components in compost organic matter. Sometimes also the term "compost maturity" is used, but this refers to the suitability of compost for plant production which is related to compost stability, the potential symbiotic microbial activity and the absence - due to degradation - of phytotoxic substances. Compost maturity is generally measured by the germination index or plant bioassays (see section on Compost Maturity in "Extra analyses for compost use in substrates"). Compost stability is a criterion for compost maturity (Bernal et al., 2017) and is assessed as the potential organic matter decomposition.

When using unstable compost, the compost will continue to decompose after soil addition. On soils where crops are planted, the degradation microorganisms will compete for N with the crop. When using unstable compost in potting soil, there might be a shortage in oxygen due to the activity of degradation microorganisms, resulting in toxic ammonia substances for the roots.

[4] http://www.adas.uk/Portals/0/Documents/Technical%20Monograph%20Growing%20Media%20Laboratory%20Methods.pdf

Standard tests for compost stability

Compost stability can be assessed through the microbial respiration, a general measure of microbial activity. Respiration can be monitored by CO_2 production, O_2 uptake or release of heat. There are different tests available to measure compost stability, commonly used ones are:

- Oxygen uptake rate (OUR): As an indicator of stability, the OUR from the microbial oxygen consumption is measured from 20 g compost in 200 mL *buffered nutrient solution* in a 1 L Schott flask during five days of shaking in a closed respirometer at 20 °C. Microorganisms consume oxygen and CO_2 is trapped in NaOH granules, resulting in a pressure drop. The height of the drop is related to the microbial activity (method described in Veeken et al. (2003)). Composts with an OUR < 15 mmol / kg OM / h are considered as stable[5].
- Self-heating test: The degree of stability can be measured using a Dewar vessel in which the compost is incubated under an optimal, *standardized moisture content*. The less stable the compost is, the higher the microbial activity and the higher the temperature will be in the Dewar vessel. The procedure is described in EN 16087-2: Soil improvers and growing media – Determination of aerobic biological acitivity – Part 2: Self heating test for compost
- Solvita test: Solvita chemistry gels are highly reactive media which respond rapidly to the concentration of CO_2 and NH_3 gases naturally released from compost into headspace of a test jar. True stability happens when both these two factors converge at low levels. For more information, see https://solvita.com/compost/

Additional tests assessing compost stability

Next to 'standard' compost stability tests, additional tests are possible for identifying the stability of composts:

- The biodegradation potential: The biodegradation potential can be estimated by the holocellulose (=hemicellulose + cellulose) / lignin ratio. These cel wall components can be assessed by measuring the neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) content in the compost, according to Van Soest et al. (1991), with %hemicellulose = %NDF - %ADF, and %cellulose = %ADF - %ADL (Vandecasteele et al., 2017). Composts with a biodegradation potential < 1.8 are considered as stable.

- CO_2 production measurement: CO_2 flux can be measured (e.g. by a Licor CO_2 flux system equipped with a CO_2 flux chamber) from moistened composts stored in

[5] Maximum OUR for composts in legislation of Flanders (Belgium): 15 mmol / kg OM / h, quality target is less than 10 mmol / kg OM / h

PVC rings. Composts can be mixed beforehand with nutrients. A high CO_2 release indicates high decomposition and low stability (Vandecasteele et al., in press).

- C/N ratio, NO_3^-/NH_4^+ ratio and N immobilization are also related to compost stability but are mostly considered as measures of compost maturity and are therefore explained in the section on Compost maturity in "Extra analyses for compost use in substrates").

Shortcomings of tests

To select a test and the test conditions, it is important to consider under which conditions you want to measure the compost stability. Do you want to measure the *in situ* stability, i.e., under the given conditions of oxygen availability, moisture content, microbial population and nutritional status, or the *absolute* stability, i.e. under conditions that are not limiting for biodegradation? E.g., the respiration index can be static (O_2 limitations in the measurement possible) or dynamic (no O_2 limitations). The measurement of OUR can be very sensitive to changes in moisture content, temperature, oxygen and N availability. For example, N shortage will slow down the degradation process, resulting in an apparent low OUR, indicating a stable product what might be not the case under changing circumstances (Vandecasteele et al., 2017). The biodegradation potential is a test of the stability which is independent of conditions as oxygen availability, moisture content, etcetera, as it is a characteristic of the organic components in the compost, and not a measurement of the microbial activity depending upon the conditions and additions of water, oxygen, nutrients and inoculum. An alternative of measuring the compost stability, is assessing the compost maturity (see section in "Extra analyses for compost use in substrates").

Organic matter stability on the long term in soils

If you want to know how much carbon in the compost will be effectively sequestered in the soil, (climate related research) it is recommended to perform a C mineralization experiment. Compost is mixed with a standard soil, placed in air-tight jars (periodically opening of the lid guarantees a sufficient O_2 supply) and incubated for 2-4 months at constant temperature. The emitted CO_2 is trapped in a vial containing 1 M NaOH and measured by titration with 1 M HCl. In order to assess the easily and more recalcitrant C fraction of the compost, a parallel first- and zero-order kinetics model can be fit to the C mineralization data (Sleutel et al., 2005).

3. Analyses for contamination and impurities

Negative aspects of compost quality are the possible presence of impurities (e.g. glass, metal, plastic) and contamination (chemical and biological). Analyses of these can be necessary because of regulation and certification, and are certainly important when the compost is used in relatively high quantities (e.g. in substrates, see below). Analyses can also be triggered if they are asked for by the grower, or if the compost feedstock was possibly contaminated (with pathogens and/or heavy metals).

Impurities in general

Impurities as glass, metal and plastic are not wanted in compost, also stones are undesired. The presence of these materials can be determined by CEN/TS 16202 Sludge, treated biowaste and soil - Determination of impurities and stones. The fresh compost is air-dried and manually sieved on sieves with a mesh width of 4, 5 or 10 mm[6], and 2 mm. In the > 4, 5 or 10 mm fraction all stones are removed, cleaned and weighed. Impurities are defined as being larger than 2 mm. In the fraction >2 mm glass, metal and plastic particles are separately removed, cleaned and weighed. Results are expressed as mass percentage (on fresh or dry weight). Plastic contamination will be underestimated by this procedure given the relatively small mass per volume for plastics. Therefore, in some quality standards the impurities are not expressed on mass base but on surface base (cm^2 per liter fresh compost) as in Germany[7].

Plastics

Plastics observed in compost can be biobased (not the same as biodegradable) or fossil based, distinction can be made by $^{13}C/^{14}C$ analysis. Truly biodegradable plastics should not be visually present in compost since by definition these plastics should not be visible any more after 12 weeks in composting process, and 90% should be mineralized after 6 months (EN13432, EN14995 or ISO17088). However, parts can still be present in the compost as micro and nano plastics. The occurrence of these small plastics is of increasing concern and the measurement in compost will probably get more attention in the future. The measurement of the presence of these plastics is less straightforward than visual determination. Methods typically involve a floatation or density separation test with dense salt solutions but these methods have limitations regarding plastic type scope and collection efficiencies (Fuller and Gautam, 2016). Possible alternatives are pressurized fluid extraction. Analyzing the plastic type is possible with FTIR, Raman spectroscopy or

[6] In the UK, stones are defined as larger than 4 mm, in Belgium as larger than 5 mm and in Germany as larger than 10 mm

[7] Bundesgütegemeinschaft Kompost (BGK) certification in Germany. Method "The determination of the surface sum of separable impurities serves the quantification and evaluation of optical/sensory impurities especially of light materials." (BGK, 2006). Limits of 15 cm^2/L fresh compost for mature and fresh compost, 10 cm^2/L for substrate compost. Impurities are unwanted materials such as glass, plastics, metals, rubber, bones and composite materials. Stones, lava and clay are not impurities.

by transmission electronic microscopy and pyrolysis coupled to gas chromatography and mass spectrometry (Watteau et al., 2018).

Heavy metal contents

Compost feedstocks (e.g. sewage sludge) can be excessively loaded with heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn) which accumulate in the compost. This negatively affects compost quality as they can inhibit plant growth or pollute soils and especially substrates (given the relatively high compost addition)[8]. Heavy metal contents in the compost can be determined on a dried and grinded sample after destruction of the sample in strong acids, e.g. *aqua regia*. After destruction, element concentrations can be measured by ICP-OES (EN 13650: Soil improvers and growing media – Digestion of aqua regia soluble elements).

Organic contaminants

In case of potentially contaminated feedstock compost can be analyzed for organic contaminants such as:

- polychlorinated biphenyls PCB
- polychlorinated dibenzodioxins and dibenzofurans (PCDD/F)
- polycyclic aromatic hydrocarbons (PAHs)
- chlorinated pesticides and adsorbable organic halogen (AOX)
- linear alkylbenzene sulphonates (LAS)
- nonylphenol (NPE)
- phtalates - Di (2-ethylhexyl) phthalate (DEHP), Butylbenzyl phtalate (BBP),
- Dibutyl phtalate (DBP)

More information can be found in https://ec.europa.eu/environment/waste/compost/pdf/hm_finalreport.pdf

Herbicide residues

Herbicide residues can be present in the feedstock, e.g. grass clippings from lawns and pastures, residues from cereals, horse manure, etcetera. Most herbicides degrade during composting, but there are also more persistent ones such as clopyralid and aminopyralid. When the herbicides are still present in the compost, they can negatively affect the growth of certain crops (especially tomato, potato, pepper, pea and bean in case of clopyralid). This is especially important for substrates in which composts can be used in relatively high quantities of for protected cultivation where relatively high amounts of compost are added to the soil.

[8] Limits in Belgium (FOD, federal): As<20, Cd<2, Cr<100, Cu<150, Hg<1, Pb<150, Ni<50, Zn<400 mg/kg dry matter content

Herbicide residues are difficult to detect chemically because harmful concentrations in compost can be lower than chemical detection limits. Therefore, it is advised to combine chemical analysis with a bio-assay. In the latter test, plant response is monitored and with a good indicator plant the detection limit can be much lower compared to chemical methods. To determine the plant response of composts the European Standard (EN 16086-1) test is used, with Chinese cabbage and barley as test species. As these species are not sufficiently sensitive for carboxylic acid herbicides, red clover (but very sensitive to nutrition status) or preferably broad bean are proposed (Geuijen and Verhagen, 2017).

Number of emerging weeds

Weeds seeds are especially not wanted in compost by growers[9]. For determination of the number of emerging weeds, 500 mL compost is mixed with 2 L white peat and spread in a layer of 2-3 cm in a container, and kept for 2 to 3 weeks at 21°C and 100% relative humidity under conditions of sufficient natural light. The number of emerging weeds are counted after two or three weeks.

Pathogens

The intensive decomposition during composting includes thermal hygienization of possibly present human, animal and plant pathogens. A combination of minimum reached temperature and minimum time period for this minimum reached temperature is necessary for killing a specific pathogen. The lower this temperature, the longer the time period is in order to hygienize the compost. There are very diverse hygienisation requirements in different regions and legislation (Vandaele et al, 2020: Report on hygienisation requirements for composting process). The proposed temperature - time period combinations should be sufficient to kill nematodes including Potato cyst nematode (*Globodera pallida*), and their cysts (Bøen et al., 2006; Noble and Coventry, 2005).

If it is not sure that this necessary combination of a certain temperature and time period was reached during the composting process[10] or in case of contamination of the feedstock, the compost can be screened for specific pathogens, e.g. plant pathogens *Fusarium*, *Verticilium*, *Pythium*, *Rhizoctonia* and Potato cyst nematodes. In case of specific possible contamination also animal pathogens as *Salmonella* and *E. coli* (indicator organism for hygienization) can be screened for. The methods used include bioassays, direct plating, dilution plating, serological and direct microscopic examination (Noble and Roberts, 2004). See section “Required increase in soil microbial activity” in “Extra analyses for matchmaking” for more information on determination of micro-organisms.

[9] There should be max. 1 emerging weed per liter compost according to Belgian Federal standards

4. Extra analyses for matchmaking

Not all analyses have to be done for all composts. Some analyses are appropriate for specific cases, in order to be able to match a specific compost to a specific soil/ cropping system/case. Below, specific intended uses and goals are listed, combined with the designated compost indicators.

Required increase in soil pH

Too low soil pH is not desirable for nutrient availability and biological processes. Increase of the soil pH is possible by compost addition since most composts have a pH between 6 and 9.5. However, rather the ability to resist to pH changes (= pH buffering capacity) than the pH of the compost itself is important. The higher the inorganic carbon (carbonate) content or the pH buffer capacity of the compost, the more protons the compost can neutralize. Therefore, a compost with high inorganic carbon content or pH buffer capacity should be selected if the soil pH increase is an important goal of the compost addition.

The inorganic C content can be measured from the CO_2 released after acidifying and purging the compost sample (EN 15936). The pH buffer capacity can be calculated from the amount of acid necessary to decrease the compost pH to a certain value, e.g. pH 4.

Shortage in secondary or trace elements in soil or crop

If the soil and/or the crop has shortage in certain secondary or trace elements (e.g. Si, B, Mo, Co, Se, S, Cu, Fe, Mn, Zn), information on the content of these elements in the compost is interesting in order to select a compost with relatively high contents of these elements in order to solve the shortages in the soil. The total content of a certain element can be determined on a dried and grinded sample after destruction of the sample in strong acids, e.g. *aqua regia*. After destruction, element concentrations can be measured by ICP-OES (EN 13650: Soil improvers and growing media – Digestion of aqua regia soluble elements).

Required increase in soil microbial degradation activity or certain microbiome groups

A lot of organisms are present in compost, and by compost application these are transferred to the soil where they can integrate in the soil community. When it is required to increase the soil microbial (degradation) activity, it can be helpful to apply less stable compost in autumn[11] (not before planting/sowing). In this case, it is especially interesting to measure the compost stability, see section on basic standard analyses above.

Addition of compost, full of bacterial and fungal life, can give a boost to the soil microbial and fungal activity. It is therefore useful to get an idea of the total bacterial and fungal

[11] http://www.eurolab.nl/meststoffen/compoststabiliteit.htm

population in the compost. Also the composition of this microbial population can be interesting. E.g. presence of mycorrhizae in the microbial population might be an indicator of compost maturity and/or C/N ratio. Such a compost is beneficial for the rhizosphere of plants. Some soils have an imbalance in the bacterial versus the fungal biomass, which might be corrected by application of composts in which the lacking group dominates. Certain crops can also require more bacterial (e.g. Brassica) or fungal (perennial crops) dominant soil life. Sometimes an increase in certain specific microbiome groups is wanted. The specific information needs determines the most appropriate analysis technique.

The total mass (absolute value) can be measured by **phospholipid fatty acid (PLFA) analysis**. Twenty different PLFAs are indicative for the absolute biomass of 6 groups: bacteria (non-specific), Gram+ bacteria, Gram- bacteria, Actinomycetes, fungi and mycorrhizae. PLFA analysis therefore gives the absolute abundance of the living organisms and a classification in 6 functional groups of the (soil) food web.

Another technique for measuring microbial life in compost is the **plating technique**. Fungi and bacteria that are (visibly) growing on the compost can be transferred and isolated. Universal media are used to estimate the absolute abundance, semi-selective media can be used to target specific organisms. The disadvantage of this techniques is that only culturable and highly abundant species can be detected. Numbers of e.g. aerobic bacteria, anaerobic bacteria, fungi, actinomycetes, etcetera can be given.

Microscopic determination of bacteria, actinobacteria, beneficial and pathogenic fungi, protozoa and nematodes is possible on the pure compost or after plating. Nematodes (and other groups) can be further identified to genus level according to taxonomic keys, but these analyses are mostly for research reasons only.

The organisms living in soil or compost form a community, a complex interacting living system called the **food web**. This system can be analyzed by a number of techniques: counting (direct counting by the naked eye and by microscope or by plate counting), measuring activity levels (respiration, nitrification and decomposition rates) and measuring cellular constituents (biomass nutrients after chloroform fumigation, enzymes, (phospho)lipids, DNA and RNA).

More detailed analysis of the microbial community, mostly for research reasons, is possible by **metabarcoding**, i.e. analysis of one specific DNA region of the organisms. Identification is possible up to genus level, but only the relative abundance can be assessed. In this way, information is gathered regarding the diversity, richness and evenness of the microbial community of the compost.

Specific particle size needs

Composts exist of very small to larger particles. Large parts can be especially wanted, e.g. to use the compost for erosion control or as mulch. In other cases, only fine composts are wanted, e.g. in substrates and for vegetables because of the specific machinery. The particle size can be visually estimated, or determined by sieving (EN 15428: Soil improvers and growing media - Determination of particle size distribution)[12].

[12] According to Flemish standards, more than 99% of the compost should be < 40 mm. Green composts are usually sieved to 20 mm. For use in substrates, finer sieving (10 or 15 mm) is possible, while for arable field application sieving to 30 mm is more common.

5. Extra analyses for compost use in substrates

In substrates, compost can be present in relatively high quantities. Impurities and contamination can therefore be of an extra concern. Also particle size and physical characteristics are important for the intended porosity and water holding capacity for plant growth in the substrates. Information on the availability of nutrients is essential in order to fine-tune the fertilizer addition in substrates. The general plant growth suitability can be assessed by several compost maturity tests.

Analyses for contamination and impurities

Analyses for contamination and impurities are listed above in a specific section on this topic. Compost to be used in substrates has sometimes more strict regulations for certification than compost for soil application[13] and therefore these analyses can be more important to perform.

Analyses for particle size

Analysis of the particle size distribution is given above. Compost to be used in substrates has sometimes more strict regulations for certification than compost for soil application[14]. Too many fine particles may limit drainage, too many coarse particles can reduce seed germination (poor seed-to-soil contact).

Physical analyses

For compost used in growing media, the physical properties are especially important for root growth, air and water availability in the growing media. The measurement of the bulk density, both wet and dry, was already discussed before, as was the analysis of particle size distribution.

Water retention is an important property of substrates, and therefore also of the compost to be blended in substrates. Water retention and release characteristics can be measured in several ways. A moisture retention curve or some key measurements of water content related to suction (tension) can be established with e.g. a hanging water column. In EN13041 (Soil improvers and growing media - Determination of physical properties - Dry bulk density, air volume, water volume, shrinkage value and total pore space) the measurement of the compost water volume at suction of -10 cm (pF 1), -50 cm (pF 1.7) and -100 cm (pF 2) is described. The water holding capacity (WHC) can be derived from the moisture retention curve. One definition of the WHC is the water volume (%) at pF 1.7 minus the water volume (%) at pF 2. Definitions and determinations differ however widely

[13] German certification for substrates compost by the Bundesgütegemeinschaft Kompost (BGK)

[14] German certification for substrates compost by the Bundesgütegemeinschaft Kompost (BGK): maximum particle size is 25 mm and at least 50 % should be smaller than 5 mm. Regulation in Belgium (reference standard and FOD standard: >99% <40 mm)

(Agnew and Leonard, 2003). Sometimes the WHC is determined as the water content after 24 hours of free drainage of a water saturated compost.

Low bulk densities of compost imply high porosity, which is important for air and gas transport. The total pore space can be derived from the particle density (dependent upon the content of organic matter and ash) and the dry bulk density (EN 13041). Another possible approach is the displacement of air by water in the compost sample and measuring the change in weight (Agnew and Leonard, 2003). The air volume at a certain tension can be calculated from the total pore space and the water volume.

Availability of elements

Information on total contents of elements in compost are most important for application on soil, but for compost blending in substrates also the plant availability of the elements needs to be known[15]. Elements as Na and K are generally highly available, but elements as N, P, Ca, Fe, etcetera can be (partly) fixed by minerals and present in organic matter in a way that they are not completely accessible to plants.

The plant available content of elements can be estimated by several extraction methods. The more harsh the extractant, the higher the extracted amount of element from the compost. The most soft extractant is water. In the **water extract** (EN 13652: Soil improvers and growing media. Extraction of water soluble nutrients and elements), the availability of e.g. Na, Cl, SO_4, NH_4-N and NO_3-N can be assessed. The method of this water extraction was already discussed in the section 'Basic standard analyses – EC). Another possible extractant is **0.01 M $CaCl_2$/DTPA** (EN 13651: Soil improvers and growing media - Extraction of calcium chloride/DTPA (CAT) soluble nutrients) for K, Mg, Fe, Mn, Na, NO3-N, NH4-N, P and SO_4. Fifty ml of compost is shaking for one hour with 250 ml of solution containing 0.01 M $CaCl_2$ and 0.002 M DTPA, and elements can be measured by ICP-OES, anion chromatography and/or spectroscopic methods. The **electrostatically bound cations** can be assessed by the CEC measurement (several methods available, see above). In the **ammonium acetate buffer** (pH 4.65) the availability of P, Ca, Mg, K, Na, Mn, Fe and SO_4 can be assessed.

The above mentioned extraction methods assess the availability of mineral elements as controlled by binding. The availability of elements as controlled by organic matter mineralization, e.g. for N, can be assessed by the measurement of the quickly released organic N[16]. This method involves incubation of the compost mixed with a standard soil at controlled conditions of temperature, moisture and density. At regular time intervals samples are taken for measurement of the amount of available N in the compost – soil blend. The mineralization of N from the compost organic matter can be assessed from

[15] German certification for substrates compost by the Bundesgütegemeinschaft Kompost (BGK): regulation for soluble P, K, Na and Cl

[16] Official protocol in Belgium: https://esites.vito.be/sites/reflabos/2019/Online%20documenten/BAM-deel1-12.pdf

the mineral N measured in the compost soil blend, with correction for N in the standard soil without compost.

Compost maturity

Compost maturity refers to the level of completeness of composting and amount of degradation of phytotoxic organic substances. This is especially important for compost use in substrates given the relative high proportion of compost used. Compost stability (explanation and methods above) is a criterium for compost maturity. There is not one single test for assessing compost maturity, a list of tests is given below (in addition to the stability tests).

Phytotoxicity

The presence of phytotoxic substances or germ inhibitors in fresh compost can be evaluated by a germination test. De germination capacity of cress (*Lepidium sativum* L.) is determined under standardized circumstances in a substrate containing fresh compost diluted with sand. The germination capacity is compared to the one in a reference substrate (e.g. pure sand). The phytotoxicity is expressed as the percentage inhibited germs relative to the reference substrate. Executing the test with sand is not always easy, better results are possible with soil. Also other tests are possible, e.g. the seed plant test and the breeding test with N increase as suggested in German regulations.

Nitrogen immobilization potential

While mature compost is a source of mineral nitrogen, immature compost can induce N immobilization. Plants can experience N shortage after application of immature compost due to N use for organic matter degradation by the microbiome.

Nitrogen immobilization can be determined by mixing the compost with a mineral N solution and incubating the mixture during one week at 37°C (Vandecasteele et al., 2016). Before mixing and after the incubation, mineral N content is measured in the compost (method: see above). The N immobilization is determined as the relative amount of added mineral N disappeared during the one week incubation.

C/N ratio

The C/N ratio is generally decreasing during composting. A high C/N ratio (> 20-25) can indicate an immature compost. However, the C/N ratio of the end product can be an inappropriate indicator of maturity or stability (Vandecasteele et al., 2017) because it is mainly affected by the initial C/N ratio of the feedstock (Nolan et al., 2011) and it can level off before the compost has stabilized (Zmora-Nahum et al., 2005).

Mineral N and NO_3-N/NH_4-N ratio

During composting, organic N is mineralized to NH_4^+. During the high-temperature decomposition, further nitrification (to NO_3^-) is inhibited. During the cooler curing phase nitrification can take place, increasing the NO_3^--N/NH_4^+-N ratio. In a well matured compost there is little or no NH_4^+-N (< 0.4 g/kg), a predominance of NO_3^--N and thus a NO_3^--N/NH_4^+-N ratio > 1. The mineral N is considered to be a better maturity indicator than the C/N ratio (Vandecasteele et al., 2017).

6. Spectroscopic methods

Composts can be scanned by “vibrational” spectroscopic methods as Near-Infrared Spectroscopy (NIRS) and Fourier-Transformation Infrared Spectroscopy (FTIRS). The resulting spectra can be linked to several measured compost indicators as listed above. When a good correlation is obtained between the spectra and a compost indicator for a range of composts, NIRS and FTIR can be used as an estimate of the compost indicator, given that control measurements are performed. The spectroscopic measurements allow thus for fast screening of chemical properties and compost stability and is time and cost efficient. In a separate report the relationships between NIRS and compost indicators are elaborated.

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