Significance of Stability-Maturity Testing and Plant Bioassays to Assess Composts for Inclusion in Soil Restoration

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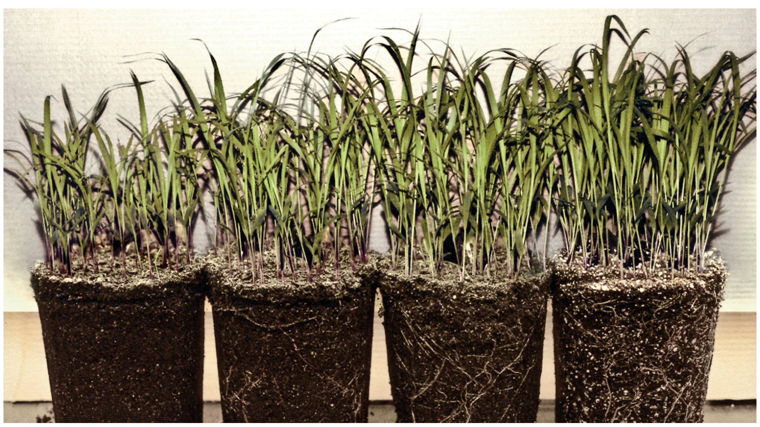

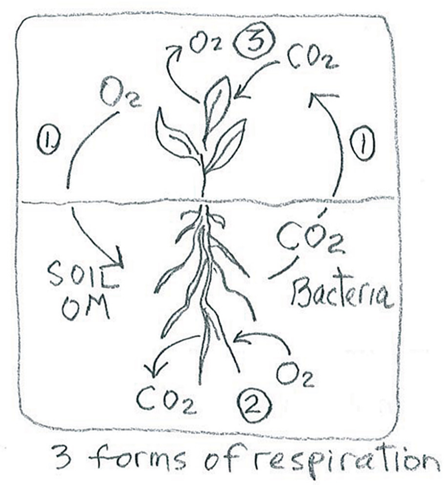

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SUMMARY

There is increasing demand for recycled organic matter composts in applications such as organic potting mixes, restoration of disturbed soils, and constructed soil ecosystems. There are different compost quality standards applied by the scientific community, by government and the industry. Understanding and accepting relevant maturity and stability standards is imperative. If inappropriate compost tests are applied to these important areas, it may be harmful and could set back the burgeoning interest. Examples described in this report are guidelines for "stability and maturity" and "plant maturity bioassays"; the issue of the high nutrient density of compost is not addressed. In the USA, "stability" protocols stem from early debates within the sludge/compost industry. In several cases, measurement units for test thresholds are scientifically obscure and it is questionable if protocols have been calibrated for end-uses. To meet this challenge for sustainable soil management, amended soils must be approached as a unit volume – the plant root environment. Properties that organic amendments bestow on a whole environment must be accurately predicted. An excellent case is CO_2 respiration used to infer stability. Stability values which some in the compost industry are using are 10 to 100 times higher than observed in natural soil-ecosystems, even when at their most fertile. Since healthy plant environments reflect the dynamic interaction of aeration, respiration rate and oxygen diffusion, the concept of stability, to be practical, must be redefined. The goal of responsible soil and ecosystem management becomes to minimize disruption of the soil-plant-root interface caused by uses of unstable and immature compost. <u>Volumetric respiration</u>, the exchange of CO_2 for O_2 per unit volume, may represent the essential unit of measure and is highly relevant to healthy, whole soil environments. Similarly, plant tests, if used to infer compost quality, must be proven to be relevant to the use. Ample scientific evidence exists in the literature to support volumetric-based tests (such as Dewar Self Heating and Solvita) or improved plant assay tests (covered containers, different biotypes). Use of uncalibrated and inappropriate test methods confuse the marketplace and jeopardize project success.

INTRODUCTION

The amendment of disturbed, depleted and manufactured soils and planting media involves skills in sourcing components that are compatible and suitably stable to foster and sustain healthy growing environments. For restoration of disturbed sites, establishment of native plant communities, and creation of new soil media composts serving as a source of organic matter and recycled nutrients are essential. The traditional use of peat moss for these purposes is now judged to be unsustainable and destructive to unique ecosystems. The challenge is, how can composts resulting from relatively recent intense, biological recycling, be safely substituted into these applications.

COMPOSTS AS RECYCLED COMPONENT

Recently, composts have been promoted as a replacement organic source both for soil and peat-based media. The principal driver to composting is driven by societal perception of the need to recycle organic matter instead of filling landfills. In contrast to traditional peat moss, horticultural media composts are relatively unstable since they result from the recent, planned decay of recycled organic matter (ROM). ROM may include, leaves, grass clippings, shredded wood, manures, food wastes, and wastewater and manure sludges. Composted ROM has been actively promoted worldwide for nearly 50 years.

SIGNIFICANCE OF RESPIRATION OF OXYGEN TO CO_2

Within a soil profile, consumption of oxygen and generation of CO_2 during decay of residual organic matter (crop residues, microbial residues, sloughed roots) is normally so low as to not result in measurable deprivation of pore space oxygen. Plant roots require a substantial influx of available air since plant-rootlet aerobic respiration occurs at very high rates when soils are warm and plants are undergoing rapid expansion. The addition to soil of high rates of fresh organic matter can result in episodic oxygen deprivation with immediate, harmful effects on plants, referred to as phytotoxicity. In an agricultural setting with proper soil management and tillage, the transient negative effect from incorporation of crop residues and manures is normally very minor. However, composts of uncertain stability are being promoted at increasing rates in soil mixes and constructed landscapes. Presently in the USA, there are only minimal national standards relating to compost production and maturity. There are no nationally applied **industry-independent** guidelines, which exist that pertain to compost use in horticulture, landscape construction and disturbed soil restoration, and for manufactured soils. Information provided in this review, using the example of some selected test methods employed by the compost industry, cast significant doubt as to whether any of these compost tests are appropriate for soil building, container media and constructed soils.

RATE OF RESPIRATION AND NITROGEN VOLATIZATION

Soil is the ultimate yardstick for plant growth by nature of the manner in which it holds nutrients and respiration in dynamic balance. Entire plant communities and plant physiological systems and the underlying cellular metabolisms have evolved in accordance. Under normal healthy soil circumstances, soil microbial respiration rates range from up to 100 ppm per day as CO_2-C, or as much as 65 pounds of CO_2-C per acre per day (USDA 1999). Importantly, at these rates, the depletion of oxygen due to microbial respiration does not interfere with plant growth as oxygen diffusion and soil-moisture drainage are balanced.

In contrast to soil, composts by nature of the quantity and rate of decaying high levels of organic matter exhibit significantly higher respiration rates, in the range of 500 - 12,500 ppm CO_2-C per day – several orders of magnitude higher than normal soils. During composting, this excess, biogenic CO_2 simply escapes to the atmosphere. However, in relation to soils, it must be logically assumed that such high respiration rates will have a significant impact when amending and constructing soils with substantial amounts of compost. By pushing the soil respiration to high levels with what some might label "stable" composts, a series of imbalances both of chemical and biological nature may ensue, for which balancing oxygen demand and availability becomes very difficult.

Composts possess other gaseous constituents, which must be taken into account to reach a determination of true maturity and stability. An example is emission of volatile ammonia, NH_3, a dissociated gas, hazardous to microbes and plants at concentrations as little as 500 ppmv. Other examples are ethylene gas (C_2H_4), methane (CH_4) and hydrogen sulfide (H_2S), all associated with environments of oxygen deficient. Such gases are rarely measurable in normal soils (waterlogged soils are an exception) and are often viewed by composters as distractions if they exceed a limit observable by neighbors. Ammonia is agriculturally very relevant and is released temporarily from applied fertilizer urea or anhydrous ammonia and also manure. In normal soil at rates typical of fertilizer or farm-spread manures, it rapidly changes to non-volatile ionic ammonium (NH_4^+) form and is adsorbed onto the soils cation (negatively charged) exchange surfaces. Subsequently, common soil bacteria transform ammonium to nitrate, which plants preferentially absorb as a nutrient.

Composting is characteristically nitrogen rate-limited and is for this reason deliberately managed with nitrogen additions to obtain C:N ratios which enable active degradation. Since organic nitrogen compounds are typically more labile than carbon compounds, the result is that free ammonia is produced and may attain levels as high as 4,000- 20,000 ppmv in the interstitial pores of the compost. Composts lack the driving force that soils possess to readily transform ammonia, an unfortunate result of suppression by heat and intoxication by ammonia of nitrifiers that should normally proliferate in soils. The result is that composts may decline in CO_2 respiration but remain at high ammonia levels for considerable periods of time. This fact is very important because it forms the basis for evaluating compost viability for the use intended.

EXAMPLES OF EFFECTS OF IMMATURE PRODUCT IN HORTICULTURE

The traditional use of manures and composts in farming at normal rates rarely results in any harmful effects (10 tons/acre is a dilution of 1:100). Perhaps existing compost standards and guidelines frequently promoted by the industry are suitable only for this form of use. Examples of harmful effects from improperly sourced composts employed in horticulture do exist, although many are private cases. A Rhode Island nursery lost an entire planting of ericaceous shrubs to immature compost in 2001, investigated both by the Univ. of Massachusetts and Woods End Lab; the cause was found to be high levels of volatile organic acids, due to fermentative immaturity. In a landscaping project in the Big Dig, Boston, a construction company (Modern Continental) sourced immature compost which, when incorporated into soils, emitted odors noticeable to passers-by, requiring the entire project to be unearthed at great cost. In Maine, after landscaping for a national bank headquarters near Camden, several high-value ornamental trees died - the cause was linked to use of immature compost in the soil mixes. At a very high profile project in lower Manhattan, the project was delayed and a street was closed to allow aeration and leaching treatment of excess ammonia in delivered compost.

Biosphere 2 may be the most notable example of undesired effects of improperly sourced compost. Launched 1990 in southern Arizona, the project was a closed, experimental ecosystem in which an eight-person crew was sealed and the system presumed to be selfsustaining. The life-support and oxygen-refresh system comprised a complex, mixed ecosystem on artificially constructed soils. However, CO_2 started climbing steadily, and oxygen dropped to dangerously low levels, which became a prime factor causing the project to be scuttled in 1994. Unsuspected at the time was the soil mix, prepared with *15% content of commercial compost* and layered to a *depth of 1 meter* (Severinghaus et al. 1994, Silverstone et al 1999). The rate of oxygen consumption of this mass of unstable soil-compost mix was eventually blamed for the situation (yet hardly evaluated in an ecological, horticultural context). In a 2011 case, the EPA reinvestigated an East-coast remediation project when the site was found to be emitting methane measurable at the boundary. Subsequent tests attributed this effect to the compost used in backfilling the site, requiring the compost to be remediated.

In contrast, sufficient and growing evidence exists that crops do better with more mature compost product, even in normal agricultural settings. A California study, conducted with a number of common field crops, found plant growth could be positively related to compost maturity when measured by the California Maturity Index (Buchanan, 2002). Around the same time, a Woods End team published evidence on how oxygen deprivation in growing media may be induced by immature composts (Brinton & Evans 2001, 2002). Research at NCSU horticulture department showed how rootlet development in containers is strongly affected by factors that reduce free oxygen levels in the pore-space (Strojny et al. 1997).

Comparisons of stability test methods have been available for many years (Ianotti et al 1994). Stofella and Kahn (2001) presented an overview of the development of stability tests believed to relate to horticultural applications. Perhaps the most thorough review of test methods for compost maturity and stability is the work of Gomez (2006). Yet, with few exceptions, these and other excellent reviews virtually overlook *respiration relevant to soil development and ecosystems*. The industry priority, perhaps necessarily so, has been developing and comparing various respiration procedures independent of virtually any specific application.

HORTICULTURALLY RELEVANT COMPOST TESTS

Compost is so important for the amendment of disturbed soils and manufacture of designed manufactured soils, it is essential to minimize deleterious impacts and maximize ecological benefits for these uses, composts must be tested for maturity-stability factors *relevant to plant growth* and *pertinent to the type of environment* into which compost is being incorporated.

Some industry-supported test methods did not sufficiently protect projects against adverse consequences of unstable and immature compost use. These tests largely based on sludge management are length of heating (based on early EPA rules for sludge composting), metals content (sludge disposal), and relative stability (extrapolated from vector attraction reduction of sludge). These guidelines generally do not address the needs and expectations of project designers for relevant criteria to specify suitable composts.

There has been progress made in other countries separating green waste composting guidelines from sludge disposal rules, with good effects for both industries (Germany, Austria, Switzerland, Denmark). The result in these cases is test standards for green compost, which are comparatively stricter, but they have proven to be attainable. In contrast, in the USA, existing compost guidelines are dated and lenient, and represent a curious compromise of sludge/MSW contingencies molded into a green composting framework, thus allowing compost production to go ahead with controls not targeted to many end uses. A good example is the USCC STA program, which confers on compost a "Seal" widely believed to be a mark of quality, but based on standards that do not address important basic requirements. Objections from the scientific community that such seeming standards do little to help end-users are countered by the expressed belief that "market forces" will, if needed, impose the relevant, higher standards (*personal communication*, Al Rubin, US EPA, 2002). An educated and thoughtful user community in the marketplace will require stronger standards.

DISCUSSION: VOLUMETRIC RESPIRATION FOR COMPOSTS

As an illustration of how compost quality tests must shift to accommodate important restoration uses, the example of respiration is chosen. This procedure is traditionally being measured gravimetrically as CO_2-release (or O_2 demand) per unit weight of material, or per unit of material volatile solids, and is based on extrapolated and uncalibrated soil protocols from the 1950's. Yet, testing compost respiration by *volumetric* as opposed to gravimetric (weight basis) protocol, provides crucial insight to relevant ecosystem behaviors.

Volume-based testing for respiration is comparable to the practice in soil science where nutrients are assessed per volume of growing media. Presently, only the Solvita® test and the Dewar self-heating test serve this function (another example is a closed-container cress test described later). The primary factor making volume-based testing so significant is the discrepancy in reporting respiration per mass versus the behavior at given bulk-density. The net effect of the forces of decay and settling is that the volume weight of compost increases from as low as 12 lb/ft^3 to as high as 65-70 lb/ft^3. This is of great significance when evaluating stability for plant systems, dependent as they are on reciprocal and opposing forces of aeration, respiration rate and oxygen diffusion. These relationships explain some of the dramatic failures attributed to composts to date. If the rate of respiration per unit of volume is not known, then the behavior *in situ*, as in a container, or a constructed soil profile, cannot be predicted.

The common compost respiration test based only on weight and used by industry in the USA and Europe, is in fact a dimensionless procedure, especially the way it is being applied as relative to percent of volatile solids (VS). The VS may vary from 20 to 60% in normal composts. Testing composts in this manner is not very meaningful. Also, it can misrepresent the potential impact in a manufactured soil environment. Respiration rate per unit volume defines ultimately the amount of air a plant root must compete for against diffusivity gradients and moisture tension, on top of compost-induced rates. Over-stressing this system can induce a microbial shift towards facultative anaerobes as the oxygen drawdown exceeds what the soil pores are capable of refreshing. This is associated with a lowering in oxidation-reduction potential (ORP) and, ultimately, chemical reduction of soil constituents (manganese, sulfur, nitrate).

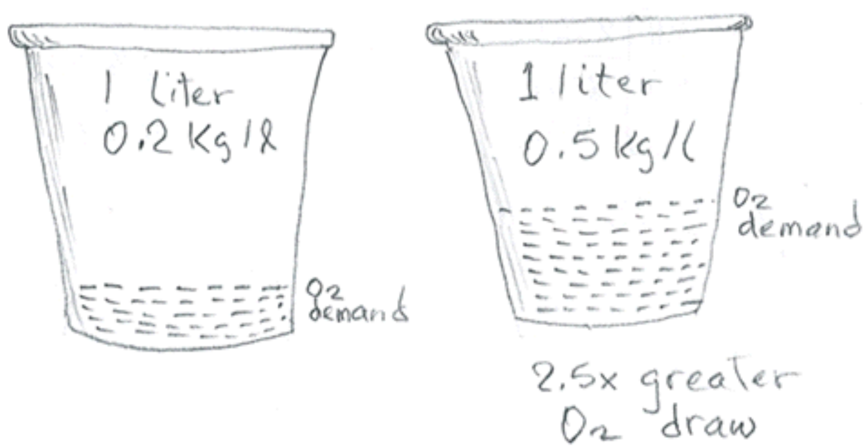

Figure 1

In addition to the work Woods End labs has done to illustrate this trait, a horticultural research station in Holland showed how reporting compost respiration per unit volume (g CO_2 per liter of media) provided a relevant means to compare how much compost may be substituted into peat media without harmful effects (Pronk, 1997). As early as 1992, Brinton showed the Dewar test correlated highly with O_2 and CO_2 rates per unit liter.

An example of the situation is shown graphically in Figure 1. Two pots contain the same volume of compost but of differing bulk-densities. The composts in both pots are gravimetrically tested and have the same rate of respiration. Yet, the pot on the right side, will exhaust oxygen in the pore space 2.5 times faster than that of the pot on the left. Plants on right could suffer apparent water-logging damage much more readily than plants on the left (Strojny et al 1998). This defines the principle dilemma is using gravimetric CO_2 rates for such purposes. A banana plantation in Honduras converted to using compost-based media for propagation of palms. Plants fared poorly and upon opening up the pots the roots were found to be growing only around the edges, due to oxygen starvation in the media (*personal communication*, Harry Hoitink and Will Brinton, 2004). Published studies have shown that oxygen deprivation from unstable growing-media may persist for substantial periods of time (Brinton & Evans, 1998).

The compost industry by and large promotes gravimetric respirometry (O_2/CO_2) as an ultimate stability guide. The units reported (mg CO_2/g TS or per g OM/VS) bear no direct practical significance to end-users (and perhaps also to composters) and the basis for the suggested thresholds used to certify or rank stability is obscure, if nonexistent. An example of the range of values is given in Table 1.

Table 1 Table of Comparative Compost Respirations

Ref (a)	Ref (b)	Ref (c)	Ref (d)	Ref (e)	Ref (f)	Ref (g)
Carbon Loss % of C/day	mg CO_2-C per g/C	mg CO2 per g/OM	mg CO_2-C per g/OM	mg CO_2-C per kg TS	RATING of COMPOST Respiration	mmoles CO_2 per liter sample*
0.0–0.2%	0–2	0–4	0–1	0–500	Very-Low rate	17
0.2–0.8%	2–8	4–15	1–4	500–2,000	Moderately Low	67
0.8–1.5%	8–15	15–28	4–7.5	2,000–3,750	Medium rate	126
l.5–2.5%	15–25	28–46	7.5–12.5	3,750–6,250	Med-High rate	210
2.5-5.0%	>25	46–93	12.5–25	6,250–12,500	High rate	421

a) Table 2-2 NRCS Part 637 National Engineering Handbook (2000). Sourced from Brinton et al (1993) On-Farm Composting. USDA Report, p 45. USDA Technical Center, Chester PA
b) arithmetical calculation from column (a)
c) recalculated as carbon dioxide (CO_2) per gram Organic Matter (British PAS100 Scale).
d) Same as col (c) except in units of Carbon, used by TMECC and STA
e) Standardized to weight of dry sample, use this column to compare to soil.
f) NRCS op. cit, Table 2-2
g) Volumetric CO_2 rate per standardized liter of compost at 0.4 g/cc

And oft cited stability value of 8 mg CO_2-C from the USCC-STA program (the unit is typically missing) can be found in the NRCS National Engineering Handbook (2001), referencing a

Woods End Laboratory study of composting manures, which proposed a similar value as a *mid-point* or the transition from active composting to curing (1993). It was not intended to be a growing-media standard.

It is helpful to look at these values in terms of natural soil respiration (Table 2). Compost values typically encountered are as much as 25-times greater than rates observed in fertile soils (compare right column, Table 1 vs Table 2). In a sol environment such high rates represent a massive respiration gradient and potentially a significant depletion of pore-space air (in compost this is often replaced by forced aeration or physical turning). The quantity of CO_2 produced by a liter of compost must be accompanied by a similar draw of oxygen, or the system may slip into semi-anaerobia typical of water-logging.

Table 2 Respiration Rates Associated with Soil Fertility

Soil Fertility Based on respiration	Soil mg CO_2-C per kg TS range: low to high	mmoles CO_2 per liter soil
Very low	10	0.8
Med-low	20	1.7
Medium	50	4.2
Med-high	80	6.7
High Fertility	125	10.5

Table 2 shows that normal gravimetric and the volumetric respiration of soils differs substantially from compost. The persistence of these differences in respiration and its effect on the soil micro-environment will depend on depth of burial, moisture and soil temperatures.

To understand stability standards, it is helpful and perhaps necessary to trace origins. Early attempts to understand compost distinctly in terms of stability are certainly evident from early literature (Willson et al. 1986). Brinton's compost lab is very likely the first to have commercially applied base-trap CO_2 respirometry as a test for compost completeness (1984). Later, this evolved into a volumetric compost protocol (Solvita®) following some disturbing compost failures at New England nurseries. Collaborative effort with the Soil Quality Institute in the 1990's led to a Solvita® soil respiration method, to aid integration into healthy-soil environments. Incidentally, since soils exhibit relatively uniform bulk densities in contrast to composts, volumetric and gravimetric respiration tests lead to nearly identical conclusions.

Brinton devised the Woods End compost CO_2 method based on comparative respiration trials with composted manures used for soil application (Brinton 1979). To derive a respiration interpretation, Woods End adapted the work of Castellanos (1981) who was perhaps the first to show how CO_2-respirometry could be used to predict carbon and nitrogen mineralization when organic amendments were soil-applied. These figures are cited in the NRCS Engineering Handbook (2001).

Volumetric respiration adds a critical dimension to this effort. It should at least be required alongside gravimetric tests. But attempts to correlate the Solvita method against gravimetric methods should be approached cautiously due to differences in bulk density. Theoretically, volumetric respiration should not necessarily correlate with gravimetric respiration. The increase in compost density over time, even if gravimetric respiration declines, can mean that the CO_2 release *per volume of soil* may *actually climb* as shown in Figure 2.

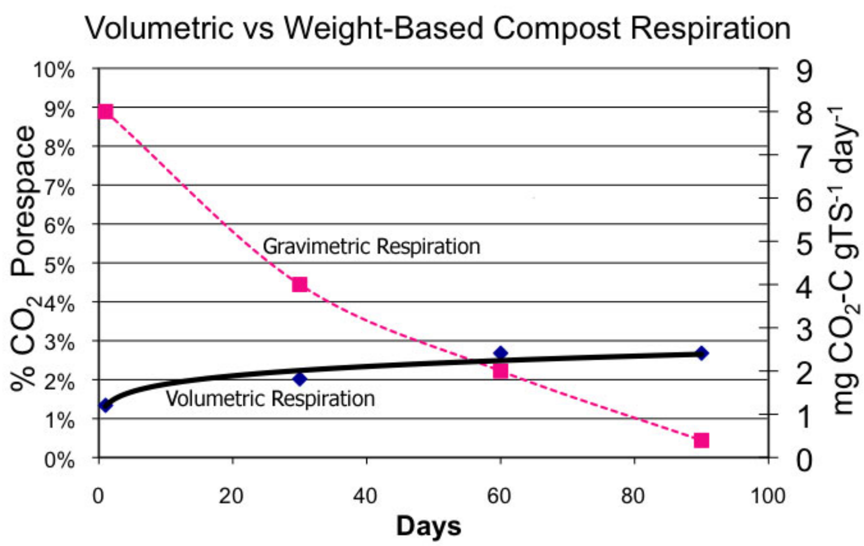

Figure 2 Gravimetric respiration may decline but volumetric may increase over time

Scientists who developed the Solvita test and the closed-cress test had this in mind since the procedures are standardized for volume. The change in gaseous composition in the sample headspace reflects potential behavior in soil mixes at given bulk density. Composts which are declining in apparent CO_2 rate, particularly if respiration is expressed per unit of organic matter, may not be any more stable in volumetric terms, and oxygen demand may be increasing, due to how the two factors cancel each other out (Figure 2). This has led some to falsely conclude that volumetric testing such as Solvita does not provide meaningful results. As discussed above, for horticultural and landscape projects where significant amounts of compost are used, the respiration potential per unit volume of material in situ is a critical factor to know. Working with this unit of measure it will be possible to come closer to recreating natural soil profiles, especially for establishment of native plant communities.

Curiously, the only other test that simulates this volumetric approach is the Swiss closed-cress test, which uses the same volume of sample as the Solvita test, but exposes a plant to the sealed environment (Fuchs et al 2001, 2008). In Figure 2, the large apparent increase in stability as indicated by a drop of respiration as measured gravimetrically, is contrasted with volumetric respiration, which due to an increase in bulk density, has increased slightly over time. Placed into a soil profile the respiration can be viewed in terms of Fig. 3, which shows how composts possess respiration 1-2 orders of magnitude higher than soils.

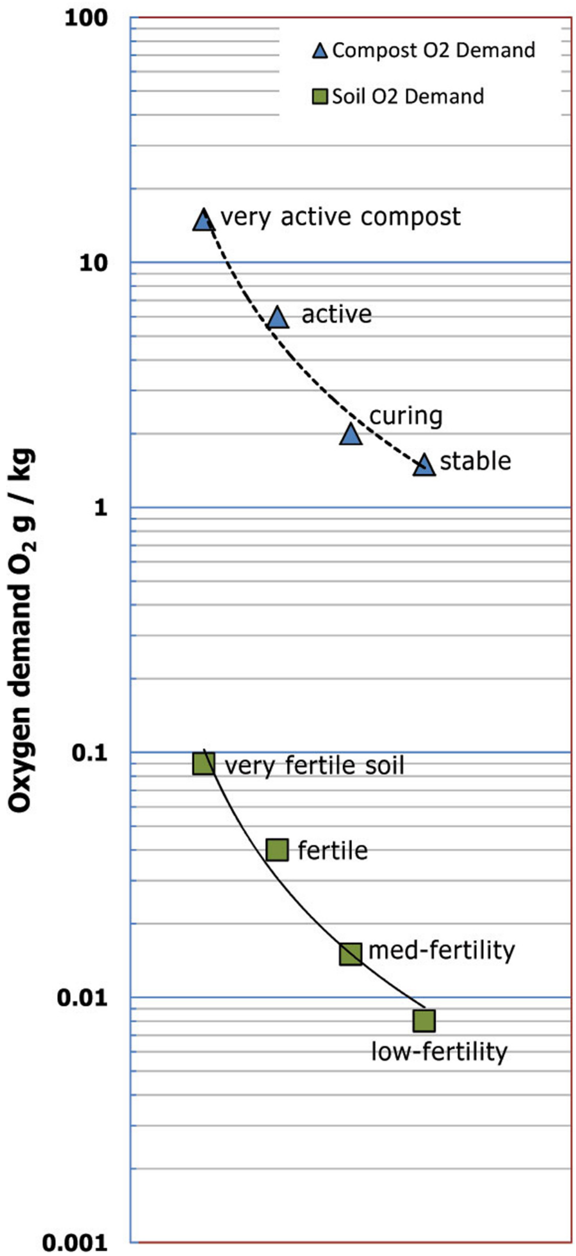

Figure 3. Compost vs Soil Respiration

<u>Other volumetric Tests</u>:

The Dewar self-heating test originated in Europe and is presently a standard in at least 4 countries. It is a form of a volumetric test. Similar to Solvita, this approach exposes a fixed 1-liter volume of compost to a heat-retaining vessel (Dewar flask r-value =250) and thereby serves to indicate the remaining potential for re-heating, an index of maturity. A study reported in the textbook *Microbiology of Composting* (Brinton & Evans 2002) showed that increasing rates of Dewar self-heating beyond 10°C were associated with increased phytotoxicty as observed in reduced plant root development. This also correlated with tested oxygen depletion.

Brinton introduced the Dewar self-heating test to America from Germany in the early 1990's (Brinton et al. 1995). Shortly afterwards, a gravimetric, liquid-based O_2-demand test for compost was published (Ianotti et al 1994 – funded by the USCC). This paper also reported several correlations showing usefulness of respirometry in relation to plant-based bioassays. Unfortunately, the recommendations in the published paper, both with regard to methods and use of plant bioassays, were not acted upon by the USCC.

In England, Lasardi and Stentiford (1998) pursued liquid O_2 respirometry while in Italy a solid-state O_2 respirometry system was designed to simulate the drawdown of oxygen in a landfill. As a result, in Europe the interpretation of O_2-demand tests for compost appears at least partly driven by landfill diversion regulations. Horticulturally-relevant guidelines for respirometry have not emerged.

As to whether the Dewar self-heating test has horticultural relevance, is somewhat in question. Dutch studies (Pronk 1997) indicated that the self-heating test was too insensitive for horticultural purposes *compared to volumetric respiration*. A similar observation surfaced in an Oregon study showing that a rise of as little as 3°C in the Dewar self-heating test corresponded to a significant quantity of compost respiration (Brewer & Sullivan 2003). This has to do with the amount of respiration per unit liter that is capable of driving heating. The Dewar test remains an intuitive procedure in the sense that heat potential, a primary factor composters closely monitor, is directly revealed in the test, and for this no calibration is required.

PLANT BASED BIOASSAYS AS COMPOST MATURITY TESTS

The concept of using plants for testing compost maturity is that, in theory, if the compost does not harm a plant, then the compost must be ok. Early workers in compost science emphasized the need to develop plant response guidelines for compost stability tests (Willson et al 1986) yet little progress has been made in this field in two decades. The challenge in the concept of using plants to represent maturity is that there are many biotypes that survive in anoxic and harsh environments, and which would be logically unsuitable indicators of compost stability.

An OECD plant used in many aerobic toxicity studies is garden cress, *Lepidium sativum,* (Gorsuch et al 1991). Cress is presently the most widely used bioassay-plant for compost quality, introduced in Europe first as a compost germination test (Zucconi et al 1981) then later as standard qualitative bioassay, especially in Switzerland and Germany. In Switzerland, the test was modified and is conducted in open and closed containers (Fuchs 2000, 2008). The significance of this innovation is its sensitivity to the whole plant-growing environment. A closed container traps gases (CO_2, NH_3, methane, ethylene, etc) emitted by unstable composts and these molecules build up in the jar headspace and can exert inhibitory effects on seedlings. The test correlates highly with oxygen demand of composts, and is attractive in that the differential plant result is readily visible. Intuitively, it may be an ideal test for horticultural environments in which compost and plants are in close proximity. Despite voluminous mention of the test in compost published literature, and some attempts to introduce the cress test into America, the compost industry has not adopted it or recognized it. Instead, the compost industry employs a cucumber assay, first proposed by the US Composting Council in 1996.

Cucumber, like the tomato, is known as a "trash plant" and will readily grow in raw food-waste compost. It is a curious plant to introduce as a maturity test. In tracing the origins of the cucumber used as a USCC required test for maturity, it was discovered that it was first examined in Minnesota-funded compost quality evaluation. The project, called MNCUP, evaluated test results for eight of the State's large MSW compost facilities, and was managed by the firm Malcolm Pirnie (an international environmental consulting firm) and completed in 1996 (MNCUP, 1996). The executive summary of the study states that the tests examined were developed together with the Composting Council for its draft TMECC manual for examining compost, funded by Procter & Gamble. While the USCC in 1996 selected the cucumber assay as the official TMECC test, the MNCUP documents suggest a contrary result, and the consultants who prepared the MNCUP report, did not include it in the recommended methods.

Examination of the data gathered in Minnesota sheds light on the problem. According to data extensively reported in 5 volumes, the cucumber assay performed poorly and gave contradictory results, when comparing different facility's compost products. In some cases, cucumber reacted *positively* to increased oxygen demand, meaning compost of increasing immaturity, while in most cases; cucumber was inconclusive with low regression results with any of the many tested compost traits. It is therefore inexplicable why this test was selected by the USCC. As the methods were being readied for inclusion in the test document to be later published, funding lapsed for the TMECC project (*personal communication*, Wayne Thompson, 2008).

Several other studies have essentially confirmed the contradictory or variable behavior of cucumber with respect of compost maturity or stability testing. A 1994 compost analysis study funded by USCC, compared cress, ryegrass, radish and cucumber and showed that only cucumber *exhibited no relationship to changes in compost maturity* over a large range of O_2 and CO_2 respirometry gradients occurring in 175 days composting (Ianotti, et al 1994).
A *Composting News* (2005) article reported studies by Woods End Labs showing conflicting results when cress was tested against cucumber. Using Compost Analysis Proficiency (CAP)

samples, the cress and cucumber tests were trialed side by side, but yielded opposite interpretation. Cucumber appeared to prefer *less stable compost* when high levels of soluble nitrogen such as ammonium were present. This contradicts common sense with compost maturity. A detailed examination of sources of variability in the actual test procedure revealed that the physical constraints of the test protocol as specified in TMECC impose significant interferences due to edge effects. After cotyledon emergence, cucumber plantlets throw out typically huge first true-leaves, which cause shade deprivation of neighboring plants, excepting those growing around the perimeter of the test trays. These effects may possibly explain some of the confounding factors evident in the original MNCUP studies. A 2004 Ohio State University trial reported in the journal *Soil Biology Biochemistry* showed contradictory results of using cucumber when evaluating differing composts of known maturity (Wang et al 2004). The cucumber plant appears to be inconclusive if not producing false positives, with regard to compost maturity evaluation. Current promotion of the cucumber-based bioassay is not founded on these scientific results.

<u>SUMMARY</u>

Composts vary widely in quality and may exert potentially drastic effects on soil-plant environments when used at typical rates. Inappropriate standards that assert that a material is adequately composted provide a false sense of safety. Uses of compost in many applications such as restoration, grow-media and soil reconstruction require that standards suitable and sufficiently sensitive for these applications be used. Test methods not designed for this purpose should be rejected. Industry may continue to emphasize tests reflecting a minimalist approach to compost quality, but this approach does not sufficiently protect the interests of using composts in the horticultural landscape.

In contrast, scientists working independently in horticulture and as advisors in compost quality have been for some time describing methods that may be very appropriate to these applications, but are yet to be nationally adopted. The great potential future of compost products may depend on it. ⌂

REFERENCES

Becker, G. (1997) Maturation of Biowaste Compost in Organic Recovery and Biological Treatment. ORBIT-97 Symposium, Harrogate UK

Becker, H (1998) A Standard Measurement for Compost Maturity. in Biological Waste Management: A Wasted Chance? International Symposium, Muenster Germany

Biosphere 2 and Plant Response to Composts

Brewer, L.J. D.M. Sullivan (2003) Maturity and Stability Evaluation of Composted Yard Trimmings. Compost Science & Utilization, Vol. 11, No. 2, 96-112

Brewer, L.J. D.M. Sullivan (2003) Maturity and Stability Evaluation of Composted Yard Trimmings. Compost Science & Utilization, Vol. 11, No. 2, 96-112

Brinton (1984) Interpretation Guidelines for Compost Testing. Woods End Laboratories manuscript. Vienna Maine.

Brinton, W (1979) Fertilizer Effects on Humus Quality. Comp. Science Util. (Biocycle)

Brinton, W and E. Evans (2002) Plant Performance in Relation to Oxygen Depletion in Container Media of Varying Maturity. in Microbiology of Composting, Ed. Insam, Riddech, Klammer. Springer Press. New York, Paris, Berlin.

Brinton, W and E. Evans (2002) Plant Performance in Relation to Oxygen Depletion in Container Media of Varying Maturity. in Microbiology of Composting, Ed. Insam, Riddech, Klammer. Springer Press. New York, Paris, Berlin.

Brinton, W E. Evans (2001) How Compost Maturity affects Container Grown Plants. Biocycle Vol 1:56-60

Brinton, W F., E. Evans, M.L. Droffner and R.B. Brinton. (1995). A standardized Dewar test for evaluation of compost self-heating. BioCycle, 36 (11):1-16

Brinton, W.F. (1992) Dewar test for evaluation of compost. Biocycle Conference, Albany NY

Buchanan M, W Brinton, F. Shields, J West, W Thompson (2001) California Compost Maturity Index on–line US EPA accessed at:www.epa.gov/osw/conserve/rrr/composting/pubs/ca-index.pdf

Buchanan, M (2002) Compost Maturity and Nitrogen Release Characteristics in Central Coast Vegetable Production. CIWMB Revised: July 2002

Castellanos, J. Z. and P. F. Pratt. 1981. Mineralization of manure nitrogen— Correlation with laboratory indexes. Soil Sci. Soc. Am. J. 45:354–357.

Changa et al. (2003) Assessment of the Reliability of a Commercial Maturity Test Kit for Composted Manures. Compost Science & Utilization 11:125-143

Francou, Poitrenaud and Houot (2005) Stabilization of Organic Matter during composting. Compost Sci. Util. Vol 13

Gorsuch, Lower, Lewis, Wang (Eds) (1991) Plants for Toxicity Assessment. ASTM.

Fuchs, J, M Bieri (2000) New biotests to measure the biological qualities of composts. Swiss Jrnl Ag Research- AGRARForschung 7 (7): 314-319

Fuchs J G, A Berner, J Mayer, K Schleiss (2008) Concept for Quality Management to Secure Benefits of Compost for Soil and Plants. International Symposium Organic Matter Management. Switzerland

Gomez R.B, F.V. Lima, A.S. Ferrer (2006) A.S. The use of respiration indices in the composting process: a revie. (2005) Waste Manage Res 24: 37–47

Iannotti D.A, M. E. Grebus, B. L. Toth, L. V. Madden, and H. A. J. Hoitink (1994) Oxygen Respirometry to Assess Stability and Maturity of Composted Municipal Solid Waste. J. Env Qual.v23:1177-1183

Jourdan, B. (1988) Zur Kennzeichnung des Rottegrads von Müll- und Müllklärschlamm kompost. [Thesis to establish Dewar Test for Compost in Germany]. Inst.

Lasaridi, K.E. & Stentiford, E.I. (1998) A simple respirometric technique for assessing compost stability . Water Research, 32, 3717-3723

Maier, U (translator) (1994) Determination of the Degree of Decomposition for Waste and Waste/Sludge Derived Compost , from Wastewater Management. Univ. of Stuttgart Germany. Original USCC document submitted by R W Beck

McEntee K (2005) Maturity Tests give conflicting results. Composting News Vol 14-4

MNCUP (1996) Municipal Solid Waste Composting Utilization Program. Vol 1-V. prepared by Malcolm Pirnie. Publication of the Minnesota Office of Environmental Assistance

Prasad, M and L NiChualain (2009) Evaluation of Three Methods for Determination of Stability of Composted Material Destined for Use as a Component of Growing Media. Acta Hort. 819, ISHS 2009

Severinghaus, J.P. et al. (1994) Oxygen Loss in Biosphere 2. EOS, American Geophysical Union. Vol 75:33-40

Sikora, L. (2003). Compost Age and Sample Storage Effects on Maturity Indicators of Biosolids Compost. J. Environ. Qual. 30:2141-2148

Silverstone, S.E. et al (1999) Soil in the Agricultural area of Biosphere 2 1991-1993. Ecological Engineering 13:179-188

Strojny, Z. P. Nelson, C. Willits (1998) Pot soil air composition in conditions of high soil moisture and its influence on growth. Scientia Horticulturae 73, 125-136

USDA (1999) Soil Quality Test Kit Guide. USDA, Agricultural Research Service, Natural Resources Conservation Service, Soil Quality Institute

Wang P, C.M. Changa, M.E. Watson, W.A. Dick, Y. Chen, H.A.J. Hoitink (2004) Maturity indices for composted dairy and pig manures. Soil Biology & Biochemistry. Elsevier. 36: 767-776

Wang, P, C.M. Changa, M.E. Watson, W.A. Dick, Y. Chen, H.A.J. Hoitink (2004) Maturity indices for composted dairy and pig manures. Soil Biology & Biochemistry. Elsevier. 36: 767-776

Wang, P, C.M. Changa, M.E. Watson, W.A. Dick, Y. Chen, H.A.J. Hoitink (2004) Maturity indices for composted dairy and pig manures. Biology & Biochemistry. Elsevier. 36: 767-776

Willson G B, D. Dalmart (1986) Measuring Compost Stability. Biocycle V2:34-37

Woods End Lab (2005) TMECC 05-05A Cucumber Bioassay Comparison to test traits OECD Cress Test and Maturity Indexes. Woods End Journal (On-line)

Zucconi, F, M Forte, A Monaco, M Bertoldi (1981) Evaluating toxicity of Immature Compost. Biocycle 22:54-57