21 ORGANIC MATERIAL

Introduction

Although plants can grow and produce optimally in the complete absence of organic material, it seems that a certain level of organic material in the soil can benefit production. The benefits are not easily quantified and their value must be regarded as relative. The value of organic material is more readily quantifiable in soils with a coarse texture (sandy soils) than in soils with a fine texture (clayey).
Unfortunately the accumulation of organic matter in citrus orchards also threatens the production of quality citrus fruit. Before the hazards can be qualified and managed, accumulation of organic material in citrus orchards cannot be promoted.

Organic material is applied for five major reasons.

- To increase the organic fraction of the soil.
- To reduce leaching of nutrient elements, mainly N from sandy soils.
- To establish a heterogeneous population of microbes.
- To mobilise accumulated fixed plant nutrients from the soil.
- To improve the general wellbeing of the soil in terms of the physical, chemical and biological aspects.

It is important to distinguish at this stage between organic farming, application of organic nitrogen and integrated fertilisation. Fertilisation with organic nitrogen has a goal to minimise the losses of nitrogen from the soil and to supply the N in smaller dosages over a longer period. It acts as a slow release N source with no aim to increase the organic fraction. Organic farming only allows organic fertilisers and aims to build the organic fraction of the soil. Integrated fertilisation consolidate the pros of organic and inorganic fertilisation to reach a sustainable profit.

Unfortunately these practises have not yet been tested and cannot be recommended for citrus production without hesitation. The old problems with accumulated organic nitrogen and fruit quality have not been resolved.

We cannot ignore the fact that there are many citrus orchards that produce well above the industry average without a single application of organic material. It is also true that the soil of many orchards is in a better condition today than before cultivation commences.

Cultivation destroys the organic material in the soil and the structure of the soil, but that cannot be the only parameter for the wellbeing of the soil. An acid soil receiving organic material will still be less productive unless it is limed. Sandy soils have no real structure that can be destroyed and liming of an acid soil will render it more productive than applying organic material.

The organic material is usually sourced from nearby. The inherent problems of the area can only be overcome by adding what is required from elsewhere. For instance, if the soil and water contains high concentrations of magnesium, this imbalance will only prolong in the orchard by applying local material.

Accumulating organic matter in the soil is not the salvation of profitable agriculture in South Africa. The solution lies in integrated fertilisation that will incorporate what is required at the lowest cost to sustain profitable production.

It is therefore necessary to be objective and evaluate the reasons for the organic drive. At this stage little information is available to conclude for or against the application of organic material to citrus orchards. Nevertheless, by looking at the pros and cons will already be a step in the right direction. It is further important to evaluate the organic, inorganic and integrated approaches scientifically without all the emotion.

Accumulation of organic material in the soil

The quantity of humus that will accumulate under conventional orchard practises is very low. It is estimated that less than 1% of the material applied will eventually converted to humus or humus-like compounds. It is however unknown how much humus is required to make a significant impact on the stability of soil structure or the water holding

© 2007 Citrus Research International (Pty) Ltd.

capacity. Such a change could more easily be done in sandy than clayey soils. Unfortunately humus will be oxidised much quicker in sandy than clayey soils.

An increase of only 0,2% in the carbon content of dry land maize, is reckon to have an impact on production. To increase the carbon content by 0,2% an application of 4000kg organic carbon or 7 tonnes (±10-15 m^3) is required per ha 15cm deep. According to information on other crops, an initial application of $10m^3$ per ha is required which can then be decreased in subsequent years and maintained at 4-5 m^3 per ha per annum. The big question is whether enough organic material will be available at affordable prices.

The quality of organic material varies a lot. Care must be taken not to add too much salt like sodium, chloride and boron with the material. Nitrogen is required during the decay of organic material. If the material contains too little N, the microbes will source for that in the environment. The plant cannot compete with the microbes for N and may suffer a temporary nitrogen deficiency. Therefore the material, compost excluded, should contain more than 1,8% N.

Compost has a higher intrinsic value than the raw organic material. It is calculated that $10m^3$ organic material has the same value than $1m^3$ compost. Furthermore $3m^3$ raw materials are required to prepare $1m^3$ compost.

Please note that compost is not rotten organic material. To prepare fungal compost for citrus, the following is required.

- 25% manure or green material.
- 30% hay and
- 45% wood.

Hay is material from a plant that has completed its life cycle to seed. Dried green grass is not hay. During the process about three times more biomass is retained by fungi compared to a composting process rich in bacteria.

Other important requirements for good compost are aeration, temperature and moisture. The magnitude of control of these three factors will determine the quality of the compost.

Reduction of losses of nitrogen and other elements through leaching

Leaching of nitrate is limited by organic material because the N is fixed in organic compounds which are less subjected to leaching. These organic compounds are not available to the trees. Once mineralised by the microbes to ammonium and nitrate, the nitrogen become available but is then also subjected to leaching.

In commercial citrus production, it is important that the nitrogen status of the trees follow a certain pattern (See Figure 3). The mineralization of organic matter is a biological process and effected by the temperature and moisture content of the soil. The grower has no control over this process and it will progress as the temperature rises during spring.

This release curve does not necessarily follow the demand curve. In fact it almost never follows the demand curve of citrus (Figure 8). If the microbes require nitrogen during the period of high demand by the trees (flowering and fruit set), it will have catastrophic consequences. The trees cannot compete with the microbes for N.

On the other hand, if nitrogen is released from the organic component during late summer and autumn when the trees require no additional N, the effect on fruit quality can ruin the crop. This release of nitrogen is at a high during the alternating hot/cool and dry/wet summer months. A release of N in late summer and autumn in the hot area will delay colour break.

© 2007 Citrus Research International (Pty) Ltd.

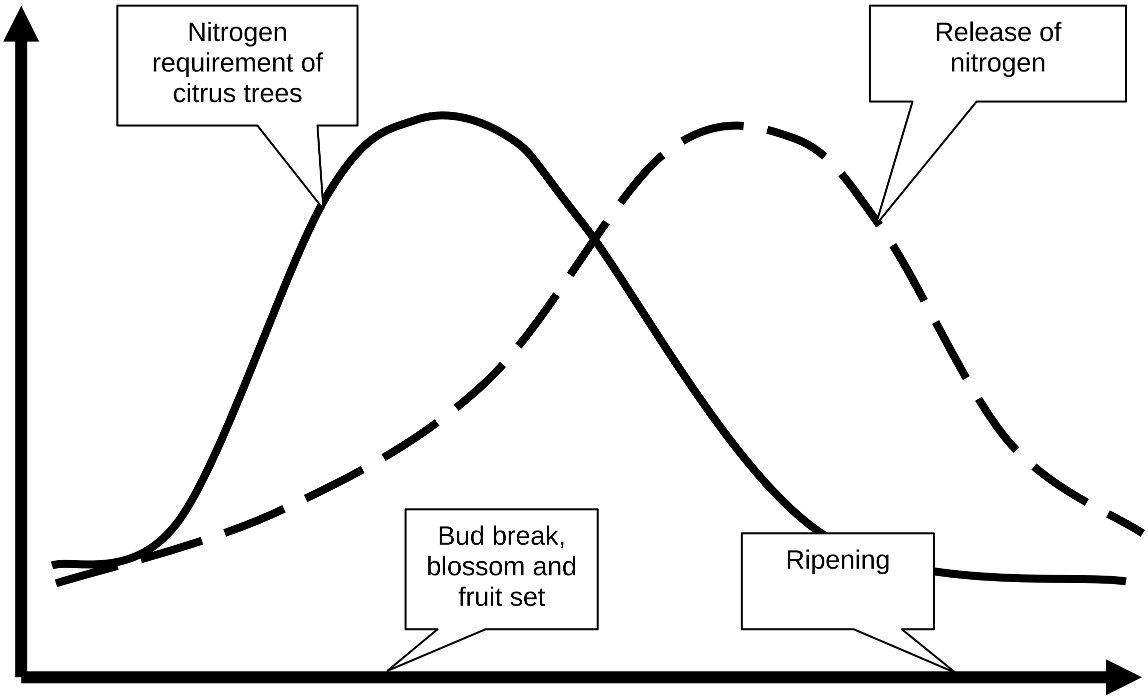

Figure 8. The relationship between the nitrogen requirement of citrus trees and the natural pattern of nitrogen release from the organic matter in the soil.

Additional nitrogen released during January to May will also stimulate vegetative growth resulting in poor quality, especially grapefruit that may turn puffy.

The mass of nitrogen released is directly related to the mass organic nitrogen in the soil. The higher the concentration of organic nitrogen in the soil, the more will be released during mineralization.

Repeated application of organic material will result in a gradual accumulation of organic nitrogen in the soil. This accumulation happens unnoticed until the release rate will be high enough to delay fruit colour. It is almost impossible to reverse the accumulation and could take years to deplete the reserves, especially in fine textured soils.

The magnitude of the accumulated N is much higher than expected. Even in a sand where no organic material other than leaves and weeds, were applied, the total nitrogen amounts to >300mg N per kg soil. If only 1% of this total is mineralised during January to May, the equivalent of >100g LAN is supplied per tree at the wrong time (Table 39).

© 2007 Citrus Research International (Pty) Ltd.

Table 39. The total N content of three soils that received no organic material and the expected mass released when 1% of the total is mineralised in grams per tree under three irrigation systems.

Clay content %	Total N in the soil mg/kg	Root volume 200 litre soil with OHS (units)	Root volume 5500 litre soil with single line drippers (units)	Root volume 10000 litre soil with microjets (units)
5	306	0,61	17	31
17	1022	2,04	56	102
28	1374	2,75	76	137

This also illustrate why nitrogen needs to be apply continuously when the OHS is used. The amount of N released from the limited volume of soil utilised with the OHS is too small to satisfy the N requirement and need to be supplemented. When microjets are used, enough N is supplied naturally by the soil and no additional N must be applied.

If the organic matter in soil no 3 accumulates to 5% the expected release can exceeds 2500mg N/kg soil under microjets. This is equal to 890g N per tree during the wrong time.

When organic material contains less than 0,50% N (like saw dust) the microbes will source nitrogen from the environment to digest the material and a nitrogen deficiency will develop. It will take about 6 months before this fixed N will be released again. If the organic material contains 1.8 to 2.0% N, no additional N will be required but it will start to release small amounts immediately. The mass of N that will be released from organic material can be estimated as follows.

- If the total N concentration is 1,80 to 2,00% ±65% will be released during the ensuing season. Therefore total N x 0,65 = available N. If we assume that the material contains 1.95% N then the available fraction = 1,95x0,65 = 1,27% or 1,27kg per 100kg organic material.
- If the material contains less than 1,00% N then an external source is required. During microbial degradation 1,00-2,00 = -1,00% or 1,00kg N per 100kg material will be required. However compost with a N content of 1,0% will not have the same requirement than uncomposted material.
- When the total nitrogen content exceeds 2,0% the available N can be estimated by N = Total N – 2,00 + 2,00x0,65. Assuming the material contains 3,43% total N, then the available N = 3,43-2,00+2,00x0,65 = 1,43 + 2 x 0,65 = 2,73% or 2,73kg N per 100kg material.

Of the remaining N about 12% will be released during the second and 5% during the third season (Fisher, 1992). These percentages will vary according to many factors and the estimations serve merely as a guideline until the local conditions can refine the calculations.

Organic materials can be use successfully on young non-bearing trees. With young trees it is not required to manipulate the N status and a continuous supply of available N at low concentrations, will suite the demand better. This is especially applicable to sandy soils. An even better approach will be to incorporate the organic material into the soil before planting. Chicken manure and other similar products serve only as a source of slow release N and other nutrient elements and not as a mulch or to improve the organic carbon content. Kraal manure contains more roughage and will also serves as a mulch.

Various trials have been conducted to establish the effect of organic and half organic fertilisers on citrus production. The results are usually variable with little if any benefits. During 1983 reports on such trials at Zebediela were published (Table 40, Bester. 1983).

© 2007 Citrus Research International (Pty) Ltd.

Table 40. Yield and fruit size as the result of organic and inorganic fertilisation. Recalculated from Bester, 1983

Treatment	Yield as % of the inorganic treatment	Fruit diameter in mm
Mixtures of guano	91	98
Chicken manure	92	95
Inorganic + organic	99	103
Inorganic fertilisers	100	100

Establishing a heterogeneous microbial population
The main advantage of accumulating organic material in the soil is to establish a natural heterogeneous population of microbes in the soil. In turn the heterogeneous population will restrict the development of a dominating and pathogenic population. The accumulation of phytotoxins will also be limited, because such a variety of microbes can deal with almost any compound.

In citriculture a fungal reach population will also help to keep the soil loose, aggregated and aerated. Fungi need a complex source of energy like wood (Lignin) and it is important to supply energy to maintain the microbes. Without the application of energy sources, the microbes will deplete the existing organic material.

It is important to distinguish between organic material, chicken and kraal manure and compost. Organic material is plant and animal waste products and has little value in establishing a fungal population. Kraal and chicken manure are sources of organic nitrogen and some other elements and are not mediums to establish a fungal population. Compost is not rotten material but a specific mix of organic materials treated under a specific set of conditions to form compost. Important components of the composting process are the mix of organic materials, the inoculum and the conditions during the composting process which will determine the value of the compost.

The value of compost is not in the mineral component but in the variety of microbes and organic compounds formed that will be applied to the soil. Therefore the compost must not being spread out but must be piled below the canopy. This will prevent drying out and give the microbes and organic compounds time to enter the root zone. One or more heaps in the shade where the microjets will irrigate are preferred. If mulches are used to keep the compost moist, it can be spread out but the layer must not be too thin.

The initial inoculum can be prepared by gathering rotten plant material from the natural bush. This is then mixed with the organic material and composted. Afterwards, the course particles from a compost heap can be used as an inoculum for the next batch.

A few successes with the establishment of a heterogeneous microbial population had been reported. The incidence of “Young tree decline” or “blight” had been reduced by adding humus to the soil (Pinckard, 1979). Applications of 100lb humus per tree stopped dying back and 46% more fruit was produced when compared to untreated trees.

Mobilising accumulated nutrients in the soil
Natural microbial populations from soils rich in humus or organic material contain microbes that can dissolve the P from the unavailable pool and left it available to the plants.

Others can fix nitrogen from the atmosphere while another mix can release potassium from unavailable sources.

Due to the activities of these microbes a variety of chemicals are released in the root zone. This includes compounds which will stimulate root growth similar to hormones.

© 2007 Citrus Research International (Pty) Ltd.

Another relative advantage of organic material in the soil is the concentration and variety of natural chelates like that of iron, manganese, zinc and copper increase. Chelates are metal-organic complexes that will not be fixed by the conditions in the soil, which render the metals available to the plant over a longer period.

It is also mentioned that the microbes will fix sodium and chloride and “desalt” the environment.

Improvement of the wellbeing of the soil
The exact meaning of this term or soil health is not quite clear. Does it refer to the activity or variety of microbes or the concentration of humus in the soil?

Organic material will also detoxify the soil by chelating heavy metals to limit their suppressing effect.

Organic material and especially stabile humus will improve the structure, water holding capacity (WHC) and cation exchange capacity (CEC) of the soil. Although this sounds wonderful, these improvements can actually be detrimental. The mass of humus required to obtain these advantages are still unknown but seems to be somewhat impractical.

Fertilisation with organic material will not really improve the WHC and CEC of the soil. These soil properties will only be improved by humus like compounds. To make humus requires many-many years of stabile conditions.

When the aeration of a soil is improved it will also improve the potential of the soil. Whether the improvement is due to the addition of organic material or cultivation is irrelevant. Citrus seedlings grow better in a growth medium with an air filled porosity (AFP) of 9% (Coetzee, 1989). Unfortunately, the incidence of *Phytophthora* infestation is also higher at AFP’s less than 12%. In soils the preferred AFP will therefore be ±15% or more.

Sources of organic material
Kraal manure, chicken litter, guano and various mixes of these are used on a commercial scale. Other sources include by-products from the sugar cane industry, compost and pig manure. The average mineral content of theses materials vary depending on the processes incurred and means of storage (Table 41).

Table 41. Average values of a few quality parameters for organic material.

Source	N%	P%	K%	Ca%	As%
Chicken manure	3,00 tot 4,00	1,25 tot 1,75	0,80 tot 1,00	5,75 tot 6,25	5 tot 12
Kraal manure	1,75tot 2,00	0,20 tot 0,50	1,75 tot 2,00	2,00 tot 3,00	15 tot 40
Guano	10 tot 14	3,00 tot 4,00	1,75 tot 2,00	4,50 tot 6,00	10 tot 20
Compost	0,80 tot 1,50	0,10 tot 0,50	0,75 tot 1,25	2,00 tot 10,00	15 tot 50

It is always advisable to submit a sample for analyses when organic material of an unknown supplier is ordered for the first time. The quality of organic materials is determined by the concentration of nitrogen, chloride, sodium, boron and organic material. The concentration of organic material can quickly and cheaply estimate in the test for the ash content. The total minus the ash = the organic component. The concentrations of P and K as well as other nutrient materials, can be considered as a bonus, but the N and ash content are the important issues. Moisture is also important when transport is involved. To register an organic material, the National Department Agriculture requires an ash content of less than 20% at a moisture content of 40%.

The mass of organic material to be applied per tree or per ha will be determined by the availability, price and the concentrations of N, Cl, Na and B in the material. The recommendation in Florida (USA) is to apply

© 2007 Citrus Research International (Pty) Ltd.

4 ton per acre to grapefruit and 5 ton per acre to oranges and they also recommend that the material be mixed with the soil. If it is not mixed, about 18% of the nitrogen is lost by volatilisation (Fisher, 1992). Mixing is not a sound practise and should not be done at existing orchards.

Sodium, chloride and boron are the factors limiting the mass to be applied per tree.
Table 42 relates the maximum mass that can be applied, of any organic material to their content of N, Cl, Na and B. The maximum is determined by the most limiting element.

Table 42. The maximum application rate (kg/ha) of kraal manure as dictated by the concentrations of sodium, chloride and boron.

	400	600	800	1000	1200	1400	1600	1800	2000
% Na	3,97	2,64	1,98	1,59	1,32	1,13	0,99	0,88	0,79
%Cl	6,06	4,04	3,03	2,42	2,02	1,73	1,52	1,35	1,21
B mg/kg	565	377	283	226	189	162	142	126	113

For example if an organic material contains 1,44% Na, 1.53 % Cl and 270mg B/kg the maximum that can be applied is 800kg per ha due to the restriction by the B content.

Compost

Compost is not rotten or aged plant material. The value of compost is more than the value of the initial ingredients provided it is properly prepared. Apart from the organic material and nutrient elements that are applied by means of compost, a heterogeneous population of microbes is also applied. The value of compost is based on the properties of this population and the microbes are the component that will add value to the soil. The properties of this microbial population will depend on the material used and the prevailing conditions during composting.

True composting of organic material has a number of basic requirements.

- Energy sources

Any plant material and animal refuge can be used as energy sources. The energy required during composting must include sources of simple compounds like sugars but also more complex molecules like wood. Green material, chicken litter and kraal manure serves as sources of simple energy sources to start the composting process. Wood and hay serve as sources of complexed compounds for the fungi.

- Inoculum.

Most green material and manures contain enough microbes to start the composting process. However, mature wood and dry material might not contain enough and without an inoculum the composting process will take longer. A number of inoculums are available and the wider the variety of microbes in the heap the better. A good quality compost can also serves as an inoculum for the next batch. About 1kg good quality compost per m^3 raw material is required as an inoculum. Compost prepared with material from the area, in the area has the most suitable spectrum of microbes for that area.
Compost or mould from the natural bush in the area can also be used as an inoculum.

- Nutrient element.

The demand for mineral nutrients during composting is usually satisfied by the contents of the plant and animal debris. However, sometimes materials like wood, contains too little nitrogen and an external source will be required. This can be done by means of N rich materials including fertilisers. Calcium is an important element helping to stabilise the compost. Calcium in the form of lime (if the pH needs adjustment) or as gypsum can be added.

- Oxygen

Compost can be prepared under aerobic or anaerobic conditions, but aerobic compost is preferred because the conditions in the soil will be aerobic. Of the total volume 50% must constitute air. Therefore do not compress the material. If proper aeration with the coarse material by it self is not possible, artificial aeration can be installed. The volume of air that is required daily is 25 to 30m^3 per m^3

© 2007 Citrus Research International (Pty) Ltd.

material.

The size of the particles used in the compost heap must therefore not be too small. Large pieces of up to 100mm must also be included. When the compost heap turns anaerobic the pH will drop due to the formation of organic acids like lactic acid.

The dimensions of the compost heap will also facilitate aeration. The maximum width is 4m and height is 3m.

Aeration will of cause also benefit when the heap is turned.

- Water

The optimal moisture content in a compost heap is 50-60% on a volume basis. During the rainy season it might be required to protect the heap from too much water. Perforated plastic, shade net or paper can be used. The heap will dry from the outside but the lower moisture content should not penetrate more than 10-15 cm. When the heap is turned, the drier material will be rewetted again.

When compost is at the right moisture content, it will feel like a wet sponge, moist but no free water is visible even if it is squeezed lightly.

- Heat.

Heat is generated by the microbes during the composting process. The heat accumulates in the heap and can lead to spontaneous combustion. Therefore when the heap reaches a temperature of 60 to 65°C it must be turned. After turning the temperature of the heap will increase again. If the temperature does not increase again after the heap was turned, the composting process is completed provided it was aerated and watered properly. The temperature graph of the heap will describe the composting process (Figure 9). The composting process can therefore be completed within 30 to 40 days.

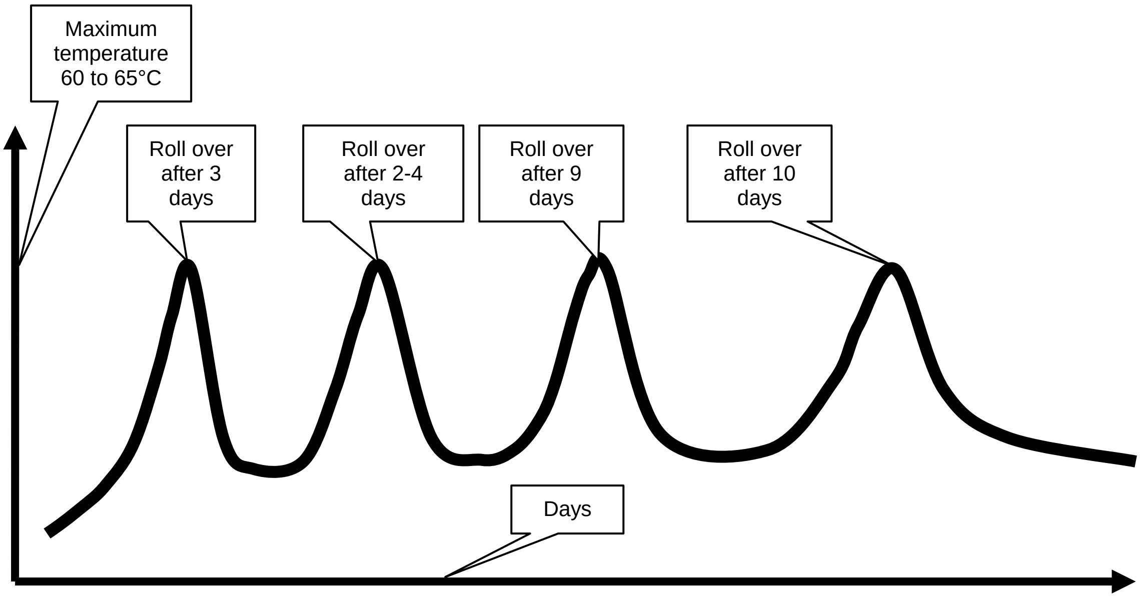

Figure 9. The temperature curve of a well constructed compost heap under optimal conditions.

Humus

The organic fraction in the soil consists of plant, animal and microbial waste in various degrees of decomposition. Another part of the organic material is present in a fairly stable state and is called humus. Humus is an amorphous (has no crystal structure) material with no resemblance to the material it originates from. The first research on humus was reported in 1786. Humus accumulated in the soil and is flocculated on the clay with the interaction of Ca. The flocculated humus is stable and cannot be digested by microbes. Through a process of condensation the humus is transformed over many years into macro molecules.

© 2007 Citrus Research International (Pty) Ltd.

To study humus it has to be separated from the soil. This was done by dissolving the humus in caustic soda (sodium hydroxide). Only a part of the humus is extracted in this manner. The remainder is called humins. The extract is then treated in several ways to fractionate the different components of humus.

The same process is used today to extract humus from materials like coal (leonardite), peat and compost. The process is illustrated in Figure 10.

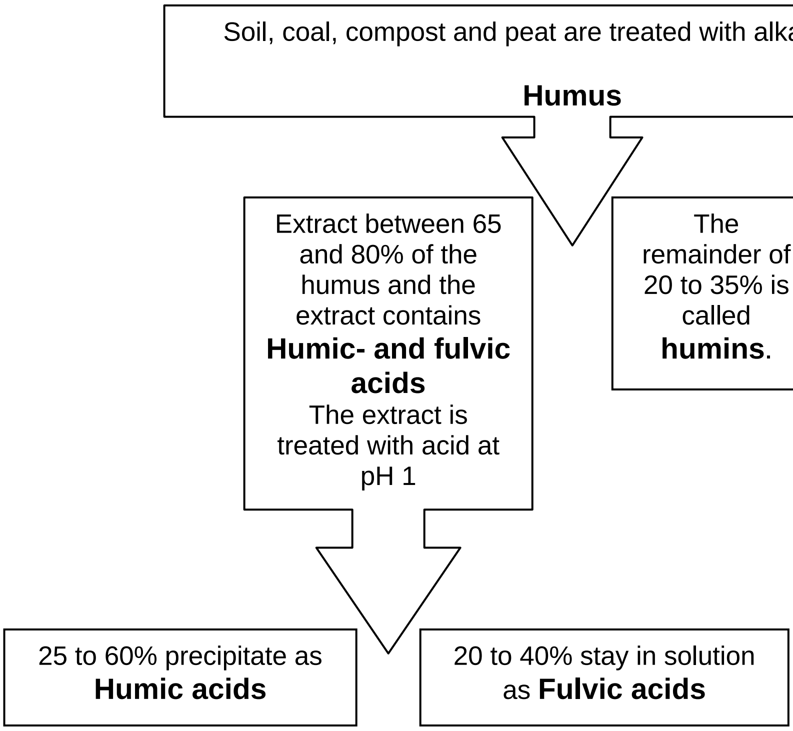

Figure 10. Schematic presentation of the extraction process to obtain humic and fulvic acids.

Humus is therefore equal to humins + humic acid + fulvic acids. The properties of humic and fulvic acids are summarised in Table 43.

Table 43. Properties of humic and fulvic acids*.

Property	Humic acids	Fulvic acids
Name of salts e.g. Ca, K, Mg, NH_4	Humate; Ca-humate, K-humate etc	Fulvate; Ca-fulvate, K-fulvate, etc
Solubility in water	Not at pH's < 7,0	Yes
Solubility in acids	Not soluble	Yes
C:O:H:N	61:31:4:4	46:48:4:2
Calculation from %C	%C x 1,64 = % Humate	%C x 2,17 = % Fulvate
Structure	No structure, amorphous	No structure, amorphous
Molecular mass	10 000 to 150 000	1 000 to 15 000
CEC in me/100g	250 to 500	450 to 1000
Active groups in me/g Total acids -COOH-groups -OH-groups	 ±5,70 ±2,80 ±5,90	 ±10,80 ± 7,20 ± 6,40

© 2007 Citrus Research International (Pty) Ltd.

Phenol OH-groups	±2,90	± 3,60
Alcoholic OH-groups	±3,00	± 2,80
C=O-groups	±3,00	-
-COH_3-groups	±0,50	± 0,20

* The origin of the humus will determine the composition.

The building blocks of humins, humates and fulvates are the same. It can be illustrated by taking an A4-page as the humins. By tearing it into two, the parts will represent humates. If the two halves are teared again into four parts, these will be equal to the fulvates. The molecular mass of humins is in the order of 1 000 000 and represents a condensate of humic and fulvic acids that took many years to stabilise but minutes to destroy. Humates will therefore be reduced by the microbes to fulvates. Fulvates are more active than humates as can be judged by the higher CEC (Table 43).

Even under conditions of optimal inorganic nutrition, applications of humus showed constantly improvements in biomass produced (Chen & Aviad, 1985). Root stimulation is normally more obvious than that of the top growth. Both root length and number of secondary roots increase. The reaction to increased applications of humic acids follow the normal responds curve and will also reach a plateau where additional humic acids will reduce yield. Fulvic acids contains more compound with low molecular weights as humic acids which is most probably why plants respond better to fulvic acids than humic acids. These molecules reduce the surface tension of the water around the roots (Vakhmistrov, 1987), increase the permeability of the membranes (Chen & Aviad, 1985) and show hormonal activities.

© 2007 Citrus Research International (Pty) Ltd.