

The Need for Better Product Specification in AS 4454

AS 4454 lists more than 12 testing methods (Appendices A to Q) for the analysis of composts, soil conditioners and mulches. However, of these methods, only the organic matter content, particle size grading, and physical contaminants are specified as normative across all four product categories. All the other tests are either conditional on the claims stated on the label, or, in the case of boron, sodium, moisture and toxicity testing, apply to soil conditioners and fine mulch products only (the exception is for ammonium N, where a threshold maximum is specified for composted products only). For all the normative tests, no results interpretation is provided. Accordingly, compost manufacturers are left to question the relevance of test outcomes, and the expense involved in undertaking them.

Composts, soil conditioners and mulches have often been considered as generic products, with application rates rarely based on agronomic criteria. At the worst, products potentially complying with AS 4454 when used in commercial agriculture can cause serious crop losses such as seedling emergence failure and yield reductions of over 30% and 25% respectively in cotton crops, the local elimination of earthworms in a vineyard, and severe leaf yellowing in oranges (Buckerfield and Webster 2000). This is not the case with AS 3743 for Potting Mixes. Seven of the nine tests listed are normative, with the informative tests restricted to an alternative method for testing air filled porosity and total water holding capacity, and a guide on demonstrating compliance with the Standard. End-users purchasing potting mixes complying with AS 3743 can be confident that the product is fit for growing plants. In contrast, the results of a survey testing 80 non-Standard potting mixes commonly available in retail outlets, revealed that 70% failed to adequately support plant growth (Handreck 1995). AS 4419 for landscape and garden soils specifies 12 testing methods, of which nine are normative. The informative methods advise users on how to sample soils for testing, how to detect the presence of viable weed propagules, and how to select soils for different applications. Whilst the majority of the tests specified in AS 4454 remain informative only, with no guidance on results interpretation or the selection of composts for different applications, justifying their use is problematic.

Composts, mulches and soil conditioners are not generic products. However, the definitions provided in AS 4454 remain generic, and do not relate to the agronomic purpose of the product. For example, a mulch is *any pasteurized organic product that is suitable for placing on soil surfaces*. In horticultural practice, mulches are typically applied at a high rate to soil as a surface cover, to suppress weeds, conserve moisture and to reduce soil temperature and erosion (Pickering et al 1998). To avoid nutrient imbalance and chemical burn, candidate mulches need to have very low concentrations of total and plant-available nutrients (Pittaway 2004). To avoid nutrient draw-down and the repulsion of soil animals such as earthworms, the mulch must be composted into the curing phase. AS 4454 offers no guidance on the specification of a mulch, other than a particle size grading. In the following pages, the case for improving the criteria for testing composts, mulches and soil conditioners, the interpretation of tests and advice on how to select products for different applications are explored.

Particle size grading as criteria for composted products:

AS 4454 currently differentiates composted products into a fine mulch or compost and a mulch or compost only. Specification is for a 16 mm screen aperture only. However, limits for the contribution of stone and lumps of clay to the dry matter are included as indicated below:

- Fine mulch/compost, not more than 20 % to be retained on a 16 mm sieve
- Mulch/compost, not less than 70 % to be retained on a 16 mm sieve
- Stones and lumps of clay larger than or equal to 5 mm shall constitute $\leq 5\%$ of dry matter (W/W), but there are no specifications for oversized organic particles

AS 4419 differentiates between a soil blend and a top dressing product, specifying the proportion of oversize (large) particles as well as the screened proportion. A sample of 1 L of compost is dried at 40 °C prior to being sieved. Examples of large particles are cited as bark, roots, clay lumps, stone, or other solid material.

- Soil blend, up to 8% by weight shall pass a 20 mm sieve but not a 10 mm sieve, and up to 2 % by weight shall be retained on a 20 mm sieve
- Top dressing, all mineral particles shall pass through a 2 mm sieve. Not more than 15 % by weight of the organic fraction which pass through a 5 mm sieve, shall be retained on a 2 mm sieve. Organic particles retained on a 5 mm sieve shall constitute less than 2% by weight of the sample.

AS 3743 does not specify a particle size range.

- particle size is indirectly assessed in the tests for air-filled porosity and water holding capacity.

Winning the Organics Game: The Compost Marketer’s Handbook (Tyler 1996) separates particle size grades into four different compost product categories. Particle size grades are based on imperial measurements, converted to the SI metric equivalent in the table below:

Table 1: Performance criteria for composted products based on particle size criteria. Product categories are based on Tyler (1996). Equivalent Australian Standard (AS) specifications have been included where they approximate the criteria of Tyler (1996).

Product category	Recommended particle size range (mm)	Equivalent AS particle size specification	Comment
Mulch	19 mm to 38 mm	>70 % retained on a 16 mm sieve AS 4454	No upper limit specified in AS 4454
Sports turf input	10 to 13 mm	90% pass through a 10 mm sieve AS 4419	Oversize limits are specified in AS 4419
Top soil blend	Less than 19 mm	< 20% retained on a 16 mm sieve AS 4454	No upper limit specified in AS 4454
Top dressing	Less than 6 mm	<15 % retained on a 2 mm sieve AS 4419	Oversize limits are specified in AS 4419

Case for specifying the bulk density and < 2 mm particle size fraction of all composted products

Upper limits for the application of both fine mulch and mulch products should be based on the concentration of soluble salts, and the immediate (plant available) fertiliser contribution of the compost to the nitrogen, phosphorus and potassium nutrition of the designated crop. Adjusting upper application rates to account for the fertiliser contribution of the compost not only avoids adverse impacts such as root burn and nutrient imbalance, but also increases the net present value of the product. For composts aimed at the potting mix market, the benchmark ‘universal extractant’ method specified in AS 3743 (Appendices D, G) should be specified. However, the results obtained using the methods specified in Appendix G cannot be used to assess the fertiliser equivalence of the compost. Instead, the methods developed for analyzing the fertility of Australian soils (Rayment and Higginson 1992) should be used for all mulch and soil conditioning products other than a peat substitute (Table 2). The results should be expressed on the oven-dry weight basis, to enable application rates to be adjusted for the water content of the product at the time of application, with the sampling procedure in AS 4419 (Appendix A) strongly recommended. The testing methods developed for Australian soils are conducted on compost fines that have passed through a 2 mm sieve. Where necessary, the compost sample should be air dried overnight (room temperature less than 35° C) to facilitate sieving. Pre-drying above 35 °C is not recommended as labile nitrogen and organic carbon compounds may be volatilized during this process.

Table 2: Composted product categories indicating the target markets and agronomic properties of each category. Performance criteria as specified in Australian Standard documents have been included where the criterion is considered as a mandatory (normative) requirement.

Category	Target market	Degree of Composting	Nutrient Content	AS Normative Criteria
Surface mulch	Land reclamation	Hygiene only	Low, for high rate application	Particle size only AS 4454
Surface mulch	Amenity & production horticulture	Hygiene, low nutrient draw-down	Low, for high rate application	Particle size only AS 4454
Peat substitute	Plant nurseries	Biologically stable	Benchmark specified	AS 3743 for Potting Mixes
Biofilter media	Livestock & food industries	Detoxification only	Must support microbe activity	none
Top soil component	Amenity horticulture	Biologically stable	Must be specified	AS 4419 for Soils
Top dressing component	Turf & amenity horticulture	Biologically stable	Must be specified	AS 4419 for Soils
Soil fumigant substitute	Agriculture, horticulture	Biologically stable	Low, for high rate application	None
Soil conditioner	Agriculture, horticulture	Biologically stable	Must be specified	Particle size only AS 4454
Fertiliser complement	Agriculture, horticulture	Biologically stable	High, must be specified	Total N only AS 4454

The plant available nutrients in a soil are most likely to reside in the fine (< 2 mm particle size) fraction. Larger particles (eg bark, roots, clay lumps, stone, or other solid material) will effectively ‘dilute’ the immediate fertiliser value of the sample. This over size fraction must be accounted for in the calculation of fertiliser equivalence. The bulk density method of AS 4419 (Appendix B) should be specified as a normative procedure for AS 4454, undertaken on the < 2 mm and > 2 mm fractions of the air dry composite sample. Results for the plant-available nutrient concentration in a soil are expressed on an oven-dry weight basis of the < 2mm particle size class. Calculation of the immediate fertiliser contribution of the original compost sample requires the bulk density value of each size fraction, and the air-dry and oven-dry moisture content of the fines.

Recommendations for Amending Particle Size Criteria in AS 4454:

- Replace the 16 mm sieve aperture specification for mulch vs fine mulch in AS 4454 with the 20 mm specified in AS 4419, which also approximates the 0.75 inch aperture (19 mm) referred to in Tyler (1996).
- Develop criteria for oversize organic particles in a mulch, based on recommendations from commercial composters. Commercial practice in USA suggests that the acceptable upper limit for a mulch is 40 mm (Tyler 1996). The specifications for < 20 % of fine mulch retained on the 20 mm sieve should still apply, but a minimum acceptable oversize percentage should be specified for both the fine and mulch/compost products (ie, acceptable % particle size fraction > 40 mm). The normative classification for the particle size specification of a fine mulch and mulch product should be retained.
- Include the soil sampling method of AS 4419 (Appendix A) as an informative method for obtaining a composite compost sample for testing purposes.
- Specify the bulk density method of AS 4419 (Appendix B) as a normative requirement for AS 4454, to be calculated for the < 2 mm and > 2 mm particle size fractions of the fine mulch and mulch products prior to determining the immediate fertiliser value of each product.
- Specify air drying overnight (< 35^o C) as a method for reducing the moisture content of a compost sample prior to sieving. Drying at 40^o C is not recommended, as volatile nutrients such as ammonia and labile organic carbon can be lost.
- Specify the air filled porosity and water holding capacity tests of AS 3743 for composts aimed at the container media market (potting mixes, glasshouse organic mixes etc) in a guide for the selection of composts for different applications.
- Include reference to AS 4419 particle size criteria for products targeting the Landscape Soils and Top Dressing markets (5.14, 5.6 in AS 4419 Requirements section) in a guide for the selection of composts for different applications.

Disinfection Criteria

Disinfection of Viable Plant Propagules

The maintenance of a high standard of quarantine is a very high priority in the management of pests and diseases in horticultural and agricultural enterprises. Contaminants present in the raw materials selected for composting, or in soil scraped from the surface of the composting pad during turning operations, constitute a risk to the quarantine status of the properties of potential end-users. As part of a Quality Assurance program, compost operators should develop a HACCP-based management program to minimize these risks. Compliance with the United States Environment Protection Agency guidelines for managing the temperature and turning of compost windrows will minimize the transmission of live biological agents in the finished compost (USEPA 1999). However, management protocols that minimize the risks of contaminating finished compost with raw materials, weed seeds and/or soil must be developed and implemented. AS 4419 nominates the testing of viable weed propagules in the testing scheme, but as an optional requirement only. AS 4454 specifies viable weed propagule testing for pasteurized products only, with a nil tolerance after 21 days incubation of the medium.

However, this assumes that the medium being tested is suitable for the germination and growth of plant propagules, which may not be the case. A guide to the interpretation of this test should be included. In AS 4419 a sample meeting the Standard for bulk density, wettability, pH, EC, ammonium, nutrient draw-down index (NDI) and toxicity is highly likely to support the germination and growth of seedlings. However, composts complying with AS 4454 containing high concentrations of plant-available nutrients, or highly active composts inducing nutrient draw-down and oxygen depletion, may inhibit seed germination and development. Weed seeds that may remain dormant but viable, undetectable in the viable weed propagule test, may subsequently germinate after application (dilution) to soil. However, composts complying with AS 4419 or 3743 for the toxicity, wettability and NDI tests should support the germination and growth of plant propagules, validating the conditions of the test. Without this supporting information, the results of the weed propagule test in AS 4454 will remain inconclusive.

Microbial Disinfection versus Microbial Stabilisation

AS 4454 requires fewer turns during the elevated heating phase of composting than the USEPA (1999) standard (3 turns minimum, with core temperature exceeding 55°C for 3 consecutive days between each turn, versus 5 turns). The criteria for describing a product as a compost under AS 4454 requires the temperature and turning criteria as above, and a minimum composting and curing period of 6 weeks. Whilst these criteria may adequately disinfect the compost, it is highly unlikely that the duration of 6 weeks will be sufficient to stabilise microbial activity. The higher the level of microbial activity, the greater the risk of nutrient draw-down. Active microbes utilize the readily available organic carbon as an energy source, releasing carbon dioxide as a by-product.

The energy acquired drives metabolic activity, including the selective uptake of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulphur (S) and other essential nutrients. Typically in soils, microbial activity is restricted due to lack of readily available organic carbon and/or moisture. When both are provided, microbes may take up luxurious amounts of the key nutrients N and P, storing them for 'hard times'. Nutrient draw-down occurs when microbial activity is stimulated to a level where the readily available nutrients in the soil are locked up in their cells, no longer available for plant uptake. As a result, plants suffer mineral deficiency, such as the extreme leaf yellowing observed by Buckerfield and Webster (2000) when an unstabilised mulch was applied to a citrus orchard. The nutrient draw-down test monitors nitrogen availability for plant uptake, but phosphorus draw-down may also occur. The risk of nutrient draw-down can be minimized by composting well into the curing phase. Chemical analyses of the total and plant available concentrations of nutrients present in the compost at the end of the curing phase are unlikely to change over the short term, because the agents of change (the microbes) are no longer active. Both AS 3743 and AS 4419 specify the nitrogen draw-down index as normative for all potting mixes and soil blends, listing threshold maximum values. AS 4454 lists the method as informative only, with no benchmark values or interpretation provided. Nutrient draw-down is a function of the activity of microbes within the compost. If processed well into the curing phase, the risks associated with nutrient draw-down should be minimal.

In the current version of AS 4454, the self-heating test is specified as an indicator of the stability or maturity of the compost. To reproduce the heat generated by microbial activity within a compost windrow, a screened compost sample is placed into an insulated flask. Testing only the particle size fraction that passes through a 10 mm aperture screen improves the likelihood of a sufficient proportion of small, water filled pores that favour microbial activity. However, the method specifies loose packing of the vessel only, which may limit the pore size distribution to large pores only. The provision of adequate moisture in the sample is also problematic, dependent on the judgement of the operator. Optimal microbial activity requires the combination of wet and well aired, achieved in soils by the combination of drainage under gravity (field capacity, Loveday 1974) and the effect of particle size and bulk density on the distribution of large and small pores (Griffin and Quail 1968). Samples that are too dry, or that lack continuous water-filled pores for bacterial activity, will not heat up. However, when appropriately moistened and packed in the field, the 'mature' compost may well re-heat, inducing nutrient draw-down. In its current form, the self-heating test cannot be recommended.

Not all compost applications require a high degree of microbial stabilisation. Of the nine product categories listed in Table 2, only six require stabilised composts. Indeed, organics selected for use in biofilters for odour control, should only be processed into the early active phase. Composting is necessary for the destruction of potentially toxic plant chemicals (phytotoxins, plant secondary compounds) that may inhibit microbial activity. However, a high degree of microbial activity is essential (small particle size but high air-filled porosity and wettability), to efficiently remove malodorous compounds from the vapour stream. The smaller surface to volume ratio of larger particles does not favour microbial activity, and is more appropriate for a surface mulch. A mulch complying with Table 1 still requires minimal composting, to degrade any toxic plant compounds that may be present. The minimum 6 week processing period specified in AS 4454 for a compost should be sufficient. However, in the absence of test results for water holding capacity, wettability and nutrient sufficiency (AS 3743 Appendices B, C & D), the results of a toxicity test may still prove inconclusive.

Recommendations for Disinfection and Microbial Stabilisation Criteria in AS 4454:

- Provide a section on Guidelines for Selecting Tests Suitable for Different Product Categories (refer Appendix 1). Combinations of tests should be recommended, referring where appropriate to existing normative test criteria as specified in AS 4419 and 3743.
- All organic products should be composted for a minimum of 6 weeks, in compliance with USEPA disinfection criteria, to overcome hydrophobicity, and plant and/or microbial toxicity associated with the presence of plant secondary compounds. Grounds for a shorter time period should be restricted to fine mulches (AS 4454) to be used in biofilter applications, requiring compliance with AS 3743 for wettability and water holding capacity, and AS 4454 for pasteurisation.
- The nutrient draw-down test should be considered as normative for all composts requiring verification of biological stability for a given product category (Table 2). Temperature and watering records should also be kept by the processor to verify that these products have been composted into the curing phase.
- In the absence of experimental data verifying that the self-heating test accurately mirrors temperature (microbial) dynamics within consolidated compost windrows watered to field capacity, this test should not be included.
- Interpretive sections should be added to the Viable Plant Propagule and Toxicity tests to explain the need to establish that the product meets other essential criteria for supporting plant growth (eg AS 4419, AS 3743, refer Appendix 1), before results can be considered conclusive.

Moisture and Organic Matter Content

Moisture Content

The moisture content can substantially dilute the fertiliser contribution of compost applied on a field weight basis to soil. For example, in Table 3, the total nutrient concentration and immediate fertiliser equivalence (plant available nutrient concentration) of four different composts is provided. Both the green waste and the feedlot cattle composts have been dried down during the curing phase, with water contributing to 30% and 38% of the mass of the compost. However, both the poultry and the cotton trash composts were watered into the curing phase, maintaining much higher water potentials. Given the relatively low bulk density values of these two composts, the mass of the water increases the cost of transport but decreases the nutrient value of the product.

Table 3: Results of chemical and physical analyses of four different composts. Chemical analyses included the total and plant-available (Av) concentration of major plant nutrients nitrogen (N), phosphorus (P) and potassium (K), organic carbon (OC wet oxidation method), electrical conductivity (EC) and pH. Physical analyses included the percentage by weight of water in the sample, and bulk density. Units for nutrient concentrations are percent by oven dry mass. The asterisk indicates that the percentage water has been calculated using the water holding capacity procedure of AS 3743, and not the oven-dry moisture percentage of the field state of the sample at collection.

Compost Sample	Bulk density g/L	% water	pH	EC dS/m	OC %	Total Kj N %	Av N %	Total P%	Av P %	Total K%	Av K %
Green waste	430	31	5.87	2.14	27.2	0.9	0.03	0.18	0.03	0.45	0.55
Cotton trash	215	67	8.4	2.96	20.8	2.4	0.05	0.31	0.11	1.33	1.1
Feedlot cattle	510	38	7.7	11.4	22.3	3.0	0.01	1.57	0.22	2.2	n.a.
Poultry layer	200	49*	7.1	3.42	15.7	1.6	0.42	0.98	0.50	0.72	0.55

Watering compost windrows into the curing phase is necessary to verify that the decline in the internal temperature of the windrow is due to the depletion of readily available substrates, and not lack of water. However, once the duration of the active phase for a specified mix has been determined, the compost should be allowed to dry out over the curing phase. The compost should contain as little water as possible, sufficient to avoid dust generation during storage and handling. AS 4454 provides a method for determining the moisture content, and specifies a minimum concentration of 25% for soil conditioners (no requirement for mulches). The maximum concentration is based on the organic matter content plus a constant (+ 6 if OM > 40%, + 10 if OM < 40%). In the examples listed in Table 3, the maximum water limits for the composts using these calculations would be 70%, 56%, 59% and 45% for the green waste, cotton trash, feedlot and poultry composts respectively.

In commercial practice, withholding water during the curing phase reduced the water content of the green waste and feedlot composts to 31 and 38% respectively (Table 3), 56 and 36% below the maximum moisture content specified in AS 4454. The fertiliser equivalence values listed in Table 3 are calculated on the oven-dry moisture content of the samples. To calculate the fertiliser contribution of the compost in its field state, the oven-dry nutrient concentration must be reduced by the amount of water present. The reduction in the moisture content from 70 to 31%, and 59 to 38% has substantial implications for the fertiliser value per tonne of compost, and therefore, the economic value of the product for agricultural producers. The specification of these very high upper limits for the moisture content of soil conditioners complying with AS 4454 is not very useful in practice, and could well be replaced with guidelines recommending passive drying during the curing phase. Setting upper and lower limits is problematic, as the water holding capacity is a function of the physical and chemical properties of the compost and will vary with different inputs and with different particle size fractions of the inputs.

Organic Matter Content

In AS 4454 the organic matter content is specified as normative, requiring all four product categories to contain >25% by mass (Appendix B). Organic matter is derived from the analysis of organic carbon, multiplied by a constant. The constant approximates the concentration by weight of the mineral fraction bound in the organic carbon component of a soil (Baldock and Skjemstad 1999) the value assigned to the constant differs with the test method (2.2 for wet oxidation, 1.7 for furnace induction). However, for composts, the concentration of nutrients bound in the organic fraction can vary substantially.

For example, the derived organic matter values for the green waste, cotton trash, feedlot and poultry composts (multiplying OC in Table 3 by 2.2) are 59.8, 45.8, 49.1 and 34.5 % respectively. The mass of the plant macronutrients (N, P and K) bound in the organic form can be derived from data in Table 3 by subtracting the plant-available concentration from the total concentration. The contribution of organically bound K to organic matter in composts is negligible, as most is dissolved in the cell sap, with little bound in the structural components of plant cells (Table 3, and Marschner 1997). On a dry weight basis, organic N and P contribute 1.02, 2.55, 4.34 and 1.66 % respectively to the organic matter content of the composts. Organic matter concentrations of 27.7, 53.0, 96.8 and 26.1% respectively are obtained if these figures are used to multiply the organic carbon concentration, instead of the constant 2.2. As this example highlights, multiplying the organic carbon concentration of all composts by the same constant to estimate their organic nutrient content is inaccurate, and can provide very misleading results. Instead, the more accurate organic carbon concentration should be specified.

The same criticism applies to AS 4419, where different upper and lower limits for organic matter are specified for low density, organic, natural or soil blend product categories. Specifying the organic carbon concentration would be much more accurate, with the recommended testing method determined by whether the threshold value relates to the biological properties of the organic carbon only (wet oxidation method), or its contribution to the biological, physical and chemical properties of the soil (furnace induction method). AS 3743 does not specify limits for organic matter, but does specify criteria such as wettability, total water holding capacity, and total porosity, properties that reflect the concentration of organic carbon in the mix.

Recommendations for Moisture and Organic Matter Criteria in AS 4454:

- Calculation of the moisture content should remain normative, but specification of the upper and lower limits should be omitted. Inclusion of the moisture content as part of the required marking or documentation specifications should be normative. Guidelines should specify that the compost should be dried out during the curing phase, to the minimum required for dust suppression during handling.
- Reference to Organic Matter should be omitted, replacing it instead with Organic Carbon. Specification of the wet oxidation method of analysis is recommended, as the furnace induction method includes biologically inert carbon such as charcoal and coal in the analysis.
- Inclusion of the organic carbon content (wet oxidation method) as part of the required marking or documentation specifications should be normative.

Electrical conductivity, pH and the suitability of composts for application to soil

Electrical conductivity

No limits have been specified for electrical conductivity (EC) in AS 4454. EC is a normative requirement for both AS 4419 and 3743. However, the relevance of these specifications to composts depends on the intended use of the product. EC is a very important property, as it relates to the potential of the product to 'burn' roots, and to contribute to salinity when incorporated into soils or potting mixes. All water-soluble salts (not just sodium and chloride), and charged organic particles contribute to the EC. Therefore, composts with high levels of plant-available K but with low levels of sodium (Na) and chloride (Cl) will also have a very high EC (eg feedlot cattle compost in Table 3). These composts are best suited as fertiliser substitutes (Table 2), with upper application rates based on the fertiliser requirements of the intended crop (refer to section on Selecting Upper Application Rates). However, for low nutrient composts aimed at the high volume mulch, potting media and/or soil blend markets the EC limits specified in AS 3743 and 4419 could be used as criteria for assessing their suitability.

The fertiliser industry has developed a salt index for commonly sold inorganic fertilisers, to assist end-users in the selection of products suitable for sensitive crops and soils already known to have a high EC (Glendinning 1999). Products are ranked against sodium nitrate, to indicate the likelihood of inducing salt burn in sensitive species. However, high concentrations of chloride in compost may also induce salt burn. Sodium and chloride ions commonly contribute to salinity in Australian soils, and repeated use of high EC composts with sodium and/or chloride present as the predominant ions may exacerbate the problem. Testing for chloride is a normative requirement of AS 3743, and the specified limits could be used as suitability criteria for compost processors targeting high rate application mulch, potting media and/or soil blend markets. The rate of application of fertiliser and soil conditioning composts, and the risks of salt burn and inducing soil salinity will differ with the crop and soil type. Including both the concentration of chloride and the EC on all packaging, marking and documentation as normative, may assist end-users in the selection of appropriate products.

Measuring pH, and cation exchange capacity

The measurement of pH is normative for AS 4454, with the range 5.0 to 7.5 specified for all four product categories. However, both AS 4419 and 3743 differentiate the specified pH range according to the use of the product for acidic, neutral or alkaline conditions. Accordingly, composted products targeting the acid or alkaline potting mix or soil blend markets may comply with AS 4419 or 3473, but not with AS 4454. For plant growth, acidity is most commonly a problem due to induced calcium (Ca) deficiency. At pH values below 5, the solubility of aluminium in the soil solution increases, antagonizing the uptake of calcium. The presence of organic acids contributing to a potentially high cation exchange capacity, and the concentration of available calcium in composts may buffer the soil to which it is added (conditioning the soil), ameliorating calcium deficiency (Marschner 1997). The pH range specified in AS 4454 is a poor predictor of these properties, and hence is not very useful. However, the pH criteria specified in AS 3743 and 4419 could be used to assess the suitability of low nutrient composts for the high volume mulch, potting media and/or soil blend markets.

The cation exchange capacity is a measure of the ability of a compost to retain and exchange positively charged nutrients (cations). The cations most commonly held by the humus-like compounds responsible for the CEC in stabilised composts are Ca, K, Mg and Na. Knowing the relative proportions of these cations can assist in assessing the potential of the compost to induce salinity, or to manage calcium deficiency in acidic soils. The management of soil acidity, and improving the nutrient holding capacity of a soil are highly valued soil conditioning attributes. However, the definition of a soil conditioner in AS 4454 is restricted to *any composted or pasteurized organic material, including vermicast, that is suitable for adding to soil*. There are no guidelines or criteria provided for assessing suitability. This is particularly problematic, as the suitability of a compost for addition to soil may change with the rate of application (refer to section on Selecting Upper Application Rates).

In the absence of product category specification (Table 2) or agronomic characterization, it is impossible to assess the suitability of a compost for addition to soil. Low nutrient composts targeting the mulch, potting media and/or soil blend markets can be assessed against the agronomic criteria specified in AS 3473 and/or 4419. However, there are no agronomic guidelines for composts targeting the soil conditioner, fertiliser substitute or soil fumigant substitute markets. Indeed, products complying with the current version of AS 4454 could still cause the serious crop losses observed by Buckerfield and Webster (2000, seedling emergence failure and yield reductions of over 30% and 25% respectively in cotton crops, the local elimination of earthworms in a vineyard, and severe leaf yellowing in oranges), after application to soil. In the absence of an objective agronomic product descriptor, the selection of an appropriate application rate suitable for addition to a specific soil type and crop cannot be determined. This is a serious impediment to market development, and remains the key reason behind the reluctance of many primary producers to purchase 'generic' product.

Recommendations for EC, CEC, exchangeable cations and pH criteria in AS 4454:

- In addition to EC, the concentration of chloride in compost should be specified as normative, to be included in the marking, packaging and documentation requirements.
- Reference to AS 3473 and 4419 limits for EC and Cl should be strongly recommended for low nutrient composts aimed at the mulch, potting media and/or soil blend markets.
- The pH value of compost should be specified as normative, to be included in the marking, packaging and documentation requirements. However, no pH range should be specified. Instead, reference to AS 3473 and 4419 limits for acidic, neutral and alkaline products should be strongly recommended for low nutrient composts aimed at the mulch, potting media and/or soil blend markets.
- The requirement for measuring the cation exchange capacity and exchangeable cations should be specified as normative for composts aimed at the soil conditioner, fertiliser and soil fumigant substitute markets, with results to be included in product marking, packaging and documentation.

Nutrient Concentrations in Composts and their Contribution to Plant Growth

Specifying the nutrient concentration of compost is not a requirement of AS 4454, unless the product claims to be suitable for phosphorus-sensitive plants. Otherwise, composted products should contain less than 200 mg/L of ammonium N in the compost extract, unless a contribution to plant nutrition is claimed (ammonium N plus nitrate N > 200 mg/L). For phosphorus-sensitive plants, the concentration of soluble P should not exceed 5 mg/L of compost extract, with total P not more than 0.1% on a dry mass basis. The maximum limit for P assumes that the product will be suitable for P sensitive species if applied at the upper application rate of 50 L/m². Whilst this upper application limit may be feasible for mulch products with a low bulk density and large particle size (Table 1), for most soil conditioners and fine mulches this is excessive. The rate of 50 L/m² equates to 75 t/ha for the cotton trash compost (Table 3). If the lesser rate of 15 L/m² was applied (32 t/ha), the application rate of Total P is 100 kg /ha, but the application rate for K is much higher, at 429 kg/ha. This is excessive for most broad acre crops, given that most of the K is plant-available. Applying the cotton trash compost in Table 3 at 32 t/ha supplies 350 kg/ha of available K. This is 8.5 times the amount of K removed in harvested cotton (Glendinning 2000), and is likely to induce the seedling emergence failure and yield decline problems observed by Buckerfield and Webster (2000).

To maximize the cost-effectiveness of the product and to minimize the risk of inducing nutrient imbalance, the fertiliser equivalence of the compost must be considered when selecting application rates. AS 3743 requires the nutrient concentration of potting media to be specified. However, the test method requires all nutrients other than ammonium N to be extracted in a common (universal) extractant. The bench mark range of values specified is based on practical experience, guaranteeing that organic media meeting all of the normative requirements of the Standard will be suitable for growing plants in containers. However, the test results cannot be used to interpret fertiliser equivalence for applications outside the scope of potting media. Similarly, the test methods for determining the concentration of total P, B, Ca, Mg and Na in AS 4454 specify nitric acid as the universal extractant. Other than the specification of an upper limit for P-sensitive plants, no interpretation of the results, and no guidelines are provided. Results cannot be compared against AS 3743 criteria as a different extractant is used, and cannot be used to interpret inorganic fertiliser equivalence, as different extractants are required to extract different nutrients (Rayment and Higginson 1992). AS 4419 specifies the determination of available P and N as normative, and the test methods are appropriate for testing fertiliser equivalence for Australian soils. However, AS 4419 does not address the concentration of slow release nutrients that may be present in manufactured soils.

Historically in Queensland, commercial products labeled as a fertiliser had to comply with minimum nutrient concentration standards (Agricultural Standards Regulation 1997, superceded). A fertiliser was defined as *a substance, including a gypsum, a lime and a soil conditioner a) containing at least 1 element in at least its minimum percentage content; and b) manufactured or sold for conditioning, decreasing the acidity of, or fertilizing soil, o supplying nutrients to crops or plants.*

The labeling requirements of manufactured fertiliser included the specification of the name, percentage content and form of the nutritional element present in the product at concentrations above the minimum percentage specified in the Regulation. Most of the specifications relate to inorganic forms of industrially produced compounds. However, some more generic concentrations are included (Tables 4 and 5). The specification of particle size distribution was also a requirement for rock minerals such as rock phosphate and gypsum. Finer particles are more likely to dissolve in the soil solution, increasing the availability of the product for plant uptake (Glendinning 2000). The finer particle size fraction of organic materials such as manures also contains higher concentrations of P and N, and the larger the surface to volume ratio increases the rate of microbial degradation (Zhang and Westerman 1997). The Agricultural Standards Regulation (1997) specified that both organically-based fertilisers and rock phosphate fertilisers must be capable of passing through a 4 mm sieve, with at least 30% passing through a 500 µm sieve.

Table 4: Specifications for the minimum concentration of plant micro-nutrients contained in a commercial product labeled as a fertiliser (source superceded QDPI Agricultural Standard Regulation 1997)

Minimum % w/w concentration of plant micro-nutrients in solid fertiliser								
Al	B	Co	Cu	Fe	Mg	Mn	Mo	Zn
0.001	0.005	0.001	0.005	0.01	0.5	0.01	0.001	0.5*

* figure for zinc refers to minimum required for added zinc fertiliser status

Table 5: Comparison of the minimum concentration of plant macro-nutrients contained in a commercial product labeled as a fertiliser (source superceded QDPI Agricultural Standard regulation 1997), and the minimum concentration contained in commercial inorganic fertilisers (source Glendinning 2000). Abbreviation ns refers to no generic minimum specified. Chemical tests referred to are described in Rayment and Higginson (1992).

	Minimum % w/w concentration of major plant nutrients in solid fertiliser				
	nitrogen	phosphorus	potassium	sulphur	calcium
QDPI Agric. Standard Regulation 1997	0.2% NH ₄ , NO ₃ ⁺ , urea, organic N, Total N 0.5%	0.2% citrate soluble (plant available P)	ns	ns	0.5%
Commercial inorganic fertiliser	10% (mono ammonium phosphate)	12% (total P reactive rock phosphate)	11% (sulphate of potash)	12% (gypsum)	18% (gypsum)
Test appropriate for organically bound nutrients	Total Kjeldahl N	Bicarbonate extract for available P	Bicarbonate extract for available K	KCl 40 (Blair et al 1991)	Gypsum Ca determination

The QDPI Regulation also specified that organic fertiliser must contain at least 95% organic matter, and that organically based fertiliser must contain at least 65% organic matter. However, as discussed in the previous section (Moisture and Organic Matter Content), the calculation of organic matter is problematic, and misleading. Using the example of the derived organic matter values for the green waste, cotton trash, feedlot and poultry composts (multiplying OC in Table 3 by 2.2 gives 59.8, 45.8, 49.1 and 34.5 % respectively), none would meet the QDPI Regulation for an organically based fertiliser. However, all composts have above the specified minimum of 0.5% total N, both the feedlot cattle and poultry layer composts have soluble P concentrations of above 0.2% (Tables 3 and 5), and all were produced exclusively from organic raw materials. The QDPI Regulation does not provide any generic concentration thresholds for total P or for potassium (K). The cotton trash and feedlot cattle composts have substantial concentrations of total K, about one tenth that of commercial inorganic fertiliser concentrates (Table 5). Farmers applying ten times as much of these composts may effectively replace the crop requirements for conventional inorganic fertilisers such as N, P and K.

Inorganic fertiliser concentrates are immediately available for plant uptake, but prone to leaching below the rooting zone. Fertilisers applied in the organic form are less prone to leaching, due to the high cation exchange capacity associated with stabilised composts, and the 'slow release' mineralisation of organically bound nutrients (Myers et al 1997). However, the rate of release of organic macro-nutrients from composts has not been established for Australian conditions. Anecdotal evidence for N and P in Southeast Qld suggests that mineralisation commences about 18 months to 2 years after the application of composts based on feedlot cattle manure. In contrast to N and P, most of the K contained in composts based on green waste and animal manures is readily available, with little mineralizing after application (Table 3). Farmers need to know the name, percentage content and form of the nutritional elements present in the composted product (Appendix 2). These concentrations are unlikely to change in the short term if the compost is biologically stabilised (Pittaway 2004). Knowing the total and plant-available nutrient concentrations present in high analysis composts enables users to adjust upper application rates to meet crop nutrient requirements, in part substituting the use of inorganic fertilisers. Soil testing should be recommended in subsequent seasons, to adjust compost and conventional fertiliser application rates for the 'slow release' fertiliser contribution from applications in previous seasons. As a benchmark, composts with nutrient concentrations close to one tenth that of conventional concentrated fertilisers (Table 5) should be considered as fertiliser substitutes or fertiliser complements (Table 2). The tests specified for analyzing the fertiliser equivalence of composts should be based on methods developed for organically bound nutrients, for the chemical analysis of the fertility of Australian soils (Rayment and Higginson 1992 and Table 5).

Recommendations for Nutrient Concentrations in Composts in AS 4454:

- Guidelines on the selection of composts for different agronomic applications should be included in AS 4454. Product categories should include at least mulch, soil conditioner, peat substitute, topsoil component, topdressing component, and fertiliser substitute product categories (Table 2). Processors should be advised to calculate the fertiliser equivalence of N, P and K (available and total nutrient forms) in compost when developing upper application rate recommendations (informative).
- Biologically stabilised composts with at least one major plant nutrient (N, P, K, S and Ca) with a concentration of above 0.5 % w/w (oven dry basis) and a particle size of < 6 mm (<15 % retained on a 2 mm sieve AS 4419) should be considered as a fertiliser complement compost (normative).
- Fertiliser complement composts should meet the requirements of the Nutrient Drawdown Index, to indicate their degree of biological stability (Normative, AS 4419)
- Fertiliser complement composts should be required to list the name, percentage content and form of the nutritional elements present in the composted product on packaging, marking and product documentation (normative).
- The chemical methods for analyzing the percentage content of nutritional elements in compost must comply with currently accepted methods for the chemical analysis of Australian soils (Rayment and Higginson 1992). Methods developed for the analysis of organically complexed nutrients such as bicarbonate extractable P and K, and KCl 40 S (Blair et al 1997) should be specified.
- If claims about the soil conditioning properties of a compost are made, the percentage content and form of the element or property associated with soil conditioning should be specified on packaging, marking and product documentation (normative). Soil conditioning properties may include high concentrations of available calcium (gypsum alternative), a high cation exchange capacity, a high water holding capacity (AS 3743), or high concentrations of slow-release nutrients refer to Appendix 2).

Microbiological Testing

Soil Foodweb Institute testing is not recommended as methodologies and benchmarks have not been validated or calibrated for Australian soil and crop conditions.

Pathogen testing requirements (ie Listeria, Faecal Coliforms, Salmonella etc.) will vary with the target market. HACCP accreditation including pathogen testing is an advantage when selling into the fresh, ready to eat horticultural market.

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Appendix 1: MATRIX OF CANDIDATE TESTS FOR COMPOSTED PRODUCT SPECIFICATIONS

	Mulch land reclamation	Mulch horticulture	Biofilter media	Peat substitute	Manufactured soil	Top-dressing	Soil conditioner #	Fertiliser complement
Bulk density	AS 4419	AS 4419	AS 4419	AS 4419	AS 4419	AS 4419	AS 4419	AS 4419
Moisture content	AS 4454 method only. Moisture content of stockpiled materials and fully composted products should be as low as possible (minimum required for dust suppression), to minimize risk of spontaneous combustion and condensation, and to reduce transport costs							
Particle size*	AS 4454	AS 4454	Air-filled porosity AS 3743	Air-filled porosity AS 3743	AS 4419	AS 4419	AS 4419 top-dressing	AS 4419 top-dressing
Visible contaminants	AS 4454	AS 4454	AS 4454	AS 4454	AS 4454	AS 4454	AS 4454	AS 4454
Chemical Contaminants	Refer to AS 4454. If close to threshold limits when used according to product recommendations, risk assessment based on Environmental Investigation Level (EIL) should be undertaken.							
Viable weed propagules##	AS 4419	AS 4419	AS 4419	AS 4419	AS 4419	AS 4419	n.a. ##	n.a. ##
Seedling toxicity ##	AS 4419	AS 4419	AS 3743	AS 3743	AS 4419	AS 4419	n.a. ##	n.a. ##
Wettability	AS 4419	AS 4419	AS 3743	AS 3743	AS 4419	AS 4419	AS 4419	AS 4419
N draw-down index	AS 4419	AS 4419	AS 3743+	AS 3743	AS 4419	AS 4419	AS 4419	AS 4419
Ammonium N	AS 4419	AS 4419	AS 3743	AS 3743	AS 4419	AS 4419	AS 4419**	AS 4419**
Electrical cond. & pH	AS 4419	AS 4419	AS 3743	AS 3743	AS 4419	AS 4419	AS 4419++	AS 4419++
Chloride ion concentration	AS 4419	AS 4419	AS 3743	AS 3743	AS 4419	AS 4419	AS 4419++	AS 4419++
Organic carbon (wet oxidation)	With the exception of manufactured soil and top-dressing (AS 4419 applies) method used should be wet oxidation (Walkley & Black). No performance-based benchmarks are currently available for product categories other than those described in AS 4419.							
CEC & exch. cations	n.a.	n.a.	Nutrient levels AS 3743	Nutrient levels AS 3743	Appendix 2	Appendix 2	Appendix 2	Appendix 2
Total N, P & K	Appendix 2	Appendix 2	Nutrient levels AS 3743	Nutrient levels AS 3743	Appendix 2	Appendix 2	Appendix 2	Appendix 2
Available N, P, K, Ca & S	n.a.	n.a.	Nutrient levels AS 3743	Nutrient levels AS 3743	Appendix 2	Appendix 2	Appendix 2	Appendix 2
Trace elements DTPA extract	n.a.	n.a.	AS 3743	AS 3743	Appendix 2	Appendix 2	Appendix 2	Appendix 2

Appendix 1 continued: MATRIX OF CANDIDATE TESTS FOR COMPOSTED PRODUCT SPECIFICATIONS

Explanation of Symbols Used.

- # **Soil Conditioner category:** Marking, packaging and documentation associated with a Soil Conditioner should specify what soil properties the product improves (refer Appendix 2). Performance based test results verifying this claim should be included (eg CEC and exchangeable cations, wettability and total water holding capacity, available calcium and ESP).
- ***Particle size distribution:** AS 4454 currently only discriminates between mulch or soil conditioner and fine mulch or fine soil conditioner. No provisions have been made for oversize particles, or for the particle grade associated with soil chemical testing requirements. Commercial practice in the USA suggests that for mulch products particles over 40 mm are oversize (Tyler 1996). The bulk density of compost particle fractions less than and greater than 2 mm must be specified for soil conditioner and fertiliser complement products (required to calculate the nutrient content of the 'as is' product). Readily available nutrients are concentrated in the small particle size fraction, with the larger particles diluting the nutrient concentration. Soil conditioning and fertiliser complement products should meet the particle size criteria specified for a top-dressing in AS 4419.
- ## **Viable weed propagules/ Seedling Toxicity:** Results of these tests are only valid where the product has been verified as suitable for the growth of plants (AS 3743, AS 4419). If the product meets the Standard/s for NDI, ammonium N, EC, pH, Cl and wettability, the results for viable weed propagules can be verified. However, poor seedling development in products complying with the Standard may indicate the presence of toxic chemical residues (eg plant secondary compounds). Poor seedling growth is to be expected in fully composted fertiliser and soil conditioner products that have high concentrations of nutrients such as N, P, K and/or Ca. Accordingly, these tests are not suitable for these products.
- + **Nitrogen Draw-Down Index (NDI):** Nutrient (N and P in particular) draw-down occurs when microbial activity is stimulated to a high level (cause of the elevated temperatures in a compost windrow). Microbes sequester available nutrients within their cells, reducing the concentration of plant-available nutrients in the soil. Plants in the vicinity lack adequate nutrition (nutrient starvation) and grow very poorly. The NDI indicates the degree of biological stability of compost, increasing as the rate of microbial activity declines. All categories of composted product with the exception of biofilter media, should meet AS 3743 or AS 4419 criteria for NDI (normative). Organic biofilter media should support active microbial growth (the 'active ingredient' removing odour compounds in filtered air), indicated as a low NDI.
- ****Ammonium N concentration:** Ammonium N is rapidly (within 14 days) converted to either organic N or nitrate in most arable soils at field capacity. High levels of ammonium N in a product indicates poor composting conditions (eg too dry, or too little available organic carbon, or too little oxygen associated with insufficient air-filled porosity and/or too much water).
- ++ **EC, pH and Cl ion concentration:** Limits specified in AS 4419 and 3743 assume high rates of incorporation of the product (equivalent to the 50 L m² applied to soil as a mulch in AS 4454). Soil conditioner and fertiliser complement products that exceed these specifications should still meet the Standard for Composts and Soil Conditioners, as rates of incorporation into soil are typically much lower (refer Appendix 2). Results for EC, pH and Cl should be printed on all marking, labeling and other documentation, to enable users to select appropriate products and application rates (eg end-users with saline soils or saline irrigation water should not purchase products with high levels of Cl).

Appendix 2: Chemical testing for soil conditioner and fertiliser complement composts.

Upper application rates should be based on the nutrient present in the highest concentration in the plant-available form (K or P for compost based on unprocessed plant or animal byproducts). Slow-release component (N and P) should be calculated to indicate the fertiliser contribution from the compost over subsequent growing seasons. Test protocols are from Rayment and Higginson (1992) 'Australian Laboratory Handbook of Soil and Water Chemical Methods' Inkata Press.

indicates soil conditioning properties other than fertiliser equivalence.

Analytical test and Method	Units	Comments
Particle size distribution and bulk density AS 4419	kg per L	Quantify fraction of sample less than 2 mm, and larger (used to calculate dilution factor for nutrients)
As received moisture content 2B1 Rayment & Higginson	% by mass	Chemical results reported on oven-dry basis, moisture in product dilutes nutrient values
Ash Proximate analysis	% by mass	Could request acid digestion of ash to quantify extent of contamination with mineral soil
Wet oxidation Organic Carbon 6A1 R & H	% by mass	Indicates the biologically available organic carbon in compost (NOT charcoal and coal)
Total Kjeldahl Nitrogen 7A Rayment & Higginson	% by mass	Indicates the oxidisable, slow-release component of organic N in the compost
Nitrate N 7B1 Rayment & Higginson	mg per kg(ppm)	Nitrate increases in curing phase, amount depends on the raw inputs and the extent of curing
Ammonium N 7C1a Rayment & Higginson	mg per kg(ppm)	Active compost should utilize all ammonium within 2 weeks assuming optimal conditions for microbes
Sulphate S (KCl 40, Blair et al 1991)	mg per kg (ppm)	KCl 40 test was developed for soils where most of the S is contained in organic matter
Total P 9A Rayment & Higginson	mg per kg (ppm)	Subtracting available P from total indicates slow release fertiliser value
Plant-available P 9B Rayment & Higginson	mg per kg (ppm)	Fertiliser P available in the soil solution for immediate plant root uptake
Total K 17A Rayment & Higginson	% by mass	Highlights contrast with soils where most K irreversibly bound in some clay minerals
Plant-available K 18A1 Rayment & Higginson	mg per kg (ppm)	Most K in composts based on unprocessed plant or animal byproducts is plant-available (80- 90% of total)
Exchangeable cations 15A1 Rayment & Higginson	mequiv/100g	Need to know relative ratio of K to Ca to Na to Mg for possible effects on soil structure (sodic soils)
Cation Exchange Capacity (from above) ##	mequiv/100g	Humic-like compounds in cured composts provide an alternative nutrient exchange for soils
Calcium (as gypsum) ## 11A Rayment & Higginson	mg per kg (ppm)	Fertiliser and soil conditioner. OC and Ca act synergistically to improve structure in clay soils
Electrical conductivity 3A1 Rayment & Higginson	dS/m	Important indicator of 'burning' potential. If due to Na or Cl, may induce salinity in susceptible soils
Chloride E Rayment & Higginson	mg per kg (ppm)	Cl is a key cause of salinity in Aus soils. Farmers with at-risk soils need to know the Cl content of products.
Trace elements Fe, Mn, Zn, Cu 12 A1 R & H	mg per kg (ppm)	Zn and Cu can be high in animal manures, useful as Aus soils are deficient in these trace elements
Nitrogen Draw-down Index AS 4419	Index	Indicates the biological stability of compost. NDI for cured composts should be high
Total water holding capacity AS 3743 ##	% by mass	Should be high for cured composts, indicating the potential to improve soil water holding capacity
Wettability ## AS 3743	mL per minute	Plant waxes repel water. Cured composts should wet up readily, as microbes have degraded the waxes.