EFFECT OF POTASSIUM HUMATE ON SOIL PROPERTIES AND GROWTH OF WHEAT

by

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ABSTRACT

Soil properties (biological and chemical) and crop response are dependent on the inherent soil organic matter content. Since South African soils are naturally low in organic matter content commercial humates serve as attractive soil amendments in improving soil quality. This is the result of commercialisation giving the impression that humates have biological and chemical properties similar to those in soil humus.

In an attempt to substantiate these claims three separate experiments were conducted at the University of the Free State to examine the effect of K-humate on soil properties and wheat response during the 2006 growing season. The biological (bacterial and fungal count) response was evaluated in growth chambers by applying three different K-humate products at rates of 0, 3 and 5 L ha^{-1} in a band on a red loamy sand topsoil. Soil cores were sampled on a weekly basis for six weeks and microscopically analysed. Bacterial and fungal count differed significantly as a result of the product by application rate interaction but no consistency was found. Over time both the bacterial and fungal activity increased rapidly for week 2 and 3 but decreased at week 3 for the bacteria. Both the organisms' reactions stabilised from week 3 to 6. The chemical soil properties were also tested in growth chambers but only K-humate (single product) was applied as a coating on granular 2:3:2 (22) fertiliser at 0 and 3 L ha^{-1} in a band 50 mm below the soil surface. The chemical soil properties showed no response after 5 months to the application of K-humate.

A glasshouse experiment was also conducted to evaluate the growth and yield response of wheat on three textural class topsoil's (8, 22 and 37% clay) and four K-humate applications (0 L ha^{-1}, 3 L ha^{-1} single application, and 3 and 6 L ha^{-1} split application – 50% at planting and 50% at tillering). K-humate as a coating on 2:3:2 (22) granular fertiliser was banded and Greensulph (27) topdressed at the required fertiliser rate for a yield potential of 8 t ha^{-1}. Plant growth parameters were analysed at tillering, stem elongation and maturity, both above- and below-ground. Virtually no significant influences were found with the K-humate application rate and soil texture interaction on the measured parameters. Notwithstanding this, positive effects were noticed and a split application whereof half of the K-humate was applied at planting and the other half at tillering showed the best results.

A field experiment was also conducted to examine K-humates influence on wheat growth and yield. Two experiments was conducted, one under full irrigation (700 mm) with a yield potential of 8 t ha^{-1} and the other supplementary irrigation (350 mm) with a yield potential of 4 t ha^{-1}. K-humate was applied as a coating on granular 2:3:2 (22) fertiliser and bandplaced either as a single application (0, 1.5, 3, 5 and 6 L ha^{-1}) or a split application (5 and 6 L ha^{-1}) 50% at planting and 50% (K-humate as a coating on Greensulph (27)) at tillering. Irrigation was applied using a line source irrigation system. The field experiment confirmed the results obtained in the glasshouse with virtually no significant effects as a result of the applied K-humate on the measured plant parameters.

UITTREKSEL

Grondeienskappe (biologies en chemise) en gewasreaksie is afhanklik van die inherente grond organiese materiaalinhoud. Aangesien Suid-Afrikaanse gronde oor ’n natuurlik lae organiese materiaal inhoud beskik word kommersiële humate as ’n aantreklike grondverbeteringsmiddel vir grondkwaliteit beskou. Dit het took tot gevolg dat kommersialisering die indruk skep dat humate oor biologiese en chemise eienskappe soortgelyk aan die van grondhumus beskik.

In ’n poging om hierdie aannames te staaf is drie verskillende eksperimente by die Universiteit van die Vrystaat uitgevoer om die invloed van K-humate op grondeienskappe en koring se reaksie daarop gedurende die 2006 groeiseisoen te ondersoek. Die biologiesie (bakteriese en swamtellings) reaksie is in groeikabinette geëvalueer deur die toediening van drie verskillende K-humaatprodukte by toedieningspeile van 0, 3 en 5 L ha^{-1} wat op ’n rooi leemsand bogrond gebandplaas is. Grondkerne is op ’n weeklikse basis vir 6 weke gemonster en mikroskopies ontleed. Bakteriese en swamtellings het betekenis verskille getoon as resultaat van die produk by toedieningspeilinteraksie, maar geen konsekwentheid in die resultaat is gevind nie. ’n Versnelde reaksie van beide die bakteriese en swamaktiwiteit is vir weke 2 en 3 waargeneem, maar het reeds by week 3 vir bakterië afgeneem. Beide organismes se reaksies het van week 3 to 6 gestabiliseer. Die chemiese grondeienskappe is ook in die groeikabinette geevalueer, maar slegs K-humaat

(enkelproduk) is as ’n deklaag op die 2:3:2 (22) korrelkunsmis teen 0 en 3 L ha^{-1} in ’n band 50 mm onder die grondoppervlak toegedien. Die chemiese grondeienskappe het geen reaksie na 5 maande op die K-humaattoediening getoon nie.

’n Glashuispotproef is ook uitgevoer om die groei en opbrengsreaksie van koring op drie bogrond tekstuurklasgronde (8, 22 en 37% klei) en vier K-humaattoedienings (0 en 3 L ha^{-1} enkeltoedienings en 3 en 6 L ha^{-1} verdeelde toedieings – 50% met plant en 50% met stoel) te evalueer. K-humaat is as ’n deklaag op gekorrelde 2:3:2 (22) kunsmis in ’n band en Greensu;ph (27) as topbemesting vir ’n opbrengspotensiaal van 8 t ha^{-1} toegedien. Plant parameters vir beide bo- en ondergrondse plantdele is op stoel-, pyp- en fisiologies rypstadia ontleed. Daar is feitlik geen betekenisvolle verskille vir die toegediende K-humaat en verskillende tekstuurklasgronde interaksie gevind nie. Nieteenstaande die waarneming is daar wel ‘n positiewe invloed waargeneem met die verdeelde toedienings waarvan die helfte van die K-humaat met plant en die ander helfte met stoel toegedien is wat die beste gevaar het.

’n Veldproef is ook uitgevoer om die invloed van K-humaat op koring se groei en opbrengs te evalueer. Twee proewe is uitgevoer waarvan een ten volle (700 mm) besproei is met ’n opbrengspotensiaal van 8 t ha^{-1} en die ander aanvullend (350 mm) besproei is met ’n opbrengspotensiaal van 4 t ha^{-1}. K-humaat is toegedien as ’n deklaag op 2:3:2 (22) wat gebandplaas is as ’n enkeltoediening (0, 1.5, 3, 5, en 6 L ha^{-1}) of ’n verdeelde toediening (5 en 6 L ha^{-1}) 50% met plant en 50% (K-humaat as ‘n deklaag op op Greensulp (27)) tydens die stoelstadium. Besproeiing is toegedien met ’n lynbronbesproeiingstelsel. Die veldproef het die glashuisproef se resultate bevestig waar daar weereens feitlik geen betekenisvolle invloed deur die toediening van K-humaat op die gemeete plantparameters gevind is nie.

Chapter 1

Motivation and objectives

1.1 Motivation

For centuries it has been documented that soils rich in organic matter are more productive than soils poor in organic matter. This is because organic matter is a major source of nutrients and microbial energy, holds water and nutrients in available form, promotes soil aggregation and root development, and improves water infiltration and water-use efficiency (Obreza *et al.,* 1989; Cooper *et al.,* 1998; Unsal & Ok, 2001; Mayhew, 2004).

In the broadest context, organic matter may be referred to as the total complement of organic substances present in a soil, including living organisms of various sizes, organic residues in various stages of decomposition and dark-coloured humus consisting of non-humic (10-15%) and humic (85-90%) substances. The non-humic substances are known organic compounds such as carbohydrates, proteins, hemicelluloses, celluloses, fats, waxes and lignin that are either decomposition products of organic residues or synthesized products of micro-organisms. On the other hand are humic substances, a large group of amorphic colloidal organic polymers that formed in the soil (Brady & Weil, 1996; Stevenson & Cole, 1999; Baldock & Nelson, 2000).

The most active fraction of humus is the humic substances. Hayes *et al*. (1989) described them as a group of natural occurring, biogenic, heterogeneous organic substances that can generally be characterized as being yellow to black in colour with a high molecular weight and refractory. This group of organic substances can be fractionated in terms of their solubility in acid and alkali reagents into (i) yellowish fulvic acid that is soluble in acid and alkali; (ii) blackish humic acid that is insoluble in acid but soluble in alkali, and (iii) humin that is insoluble in acid and alkali (Stevenson & Cole, 1999). It is generally accepted today that humin is actually humic acid that is linked to clay and that the fulvic and humic acids are a continuous series of compounds. Their molecular mass and carbon content increase from fulvic to humic acid. All soils contain both acids though their

distribution pattern varies from soil to soil and with depth in a soil. Fulvic acids dominate in forest soils whereas humic acids dominate in grassland soils (Baldock & Nelson, 2000). Humic acids are among the most widely distributed organic materials in the earth. They are found not only in soils but also in sewage, manure, compost, peat, carbonaceous shales, brown coal and miscellaneous other deposits. This provides opportunities for the manufacturing of commercial humic substances whereof many are available today worldwide. Mostly, although not solely, these products are derived from lignite. Another common source is peat (Stevenson & Cole, 1999; Chen *et al*., 2004).

Actually, it is oxidized lignites that are used in the production of humic substances also known as humates. Oxidized lignite is a brown coal substance with a low caloric content and therefore normally discarded during mining. However, oxidized lignites are used as soil and plant amendments primarily on account of their unusually high content of humic acids, namely 30 to 60%. The humates are marketed either as fortified with commercial fertilizer or as a soluble product containing available N, P and K (Stevenson & Cole, 1999).

Promoters of commercial humates often give the impression that they have biological and chemical properties similar to those of humus in soil. In reality, the composition and properties are substantially different as these products are essentially free of such biological important compounds as proteins and polysaccharides. Furthermore, they contain few if any fulvic acids. In comparison with soil humic acids, lignite humic acids have a higher C content, which indicates they will be less soluble (Stevenson & Cole, 1999). Therefore, it is not surprising that some of the benefits attributed to commercial humates are questioned. This situation is not alleviated by the fact that only a small fraction of trials with these products have been conducted in a manner that meets the standards required to report data in scientific articles, whereas an even smaller fraction has found its way to reviewed journals (Chen *et al.*, 2004).

1.2 Objectives

Some commercial humates are marketed also nowadays in South Africa and they are relatively expensive. Hence, their use can be justified only if it is beneficial for either soil or crop that ultimately results in higher yields. This investigation was therefore conducted

to establish the effects of locally available potassium humates on firstly, some biologically and chemically properties of arable soils and secondly, the growth and development of irrigated wheat.

These two objectives were accomplished through a:

- Literature survey on soil organic matter, origin and structure of humic substances and their effects on soils and plants (Chapter 2).
- Growth chamber experiment to evaluate the response of biologically and chemically soil properties to K-humate application (Chapter 3).
- Glasshouse experiment to measure growth and yield response of irrigated wheat to K-humate application (Chapter 4).
- Field experiment to record the growth and yield response of irrigated wheat to K-humate application (Chapter 5).

Chapter 2

Literature review

2.1 Introduction

Organic matter is arguably the most complex and least understood component of soils, especially humus which is the largest fraction. This fraction remains after the major portion of added plant and animal residues have decomposed and is therefore more or less stable. Humic composes of non-humic and humic substances with the latter substances regarded as the most active. Humic substances consists of a conglomeration of relatively recalcitrant organic molecules. The chemical structure of these organic molecules is highly variable and not yet well understood despite active investigation. Classically, fulvic acid, humic acid and humin are distinguished as soil humic substances.

Humus, especially through its humic substances influences many properties of soils disproportioned by the quantities present. These influences generally improve soil porosity which ultimately favors cropping. On account of this are commercial humates produced from organic materials like peat and brown coal. These humates contain large amounts of humic acids and it is claimed therefore that humates are beneficial amendments to soils and crops.

The aim with the literature review was to focus on the characteristics and behavior of only humic acids as they are the common feature to soil humus and commercial humates. It was difficult to accomplish since researchers used in many instances humic substances and humic acids interchangeable. As a result of this phenomenon in scientific literature the two terms are applied sometimes in a similar manner here.

2.2 Soil organic matter

Organic matter is one of the most important components when evaluating the general fertility of a soil (Pera *et al*., 1983; Ding *et al*., 2002). Hence, loss of soil organic matter is usually regarded as an important factor contributing to soil degradation (Dominy & Hayes, 2002). Tillage is a major cause of organic matter decline and this is because aggregates are disrupted which exposed the organic matter to microbial attack. Other factors that can lead

to organic matter loss are intensive grazing and frequent burning and this can all be attributed to vegetation loss (Mills & Fey, 2003). In agricultural soils, organic matter consists mainly of plant biopolymer residues, materials derived from them via the decomposition processes, microbial tissues and humic substances (Chefetz *et al*., 2000).

According to Pera *et al*. (1983) no mineral fertilizer is able to substitute organic matter loss from soil. Several researchers (eg. Carter, 2000; Dominy & Hayes, 2002) said that loss of organic matter can have great effects on soil physical, chemical and biological properties. Doyle *et al*. (2004) found that most agricultural practices have not been implemented with the primary focus to manage soil organic matter optimum. Practices such as crop rotation, conservation tillage, and manuring have instead focused on conserving soil loss and increasing crop yields, whereas the maintenance of organic matter content was of secondary importance. In South Africa the loss of soil organic matter are still not generally considered as an important factor (Dominy & Hayes, 2002).

South African soils are extremely vulnerable to various forms of degradation and have a low recovery potential once it had been degraded (Laker, 2005). When a soil has a low organic matter content it usually has a weak structure, one reason for a low water holding capacity. According to Diaz-Zorita *et al*. (1999) the organic matter content is a reliable index of crop productivity in semi-arid regions as it positively affects soil water holding capacity. They found that wheat yield increased as organic matter increased and the reason for this was attributed to the better water holding capacity of the soil under water deficit conditions and also better nutrient availability to plants exposed to reduced or no water deficit.

Chefetz *et al*. (2000) found that the level of organic matter increased with aggregate size and this suggested that the presence of partially decomposed roots and hyphae within macroaggregates increased the C concentration and contributed to aggregate stability. In 2:1 clay dominated soils, organic matter is a major binding agent because polyvalent metal-organic matter complexes form bridges between the negatively charged 2:1 clay platelets. In contrast to this, in oxide and 1:1 clay mineral dominated soils, organic matter is not the only binding agent. Part of the soil stability in oxide and 1:1 clay dominated soils is induced by the binding capacity of oxides and 1:1 minerals. The mineralogical

characteristics of a soil can influence the potential soil stability and the relationship between soil organic matter content and soil stability (Six *et al*., 2000). Soils dominated by clay minerals with a high specific surface area have a high capacity for adsorbing humic substances and hence for stabilizing aggregates (Caravaca *et al*., 1999). There is a close relationship between the proportion of stable macroaggregates and soil clay content as well as between aggregation and organic matter associated with the clay fraction.

Soil organic matter promotes the capture of nutrients, generally N, P and S into its structure. This soil component is maid up mostly of C (55%), N (5-6%), P (1%) and S (1%). During the decomposition of soil organic matter, nutrients are released and mostly taken up by plants. A high C content of soil organic matter fractions can often lead to microbial immobilization of nutrients through the production of biomass that require additional N for growth (Horwath, 2005).

When soils are cultivated for the first time it usually leads to a decrease in the organic matter content and hence nitrogen levels. The balance between gain and loss of organic matter is of vital importance for the availability of nitrogen to plants (Schmidt & Schmidt, 1963; Mills & Fey, 2003). Ding *et al*. (2002) also reported that a decline in soil organic matter significantly reduced the N supply and resulted in a deterioration of soil physical conditions that lead to yield reduction. The decline in soil organic matter can be attributed to biological oxidation or erosion. Thus, the maintenance of proper soil organic matter levels to sustain soil productivity is important and with humic acids probably being the largest single soil organic matter pool this could be achieved.

2.3 Origin and structure of humic substances

The term “humus” originated from the Romans when it was familiarly used to signify the entire soil. Later the term was used to denominate soil organic matter and compost or for different parts of this organic matter, as well as for complexes created by chemical agent treatments to a wide palette of organic substances. The principal definition of humus, as decomposed organic matter, originated from 1761 (Peňa-Méndez *et al*., 2005).

Humic substances are a major component of aquatic organic colloids and ubiquitous in natural groundwater (Chen *et al*., 2007). Thus they constitute a large portion of the total

organic carbon pool in terrestrial and aquatic environments (Christl *et al*., 2000; Fan *et al*., 2003). More specifically, humic acids are widely spread in nature and occur mainly in heavy degraded peat but also in all natural environments in which organic materials and microorganisms can be found (Jooné & Janse van Rensburg, 2004; Peňa-Méndez *et al*., 2005). Not only can humic acids be found in soil, natural water, rivers, sea sediments, plants, peat and other chemically and biologically transformed materials but also in lignite, oxidized bituminous coal, leonardite and gyttja (Karaca *et al*., 2006). According to Kulikova *et al*. (2005) humic acids comprises 50 – 90% of the organic matter from these products.

Humic acids derived from coal are defined as dark coloured substances, that are soluble in aqueous alkali but insoluble in acid. These substances also occur naturally in some lignites and brown coals, but little or no alkali-soluble material is present in bituminous coals. Humic acids isolated from coal samples differ from one another according to the grade of coalification and conditions under which they were formed (Mackowiak *et al*., 2001; Li *et al*., 2003; Karaca *et al*., 2006; Imbufe *et al*., 2004; Skhonde *et al*., 2006).

The structure of humic substances is not completely understood (Avena *et al*., 1998) and over the last decades nuclear magnetic resonance spectroscopy has provided key insight into structural details of humic substances (Hertkorn *et al*., 2002). However, humic acids are made up of complicated mixtures which are linked together in no specific order. The result of this is extraordinary complex materials and no two molecules are exactly the same (Mikkelsen, 2005). Thus, humic acids have a highly heterogeneous structure, functionalities and varied elemental composition (Li *et al*., 2003; Mikkelsen, 2005).

The characterization of the size, shape, conformation, structure and composition of humic substances is crucial to understand the physiochemical reactions and to evaluate their role in the natural environment. The macromolecular structure of different humic substances is quite different and sometimes inconsistent under similar conditions (Chen *et al*., 2007). According to Myneni *et al*. (1999) humic substances had a great deal of structural variety that included sheets and globular configurations, thread and net like shaped and small uniform aggregates. The observed changes in microstructure can modify the exposed

surface area and alter the functional group chemistry of the humic substances affecting protonation and cation complexation.

Humic acids may be aggregates of smaller heterogeneous organic molecules including sugars, organic acids and other aliphatic and aromatic components likely to be having a molecular weight of several hundred Daltons (Da). Simpson *et al*. (2002) suggested that it can exceed one million Da and recently it was suggested that the high molecular weights observed could be explained by the association of small components to form aggregates in aqueous solutions with macromolecular-like properties. These small molecules may be held loosely by H bonding and hydrophobic forces instead of covalently bonded cross linkages (Li *et al*., 2003). According to Peňa-Méndez *et al*. (2005) and Alvarez-Puebla *et al*. (2005) humic substance of which humic acids (insoluble at acidic pH) and fulvic acids (water soluble at acidic to alkaline pH) are the major fractions, also consists of a conglomerate chemically reactive functional groups, including carboxyls, phenolic, and alcoholic hydroxyls with pH dependent properties. The solubility of these fractions are closely related to molecular mass, structural branching complexity, molecular polarity and chemical composition (Alvarez-Puebla *et al*., 2005).

Humic acid molecules are created through hydrocarbon bonds forming chains that roll into a ball in their natural state. These balls form larger aggregates that constitute the organic part of soil that is the humus (Levinsky, 1996). To ensure soil fertility the humus content should be rather high. When humic acids are treated with alkaline agents it transform into water-soluble salts, sodium and potassium humate. When the humic acid get charged the charges are located throughout the molecular chain. The charge takes place and the ball unrolls. This allows the humic acid molecules to pass into solution and become biologically active and each functional group has its own function. There are many of these groups and each one of them influence the humates on all stages of plant’s growth and development (Levinsky, 1996).

Humic substances have marked influence on the species of cations and thereby can affect the biological availability, physiochemical properties and environmental sorption or desorption of macro- and micronutrients, toxic metals and xenobiotic organic cations. This is because of their colloidal character and large number of surface functional groups.

Because of this they play an important role in determining the mobilization and immobilization behavior of metals in the environment. They also show a strong retention of atmospheric gases such as O_2, N_2 and CO_2 making them available to microorganisms and plants and also for biomineralization. When humic substances are adsorbed to mineral surfaces the humic substances may bind to metal ions (Alvarez-Puebla *et al*., 2005; Chen *et al*., 2007). Hence, the amphipathic nature of humic acids enable them to interact with a wide variety of inorganic and organic pollutants including heavy metals and charged organic pollutants via chemical bonding and less polar organics through nonspecific physical interactions (Li *et al*., 2003; Chen *et al*., 2007). Sorption of metal ions to humic substances generally depends on pH values and other foreign cations (Chen *et al*., 2007). The physico-chemical properties of humic acids and their physiological activity are mostly determined by the qualitative and quantitative composition of oxygen-containing functional groups that varies during coalification, pyrolysis and oxidation (Butuzova *et al*., 1998).

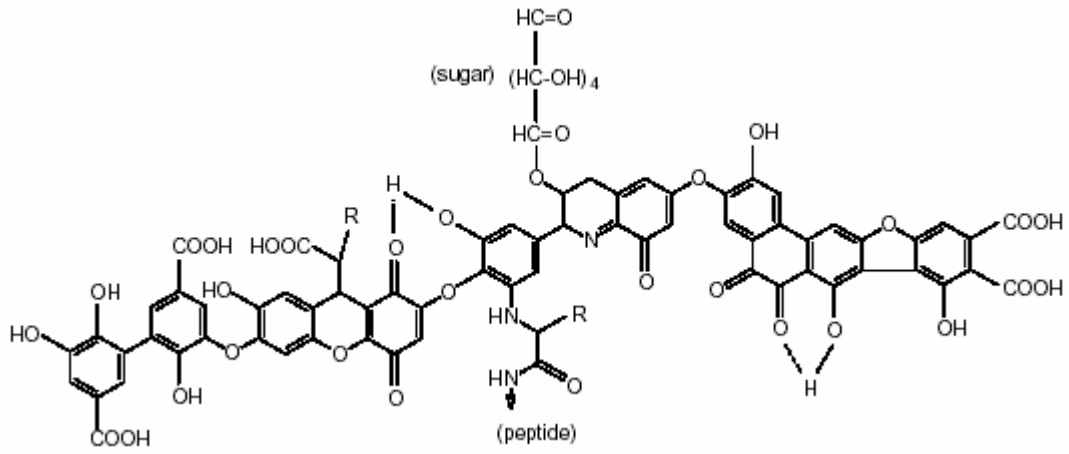


Figure 2.1 Model structure of humic acid. R can be alkyl, aryl or aralkyl (Peňa-Méndez *et al*., 2005).

Avena *et al*. (1998) proposed a structure for humic acids from a comprehensive investigation that combined different experimental techniques with molecular mechanics and dynamic calculations. The optimized structure turned out to be a crosslink network with voids and various dimensions that can trap and bind other organic components such as carbohydrates or proteinaceous materials as well as inorganic components and water. When humic acids are naturally oxidized it gives a negative charge to which positive ions

can attach. This creates sites for micronutrients and microflora to attach. According to Christl *et al*. (2000) and Mikkelson (2005) humic substances are macromolecular, negatively charged, branched polyelectrolytes with mainly carboxylic and phenolic type acidic functional groups. An alternative model of humic acids have also been proposed stating that they are self-associated of small, uniform humic acid molecules held together by weak hydrophobic forces. Notwithstanding this, humic acids exhibits both hydrophobic and hydrophilic properties (Mikkelson, 2005). Evidence for these views stems from size exclusion chromatography in which the addition of low molecular weight organic acids leads to a drastic decrease in the apparent molecular size (Christl *et al*., 2000).

2.4 Humic acids and soil properties

Organic matter and particularly humic acid may contribute to stop, reduce or better the already poor or degraded soil conditions of the semiarid crop production areas of South Africa. According to various researchers (Obreza *et al*., 1989; Cooper *et al*., 1998; Barzegar *et al*., 2002; Mikkelsen, 2005) humic acids improved soil structure, cation exchange capacity, nutrient retention and soil microbial activity. The impact of humic acids will therefore be comprehensively discussed under physical, chemical and biological soil properties.

2.4.1 Physical soil properties

The physical quality of a soil refers to the soil's strength, fluid transmission and storage characteristics in the crop root zone (Reynolds *et al*., 2002). In many agricultural soils the top two horizons are characterized by massive structure, sandy texture and low organic matter content. These horizons can have soil strength high enough to reduce or even prevent root growth at a soil water content of field capacity. Soil strength can be reduced with tillage, an expensive but an alternative operation that would amend the soil and have a longer advantageous effect (Busscher *et al*., 2006). Agricultural soil with a good physical quality is one that is strong enough to maintain good structure, hold crops upright and resist compaction and erosion. The soil must also be weak enough to allow root growth and proliferation of soil fauna and flora (Reynolds *et al*., 2002).

Loss of topsoil reduces the potential yield by degrading the soil structure and by reducing soil fertility. Research has shown that the application of organic matter to eroded soil

improved soil quality and crop yield (Cox *et al*., 1999; Celik *et al*., 2002). In most sandy soils organic matter content and water holding capacity are the two major constraints making dry land farming difficult.

Aggregate stability is in most agricultural soils climate dependent. Exposure to wetting and drying of soils can reduce the stability of aggregates. In naturally well aggregated agricultural soils, cyclic wetting and drying of soils may induce structural collapse and thereby producing erodible microaggregates. Reduced aggregate stability can be enormous and include reduced water infiltration, increased slaking and crusting, accelerated runoff erosion and poor crop productivity. It has been found that the application of a mixture of humic and fulvic acids to soil increased soil aggregation (Barzegar *et al*., 2002). Improved soil aggregation can positively affect seed germination and the growth and development of plant roots and shoots (Celik *et al*., 2002). Soil organic matter compounds bind the primary particles in the aggregates, physically and chemically, and thus in turn increase the stability of the aggregates and limit their breakdown during the wetting process. These organic matter compounds can be divided into three groups (i) polysaccharides (ii) roots and fungal hyphae and (iii) resistant aromatic compounds associated with polyvalent metal cations and strongly sorbed polymers (Lado *et al*., 2004). Soil structure can also influence losses of agrochemicals as well as sequestration of C and N gas losses. Hence, soil structure has to be maintained to reduce the environmental impact of agricultural practices (Six *et al*., 2000).

Application of organic materials to soil is known to significantly affect the surface soil chemical (nutrient recycling) and especially physical characteristics. These include aggregate stability, lower bulk density, less soil compaction, higher soil porosity and this increased water infiltration rate (Barzegar *et al*., 2002; Zeleke *et al*., 2004). Large amounts of organic residues are normally worked into the plough layer in an attempt to increase the organic matter and thus assist in improving aggregate stability. Attention has therefore been focused on identifying soil conditioners that can be effective at low rates and humic substances have been evaluated as potential soil conditioners. The advantage of humic substances is the refractory nature of their chemical structures that make them more resistant to microbial attacks. Reports have shown that humic substances that have been extracted from farmyard manure improved and prolonged aggregate stability more than

the bulk farmyard manure. This was also shown even when higher rates of manure were applied than the humic substances that was used (Piccolo *et al*., 1997).

In 2:1 clay dominated soils, soil organic matter is the major binding agent because of polyvalent metal organic matter complexes form bridges between the negatively charged 2:1 clay platelets. Soil organic matter is not the only major binding agent in oxide and 1:1 clay mineral dominated soils. Part of the soil stability in oxide and 1:1 clay dominated soils is induced by the binding capacity of oxides and 1:1 clay minerals as previously mentioned. Consequently the mineralogical characteristics of a soil can influence the potential soil stability and the relationship between soil organic matter content and soil stability (Six *et al*., 2000).

Regardless of the waste type, both long term and short term studies have indicated a significant linear relationship between reduction in bulk density and an increase in soil organic C. This can be attributed to the organic waste application or application of humic acid extracts (Bresson *et al*., 2001).

2.4.2 Chemical soil properties

There is a close relationship between soil organic matter content and soil fertility. Therefore, one of the most important ways of soil regeneration is the addition of organic materials to conserve organic matter and maintain or enhance soil fertility (Tan & Nopamornbodi, 1979; Filip & Bielek, 2002). Organic amendments increase the organic carbon and nitrogen contents (Melero *et al*., 2007).

Mikkelsen (2005) stated that humic materials are able to complex various cations and serve as a sink for polyvalent cations in the soil. They have a negative surface charge at all pH values where crop growth occurs. Organic substances have been demonstrated to enhance the solubility of soil phosphorus through the complexation of Fe and Al in acid soils and Ca in calcareous soils. One of the most striking characteristics of humic acids in soils and other environments is their ability to interact with metal ions and soil minerals to form complexes of varying properties and increasing chemical stability (Filip & Bielek, 2002). Uptake of macronutrients and Fe by plants grown in nutrient solutions was reported to increase in the presence of humic compounds (Ayuso *et al*., 1996). Studies on tomato

seedlings grown in water cultures showed that plants were able to utilize Fe more efficiently as a result of a larger chlorophyll content in the presence of humic substances (Tan & Nopamornbodi, 1979).

The buffer capacity of a solution is as or more important than the pH value of that solution. Buffer capacity is an indication of the amount of acid or base that can be added before the buffer loses its ability to resists pH change which is dependent on the amount of conjugated acid or base available in the system (Pertusatti & Prado, 2007). Soils with a strong buffer capacity and high carbonate content will only show a little effect on the pH over an extended period (Melero *et al*., 2007). One of the most important properties of humic acids is its large buffer capacity in a wide pH range, which arises essentially from the dissociation of acidic functional groups of which they are particularly rich (Campitelli *et al*., 2008).

Pertusatti & Prado (2007) found that humic acid did not have a strong buffer capacity to a strong acid, but showed an excellent buffer capacity to base additions. They also found that humic acid resisted pH change in the range between pH 5.5 and 8. Humic acids contain chemical reactive functional groups such as carboxyls as well as phenolic and alcoholic hydroxyls that have pH dependent charge properties. Humic acids have also acid groups and proton-binding abilities that have a direct effect on the acid-base buffering capacity of soils. It is strongly supported by literature that soils rich in humic substances are well buffered (Pertusatti & Prado, 2007).

Another benefit of humic acids in a agricultural system is its ability to complex metal ions. Humic acids can form aqueous solutions with micronutrients, though not to the same extend as many synthetic chelating agents (Pinheiro *et al*., 2007). Since humic acids bind to soil colloidal surfaces, it will not easily leach out of the soil (Mackowiak *et al*., 2001). Humic acid also promotes heavy metal sorption to soil minerals like Cu and Zn. Synthetic chelate availability can decrease by as much as 50% through soil sorption processes and this can make field application costly. The humic acids on the other hand can be inexpensively incorporated into soils through biowastes such as manure and the resulting organic matter has the added benefit of improving soil physical properties (Mackowiak *et*

al., 2001). The question also remains: are humic extracts also more effective for chemical reactions than bulk applied farmyard manure as is the case for soil physical properties?

2.4.3 Biological soil properties

Soil organic matter is an indicator of soil quality and agronomic sustainability because of its impact on other physical, chemical and biological properties and its evolution into humic substances is arguably the best single indicator of soil quality. Humic substances can influence microorganisms indirectly by their cation exchange capacity which is five times higher than in soil minerals. Humic acids can supply essential cations such as chelated Fe or can chelate toxic concentrations of Cu and this facilitates microbial growth. Humic substances may also indirectly affect the microbial metabolism when their molecular size is adequate for uptake (Charest *et al*., 2004)

In a soil nutrient cycle, one of the most critical aspects is litter decomposition for which microbes are directly responsible. These soil animals are microarthropods, isopods and earthworms that can stimulate decomposition via litter fragmentation and defecating into the soil, and through altering the activity and composition of the microbial activity (Ayres *et al*., 2005). Humic substances were found to stimulate plant growth since they increase the absorption of soil nutrients. When humic acids are applied to a selected media it could increase the growth of a wide range of taxonomic and functional groups of soil bacteria and it has been hypothesized that a modification of cellular activity and growth might be promoted by humic substances through their influence on cell membrane permeability or on nutrient absorption (Vallini *et al*., 1993).

Organic amendments not only act by improving soil structure and as a source of nutrients but they also have an effect on the soil microflora. The addition of good quality compost may increase the microbial biomass and enhance soil enzyme activity (Charest *et al*., 2004; Pérez-Piqueres *et al*., 2005). Green manure has the advantage to soil microbial activity because it provides nutrients rich in organic carbon for the microbial biomass which converts unavailable nutrients in plant residues to ones available for crops. Another reason is the enhanceed biodiversity in soil microorganisms (Manici *et al*., 2003).

Filip & Bielek (2002) found that there was an increase in the number of bacteria and also larger yields of microbial biomass in cultures that had humic acids added to the full strength nutrient broth. They also reported that several authors have found that the growth of soil micro-organisms to be strongly enhanced in cultures containing humic acids. The response of soil micro-organisms to humates from green compost is equal. Both heterotrophic and chemolytotrophic bacteria reacted positively when humic acid was applied to soil. The heterotrophic bacteria probably benefit from uptake of compounds readily available in the humic matrix. This can be reducing sugars, organic acids, amino acids, peptides, and amino sugars. This assistance appears less likely for microbes such as autotrophic nitrifiers. The direct influence of surfactant activity on absorption of mineral nutrients remains the prime explanation for enhanced microbial growth by humic acids (Valdrighi *et al*., 1996).

2.5 Humic acids and plant reactions

It has long been known that organic matter have a high value to crops when added to soil. Some benefits are improved tilth, increased water retention and enlarged nutrient reservoir. For organic matter to have an effect on soil properties time is required and a large amount of organic matter need to be applied to the soil. Humic acids can be very feasible in changing a localized zone in the soil. This localized zone can either be the seedbed or a fertilizer band (Mikkelsen, 2005).

2.5.1 Root growth

Roots provide an important means by which plants can increase their absorptive area and their capacity to exploit soil resources. The effective nutrient and water uptake of a root system depends on root length, root number, root tips and branching of the root system (Draye, 2002). The root length density distributions are often utilized to analyze soil-root-shoot-atmosphere interactions (Zuo *et al*., 2004). Humic substances may be absorbed by roots and translocated to shoots thereby enhancing plant growth. Application of humic substances to soils with low percentages of clay and organic matter, to nutrient solutions or to sand and water cultures have produced significant growth response (Lulakis & Petsas, 1995). Stimulation of root growth is generally more apparent than shoot growth (Nardi *et al*., 2002) and the reason for this can be because of the hormone-like activity of humic substances (Mayhew, 2004).

It has been found that granular humate induced a significantly greater root mass than foliar applied humic acids as a result of the more direct contact with the plant roots than the foliar applied humate (Cooper *et al*., 1998). The increase in root growth, particular root length, was also supported by Delfine *et al*. (2005). Muller-Wegener (1988) also stated that humates had a direct effect on roots. This stimulating effect could be the result of an alteration of membrane characteristics or as a result of plant energy metabolism (Atiyeh *et al*., 2002). It has been considered that the hydroxyl and carboxyl groups were mainly responsible for the response obtained with humic substances (Ayuso *et al*., 1996).

In the plant-soil system the interaction between root cells and humic substances is possible when humic molecules present in the soil solution are small enough to flow in the apoplast and reach the plasma membrane (Varanini *et al*., 1993). Humic substances may play a favorable role in regulating the plant root metabolism by inducing or repressing the mechanism of protein synthesis, enzyme activation or inhibition resulting in morpho-functional changes in plant root tissues (Cacco *et al*., 2000).

2.5.2 Nutrient uptake

Traditionally wheat was cultivated under adverse conditions and producing a poor yield with inferior quality. This has changed and now fertilizer responsive dwarf type wheat is planted (Singh & Arora, 2001). It is known that the presence, uptake and transport of nutrients are influenced by humic substances. Thus when nutrients are absorbed by an active metabolic process humic substances could inhibit absorption since they tend to complex the ions but if the same ions are absorbed by means of passive mechanism like diffusion through plant tissues humic substances do not intervene at all in the absorption or it could even have a positive effect (Ayuso *et al*., 1996). It was also found that humic acids played an important role in the transport of trace elements (Huljev & Strohal, 1983).

Cooper *et al*. (1998) stated that whether nutrient uptake increased, decreased or remained constant in response to humic substances depends to a large extent on plant species and the humic materials evaluated. The effects of humic substances on ion uptake appear to be more or less selective and variable in relation to their concentration and the pH of the medium (Nardi *et al*., 2002). Several investigations suggested that humic acids extracted from the soil could affect plant nutrition through an action at the level of cell membranes.

According to Varanini *et al*. (1993) the interactions between the lipid matrix of the plasma membrane leading to modifications of membrane permeability and fluidity had been interpreted on the basis of a surface-active effect of humic acids.

The stimulatory effect of humic substances have been directly correlated with enhance uptake of macronutrients such as nitrogen, phosphorus, potassium and sulfur (Caccco *et al*., 2000; Delfine *et al*., 2005). An enhanced uptake of micronutrients such as Fe, Zn, Cu and Mn was also found. Humic substances enhance the uptake of nutrients through the stimulation of microbial activity (Mayhew, 2004). More specifically humic acids likely increased P availability and uptake by inhibiting calcium phosphate precipitation rates, forming phosphohumates that are competing for adsorption sites or it decreases the number of adsorption sites by promoting dissolution of metal solid phases via chelation. Metal micronutrient availability and uptake in the soil system have also been found to be increased in the presence of humic acids and this could be the result of increased chelation (Jones *et al*., 2007).

Humic substances have widely been regarded as playing a beneficial role in Fe acquisition by plants. This effect is mainly because of the complexing properties of humic substances which increase the availability of micronutrients from sparingly soluble hydroxides (Nardi *et al*., 2002). The humic substances work on the metabolism of a plant and the effect mainly exerted on the cell membrane functions and thus promoting nutrient uptake or plant growth and development by acting as a hormone-like substance. The fact that these humic substances have a direct effect on the plants' metabolism means that they are taken up into the plant tissues (Nardi *et al*., 2002).

2.5.3 Plant biology and physiology

Several studies have shown that humic substances can have a positive effect on plant growth (Van de Venter *et al*., 1991; Arancon *et al*., 2002). These substances can have a direct effect through absorption of humic compounds by the plant and thus affecting the enzyme activities and membrane permeability (Nardi *et al*., 2002). The humic substances can also have an indirect effect on the plant by changing the soil structure, increase cation exchange capacity, stimulate microbial activity and has the capacity to solubilize or complex certain soil ions (Ayuso *et al*., 1996).

The biological activity of humic substances encompasses all its activities in regulating plant biochemical and physiological processes, irrespective of their stimulatory or inhibitory effect. In general plant biochemical mechanisms were affected by humic substances. Known affected mechanisms are membrane permeability (Valdrighi *et al*., 1996), protein carriers of ions, Kreb's cycle and respiration activation, photosynthesis, formation of ATP, amino acids, carbohydrates and proteins, nucleic acid synthesis and selective effects on enzyme activities (Vaughan *et al*., 1974; Muller-Wegener, 1988; Vallini *et al*., 1993; Valdrighi *et al*., 1996; Nardi *et al*., 2004; Charest *et al*., 2004).

Purchase *et al*. (1995) stated that humic substances are stimulating plant growth under certain conditions. Some of these stimulatory effects are increases in the length of roots and shoots. There have also been reports of increases in wheat grain yield. When coal derived humate products were applied as a foliar spray to seedlings in Petri dishes, a 268% increase in root and shoot growth were found.

Humic substances are known to stimulate the germination of several seed varieties. When seeds were put in a sodium humate solution germination, water absorption, respiration, root and shoot length as well as the fresh and dry weight of roots and shoots increased. Crop yield and nutrient uptake was also enhanced by humic substance application (Van de Venter *et al*., 1991; Piccolo *et al*., 1992; Atiyeh *et al*., 2002; Arancon *et al*., 2006). Causes of growth and yield response include increased water holding capacity, nutrient availability, hormonal activity or microbial growth and an increased organic matter mineralization (Tan & Nopamornbodi, 1979; Jones *et al*., 2007). More specifically humic acids was also used as growth regulators to regulate hormones, improve plant growth and enhance stress tolerance (Delfine *et al*., 2005).

It was generally argued that changes in microbial activity were responsible for the enhanced plant growth (Vaughan & Linehan, 1976). This could be possible because auxines and gibberellins are known microbial products. However, the possibility also exists that humic acids might have a direct influence on plants through effects on ion uptake or on the growth regulation of the plant. According to Nardi *et al*. (2000) and Atiyeh *et al*. (2002) humic acids have shown to have stimulated plant growth in auxin, gibberellin and cytokinin bioassays.

There is little information available on the optimum amount of humic acid that needs to be applied to induce beneficial effects on plants. The nature, source and concentration of humic substances, pH and condition of the culture medium, plant species and the growth parameter being measured are all interacting factors complicating the evolution of humic acid applications effect on plant growth and development (Lulakis & Petsas, 1995).

2.6 Conclusion

Organic matter is an important component when biological, chemical and physical soil properties are evaluated. In an attempt to increase the already organic poor soils of South Africa different products, of which humic substances are but one, are applied. From literature these soil applied humic substances may improve soil quality through improved soil structure and water holding capacity, increased cation exchange capacity, enhanced pH buffer capacity as well as increased microorganism activity. Notwithstanding the fact that humic substances improved crop growth and yield indirectly by the forementioned factors it was also argued that it could improve crop response directly acting as plant growth regulators. Considering the potential advantages of humic substances on soil quality and crop response promoted this study.

Chapter 3

Biological and chemical soil properties response to potassium humate application

3.1 Introduction

Organic matter content is generally low in South African agricultural soils. This can be attributed to the warm and dry climate in combination with cultivation that usually lead to a continuous decrease in organic matter content (Karaca *et al*., 2006). Organic matter content in such soils can be maintained and even increased through addition of animal and plant residues and this strongly affects the biological, chemical and physical properties of soil (Gaur *et al*., 1971).

Organic matter consists interalia of a range of above and below ground plant and microbial residues. Biological, chemical and physical processes in the soil affects, to a large extent, the decomposing rate of these residues at any stage of decomposition (Charest *et al*., 2004). In addition to mineralization in soil, the residues are also subjected to microbial resynthesis, selected preservation and direct transformation. Microbial biomass composition and activity is an important determinant of the quality and the amount of soil organic matter that build up in the soil (Guggenberger *et al*., 1999). When organic materials are applied to soil it can support the organic matter and nutrient status of the soil and these soils have generally a more active microbial population. This improves soil quality as a result of increased organic matter content and simultaneously soil born diseases and pathogens are inhibited. This inhibition is the result of organic matter stimulating rhizobacteria and producing antagonists to soil born phytopathogenic fungi (Charest *et al*., 2004; Karaca *et al*., 2006).

Humified organic matter enhances microbial growth and activity, thus by applying humic substances to soil, taxonomic and functional groups of soil bacteria are increased (Vallini *et al*., 1993). Indirectly humic substances influence microorganisms through its cation exchange capacity which is five times greater than that of soil minerals. Hence essential cations are either made available such as Fe or toxic concentrations of Cu are chelated, allowing microbial growth (Charest *et al*., 2004). According to these authors humic

substances can also influence microorganisms directly if humic substances of adequate size are to be taken up by microorganisms.

Research has shown that humic acids not only influences microorganisms but it also improves soil fertility by releasing plant nutrients slowly, increasing cation exchange capacity, enhancing pH buffer capacity and promoting interaction with micronutrients (García-Gil *et al*., 2004; Brunetti *et al*., 2006). Through these processes crop growth will be improved as the maintenance of soil fertility is one of the most important priorities in sustainable crop production without harming the natural ecosystem (González-Perez *et al*., 2006; Sarir *et al*., 2006).

The importance of soil fertility is also supported by improved soil physical properties. This can be achieved through the application of organic matter of which humic substances are but one source (Mackowiak *et al*., 2001). Evidence of this is the application of humic polymers binding soil particles by enforcing an intrinsically stable bond which improving soil structure (Chizoba & Chinyere, 2006; Weber *et al*., 2007).

Considering the potential advantages of humic substances on soil quality necessitated this investigation. The objective was to evaluate the effects of selected commercial K-humate products on some biological and chemical soil properties.

3.2 Materials and methods

Two experiments were conducted to establish the effects of K-humate products on soil properties. The focus with the first one was only on biological soil properties while with the second one the focus was on chemical soil properties.

3.2.1 Biological soil properties

A pot experiment was conducted at the University of the Free State in controlled growth chambers during 2006. Soil collected from the Kenilworth Field Research Facility of the Department of Soil, Crop and Climate Sciences, University of the Free State was used to fill polyethylene pots with a volume of 5 L. Each pot was filled with 8.4 kg of this red loamy sand Bainsvlei topsoil (particle size distribution: 87% sand, 5% silt and 8% clay) after the soil was dried and sieved through a 2 mm screen.

Before filling the pots a representative sample was analysed by Omnia Nutriology^{TM} using standard procedres (Table 3.1) to assist in making a fertilization recommendation. A yield potential of 8 ton wheat per hectare was selected and accordingly the fertiliser rates were calculated. The sources listed in Table 3.2 were applied before the experiment commenced according to the methods and rates given in this table.

Table 3.1 Some chemical properties of the topsoil used in both pot experiments

Property		
P	(mg kg^{-1}) (Bray 1)	17
K	(mg kg^{-1}) (NH_4OA_C)	198
Ca	(mg kg^{-1}) (NH_4OA_C)	582
Mg	(mg kg^{-1}) (NH_4OA_C)	181
Na	(mg kg^{-1}) (NH_4OA_C)	36
Zn	(mg kg^{-1}) (Melich 3)	0.3
Fe	(mg kg^{-1}) (Melich 3)	49
Mn	(mg kg^{-1}) (Melich 3)	45
Cu	(mg kg^{-1}) (Melich 3)	0.2
B	(mg kg^{-1}) (Warm water)	0.12
S	($Ca(H_2PO_4)_2$)	56
Ca/Mg		1.96
(Ca+Mg)/K		8.68
pH	(KC*l*)	6.5
Org C	(% m/m)	0.19
CEC	($cmol_c kg^{-1}$)	5.06

Table 3.2 Source, method and rate of fertiliser application

Source	Application method	Application rate		Contribution of each element		
				N	P	K
		(kg ha^{-1})	(g pot^{-1})	(kg ha^{-1})		
Greensulph (27)	Broadcast (incorporated in soil)	592	2.137	159.84		
2:3:2 (22)	Banded (0.2 m row spacing)	320	1.216	20.11	30.17	20.11
Total				180	30	20

Humic acids have the tendency to differ in their chemical structure, as already explained in the literature review, therefore three K-humate products were used. Hence treatments consisted of two main factors *viz*. products (K-humate, SG/2004/36/05 and SG/2004/37/05) and application rates (0, 3 and 5 L ha^{-1}), replicated four times. These products were applied in a band on top of the soil for 0.2 m row spacings at rates equivalent of 0 L ha^{-1} (0 ml pot^{-1} – control); 3 L ha^{-1} (0.0114 ml pot^{-1}) and 5 L ha^{-1} (0.019 ml pot^{-1}). Thereafter the pots were watered and maintained at field capacity for six weeks while incubated in growth chambers at a constant humidity of 60% and a day/night temperature regime of 25/15^{o}C. Soil samples (cores – 40g) were taken randomly on a weekly basis from the 0 – 100 and 100 – 200 mm layers. These cores were dispatched to and analysed by Omnia Nutriology^{TM}. During examination, bacteria and fungi were quantified microscopically using extraction plating on a growth medium.

3.2.2 Chemical soil properties

The preparation of the pots for this experiment was exactly as described in the previous section, except that only K-humate was applied as a coating on the 2:3:2 (22) fertiliser. As a result of this the K-humate was banded equivalent to a rate of 3L ha^{-1} at a depth of 50 mm. Three replications were prepared for the control and K-humate treatments.

Pots were also kept in growth chambers at 60% humidity and a day/night temperature regime of 25/15^{o}C after they were watered to field capacity. This water content was maintained throughout the duration of the experiment that was five months. At termination 100g of soil was sampled in the middle of each pot from the 0 – 100 and 100 – 200 mm layers.

These samples were analysed by Omnia Nutriology^{TM} with standard procedures to determine in addition to pH also their P, K, Ca, Mg, Na, Al, Zn, Fe, Cu and B contents. Then relevant values were used to calculate cation ratios, cation exchange capacity (CEC), exchangeable sodium percentage (ESP) and acid saturation (AS).

3.3 Results and discussion

3.3.1 Biological soil properties

3.3.1.1 Bacterial response

Bacterial count for both soil layers showed a significant difference as a result of the interaction between product and application rate (Appendix 3.1 and 3.2). As displayed in Table 3.3 bacteria count for the first layer varied from 83 743 (3 L ha^{-1} of SG/2004/37/05) to 106 683 (0 L ha^{-1} of SG/2004/36/05). However, for the second soil layer bacteria count ranged from 87 077 (0 L ha^{-1} of SG/2004/37/05) to 111 345 (5L ha^{-1} of K-humate). It is interesting to note that the bacterial count of this layer of soil was slightly higher than that of the upper soil layer. No consistency or clear tendency was observed in bacterial count for both soil layers as a result of product by application rate interaction. Therefore, it would be worth while to evaluate each of the main factors.

Table 3.3 Bacterial count in response to different products and application rates for two soil layers

Soil layer (mm)	Application rate (L ha^{-1})	Product			Average
		K-humate	SG/2004/36/05	SG/2004/37/05	
0 - 100	0	89 861	106 683	85 360	93 968
	3	101 033	104 344	83 743	96 374
	5	102 752	91 283	92 657	95 564
Average (0 – 100)		97 882	100 770	87 253	95 302
100 - 200	0	89 741	109 217	87 077	95 345
	3	104 597	101 392	87 864	97 951
	5	111 345	92 609	87 676	97 210
Average (100 – 200)		101 894	101 073	87 539	96 835

P = Product R = Application rate P x R = Product x Application rate

Depth 0–100: P = LSD $_{T\leq0.05}$=8180.9
R = ns
PxR = LSD $_{T\leq0.05}$=18752.7

Depth100–200: P = LSD $_{T\leq0.05}$=7365.6
R = ns
P x R = LSD$_{T\leq0.05}$=16883.9

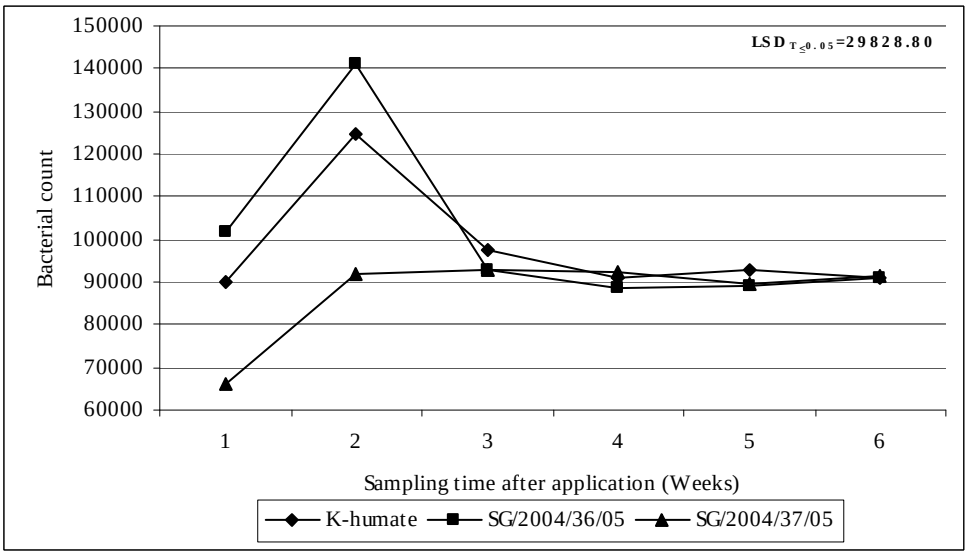
Evaluation of the products showed that for both soil layers the bacterial count of SG/2004/37/05 was significantly lower compared to the bacteria count of K-humate or SG/2004/36/05 (Appendix 3.1 and Table 3.3). Though insignificant, an application of 3 L ha^{-1} increased bacteria count with 2.6% in the 0 – 100 mm layer and with 2.7% in the 100 – 200 mm layer compared to the controls. In both layers the bacterial count of the 3 L ha^{-1} rate was also greater than that of 5 L ha^{-1} rate.

The analyses of variance for both soil layers indicated that bacterial count was significantly affected by the interaction of product applied and time of sampling (Appendix 3.1 and 3.2). Bacteria count in the first layer increased significantly from the first to second week on account of the K-humate products applied (Figure 3.1). At both samplings bacteria count of SG/2004/36/05 was the highest, followed by K-humate and then SG/2004/37/05. Thereafter the bacteria count of SG/2004/36/05 and K-humate decreased significantly to the same order as that of SG/2004/37/05. Hence from the third week after application bacteria count for the products remained almost constant with no difference between them.

The bacteria count in the second layer (Figure3.2) was almost a mirror image of that in the first layer (Figure3.1). However, two differences are worth mentioning. In the second layer a similar bacteria count was recorded for SG/2004/36/05 and K-humate from week 1 to 6 after application while their bacteria count in the first layer differed somewhat until week 2 after application. The bacteria count from week 3 to 6 declined slightly in the second layer but not in the first layer.

These trends in bacteria count were expected since any form of organic matter applied to soil would serve as a “food” source for microorganisms. This was confirmed by Vallini *et al*. (1993) who reported increased bacterial and actinomycete growth and activity in soil on account of humic acid application.

(a)



(b)

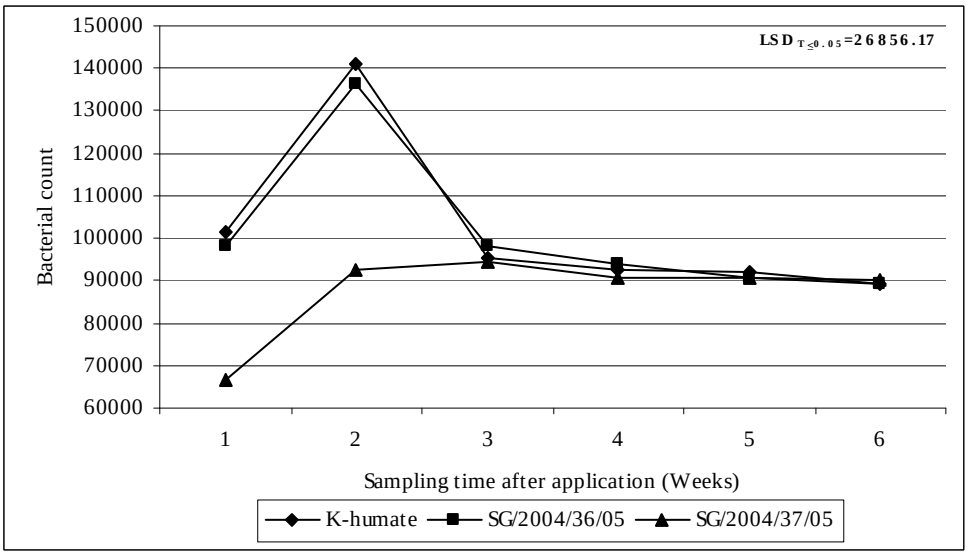


Figure 3.1 Bacterial count for the 0 – 100 mm (a) and 100 – 200 mm (b) soil layers in response to different products at different sampling dates

3.3.1.2 Fungal response

Fungal count in the 0 – 100 mm layer showed a significant difference for the interaction between product and application rate (Appendix 3.3). In the 100 – 200 mm layer fungal response was only affected by the products used (Appendix 3.4). Fungal count in both layers also showed a significant reaction over sampling period (Appendix 3.3 and 3.4).

The control treatments of K-humate, SG/2004/36/05 and SG/2004/37/05 resulted in the highest fungal counts for the first layer (Table 3.4). Having said this, it is also important to note that the fungal count decreased with increasing application rates for all products with the exception of K-humate where the fungal count was higher at the 5 than 3 L ha^{-1} rate. Fungal count in the second layer reacted to the different products with SG/2004/36/05 resulting in the highest fungal count, followed by K-humate and then SG/2004/37/05 (Appendix 3.4 and Table 3.4).

Table 3.4 Fungal count in response to different products and application rates for two soil layers

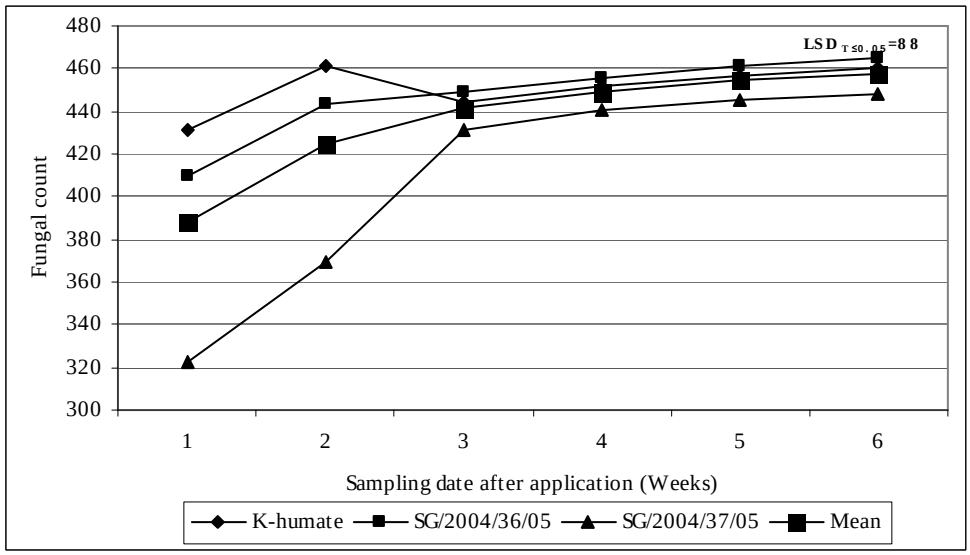
Soil layer (mm)	Application rate (L ha^{-1})	Product			Average
		K-humate	SG/2004/36/05	SG/2004/37/05	
0 - 100	0	488.62	499.92	419.13	465.89
	3	390.71	436.50	414.13	413.78
	5	473.08	415.54	395.50	428.04
Average (0 – 100)		450.81	447.32	409.58	435.90
100 - 200	0	435.63	471.79	408.67	438.69
	3	434.71	444.21	393.96	424.29
	5	432.71	410.21	430.63	424.51
Average (100 – 200)		434.35	444.07	411.08	429.17

Depth 0–100: P = $LSD_{T\leq0.05}$=24.2
R = $LSD_{T\leq0.05}$=24.2
PxR = $LSD_{T\leq0.05}$=55.5

Depth100–200: P = $LSD_{T\leq0.05}$=28.8
R = ns
PxR = ns

As mentioned earlier fungal count in both soil layers was also significantly affected by sampling time (Appendix 3.3 and 3.4). The fungal count for all three products increased initially sharply until 2 to 3 weeks after application (Figure 3.3 and 3.4). Thereafter fungal count increased at a slower rate. Though insignificant SG/2004/37/05 resulted in lower fungal counts than K-humate and SG/2004/36/05, especially at the first two sampling dates. These results once more confirm the results published by other researchers. Dackman *et al*. (1987), Manici *et al*. (2003) and Albertsen *et al*. (2005) found an increase in the number of fungi with the application of organic substances.

(a)



(b)

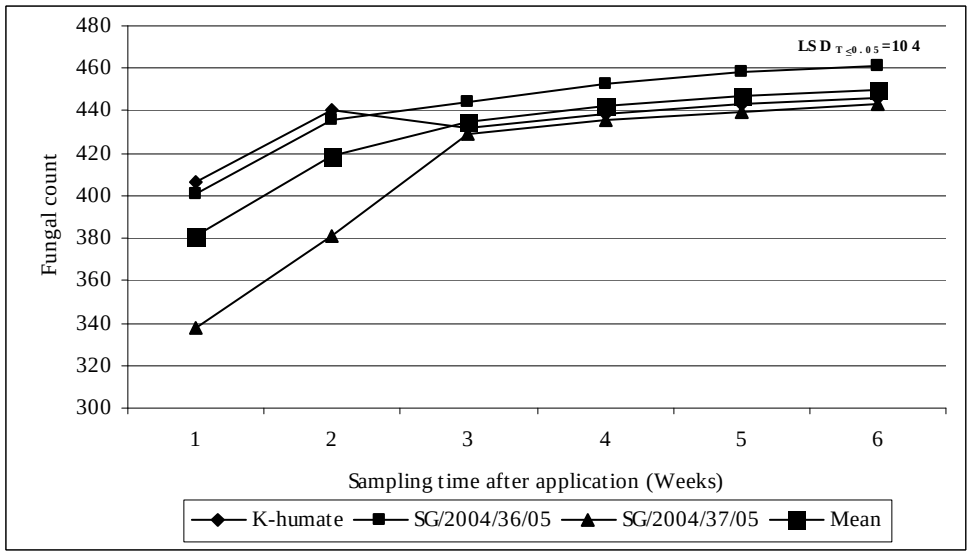


Figure 3.2 Fungal count for the 0 – 100 mm (a) and 100 – 200 mm (b) soil layers in response to different products at different sampling dates

From the results on bacterial and fungal counts it can be concluded that the application of the K-humate products increased microbial activity in this particular Bainsvlei topsoil. The response of bacteria and fungi were initially rapid. However, the activity of bacteria stabilized after 2 to 3 weeks while that of fungi continue increasing although at a slower rate. Generally, K-humate and SG/2004/36/05 performed better than SG/2004/37/05. This phenomenon could be ascribed to differences in the structure of humic acids as explained in the literature review.

3.3.2 Chemical soil properties

The band placement of K-humate at 50 mm depth resulted not in any significant changes of the Bainsvlei topsoil chemical composition when the 0 and 3 L ha^{-1} treatments are compared (Table 3.4). However, in the 0 – 100 mm layer the contents of Ca and B increased slightly while that of all other nutrients decreased. This lead to an increase in the Ca/Mg as well as (Ca + Mg)/K ratio's. Likewise an increase in the amount of exchangeable acids as well as the percentage acid saturation with decrease in pH was observed. This is in contrast with findings reported in literature, namely that the application of K-humate reduced acid saturation and increased pH.

Only Fe and Mn showed signs of an increase in the 100 – 200 mm layer. In comparison to the upper layer the exchangeable acid content and percentage acid saturation decreased. Despite of this the pH still decreased from 4.42 to 4.38. Humic acids have a large buffer capacity over a wide pH range, which arises essentially from the dissociation of acidic functional groups of which they are particularly rich (Campitelli *et al*., 2005). Pertusatti & Prado (2007) also found that humic acids did have poor buffer capacity to strong acid, but showed an excellent buffer capacity to base addition.

Generally, the concentration of most nutrients decreased upon band placement of K-humate in this particular soil. Hence the findings were not always in agreement with that established by other research. Sarir *et al*. (2006) found that application of humic acid increased the mineralization of organic P which enhance plant available P in soil.

Table 3.5 Chemical property response to the band placement of K-humate at 50 mm depth

Property		Soil layer			
		0 – 100 mm		100 – 200 mm	
		0 L ha^{-1}	3 L ha^{-1}	0 L ha^{-1}	3 L ha^{-1}
Nutrients	(mg kg^{-1})				
P	(Bray 1)	60.6	59.0	39.2	35.0
K	(NH_4OA_C)	200.4	192.2	192.2	186.2
Ca	(NH_4OA_C)	451.8	456.4	406.6	381.6
Mg	(NH_4OA_C)	112.0	108.8	113.8	107.2
Na	(NH_4OA_C)	26.80	23.80	20.40	17.00
Zn	(Melich 3)	7.900	6.680	6.360	2.340
Fe	(Melich 3)	97.98	92.62	87.82	91.10
Mn	(Melich 3)	131.6	122.2	116.0	121.4
Cu	(Melich 3)	0.28	0.12	0.10	0.10
B	(Warm water)	0.010	0.014	0.014	0.010
Ratios					
(Ca/Mg)		2.468	2.594	2.178	2.170
(Ca+Mg)/K		6.214	6.482	6.040	5.852
pH	(KCl)	4.46	4.42	4.42	4.38
ESP	(%)	2.938	2.656	2.400	2.118
AS	(%)	3.6	4.6	5.6	5.4
Al	($cmol_c kg^{-1}$)	0.020	0.018	0.020	0.013
CEC	($cmol_c kg^{-1}$)	3.948	3.898	3.698	3.494
Ex Acid	(m mol)	0.142	0.202	0.200	0.178

3.4 Conclusion

Both bacterial and fungal response showed some differences in the products used at different application rates. Unfortunately, no consistency was observed and therefore it is difficult to conclude if any one product at a specific application rate was superior to the other. What was evident is the fact that bacterial and fungal growth was stimulated by the products until 2 to 3 weeks after application. During this period K-humate and SG/2004/36/05 were superior to SG/2004/37/05. Both bacterial and fungal growth stabilized 2 to 3 weeks after application of the products with no obvious difference between them.

The chemical soil properties showed no response to the application of K-humate and the results obtained were conflicting with previous work. Therefore, it can be concluded that the humates do promote biological growth and activity in this soil.

Chapter 4

Irrigated wheat growth and yield response to potassium humate under glasshouse conditions

4.1 Introduction

In South Africa irrigated wheat contributes about 17% to the total wheat production (United States Department of Agriculture – USDA, 2006). The total wheat production of the country averaged 1.95 million ton annually since 2002. During the same period total wheat consumption was estimated at 2.63 million ton per annum (National Department of Agriculture – NDA, 2007). Hence since 2002 between 0.83 and 1.35 million ton of wheat was imported annually from Argentina, United States, Australia, Canada and some European countries (USDA, 2006). This is one of the reasons why wheat production has to be enhanced, especially under irrigation for its stabilizing effect.

Research showed that the application of commercial products like humates to soil could be useful in enhancing the growth and yield of crops like wheat (Majathoud, 2004). Considering the benefits attributed to the usages of humates they may also be of great value in South Africa since cropping has lead to a decrease of organic matter in soils (Almendros *et al*., 2005). In many instances the decline of organic matter is 50% or more. This is alarming since organic matter is one of the most important contributers to maintain soils in good quality. Soils of good quality are essential for sustained cropping (Percival *et al*., 2000).

It is especially the humus fraction of organic matter that has beneficial influences on soils and plants (Hopkins & Stark, 2003). This fraction comprise of a heterogeneous mixture of humic substances that arise from the decay of animal and plant residues. These humic substances can benefit plants directly or indirectly by influencing the soil. Benefits ascribed to them are increased water and nutrient holding capacity, increased reserves of slow releasing nutrients, enhanced solubility of phosphorus, zinc, iron, manganese and copper (Vaughan & Linehan, 1976; Mylonas & McCants, 1980; Majathoud, 2004). They are also able to buffer pH changes, improve aggregation, decrease erosion, enlarge the root

systems, and increase growth of plants as a result of inert hormones (Hopkins & Stark, 2003; Jones *et al*., 2007).

Taking all the benefits addressed to humic substances of organic matter into consideration an investigation on commercial humates is justified. The objective with this glasshouse research was to establish whether application of a commercially available K-humate to soils enhanced the growth and yield of irrigated wheat.

4.2 Materials and methods

4.2.1 Pot experiment

A pot experiment was conducted during the 2006 growing season in a glasshouse at the University of the Free State, Bloemfontein.

Baviaans, a spring type wheat with a high yielding ability and well adapted to the summer rainfall irrigation areas of South Africa, was selected. This cultivar also exhibits a good hectoliter mass, tillering ability, sprouting resistance and straw strength. The latter is of great importance to counteract lodging during the grain filling and mature growth stages. Regarding diseases, it is susceptible to stem rust, moderately susceptible to leaf rust and scab but resistant against stripe rust (ARC-Small Grain Institute, 2007). The recommended planting date for Baviaans is 1 to 30 June. Hence this experiment was planted on the 12th of June at the recommended seeding rate of 100 kg ha^{-1} (0.68 g pot^{-1}) with a 0.2 m row spacing.

Topsoils of three textural classes (Table 4.1) were selected for this experiment *viz*. a loamy sand (Soil 1), sandy clay loam (Soil 2) and clay loam (Soil 3). Asbestos pots (0.34 x 0.34 x 0.35 m) with a volume of 40.5 L were used (Figure 4.1 – a). A gravel layer approximately 30 mm thick (5 kg) was placed at the bottom of each pot to facilitate drainage. A cloth was placed on the gravel layer separating the soil and the gravel to prevent the soil from penetrating the gravel. Each pot was filled with approximately 55 kg of soil after the soil was air-dried, sieved through a 2 mm screen and thoroughly mixed.

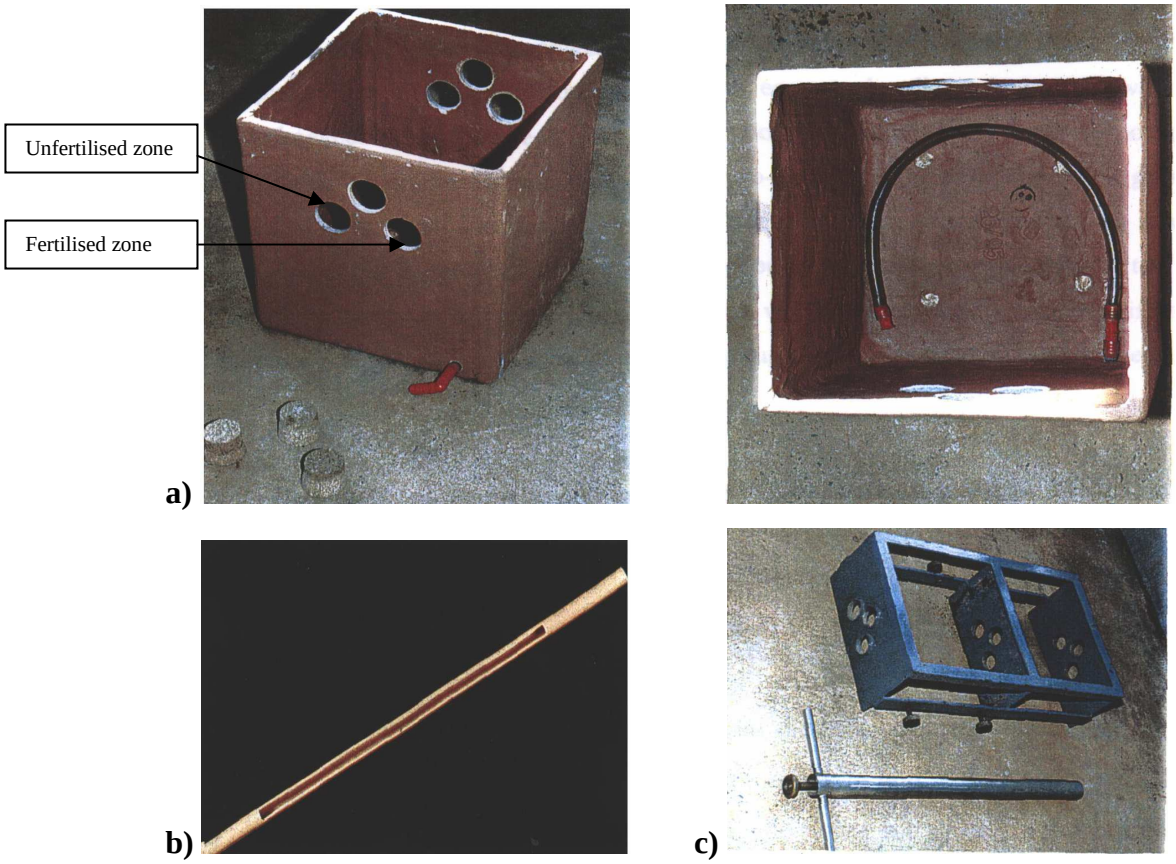


Figure 4.1 Example of experimental pots (a – side and top view, b – tube to apply fertiliser in the band, and c – stainless steel tube and frame for root extraction from the fertilised zone and unfertilised zones).

Table 4.1 Physical properties of the topsoils used in this experiment

Property	**Soil**		
	Loamy sand (S1)	**Sandy clay loam (S2)**	**Clay loam (S3)**
Bulk density (kg m^{-3})	1.47	1.53	1.45
Particle size distribution (%)			
Sand	86	67	44
Silt	6	11	19
Clay	8	22	37

Fertilisation was based on a yield potential of 8 t ha^{-1} and the fertility status as reported by Omnia Nutriology™ of the three soils (Table 4.2). Their fertility status was generally good

except for P in soil 3. Hence to reduce the complexity of the experiment it was decided to follow a collective fetiliser approach for the soils. Therefore, a total of 180 kg N ha^{-1}, 30 kg P ha^{-1} and 20 kg K ha^{-1} were applied to soils 1, 2 and 3. The P deficiency of soil 3 was corrected by applying an additional 20 kg P ha^{-1}. The time, source, rate and method of fertiliser application is summarised in Table 4.3.

The K-humate treatments were applied to the soils as coatings on the granular fertiliser either as a single application (100% at planting) or as a split application (50% banded at planting and 50% topdressed at tillering). The granular fertiliser at planting was applied with a tube (Figure 4.1 – b) exactly in the middle of the fertilised zone as in Figure 4.1 – a and the roots were extracted from the fertilised and unfertilised zones by means of a 50 mm stainless steel tube (Figure 4.1 – c).

The experiment was laid out as a complete randomised block design with a factorial combination consisting of two main factors, *viz*. three textural classes (8, 22 and 37% clay) and four K-humate applications (0 L ha^{-1} control, 3 L ha^{-1} single application and 3 and 6 L ha^{-1} split application). Effects of the treatment combinations were evaluated at three growth stages (tillering = G5; stem elongation = G10 and maturity = G25). Every treatment combination was replicated thrice for each growth stage, therefore, 108 pots were used.

The soils were maintained at field capacity by weighing the pots on a weekly basis. Distilled water was used to eliminate further addition of nutrients. Care was also exercised not to water soils above field capacity to avoid leaching of nutrients. The glasshouse temperatures were maintained at 18 ± 5 ^{0}C during the day and at 10 ± 5 ^{0}C during the night with a natural light regime. Throughout the duration of the experiment the plants were free of diseases and/or pests, hence no control measures were necessary.

Table 4.2 Chemical properties of the topsoils used in this experiment

Property		Soil		
		Loamy sand (S1)	**Sandy clay loam (S2)**	**Clay loam (S3)**
Nutrients	(mg kg^{-1})			
P	(Bray 1)	17	17	6
K	(NH_4OA_C)	198	143	153
Ca	(NH_4OA_C)	582	257	441
Mg	(NH_4OA_C)	181	68	131
Na	(NH_4OA_C)	36	6	6
Zn	(Melich 3)	0.3	0.8	0.4
Fe	(Melich 3)	49	64	134
Mn	(Melich 3)	45	18	49
Cu	(Melich 3)	0.2	1.9	1.5
B	(Warm water)	0.12	0.13	0.19
S	($Ca(H_2PO_4)_2$)	56	56	100
Ratios				
(Ca/Mg)		1.96	2.27	2.05
(Ca+Mg)/K		8.68	5.06	8.38
pH	(KCl)	6.4	4.6	4.8
Org C	(m/m)	0.19	0.11	0.35
CEC	(%)	5.06	2.24	3.7

Table 4.3 Time, source, method and rate of fertiliser application

Time of application	Source	Method of application	Rate		Contribution for each element		
			(kg ha^{-1})	(g pot^{-1})	N	P	K
Pre-plant	Superphosphate (10.5) only to clay loam soil	Broadcast, incurporated to 100 mm	190	2.196		19.95	
	Greensulph (27)	Broadcast, incurporated to 100 mm	370	4.277	99.9		
At planting	2:3:2 (22)	Banded	320	2.176	20.16	30.08	20.16
Tillering	Greensulph (27)	Topdressed	111	1.283	29.97		
Flag leaf	Grensulph (27)	Topdressed	111	1.283	29.97		
Total					180	50	20

4.2.2 Observations

All the above- and below-ground plant parameters listed were measured at the three growth stages, except leaf area.

4.2.2.1 Above-ground plant parameters

1. Leaf area (cm^2 m^{-2}) – a LICOR 3000 leaf area meter was used to determine the leaf area of each plant after it was cut just above the soil surface. The total leaf area of all plants per pot was measured by using only the leaf blades.
2. Total biomass (g m^{-2}) – after the leaf area was measured the plant material was dried at 60^{o}C until a constant water content to determine the dry mass.
3. Number of ears (m^{-2}) – the number of ears of all plants per pot was counted.
4. Numbers of spikelets (spikelets ear^{-1}) – the number of spikelets per ear of all plants per pot was counted.
5. Numbers of kernels (kernels ear^{-1}) – the number of kernels per ear of all plants per pot was counted.
6. Grain yield (g m^{-2}) – the total grain yield per pot was weighed after the seed was dried to a constant moisture content.

4.2.2.2 Below-ground plant parameters

1. Root length (mm) – the roots were separated from the soil by washing it over a 2 mm screen with water at low pressure. A modified infrared root line intersection counter was used to measure the root lengths (Rowse & Phillips, 1974). Roots in the fertilised zone, unfertilised zone and remaining soil of a pot were measured separately.
2. Root mass (g) – after the root length was measured, roots were dried at 60^{o}C to a constant moisture content and weighed.

4.2.3 Statistical analyses

As described in section 4.2.1 a complete radomised block design with a factorial combination consisting of two main factors, *viz.* three soils and four K-humate applications replicated thrice for each of the three growth stages was used. The experimental data was analysed with the NCSS (Number Cruncher Statistical System) statistical package (Hintze, 1998). The least significant difference (LSD) was calculated at $P \leq 0.05$. This was done to compare the treatment means using the Tukey-Kramer multiple comparison test (Gomez & Gomez, 1984).

4.3 Results and discussion

A summary on the analyses of variance evaluating the effect of treatment factors, *viz*. K-humate and soil type at three growth stages on selected plant parameters is given in Table 4.4. Inspection of the results showed that with the exception of tiller number at stem elongation, the application of K-humate as a main factor had no significant effect on any of the measured plant parameters. Soil type as a main factor showed that there was a significant difference at the three growth stages, especially at maturity for the majority of parameters. A significant interaction between K-humate and soil type was also observed for leaf area at tillering.

Both growth and yield component parameters were used to evaluate the effect of K-humate application rates with the three textural soils on wheat production. The growth and production were evaluated at different growth stages and are presented in Tables 4.4 - 4.20. For all parameters the growth stages were grouped where applicable and the different

soil textures were annotated as: 8% clay - S1; 22% clay - S2 and 37% clay - S3. Analysis of variance is presented in Appendix 4.1 – 4.35.

4.3.1 Above ground plant parameters

4.3.1.1 Total biomass

Total biomass production in above-ground vegetative parts of wheat were not significantly influenced by either K-humate application or soil used at any of the growth stages (Appendix 4.1 – 4.3). Though insignificant the 6 L K-humate ha^{-1} split application increased total biomass production slightly at tillering (9.2%) and maturity (2.9%) compared to the control (Table 4.5).

Total biomass production showed no significant differences as a result of the soils used. However the same trend was observed for the different growth stages regarding soil. The loamy sand soil (S1) and sandy clay loam soil (S2) yielded similarly but constantly higher dry matter yields than the clay loam soil (S3), *viz*. on average 15.3% at tillering, 13.0% at stem elongation and 10.6% at maturity.

The observed increase in dry matter production is in correspondence with findings of researchers using fulvic and humic acids that positively influenced shoot growth of various plants when applied as a foliar or in a nutrient solution (Chen *et al*., 2004). Aparicio *et al*. (2002) stated that increased grain yields were mainly due to increases in total dry matter with negligible increases in harvest index. Final yields often depended on the translocation of assimilates from leafs and stems to the grain meaning that the higher the total biomass at anthesis, the higher the yield.

Table 4.4 Summary on analyses of variance indicating the effect of treatment factors on the measured plant parameters

Factors	Dry matter	Leaf area	Tiller number	Root mass in fertilised zone	Root mass in unfertilised zone	Total root mass	Root length in fertilised zone	Root length in unfertilised zone	Total root length	Seed yield	Number of spikelets per ear	Number of kernels per ear	Yield per ear	Thousand kernel mass	Number of ears
Tillering															
Application rate (R)	ns	ns	ns	ns	ns	ns	ns	ns	ns						
Soil (S)	ns	*	*	ns	ns	ns	ns	ns	ns						
R x S	ns	*	ns	ns	ns	ns	ns	ns	ns						
Stem elongation															
Application rate (R)	ns	ns	*	ns	ns	ns	ns	ns	ns						
Soil (S)	ns	ns	*	*	*	ns	ns	*	ns						
R x S	ns	ns	ns	ns	ns	ns	ns	ns	ns						
Maturity															
Application rate (R)	ns		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Soil (S)	ns		ns	*	*	*	*	*	ns	*	*	*	*	ns	ns
R x S	ns		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

* - $P \leq 0.05$

ns - not significant

Table 4.5 Total biomass production (g m^{-2}) at three growth stages as affected by K-humate applications to three soils

Growth stage	Soil	K-humate application (L ha^{-1})				
		0 - control	3 - single	3 - split	6 - split	
	S1	128.0	125.2	128.8	132.6	126.8
Tillering	**S2**	126.6	113.2	118.0	139.1	124.2
	S3	98.0	116.0	100.8	113.6	107.1
		117.5	118.1	115.9	128.4	
Stem	**S1**	537.5	417.2	433.4	508.0	474.0
elongation	**S2**	461.6	457.4	508.1	437.2	466.1
	S3	431.4	419.0	401.5	383.1	408.8
		476.8	431.2	447.7	442.8	
	S1	1244.9	1322.6	1288.7	1313.5	1292.4
Maturity	**S2**	1327.7	1323.1	1173.6	1401.3	1306.4
	S3	1180.3	1165.0	1183.4	1151.4	1170.0
		1251.0	1270.3	1215.2	1288.7	

S = Soil **R = Application** **SxR = Soil x Application**

Tillering S = ns
R = ns
SxR = ns

Stem elongation S = ns
R = ns
SxR = ns

Maturity S = ns
R = ns
SxR = ns

4.3.1.2 Leaf area

Appendix 4.4 clearly indicated a significant difference in leaf area as a result of the interaction between K-humate application and soil texture. At tillering the greatest leaf area was obtained with the 6 L K-humate ha^{-1} split application on the loamy sand soil (S1) (Table 4.6). This leaf area was significantly greater than that obtained with the 3 L K-humate ha^{-1} single application on the sandy clay loam soil (S2), and with the control and 6 L K-humate ha^{-1} split application on the clay loam soil (S3).

No significant difference in leaf area was observed at stem elongation for either of the main effects (Appendix 4.5). Leaf area on the clay loam soil (16324.2 cm^2m^{-2}) at tillering was 17.5% and 5.0% smaller than the leaf areas of the loamy sand soil and sandy clay loam soil, respectively. At stem elongation the leaf area of the clay loam soil was on average 9.5% smaller than that of the other two soils. This corresponds with the reported dry matter production (section 4.3.1) and verifies the reduction in dry matter as a result of a smaller leaf area.

Table 4.6 Leaf area (cm^2cm^{-2}) at different growth stages as affected by K-humate applications to three soils

Growth stage	Soil	K-humate application (L ha^{-1})				
		0 - control	3 - single	3 - split	6 - split	
	S1	18644.4	19228.1	19143.6	22102.8	19779.7
Tillering	S2	19982.1	13532.4	18298.2	17449.7	17315.6
	S3	13699.5	17572.9	19051.8	14972.6	16324.2
		17442.0	16777.8	18831.2	18175.1	
Stem	S1	42653.1	36646.0	30081.6	37533.2	36728.5
elongation	S2	36359.2	39423.9	37838.0	34690.6	37077.9
	S3	34589.0	35775.7	32518.2	30790.5	33418.4
		37867.1	37281.9	33479.3	34338.1	

Tillering S = $LSD_{T\leq0.05}$ = 2376.0 **Stem elongation S = ns**
R = ns **R = ns**
SxR = $LSD_{T\leq0.05}$ = 6860.9 **SxR = ns**

As mentioned earlier an increase in the photosynthetic area especially during early growth stages resulted in higher yields. Hence, to increase the incident radiation intercepted by crops and the total biomass produced, leaf area has to be increased. This was achieved at tillering with the 6 L K-humate ha^{-1} split application. It is known that the leaf area increases rapidly to a maximum 17 weeks after planting, followed by a sudden decrease to half the maximum size three weeks after ear emergence. It is also known that the green mainly derive it's carbohydrates from the ear leaves (flag leaf) and stem (Davidson, 1965). Therefore, increasing the photosynthetic area will increase a crop's canopy and thus the leaf area index which is vital for higher biomass and yield production (Lawless *et al*., 2004). Haboudane *et al*. (2004) also stated that variables such as crop and soil factors influence leaf area index, e.g. nutrient balances and disease occurrences.

Delfine *et al*. (2005) found that humic acid had a marginal positive effect on growth when applied to plants grown in a relatively poor soil while plants that were adequately supplied with nutrients had a limited response to humic acid. They also suggested that a positive effect can be expected when humic acid is applied to wheat leaves in a period of water shortage and in the final stages of the crop's growth cycle.

4.3.1.3 Tiller/ear number

Appendix 4.6 and 4.7 clearly indicated a significant difference in the number of tillers per square meter at tillering on account of soil textures, and at stem elongation on account of both soil textures and K-humate applications. At tillering and stem elongation the greatest

number of tillers was produced by the loamy sand soil, followed by the sandy clay loam soil and then the clay loam soil. Thus, with an increase in clay content the number of tillers produced decreased. Contrasting but not significantly (Appendix 4.8) at maturity a smaller number of ears were produced by the loamy sand than the two other soils (Table 4.7).

Table 4.7 Tillering and/or ear number at different growth stages as affected by K-humate applications to three soils

Growth stage	Soil	K-humate application (L ha^{-1})				
		0 - control	3 - single	3 – split	6 - split	
	S1	317.185	325.836	331.603	351.787	331.603
Tillering	**S2**	354.671	297.001	305.651	348.904	326.556
	S3	268.166	322.952	262.399	282.583	284.025
		313.340	315.263	299.884	327.758	314.061
Stem	**S1**	472.894	374.855	380.622	346.02	393.598
elongation	**S2**	395.040	360.438	377.739	374.855	377.018
	S3	322.952	308.535	299.884	294.117	306.372
		396.962	347.942	352.748	338.331	358.995
	S1	175.894	207.612	175.894	198.962	189.590
Maturity	**S2**	219.146	233.564	190.311	253.748	224.192
	S3	224.913	213.379	236.447	213.379	222.030
		206.651	218.185	200.884	222.030	211.937

Tillering S = LSD $_{T\leq0.05}$=43.604 R = ns SxR = ns

Stem elongation S = LSD $_{T\leq0.05}$=37.417 R = LSD $_{T\leq0.05}$=47.727 SxR = ns

Maturity S = ns R = ns SxR = ns

Earlier mentioned, K-humate affected the number of tillers at stem elongation significantly (Appendix 4.7). The control yielded the greatest number of tillers and this was significantly more than the number of tillers obtained with the 6 L K-humate ha^{-1} split application.

The number of tillers increased from tillering (314 tillers m^{-2}) to the stem elongation (359 tillers m^{-2}), but dramatically decreased to 212 ears m^{-2} at maturity. This reduction is a natural occurring phenomenon in wheat. Wheat plants, depending on the cultivar, have the ability to produce numerous tillers but with resource limitations not all tillers reach maturity (Miralles & Slafer, 1999). Therefore, some tillers will either stop to develop into mature ears or will be absisiced depending on the severity of stress or resource limitations.

4.3.2 Below-ground plant parameters

4.3.2.1 Root mass in the fertilised zone

Root mass in the fertilised zone showed no significant differences as a result of either the K-humate application by soil texture interaction or K-humate application at any of the growth stages (Appendix 4.9 – 4.11). At tillering root mass of the control was the greatest with the K-humate treatments showing a decrease of approximately 30% in root mass. At stem elongation and maturity the mentioned tendency was not observed.

At tillering no significant differences as a result of soil texture was observed (Appendix 4.9). Though insignificant, the loamy sand and sand clay loam soils produced greater root masses in the fertilised zone than the clay loam soil. This was not observed at stem elongation and maturity (Appendix 4.10 and 4.11). At these growth stages the mass of roots grown in the fertilised zone decreased with an increase in clay content and the loamy sand soil had a greater root mass than the clay loam soil (Table 4.7).

Table 4.8 Root mass in the fertilised zone (g m^{-2}) at different growth stages as affected by K-humate applications to three soils

Growth stage	Soil	K-humate application (L ha^{-1})				
		0 - control	3 - single	3 - split	6 - split	
	S1	1.2883	1.2696	1.2578	1.0257	1.2103
Tillering	S2	1.8593	1.2010	1.1332	1.3962	1.3974
	S3	1.3849	0.7373	0.8518	0.6750	0.9123
		1.5109	1.0693	1.0809	1.0323	1.1733
Stem	S1	3.1646	3.2275	3.0533	2.4683	2.9784
elongation	S2	2.2223	1.6251	2.4417	2.2777	2.1417
	S3	1.8155	1.5003	2.1032	2.5314	1.9876
		2.4008	2.1176	2.5328	2.4258	2.3693
	S1	4.0450	4.2367	3.1122	5.0934	4.1218
Maturity	S2	2.9118	2.8555	3.5545	4.5450	3.4667
	S3	2.2376	3.1796	2.9302	1.9833	2.5827
		3.0648	3.4240	3.1990	3.8739	3.3904

Tillering S = ns **Stem elongation S = LSD $_{T\leq0.05}$=0.89917** **Maturity S = LSD $_{T\leq0.05}$=1.27023**
R = ns **R = ns** **R = ns**
SxR = ns **SxR = ns** **SxR = ns**

4.3.2.2 Root mass in the unfertilised zone

Similarly to root mass in the fertilised zone root mass in the unfertilised zone also did not differ on account of either the K-humate application by soil interaction or K-humate application at any of the growth stages (Appendix 4.12 – 4.14). However, soil texture

significantly influenced root mass in the unfertilised zone at stem elongation and maturity. At both these stages the loamy sand soil produced a significantly greater root mass than the clay loam soil (S3) (Table 4.9).

In comparison, root mass in the fertilised zone was on average three times greater than in the unfertilised zone at stem elongation and maturity. At tillering the difference was smaller with root mass of the unfertilised zone half that of the fertilised zone (Tables 4.8 and 4.9).

Table 4.9 Root mass in the unfertilised zone (g m^{-2}) at different growth stages as affected by K-humate applications to three soils

Growth stage	Soil	K-humate application (L ha^{-1})				
		0 - control	3 - single	3 - split	6 - split	
	S1	0.8097	0.5533	0.7416	0.6522	0.6892
Tillering	S2	0.6719	0.8552	0.9665	0.4438	0.7344
	S3	0.6300	0.3385	0.4908	0.5288	0.4970
		0.7039	0.5824	0.7330	0.5416	0.6402
Stem	S1	1.7976	1.8192	1.9097	2.1551	1.9204
elongation	S2	1.2223	1.2483	1.4418	1.1681	1.2701
	S3	1.0084	1.2056	1.2491	1.8397	1.3257
		1.3428	1.4244	1.5335	1.7210	1.5054
	S1	2.9412	3.1632	4.2546	3.2102	3.3923
Maturity	S2	2.0574	1.9354	1.5274	2.6693	2.0474
	S3	0.9452	1.1649	1.7056	1.4071	1.3057
		1.9813	2.0878	2.4959	2.4289	2.2485

Tillering S = ns, R = ns, SxR = ns
Stem elongation S = $LSD_{T\leq0.05}$=0.6259, R = ns, SxR = ns
Maturity S = $LSD_{T\leq0.05}$=0.9165, R = ns, SxR = ns

4.3.2.3 Root mass in remaining soil

Root mass in the remaining soil was not significantly affected by the K-humate application and soil texture interaction or K-humate application as a main factor. Only soil texture significantly affected root mass (Appendix 4.15 – 4.17) at maturity. It is worth mentioning that at maturity root mass tended to be higher with K-humate application.

Interestingly, soil texture influenced root mass differently in the remaining soil than in either the fertilised or unfertilised zones. The root mass in the remainder of the sandy clay loam soil was the greatest at stem elongation and maturity (Table 4.10). This root mass

was however only significantly different from the loamy sand soil at maturity (Appendix 4.17).

Table 4.10 Root mass in the remaining soil (g) at different growth stages as affected by K-humate applications to three soils

Growth stage	Soil	K-humate application (L ha^{-1})				
		0 - control	3 - single	3 - split	6 - split	
	S1	39.8318	28.9982	34.1925	27.4639	32.6216
Tillering	S2	38.6366	36.9757	47.0037	31.4319	38.5120
	S3	40.8999	32.0461	36.7577	55.2770	41.2452
		39.7894	32.6733	39.3180	38.0576	37.4596
Stem	S1	132.4905	115.1278	122.1552	127.6771	124.3627
elongation	S2	147.6476	120.5170	160.0262	95.7530	130.9859
	S3	110.8464	100.8963	121.3685	141.3982	118.6274
		130.3282	112.1804	134.5166	121.6094	124.6587
	S1	93.8723	143.5784	130.7388	117.1811	121.3427
Maturity	S2	142.1038	186.5636	258.8734	158.3811	186.4805
	S3	154.1069	141.9458	101.6760	127.6301	131.3397
		130.0277	157.3626	163.7627	134.3974	146.3876

Tillering S = ns, R = ns, SxR = ns; **Stem elongation** S = ns, R = ns, SxR = ns; **Maturity** S = ns, R = ns, SxR = ns; $LSD_{T \leq 0.05}$ = 62.0099

Trials on maize with humic acids showed significant increases in shoot and root growth (Tan & Nopamornbodi, 1979). Lulakis and Petsas (1995) also found positive results with humic acid application on tomato seedling roots. They reported that the highest number of roots were produced at concentrations of 50 to 100 ppm humic acid but an inhibitory effect was obtained when humic acid was applied at concentrations of 1000 to 2000 ppm. Vaughan and Linehan (1976) found similar results for wheat and according to Atiyeh *et al*. (2002) humic acids increased tomato and cucumber growth significantly. In contrast this experiment did not show a positive effect on root mass of wheat with the addition of K-humate to soil.

4.3.2.4 Root length in the fertilised zone

Root length was not significantly affected by the K-humate application and soil texture interaction, nor the main factor K-humate application (Appendix 3.18 – 3.20). However, at stem elongation a split application of 3 L K-humate increased root length with 38% compared to the control. At maturity a single application of 3 L K-humate increased root length with 33% over the control (Table 4.11).

Root length in the fertilised zone was significantly affected at maturity by soil texture. The loamy sand soil showed a significantly greater root length (almost double) than either the sandy clay loam or clay loam soils. However, one suspects roots to develop better in sandy than more clayey soils (Pietola, 2005). At tillering root length was greatest in the sandy clay soil but at the stem elongation root length was greatest in the loamy sand soil.

Table 4.11 Root length of the fertilised zone (mm) at different growth stages as affected by K-humate applications to three soils

Growth stage	Soil	K-humate application (L ha^{-1})				
		0 - control	3 - single	3 - split	6 - split	
	S1	705.7704	658.9238	523.6179	555.6235	610.9839
Tillering	S2	777.0099	522.2617	497.1725	867.2564	665.9251
	S3	686.0594	400.4775	617.5519	457.9792	540.5170
		722.9465	527.2210	546.1141	626.9530	
Stem	S1	1365.6470	1276.8300	1428.3640	1152.8510	1305.9230
elongation	S2	851.7490	944.6678	1369.8090	1111.1620	1069.3470
	S3	748.1607	698.5483	1290.8970	1344.1720	1020.4440
		988.5190	973.3488	1363.0230	1202.7280	
	S1	1736.3700	2581.3240	1707.6810	2373.9080	2099.8210
Maturity	S2	1407.7090	1000.3920	1141.2690	1503.6480	1263.2540
	S3	670.5283	1473.7260	1343.7440	596.4258	1021.1060
		1271.5360	1685.1470	1397.5650	1491.3270	

Tillering S = ns, R = ns, SxR = ns; **Stem elongation** S = ns, R = ns, SxR = ns; **Maturity** S = ns, R = ns, SxR = ns; $LSD_{T\leq0.05}$ = 723.63

4.3.2.5 Root length in the unfertilised zone

Root length in the unfertilised zone was not significantly influenced by the different K-humate applications or the interaction of K-humate application and soil texture (Appendix 4.21 to 4.23). However, at tillering the greatest root length was obtained with a split application of 3 L K-humate ha^{-1} in the sandy clay loam soil. At stem elongation and maturity a split application of 6 L K-humate ha^{-1} increased root length by 25 and 29.6% respectively to the control (Table 4.12).

Root length of the unfertilised zone like that of the fertilised zone responded similar to soil texture for the same reasons (Pietola, 2005) mentioned earlier. It had to be noted that root length of the unfertilised zone was much shorter than that of the fertilised zone.

Table 4.12 Root length in the unfertilised zone (mm) at different growth stages as affected by K-humate applications to three soils

Growth stage	Soil	K-humate application (L ha^{-1})				
		0 - control	3 - single	3 - split	6 - split	
	S1	452.9613	316.8017	412.4118	458.2504	410.1063
Tillering	S2	387.7295	456.4874	503.9323	317.2085	416.3394
	S3	295.3742	165.0461	373.2184	385.1834	304.7055
		378.6883	312.7784	429.8542	386.8808	
Stem	S1	815.5069	954.9988	1023.4610	962.7506	939.1794
elongation	S2	482.1658	617.4884	643.1071	490.6114	558.3431
	S3	587.3579	665.7825	668.5630	903.1107	706.2036
		628.3436	746.0899	778.3771	785.4909	
	S1	1442.7840	1252.6590	1541.0930	1528.1560	1441.1730
Maturity	S2	814.0221	427.7365	470.0491	1122.3700	708.5443
	S3	322.2264	484.0605	474.1176	692.7627	493.2918
		859.6776	721.4853	828.4199	1114.4300	

Tillering S = ns R = ns SxR = ns **Stem elongation S = LSD$_{T\leq0.05}$=254.88 R = ns SxR = ns** **Maturity S = LSD$_{T\leq0.05}$=430.63 R = ns SxR = ns**

4.3.2.6 Root length in remaining soil

The root length in the remaining soil was not significantly affected by the K-humate applications nor soil texture at any of the growth stages (Appendix 4.24 – 4.26). At tillering and stem elongation the greatest root length was obtained with a split application of 3 L K-humate ha^{-1}, but at maturity a single application of 3 L K-humate ha^{-1} induced the greatest root length (Table 4.13). At the forementioned growth stages the clay loam soil produced the greatest root length followed by the sandy clay loam soil and then the loamy sand soil. However, at maturity the loamy sand soil produced the largest root length, followed by the sandy clay loam soil and then the clay loam soil.

It was reported that the incorporation of humic acids into soils stimulated root growth (Cooper *et al*., 1998). According to Atiyeh *et al*. (2002) humic acids stimulated the proliferation, branching and initiation of root hairs and could partially be attributed to enhanced nutrient uptake. The results that evolved from this experiment did not verify these researchers' observations.

Table 4.13 Total root length in the remaining soil (mm) at different growth stages as affected by K-humate applications to three soils

Growth stage	Soil	K-humate application (L ha^{-1})				
		0 - control	3 - single	3 - split	6 - split	
	S1	11801.4200	9277.3080	10632.2200	8258.6050	9992.3890
Tillering	**S2**	11217.7900	13499.1700	11125.0500	8885.1880	11181.8000
	S3	12027.7400	9706.5630	15721.0200	18851.9800	14076.8300
		11682.3200	10827.6800	12492.7700	11998.5900	
Stem	**S1**	21979.2400	22504.3400	28422.0700	28645.9600	25387.9000
elongation	**S2**	30635.9600	37902.0600	36021.2700	20929.1200	31372.1000
	S3	38203.7300	24060.4600	44465.1000	36580.9700	35827.5700
		30272.9800	28155.6200	36302.8200	28718.6800	
	S1	24457.1000	40108.7400	36661.9900	23584.0200	31202.9600
Maturity	**S2**	29380.1500	31823.8200	23924.0500	23825.1800	27238.3000
	S3	31017.61	31772.9900	16783.0800	23767.1800	25835.2100
		28284.9500	34568.5200	25789.7100	23725.4600	

Tillering S = ns
R = ns
SxR = ns

Stem elongation S = ns
R = ns
SxR = ns

Maturity S = ns
R = ns
SxR = ns

4.3.2.7 Root length index

Root length index was estimated by expressing the total root length of a pot in mm mm^{-2}. As could be expected this index showed almost the same pattern as root mass and root length. Application of K-humate had no significant effect on root length index. The greatest root length index was once more been obtained with the split application of 3 L K-humate ha^{-1} at the tillering and stem elongation growth stages while at maturity a single application of 3 L K-humate yielded the greatest root length index (Table 4.14 and Appendix 4.27 - 4.29). In contrast to root mass and root length soil texture had no significant effect on root length index although that the three parameters showed similar trends.

Several studies showed that humic acid incrase root length, root number and root branching. These increases varied from single percentage digits but usually amounted to between 25 and 50% (Cooper *et al*., 1998). This was also supported by other researchers, but root growth inhibition was also established at high humic acids concentrations (Mylonas & McCants, 1980: Baraldi *et al*., 1991; Rajala & Peltonen-Sainio, 2001). In this study increases in root growth as manifested in the different parameters were mainly minute. In some instances however increases of 18% were recorded. The reason for not

being significant could be the result of a high coefficient of variance that is typical of root studies.

Table 4.14 Root length index (mm mm^{-2}) at different growth stages as affected by K-humate applications to three soils

Growth stage	Soil	K-humate application (L ha^{-1})				
		0 - control	3 - single	3 - split	6 - split	
	S1	1.1211	0.8869	1.0007	0.8021	0.9527
Tillering	**S2**	1.0712	1.2524	1.0489	0.8711	1.0609
	S3	1.1254	0.8886	1.4457	1.7037	1.2908
		1.1059	1.0093	1.1651	1.1256	
Stem	**S1**	2.0899	2.1398	2.6707	2.6610	2.3904
elongation	**S2**	2.7656	3.4139	3.2901	1.9490	2.8546
	S3	3.4203	2.1994	4.0159	3.3588	3.2486
		2.7586	2.5843	3.3256	2.6530	
	S1	2.3907	3.8013	3.4525	2.3777	3.0055
Maturity	**S2**	2.7337	2.8765	2.2089	2.2882	2.5268
	S3	2.7691	2.9179	1.6091	2.1675	2.3659
		2.6312	3.1985	2.4235	2.2778	

Tillering S = ns **Stem elongation S = ns** **Maturity S = ns**
R = ns **R = ns** **R = ns**
SxR = ns **SxR = ns** **SxR = ns**

4.3.3 Yield and yield components

All yield and yield components were measured at maturity.

4.3.3.1 Seed yield

Seed yield was not significantly affected by the application of K-humate (Appendix 4.30). Soil texture however significantly influenced seed yield. The loamy sand soil and sandy clay loam soil producing significantly higher yields than the clay loam soil (Table 4.14). Though insignificant, the greatest yield was obtained with a split application of 6 L K-humate ha^{-1} that was 3.5% more than the control. This may seem like a small percentage but it was a yield increase of 200 kg per hectare.

Table 4.15 Seed yield (g m^{-2}) as affected by different K-humate applications to three soils

Soil	K-humate application (L ha^{-1})				
	0 - control	**3 - single**	**3 - split**	**6 - split**	
S1	631.0520	679.4818	655.6687	664.3893	657.6480
S2	667.8731	666.5213	582.7940	715.6974	658.2215
S3	586.1801	575.4771	578.9581	573.9140	578.6323
	628.3684	640.4934	605.8069	651.3336	631.5006

S = $LSD_{T\leq0.05}$ = 76.3810 **R = ns** **SxR = ns**

4.3.3.2 Number of ears

Number of ears was not significantly influenced by the K-humate applications or soil textures (Appendix 4.31). Even though not significant, the number of ears was greater with a split application of 6 L K-humate ha^{-1} (3.9%) and a single application of 3 L K-humate (3%) when compared to the control (Table 4.16). The sandy clay loam and clay loam soils produced the greatest number of ears that exceeded the loamy sand soil with 9.1 to 9.8%.

Table 4.16 Number of ears (m^{-2}) as affected by different K-humate applications to three soils

Soil	K-humate application (L ha^{-1})				
	0 - control	**3 - single**	**3 - split**	**6 - split**	
S1	340.2530	371.9715	340.2530	363.3210	353.9496
S2	383.5055	397.9230	354.6705	418.1075	388.5516
S3	389.2725	377.7385	400.8065	377.7385	386.3890
	371.0103	382.5443	365.2433	386.3890	376.2968

S = ns **R = ns** **SxR = ns**

4.3.3.3 Spikelets per ear

The application of K-humate had no significant effect on the spikelets per ear (Table 4.17; Appendix 4.32).

Table 4.17 Number of spikelets per ear as affected by different K-humate applications to three soils

Soil	K-humate application (L ha^{-1})				
	0 - control	**3 - single**	**3 - split**	**6 - split**	
S1	14.9062	15.1778	15.4788	15.7173	15.3200
S2	15.0738	14.6586	14.2256	15.3910	14.8372
S3	13.5966	14.2305	13.8765	13.3412	13.7612
	14.5255	14.6890	14.5270	14.8165	14.6395

S = $LSD_{T\leq0.05}$=1.3045 **R = ns** **SxR = ns**

A small increase in the of spikelets per ear with the 6 L K-humate ha^{-1} split application (2%) and the 3 L K-humate ha^{-1} single application (1.1%) was noted. Once more, soil type had a significant influence on the spikelets per ear with the clay loam producing 10.2% less than loamy sand.

4.3.3.4 Kernels per ear

Kernels per ear were not significantly influenced by the application of K-humate (Appendix 4.33). The greatest number was recorded with the control treatment. Soil texture however, had a significant effect on the kernels per ear where the greatest number was counted on the loamy sand soil and this was significantly greater than that of the clay loam soil.

Table 4.18 Number of kernels per ear as affected by different K-humate applications to three soils

Soil	K-humate application (L ha^{-1})				
	0 - control	**3 - single**	**3 - split**	**6 - split**	
S1	37.5641	37.6491	38.4456	38.1324	37.9478
S2	37.0786	34.7936	32.5050	36.4820	35.2148
S3	31.8076	32.2255	31.4173	31.3153	31.6914
	35.4834	34.8894	34.1226	35.3099	34.9513

S = $LSD_{T\leq0.05}$=3.5023 **R = ns** **SxR = ns**

4.3.3.5 Seed yield per ear

Seed yield per ear was determined by dividing seed mass by the number of ears. This is an indication of how every ear responded to K-humate application and once more no significant change in this parameter was found (Appendix 4.30). The control treatment produced the highest seed mass per ear and the application of K-humate had neither a positive nor negative effect.

Soil type significantly influenced seed yield per ear (Table 4.19; Appendix 4.34). The loamy sand soil resulted in the highest seed yield per ear, followed by the sandy clay loam soil with a decrease of 8.9% and then the clay loam soil with a 19.4% decrease.

Table 4.19 Seed yield per ear (g ear^{-1}) as affected by different K-humate applications to three soils

Soil	K-humate application (L ha^{-1})				
	0 - control	**3 - single**	**3 - split**	**6 - split**	
S1	1.8529	1.8429	1.9374	1.8225	1.8639
S2	1.7738	1.6804	1.6267	1.7112	1.6980
S3	1.5060	1.5314	1.4444	1.5249	1.5017
	1.7109	1.6849	1.6695	1.6862	1.6879

S = $LSD_{T\leq0.05}$=0.1728 **R = ns** **SxR = ns**

4.3.3.6 Thousand kernel mass

Neither the application of K-humate, nor soil type had a significant effect on thousand kernel mass (Table 4.20; Appendix 4.35). This was expected since thousand kernel mass is one of the quality parameters of wheat, genetically determined, and is only to a small extent influenced by the environment or production factors (Bahrani *et al*., 2007).

Table 4.20 Thousand kernel mass (g) as affected by K-humate applications to three soils

Soil	K-humate application (L ha^{-1})				
	0 - control	**3 - single**	**3 - split**	**6 - split**	
S1	49.3056	48.9326	50.3367	47.7908	49.0914
S2	47.6605	48.4405	50.2614	46.9147	48.3193
S3	47.3830	47.5426	46.1185	48.7794	47.4559
	48.1164	48.3052	48.9055	47.8283	48.2889

S = ns **R = ns** **SxR = ns**

4.4 Conclusion

Wheat yield and quality need to be enhanced to meet the demands of the South African market so that importation can be reduced. In order to enhance yield and quality all possible resources must be exploited to its full potential and soil is one but it also has to be protected. Soil organic matter is essential for wheat production and K-humate can be used to increase organic matter in soil (Almedros *et al*., 2005). Commercial products like K-humate can influence wheat growth in a direct or an indirect manner by improving soil structure or by facilitating nutrient uptake by plants.

Even though K-humate, with the exception of tiller number at stem elongation did not significantly increased any of the measured plant parameters in this experiment a positive effect was noticed. Leaf area and above-ground mass increased slightly with K-humate application to soil. Root mass and length also showed positive effects. A split application

whereof half of the K-humate is applied at planting and the other half at tillering showed the best results. The positive influence of humic acids on plant growth and productivity seems to be concentration specific. Humic acids have an influence on plants through their effect on cell respiration, photosynthesis, oxidative phosporylation, protein synthesis and various enzymatic reactions (Arancon *et al*., 2002).

The results evolved from this glasshouse study justify further investigation to establish whether K-humate when applied to soil is beneficial for wheat production under irrigation or not.

Chapter 5

Irrigated wheat growth and yield response to potassium humate under field conditions

5.1 Introduction

Wheat is one of the most important grain crops grown throughout the world but also in South Africa (Tavakkoli & Oweis, 2004; NDA, 2007). Unfortunately, the economic sustainable production of wheat is currently questionable in South Africa. The optimisation of controllable factors such as the use of water and the efficient uptake and utilization of fertilisers has become essential in an effort to minimise risk and increase crop yield and quality.

The continued cultivation of arable land enforced a rapid decline in soil fertility and became a threat to sustainable crop production as a result of overall degradation in soil quality over time (Gajri *et al*., 2002). In an attempt to prevent a decrease in soil fertility inorganic fertilisers are applied to address the withdrawal of nutrients with the removal of either grain and/or residues. Through this process soil fertility has to be maintained or even build-up in time. The application of inorganic fertilisers is only addressing soil fertility but a more holistic approach is needed to better soil quality. This includes the improvement of soil biological, chemical and physical characteristics.

Improvement of soil biology can be achieved through the application of organic amendments. Not only is the soil microflora affected but these amendments also act as a source of nutrients and it improves soil structure (Charest *et al*., 2004; Pérez-Piqueres *et al*., 2005; Mackowiak *et al*., 2001). Organic amendments also include humic substances. These humic substances have also been claimed to improve the soil cation exchange capacity (CEC), pH buffer capacity, nutrient availability and absorption by plants (Vallini *et al*., 1993; Ayosu *et al*., 1996, Pertusatti & Prado, 2007). Hence, by promoting soil fertility crop growth and response would also be affected.

Marked crop growth response was documented when humic substances were applied to soils low in organic matter and clay (Lulakis & Petsas, 1995; Aroncon, 2002). Generally

root growth response exceeded that of shoot growth. Root development and the distribution thereof is of utmost importance in the uptake of water and effective nutrient absorption (Nardi *et al*., 2002; Zuo *et al*., 2004). Though humic substances influences water and nutrient uptake as a soil amendment, Delfine *et al*. (2005) found that wheat plants reacted positively to humic acids, a fraction of humic substances. These acids are applied as a foliar spray in times of water shortages. Foliar application of humic acids may also be used as a source of foliar fertilization and can act as a source of nitrogen at grain filling (Delfine *et al*., 2005). It can be assumed that humic acids may influence the quality of grain since nitrogen affects the protein content when applied later than stem elongation.

The question arises: can humic acids influence crop growth, yield and grain quality when either bandplaced or topdressed with granular fertilisers as a coating? Hence this investigation was done to establish the response to a commercial K-humate product applied in this manner.

5.2 Materials and methods

5.2.1 Experimental site

Two field experiments was conducted during the 2006 season at the Kenilworth Field Research Facility of the Department of Soil, Crop and Climate Sciences, University of the Free State near Bloemfontein ($29^0$01’00’’ S, $26^0$08’50’’ E). The soil used is a red loamy sand Bainsvlei Amalia according to the Soil Classification Working Group (1991). The topsoil has a clay content of 8% and that of the subsoil 10%. A representative soil sample of the experimental site was collected and analysed by Omnia Nutriology^{TM} using standard procedures. The results are summerised in Table 5.1.

A spring type wheat cultivar, Baviaans, was selected on its high yielding ability and adaptability to the irrigation conditions of the summer rainfall regions of South Africa. This cultivar also exhibits a great hectoliter mass, tillering ability, sprouting resistance and straw strength. The latter is of great importance to counteract lodging during the grain filling and mature growth stages. Regarding diseases it is susceptible to stem rust, moderately susceptible to leaf rust and scab but resistant against stripe rust (ARC – Small Grain Institute, 2007). The recommended planting date is 1 to 30 June and this experiment was planted on the 4th of July. A John Deere 450 Grain Drill with 0.2 m row spacing was

used to plant the experiment. Two plant densities were selected according to the yield potential expected with 350 mm supplemental irrigation (Experiment 1) and with 700 mm full irrigation (Experiment 2). The yield potentials were 4 and 8 t ha^{-1} and the corresponding seeding rates 60 and 100 kg seed ha^{-1}.

Table 5.1 Chemical soil properties of the topsoil (0 – 300 mm) and the subsoil (300 – 600 mm)

Property		**Topsoil**	**Subsoil**
Nutrients	(mg kg^{-1})		
P	(Bray 1)	17	20
K	(NH_4OA_C)	198	356
Ca	(NH_4OA_C)	582	480
Mg	(NH_4OA_C)	181	181
Na	(NH_4OA_C)	36	12
Zn	(Melich 3)	0.3	0.3
Fe	(Melich 3)	49	57
Mn	(Melich 3)	45	44
Cu	(Melich 3)	0.2	0.3
B	(Warm water)	0.12	0.17
S	($Ca(H_2PO_4)_2$)	56	111
Ratios			
(Ca/Mg)		1.96	1.62
(Ca+Mg)/K		8.68	4.27
pH (KCl)	(KCl)	6.4	4.5
Org C	(m/m)	0.19	0.39
CEC	(%)	5.06	4.99

Irrigation was applied with a line source irrigation system. With this system plots further away from the sprinkler line received progressively less water. Therefore, all the plots parallel to the sprinkler line received the same amount of water (Willardson *et al*., 1987). Plots next to the line received 700 mm irrigation and plots 7 m away from the line received 350 mm irrigation. Irrigation scheduling was done according to the BEWAB model (Bennie *et al*., 1988). The scheduling is summarised in Table 5.2

Table 5.2 Water applied according to the BEWAB model (Bennie *et al*., 1988).

Days after plant	Irrigation (mm)	Rain (mm)	Total (mm)
10	3	0	3
17	6	0	6
24	9	0	9
31	12	0	12
38	16	0	16
45	22	0	22
52	27	0	27
59	33	0	33
66	38	0	38
73	29	15	44
80	44	5	49
87	53	0	53
94	56	0	56
101	48	10	58
108	32	26	58
115	47	10	57
122	44	10	54
129	41	8	49
136	0	85	85
143	0	20	20
150	18	0	18
Total	578	189	767

The experiment was laid out as a randomised block design consisting of one main factor *viz*. seven K-humate applications (0 L ha^{-1} control, 1.5, 3, 5 and 6 L ha^{-1} single applications, and 5 and 6 L ha^{-1} split applications) replicated four times. This lay-out was used for both irrigation levels and observations were maid at three growth stages (tillering – G5; stem elongation – G10 and maturity – G25) to evaluate crop growth response.

Fertilisation was based on the 4 t ha^{-1} yield potentials for the 350 mm supplemental irrigation and the 8 t ha^{-1} yield potential for the 700 mm full irrigation with 0.2 m row spacings for both. The K-humate treatments were applied as coatings on the fertiliser granules. Single applications were band applied at planting whereas split applications were band applied at planting (50%) and topdressed at tillering (50%). The time, source, method and rate of fertiliser application is summerised in Tables 5.3 and 5.4.

Table 5.3 Time, source, method and rate of fertiliser application for 350 mm supplemental irrigation experiment

Time of application	**Source**	**Method of application**	**Rate (kg ha^{-1})**	**Contribution for each element**		
				N	**P**	**K**
Pre plant	Greensulph (27)	Incorporated in soil	104	28.08		
At plant	2:3:2 (22)	In band (coated)	266	16.72	25.08	16.72
Tillering	Greensulph (27)	Topdressed (coated)	111	29.97		
Total				74.77	25.08	16.72

Table 5.4 A summary of the time, source, rate and method for N, P and K application with a 0.2 m row spacing at 700 mm water

Time of application	**Source**	**Method of application**	**Rate (kg ha^{-1})**	**Contribution for each element**		
				N	**P**	**K**
Pre plant	Greensulph (27)	Incorporate in soil	370	100		
At plant	2:3:2 (22)	In band (coated)	320	20.11	30.17	20.11
Tillering	Greensulph (27)	Topdressed (coated)	111	29.97		
Flag leaf	Greensulph (27)	Topdressed	111	29.97		
Total				180.05	30.17	20.11

Pests and diseases were controlled when necessary. Aphids were controlled twice with a cover spray application using *Oxydemeton-methyl* 250 ai L^{-1} (Metasystox® R 250 EC) at a rate of 500 m*l* ha^{-1}.

5.2.2 Observations

5.2.2.1 Growth response parameters

1. Chlorophyll florescence (SPAD units) – The chlorophyll florescence content was measured at tillering and stem elongation using a Minolta SPAD 502 PL chlorophyll meter.

2. Leaf area (cm^2m^{-2}) – A LICOR 3000 leaf area meter was used to determine the leaf area after it was cut just above the soil surface. Leaf area was measured at tillering and stem elongation by using only the leaf blades.
3. Total biomass (g m^{-2}) – Following the measuring of leaf area plants were dried at 60^oC until a constant water content and weighed.
4. Number of tillers (tillers m^{-2}) – The tillers of a 2 m row were counted at tillering and stem elongation.
5. Number of ears (ears m^{-2}) – The ears of 6 m^{-2} plot were counted at harvesting.
6. Number of spikelets (spikelets ear^{-1}) – The number of spikelets per ear was counted at harvesting.
7. Number of kernels (Kernels ear^{-1}) – The number of kernels per ear was counted at harvesting.
8. Seed mass (g ear^{-1}) – The seed mass per ear was determined after seed was dried to a constant moisture content.
9. Grain yield (g m^{-2}) – The seed mass of a 6 m^{-2} harvested plot was weighed after dried to a constant moisture content.

5.2.2.2 Grain quality parameters

Several qualitative parameters were analysed by the ARC-Small Grain Institute at Bethlehem. The method of analysis is either explained or the procedure is referred to as prescribed by the International Association of Cereal Chemistry and the American Association of Cereal Chemists.

1. Thousand kernel mass – Thousand kernel mass was determined by counting a thousand kernels with a Numigral Seed counter and weighed.
2. Falling number – ICC107/1.
3. Sedimentation volume – AACC 56 – 61 A.
4. Flour yield – AACC 26 – 50.
5. Flour protein content – AACC 39 – 11.
6. Mixograph mixing development time – AACC 54 – 40 A.

5.2.3 Statistical analyses

As described in section 5.2.1 a radomised block design consisting of one main factor, *viz.* seven K-humate applications replicated four times were used for each of the experiments. The data was analysed with the NCSS (Number Cruncher Statistical System) statistical package (Hintze, 1998). The least significant difference (LSD) was calculated at $P \leq 0.05$. This was done to compare the treatment means using the Tukey-Kramer multiple comparison test (Gomez & Gomez, 1984).

5.3 Results and discussion

A summary of the analyses of variance evaluating for each irrigation level the effect of K-humate application on the plant parameters at three growth stages is given in Table 5.5. All the analyses of variance are presented in Appendix 5.1 to 5.40. Growth response was evaluated at tillering, stem elongation and maturity whereas the quality parameters were only measured at maturity. Inspection of the results showed that with the exception of chlorophyll content at stem elongation for the 350 mm irrigation and dry matter production at tillering for the 700 mm irrigation K-humate as a main factor had no significant effect on the parameters.

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Table 5.5 Summary on analyses of variance indicating the effect of treatment factors on selected crop parameters at two irrigation levels

Factors	Chlorophyll content	Leaf area	Number of tillers and ears	Above ground wet mass	Above ground dry mass	Number of spikelets	Number of seeds	Seed mass	Total seed mass	Thousand kernel mass	Falling number	Sedimentation volume	Flour yield	Flour protein content	Mixograph mixing development time
350 mm															
Tillering	ns	ns	ns	ns	ns										
Stem elongation	*	ns	ns	ns	ns										
Maturity			ns		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
700 mm															
Tillering	ns	ns	ns	ns	*										
Stem elongation	ns	ns	ns	ns	ns										
Maturity			ns		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

* - $P \leq 0.05$

ns - not significant

5.3.1 Growth response parameters

5.3.1.1 Chlorophyll content

Wheat's chlorophyll content at stem elongation was significantly influenced by the K-humate treatments for the 350 mm irrigation level (Appendix 5.1 – 5.4). Despite of the significant difference shown by the analysis of variance no significant difference at $P \leq 0.05$ was found with the Tukey-Kramer test. This could be ascribed to the fact that the Tukey-Kramer test is strict and therefore we refered to the Fisher's test that is not as strict as the forementioned test. Fisher's test showed that a split application of 5 L K-humate ha^{-1} was the only treatment that significantly increased the chlorophyll content compared to the control (Table 5.6).

Table 5.6 Chlorophyll content at tillering and stem elongation as affected by K-humate application at two irrigation levels

Growth stage	Irrigation level (mm)	L K-humate ha^{-1}						
		0-single	1.5-single	3-single	5-single	6-single	5-split	6-split
Tillering	**350**	46.250	51.325	47.000	47.550	45.550	44.150	48.200
Stem elongation	**350**	56.275	55.250	50.450	52.250	52.300	56.925	53.575
Tillering	**700**	40.800	50.225	50.350	48.625	47.925	44.050	48.550
Stem elongation	**700**	52.200	50.950	53.750	50.725	49.575	53.675	53.200

T = K-humate application

Tillering = $T_{350\ mm}$ = ns **Tillering = $T_{700\ mm}$ = ns**
Stem elongation = $T_{350\ mm}$ $LSD_{F\leq0.05}$ = 1.5316 **Stem elongation = $T_{700\ mm}$ = ns**

Further evaluation of the data showed no clear tendency between K-humate treatments and chlorophyll content, except for the single 3 L K-humate application at the 700 mm irrigation level. This treatment resulted in the highest chlorophyll content at tillering and stem elongation compared to the control (Table 5.6).

Chlorophyll readings are often used to evaluate the crop status at a precise stage of the crop growth cycle. Soil plant analysis development (SPAD) readings are used to predict crop nitrogen fertiliser requirements before crop flowering. Recently it was also used at later growth stages to predict grain yield and grain protein concentration. These two parameters are sensitive to growth conditions after flowering has occurred. The SPAD values differ between different cultivars and should therefore be used with caution (Le Bail *et al.*, 2005).

5.3.1.2 Leaf area

Leaf area was not significantly influenced by the K-humate treatments for both irrigation levels (Appendix 5.5 – 5.8). For the lower irrigation level leaf area at tillering ranged from 4911 cm^2cm^{-2} with the 3 L K-humate ha^{-1} single application to 7401 cm^2cm^{-2} with the 1.5 L K-humate single application (Table 5.7). At stem elongation leaf area varied from 7692 cm^2cm^{-2} with the 3 L K-humate single application to 10 214 cm^2cm^{-2} with the 5 L K-humate single application. Hence no similarities were found at the two growth stages for leaf area as a result of the K-humate treatments. In contrast to this it seems that for the higher irrigation level K-humate treatments inhibited leaf area at both growth stages as the control resulted in the highest leaf area, *viz.* 14 383 cm^2cm^{-2} at tillering and 15 852 cm^2cm^{-2} at stem elongation.

Table 5.7 Leaf area (cm^2m^{-2}) at tillering and stem elongation as affected by K-humate application at two irrigation levels

Growth stage	Irrigation level (mm)	L K-humate ha^{-1}						
		0-single	1.5-single	3-single	5-single	6-single	5-split	6-split
Tillering	**350**	7214.700	7401.431	4911.900	6751.544	6366.500	5305.913	4994.219
Stem elongation	**350**	9078.013	8433.688	7671.913	10214.420	8082.513	8037.587	9253.750
Tillering	**700**	14382.610	12201.350	10372.620	11046.850	9475.956	9934.831	9582.544
Stem elongation	**700**	15851.460	15158.340	14174.400	15307.710	13401.390	13923.110	13939.010

Tillering = $T_{350\ mm}$ = ns **Tillering = $T_{700\ mm}$ = ns**
Stem elongation = $T_{350\ mm}$ = ns **Stem elongation = $T_{700\ mm}$ = ns**

Since the yield potential of wheat is determined by light interception when the crops nutrient and water supply is at an optimum, it is important that the crop canopy closes up as soon as possible after crop establishment (Hsu & Walton, 1969; Soltani & Galeshi, 2002). Unfortunately leaf area is not just determined by factors such as nutrient and water supply but is also dependent on the rate of leaf emergence, crop phenology, potential leaf size as well as stem morphology (Royo *et al.*, 2004). Therefore, any factor that could contribute to an enlarged leaf area should be exploited even with the slightest increase. Indications from literature stated that the applications of humic acids prove to stabilise or increase crop growth and yield when plants were subjected to unfavorable conditions (Chen *et al.*, 2004). From these experiments no beneficial influence was observed at 700 mm irrigation but signs of an enlarged leaf area was found at 350 mm of irrigation. This could be an indication of K-humate assisting plant growth at lower water application.

5.3.1.3 Dry matter

Above-ground dry matter production was, with exception to the tillering stage at the 700 mm irrigation level not significantly affected by the K-humate treatments (Appendix 5.9 – 5.14). At tillering the greatest dry matter production was obtained with the control treatment whereas the K-humate treatments produced lower dry matter yields. A significant lower dry matter production was measured at the 700 mm irrigation level with the split application of 5 L K-humate ha^{-1} compared to the control (Table 5.8).

Table 5.8 Above ground dry mass (g m^{-2}) at tillering, stem elongation and maturity as affected by K-humate application at two irrigation levels

Growth stage	Irrigation level (mm)	L K-humate ha^{-1}						
		0-single	1.5-single	3-single	5-single	6-single	5-split	6-split
Tillering	**350**	77.3250	62.0188	56.7375	67.4625	63.7750	55.0938	50.8563
Stem elongation	**350**	330.2687	332.5375	295.1875	362.1812	300.7563	276.8312	309.9250
Maturity	**350**	576.7857	470.5357	523.2143	591.0714	555.3572	521.4286	490.1786
Tillering	**700**	135.2375	100.7750	94.0938	99.2313	89.6875	71.3000	83.7938
Stem elongation	**700**	465.4562	488.6437	392.4063	488.5750	379.1875	461.5562	442.8188
Maturity	**700**	977.6786	986.6071	942.8571	875.0000	843.7500	922.7679	822.3214

Tillering $= T_{350\ mm}$ **= ns** **Tillering** $= T_{700\ mm}$ $LSD_{T\leq0.05}$ **= 52.998**
Stem elongation $= T_{350\ mm}$ **= ns** **Stem elongation** $= T_{700\ mm}$ **= ns**
Maturity $= T_{350\ mm}$ **= ns** **Maturity** $= T_{700\ mm}$ **= ns**

At stem elongation and maturity dry matter production was not as negatively affected as at tillering. Dry matter production at both growth stages showed insignificant reductions and increases on accounts of the K-humate treatments regardless of the irrigation level. Hence it is impossible to conclude on dry matter production at stem elongation and maturity whether the K-humate treatments were beneficial or not.

Researchers found that above-ground dry matter yield is mainly a function of leaf size or area. In an attempt to increase dry matter the objective of plant breeders should therefore be to increase leaf area (Hsu & Walton, 1969; Lawless *et al*., 2004). A greater leaf area and thus dry matter yield could ultimately increase grain yield (Arduini *et al*., 2006). Data from this experiment generally showed a decrease in dry matter production due to the K-humate treatments. This was also observed for leaf area and therefore the use of K-humate to increase dry matter and leaf area is questionable (Section 5.3.1.2).

5.3.1.4 Number of tillers and ears

Tillers were counted at tillering and stem elongation whereas ears only at maturity. These parameters are indicators of the potential yield of wheat and form part of yield components that attribute to the final yield (ARC – Small Grain institute, 2007). The K-humate treatments did not significantly influence tiller number at both tillering and stem elongation regardless irrigation levels (Appendix 5.15 – 5.16 and 5.18 – 5.19). In all instances the control produced the highest number of tillers (Table 5.8).

Table 5.9 Number of tillers (m^{-2}) at tillering and stem elongation and ears (m^{-2}) at maturity as affected by K-humate application at two irrigation levels

Growth stage	Irrigation level (mm)	L K-humate ha^{-1}						
		0-single	1.5-single	3-single	5-single	6-single	5-split	6-split
Tillering	**350**	640.6250	626.2500	503.1250	588.1250	561.8750	475.0000	493.1250
Stem elongation	**350**	347.5000	310.0000	310.0000	346.2500	301.2500	288.7500	325.6250
Maturity	**350**	232.1875	210.5804	223.8839	229.8214	223.4375	206.6964	215.0893
Tillering	**700**	1048.1250	900.0000	835.6250	834.3750	848.7500	779.3750	798.7500
Stem elongation	**700**	572.5000	545.6250	441.8750	498.1250	510.0000	508.1250	446.8750
Maturity	**700**	386.1607	390.5357	358.5714	346.5625	351.4286	343.4821	341.2054

Tillering = $T_{350\ mm}$ = ns **Tillering = $T_{700\ mm}$ = ns**
Stem elongation = $T_{350\ mm}$ = ns **Stem elongation = $T_{700\ mm}$ = ns**
Maturity = $T_{350\ mm}$ = ns **Maturity = $T_{700\ mm}$ = ns**

The number of ears at maturity was also not significantly influenced by the K-humate treatments at either the 350 and 700 mm irrigation levels (Appendix 5.17 and 5.20). It has to be noted that the ear count at maturity was 70% of the tiller count at tillering. This reduction in tiller count is attributed to the abscission of tillers with crop growth and development. Additional tillers are initiated during tillering and this is an ongoing process but resources become limited with crop growth and the youngest tillers will die back in order of appearance (Sharma, 1994; Satorre & Slafer, 1999). This was once more found in this experiment and it was evident that the application of K-humate was not able to reverse this process.

5.3.1.5 Spikelets per ear

Spikelets per ear was not significantly influenced by the K-humate treatments (Appendix 5.21 and 5.22). The control treatment of the 350 mm irrigation level resulted in 16.4 spikelets per ear and not one of the K-humate treatments exceeded this. However, at the

700 mm irrigation level the 15.6 spikelets per ear of the control treatment was exceeded with 3.7 % by that of the 5 L K-humate ha^{-1} single application (Table 5.10).

Table 5.10 Number of spikelets (ear^{-1}) at maturity as affected by K-humate application two irrigation levels

Irrigation level (mm)	L K-humate ha^{-1}						
	0-single	**1.5-single**	**3-single**	**5-single**	**6-single**	**5-split**	**6-split**
350	16.375	15.750	15.750	15.975	16.325	16.025	15.575
700	15.625	15.450	14.775	16.200	15.225	15.625	15.225

Maturity $= T_{350\ mm}$ = ns **Maturity $= T_{700\ mm}$ = ns**

5.3.1.6 Kernels per ear

The K-humate treatments showed no significant influence on kernel number (Appendix 5.23 and 5.24). Either insignificant increases or reductions in the kernels per ear were counted on account of the K-humate treatments at the 350 mm irrigation level. However, at the 700 mm irrigation level kernels per ear was with the exception of 6 L K-humate ha^{-1} single application increased by the other K-humate treatments compare to the control (Table 5.11). The kernels per ear was greatest with the 5 L K-humate ha^{-1} single application which exceeded that of the control with 8.5%.

The number of spikelets and kernels number per ear are interrelated (Pithus, 1967). Consequently an increase in spikelets will result in more kernels per ear and eventually a greater yield. This was proved by the 3.7% increase in spikelets per ear (section 5.3.1.5) and the 8.5% increase in kernels per ear with the 5 L K-humate ha^{-1}single application at the 700 mm irrigation level.

Table 5.11 Number of kernels (ear^{-1}) at maturity as affected by K-humate application at two irrigation levels

Irrigation level (mm)	L K-humate ha^{-1}						
	0-single	**1.5-single**	**3-single**	**5-single**	**6-single**	**5-split**	**6-split**
350	29.275	28.425	28.225	29.775	29.125	29.850	26.375
700	29.500	29.725	30.675	32.000	28.700	29.600	31.775

Maturity $= T_{350\ mm}$ = ns **Maturity $= T_{700\ mm}$ = ns**

5.3.1.7 Seed mass per ear

Similar to previous parameters no significant change in seed mass per ear was found as a result of the different K-humate treatments (Appendix 5.25 and 5.26). At the 350 mm irrigation level the greatest seed mass per ear was recorded with the control treatment. Compared to the control of the 700 mm irrigation level the 5 L K-humate ha^{-1} single application increased seed mass per ear with 6.3% (Table 5.12). As discussed in the previous section such an increase was predictable.

Table 5.12 Seed mass (g per ear) at maturity as affected by K-humate application at two irrigation levels

Irrigation level (mm)	L K-humate ha^{-1}						
	0-single	1.5-single	3-single	5-single	6-single	5-split	6-split
350	1.3148	1.2345	1.2198	1.253	1.2926	1.3057	1.1001
700	1.3201	1.3298	1.3865	1.4028	1.2863	1.3384	1.3990
Maturity	$= T_{350\ mm} = ns$			Maturity	$= T_{700\ mm} = ns$		

5.3.1.8 Grain yield

The grain yield was not significantly influenced by the K-humate treatments (Appendix 5.27 and 5.28). At the 350 mm irrigation level the control product produced the greatest grain yield, *viz.* 247 g m^{-2}. Only the 3 L K-humate ha^{-1} single application produced a 2.6% greater grain yield than the control at the 700 mm irrigation (Table 5.13).

Table 5.13 Grain yield (g m^{-2}) at maturity as affected by K-humate application two irrigation levels

Irrigation level (mm)	L K-humate ha^{-1}						
	0-single	1.5-single	3-single	5-single	6-single	5-split	6-split
350	247.0344	191.8656	213.0357	237.1080	218.3884	223.6429	188.6165
700	397.3058	392.6746	407.4777	369.3335	350.6897	392.0638	350.7134
Maturity	$= T_{350\ mm} = ns$			Maturity	$= T_{700\ mm} = ns$		

From section 5.3.1.4 to 5.3.1.6 it is clear that the 5 L K-humate ha^{-1} single application at the 700 mm irrigation level increased spikelet and kernel number and consequently seed mass per ear. This was not found for grain yield which was approximately 10% lower than the control. The primary reason for this phenomenon could be ascribed to a lower tiller and ear count (section 5.3.1.4) that resulted in a lower grain yield. Wheat grain yield is

dependent on the number of spikes, number of kernels per spike and the weight of the kernels. These components are co-dependent on one another in order to stabilise yield as cultural and climate conditions tend to change over time (Arduini *et al*., 2006).

5.3.2 Grain quality parameters

5.3.2.1 Thousand kernel mass

At both irrigation levels thousand kernel mass was not influenced by the K-humate treatments (Appendix 5.29 and 5.30). The highest thousand kernel mass at the 350 mm irrigation level was found with the 6 L K-humate ha^{-1} single application and this was just slightly higher than that of the control. At the 700 mm irrigation level the highest thousand kernel mass was obtained with the 5 L K-humate ha^{-1} split application which was 5.57% higher than that of the control (Table 5.14).

Table 5.14 Thousand kernel mass (g) at maturity as affected by K-humate application at two irrigation levels

Irrigation level (mm)	**L K-humate ha^{-1}**						
	0-single	**1.5-single**	**3-single**	**5-single**	**6-single**	**5-split**	**6-split**
350	44.1250	44.0225	44.0275	43.0625	44.1575	41.1500	41.8525
700	44.5825	45.0950	45.1725	45.8700	44.9675	47.0650	44.5850

Maturity = $T_{350\ mm}$ = ns **Maturity = $T_{700\ mm}$ = ns**

Thousand kernel mass is a good indication of the wheat milling potential and in South Africa it is most favorable to produce grain with a thousand kernel mass higher than 32 gram (Koen, 2006). All the grain samples tested produced thousand kernel masses well above this minimum level.

5.3.2.2 Falling number

K-humate treatments did not significantly influenced the falling number at any of the two irrigation levels (Appendix 5.31 and 5.32). The falling number at the 350 mm irrigation level ranged from 408 with either the 1.5 L K-humate ha^{-1} single application or the 5 L K-humate ha^{-1} split application to 414 with the 5 L K-humate ha^{-1} single application. At 700 mm irrigation level the falling number varied from 410 with the 5 L K-humate ha^{-1} split application to 413 with the 3 L K-humate ha^{-1} single application (Table 5.15). These inconsistencies hindered any conclusion whether K-humate is beneficial or not.

Table 5.15 Falling number (s) at maturity as affected by K-humate application at two irrigation levels

Irrigation level (mm)	L K-humate ha^{-1}						
	0-single	**1.5-single**	**3-single**	**5-single**	**6-single**	**5-split**	**6-split**
350	410.7500	408.2500	409.7500	413.7500	409.0000	408.2500	410.7500
700	411.7500	407.5000	413.2500	411.2500	411.5000	410.2500	412.0000

Maturity = $T_{350\ mm}$ = ns **Maturity = $T_{700\ mm}$ = ns**

5.3.2.3 Sedimentation volume

The K-humate treatments had no significant effect on the sedimentation volume at both irrigation levels (Appendix 5.33 and 5.34). At the 350 mm irrigation level sedimentation volume ranged from 81.75 ml with the 5 L K-humate ha^{-1} single application to 83.00 ml with the 5 L K-humate ha^{-1} split application. Sedimentation volume at the 700 mm irrigation level varied from 78.00 ml with the control to 81.00 ml with the 6 L K-humate ha^{-1}single application (Table 5.16). Noteworthy is that the sedimentation volumes of the K-humate treatments at the 350 mm irrigation level exceeded that of the corresponding K-humate treatments at the 700 mm irrigation level. A sedimentation volume of 70 ml or higher is an indication of high protein wheat with immense baking quality (Koen, 2006). Hence the wheat from all the treatments easily fulfill this requirement.

Table 5.16 Sedimentation volume (ml) at maturity as affected by K-humate application at two irrigation levels

Irrigation level (mm)	L K-humate ha^{-1}						
	0-single	**1.5-single**	**3-single**	**5-single**	**6-single**	**5-split**	**6-split**
350	82.5000	82.0000	82.7500	81.7500	82.2500	83.0000	82.2500
700	78.0000	79.5000	79.2500	80.0000	81.0000	79.2500	80.0000

Maturity = $T_{350\ mm}$ = ns **Maturity = $T_{700\ mm}$ = ns**

5.3.2.4 Flour yield

Flour yield is an important measuring of milling quality (Mason *et al*., 2007). The application of K-humate did not succeed in increasing this parameter (Table 5.17) significantly over that of the control (Appendix 5.35 and 5.36).

Table 5.17 Flour yield (%) at maturity as affected by K-humate application at two irrigation levels

Irrigation level (mm)	L K-humate ha^{-1}						
	0-single	**1.5-single**	**3-single**	**5-single**	**6-single**	**5-split**	**6-split**
350	70.1192	69.5957	69.7746	69.8307	69.2575	70.1749	68.5435
700	69.8550	70.1725	69.8400	70.5625	70.7950	69.9225	69.2650
Maturity	**= $T_{350\ mm}$= ns**			**Maturity**	**= $T_{700\ mm}$ = ns**		

5.3.2.5 Flour protein content

Protein content is one of the most important parameters used to determine the quality of wheat and is of high value for the end use of wheat (Arduini *et al*., 2006). This is because protein gives strength to the dough and is important to trap CO_2 during the fermentation process. Usually a protein content of between 10.5 and 13.5% is required for this purpose (Van Lill & Purchase, 1995; Mason *et al*., 2007). All of the treatments yielded a protein content higher than the minimum required (Table 5.18) but no significant differences were obtained with the K-humate applications (Appendix 5.37 and 5.38). Protein content is genetically controlled but factors such as cultivar, location, soil fertility and environment conditions can have an influence on the protein content. Nitrogen plays especially a vital role in protein content and thus by improving soil fertility grain protein content can be enhanced (Metho, 1999). Grain protein decline as seeding rate increase and a reason for this can be because of the greater competition for nitrogen among plants (Arduini *et al*., 2006). This was not found in this study because the protein content for corresponding K-humate treatments was higher at the 700 mm irrigation level with a 100 kg ha^{-1} seeding rate than the 350 mm irrigation level with a 60 kg ha^{-1} seeding rate. The only exception was with the 5 L K-humate ha^{-1} single application.

Table 5.18 Flour protein content (12% m.b.) at maturity as affected by K-humate application at two irrigation levels

Irrigation level (mm)	L K-humate ha^{-1}						
	0	**1.5**	**3**	**5**	**6**		**3 + 3**
350	13.5750	13.8500	13.7750	13.9500	13.6750	13.6250	13.5250
700	14.2000	14.0250	13.9500	13.8500	13.9250	14.0000	13.9500
Maturity	**= $T_{350\ mm}$ = ns**			**Maturity**	**= $T_{700\ mm}$ = ns**		

5.3.2.6 Mixograph mixing development time

Mixograph mixing development time was also not significantly influenced by the K-humate treatments at both irrigation levels (Appendix 5.39 and 5.40). In South Africa a mixing development time of 2.5 min is recommended but a variation of 2 to 3 min are allowed (Koen, 2006). Evaluation of the data revealed that the mixing time of all the treatments at the 350 mm irrigation level were within the set parameters. At the 700 mm irrigation level neither the 5 L K-humate ha^{-1} split application nor the 6 L K-humate ha^{-1} single application meet the required standards (Table 5.19)

Table 5.19 Mixograph mixing development time (min) at maturity as affected by K-humate application at two irrigation levels

Irrigation level (mm)	**L K-humate ha^{-1}**						
	0	**1.5**	**3**	**2.5 + 2.5**	**5**	**3 + 3**	**6**
350	2.2000	2.1500	2.1750	2.2000	2.1500	2.1750	2.2000
700	2.0500	2.0250	2.0250	1.9500	1.9750	2.0250	1.8750
Maturity	**= $T_{350\ mm}$ = ns**			**Maturity**	**= $T_{700\ mm}$ = ns**		

5.4 Conclusion

Generally, application of K-humate did not influence wheat growth, yield and quality parameters significantly. The only significant increases found were with the chlorophyll content and above-ground mass. It seems however that K-humate had a greater influence on wheat growth at the 350 mm irrigation level, thus where wheat plants experience some kind of stress. No consistency was found with the K-humate treatments and it is difficult to deduct that one specific application always produced better results than the control or other treatments. The application of K-humate had also no significant influence on wheat quality.

Chapter 6

Summary and recommendations

Generally South African soils are low in organic matter content (Karaca *et al*., 2006) and the continuous cultivation of these soils lead to an inevitable degradation of soil quality (Dominy & Hayes, 2002). Unfortunately no fertiliser is able to substitute organic matter loss in soil (Pera *et al*., 1983). However, according to literature, some soil amendments like commercially available humic substances could enhance soil quality in the sense that it act similarly to humus in the soil. In this context, a growth chamber experiment was conducted to evaluate the response of biologically and chemically soil properties to K-humate application. Both glasshouse and field experiments were conducted to evaluate the growth and yield response of irrigated wheat to K-humate application.

- A pot experiment was conducted with 5 L pots each filled with 8.4 kg of this red loamy Bainsvlei topsoil. The biological properties were tested through integrated treatments consisting of two main factors *viz*. products (K-humate, SG/2004/36/05 and SG/2004/37/05) and application rates (0, 3 and 5 L ha^{-1}), replicated four times. Treatments were bandplaced on top of the soil for 0.2 m spacings. Pots were watered and maintained at field capacity for six weeks while incubated in growth chambers at a constant humidity of 60% and a day/night temperature regime of 25/15^{o}C. Soil samples (cores – 40 g) were randomly taken on a weekly basis from the 0 – 100 mm and 100 – 200 mm layers. Bacteria and fungi were microscopically quantified by Omnia Nutriology^{TM}.

Both bacteria and fungal response showed differences in the products used at different application rates. Inconsistent responses made it difficult to conclude if any of the products at a specific rate was superior to the other. Both bacterial and fungal growth was stimulated by the application of products for the first two to three weeks with K-humate and SG/2004/36/05 superior to SG/2004/37/05. Bacterial growth was reduced and fungal growth marginally increased two weeks after application of the products, but both their response stabilized two to three weeks after product application with no differences between products.

The chemical properties were tested with the application of K-humate as a coating on granular 2:3:2 (22) fertiliser at a rate of 0 and 3 L ha^{-1}. This was banded at a depth of 50 mm below the soil surface. Theses pots (5 L) were also watered and kept at the same conditions as explained for the biological properties. The duration of this experiment was five months after which a 100 g of soil was sampled from the middle of each pot at 0 – 100 mm and 100 – 200 mm soil depths and send for analyses by Omnia Nutriology™. No significant response of the chemical soil properties was observed and this was conflicting to previous work.

- A glasshouse pot experiment (40.5 L pots) was conducted to evaluate the effects of K-humate treatments on wheat (cv. Baviaans) growth and yield response. Fertilisation was based on the soil analysis and yield potential of 8 t ha^{-1}. K-humate treatments were applied to the soil as coatings on the granular fertiliser either as a single application (100% at planting) or a split application (50% at planting and 50% at tillering – K-humate as a coating on granular Greensulph (27)). The experiment was laid out as a complete randomised block design with a factorial combination consisting of two main factors *viz*. three textural classes (8, 22 and 37% clay) and four K-humate applications (0 L ha^{-1} – control, 3 L ha^{-1} – single application, and 3 and 6 L ha^{-1} – split applications). The effects of K-humate on wheat growth were evaluated at tillering, stem elongation and maturity. Every treatment combination was replicated three times.

At tillering leaf area was significantly influenced by the soil and application rate interaction. Tiller number was also significantly influenced by soil texture used. All the other growth parameters were not significantly influenced by soil and or K-humate application rate.

At stem elongation K-humate application rate significantly influenced tiller number. Soil texture used had a significant effect on tiller number, root mass in the fertilised zone, and root mass and root length in the unfertilised zone. All other growth parameters were not significantly influenced.

The growth and yield parameters were not significantly influenced by the K-humate application rate and soil interaction at maturity. Soil texture was the only variable factor

that significantly influenced root mass in the fertilised zone, root mass in the unfertilised zone, total root mass, root length in the fertilised zone, root length in the unfertilised zone, seed yield, number of spikelets per ear, number of kernels per ear and yield per ear. Even though K-humate did not significantly increased any of the measured plant parameters a positive effect was noticed.

- Two field experiments were conducted to evaluate the effect of K-humate on supplementary (350 mm) and full (700 mm) irrigated wheat. Two plant densities (60 and 100 kg seed ha^{-1}) were selected with yield potentials set at 4 t ha^{-1} and 8 t ha^{-1} for the supplementary and full irrigations respectively. The experiment was laid out as a randomised block design consisting of one main factor *viz*. seven K-humate applications (0 L ha^{-1} – control, 1.5, 3, 5 and 6 L ha^{-1} – single applications and 5 and 6 L ha^{-1} split applications), replicated four times. Fertilisation was based on the soil analysis and the respective yield potentials for the two irrigation levels. K-humate treatments was band placed as coatings on the granular fertiliser as single applications (100% at planting) or as split applications (50% at planting and 50% topdressed at tillering). Observations were done at tillering, stem elongation and maturity to evaluate crop growth and yield response.

The chlorophyll content was significantly influenced by the K-humate application at tillering with the 350 mm supplementary irrigation. All the other growth and yield parameters with the 350 mm supplementary irrigation were not significantly influenced by K-humate application.

Only above ground dry mass with 700 mm irrigation was also significantly influenced by the K-humate application at tillering. All the other growth and yield parameters were not significantly influenced. Therefore, it could be concluded that the application of K-humate did not significantly increased any of the growth, yield and wheat quality parameters on this soil in this specific season.

It is therefore recommended that:

- on account of the biological and chemical soil properties the level of K-humate applied be increased;
- the level of K-humate increased in both the glasshouse and field experiments;

- the effect of K-humate be evaluated over more than one growing season, and
- higher income generated crops such as potatoes and tomatoes be evaluated.

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APPENDIX 3

Appendix 3.1 Analysis of variance of the bacterial count as affected by product and K-humate application rate over six weeks at 0 – 100 mm soil depth

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Product	2	7.296462E+09	3.648231E+09	8.32	0.000350*	0.928268
B: Application	2	2.157969E+08	1.078985E+08	0.25	0.782190	0.082536
AB	4	6.523714E+09	1.630929E+09	3.72	0.006192*	0.821936
C: Week	5	2.608268E+10	5.216536E+09	11.89	0.000000*	0.999984
AC	10	1.620087E+10	1.620087E+09	3.69	0.000161*	0.987712
BC	10	2.723301E+08	2.723301E+07	0.06	0.999980	0.065997
S	182	7.983057E+10	4.386295E+08			
Total (Adjusted)	215	1.364224E+11				
Total	216					

*Term significant at alpha = 0.05

$LSD_{(Tukey=0.05)}$=18752.7 (Prod x Treat)

$LSD_{(Tukey=0.05)}$=29828.8 (Prod x Week)

Appendix 3.2 Analysis of variance of the bacterial count as affected by product and K-humate application rate over six weeks at 100 – 200 mm soil depth

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Product	2	9.357337E+09	4.678668E+09	13.16	0.000005*	0.991975
B: Application	2	2.596226E+08	1.298113E+08	0.37	0.694642	0.099246
AB	4	8.925505E+09	2.231376E+09	6.28	0.000094*	0.972712
C: Week	5	3.157623E+10	6.315246E+09	17.76	0.000000*	1.000000
AC	10	1.678056E+10	1.678056E+09	4.72	0.000005*	0.998253
BC	10	3.188646E+08	3.188646E+07	0.09	0.999886	0.073754
S	182	6.471213E+10	3.555612E+08			
Total (Adjusted)	215	1.319303E+11				
Total	216					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=16883.9 (Prod x Treat)

$LSD_{(Tukey=0.05)}$=26856.2 (Prod x Week)

Appendix 3.3 **Analysis of variance of the fungal count as affected by product and K-humate application rate over six weeks at soil depth**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Product	2	75250.53	37625.27	9.80	0.000091*	0.962122
B: Application	2	104434.5	52217.27	13.60	0.000003*	0.993527
AB	4	106518.4	26629.61	6.94	0.000032*	0.984139
C: Week	5	125596.9	25119.39	6.54	0.000013*	0.991983
AC	10	68853.59	6885.358	1.79	0.064428	0.768467
BC	10	43817.92	4381.792	1.14	0.333721	0.527252
S	182	698627	3838.61			
Total (Adjusted)	215	1223099				
Total	216					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=55.5 (Prod x Treat)

$LSD_{(Tukey=0.05)}$=Ns (Prod x Week)

Appendix 3.4 **Analysis of variance of the fungal count as affected by product and K-humate application rate over six weeks at 100 – 200 mm soil depth**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Product	2	37463.53	18731.76	3.45	0.033814*	0.569773
B: Application	2	9805.861	4902.931	0.90	0.407079	0.180383
AB	4	52319.28	13079.82	2.41	0.050936	0.612711
C: Week	5	120501.7	24100.33	4.44	0.000770*	0.937510
AC	10	31361.3	3136.131	0.58	0.830845	0.263155
BC	10	4003.806	400.3806	0.07	0.999954	0.069230
S	182	987966.6	5428.388			
Total (Adjusted)	215	1243422				
Total	216					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns (Prod x Treat)

$LSD_{(Tukey=0.05)}$=Ns (Prod x Week)

APPENDIX 4

Appendix 4.1 Analysis of variance of the total biomass as affected by K-humate application at tillering

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	3107.154	1553.577	2.17	0.135918	0.309572
B: Application	3	879.1779	293.0593	0.41	0.747556	0.102648
AB	6	1092.501	182.0835	0.25	0.952591	0.095281
S	24	17172.54	715.5225			
Total (Adjusted)	35	22251.37				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.2 Analysis of variance of the total biomass as affected by K-humate application at stem elongation

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	30425.03	15212.51	1.79	0.188504	0.261142
B: Application	3	10182.94	3394.313	0.40	0.754629	0.101240
AB	6	32055.33	5342.555	0.63	0.705803	0.178351
S	24	203941.4	8497.561			
Total (Adjusted)	35	276604.8				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.3 Analysis of variance of the total biomass as affected by K-humate application at maturity

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	135144.5	67572.23	3.09	0.063962	0.423558
B: Application	3	26671.17	8890.391	0.41	0.749671	0.102226
AB	6	68346.14	11391.02	0.52	0.786713	0.152780
S	24	524840.1	21868.34			
Total (Adjusted)	35	755001.9				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.4 Analysis of variance of the leaf area as affected by K-humate application at tillering

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	7.598205E+07	3.799102E+07	7.00	0.004041*	0.782030
B: Application	3	2.139242E+07	7130806	1.31	0.293221	0.242380
AB	6	1.21156E+08	2.019267E+07	3.72	0.009345*	0.840475
S	24	1.30346E+08	5431085			
Total (Adjusted)	35	3.488765E+08				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=6860.9 (Soil x Treat)

Appendix 4.5 Analysis of variance of the leaf area as affected by K-humate application at stem elongation

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	9.788538E+07	4.894269E+07	1.73	0.198970	0.253268
B: Application	3	1.258034E+08	4.193445E+07	1.48	0.244891	0.270160
AB	6	1.948279E+08	3.247132E+07	1.15	0.366533	0.312199
S	24	6.796552E+08	2.831897E+07			
Total (Adjusted)	35	1.098172E+09				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.6 Analysis of variance of the tiller/ear number as affected by K-humate application at tillering

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	16392.18	8196.09	4.48	0.022206*	0.578271
B: Application	3	3514.985	1171.662	0.64	0.596370	0.135974
AB	6	12941.63	2156.939	1.18	0.350202	0.320929
S	24	43900.94	1829.206			
Total (Adjusted)	35	76749.73				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=43.604 (Soil)

Appendix 4.7 **Analysis of variance of the tiller/ear number as affected by K-humate application at stem elongation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	51496.3	25748.15	19.12	0.000011*	0.996615
B: Application	3	18267.12	6089.039	4.52	0.011932*	0.709194
AB	6	12176.69	2029.448	1.51	0.218438	0.408681
S	24	32327.06	1346.961			
Total (Adjusted)	35	114267.2				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=37.417 (Soil) $LSD_{(Tukey=0.05)}$=47.727 (Treat)

Appendix 4.8 **Analysis of variance of the tiller/ear number as affected by K-humate application at maturity**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	9017.153	4508.577	2.56	0.098164	0.358633
B: Application	3	2619.09	873.0301	0.50	0.688579	0.114838
AB	6	7246.15	1207.692	0.69	0.662763	0.192356
S	24	42254.66	1760.611			
Total (Adjusted)	35	61137.05				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.9 **Analysis of variance of the root mass in the fertilised zone as affected by K-humate application at tillering**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	1.436865	0.7184325	3.34	0.052530	0.453218
B: Application	3	1.378596	0.4595319	2.14	0.122079	0.379012
AB	6	0.6663242	0.111054	0.52	0.790149	0.151701
S	24	5.163008	0.2151253			
Total (Adjusted)	35	8.644793				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.10 **Analysis of variance of the root mass in the fertilised zone as affected by K-humate application at stem elongation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	6.822492	3.411246	4.39	0.023804*	0.568578
B: Application	3	0.8481407	0.2827136	0.36	0.779950	0.096274
AB	6	3.113826	0.5189709	0.67	0.676816	0.187736
S	24	18.66818	0.7778407			
Total (Adjusted)	35	29.45263				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=0.89917 (Soil)

Appendix 4.11 **Analysis of variance of the root mass in the fertilised zone as affected by K-humate application at maturity**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	14.31849	7.159243	4.61	0.020189*	0.591416
B: Application	3	3.398108	1.132703	0.73	0.544362	0.149392
AB	6	10.97157	1.828594	1.18	0.350782	0.320613
S	24	37.25526	1.552302			
Total (Adjusted)	35	65.94342				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=1.27023(Soil)

Appendix 4.12 **Analysis of variance of the root mass in the unfertilised zone as affected by K-humate application at tillering**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	0.3811544	0.1905772	1.00	0.381711	0.162545
B: Application	3	0.2315233	7.717444E-02	0.41	0.749991	0.102162
AB	6	0.4819708	8.032847E-02	0.42	0.856549	0.130554
S	24	4.561108	0.1900462			
Total (Adjusted)	35	5.655757				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.13 Analysis of variance of the root mass in the unfertilised zone as affected by K-humate application at stem elongation

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	3.1187	1.55935	4.14	0.028575*	0.542702
B: Application	3	0.7225705	0.2408568	0.64	0.597206	0.135769
AB	6	0.8024095	0.1337349	0.35	0.899960	0.115884
S	24	9.044158	0.3768399			
Total (Adjusted)	35	13.68784				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=0.6259(Soil)

Appendix 4.14 Analysis of variance of the root mass in the unfertilised zone as affected by K-humate application at maturity

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	26.85066	13.42533	16.61	0.000030*	0.991238
B: Application	3	1.718559	0.5728531	0.71	0.556188	0.146228
AB	6	4.348829	0.7248049	0.90	0.513104	0.246000
S	24	19.39602	0.8081677			
Total (Adjusted)	35	52.31407				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=0.9165 (Soil)

Appendix 4.15 Analysis of variance of the total root mass as affected by K-humate application at tillering

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	466.1277	233.0638	1.54	0.235444	0.229030
B: Application	3	289.3284	96.44279	0.64	0.599092	0.135306
AB	6	1272.38	212.0634	1.40	0.255801	0.379847
S	24	3639.139	151.6308			
Total (Adjusted)	35	5666.975				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.16 **Analysis of variance of the total root mass as affected by K-humate application at stem elongation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	917.9885	458.9943	0.15	0.863731	0.064995
B: Application	3	2648.956	882.9854	0.28	0.836759	0.085476
AB	6	7971.255	1328.543	0.43	0.853878	0.131424
S	24	74738.41	3114.1			
Total (Adjusted)	35	86276.61				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.17 **Analysis of variance of the total root mass as affected by K-humate application at maturity**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	29533.55	14766.77	3.99	0.031875*	0.526975
B: Application	3	7503.802	2501.268	0.68	0.575148	0.141298
AB	6	25132.58	4188.764	1.13	0.373935	0.308354
S	24	88785.56	3699.398			
Total (Adjusted)	35	150955.5				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=62.0099 (Soil)

Appendix 4.18 **Analysis of variance of the root length of the ferilised zone as affected by K-humate application at tillering**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	94845.32	47422.66	1.06	0.363309	0.169096
B: Application	3	215170.5	71723.5	1.60	0.216037	0.289636
AB	6	317364.3	52894.04	1.18	0.350613	0.320705
S	24	1077334	44888.91			
Total (Adjusted)	35	1704714				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.19 Analysis of variance of the root length of the fertilised zone as affected by K-humate application at stem elongation

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	559432.3	279716.2	1.36	0.274700	0.207266
B: Application	3	937180.8	312393.6	1.52	0.233912	0.277274
AB	6	723185	120530.8	0.59	0.736664	0.168525
S	24	4920969	205040.4			
Total (Adjusted)	35	7140767				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.20 Analysis of variance of the root length of the fertilised zone as affected by K-humate application at maturity

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	7688417	3844208	7.63	0.002722*	0.818410
B: Application	3	819736.4	273245.5	0.54	0.657933	0.121543
AB	6	3283334	547222.4	1.09	0.398538	0.296032
S	24	1.209086E+07	503785.8			
Total (Adjusted)	35	2.388234E+07				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=723.63 (Soil)

Appendix 4.21 Analysis of variance of the root length in the unfertilised zone as affected by K-humate application at tillering

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	94441.18	47220.59	0.93	0.410045	0.153165
B: Application	3	63166.04	21055.35	0.41	0.745415	0.103076
AB	6	127507.5	21251.25	0.42	0.860715	0.129190
S	24	1224601	51025.04			
Total (Adjusted)	35	1509716				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.22 Analysis of variance of the root length in the unfertilised zone as affected by K-humate application at stem elongation

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	884706.6	442353.3	7.08	0.003836*	0.787073
B: Application	3	143358.9	47786.3	0.76	0.525053	0.154716
AB	6	157316.7	26219.46	0.42	0.858683	0.129856
S	24	1499992	62499.66			
Total (Adjusted)	35	2685374				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=254.88 (Soil)

Appendix 4.23 Analysis of variance of the root length in the unfertilised zone as affected by K-humate application at maturity

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	5926231	2963116	16.61	0.000030*	0.991226
B: Application	3	748382.3	249460.8	1.40	0.267573	0.256464
AB	6	573732.6	95622.11	0.54	0.775548	0.156285
S	24	4281876	178411.5			
Total (Adjusted)	35	1.153022E+07				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=430.63 (Soil)

Appendix 4.24 Analysis of variance of the total root length in the remaining soil as affected by K-humate application at tillering

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	1.059142E+08	5.295708E+07	1.41	0.262784	0.213478
B: Application	3	1.321877E+07	4406257	0.12	0.948881	0.064143
AB	6	1.867371E+08	3.112285E+07	0.83	0.557849	0.228909
S	24	8.990499E+08	3.746041E+07			
Total (Adjusted)	35	1.20492E+09				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.25 **Analysis of variance of the total root length in the remaining soil as affected by K-humate application at stem elongation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	6.585933E+08	3.292967E+08	2.84	0.078282	0.392956
B: Application	3	3.768093E+08	1.256031E+08	1.08	0.375346	0.204788
AB	6	9.218716E+08	1.536453E+08	1.32	0.284860	0.359902
S	24	2.784728E+09	1.160303E+08			
Total (Adjusted)	35	4.742002E+09				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.26 **Analysis of variance of the total root length in the remaining soil as affected by K-humate application at maturity**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	1.859998E+08	9.299989E+07	0.57	0.575335	0.110802
B: Application	3	5.971477E+08	1.990492E+08	1.21	0.327171	0.225624
AB	6	6.306002E+08	1.051E+08	0.64	0.697786	0.180929
S	24	3.945318E+09	1.643883E+08			
Total (Adjusted)	35	5.359066E+09				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.27 **Analysis of variance of the root length index as affected by K-humate application at tillering**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	0.7155592	0.3577796	1.28	0.296156	0.196824
B: Application	3	0.1183228	3.944093E-02	0.14	0.934307	0.067077
AB	6	1.424468	0.2374114	0.85	0.544732	0.233807
S	24	6.704667	0.2793611			
Total (Adjusted)	35	8.963017				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.28 Analysis of variance of the root length index as affected by K-humate application at stem elongation

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	4.429271	2.214635	2.41	0.110848	0.340248
B: Application	3	3.071186	1.023729	1.12	0.362175	0.210187
AB	6	7.028864	1.171477	1.28	0.304827	0.347219
S	24	22.01706	0.9173775			
Total (Adjusted)	35	36.54638				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.29 Analysis of variance of the root length index as affected by K-humate application at maturity

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	2.656846	1.328423	1.01	0.380252	0.163050
B: Application	3	4.409143	1.469714	1.11	0.362906	0.209882
AB	6	4.613739	0.7689564	0.58	0.740410	0.167340
S	24	31.66229	1.319262			
Total (Adjusted)	35	43.34202				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.30 Analysis of variance of the seed yield as affected by K-humate application at maturity

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	50312.91	25156.46	4.48	0.022185*	0.578401
B: Application	3	10297.73	3432.576	0.61	0.614083	0.131676
AB	6	21134.91	3522.485	0.63	0.706662	0.178075
S	24	134707.5	5612.812			
Total (Adjusted)	35	216453				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=76.3810 (Soil)

Appendix 4.31 Analysis of variance of the number of ears as affected by K-humate application at maturity

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	9017.153	4508.577	2.56	0.098164	0.358633
B: Application	3	2619.09	873.0301	0.50	0.688579	0.114838
AB	6	7246.15	1207.692	0.69	0.662763	0.192356
S	24	42254.66	1760.611			
Total (Adjusted)	35	61137.05				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 4.32 Analysis of variance of the number of spikelets per ear as affected by K-humate application at maturity

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	15.28367	7.641836	4.67	0.019391*	0.596927
B: Application	3	0.5349343	0.1783114	0.11	0.954059	0.063068
AB	6	4.205842	0.7009737	0.43	0.852819	0.131769
S	24	39.29042	1.637101			
Total (Adjusted)	35	59.31487				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=1.3044 (Soil)

Appendix 4.33 Analysis of variance of the number of kernels per ear as affected by K-humate application at maturity

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	236.1035	118.0518	10.00	0.000692*	0.912237
B: Application	3	9.92061	3.30687	0.28	0.839121	0.085034
AB	6	30.98074	5.163457	0.44	0.846408	0.133847
S	24	283.2223	11.80093			
Total (Adjusted)	35	560.2272				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=3.5023 (Soil)

Appendix 4.34 Analysis of variance of the seed yield per ear as affected by K-humate application at maturity

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	0.7891992	0.3945996	13.73	0.000106*	0.975073
B: Application	3	7.923989E-03	2.64133E-03	0.09	0.963777	0.060981
AB	6	6.323161E-02	0.0105386	0.37	0.892721	0.118417
S	24	0.68957	2.873208E-02			
Total (Adjusted)	35	1.549925				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=0.1728 (Soil)

Appendix 4.35 Analysis of variance of the kernel mass as affected by K-humate application at maturity

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Soil	2	16.06717	8.033586	2.50	0.102927	0.351458
B: Application	3	5.601545	1.867182	0.58	0.632654	0.127301
AB	6	33.57827	5.596378	1.74	0.153928	0.470690
S	24	77.01714	3.209047			
Total (Adjusted)	35	132.2641				
Total	36					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

APPENDIX 5

Appendix 5.1 **Analysis of variance of the chlorophyll content at tillering as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	124.3421	20.72369	1.03	0.435597	0.314259
S	21	423.8875	20.18512			
Total (Adjusted)	27	548.2296				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.2 **Analysis of variance of the chlorophyll content at stem elongation as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	135.5743	22.59571	2.80	0.036795*	0.763026
S	21	169.5525	8.073929			
Total (Adjusted)	27	305.1268				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Fisher=0.05)}$=1.5316

Appendix 5.3 **Analysis of variance of the chlorophyll content at tillering as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	297.3286	49.55476	0.88	0.525645	0.270670
S	21	1181.132	56.2444			
Total (Adjusted)	27	1478.461				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.4 **Analysis of variance of the chlorophyll content at stem elongation as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	63.82429	10.63738	1.09	0.398444	0.334405
S	21	204.2825	9.727738			
Total (Adjusted)	27	268.1068				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.5 **Analysis of variance of the leaf area at tillering as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	2.675224E+07	4458707	1.05	0.422914	0.320971
S	21	8.926227E+07	4250585			
Total (Adjusted)	27	1.160145E+08				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.6 **Analysis of variance of the leaf area at stem elongation as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	1.875448E+07	3125746	1.19	0.348329	0.364226
S	21	5.504998E+07	2621428			
Total (Adjusted)	27	7.380446E+07				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.7 **Analysis of variance of the leaf area at tillering as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	7.499034E+07	1.249839E+07	1.11	0.391884	0.338123
S	21	2.37347E+08	1.130224E+07			
Total (Adjusted)	27	3.123373E+08				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.8 **Analysis of variance of the leaf area at stem elongation as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	1.94536E+07	3242267	0.18	0.978893	0.085508
S	21	3.755155E+08	1.788169E+07			
Total (Adjusted)	27	3.949691E+08				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.9 **Analysis of variance of the dry matter at tillering as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	1869.37	311.5616	0.61	0.720365	0.192189
S	21	10742.01	511.5244			
Total (Adjusted)	27	12611.38				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.10 **Analysis of variance of the dry matter at stem elongation as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	19375.06	3229.177	0.69	0.663223	0.213746
S	21	98890.2	4709.057			
Total (Adjusted)	27	118265.3				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.11 **Analysis of variance of the dry matter at maturity as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	0.0470144	7.835733E-03	0.51	0.793054	0.165534
S	21	0.3218814	1.532768E-02			
Total (Adjusted)	27	0.3688958				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.12 **Analysis of variance of the dry matter at tillering as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	9498.982	1583.164	2.98	0.028950*	0.792734
S	21	11163.22	531.582			
Total (Adjusted)	27	20662.21				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=52.998

Appendix 5.13 **Analysis of variance of the dry matter at stem elongation as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	46385.5	7730.916	0.60	0.726785	0.189812
S	21	270352.6	12873.93			
Total (Adjusted)	27	316738.1				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.14 **Analysis of variance of the dry matter at maturity as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	9.997244E-02	1.666207E-02	0.49	0.805866	0.160849
S	21	0.7089118	3.375771E-02			
Total (Adjusted)	27	0.8088843				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.15 **Analysis of variance of the number of tillers at tillering as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	105883.5	17647.25	0.78	0.597834	0.239692
S	21	477692.2	22747.25			
Total (Adjusted)	27	583575.7				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.16 **Analysis of variance of the number of tillers at stem elongation as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	11955.8	1992.634	0.67	0.677701	0.208204
S	21	62810.94	2990.997			
Total (Adjusted)	27	74766.74				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.17 **Analysis of variance of the number of tillers at maturity as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	2245.262	374.2104	0.46	0.826609	0.153225
S	21	16916.04	805.5257			
Total (Adjusted)	27	19161.3				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.18 **Analysis of variance of the number of ears at tillering as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	194124.1	32354.02	1.08	0.403308	0.331681
S	21	626506.3	29833.63			
Total (Adjusted)	27	820630.4				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.19 **Analysis of variance of the number of tillers at stem elongation as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	54527.23	9087.872	0.71	0.642515	0.221788
S	21	267335.9	12730.28			
Total (Adjusted)	27	321863.2				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.20 **Analysis of variance of the number of ears at maturity as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	9993.461	1665.577	0.71	0.648939	0.219278
S	21	49604.64	2362.126			
Total (Adjusted)	27	59598.1				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.21 **Analysis of variance of the number of spikelets per ear at maturity as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	2.183571	0.3639286	0.46	0.829884	0.152014
S	21	16.6175	0.7913095			
Total (Adjusted)	27	18.80107				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.22 **Analysis of variance of the number of spikelets per ear at maturity as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	4.722143	0.7870238	0.84	0.552346	0.258871
S	21	19.6475	0.9355952			
Total (Adjusted)	27	24.36964				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.23 **Analysis of variance of the number of kernels per ear at maturity as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	34.77214	5.795357	0.22	0.965793	0.094060
S	21	551.915	26.28167			
Total (Adjusted)	27	586.6871				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.24 **Analysis of variance of the number of kernels per ear at maturity as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	36.89857	6.149762	0.44	0.842302	0.147400
S	21	292.1225	13.91059			
Total (Adjusted)	27	329.0211				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.25 **Analysis of variance of the seed mass per ear at maturity as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	0.1304568	2.174279E-02	0.33	0.912748	0.119764
S	21	1.377725	6.560593E-02			
Total (Adjusted)	27	1.508181				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.26 **Analysis of variance of the seed mass per ear at maturity as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	4.795324E-02	7.992206E-03	0.23	0.962844	0.095774
S	21	0.7354435	3.502112E-02			
Total (Adjusted)	27	0.7833967				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.27 **Analysis of variance of the grain yield at maturity as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	11221.83	1870.305	0.48	0.816154	0.157075
S	21	81951.3	3902.443			
Total (Adjusted)	27	93173.13				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.28 **Analysis of variance of the grain yield at maturity as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	12765.4	2127.566	0.31	0.924728	0.114587
S	21	144222.4	6867.731			
Total (Adjusted)	27	156987.8				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 29 **Analysis of variance of the thousand kernel mass at maturity as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	36.68342	6.113904	0.63	0.705319	0.197790
S	21	204.0595	9.717118			
Total (Adjusted)	27	240.7429				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.30 **Analysis of variance of the thousand kernel mass at maturity as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	18.50774	3.084624	0.92	0.498876	0.282966
S	21	70.22973	3.344273			
Total (Adjusted)	27	88.73746				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.31 **Analysis of variance of the falling number at maturity as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	89.35714	14.89286	2.00	0.111469	0.591852
S	21	156.5	7.452381			
Total (Adjusted)	27	245.8571				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.32 **Analysis of variance of the falling number at maturity as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	78.85714	13.14286	1.67	0.177176	0.504895
S	21	165	7.857143			
Total (Adjusted)	27	243.8571				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 33 **Analysis of variance of the sedimentation volume at maturity as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	4.428571	0.7380952	0.07	0.998654	0.061949
S	21	238	11.33333			
Total (Adjusted)	27	242.4286				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.34 **Analysis of variance of the sedimentation volume at maturity as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	20.35714	3.392857	0.49	0.806226	0.160717
S	21	144.5	6.880952			
Total (Adjusted)	27	164.8571				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 35 **Analysis of variance of the flour yield at maturity as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	7.663404	1.277234	0.59	0.734278	0.187046
S	21	45.42265	2.162983			
Total (Adjusted)	27	53.08605				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.36 **Analysis of variance of the flour yield at maturity as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	6.186943	1.031157	0.25	0.955507	0.099814
S	21	87.96493	4.188806			
Total (Adjusted)	27	94.15187				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 37 **Analysis of variance of the flour protein content at maturity as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	0.5692857	9.488095E-02	0.46	0.831745	0.151325
S	21	4.3575	0.2075			
Total (Adjusted)	27	4.926786				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.38 **Analysis of variance of the flour protein content at maturity as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	0.2892857	4.821429E-02	0.81	0.571543	0.250646
S	21	1.245	5.928572E-02			
Total (Adjusted)	27	1.534286				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 39 **Analysis of variance of the mixograph mixing development time at maturity as affected by K-humate treatments at 350 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	1.214286E-02	2.02381E-03	0.27	0.942828	0.106234
S	21	0.155	7.380953E-03			
Total (Adjusted)	27	0.1671429				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns

Appendix 5.40 **Analysis of variance of the mixograph mixing development time at maturity as affected by K-humate treatments at 700 mm irrigation**

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: Application	6	8.928572E-02	1.488095E-02	1.13	0.381278	0.344247
S	21	0.2775	1.321429E-02			
Total (Adjusted)	27	0.3667857				
Total	28					

* Term significant at alpha = 0.05 $LSD_{(Tukey=0.05)}$=Ns