THESIS

CHIHANI ABDELGHANI

MSc. Plant Protection

Keszthely

2023

Hungarian University of Agriculture and Life Sciences

Georgikon Campus

MSc. Plant Protection

THE EFFECT OF HUMIC ACID TREATMENTS ON POTATO

Primary Supervisor: Dr. Polgár Zsolt Géza

Professor

Author: Chihani Abdelghani

R4I1QL

Institute of Plant Protection

Keszthely

2023

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

One of the most significant vegetable crops in the world, the potato crop (Solanum tuberosum L.), is grown in the second stage after grain crops and is a good and affordable source of nutrition. It is crucial to the food security of many nations throughout the world (Alsayed, 2009).In Hungary, the area used for potato production fell from 50.000 to 10,270 ha over the past 15 years (FAO, 2020). The potato crop is important in Hungary for its contribution to food security, economic value, employment opportunities, crop diversity and resilience, and cultural significance.

One of the essential inputs for raising crop output is fertiliser. Because they need more nutrients, high yielding varieties are more receptive to fertiliser and irrigation low nutrient utilization efficiency is the main issue with traditional fertilisers, though (Selladurai and Purakayastha, 2016).It is true that crops' utilization efficiency for nitrogen (N), phosphorous (P), potassium (K), and micronutrients rarely reach 58%, 31%, 51%, and 10%, respectively(Pathak et al., 2003).Due to the inefficient utilization of nutrients, expensive chemical fertilisers that could otherwise damage the soil, water bodies, ground water, and atmosphere are not used (Selladurai and Purakayastha, 2016).Numerous studies were conducted to enhance the growth of potato plants to increase their production per unit area, such as using a variety of fertilisers, which is essential to ensure the crop needs nutrients, but excessive use resulted in a decline in crop quality and pollution of the surface and groundwater, which has a detrimental impact on the climate (Tilman et al., 2011).

Therefore, efforts were made to modify the current fertilisers in order to increase the efficiency of nutrient use. Consequently, a number of modified fertilisers have been created, and some of them have shown promise (Purakayastha and Katyal, 1998).As the modification is cost intensive, the modified fertilisers sometimes were not economically attractive. Therefore, we should look fornaturally occurring materials, the employment of which could make the modified fertilisers as economically viable, ecologically sustainable and socially acceptable product. In this respect humic acid (HA) showed to be promising as is reported to enhance uptake and utilization of nutrients (Guo et al., 2000; Hui-Ying et al., 2007; Shuixiu and Ruizhen, 2001).

In comparison to inorganic fertilisers, HA-based fertilisers improved the uptake and utilization of N, P, and K by plants (Hui-Ying et al., 2007).The positive effect of humic substances on the growth of numerous plants is well documented (Chen and Aviad, 1990).Several authors have shown that adding specific concentrations of humic substances can promote the growth of the plant's root and aerial parts and promote nutrient absorption (Ayuso et al., 1996).Combining the use of NPK fertilisers and humic substances can result in a 100% increase in the yield of potatoes and cabbage (Syabryai et al., 1965).The effects of humic substances on plant production and nutrient absorbance generally depends on their origin, type and concentration and on the species and variety of the plant treated (Chen and Aviad, 1990).Keeping the above points in mind a greenhouse experiment was conducted to study the effect of four types of fertilisation enriched with humic acid (Humin aqua) on tuber yield of two varieties of potato Balatoni rózsa and Botond.

2. LITERATUREREVIEW

2.1. Origin and importance of potato crops:

Cultivation of the *Solanum tuberosum* L. potato began around 8000 BC, in South America. It is in the south of Peru on the border of Bolivia; that the Man would have cultivated potatoes for the first time, its cultivation then spread to the rest of the Andes Cordillera (Polese, 2006).

The potato was introduced to the European continent for the first time by Spanish sailors around 1535 (Pelt, 1993). It was brought to England by English navigators who had captured Spanish ships around 1590. From Spain, the potato invaded all of continental Europe. In Africa, its introduction took place after colonization (FAO, 1991).

According to FAO (2019), world production increased from less than 30 million tons in the early 1960s to over 388 million tons in 2017. The top 10 potato producers in the world are currently China, Russia, India, USA, Ukraine, Poland, Germany, Belarus, Netherlands and France.

In Hungary, the area used for potato production fell from 50.000 to 10,270 ha over the past 15 years. The area used to grow seed potatoes likewise dramatically shrunk from 1500 hectares to 350 ha when Hungary joined the EU. 600.000 Mt of potatoes were produced overall, however only 5000 Mt were seed potatoes (FAO, 2020). Only the local market's needs could be met by the overall production, which represented barely 1% of the EU's total potato crop. About 25–27 Mts/ha are the average yield across the country. Less than 10% of that is eaten as processed food. In Hungary, each person consumes about 65 kg of potatoes year. In terms of production amount, Hungary is ranked 50th in the FAO report. Hungarian cultivars, primarily developed in Keszthely, occupy 20% of the overall production area. Red Scarlet (NL), Laura (D), Kondor (NL), Desiree (NL), Cleopatra (NL), Agria (D), Balatoni Rózsa (HU), Hópehely (HU), Katica (HU), Démon (HU), Góliát (HU), and Rioja are the top varieties (HU)(Ahmadvand, 2013).

The potato is regarded as a significant source of useful elements, including vitamins, proteins, minerals, and carbohydrates,, which act as supplemental nutrition and antioxidants for the human body(Burlingame et al., 2009; King and Slavin, 2013). For example, 100 g of cooked white potatoes have 390 kJ (93 kcal) of energy, the majority of which comes from carbohydrates and relatively little from fat and protein. Nowadays, potatoes provide 2% of the world's nutritional energy (Zaheer and Akhtar, 2016).

2.1.1. Botanical Description:

Potato is an herbaceous perennial flowering plant, which can reach 1 meter in height and produces tubers (Figure1.). It is rich in starch, which why it is one of the main food crops in the world(Anonyme, 2008).

2.1.2. Air system:

The aerial apparatus consists of aerial stems, which have a more or less erect habit and a regular section, their number per plant varies from 2 to 10 and sometimes more. The leaves are composed, allowing by their differences in appearance and coloring to characterize the varieties. The flowers are autogamous but often sterile, the color and the number constitute an important element of varietal identification. The fruits or berries that potatoes produce contain seeds whose interest is abrogated in cultivation, but essential in breeding (Soltner, 2012).

2.1.3. Underground System:

The underground system is made up of the stolons, on which the tubers are formed, which are organs full of reserve substances (Polese, 2006), 20. They have a hooked shape at the top, with long internodes, and leaves reduced to scales (Rousselle et al., 1996).

The tuber of the apple is not a root, but an underground stem, like all stems, it is made up of between nodes, short and thickened, and carries buds called eyes, located in small depressions. As they develop, the buds give rise to the seeds and future aerial stems (Polese, 2006).

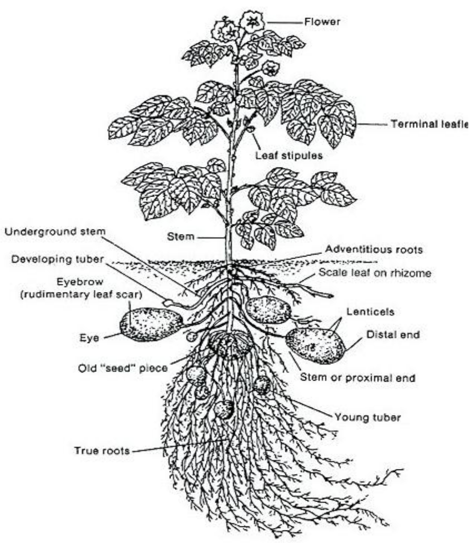

Figure 1. A Potato plant's diagram.

Just one main stem is displayed for simplicity. Plants that produce well may have two or more main stems. The real roots appear near the stem's base, while the stolons and tubers grow from the stem tissue (Pajerowska-Mukhtar, 2005).

http://www.gov.mb.ca/agriculture/crops

2.1.4. Biochemical composition of the tuber:

The potato tuber is a storage organ containing at maturity an average of 77.5% water. The dry matter is globally divided into 19.4% total carbohydrates (mainly starch, sucrose, glucose, fructose, crude cellulose and pectic substances), 2.0% proteins (proteins, free amino acids and nitrogenous bases), 1 .0% minerals (mainly potassium) and 0.1% lipids. Organic acids (citric and ascorbic acids among others), phenolic substances (chlorogenic and caffeic acids, pigments, etc.) complete this composition, but are only present in small quantities in the tuber (Mattila and Hellström, 2007).

2.1.5. Potato varieties:

Potato biodiversity is vast, with more than 4000 known varieties (Burlingame et al., 2009). The species of potato cultivated in the world is S. tuberosum L.; it includes several hundred varieties different in shape, color, texture or even in the starch content of the tubers(Delaplace, 2007).

According to Polese (2006), potato varieties are innumerable, some have more than 3000, and others claim to have counted 5000. However, most are not used for human food, and a few less than 200 varieties are registered in the French catalogs and 700 in the Community catalog.

2.1.6. Nutrient requirements:

The potato is a large consumer of nitrogen and potassium. It also needs phosphorus, calcium and magnesium in good quantities and requires a balanced soil in trace elements. It prefers slightly acidic soil with sufficient humidity to allow it to absorb these elements. The needs of the potato vary as it grows (Fraser, 2000).

2.2. Humic substances:

2.2.1. Origin of humic substances:

The term organic matter is used to designate all the organic substances of a natural ecosystem other than living organisms and compounds of human origin (Filella, 2009). By definition, a natural organic matter is a material made up of organic compounds that come from the decomposition of organisms that were once living things such as plants, animals and microorganisms and their waste products in the natural environment (Chung et al., 2012).

Large molecules of organic matter are formed by polymerization of various short chains produced by the decomposed matter. Organic matter can vary considerably, depending on its origin, mode of transformation, age and environment. The term organic here refers to carbon and hydrocarbon compounds composed mainly of carbon, hydrogen, oxygen and sometimes nitrogen atoms. In general, there are two main groups in natural organic matter: humic substances and non-humic substances.

Non-humic substances include molecules belonging to identified chemical families: carbohydrates, proteins and amino acids, lipids, tannins, lignins, terpenoids and organic acids. They are sometimes qualified as biomolecules to recall their biological origin because they come either from the degradation of cellular constituents, or from microbial syntheses. These low molecular weight organic substances are generally labile and relatively easy to metabolize and/or degrade by hydrolytic enzymes produced by microorganisms (Nasir et al., 2011).

Humic substances are made up of a complex mixture of organic compounds. These are macromolecules whose molecular masses can reach 100,000 g/mol. They are subdivided into three fractions (Stevenson and Cole, 1999).

2.2.2 General description of humic substances:

Humic substances (HS) are polyelectrolyte organic compounds formed from plants and animals by a wide variety of biochemical pathways (Kononova, 1966).

Humic substances cannot be defined as unique chemical compounds. It's hard to describe them in terms exact chemicals.

AIKEN and COLL, give the following definition of these substances: "Humic substances belong to the category of natural, heterogeneous organic substances with a high molecular weight, which are isolated from the environment and which are defined by their solubility"(Stevenson, 1982; Twagiramungu, 2003).

In soils, the origin of humus linked to the transformation of precursor compounds represented essentially by lignin, cellulose, hemicelluloses and tannins. During the decomposition of plants, these high molecular weight compounds depolymerize and release small molecular fractions, some of which, in the presence of favorable environmental conditions (pH, redox potential, etc.), acquire a "reactivity" which contributes, in association with other nitrogenous molecules, to the formation of prehumic derivatives which, after a long period of maturation, will give the so-called humic compounds. During this process humification , both auto -oxidative and enzymatic reactions are involved (Langford et al., 1983; Yanze Kontchou, 1992).

2.2.3.Classification of humic substances:

In 1861, BERZELIIUS proposed the first classification of humic compounds, based on their solubility in different acidic and basic solutions (Yanze Kontchou, 1992)which are conventionally split into:

Non-extractable fraction: humin, strongly associated with fractions soil minerals and insoluble in alkaline solutions commonly used to solubilize soil organic matter: its chemical composition is still debated.

Extractable fraction which is composed of two groups of substances:

- Fulvic acids (FA) which are soluble at acid pH.
- Humic acids (HA) which correspond to molecules which precipitate at acidic pH (pH $\leq$ 2).

2.2.3.1. Humine:

The humin is the fraction insoluble in the alkaline extractant. It is an important constituent both by the mass of organic carbon that it represents and by its role in the biogeochemical cycle of carbon. Humin often represents more than 50% of organic carbon in soils and more than 70% of organic carbon in unconsolidated sediments. Moreover, it is a constituent which is located at the interface between the biosphere and which occupies a key place in the carbon cycle. This constituent plays a decisive role in the fate of many substances, pollutants in particular (Duchaufour, 1970; Kononova, 1966; Morel, 1996)

2.2.3.2. Fulvic acids:

Fulvic acids are considered macromolecular polymers, whose structure and characteristics are variable depending on their origins and the humification process. Like HA, FA can be found in the natural environment, in water, in the ground. They are produced, in the process of humification, by the chemical and microbial decomposition of plants. In time, FA are probably formed after HA (Duchaufour, 1970)

HA and FA are generally considered two different products and their characteristics are described as such: FA is normally richer in oxygen, and less rich in carbon than HA. FA also contain many functional groups that are ready to react, including carboxylic, hydroxylic, carbonyl, phenol, quinone and semiquinon groups. In general, the molecular weight of FA should be smaller than that of HA (Eyheraguibel, 2004; Peña-Méndez et al., 2005; Sposito, 1989).

2.2.3.3. Humic Acids: Structural and Chemical Characteristics:

Humic acids are structurally large macromolecular complexes having a brown-black appearance in solution of pH greater than 2, they are generally heterogeneous and consist mainly of carbon, oxygen, hydrogen, nitrogen and occasionally sulfur and of phosphorus.

Despite several decades of research, the structure of humic acids remains poorly defined so far. Current knowledge is limited to behavioral studies, structural hypotheses of these macromolecules (modeling, identification of fragments) but the biochemistry of formation of these compounds remains one of the least known aspects (Duchaufour, 1970; Li, 2004; Twagiramungu, 2003).

The general concept of humic acids is that they are complex macromolecules in which are linked amino acids, aminoglycoses, peptides, aromatic rings and aliphatic compounds. The bridges between the different entities are OH groups free or fixed phenolics, quinone structures, nitrogen and oxygen atoms, and carboxylic groups attached to aromatic rings(Duchaufour, 1970; Twagiramungu, 2003).

2.2.3.4. Composition of humic substances:

The characterization of organic matter requires a stage of fractionation of these constituents. This separation is based on the solubility of molecules in water as a function of Ph(Schnitzer and Khan, 1978). In addition to the water-soluble humic substances obtained by simple aqueous extraction, three fractions are classically highlighted(MacCarthy et al., 1990): the humin, fraction of black color, insoluble in water whatever the pH value, humic acids (HA), brown or black, soluble in basic medium and insoluble in the range of acidic pH (pH<2) , fulvic acids (FA), yellow in color, soluble in water regardless of pH value(Figure 2.).

The extraction of humic substances is carried out using alkaline solutions (soda, sodium pyrophosphate from 0.1 to 1N). It results in the formation of an insoluble phase, the humin, and a soluble phase. This soluble phase shows a brown color and it acidification forms two fractions, a fluffy brown precipitate (humic acids) and a soluble supernatant (fulvic acids) (Figure 2.). Humic acids can also be subdivided into more or less condensed fractions: hymatomelanic acids, brown humic acids (little condensed) and gray humic acids (condensed). The separation of humic substances can also be carried out by permeation chromatography, which makes it possible to characterize the molecular distribution of the humic fractions according to their size. A distinction is thus made between fulvic acids, a fraction of low molecular weight (<1000 Da), and humic acids, a fraction of high molecular weight (from 5000 to 300,000 Da).

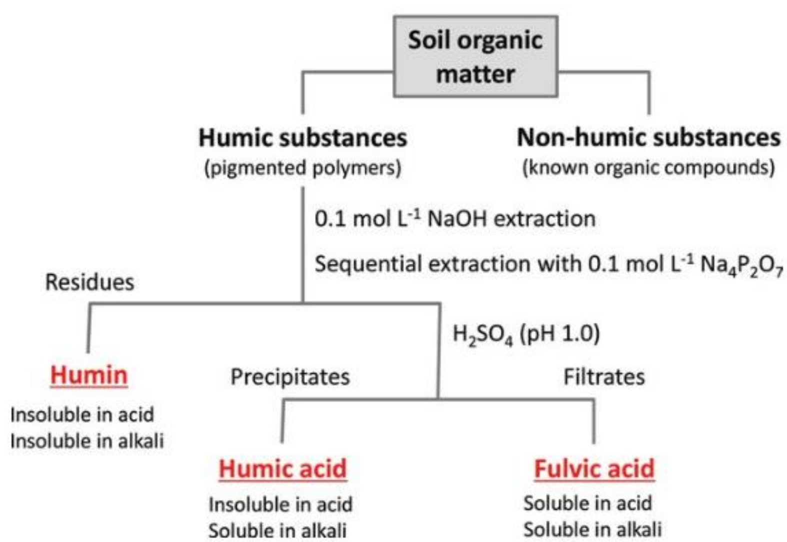

Figure 2. The Nagoya technique procedures for fractionating soil organic matter into fulvic acid, humic acid, and humin (Kumada et al., 1967; Moritsuka and Matsuoka, 2018).

Elemental analysis is used to determine the composition of HS. Due to their organic nature, humic substances are composed of carbon (C), hydrogen (H), nitrogen (N), sulfur (S) and oxygen (O) (Schnitzer, 1978). The major constituents of humic and fulvic acids are carbon and oxygen. The presence of carbon and nitrogen is higher in humic acids than in fulvic acids. Conversely, the fulvic fraction contains more oxygen (Table 1& 2). The O/C ratio makes it possible to differentiate humic acids (O/C =0.5) from fulvic acids (O/C =0.7). The H/C ratio is inversely proportional to the aromaticity or the degree of condensation.

Table 1. Elemental composition of humic substances inpercentage(%) (Stevenson, 1982).

Element	C	O	H	N	S
Fulvic acids	40-50	44-50	6-Apr	<1-3	0-2
Humic acids	50-60	30-35	6-Apr	6-Feb	0-2

Table 2. Characteristics of humic substances(Stevenson and Cole, 1999).

	Fulvic acids	Humic acids
Color	Yellow	brown
Degree of polymerization	Low	high
Molecular weight (Da)	< 1000	300 000
Carbon	45 %	62 %
Oxygen	48 %	30 %
Exchangeable acidity	1400	< 500
Degree of solubility	High	low

2.2.4. Properties of humic substances:

The acidic nature of the functional groups gives the HS a character poly-electrolytic of the anionic type resulting in their complexing properties with respect to metal ions. The pH and the concentration of molecules influence the structure of humic substances (Schnitzer and Khan, 1978) and indirectly their complexing power. Through hydrogen and Van der Waals bonds, the molecules articulate and take on helical structures. In concentrated solution, humic substances adopt a condensed structure which limits the number of free acid groups for complexation. This conformation branches when the concentration decreases(Bailly, 1985). The pH of solutions also influences the complexing power of humic acids. At acidic pH, humic substances present a folded structure having the property of unfolding in the event of alkalinization of the environment (Schnitzer and Khan, 1978).

2.2.5. Roles and effects of humic substances:

The many physico-chemical properties of humic substances explain their impact on soil and plants.

2.2.5.1. Soil Influences:

Humic substances influence soil fertility by improving its structure, increasing biological activity, nutrient availability and complexing toxic metals (Stevenson, 1985).

The role and importance of HS in soils, and in particular humus, have long been proven. By their presence in all environments, their multiple properties, reducing, surfactant and especially their "sequestering" power (adsorbent, complexing, chelating) vis-à-vis organic and mineral compounds (metals and pesticides among others) give them a role essential in the solubilization, accumulation, bioavailability, degradation, transport and exchange of these compounds in waters, soils and sediments (Busnot et al., 1995).

As EYHERAGUIBEL(Eyheraguibel, 2004) points out, the acidic nature of the functional groups gives the SHs the character of anionic-type poly-electrolytes, from which result their complexing properties with respect to metal ions. STEVENSON(Stevenson, 1982) summarizes in the(Table 3.), the different properties of HS.

Table 3. General properties of HS and their effects in the soil (Stevenson, 1982).

Property	Remarks	Effects in the soil
Water retention	HS retain up to 20 times their weight in water	Helps prevent drying out and improves water retention in sandy soils.
Bond with clays	Bind soil particles together forming aggregates.	Allow gas exchange, permeability and stabilize soil structure.
Chelation	Form stable complexes with Cu^{2+}, $Mn^{2+,}$ $Zn^{2+,}$ and other polyvalent cations.	Promote the bioavailability of micronutrients to plants.
Buffer effect	Have great buffering power.	Help maintain a uniform reaction in the soil.
Cation exchange	The total acidity of the humus fractions varies from 300 to 1400 cmol/Kg.	Increase capacity and cation exchanges.
Mineralization	The decomposition of the SHs gives:CO_2, NH_4^+, NO_3^-, SO_4^{2-} ,PO_4^{3-}	Nutrient source for plants of N, P and S.

Humic acid fertiliser can enhance the soil's physical characteristics and its capacity to control moisture, nutrients, and air temperature. By polymerizing with the calcium in the soil, the humic acid's hydroxyl and carboxyl groups in fertiliser reduce the bulk density of the soil, increase porosity, and have good permeability, enhancing the soil's structure (Li, 2020).

2.2.5.2. Influences on plants:

Many factors make the study of the effects of humic substances on plants difficult and the analysis of bibliographic data shows very different results (MacCarthy et al., 1990; Vaughan and Malcolm, 2012). The nature and intensity of the responses may vary depending on the humic substances, the plants and the experimental conditions.

The use of different fractions of organic matter, humic or fulvic acids influences the specificity of the responses. Through their penetration into the plant, low molecular weight particles (fulvic acids) have a different mode of action from humic acids and modify the cellular metabolism more intensely (Vaughan and Malcolm, 2012).

These variabilities of action are directly linked to the composition of humic molecules. The characterization of humic molecules provides information on their molecular weight, the presence of functional groups, and makes it possible to establish relationships between their structure and their biological activity. The quality of the extraction of the humic fractions also appears as a factor of variability because it influences the chemical characteristics of the compounds, and consequently on their activity.

The use of humic substances shows different effects depending on the experimental conditions and the mode of application (soil, solid substrate, nutrient solution or foliar application). The intensity of the response most often depends on the dose tested and many studies begin by determining the optimal dose (Hartwigsen and Evans, 2000).

Plant species react differently to stimulation of humic substances and the effects observed Vary in their nature and intensity (Piccolo, 1996).

Humic treatments mainly affect the growth and development of seeds, seedlings or whole plants. Specific effects are observed on organs, cells or cellular metabolism.

2.2.5.3. Plant germination and growth:

2.2.5.3.1. Germination and rhizogenesis:

From the earliest stages of development, HS exhibit positive effects on germination. Humic treatments increase the rate of germination, but do not modify the percentage of germinated seeds. This stimulation would be linked to the increase in the enzymatic activity of the tissues of the seed (Chen and Aviad, 1990).

Humic fractions show important effects on rhizogenesis. The responses are reflected in an increase in the number and length of roots for low concentrations (50 to 100 mg of carbon per liter) of humic and fulvic acids (from soil or commercial preparation)(Mylonas and McCants, 1980). The fresh weight of the roots can also be increased for doses ranging from 2500 to 5000 $mg.L^{-1}$ of humic acids (Hartwigsen and Evans, 2000).

Humic treatments also increase fresh weights (Cooper et al., 1998; Hartwigsen and Evans, 2000) and dried young shoots from the treated seeds.

The study of the germination of tomato seeds pretreated with preparations of humic acids (oxidized carbon) indicates an increase in the fresh and dry masses of the seedlings, proportional to the concentration of humic acids. Piccolo (1993) attributes this phenomenon to better water efficiency and greater cell elongation.

Finally, in general, high concentrations of humic acids inhibit the effects observed on germination. These concentrations vary according to the studies (Mylonas and McCants, 1980).

2.2.5.3.2. Growth of roots and aerial parts:

Regardless of their method of application, humic substances improve plant growth, by inducing a quantitative increase in the length, surface area, volume or mass of plant organs (Chen and Aviad, 1990).

These modifications are observed on root growth by the appearance and elongation of new roots. Thus Rauthan (1981) emphasize an acceleration of root growth (length, dry weight) in cucumber grown in aquaculture in the presence of 100 to 300 mg.L^{-1} of fulvic acids extracted from the soil. The use of humic solutions on a culture of *Agrostis Stolonifera* L. (grass) also makes it possible to observe an increase of 38 to 45% in the root biomass and an increase of 15% in the length of the roots treated (Cooper et al., 1998).

Numerous studies show that the addition of HS to hydroponic crops promotes the growth of aerial parts (Chen and Aviad, 1990; Vaughan and Malcolm, 2012) .The main effects are observed on the production of biomass of leaves, flowers, stems and fruits.

The study of the impact of humic acids on the growth of teak (*Tectona grandis*L.f.) makes it possible to positively correlate the concentration of humic matter with the height of the plants, the diameter of the stem and the content of total dry matter (Fagbenro and Agboola, 1993).

Other studies comparing the effects of humic substances on maize and algae reveal an increase of 30 to 50% in the biomass of maize for a concentration of 5 mg .L^{-1} and of 100% in the biomass of algae for a concentration of 60 mg .L^{-1}(Lee and Bartlett, 1976).

The concentration of humic substances plays an important role in plant response. There is an optimum application concentration which varies from plant to plant (Lee and Bartlett, 1976). Like germination, plant growth is inhibited by high concentrations (Chen and Aviad, 1990).

2.2.5.3.3. Plant development:

In addition to their impacts on growth, HS can induce cell differentiation involving new morphological and functional properties. These qualitative changes result in the appearance of new organs (leaves or flowers).

Thus, additions of compost to *Pelargonium x hortorum* grown in solid substrates show a significant increase in the number of floral bouquets per plant, and in the number of flowers per floral bouquet for contents of up to 20% compost by volume (Ribeiro et al., 2000). The tests carried out with the SHs also show positive results on the number of leaves and flowers of the pelargonium (Galy, 2002).

The impact of HS on plant growth has long been attributed to hormonal action (Bottomley, 1917) and many authors compare the effect of humic substances to an auxin activity, Indole-3-acetic acid (AIA) (Muscolo et al., 1999).

The hormonal activity attributed to humic substances is probably carried out indirectly. The detection of auxin structure within the humic substances of soil or compost can be attributed to a plant or microbial origin (Lebuhn and Hartmann, 1993).

The action of humic substances on hormonal activity is expressed through interactions with the mechanisms regulating auxin metabolism.HS stimulate endogenous auxin production, or inhibit the action of AIA oxidase, the enzyme responsible for auxin degradation (Mato et al., 1972). This inhibition increases with concentration of humic and fulvic acids and causes the accumulation of auxin in plants.

2.2.5.3.4. Mineral nutrition:

The growth of plants is largely influenced by their mineral nutrition, water and air supplied to the roots. The effects of HS on plant growth are generally linked to the high absorption of mineral elements (Lulakis and Petsas, 1995; Tan and Nopamornbodi, 1979).

Several studies show that humic substances promote the uptake of mineral elements by plants (Chen and Aviad, 1990). The absorption of macroelements (N, P, K, Mg, Ca) and microelements (Cu, Fe, Zn.) increases in the presence of humic acids (De Kreij and Başar, 1995).

The solubilization of mineral elements is an essential factor in the stimulation of plant growth. The influence of HS on the mineral nutrition of plants is explained by a direct action on the availability of the elements.The presence of humic substances in the soil influences fertility and mineral reserves by promoting the release and dissolution of macroelements contained in the mineral components of the soil (Chen and Aviad, 1990).

The transport of ions and their positioning in the form of complexes around the rhizosphere condition the absorption of mineral elements. Through their physico-chemical properties, HS complex mineral elements and promote their absorption by plants. Thus, humate granules incorporated into the soil increase soil fertility, improve water efficiency and the retention of elements essential to plants in the rhizosphere (Cooper et al., 1998).

Mineral nutrition can be indirectly affected by humic substances. The structural modification of the root system increases the number of roots and the effective exchange surface and allows better absorption of mineral elements.In addition, humic substances interfere with the metabolic processes involved in the active absorption of elements (Canellas et al., 2002; Vaughan and Malcolm, 2012) and Malcom, 1985b). The stimulation of the consumption of mineral elements by humic treatments reflects the impact of this material on the ion transport proteins (Pinton et al., 1999).

The absorption of elements by the root is however highly dependent on the concentration of humic substances in the milieu, the high levels remain inhibitory (Vaughan and Malcolm, 2012) .

2.2.5.3.5. Energy metabolism:

The direct effect of humic substances on growth occurs at the level of energetic metabolic processes such as respiration, photosynthesis or protein synthesis. The action of humic substances on these processes modifies the production of energy metabolites (ATP) and affects plant growth. Many studies show that humic substances of various origins improve plant respiration (Nardi et al., 2002). The increase in respiratory activity results in a significant consumption of oxygen and is observed following the foliar application or in nutrient solution of humic matter (Vaughan, 1985). Under certain conditions, particularly at ground level, the action of humic fractions on respiration is considered indirect. The molecules serving as a substrate for the microflora, the microbial activity generates by-products that promote the growth of the plant and its respiration.

The use of humic substances also causes an increase in chlorophyll content (Tejada and Gonzalez, 2004). This results in a higher photosynthetic assimilation favoring the production of ATP, amino acids, sugar and proteins, therefore the growth of plants (Vaughan, 1985).

2.2.5.3.6. Synthesis of proteins and nucleic acids:

Humic substances modify the synthesis of nucleic acids, DNA and RNA, and particularly influence the production of messenger RNA, essential in many biochemical processes (Nardi et al., 2002). Changes in RNA synthesis reflect changes in plant growth. Being strongly linked to transcription and translation, protein synthesis, in particular enzymatic synthesis is also influenced by humic substances. The action of humic fractions is targeted on the synthesis of certain structural proteins and enzymes such as invertases, catalases and peroxidases (Malcolm and Vaughan, 1979; Nardi et al., 2000).

2.2.5.4. Effects of humic acid on potato crop:

In the study of (Azamshah et al., 2016), the effects of foliar applications of urea, zinc, boron, and humic acid alone and in combination on potato yield and nutrient contents were examined. When compared to other treatments, the humic acid plots had the highest yield of potato tubers.

On potato fields, humic substance application resulted in a significant increase in tuber output (Verlinden et al., 2009).

Many studies were reported by (Selim et al., 2009) and (Ezzat et al., 2009) confirm that the application of humic substances to potato enhanced tuberous yield quantity and quality.

3. MATERIALS AND METHODS

3.1. Experiment site:

The experiments were conducted during the season of 2022-2023 in greenhouse of the Potato Research Centre (Keszthely) to study the influence of humic acid with presence of four types of fertilisers on two varieties of potato (Balatoni rózsa and Botond).

3.2. Plant material:

- Balatoni rózsa

Maturity: Early, 85-90 days

Tuber: Red skin, yellow flesh, attractive, oval shape, bigsized uniform, shallow eyes. Tuber set 10-12/plant. Dry matter content medium (19-20%).

Haulm: Medium high, strong shoots with large sized, mat green leaves.

Flower: Common, pale purple coloured.

Resistances: Highly resistant against PVY, PVA and PLRV.

Consumption quality: General use table potato, cooking type "B", firm cooking, excellent taste, free from fresh and after cooking darkening. Potential for French fries production.

Production: Very high yielder, up to 80 t/ha.

- Botond

Maturity: Very early (~85 days)

Tuber: Round oval, large sized, red skin, pale yellow flesh with shallow eyes and stabile shape.

Attractive appearance: Tuber set 10-12/plant.

Dry matter content medium (17-18 %).

Haulm: Strong, erect shoots with dark green leaves.

Flower: Abundant, pale red with white tips.

Resistances: Highly resistant against PVY, PVA and PLRV.

Consumption quality: Table potato, cooking type "B", not floury, with fine tuber structure and good taste. Free from fresh and after cooking discoloration.

Production: Moderately high yielder, up to 60 t/ha.

3.3. Experimental protocol:

3.3.1 Experiment I.

The effect of four fertilisation (F1-F4) differing in the ratios of macro nutrients and application was tested based on the size distribution and number of developed tubers.

Growing substrate preparation:

Before planting; plastic crates (size: W: H: L, 40:60:20 cm) were filled with Baltic peat. Peat was mixed with selected fertilisers (see Table 4). and watered evenly. For planting 125 pieces of seed tubers/crate were applied. Planting was done on 12.05.2022.

Four different fertilisation methods were applied with or without humic acid enrichment. Five crates per fertilisation were prepared. One crate represented one repetition. All together yields of 80 crates were evaluated (2 variety x 8 fertilisation, 4 with or without humic acid x 5 repetitions).

Fertilisation 1 (F1): 10g of fertiliser Poly Feedand 1g of Pétisó was applied for each crate before planting.

Fertilisation 2 (F2): 10g of FerticareHydro I was applied for each crate before planting.

Fertilisation 3 (F3): 10g of Ferticare Hydro I was applied for each crate before planting.7.5g of Ferticare Hydro II was applied 60 days after planting.

Fertilisation 4 (F4): 10g of Ferticare Hydro I was applied for each crate before planting. 7.5g of Ferticare Hydro IIwas applied 30 days and 60 days respectively after planting.

3.3.2 Experiment II.

The effect of humic acid treatment combined with the four fertilisation (F1-F4) methods was tested based on the size distribution and number of developed tubers.

The same F1-F4 fertilisation method was used but for each crate was enriched by 1.25 ml humic acid solution (Humin Aqua Humusol product of HUMIN AQUA® System Company). The product is certified as: biological 100% organic, bee-friendly, soil improving humic acid, harmless to human health and concentrate with a min. 60% humic acid content.

(https://huminaqua.hu/wp-content/uploads/2019/05/142_ENG_Terraform_2019_HUMIN_Aqua_bio_system.pdf)

Tuber yield of each crate was individually evaluated.The number and weight of tubersrepresenting four size categories was measured (Big, above 3 cm (M1), Middle, 2-3 cm (M2), Small 1-2 cm (M3), Mini below 1cm in diameter (M4);see Figure 3.).

Table 4. Detailed chemical composition of fertilisers applied.

Chemicals properties %	**Fertilisers**			
	Poly Feed Foliar vine	Ferticare Hydro I	Ferticare Hydro II	Pétisó
Total Nitrogen (N)	4	6	15	27
Total Phosphorus (P2O5)	15	14	30	
Total Potassium (K2O)	37	30	15	
Magnesium (MgO)	3	4	2.5	5
Nitric Nitrogen (N-NO3)	4			
Calcium oxide (CaO)				7
Zinc (Zn)	0.015	0.02	0.01	
Iron (Fe)	0.23	0.2	0.1	
Boron (B)	0.02	0.03	0.02	
Copper (Cu)	0.011	0.02	0.01	
Manganese (Mn)	0.05			
Other Micronutrients	Molybdenum (Mo),EDTA-Chelates	Molybdenum nitride(MoN),Chlorine-free	Sulfur trioxide (SO4),Molybdenum nitride(MoN),Chlorine-free	

Figure 3. The different sizes of harvested tubers.

3.4. Statistical evaluation

The data recorded and the results obtained for yield were analyzed statistically using the One-Way ANOVA performed with SPSS statistical software.

4. RESULTSANDDISCUSSION

4.1. Effect of different types of fertilisers on tubers weight of Balatoni rózsa with different diameters:

Data presented in Table 5 showed that the difference on tubers weight means between all fertilisers F1-F4 for the different measurements M1-M4 was not significant. The highest value for M1 was 1238.02g using F3 and the lowest was 938.22g using F1. The values of means for M2 utilizing F1-F4 were respectively 132.04g, 132.04g, 137.54g and 176.64g. For M3 the values of different average of using F1-F4 were 8.06g, 5.24g, 6.52g and 4.92g respectively. For the smallest size M4 the values were varied in F1-F4 between 4.34g and 6.82g.

Table 5. Effect ofdifferent types of fertilisers without treatment of humic acid on tubers weight of Balatoni rózsa with different diameters

Treatment	Big above 3 cm M1	Middle 2-3 cm M2	Small 1-2 cm M3	Mini below 1 cm M4
	The mean of weight (g) ± SD			
Fertiliser 1	938.22±135.74	132.04±45.58	8.06±2.75	4.34±1.00
Fertiliser 2	1058.220±160.77	132.04±32.36	5.24±1.90	4.82±1.34
Fertiliser 3	1238.02±184.06	137.54±28.83	6.52±2.65	4.10±1.96
Fertiliser 4	1176.15±232.90	176.64±40.85	4.92±3.30	6.82±2.79

(SD): Standard Deviation, (g): gram

4.2. Effect of different types of fertilisers enriched with humic acid on tubers weight of Balatoni rózsa with different diameters:

Data in Table 6 showed that humic acid application has significant effects ($p<0.05$)on tubers weight means in M1 and M3 between the different fertilisers (F1-F4). However; it didn’t show significant effects for M2 and M4.

The highest significant value of weight mean in M1 was 1411.56 [a]g using F4 with humic acid, and the lowest in the same size was 1010.76[c]g using F2 with humic acid. The significant values in M3 using F1-F4 with humic acid were respectively 5.26 [b] g, 9.68 [a] g, 4.12 [b] g and 3.52 [b] g.

The non significant values of means in M2 utilizing F1-F4 with humic acid were respectively 108.38g; 152.52g, 171.06g and 141.74g.While in M4 were respectively 3.86g, 7.22g, 4.32g and 5.82g.

Table 6. Effect of different types of fertilisers with treatment of humic acid on tubers weight of Balatoni rózsa with different diameters

Treatment	Big above 3 cm M1	Middle 2-3 cm M2	Small 1-2 cm M3	Mini below 1 cm M4
	The mean of weight (g) ± SD			
Fertiliser 1+HA	1069.98±274.05 [bc]	108.38±37.25	5.26±3.70 [b]	3.86±3.77
Fertiliser 2+HA	1010.76±136.26 [c]	152.52±34.17	9.68±3.23 [a]	7.22±2.07
Fertiliser 3+HA	1323.1±238.26 [ab]	171.06±50.30	4.12±2.79 [b]	4.32±3.34
Fertiliser 4+HA	1411.56±185.46 [a]	141.74±29.30	3.52±3.09 [b]	5.82±2.74

Mean values in a given column followed by same letters are not statistically different at p-value ≤0.05
(HA):Humic Acid, (SD): Standard Deviation, (g): gram

4.3. Effect of different types of fertilisers on tubers weight of Botond with different diameters:

Data presented in Table 7 showed that the difference on tubers weight means between all fertilisers in M1, M2 and M3 was highly significant ($p<0.05$); especially for M3 ($p=0.002$). However; for the smallest size (M4) the difference was not significant.

The significant values of tubers weight means in M1 using F1-F4 were respectively 576.42 [b] g,657.90 [ab] g, 794.02 [a] g and 680.02[ab] g.

The significant values of tubers weight means in M2 using F1-F4 were respectively406.76 [a] g, 313.72 [b] g, 304.18 [b] g and 296.44 [b] g.

The significant values of tubers weight means in M3 using F1-F4 were respectively 19.54 [b] g, 18.22 [b] g, 64.06 [a] g and 51.72 [a] g.

The non significant values of means in M4 utilizing F1-F4 were respectively18.22 g, 21.26 g, 18.58 g and 14.64 g.

Table 7. Effect of different types of fertilisers without treatment of humic acid on tubers weight of Botond with different diameters

Treatment	Big above 3 cm M1	Middle 2-3 cm M2	Small 1-2 cm M3	Mini below 1 cm M4
	The mean of weight (g) ± SD			
Fertiliser 1	576.42±96.31 [b]	406.76±71.69 [a]	19.54±5.30 [b]	18.22±4.79
Fertiliser 2	657.90±95.77 [ab]	313.72±55.35 [b]	18.22±5.25 [b]	21.26±4.14
Fertiliser 3	794.02±76.25 [a]	304.18±57.06 [b]	64.06±25.77 [a]	18.58±5.06
Fertiliser 4	680.02±151.49 [ab]	296.44±68.55 [b]	51.72±26.06 [a]	14.64±10.06

Mean values in a given column followed by same letters are not statistically different at p-value ≤0.05
(SD): Standard Deviation, (g): gram

4.4. Effect of different types of fertilisers enriched with humic acid on tubers weight of Botond with different diameters:

The results represented in Table 8 showed that humic acid application has significant effects(p=0.001) on tubers weight means between all fertilisers for the biggest size (M1). However; for all other sizes (M2, M3 and M4) theeffectwas not significant.

The significant values of weight average in M1 using F1-F4 with humic acid were respectively 610.56 [b] g, 748.30 [b] g, 915.36 [a] g and 907.14 [a] g.

The non significant values of means in M2 utilizing F1-F4 with humic acid were respectively 386.74 g, 274.02 g, 320.40 g and 271.36 g.

The non significant values of means in M3 utilizing F1-F4 with humic acid were respectively 24.16 g, 23.6 g,22.64 g, and 16.64 g.

The non significant values of means in M4 utilizing F1-F4 with humic acid were respectively 22.84 g, 23.38 g, 23.20 g and 17.38 g.

Table 8. Effect of different types of fertilisers with treatment of humic acid on tubers weight of Botond with different diameters

Treatment	**Big above 3 cm M1**	**Middle 2-3 cm M2**	**Small 1-2 cm M3**	**Mini below 1 cm M4**
	The mean of weight (g) ± SD			
Fertiliser1 +HA	610.56±71.45 [b]	386.74±55.75	24.16±4.17	22.84±9.85
Fertiliser 2 +HA	748.30±73.61 [b]	274.02±56.04	23.6±6.17	23.38±3.68
Fertiliser 3 +HA	915.36±154.88 [a]	320.40±125.60	22.64±8.19	23.20±9.58
Fertiliser 4 +HA	907.14±95.06 [a]	271.36±80.40	16.64±4.59	17.38±3.72

Mean values in a given column followed by same letters are not statistically different at p-value ≤0.05
(HA):Humic Acid, (SD): Standard Deviation, (g): gram

Effect of different kind of fertilisers (F1-F4), at various compositions, influenced economic yield and tubers weight of two varieties of potato Balatoni rózsa and Botond (Table 5&7.).It was observed that the highest value of tuber weight mean for Balatoni rózsa within the treatment without humic acid is for the biggest size 1238.2 g (M1, F3) (Table 5.); and 794.02 g (M1, F3) (Table 7.) for Botond. We assume that this is due to the addition of Ferticare Hydro II fertiliser and its use in a regulated and appropriate quantity comparing with the values that we have obtained from the treatment of fertiliser4 without humic acid (Table 5&7).From all treatments (Table 5, 6, 7&8), we observed that the variety of Balatoni rózsa was the most productive.

Results indicated that the application of humic acid with combination of different fertilisers (F1-F4) of all varieties had a positive effects on tubers yield and weight (Table 6&8) comparing with control treatments, but with F3 and F4 had more significant effects ($p<0.05$), where; for example the highest rate of weigh for the big measurement(M1) using (F4) with humic acid was 1411.56g (Table 6.), while the lowest was obtained from the control (treatment without humic acid) which produced 1176.15 g (Table5.) for Balatoni rózsa.

The highest rates of weigh for M1 using F3 with humic acid was 915.36 g (Table 8.), while the lowest was obtained from the control (treatment without humic acid) which produced 794.02 g (Table 7.) for Botond. Humic substances have beenreported to influence plant growth (Chen and Aviad, 1990). The findings of present research is in line with the findings other researchers (Radwan et al., 2011), who reported that the best method for increasing N, P, and K uptake percentage by straw and tubers is to treat potato plants with humic acid.(Verlinden et al., 2009) reported that the largest effects of application of humic substances at the start of the growing season in the field and pot experiments on dry matter yield were observed for the potato yield.

Plants may benefit from humic acid in a number of ways, including increased nutritional content and a larger supply of slow-release nutrients, enhanced solubility of phosphorus, zinc, iron, manganese, and copper, improved soil aggregation, enlarged root system and then increased the uptake of these elements by plant (Mikkelsen, 2005). It is consonance with the current investigation that applications of humic acid with multinutrient fertilisers increase the weight of tubers and yield of potato. The similar results were reported in apple (Guo et al., 2000), soybean (Shuixiu and Ruizhen, 2001) and grape (Hui-Ying et al., 2007) due to application of humic acid multinutrient complex fertilisers.

Finally, it could be concluded that, the best interaction treatment for increasing tubers weight was obtained by fertilisation 3&4 (Table 4.) enriched with humic acid.

5. CONCLUSION

The results showed thatthe use of humic acid at planting time in combination with different fertilisers (F1-F4) in greenhouse conditions had a positive effect on both tuber yield and weight across all varieties tested (Balatoni rózsa and Botond), compared to control treatments without humic acid.Our studies show that the results of humic acid application were more significant with the fertilisation 3&4. This could be attributed to the use of Ferticare Hydro II fertiliser in regulated and appropriate quantities. This suggests that the use of humic acid in combination with appropriate fertilisation methods at planting time could be an effective strategy for increasing potato yields and weight in greenhouse conditions. Additionally, Balatoni rózsa was observed to be the more productive variety among all treatments.

The origin, type, and concentration of humic substances, as well as the species and variety of the plant being treated, all have an impact on how well plants produce and absorb nutrients. It is recommended that future research should focus on determining the optimal amount and frequency of humic acid application at different stages of plant growth, as well as the specific fertiliser compositions and application methods that would be most effective for increasing potato yields and weight in greenhouse conditions.

It may also be useful to study the long-term effects of these treatments on soil health and nutrient availability. Additionally, conducting field experiments to validate the results of greenhouse studies and evaluating the economic feasibility of incorporating these treatments into potato production systems.

6. SUMMARY

The potato crop (*Solanum tuberosum* L.) is one of the most significant vegetable crops in the world. The positive effect of humic substances on the growth of numerous plants is well documented.

A greenhouse experiment was conducted during the season of 2022-2023 inthe Potato Research Centre (Keszthely) to study the influence of humic acid with presence of four types of fertilisers on tuber's weight of two varieties of potato (Balatoni rózsa and Botond).Four different fertilisation methods were applied with or without humic acid enrichment at planting time. Five crates per fertilisation were prepared. One crate represented one repetition. All together yields of 80 crates were evaluated (2 variety x 8 fertilisation, 4 with or without humic acid x 5 repetitions).

The results showed that the use of humic acid at planting time in combination with different fertilisers (F1-F4) in greenhouse conditions had a positive effect on tuber yield by increasing tuber weight of each varieties tested (Balatoni rózsa and Botond). Our studies show that the results of humic acid application were more significant with the fertilisation 3&4. Additionally, Balatoni rózsa was observed to be the more productive variety among all treatments.

It is recommended to conducting field experiments with the optimal amount and frequency of humic acid application to validate the results of greenhouse studies and evaluating the economic feasibility of incorporating these treatments into potato production systems.

7. ACKNOWLEDGEMENTS

First of all, I would like to express my sincere gratitude to FAO and Hungary Government for given me the scholarship. Also to those who have been providing me with the required support to make sure I succeed and complete this project and throughout my studies.

I gratefully acknowledge the unflinching support and advice of my supervisor Dr. Polgár Zsolt Géza for assisting me throughout this thesis work. I want to express my thanks to the staff and students of Department of Plant Protection, Keszthely, Georgikon Campus for providing me with good and conducive environment and facilities during my studies and thesis work.

Finally, I would like to indulge and thank my family, especially my parents and my beloved wife for their love, support, resilience and understanding during my studies and thesis work.

God richlyblessand increaseusall.

8. REFERENCES

1. Ahmadvand, R. (2013). Analysis of resistance genes in potato with special attention to expressional approaches, PhD dissertation. http://konyvtar. uni-pannon. hu/doktori/2013 ….
2. Alsayed, S. (2009). Production of Cold Season Vegetables in Desert Lands. *College of Agriculture-Cairo University*. *Egyptian Library for Printing and Publishing. pp* 783.
3. Anonyme (2008). La pomme de terre. *internationale de la pomme de terre un*
4. *trésor enfoui*. *Organisations des nations unies*, 12-45.
5. Ayuso, M., Hernandez, T., Garcia, C., and Pascual, J. (1996). Stimulation of barley growth and nutrient absorption by humic substances originating from various organic materials. *Bioresource Technology* 57, 251-257.
6. Azamshah, S., Mohammad, W., S Shahzadi, S., Elahi, R., Ali, A., and A Basir, A. (2016). The effect of foliar application of urea, humic acid and micronutrients on potato crop. *Iran Agricultural Research* 35, 89-94.
7. Bailly, J.-R. (1985). Sur la structure des substances humiques et le rôle des microorganismes dans leur formation, Toulouse 3.
8. Bottomley, W. (1917). Some effects of organic growth-promoting substances (auximones) on the growth of Lemna minor in mineral culture solutions. *Proceedings of the Royal Society of London. Series B, Containing Papers of a Biological Character* 89, 481-507.
9. Burlingame, B., Mouillé, B., and Charrondiere, R. (2009). Nutrients, bioactive non-nutrients and anti-nutrients in potatoes. *Journal of Food Composition and Analysis* 22, 494-502.
10. Busnot, A., Busnot, F., Le Querler, J., and Yazbeck, J. (1995). Caractérisation de matériel humique, d'origine terrestre de la région Bas-Normande. *Thermochimica Acta* 254, 319-330.
11. Canellas, L. P., Olivares, F. L., Okorokova-Façanha, A. L., and Façanha, A. R. (2002). Humic acids isolated from earthworm compost enhance root elongation, lateral root emergence, and plasma membrane H+-ATPase activity in maize roots. *Plant physiology* 130, 1951-1957.
12. Chen, Y., and Aviad, T. (1990). Effects of humic substances on plant growth. *Humic substances in soil and crop sciences: selected readings*, 161-186.
13. Chung, T.-L., Chen, J.-S., Chiu, C.-Y., and Tian, G. (2012). 13C-NMR spectroscopy studies of humic substances in subtropical perhumid montane forest soil. *Journal of forest research* 17, 458-467.
14. Cooper, R., Liu, C., and Fisher, D. (1998). Influence of humic substances on rooting and nutrient content of creeping bentgrass. *Crop Science* 38, 1639-1644.
15. De Kreij, C., and Başar, H. (1995). Effect of humic substances in nutrient film technique on nutrient uptake. *Journal of Plant Nutrition* 18, 793-802.

16. Delaplace, P. (2007). Caractérisation physiologique et biochimique du processus de vieillissement du tubercule de pomme de terre (Solanum tuberosum L.).
17. Duchaufour, P. (1970). Humification et ecologie. *Cah ORSTOM Sér Pédol* 8, 1-12.
18. Eyheraguibel, B. (2004). Caractérisation des substances humiques biomimétiques: effets sur les végétaux.
19. Ezzat, A., Eldeen, U. S., and Abd El-Hameed, A. (2009). Effect of irrigation water quantity, antitranspirant and humic acid on growth, yield, nutrients content and water use efficiency of potato (Solanum tuberosum L.). *J. Agric. Sci. Mansoura Univ* 34, 11585-11603.
20. FAO (2020). Crops and livestock products (https://www.fao.org/faostat/en/#data/QCL).
21. Fagbenro, J., and Agboola, A. (1993). Effect of different levels of humic acid on the growth and nutrient uptake of teak seedlings. *Journal of Plant Nutrition* 16, 1465-1483.
22. Filella, M. (2009). Freshwaters: which NOM matters? *Environmental chemistry letters* 7, 21-35.
23. Fraser, N. (2000). La production biologique de la pomme de terre: Resultats des essais et experimentations en production commerciale. *In* "Colloque sur la pomme de terre, Canada", pp. 81-91.
24. Galy, C. (2002). Influence de l'ajout de substances humiques-likes dans des solutions fertilisantes sur des cultures de pélargoniums X hortorum, Toulouse, INPT.
25. Guo, B., Yang, J., Lu, R., and Yu, S. (2000). Effect of KOMIX on the growth and fruiting of Red Fuji apple variety. *Journal of fruit Science* 17, 73-75.
26. Hartwigsen, J. A., and Evans, M. R. (2000). Humic acid seed and substrate treatments promote seedling root development. *HortScience* 35, 1231-1233.
27. Hui-Ying, D., Shi-Chuan, X., and Zhong-Fu, S. (2007). Effects of different application rates of humic acid compound fertiliser on leave nutrient accumulation and physiological mechanism of grape. *中国生态农业学报(中英文)* 15, 49-51.
28. King, J. C., and Slavin, J. L. (2013). White potatoes, human health, and dietary guidance. *Advances in nutrition* 4, 393S-401S.
29. Kononova, M. (1966). Soil organic matter.,(Pergamon: Elmsford, NY).
30. Kumada, K., Sato, O., Ohsumi, Y., and Ohta, S. (1967). Humus composition of mountain soils in central Japan with special reference to the distribution of P type humic acid. *Soil science and plant nutrition* 13, 151-158.
31. Langford, C. H., Gamble, D., Underdown, A., and Lee, S. (1983). Interaction of metal ions with a well characterized fulvic acid. *Aquatic and terrestrial humic materials*, 219-237.
32. Lebuhn, M., and Hartmann, A. (1993). Method for the determination of indole-3-acetic acid and related compounds of L-tryptophan catabolism in soils. *Journal of Chromatography A* 629, 255-266.
33. Lee, Y. S., and Bartlett, R. J. (1976). Stimulation of plant growth by humic substances. *Soil Science Society of America Journal* 40, 876-879.

34. Li, X. (2004). Transformation and mineralization of organic matter by the humivorous larva of Pachnoda ephippiata (Coleoptera: Scarabaeidae).

35. Li, Y. (2020). Research progress of humic acid fertiliser on the soil. *In* "Journal of Physics: Conference Series", Vol. 1549, pp. 022004. IOP Publishing.

36. Lulakis, M., and Petsas, S. (1995). Effect of humic substances from vine-canes mature compost on tomato seedling growth. *Bioresource Technology* 54, 179-182.

37. MacCarthy, P., Bloom, P., Clapp, C., and Malcolm, R. (1990). Humic substances in soil and crop sciences: an overview. *Humic substances in soil and crop sciences: selected readings*, 261-271.

38. Malcolm, R., and Vaughan, D. (1979). Effects of humic acid fractions on invertase activities in plant tissues. *Soil Biology and biochemistry* 11, 65-72.

39. Mato, M., Olmedo, M., and Mendez, J. (1972). Inhibition of indoleacetic acid-oxidase by soil humic acids fractionated on sephadex. *Soil Biology and biochemistry* 4, 469-473.

40. Mattila, P., and Hellström, J. (2007). Phenolic acids in potatoes, vegetables, and some of their products. *Journal of Food Composition and Analysis* 20, 152-160.

41. Mikkelsen, R. (2005). Humic materials for agriculture. *Better crops* 89, 6-10.

42. Morel, R. (1996). Les sols cultivés.

43. Moritsuka, N., and Matsuoka, K. (2018). An overview of the effects of heat treatments on the quality of organic wastes as a nitrogen fertiliser. *Nitrogen in Agriculture: Updates*, 53.

44. Muscolo, A., Bovalo, F., Gionfriddo, F., and Nardi, S. (1999). Earthworm humic matter produces auxin-like effects on Daucus carota cell growth and nitrate metabolism. *Soil Biology and biochemistry* 31, 1303-1311.

45. Mylonas, V., and McCants, C. (1980). Effects of humic and fulvic acids on growth of tobacco: I. Root initiation and elongation. *Plant and soil* 54, 485-490.

46. Nardi, S., Pizzeghello, D., Gessa, C., Ferrarese, L., Trainotti, L., and Casadoro, G. (2000). A low molecular weight humic fraction on nitrate uptake and protein synthesis in maize seedlings. *Soil Biology and biochemistry* 3, 415-419.

47. Nardi, S., Pizzeghello, D., Muscolo, A., and Vianello, A. (2002). Physiological effects of humic substances on higher plants. *Soil Biology and biochemistry* 34, 1527-1536.

48. Nasir, S., Sarfaraz, T. B., Verheyen, T. V., and Chaffee, A. (2011). Structural elucidation of humic acids extracted from Pakistani lignite using spectroscopic and thermal degradative techniques. *Fuel processing technology* 92, 983-991.

49. Pajerowska-Mukhtar, K. (2005). Isolation and characterization of potato homologues of Arabidopsis thaliana genes operating in defense signal transduction, Universität zu Köln.

50. Pathak, H., Aggarwal, P., Roetter, R., Kalra, N., Bandyopadhaya, S., Prasad, S., and Van Keulen, H. (2003). Modelling the quantitative evaluation of soil nutrient supply, nutrient use efficiency, and fertiliser requirements of wheat in India. *Nutrient cycling in agroecosystems* 65, 105-113.

51. Pelt, J.-M. (1993). "Des légumes," Fayard, Paris.

52. Peña-Méndez, E. M., Havel, J., and Patočka, J. (2005). Humic substances-compounds of still unknown structure: applications in agriculture, industry, environment, and biomedicine. *J. Appl. Biomed* 3, 13-24.

53. Piccolo, A. (1996). "Humic substances in terrestrial ecosystems," Elsevier.

54. Pinton, R., Cesco, S., Santi, S., Agnolon, F., and Varanini, Z. (1999). Water-extractable humic substances enhance iron deficiency responses by Fe-deficient cucumber plants. *Plant and soil* 210, 145-157.

55. Polese, J.-M. (2006). "La culture des pommes de terre," Editions Artemis.

56. Purakayastha, T., and Katyal, J. (1998). Evaluation of compacted urea fertilisers prepared with acid and non-acid producing chemical additives in three soils varying in pH and cation exchange capacity; I. NH 3 volatilization. *Nutrient cycling in agroecosystems* 51, 107-115.

57. Radwan, E., El-Shall, Z., and Ali, R. (2011). Effect of potassium fertilisation and humic acid application on plant growth and productivity of potato plants under clay soil. *Journal of Plant Production* 2, 877-890.

58. Ribeiro, H., Vasconcelos, E., and Dos Santos, J. (2000). Fertilisation of potted geranium with a municipal solid waste compost. *Bioresource Technology* 73, 247-249.

59. Rousselle, P., Crosnier, J.-C., and Robert, Y. (1996). La pomme de terre: production, amélioration, ennemis et maladies, utilisations. *La pomme de terre*, 1-640.

60. Schnitzer, M., and Khan, S. U. (1978). "Soil Organic Matter," Elsevier scientific co., New york.

61. Selim, E., Mosa, A., and El-Ghamry, A. (2009). Evaluation of humic substances fertigation through surface and subsurface drip irrigation systems on potato grown under Egyptian sandy soil conditions. *Agricultural water management* 96, 1218-1222.

62. Selladurai, R., and Purakayastha, T. J. (2016). Effect of humic acid multinutrient fertilisers on yield and nutrient use efficiency of potato. *Journal of Plant Nutrition* 39, 949-956.

63. Shuixiu, H., and Ruizhen, W. (2001). Studies on the effect of KOMIX humic acids containing organic fertiliser on spring soybean. *Jiangxi Nongye Daxue Xuebao (China)*.

64. Soltner, D. (2012). "Les grandes productions végétales: manuel d'agronomie ou de phytotechnie" spéciale: les céréales, les plantes dites" sarclées", les plantes fourragères," Collection Sciences et techniques agricoles.

65. Sposito, G. (1989). The Chemistry of Soils Oxford Univ. *Press, New York, USA*.

66. Stevenson, F. (1982). Humus Chemistry: Genesis, Composition, Reactions. John Wiley & Sons, New York.-443 pp.

67. Stevenson, F. (1985). Geochemistry of soil humic substances.

68. Stevenson, F. J., and Cole, M. A. (1999). "Cycles of soils: carbon, nitrogen, phosphorus, sulfur, micronutrients," John Wiley & Sons.

69. Syabryai, V., Reutov, V., and Vigdergauz, L. (1965). Preparation of humic fertilisers from brown coal. *Geol. Zh. Akad. Nauk Ukr* 25, 39-47.

70. Tan, K., and Nopamornbodi, V. (1979). Effect of different levels of humic acids on nutrient content and growth of corn (Zea mays L.). *Plant and soil* 51, 283-287.

71. Tejada, M., and Gonzalez, J. (2004). Effects of foliar application of a byproduct of the two-step olive oil mill process on rice yield. *European journal of agronomy* 21, 31-40.

72. Tilman, D., Balzer, C., Hill, J., and Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. *Proceedings of the national academy of sciences* 108, 20260-20264.

73. Twagiramungu, F. (2003). Etude potentiom, Ghent University.

74. Vaughan, D. (1985). Influence of humic substances on biochemical processes in plants In: Soil Organic Matter and Biological Activity (Vaughan, D. and Malcolm, RE, Eds.). Kluwer Academic Publishers, Dordrecht.

75. Vaughan, D., and Malcolm, R. (2012). "Soil organic matter and biological activity," Springer Science & Business Media.

76. Verlinden, G., Pycke, B., Mertens, J., Debersaques, F., Verheyen, K., Baert, G., Bries, J., and Haesaert, G. (2009). Application of humic substances results in consistent increases in crop yield and nutrient uptake. *Journal of Plant Nutrition* 32, 1407-1426.

77. Yanze Kontchou, C. (1992). Biodégradation des acides humiques par Streptomyces viridosporus, Lille 1.

78. Zaheer, K., and Akhtar, M. H. (2016). Potato production, usage, and nutrition—a review. *Critical reviews in food science and nutrition* 56, 711-721.

DECLARATION

on authenticity and public assess of final mater's thesis

Student's name:	CHIHANI ABDELGHANI
Student's Neptun ID:	R4I1QL
Title of the document:	The effect of humic acid treatments on potatoes
Year of publication:	2023
Department:	Plant Protection

I declare that the submitted final master's thesis is my own, original individual creation. Any parts taken from an another author's work are clearly marked, and listed in the table of contents.

If the statements above are not true, I acknowledge that the Final examination board excludes me from participation in the final exam, and I am only allowed to take final exam if I submit another final master's thesis.

Viewing and printing my submitted work in a PDF format is permitted. However, the modification of my submitted work shall not be permitted.

I acknowledge that the rules on Intellectual Property Management of Hungarian University of Agriculture and Life Sciences shall apply to my work as an intellectulal property.

I acknowledge that the electric version of my work is uploaded to the repository sytem of the Hungarian University of Agriculture and Life Sciences.

Place and date: Keszthely 2023 year 05 month 05 day

Student's signature

STATEMENT ON CONSULTATION PRACTICES

As a supervisor of Chihani Abdelghani (Student's NEPTUN ID R4I1QL), I here declare that the final master's thesis has been reviewed by me, the student was informed about the requirements of literary sources management and its legal and ethical rules.

I recommend the final master's thesis to be defended in a final exam.

The document contains state secrets or professional secrets: yes no*

Place and date: Keszthely, 2023. May 02.

Internal supervisor

Dr. Zsolt Polgár