

**Influence of a coal derived potassium humate on the yield
and nutrient content of tomato (*Lycopersicum esculentum* L.)
under field conditions.**

By

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Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.



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18-11-97

Date

Uittreksel.

Die presiese samestelling en fisiese eienskappe van humate is nog nie bepaal nie. Humate is alomteenwoordig in alle gronde. Humate word geklasifiseer in humiensure, fulviensure en humien, gegrond op hul oplosbaarheid in water. Die eienskappe van humate verskil ten opsigte van die ekstraksie metode wat gevolg word. Dit maak die vergelyking tussen die verskillende tipes humate baie moeilik. Die belangrikheid van humate in plantvoeding is al omskryf. Elemente vorm komplekse met humate wat die grond se voedingstatus verhoog en plantgroei verbeter. Plaagdoders en onkruidodders word of afgebreek of ge-adsorbeer deur humate. Dit neutraliseer die nadelige langwerkende aksie wat die gifstowwe op die omgewing mag uitoefen. Die verhouding tussen humate en grondmikrobes kan 'n positiewe effek op plantegroei uitoefen. Alhoewel humate redelike bestandheid toon teen mikrobiële afbraak, word sommige koolstof verbindings geredelik afgebreek. Die mees beduidende effek van humate is op die wortelgroei van plante. Dit blyk dat wortels meer geredelik reageer op toedienings van humien- en fulviensure as blare of stingels. Sodra humate teen lae dosisse toegedien word is die effek meer hormonaal van aard as 'n voedings reaksie. Die laer molekulêre massa humate blyk meer effektief te wees in die verband. In die studie is die invloed van 'n steenkool afgeleide kalium humaat op die opbrengs, kwaliteit en konsentrasie van elemente in die blare en vrugte van tamaties onder veld toestande bepaal. Daar was geen beduidende verskille in opbrengs, kwaliteit of konsentrasie van elemente in die vrugte en blare van die tamatieplante gevind nie. Die bevindinge kan toegeskryf word aan die hoë

koolstof konsentrasie asook die hoë voedingswaarde van die grond waarin die plante geplant is. Die tempo van kalium vrystelling van die steenkool afgeleide kalium humaat, 'n kommersiële KCl bemestingstof en grond alleen is bepaal onder verskeie toestande. Die tempo van kalium vrystelling deur diffusie in 'n grond waar die kalium humaat gevoeg was, was hoër as die waar die kommersiële KCl toegevoeg was. In 'n tweede eksperiment waar die logingsfraksie van die grond opgevang is, het die kommersiële KCl die hoogste tempo van kalium vrystelling getoon. Die tempo van vrystelling van kalium is ook bepaal deur die temperatuur en hoeveelheid water wat deur die grond beweeg te varieer. Daar is gevind dat soos die temperatuur styg, minder kalium vrygestel is van beide kalium humaat en kommersiële KCl. By alie temperature het die tempo van kalium vrystelling verlaag met toename in volume water wat deur die grond beweeg het.

Abstract.

The exact composition and physical properties of humic substances has not been clearly defined. Humic substances are ubiquitous and are found in all soils. Humic substances are classified into humic acids, fulvic acids and humin on the basis of their solubility in water. The characteristics of humic substances also vary according to the extraction method. This makes the comparison between various types even more difficult. The importance of humic substances in plant nutrition has also been identified. Various elements are bound to humic substances which improve the soil nutritional status. Pesticides and herbicides are degraded or adsorbed by humic substances which neutralises these chemicals in the soil. It has been found that the relation between humic substances and microbial growth can have positive effect on plant growth. Although humic substances are resistant to microbial breakdown, there are some carbon compounds associated with humates that were readily decomposable. The most significant effects of humic substances have been found on root growth. It seems that roots react more readily than leaves and stems to applications of humic and fulvic acids. When humic acids are applied in low concentrations, its effect is more hormonal than nutritional. The humic substances with lower molecular mass have higher hormone-like activity than the high molecular humic substances. A coal derived potassium humate was used in this study to determine the yield, quality and elemental status of tomatoes under field conditions. In the field study no significant differences in yield, quality or the elemental status of fruits and leaves were found. This was primarily ascribed to the high soil nutrient status and carbon content of the soil. The

rate of potassium release from a coal derived potassium humate, a commercial potassium chloride fertilizer and soil alone was also determined under varying conditions. The rate of potassium release through diffusion in a soil with added potassium humate and without was higher than soils added with a commercial available potassium chloride. When the leachate of soil water was measured, the soil with the commercial potassium chloride had the highest rate of potassium release. The release of potassium was also measured varying the temperature and total amount of water. At lower temperatures more potassium was released than the higher temperatures and the lower water volumes released more potassium than the higher water volumes at all tested temperatures.

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1. LITERATURE REVIEW.

1.1 Introduction.

Soil humus is one component of the soil-plant relationship that has attracted the attention of not only soil-scientists, but also agronomists, geologists, geochemists, biologists, chemists, engineers and specialists in the fields of hygiene. This wide interest is understandable since almost all carbon reserves are trapped in humus and these reserves surpass the biomass of living organisms on earth. It is estimated that, in a metre-deep layer of soil, the humus content can reach up to $426 \text{ ton} \cdot \text{ha}^{-1}$. Despite the wide interest, not all aspects of the role of humus are clear, but it is estimated that almost all soil properties that are beneficial to plants, depend on the content and composition of soil organic matter (Orlov, 1986).

Soil organic matter can improve the aggregation of soil colloids, increase water retention capacity, aeration and permeability of soils, which may improve the uptake of mineral elements by plants. Organic matter (OM) also provides an important source of energy for various soil micro-organisms which supply nitrogen to plants (Nishita, Kowalewsky and Larson, 1956; Tan and Tantiwiramond, 1983). Because of its positive effects on soils, OM has always been linked to soil fertility. The most important fraction in OM is the humic acid fraction. This has led to widespread use of commercial humic acids in the agricultural sector (Garcia, Hernandez and Costa, 1992).

The fact that certain organic wastes can improve the chemical and physical properties of soils has increased the use of organic waste products world wide. It is also realised that organic matter improves the capacity of soil to reduce leaching of pollutants. This positive effect has increased research efforts on organic matter and its usefulness in agriculture (Piccolo, Zaccheo and Genevini, 1992).

1.2 Characteristics and composition of humic substances.

The exact reactions that are responsible for the formation of humic substances are not known. This makes the characterisation of the composition and physical properties of humic substances very difficult and is consequently the focus of work in many laboratories. As to date, no product of humic substances with uniform chemical structure has been isolated (Apfelthaler, 1992). The term humic substances refers to a complex heterogeneous mixture of naturally occurring organic materials. Humic substances cannot be classified into any discrete compound such as proteins, polysaccharides or poly-nucleotides, but are rather ubiquitous and found in all soils, sediments and streams. Humic substances are classified into humic acid, fulvic acid and humin, on the basis of their solubility in water as a function of pH. Humic acids are that fraction of humic substances that are not soluble in water with a pH lower than 2. Fulvic acids are fractions of humic substances that are soluble under all pH conditions. Humic acid is the major component of humus whereas fulvic acids form only a small part of humus. Humin is the non-extractable component of humus and is not soluble in water at any pH value (Davies and Coulson, 1959; MacCarthy, Malcomb, Clapp and Bloom, 1990; Stott and Martin, 1990a)

The structural characteristics of humic acids vary depending on the base material from which it was formed. A comparison between humic acids from composted and uncomposted city refuse and more developed humic acids showed that the composted city refuse humic acids had lower N and H contents and the more developed humic acids derived from leonardite had even lower N and H values (Garcia, Hernandez and Costa, 1992). Humic acid characteristics varied depending on the method of extraction. In an experiment using a two step fermentation process, it was found that in the first fermentation phase, the humic acids were much more complex in configuration and had a larger amount of functional groups with oxygen and a lower H:C ratio than those humic acids extracted after humification (Kakezawa, Nishida and Takahara, 1992). Differences in composition of humic substances are reflected by the

ratio of optical densities of dilute aqueous humic solutions at 465 nm and 665 nm (E4/E6), C:N, C:H and O:C ratios (Valla, 1992)

The type of ground cover has a significant effect on the structure and composition of humic acids. Those found under monoculture had higher specific reactivity in oxidation and photo degradation than did humic acids that were found under crop rotation (Szcudowska, Golebiowska, Milczarek and Puzyna, 1990). The position in the soil also had an effect on the structure of humic acids. Those close to the surface were less filamentous and more stable than those from subsurface layers, regardless of the type of vegetation (Singhal and Kumar, 1992). Simon, Garcia, Gil and Polo (1994) found that humic acids extracted from pine groves had lower humification indices, higher ratios of aliphatic chains and less condensed aromatic type structure as the pH and base saturation were lower. Malcomb (1990) reported that humic acids found in soils differed significantly from those found in streams or ground waters. Those in soils had a higher percentage aromatic carbon, higher colour intensity per carbon atom and a higher polysaccharide content. It was also found that humus in soils comprised primarily of humic acids and that fulvic acids constituted 90 % (m/v) of stream humus. Fulvic acid did not vary significantly under various climatic or vegetative conditions. It seems as if fulvic acids are more stable in physical structure and composition than humic acids since fulvic acids, found in various rivers in different climatic conditions and vegetation types, are quite similar. The only highly variable component of fulvic acids is degraded carbohydrates. Humic substances were extracted from cattle manure compost at different stages of decomposition. It was found that the total humic substances increased as the organic matter decomposed but the fulvic acids remained relatively constant (Inbar, Chen and Hadar, 1990). Although vegetation plays an important part in the type of humic acids formed, Drijber and Lowe (1990) found no significant differences between the E4/E6 ratio of humic acids in three different soil zones, except in the Ah horizons. Kumada (1985) however found significant differences in the E4/E6 ratio in different soils.

There are four main groups in which humic acids are classified, Rp, P, B and A-type

humic acids. The main differences are in their absorption spectra (Figure 1-2.) and these differences influence whole soil properties and processes. The RF and ΔLogK values are an expression of the degree of humification according to the definition by Kumada, Sato, Ohsumi and Ohta (1967). The values were calculated with the following formula:

$$\text{RF} = K_{600}/S * 100$$

(S = volume (ml) of 0.1 N KMnO_4 consumed by 30 ml of the humic acid solution used for determining the adsorption spectrum)

$$\Delta\text{LogK} = \text{LogK}_{400} - \text{LogK}_{600} \text{ (K = absorption coefficient at 400 or 600 } \mu\text{m)}$$

The differences found in the RF ΔlogK values are based on the presence and absence of various molecules such as alkyl- methoxyl- carbohydrate-1, phenol- and aromatic-carbon in the humic acids.

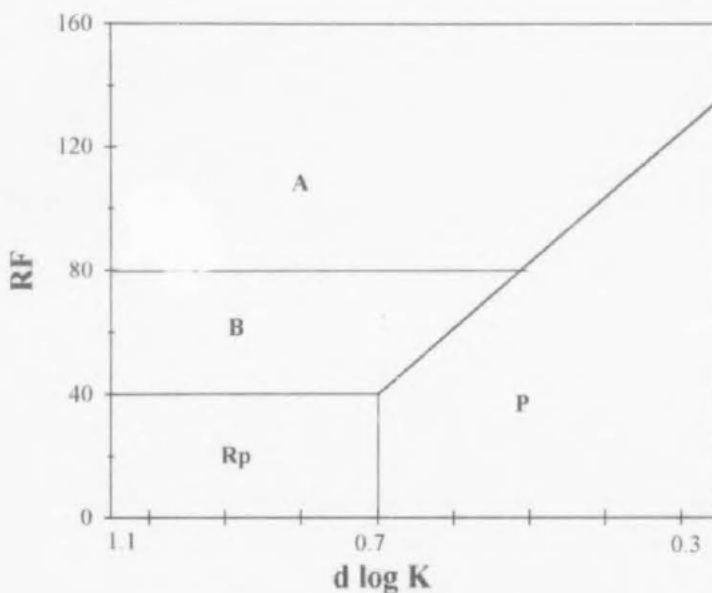


Figure 1-1. Classification of A-, B- Rp- and P-type humic acids according to RF and ΔLogK values (Kumada *et al.*, 1967).

Soils that were formed through volcanic ash have A-type humic acids, whereas those with less humified humic acids are of the B and P type. Most black soils contain A-type humic acids with B- or P-type occurring in the B horizons.

The main humic acid type found in podzolic soils are of the P-type. P-type absorption bands are found near 615, 570 and 450 nm. Originally the P-type humic acids were divided into two groups, the green types (Pg) and brown types (Pb), depending on the colour in alkaline solution (Kumada, 1965). In a comprehensive study of the forest vegetation in the mountainous area of central Japan, Kumada, Sato, Ohsumi and Ohta (1967), found that the Pg humic acid within the P type apparent. They suggested a more detailed classification of the various humic acid types. Kumada and Sato (1980) divided P-types into six groups, B₁, B₂, BG, G₁, G₂ and G₃, in decreasing absorption spectra between wavelengths 200 to 700 nm. Each fraction has its own colour in

alkaline solution. The types B₁ and B₂ are dark brown, BG green-brown and G₁, G₂ and G₃ green. The green fraction of the P-type humic acids are of lower molecular weight while the B₁- and B₂-types are humic substances with higher molecular weights and include the G types. The BG-type is a mixture of the B and G types.

Rp-type humic acids are found in Ao horizons of various forests, red yellow soils and peat soils, farmyard manures and composts. They are believed to be responsible for the initial stages of humification and are also formed from rotting plant material. Rp-type humic acids can be divided into four groups to indicate their origin. The first group consists of rotted material such as needle and broad leaved trees and are characterised by lignin's (L-type). The second is from rotted leaves of needle- and broad leaved trees and are characterised by tannins (T-type). The third is from farmyard manure's and compost made from rice and straw and is also characterised by lignin's (L-type) while the fourth is from rotted pastures and is characterised by its nitrogenous compounds (M-type) (Suzuki and Kumada, 1972). Transformations between the various types are also possible. The fact that B-type humic acids contain a high percentage alkyl-C, which is also a major component of the P- and A-types, confirms that transformation between humic acids is possible. It has been found that the B-type is a transition form between the P- and A-types. A-Type humic acids are also related to the burning of vegetative material while P-types are mostly found in soils that were under pastures and volcanic ash. (Tate, Yamamoto, Churchman, Meinhold and Newman, 1990).

Humic acids contain proteins, simple phenols, polysaccharides and metals, chemically or physically attached to a core (Figure 1-2). There is no proper definition for humic acid since it is not an individual compound exhibiting well defined chemical properties. Humic acids are a mixture of organic compounds of unknown structure, each with its own properties such as electrical charge, pH, surface activity and gel formation. The elementary composition of four humic acids are listed in Table 1-1 and are expressed in terms of weight per cent. It was found that the lower the hydrogen content of the humic acids were, the higher the degree of humification and the deeper the visible light

absorption spectra. Nitrogen content of humic acids showed similar trends as those of hydrogen (Kuwatsuka, Tsutsuki and Kumada, 1978). The molecular weights varied between 1 000 to 300 000 (Haworth, 1971; Tschapek, Wasowski and Sanchez, 1981; Stott and Martin, 1990a). According to Orlov (1986), the molecular weights should be divided into two groups, the first group with values ranging from a few hundred to about $20\,000\text{ g mol}^{-1}$ and the second group with values from $20\,000\text{ g mol}^{-1}$ to more than $300\,000\text{ g mol}^{-1}$. The sharp differences in molecular weight could be due to the various methods of extraction of the humic acids and determination of molecular weights. A distinction must be made between the molecular and particle weight of humic acids.

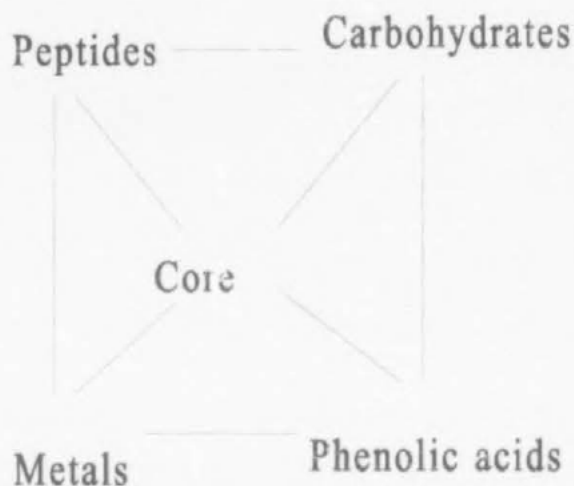


Figure 1-2. Diagrammatic representation of a humic acid and its basic components (Haworth, 1971).

Table 1-1. Elementary composition of A, B, Rp, P₀ humic acids expressed in terms of weight per cent. (Kuwatsuka *et al.*, 1978).

Element	Humic acid type			
	A	B	Rp	P ₀
C%	57.4	56.8	55.2	57.5
H%	3.61	3.81	5.66	5.99
N%	3.11	4.13	5.20	4.10
O%	35.8	34.3	33.9	32.4

1.3 Humic substances and their influence on and interaction with nutrient elements.

Organic matter form metal-organic complexes of different stabilities and characteristics through ion exchange, chelation, surface adsorption, peptization and complex coagulation. These complexes affect soil formation and plant nutrition. The capacity of humic acids to bind metal ions is determined by the number of titratable H⁺-ions which are determined by the amount of carboxyl (COOH), hydroxyl (OH) and carbonyl (C=O) groups, divided by the valency of the metal ion being bound. The exact method of binding with the various metals is still controversial since most of the experiments done are not standerized and the humic and fulvic acids used, vary.

It has been determined that there is no significant difference in the binding strength between Ba²⁺, Ca²⁺, Mg²⁺, Mn²⁺, Co²⁺, Ni²⁺, Fe²⁺ and Zn²⁺ (Piccolo and Stevenson, 1982; van Dijk, 1970).

Organic material adsorbs copper in the soil solution until saturation of its cation exchange capacity, after which it is adsorbed by clay minerals, especially in soils with high pH. It has been found that soils with high organic matter are more able to adsorb high levels of iodine, boron and manganese and that sandy soils without organic matter have no ability to complex zinc, which is vital for plant growth (Mortensen, 1963).

Organic acids play an important role in inhibiting the precipitation of phosphate through the formation of insoluble stable complex molecules (undissociable organo-metallic phosphates) with iron and aluminium and therefore increasing the activity and availability of phosphate to plants. By applying organic material, either sludge or manure, a higher solubility of phosphate has been found than with inorganic phosphorus fertilizers (Dalton, Russel and Sieling, 1952; Sinha, 1971; Singh and Amberger, 1990; Grossl and Inskeep, 1991). Humic acid was less effective in this regard. It is assumed that the fulvic acid metal phosphate compounds has higher mobility and therefore the phosphorus should be more available to plants. In contrast to the above observations, phosphate uptake was decreased by 60 % in a 24 hour period in the presence of fulvic acid (Asp and Berggren, 1990).

The reduction of potassium fixation by organic matter in vermiculite soils has been studied on cotton. It was found that the rate of potassium fixation was inversely related to the soil organic carbon content. Calcium humates had no significant effect on the fixation of added potassium, but humic acids increased potassium availability between 7 and 25 % (Olk and Cassman, 1993). It was found that liming of soils increased the percentage humic acid bound to calcium. Fortunately, this process is reversible and depends on the physicochemical conditions of the soil (Orlova, Bakina and Plotnikova, 1992). The binding of calcium on fulvic acid depends on the molecular mass of the fulvic acids and the pH of the solution. The higher the molecular mass, the higher the complexation capacity of fulvic acid. The availability of calcium uptake from organic compounds depends on what type of organic material is bound to calcium. Platonov and Karpukhina (1994), found that calcium availability increased when complexed with organic substances. The Ca complexed with EDTA was the least

available between fulvic-, citric and humic acids. The Ca bounded to humic acids was the most available.

Aluminium uptake by beech seedlings was significantly less in the presence of fulvic acids. Calcium uptake was not affected by the presence of fulvic acids since they formed complexes with aluminium.

There is a difference in the ability of humic and fulvic acids to adsorb different ions. Inorganic Se is bound to fulvic acids whereas humic acid bounds Se in an organic seleno-amino form (Kang, Yamada, Kyuma, Hattori and Kigsawa, 1991)

1.4 Interactions between humic acids and herbicides and pesticides.

The various compounds that constitute humic acids and that give it its own specific characteristics are also responsible for the formation of bonds that help in the adsorption phenomenon between other humic acids, herbicides and pesticides (Senesi, 1989). The organic matter-pesticide interaction (including herbicides, insecticides and fungicides) have two main aspects. Adsorption of pesticides by organic matter and the non-biological degradation of pesticides by organic matter. Degradation of herbicides and pesticides is influenced by temperature, moisture and pH (Chen and Li, 1994; Sabadie, 1993; Chiou, 1990). Both adsorption and non biological degradation influences the processes that determine the final fate of the pesticides, however, adsorption has the greatest influence. The concentration of the pesticide in soil solution determines its persistence, leaching, mobility and bio-availability. There are various mechanisms involved in the adsorption of herbicides and pesticides to organic matter. It is possible that some may occur simultaneously. The adsorption can be classified into two types, physical or van der Waals adsorption. Van der Waals adsorption are mainly due to dipole-dipole interactions, polarisation or induced dipole interactions, ion-dipole interactions and hydrogen bonds. Chemical adsorption include ionic bonds, complexation through electron donor acceptor groups and co-ordination

through an attached metal ion. Other types of adsorption include charge transfer, ion exchange, ligand exchange, chemical-, physicochemical bonding and polymerisation reactions. (Khan, 1978; Senesi and Testini, 1980; Hsu and Bartha, 1974). The release of partial biodegraded herbicides (chloroanilines) is caused by microbial activity, rather than any chemical or physical reaction. The processes involved in the binding of herbicides and pesticides onto humic substances are mainly due to the content of acidic functional groups and hydrogen binding capacity (Senesi and Testini, 1982).

Various researchers have studied the effect of different herbicides and pesticides in combination with humic and fulvic acids on plant growth. Senesi, Loffredo and Padovano (1990), found that the positive effect of humic acids on the growth of *Pisum sativum*, in a controlled environment, was suppressed when these humic substances interacted with certain herbicides, however, the negative effect of the herbicides on plant growth was suppressed. The herbicides used in the study were cycluron, prometon (a s-triazine), alachlor and 2,4-dichlorophenoxyacetic acid.

The strength of adsorption varies between herbicides and pesticides. Senesi and Testini (1980) found that acids groups (mainly the carboxylic content) determine humic acid's adsorption capacity to herbicides. Additional bonds are created through the amount of polar C=O and O-H groups which forms H-bonds and van der Waals forces. The extent of adsorption increased in the order prometon, methoprotetryne, monuron and fenuron. The presence of salts in the soil solution decreased the strength of the interaction (Cserha, 1993). Increasing the concentration of humic acid also increased the solubility of copper(II)oxinate (Fukushima, Taga and Nakamura, 1994).

Organic matter determines the activity of soil micro-organisms including their ability to convert xenobiotic compounds. Organic matter provides nutrients and energy for the micro-organisms. It was found that the degradation process was increased with addition of organic matter (Kunc, 1992).

1.5 The relation between humic acids and soil micro-organisms.

The bio degradation of organic residues by micro-organisms in soil and water ensures that organic carbon may be used by future generations of plants and animals. It is estimated that 60 to 80 % of the carbon of most plant residues is returned to the atmosphere as CO₂ after one year and that 5 to 15 % of the remaining carbon remains in the microbial biomass. The remainder is used to form new humus (Stott and Martin, 1990b). Soil organisms play an important part in the degradation of plant residues which help in the formation of humic substances. Earthworms help with the incorporation of plant residues into the soil but bacteria and fungi play the most significant role in the breakdown and decomposition of organic material into simple organic compounds (Campbell, 1978). Varshovi and Sartain (1993) studied the chemical characteristics and microbial degradation of humates and found that the humates were relatively resistant to microbial degradation. There were, however, some carbon compounds associated with the humates that were readily decomposable. If more reactive humus material could be developed it could be of agricultural importance.

Lignin's are phenolic acids found in many plant parts. They are also considered to be the primary source of phenolic units for humic acid synthesis. Lignin's are relatively resistant to microbial decomposition but certain basidiomycetes ("white rot fungi") and basidiomycetes use lignin as main carbon and energy source. During the decomposition of lignin, small amounts of dark coloured humic acids are formed in which phenols can be detected. Phenolic units may also be synthesised from non-aromatic carbon sources by microbes, such as *streptomyces*. Other fungi are also involved in the production of units which form part of humic acids such as *Aspergillus niger*, *A. sydowi*, *Epicoccum nigrum*, *Stachybotrys atra*, *S. chartarum* and *Hendersonula toruloides*.

Gaur and Bhardwaj (1971) found that the number of cells of *Rhizobium trifolii* and *Azotobacter chroococcum* increased when a sodium humate was applied to the soil. It was found that the dry matter yield and nitrogen uptake of berseem (*Trifolium alexandrinum*) inoculated with specific rhizobia was significantly influenced by the application of a sodium humate. Even without inoculation, growth was stimulated by the sodium humate. Fialová (1969) found that the growth rate of wheat (*Triticum aestivum* L.) treated with sodium humate increased significantly in comparison with those without the humate. It was also found that the presence of sodium humate influenced the ribosomal ribonucleic acid content. Vallini, Pera, Avio, Valdrighi and Giovanetti (1993) studied the effects of increasing concentrations of humic acid on laurel (*Laurus nobilis*) in sandy loam soils. Aerobic bacteria and actinomycetes were stimulated by humic acid levels from 1500 to 3 000 mg.kg⁻¹ but only to the first harvest, after which no significant difference were found between the various levels of humic acid. The hyphal growth of *Glomus mosseae* decreased with increasing concentration of humic acid and vesicular-arbuscular mycorrhiza was only slightly affected.

1.6 Effect of humic substances on root growth.

Plant roots are in close contact with humic substances. The cation exchange capacity and ability of humic substances to complex metal ions affect the availability of nutrients to plant roots. The beneficial effect of organic matter on soil properties such as permeability, aeration and water holding capacity, may improve root growth.

Metabolic processes of plants *in vivo* (Vaughan and Malcolm, 1985) and *in vitro* (Vaughan and Ord, 1985) are affected by humic substances. In an experiment with winter wheat roots, under axenic conditions in order to avoid complications with micro-organisms, it was found that soil organic matter inhibited the uptake of glucose into the roots and that the uptake of inorganic phosphate was stimulated. This effect was ascribed to the effect of soil organic matter on the activity of invertase and

phosphatase (Vaughan, Ord and Malcolm, 1978). A positive reaction on onions, lettuce and cantaloupe seedling root growth was found with a coal derived sodium humate. The stimulatory effect of the sodium humate on onions and lettuce could not be ascribed to an increased supply of nutrients, since root stimulation was higher in water solution than in a solution with nutrients. Cantaloupe, however, showed an increase in root growth in the presence of nutrient solution (Van de Venter, Furter, Dekker and Cronje, 1991). Mylonas and Mccants (1980) also found that the stimulation of tobacco root initiation and elongation by humic and fulvic acids was affected by means other than as a source of nutrients. It was found that humic acids increased root length by 30 % at concentrations between 75 and 100 ppm and fulvic acids by 25 % at concentrations between 50 and 100 ppm. Vaughan (1974), found that with low concentrations of humic acid, the increase in the length of root segments in peas (*Pisum sativum*), was due to cell elongation rather than cell division since no increase in number of cells per segment was found. The author suggested that iron-humic acid complexes formed in plants, preventing biochemical processes, causing cessation of cell elongation. Schnitzer and Poapst (1967), found maximum root initiation in beans at a fulvic acid concentration of 3 000 ppm and it remained at that level up to a concentration of 6 000 ppm. Differences in reaction to humic substances between plant species were also found by Vaughan and Malcolm (1985).

Pinton, Varanini, Vizzotto and Maggioni (1992) found that the main target of humic acids is the electrical membrane potential of roots which interferes with other naturally occurring substances involved with biochemical mechanisms in plant nutrition. The molecular weight of the humic fraction affects the various types of oxidoreductase activities at the root surface of roots in oats. Low molecular weight humic substances influences the transport properties of the plasma membrane and the tonoplast of roots by stimulating ATP-phosphohydrolase enzyme- and ATP-dependant proton pumping activity. A stimulation of NO_3^- transport in plasma membrane vesicles was also found in the presence of low molecular weight humic substances. The stimulation of NO_3^- transport over plasma membranes means that humic substances directly affect on the system(s) that are involved with NO_3^- uptake (Maggioni, Varanini, Pinton and de Biasi,

1992). Redox activities play an important part in certain physiological processes such as growth control, signal transduction, cell wall synthesis, the generation of transmembrane proton gradients and iron reduction (Pinton, Cesco, Santi and Varanini, 1995).

1.7 Hormone-like effects of humic acids.

Humic substances has hormone-like effects on plant growth at very low concentrations. The opposite is also true, at high concentrations, humic substances has toxic effects on plant growth. Humic substances has growth promoting substances corresponding to indole-acetic-acid (IAA) or its precursors, but the effect seems to be 100 times smaller than that of IAA and 10 times smaller than that of benzyladenone (BA). High concentrations have a greater inhibitory effect on lettuce germination than on its vegetative growth process. The effect of high humic acid concentrations may be due to auxin-like action rather than the effect of growth inhibitors (O'Donnel, 1973; Cacco and Dell'Agnola, 1984; Casenave de Sanfilippo, Arguello, Abdala, Orioli, 1990). Piccolo, Nardi and Concheri (1992), found that low molecular weight humic substances with high acidic functionality had the highest hormone-like activity on watercress and lettuce. Stimulation of root growth due to auxin-like effects was studied on various crops such as potatoes, beans and soybeans. In both cases increased yields were found with the application of humic acids. Geranium cuttings were treated with various concentrations of a humic acid. It was found that those cuttings which received the humic acid showed a proliferation of root growth while those without the humic acid were long and unbranched. The same effect was found with pea root tip elongation which proved that humic acid has some auxin-like effect on root growth (O'Donnel, 1973).

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2. INFLUENCE OF A COAL DERIVED POTASSIUM HUMATE ON THE YIELD AND NUTRIENT CONTENT OF TOMATO (*Lycopersicum esculentum* L.) UNDER FIELD CONDITIONS.

2.1 Abstract.

A coal derived potassium humate (K-HA) was found not to have a significant effect on the yields of tomato (*Lycopersicum esculentum* L.) grown under field conditions. K-HA was applied to a Hutton (Oxisol) with 15-20 % clay. Six levels of K-HA were applied which included 0, 400, 600, 800, 1 000 and 1 200 kg ha⁻¹. Total yields, marketable and unmarketable yields were determined. Marketable yields were classified into three sizes, > 70 mm, 70 to 50 mm and 50 to 30 mm. Unmarketable fruit were classified according to disorders such as cat faced fruit, cracked fruit, sun scald, rotten fruit, fruit with zip marks and virus infected fruit. No significant difference in mineral element content was found in fruit for both cultivars treated with various levels of K-HA. There were no significant differences in N, P, K, Ca, Na, Mn, Cu, Zn, Al, B and Fe content in petioles, 78 days after planting for both cultivars treated with various levels of K-HA. The high organic matter content of the soil and low activity of the humic acid, due to the high molecular weight of the coal derived potassium humate, could be the reason why no significant results were not found.

2.2 Introduction.

When absorbed, humic acids may improve plant growth in a direct way by affecting various biochemical processes in cell walls, membranes and in the cytoplasm (Vaughan, 1974). By improving soil physical properties and chemical properties, humic acids may enhance plant growth indirectly (Vaughan, Ord and Malcomb, 1978). Some of the important mineral elements may be chelated by humic acids, thus improving nutrient uptake. Those nutrients that cannot be absorbed directly are chelated by humic acids, thus improving nutrient uptake (Malik and Azam, 1985; Chen and Aviad, 1990).

Positive effects of humic acids on plant growth have been found with various crops. Tan and Tantiwiranond (1983) found an increase in total dry matter of shoots, roots and nodules of soybean, peanut and clover plants with increasing levels of humic acids and fulvic acids in soil. Poapst, Genier and Schnitzer (1970), found that when increasing fulvic acid concentration to 4 000 ppm, stem elongation was inhibited due to toxic effects. Mylonas and Mccants (1980) found increased number and length of tobacco roots at low concentrations of extracted humic and fulvic acids from commercial organic matter (Aqua Humus). It was also found that at high concentrations of humic acids, root growth was inhibited. Tomato plants reacted positively to humic and fulvic acids. According to Sladký (1959), the length of the roots and stems increased while the level of oxygen intake by the leaves increased in the presence of humic acids in nutrient solution. It was found that the effect of humic acids was less pronounced than with fulvic acids.

A coal-derived potassium humate, developed through the wet oxidation of bituminous coal, was used in this study to determine its effect on the growth, yield and quality of two tomato cultivars, Floradade and Rodade under field conditions.

2.3 Materials and methods.

A Hutton (Oxisol) soil with a K content of 82.11 mg.kg⁻¹ soil was chosen for the trial. The soil was treated with Herbifume four weeks prior to planting to eradicate Yellow nutsedge (*Cyperus esculentus*) and Purple nutsedge (*Cyperus rotundus*) and to control nematodes. The soil was analysed for various mineral elements (Table 2-1) and the fertilizer requirements estimated.

Six different levels consisting of 0, 400, 600, 800, 1 000 and 1 200 kg.ha⁻¹ of a coal derived potassium humate (9% K) was applied to the soil. Each treatment was replicated four times for each cultivar in randomized blocks. Treatments higher than 400 kg.ha⁻¹ were applied throughout the growing season with top dressings 14 days apart as shown in Table 2-2. The first 400 kg.ha⁻¹ was cultivated into the soil. The other pre-plant applied fertilizers were simultaneously worked into the soil to a depth of 200 mm. The amount of potassium fertilizer (KCl) applied to each treatment was reduced according to the level of K-HA applied. The total amount of N, P and K applied to the soil was the same for all the treatments (100 kg.ha⁻¹ N, 50 kg.ha⁻¹ P and 108 kg.ha⁻¹ K).

Table 2-1. Analysis of the Hutton (Oxisol) soil used.

Carbon	pH	Resistance	K	Ca	Mg	Na	P
%	Water	ohm			mg.kg ⁻¹		
1.23	7.74	1700	82.11	1779.55	563.76	50.6	7.1

Table 2-2. Various levels of a coal derived potassium humate (K-HA) applied and the number of top dressings for each level.

Days after planting	K-HA applications					
	(kg.ha ⁻¹)					
Pre-plant	0	400	400	400	400	400
14 days			100	200	200	200
28 days			100	200	200	200
42 days					200	200
56 days						200
Total	0	400	600	800	1 000	1 200

The two fresh market tomato cultivars, Floradade and Rodade, were used in the field trial. The plants were drip irrigated at a rate of 30 mm.week⁻¹. The plants were trellised every second week up to a height of 1 200 mm. Fruit were harvested weekly for eight weeks and categorised into marketable and unmarketable yield in t.ha⁻¹ as well as number of fruit.ha⁻¹. The marketable fruit were sized into three categories: Fruit sizes between 30 and 50 mm, between 50 and 70 mm and fruit larger than 70 mm. Unmarketable yield were categorised into fruit with cat faces, cracks, sun burnt, virus infected and rotten fruit. The pH and total soluble solids (TSS) of fruit from each harvest was measured. The fruit of the sixth harvesting week were analysed for N, P, K, Ca, Mg, Na, Mn, Cu, N, Al, B and Fe. The concentration of P, K, Ca, Na, Mn, Cu, Zn, Al, B and Fe was determined in petioles of the youngest mature leaves 78 days after planting, using standard techniques.

2.4 Results.

The marketable yields ($\text{t} \cdot \text{ha}^{-1}$ and $\text{fruit} \cdot \text{ha}^{-1}$) of fruit larger than 70 mm, between 70 mm and 50 mm and between 50 mm and 30 mm were not significantly affected by increasing applications of K-HA (Table 2-3 and Table 2-4).

Floradade produced significantly higher yields ($\text{t} \cdot \text{ha}^{-1}$ and $\text{fruit} \cdot \text{ha}^{-1}$) than Rodade for fruit > 70 mm but Rodade produced significantly higher yields for fruit between 70 mm and 50 mm and between 50 mm and 30 mm (Figure 2-1 and Figure 2-2).

Table 2-3 Marketable yield of three fruit sizes produced by Floradade and Rodade treated with various levels of a coal derived potassium humate (K-HA).

K-HA ($\text{kg} \cdot \text{ha}^{-1}$)	Fruit size		
	> 70 mm	70 - 50 mm ($\text{t} \cdot \text{ha}^{-1}$)	50 - 30 mm
0	6.571	43.973	3.090
400	6.554	48.386	2.603
600	7.943	39.576	2.411
800	5.764	48.270	4.711
1 000	6.211	47.038	2.555
1 200	7.180	43.541	2.801
$P_{(K-HA)}$	0.975	0.815	0.369
$LSD_{(0.05)}$	NS	NS	NS

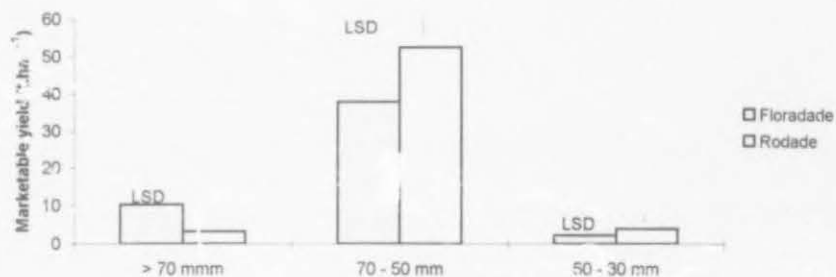


Figure 2-1 Classification of marketable fruit > 70 mm, between 70 mm and 50 mm and fruit between 50 mm and 30 mm (t.ha^{-1}) produced by Floradade and Rodade treated with various levels of K-HA (LSD: $p = 0.05$)

Table 2-4 Yield of different fruit sizes produced by Floradade and Rodade treated with various levels of a coal derived potassium humate (K-HA.).

K-HA (kg.ha^{-1})	Fruit size		
	> 70 mm	70 - 50 mm (fruit.ha^{-1})	50 - 30 mm
0	31468.50	404844.80	61438.50
400	31385.25	415084.50	51698.25
600	39210.75	331921.1	47702.25
800	27472.50	424075.50	86163.75
1 000	28638.00	405261.00	49533.75
1 200	33300.00	372793.50	58941.00
$P_{(\text{K-HA})}$	0.948	0.740	0.473
$\text{LSD}_{(0.05)}$	NS	NS	NS

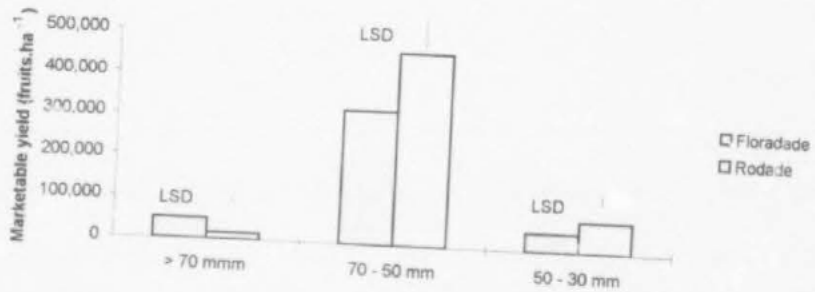


Figure 2-2 Marketable fruit sizes produced by Floradade and Rodade (LSD: $p = 0.05$).

The unmarketable yields ($t.ha^{-1}$ and $fruit.ha^{-1}$) of fruit with cat face's, cracks, sun scald, virus infected, rotten and with zip marks were not significantly affected by increasing applications of K-HA (Table 2-5 and Table 2-6).

Floradade produced significantly more fruit with cat face, cracks and rotten fruit than Rodade (Figure 2-3 and Figure 2-4). Cultivar differences in sun scald were inconsistent. No significant difference in virus infected fruit could be found between Floradade and Rodade. Rodade produced significantly more fruit ($t.ha^{-1}$ and $fruit.ha^{-1}$) with zip marks than Floradade (Figure 2-3 and Figure 2-4).

Table 2-5 Classification of unmarketable fruit ($\text{t} \cdot \text{ha}^{-1}$) produced with various levels of a coal derived potassium humate (K-HA).

K-HA ($\text{kg} \cdot \text{ha}^{-1}$)	Cat face	Cracks	Sun scald	Virus	Rot	Zip
	(t.ha ⁻¹)					
0	5.713	4.174	0.666	10.485	1.644	5.056
400	5.763	5.434	0.651	10.223	2.529	5.526
600	5.858	5.081	0.955	6.935	2.180	5.325
800	6.820	6.008	1.045	9.176	2.941	5.799
1 000	5.394	5.716	0.393	8.999	2.291	5.089
1 200	6.274	4.526	0.693	9.926	2.598	5.480
$P_{(K-HA)}$	0.992	0.941	0.313	0.932	0.488	0.935
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	NS

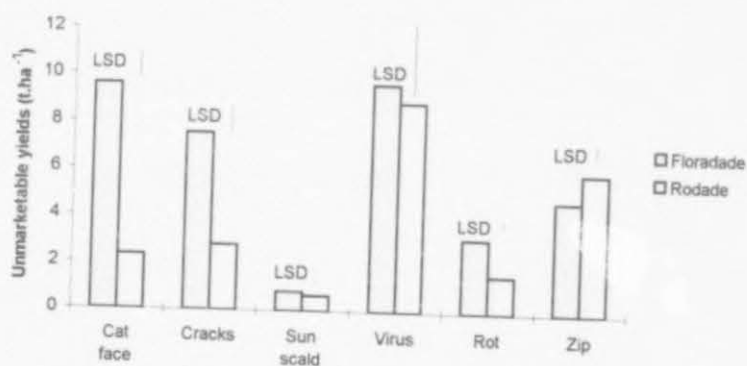


Figure 2-3 Unmarketable yield categories ($\text{t} \cdot \text{ha}^{-1}$) for Floradade and Rodade(LSD: $p = 0.05$).

Table 2-6 Classification of unmarketable fruit ($\text{fruit} \cdot \text{ha}^{-1}$) produced by Floradade and Rodade treated with various levels of a coal derived potassium humate (K-HA.).

K-HA ($\text{kg} \cdot \text{ha}^{-1}$)	Cat face	Cracks	Sun scald	Virus	Rot	Zip
	(fruit.ha ⁻¹)					
0	31884.75	29803.50	6410.25	145021.50	22394.25	45121.50
400	34132.50	42790.50	6576.75	118215.00	34215.75	49117.50
600	33799.50	38961.00	9407.25	86913.00	28554.75	48285.00
800	44205.75	47369.25	10323.00	122377.50	40626.00	53946.00
1 000	32134.50	44788.50	3996.00	109140.80	27555.75	44788.50
1 200	35714.25	35464.5	5161.50	128454.80	32134.50	47868.75
$P_{\text{K-HA}}$	0.937	0.835	0.248	0.901	0.291	0.924
$\text{LSD}_{(0.05)}$	NS	NS	NS	NS	NS	NS

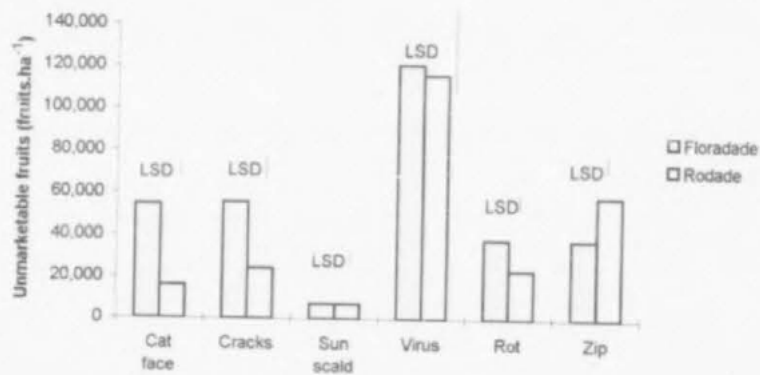


Figure 2-4 Unmarketable yield categories ($\text{fruit} \cdot \text{ha}^{-1}$) of Floradade and Rodade (LSD: $p = 0.05$).

Marketable yields, unmarketable yields and total yields were not significantly affected by increasing applications of K-HA (Table 2-7 and Table 2-8). No significant difference in marketable, unmarketable and total yields (t.ha^{-1} and fruit.ha^{-1}) were found between Floradade and Rodade (Figure 2-5 and Figure 2-6).

Table 2-7 Total yields (t.ha^{-1}) produced with various levels of a coal derived potassium humate (K-HA.).

K-HA (kg.ha^{-1})	Marketable	Unmarketable (t.ha^{-1})	Total
0	53.630	27.728	81.359
400	57.535	30.114	87.649
600	49.924	26.323	76.249
800	58.741	31.771	90.506
1 000	55.799	27.873	83.670
1 200	53.519	29.516	83.030
$P_{(\text{K-HA})}$	0.856	0.938	0.737
$\text{LSD}_{(0.05)}$	NS	NS	NS

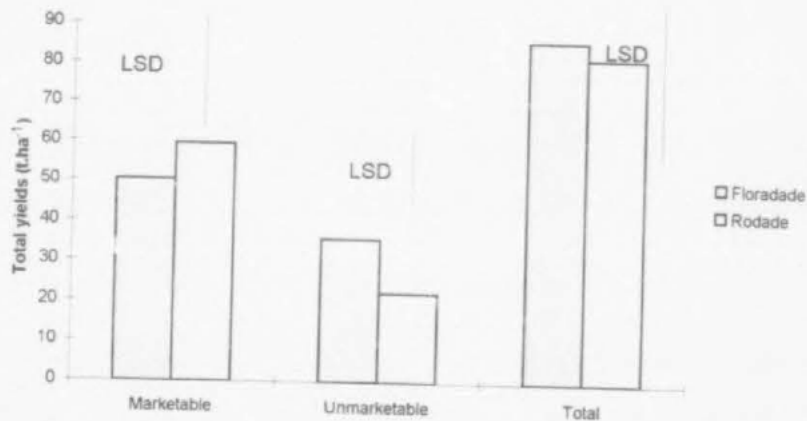


Figure 2-5 Marketable, unmarketable and total yields (t.ha⁻¹) for Floradade and Rodade (LSD: $p = 0.05$).

Table 2-8 Total number of fruit produced (fruit.ha⁻¹) with various levels of a coal derived potassium humate (K-HA.).

K-HA (kg.ha ⁻¹)	Marketable	Unmarketable (fruit.ha ⁻¹)	Total
0	497 751.8	280 635.8	778 387.5
400	498 168.0	285 048.0	783 216.0
600	418 834.1	245 920.5	664 754.6
800	537 711.8	318 847.5	856 559.3
1 000	483 432.8	262 404.0	745 836.8
1 200	465 034.5	284 798.3	749 832.8
$P_{(K-HA)}$	0.727	0.884	0.586
LSD _(0.05)	NS	NS	NS

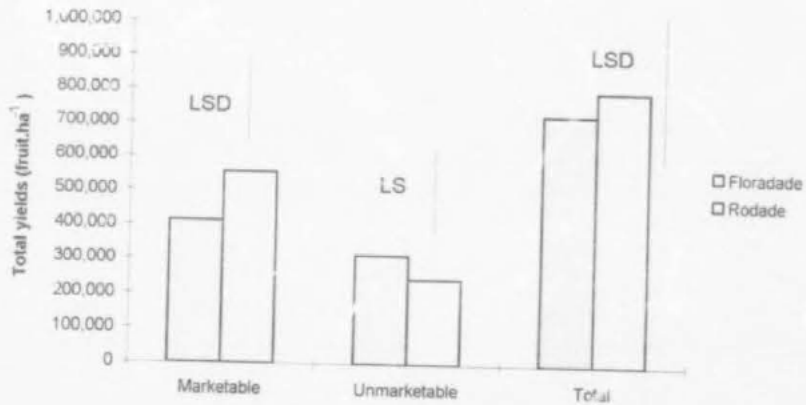


Figure 2-6 Total marketable, unmarketable and total yields (fruit ha⁻¹) for Floradade and Rodade (LSD: $p = 0.05$).

There were no significant differences in total soluble solids (TSS) and pH between the two tomato cultivars and between the various applications of K-HA (Table 2-9). A significant difference in fruit TSS was found during the nine harvesting weeks. The highest TSS was found in the last week (Figure 2-7). This could be ascribed to an increased amount of small fruit towards the end of the growing period and that less water was applied during the last two weeks of harvesting. The lowest TSS in fruit was found during the fourth week.

Table 2-9 Total soluble solids and pH of fruit from Fioradade and Rodade treated with various levels of K-HA.

K-HA (kg.ha ⁻¹)	TSS (Brix %)	pH
0	4.46	4.15
400	4.21	4.04
600	4.26	4.15
800	4.25	4.05
1 000	4.17	4.03
1 200	4.28	4.15
$P_{(K-HA)}$	0.620	0.638
LSD _(0.05)	NS	NS

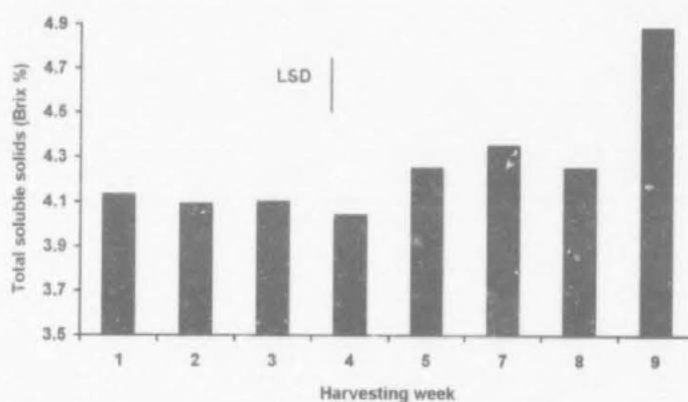


Figure 2-7 Total soluble solids for fruit harvested during the nine harvesting weeks for both cultivars (LSD_{0.05} = 0.22 brix %).

No significant differences were found between the concentration of various mineral elements in the fruit (Table 2-10), harvested during the sixth week, or the petioles (Table 2-11). The correlation between increasing levels of K-HA and the concentration of mineral elements in both the fruit (Table 2-12) harvested during the sixth week, and petioles (Table 2-13) of Floradade and Rodade were not significant.

Table 2-10. Mineral composition of tomato fruit during the sixth harvesting week for Floradade and Rodade, treated with various levels of a coal derived potassium humate (K-HA).

K-HA (kg.ha ⁻¹)	Mn	Zn	Cu	Fe	N	Mg	B	Al	P	K	Na	Ca
	mg.kg ⁻¹								%			
0	14.00	30.74	17.37	64.69	5.26	0.22	13.35	16.70	0.357	2.515	0.071	0.108
400	17.36	35.83	21.81	103.9	6.47	0.28	14.38	16.93	0.453	2.611	0.090	0.140
600	18.22	33.87	19.68	191.1	5.49	0.27	15.99	18.04	0.432	2.707	0.080	0.125
800	18.96	42.42	22.64	69.98	6.16	0.25	12.55	22.29	0.416	3.241	0.074	0.136
1 000	20.09	40.14	25.06	117.0	6.73	0.32	17.07	18.85	0.553	3.157	0.109	0.162
1 200	15.69	36.59	22.23	78.00	6.43	0.23	12.72	17.78	0.350	2.216	0.074	0.126
<i>P</i> _(K-HA)	0.750	0.734	0.859	0.305	0.468	0.451	0.840	0.808	0.220	0.234	0.313	0.664
LSD _(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2-11 Mineral composition of petioles during the sixth harvesting week for Floradade and Rodade treated with various levels of a coal derived potassium humate (K-HA).

K-HA	Zn	Mn	Cu	Fe	B	Al	P	K	Na	Ca
<i>kg.ha⁻¹</i>	<i>mg.kg⁻¹</i>						<i>%</i>			
0	48.08	190.55	652.23	178.28	30.70	75.63	0.28	5.57	0.18	1.60
400	44.74	174.66	626.11	153.64	30.41	62.88	0.28	5.32	0.17	1.60
600	57.89	175.23	592.68	171.65	30.76	60.75	0.27	5.59	0.18	1.69
800	53.26	197.71	658.05	164.98	27.53	74.38	0.31	5.35	0.17	1.69
1 000	53.11	226.15	785.15	187.96	37.25	84.88	0.32	5.50	0.19	1.89
1 200	53.78	202.35	690.31	189.59	31.68	116.00	0.31	5.48	0.16	1.64
$P_{(K-HA)}$	0.834	0.808	0.878	0.864	0.228	0.740	0.666	0.943	0.688	0.278
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2-12 Correlation between nutrient concentration in fruit of the sixth harvesting week and increasing levels of a coal derived potassium humate (K-HA) for Floradade and Rodade.

		Mn	Zn	Cu	Fe	N	Mg	B	P	K	Na	Al	Ca
Floradade	<i>r</i>	0.07	0.17	0.17	-0.06	0.05	-0.03	0.14	0.06	0.08	0.003	-0.02	-0.15
	<i>p</i>	0.738	0.414	0.422	0.760	0.832	0.897	0.517	0.791	0.720	0.987	0.935	0.478
Rodade	<i>r</i>	0.14	0.15	0.14	0.02	0.35	0.17	-0.07	0.08	0.05	0.16	0.19	0.32
	<i>p</i>	0.527	0.492	0.511	0.929	0.091	0.419	0.729	0.708	0.826	0.462	0.366	0.123

Table 2-13 Correlation between nutrient concentration in petioles and increasing levels of a coal derived potassium humate (K-HA) for Floradade and Rodade.

		Zn	Mn	Cu	Fe	B	P	K	Na	Al	Ca
Floradade	<i>r</i>	0.13	0.07	0.05	0.34	0.07	0.12	0.09	-0.08	0.31	0.22
	<i>p</i>	0.564	0.765	0.821	0.118	0.734	0.582	0.671	0.727	0.154	0.305
Rodade	<i>r</i>	0.15	0.16	0.12	0.23	0.36	0.37	-0.18	0.04	0.07	0.18
	<i>p</i>	0.500	0.478	0.599	0.294	0.095	0.082	0.400	0.852	0.736	0.413

2.5 Discussion.

It is difficult to compare different studies done with humic and fulvic acids since the origins of the various humic and fulvic acids differ. Humic and fulvic acids may be extracted from either synthetic or natural organic materials. The humic acid in this study was extracted from a natural source. The intensity of the effect of the different humic substances on higher plants varies according to the origin and conditions of formation of the final humic product. Therefore the chemical, physical and physio-chemical characteristics of humic substances must be compared before comparing their effects on plant growth. Piccolo, Nardi and Concheri (1992), found that the most effective humic substances enhancing nitrate uptake and hormone-like activity are those humic substances with the highest acidic functionality and smallest molecular size. Lee and Bartlett (1976) studied the effects of humic substances prepared by different extraction methods from different sources of organic material on their effects on growth of maize seedlings. Although the yields of corn did not differ significantly from various prepared humic substances, the organic matter content of the soil to which these substances were applied, had a significant effect. Maize grown on soils with low organic content had the greatest growth response to humic substances, while soils with high organic content gave little growth response.

The fact that no significant difference in yields, soluble solids, pH and concentration of mineral elements in fruit and petioles of the two tomato cultivars were found may be ascribed to the high concentration of organic material in the Hutton soil and high soil fertility status. Prät (1960), found that the lower molecular weight humic substances, such as fulvic acids, were generally more active components of humic matter. Lower molecular weight humic substances are more easily taken up by living cells. Higher molecular weight humic substances are irreversibly fixed onto the cell's exterior (Vaughan and Ord, 1981). Maggioni, Varanini, Pinton and de Biasi (1983), found that low molecular weight humic substances pass through cell walls in roots more readily,

thus enabling the stimulation of ion uptake. In preliminary trials, toxic levels of coal derived potassium humate was reached at 12 t.ha^{-1} . At this level growth was retarded and no fruit developed. Plants that received 16 t.ha^{-1} died after one week.

2.6 Conclusion.

The fact that no significant reaction to the various applications of K-HA could be found may indicate that the activity of the humic acids in the specific coal derived potassium humate was too low. The nutrient status of the soil could also have been too high for the plants to show any yield response to the various K-HA applications. The only reaction was above 12 t.ha^{-1} where these levels seemed to be toxic to both cultivars, possibly due to the associated high K level of $1\,080 \text{ kg.ha}^{-1} \text{ K}$. More positive results have been found in other trials (unpublished) where a liquid form of the same coal derived potassium humate was used.

2.7 Literature.

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3. RATE OF POTASSIUM RELEASE FROM POTASSIUM CHLORIDE FERTILIZER AND A COAL DERIVED POTASSIUM HUMATE UNDER DIFFERENT CONTROLLED CLIMATIC CONDITIONS.

3.1 Abstract.

The rate of K release from a Hutton (oxisol) soil was determined in three separate pot experiments. Three treatments which consisted of a control (untreated soil), soil + KCl and soil + potassium humate (K-HA) was used. In the first experiment the K release was determined through the process of diffusion in which the soil alone and soil + K-HA released K at a significantly higher rate than the soil + KCl. In the second experiment the K release was determined through the process of leaching in which the soil + KCl released K at a significantly higher rate than both the control and soil + K-HA. The release rate of the control and soil + KCl was significantly higher during the first five days than thereafter while the K release rate of the soil + K-HA was linear during the period of measurement. In the third experiment the K release of soil + KCl and soil + K-HA at temperatures of 7, 13, 19 and 25 °C was determined, using four different volumes of water for leaching. Temperature and the amount of water had significant effects on the K release rate of both soil + KCl and soil + K-HA. The release rate of soil + KCl was exponential and steadied after 5 days while the K release rate of soil + K-HA was linear. The K released by the soil + KCl was significantly higher than that of soil + K-HA.

3.2 Introduction.

Potassium is not considered to be a high environmental pollutant such as $\text{NO}_3\text{-N}$ and $\text{PO}_4\text{-P}$, but the leaching of K can affect plant growth. K is highly mobile and leaches easily to the sub soil. This may cause an accumulation of K-salts which may injure plant roots. To prevent salt build up and excessive nutrient leaching, controlled release fertilisers have been used with some success in container grown plants (Broschat, 1995). Bekker, Hue and Chase (1994) found that with liming, K losses increased. Since most farmers lime their soils at some stage, K leaching may be quite significant over time.

In a study done by Littlemore, Martin and Van Nordheim (1990), it was found that at least 160 kg ha^{-1} K was leached from soil on tobacco farms before first picking. On sandy soils, Gillman, Bristow and Hallman (1989), found that K and P leached vertically to a depth of 0.5 - 0.65 m after which it also moved 0.8 to 0.9 m horizontally in the soil. The horizontal movement of salts in the lower root zone may increase subsoil salinity problems.

Rubio and Gil-Sotres (1995), found that when K application rates were increased, K fixation also increased. They also found that K fixation decreased with temperatures increasing from 3 to 40°C . The clay mineralogy also affected K fixation to some extent. These factors should be kept in mind when applying K fertilizer to soils.

With KCl, K_2SO_4 and KNO_3 as sources of K, KCl was found to be the most suitable for crops not sensitive to the Cl^- ion. It has the highest K content, it is the least sensitive to temperature and is the cheapest. However, on soils with high leaching potential, it will leach the most since it has the highest dissolution capacity (Elam, Ben-Ari and Magen, 1995). To our knowledge, no studies have been done on the leaching of K from a coal derived potassium humate, this study was initiated to compare the K release of a commercial potassium chloride (KCl) with 49 % K and a coal derived

potassium humate (K-HA) with 9 % K.

3.3 Materials and methods.

The materials and methods of the three experiments were adapted from experiments done by Holcomb (1981) to determine potassium release from a slow-release fertilizer.

3.3.1 Determination of K-release from an untreated soil and KCl and K-HA treated soils through diffusion (Experiment 1).

Fifteen pots, each with a volume of 0.35 dm^3 , were filled with equal volumes of water saturated soil. A coal derived potassium humate (K-HA) containing 9 % K, KCl with 49 % K and a control were used in this study. One gram of K-HA and KCl was added to the pots. Capillary sponge mats (\varnothing 56 mm and 40 mm thick) were cut and placed at the bottom of slightly larger (0.5 dm^3) pots. The pots with the soil were placed on the sponge mats. The capillary mats were saturated with 100 ml distilled water to ensure capillarity with the medium from the smaller pots. The water saturated mats were removed every second day, the solution extracted from the mat and the capillary mats saturated with 100 ml distilled water before replacing them. A plastic bag was placed over the soil filled pots, held in place by an elastic band to prevent water loss through evaporation. Measurements were taken over a period of 42 days. Potassium content was determined with an atomic adsorption spectrophotometer.

3.3.2 Determination of K-release from an untreated soil and KCl and K-HA treated soils through leaching (Experiment 2).

Fifteen pots, each with a volume of 0.35 dm^3 , were filled with equal volumes of water saturated soil. A coal derived potassium humate (K-HA) containing 9 % K, KCl with 49 % K and a control were used. One gram of K-HA and KCl was added to the pots. Capillary sponge mats (\varnothing 56 mm and 40 mm thick) were cut and placed at the bottom of slightly larger (0.5 dm^3) pots. The pots with the soil were placed on the sponge mats. The capillary mats were saturated with 100 ml distilled water to ensure capillarity with the medium from the smaller pots. Every second day 100 ml water was poured into the pots with the soil in order to produce a leachate to saturate the capillary mat. The water saturated mats were removed every second day and the solution extracted from the mat before replacing it. The pots with soil were again placed onto the capillary mat. A plastic bag was placed over the soil filled pots which was held in place by an elastic band to prevent water loss through evaporation. Measurements were taken over a period of 42 days. Potassium content was determined with an atomic adsorption spectrophotometer.

Data for each treatment was analysed separately using linear regression analysis $f(x) = a + bx$, where Y equals the potassium released (mg.l^{-1}) every second day and x the days from 1 to 42.

3.3.3 Determination of leached K from a soil fertilized with KCl or K-HA at varying temperatures and water applications (Experiment 3).

A total of 128 pots, each with a volume of 0.35 dm^3 , were filled with equal volumes of water saturated soil. A coal derived potassium humate (K-HA) containing 9 % K and KCl with 49 % K were used. One gram of either K-HA and KCl was added to the pots and mixed thoroughly in the soil. Capillary sponge mats (\varnothing 56 mm and 40 mm

thick) were cut and placed at the bottom of slightly larger (0.5 dm^3) pots. The pots with soil were placed on the sponge mats. The capillary mats were saturated with 100 ml distilled water to ensure capillarity with the medium from the smaller pots. Four phytotron chambers were pre-set at 7, 13, 19 and 25°C . The 128 pots were divided equally into the chambers. Every 24 hours 25, 50, 75 or 100 ml water was poured into the K-HA or KCl soil filled pots. Leachate flowed into the larger pots and saturated the capillary mat. The water saturated mats were removed every second day and the solution extracted from the mat before replacing it. A plastic bag was placed over the soil filled pots which was held in place by an elastic band to prevent water loss through evaporation. Measurements were taken over a period of 19 days. Potassium content was determined with an atomic adsorption spectrophotometer.

Data for each treatment was analysed separately using linear regression analysis $f(x) = a + bx$, where Y equals the potassium released (mg.l^{-1}) each second day and x the days from 1 to 19.

3.4 Results.

3.4.1 Determination of K-release from untreated soil and KCl and K-HA treated soils through diffusion processes (Experiment 1).

No significant difference in the rate of potassium release from the soil alone, soil + KCl and soil + K-HA was found (Table 3-1, Figure 3-1, Figure 3-2 and Figure 3-3). However a significant difference in value of the Y intercept ($f(x) = 0$) was found between the various treatments (Table 3-1). For the first 10 days there was no significant difference in K release between the control and soil + KCl. There was no significant difference in K release per day between the control, soil + K-HA and soil + KCl.

Table 3-1 Summary of regression analysis values for K released through diffusion from untreated soil, soil + KCl and soil + K-HA.

Treatment	K release ($\text{mg.l}^{-1}.\text{day}^{-1}$)	<i>r</i>	<i>p</i>
Soil (Control)	0.103	0.9019	< 0.001
Soil + KCl	0.057	0.5842	< 0.001
Soil + K-HA	0.106	0.8696	< 0.001
LSD _(=0.001)	0.277		

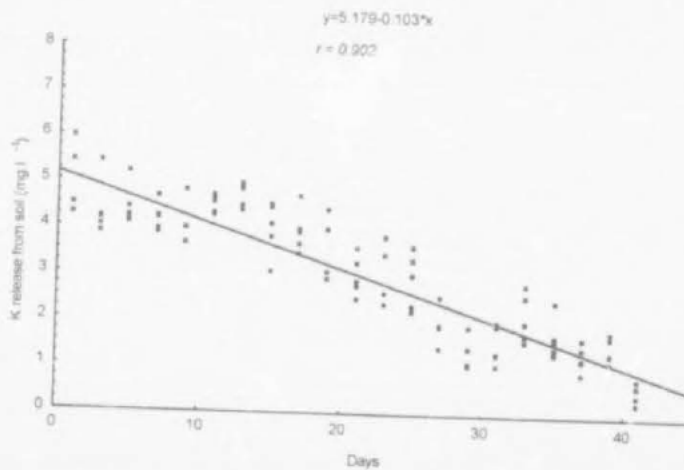


Figure 3-1 Rate of K release from a Hutton (oxisol) over a period of 41 days.

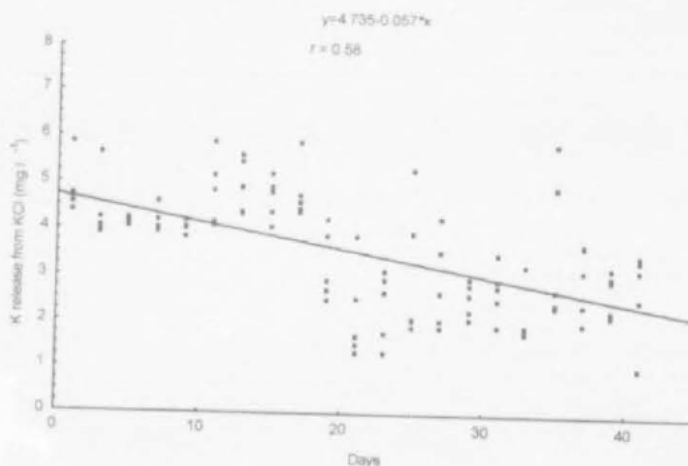


Figure 3-2 Rate of potassium release from a Hutton (oxisol) soil with KCl added over a period of 41 days.

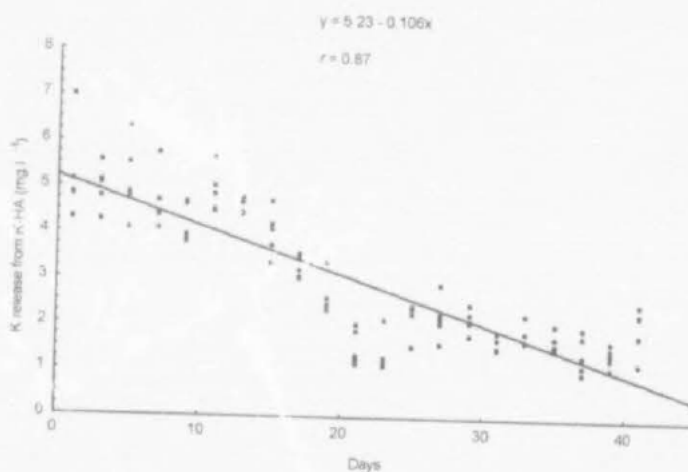


Figure 3-3 Rate of potassium release from a Hutton (oxisol) soil with K-HA added over a period of 41 days.

3.4.2 Determination of released K from an untreated soil and KCl and K-HA treated soils through leaching (Experiment 2).

Two trends were fitted for each of the three treatments to form a linear knot (broken stick) regression. The knot was applied on day 5 of the experiment (Figure 3-4, Figure 3-5 and Figure 3-6). The soil + KCl released significantly more K *per day* during the first five days than both soil alone and soil + K-HA. There was no significant difference in release of K *per day* between soil alone and soil + K-HA during the same period (Table 3-2). The soil + KCl combination had a significantly higher K release rate *per day* from day five until the last day, than both the soil alone and soil + K-HA (Table 3-4). There was a significant difference in the K release *per day* from day five until the last day between all three treatments (Figure 3-4, Figure 3-5 and Figure 3-6). The only correlation that was not significant was that between K released from the soil + K-HA during the first five days ($p = 0.646$, $r = 0.305$). However, the correlation between K release from the first day until the last day, thus without a knot, was found to be significant at $p < 0.001$ and $r = 0.705$. This meant that a knot regression was not applicable and a regression without the knot was done as found in Figure 3-6. The correlation of K release over a period of 19 days is now expressed as $f(x) = 21.344 - 0.654x$.

Table 3-2 Summary of regression analysis values for K released during the first 5 days of the experiment through leaching from an untreated soil, soil + KCl and soil + K-HA.

Treatment	Rate of K release (mg.l ⁻¹)	<i>r</i>	<i>p</i>
Soil (Control)	0.391	0.812	< 0.001
Soil + KCl	82.000	0.820	< 0.001
Soil + K-HA	1.640	0.305	0.1917
LSD _(=0.001)	58.767		

Table 3-3 Summary of regression analysis values for K released from day 5 to 19 of the experiment through leaching from soil, soil + KCl and soil + K-HA.

Treatment	Rate of K release (mg.l ⁻¹)	<i>r</i>	<i>p</i>
Soil (Control)	0.190	0.931	< 0.001
Soil + KCl	4.201	0.859	< 0.001
Soil + K-HA	0.529	0.657	< 0.001
LSD _(=0.001)	1.828		

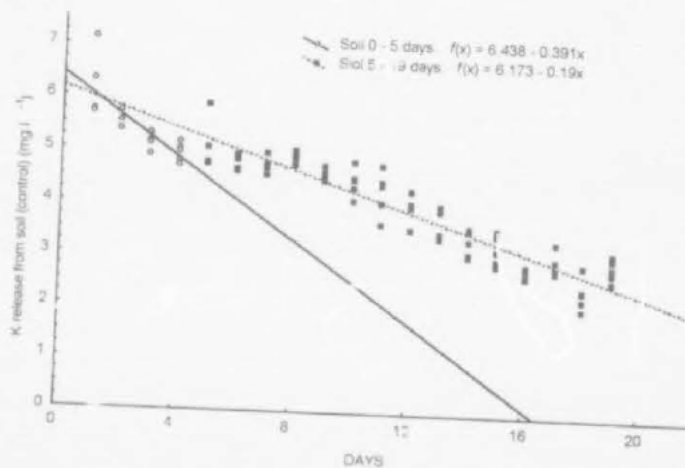


Figure 3-4 Linear knot regression of potassium release from a Hutton (oxisol) soil through leaching over a period of 19 days.

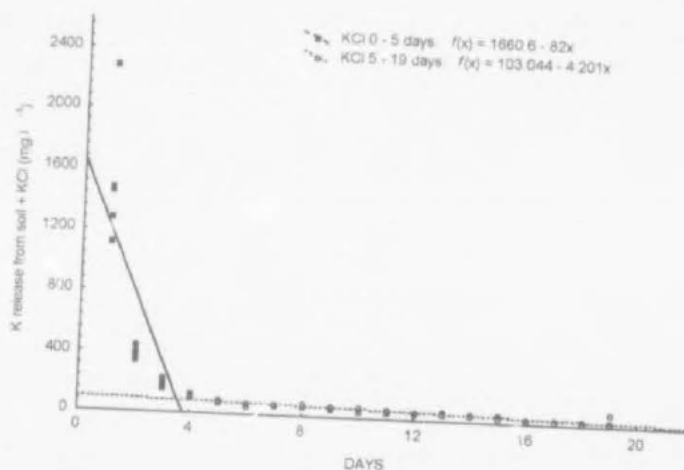


Figure 3-5 Linear knot regression of potassium release from a Hutton (oxisol) soil + KCl through leaching over a period of 19 days.

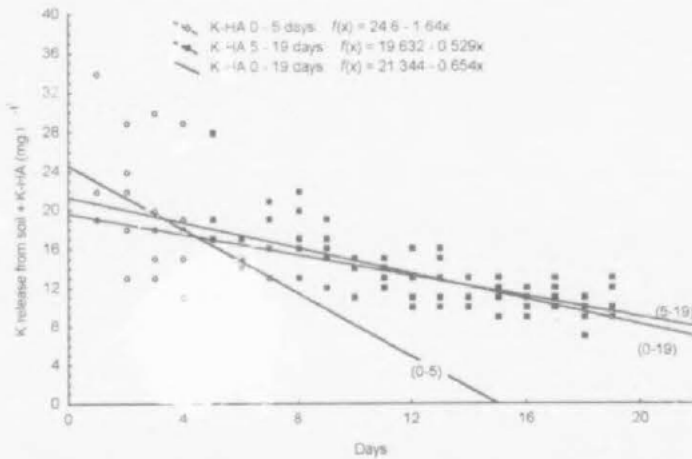


Figure 3-6 Linear knot regression of potassium release from a Hutton (oxisol) soil + K-HA through leaching over a period of 19 days.

3.4.3 Determination of released K from an untreated soil and KCl and K-HA treated soils at varying temperatures and water applications (Experiment 3).

The K release from a soil + KCl as affected by temperature and volume of water used to percolate through 0.35 dm^3 pots is shown in Figure 3-7. The K release from a soil + K-HA is shown in Figure 3-8. The K release rate of soil + KCl was exponential in the form, $f(x) = a \cdot e^{-k \cdot x}$ and the K release rate of the soil + K-HA was linear in the form $f(x) = a + bx$. Temperature had a significant effect on the K release rate *per day* with the soil + KCl ($p = 0.006$) as well as the soil + K-HA ($p = <0.001$) combination at all levels of water applied. In both soil + KCl and soil + K-HA and at all four the temperatures, were the K concentration with 25 ml the highest ($p < 0.001$) and the K concentration with 100 ml the lowest. The K release on the first day of the soil + KCl combination was the highest at 7°C and the lowest at 25°C with 25 ml, 50 ml, 75 ml

and 100 ml water (Figure 3-7). The K release on the first day of soil + K-HA combination receiving 25 ml decreased from 7 °C to 25 °C but not with 50 ml, 75 ml and 100 ml (Figure 3-8). At 7 °C and 13 °C the K release rate decreased and stabilized within four days with soil + KCl combinations receiving 50 ml, 75 ml and 100 ml water (Figure 3-7). The K release rate of the soil + KCl receiving 25 ml water decreased and stabilized on the seventh day at 7 °C and at 13 °C on the eighth day. At 19 °C the K release rate of the soil + KCl receiving 50ml, 75 ml and 100 ml decreased and steadied on the eighth day while the K release rate receiving 25 ml was still decreasing. At 25 °C the K release rate of all the water treatments was still decreasing on the ninth and last day of the trial.

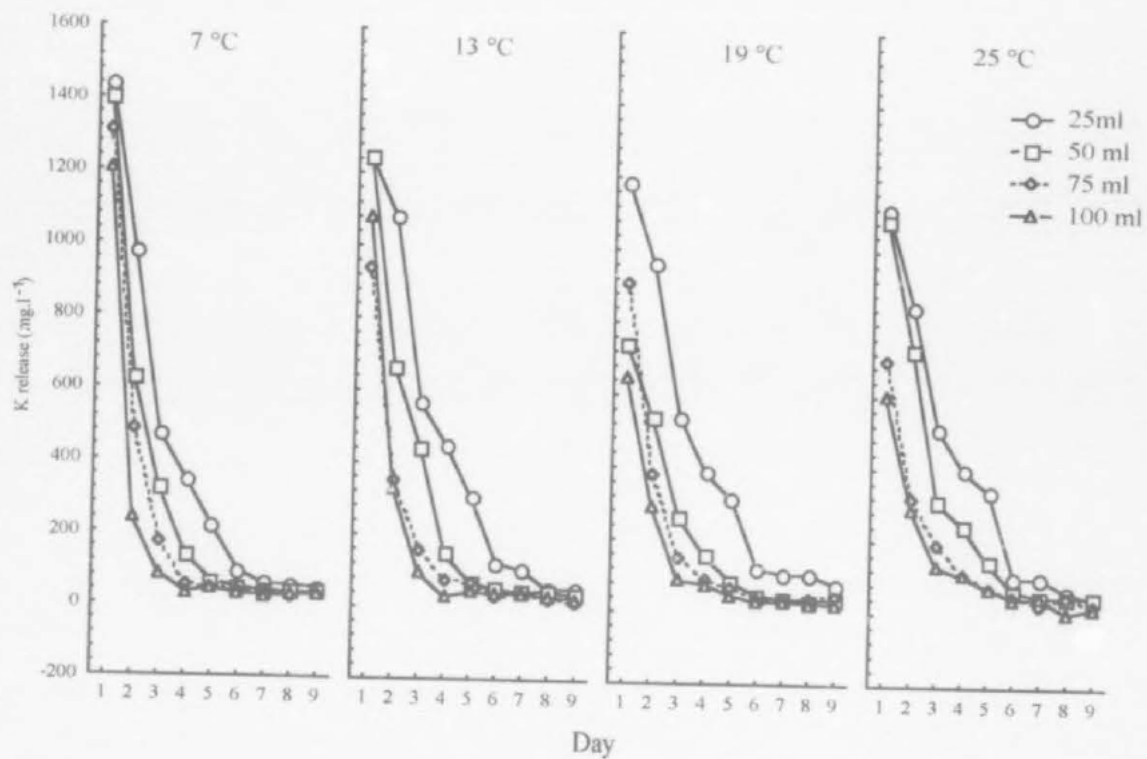


Figure 3-7 The influence of temperature and applied water on K release from a soil with KCl added at 7 °C, 13 °C, 19 °C and 25 °C and at a during a nine day period.

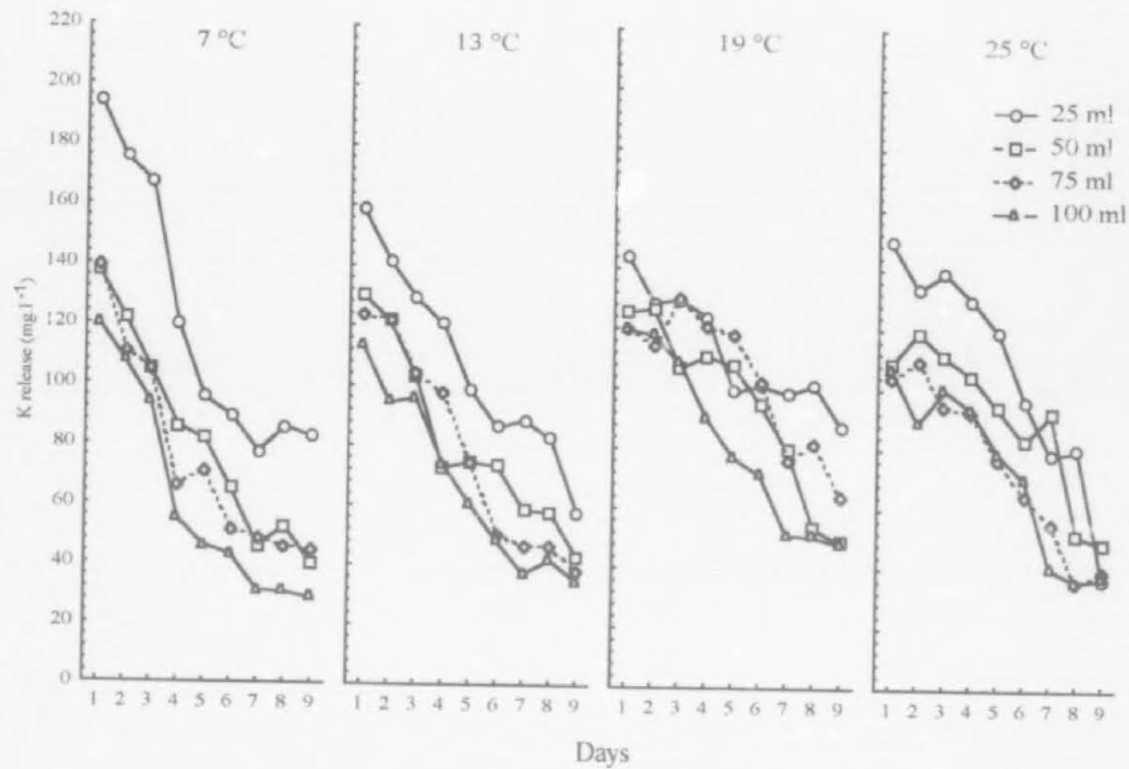


Figure 3-8 The influence of temperature and applied water on K release from a soil with K-HA added at 7 °C, 13 °C, 19 °C and 25 °C during a nine day period.

3.5 Discussion.

Soil moisture plays a vital role in the transport and availability of nutrients to plant roots. Depending on soil physical structure and aggregate size, capillary and non-capillary soil water forms pathways for nutrients to move from high concentrations to low concentrations by means of diffusion and mass movement. It was estimated that 90% of potassium reaching the plant roots, can be attributed to diffusion and is considerably influenced by soil moisture. The importance of soil moisture is explained when the mechanisms involved in replenishing the depleted K adjacent to the roots in the soil solution are investigated. The soil medium adjacent to the root cylinder contains only 6 % of the total K required by the plant in exchangeable form. Since root movement is insignificant in the short term in acquiring K, the rest of the K has to be acquired by means of diffusion or mass movement (Mengel and Braunschweig, 1972). In the first experiment, there was no significant difference in the K release rate between the soil (control), soil + KCl and soil + K-HA. The importance of this fact in commercial application of KCl fertilisers and K-HA, is that diffusion which is the main mechanism bringing nutrients into contact with plant roots, was not significantly affected by the type of fertilizer applied. However, the K buffering capacity of the soil was not taken into account and the time of depletion was not calculated. The second experiment is a closer representation of what happens to K under field conditions where soil moisture fluctuates due to rainfall and irrigation. The K release from the soil + KCl was significantly higher than from the soil alone and soil + K-HA combination. The K release rate of soil + KCl during the first five days was also significantly higher than during the period from day five until the last day, which is an indication of the high solubility of KCl fertilizer. The soil + K-HA had a steady K release from the first day until the last. This is an indication of low solubility of the K-HA fertilizer. A significant amount of K is lost during the first five days after applying KCl to the soil through leaching. It is estimated from the data that 19 times more K is released during the first five days than during the following five days. By using K-HA as a source of K

to replace soluble K sources, these losses may be avoided.

The effect of temperature on K release was more pronounced with the soil + KCl combination than with the soil + K-HA combination. Both treatments released more K at lower temperatures. The volume of water had a significant effect on the K concentration in the soil. The soil + KCl and soil + K-HA treatments both released significantly higher K concentrations at lower water volumes percolating through the soil. The release rate of K in the soil + KCl combination was exponential at all temperatures and water applications in comparison with the linear rate of K release with the soil + K-HA.

3.6 Conclusion.

No difference in K release between the untreated soil (control), : KCl and soil + K-HA was found in the experiment where K diffusion was measured. In a regularly irrigated soil, diffusion would not be the prime method of K movement. Under irrigated conditions leaching occurs. It was found that a significant amount of K was leached in the first five days when the soluble KCl fertilizer was used. The less soluble coal derived potassium humate released K at a steady linear rate. If the K content of the humate could be increased, K-HA may be used as a K fertilizer. Temperature and water application significantly affected K release over time. Lower temperatures and less water increased K concentration in solution over time. This may affect fertilizer recommendations in different climatic areas.

3.7 Literature.

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