Chapter 27
Effect of the Application of Humic Substances on Yield, Quality, and Nutrient Content of Potato Tubers in Egypt

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Abstract Modern potato cultivation systems in the arid climate of Egypt require the use of non-traditional strategies to improve water use efficiency and soil nutrient supplies. This chapter reviews a few studies conducted in Egypt that used fertigation to apply humic substances (HS) to potato fields. When applied to soil, HS tend to increase moisture retention in the root zone, and therefore can increase irrigation efficiency. Moreover, HS can increase the nutrient content of soil and the nutrient supply potential, which is reflected in increased fertilizer use efficiency. In addition, application of HS can play a considerable role in increasing plant resistance against common potato diseases. Based on these effects, we conclude that application of HS to potato production systems can increase both quantitative and qualitative characteristics of tubers, and can also improve soil fertility and quality.

27.1 Introduction

Egypt has an area of about one million square kilometers. The total agricultural land in Egypt amounts to nearly 3.5 million ha, accounting for around 3.5% of the total land area; however, this area is primarily considered to be virgin desert, with a sandy soil texture that is not optimal for crop production. The imbalance between a growing population and available agricultural land has led to a shortage in food supplies; therefore, the implementation of management practices that can increase crop productivity is of great interest in an area where the amount of land available for cultivation is continuously declining as a result of urbanization (Adriansen 2009). Land reclamation in the Egyptian context means converting desert areas to agricultural land and rural settlements. This is not only done by extending the water canals

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from existing agricultural land into the desert, but also by working with the soil, ploughing in manure in order to enhance its fertility, and finally by providing the infrastructure for making new villages (Ibrahim and Ibrahim 2003). Agronomic productivity in the newly reclaimed soil in Egypt is limited by low water holding capacities, high infiltration rates, high evaporation rates, low fertility levels, very low organic matter content, and excessive deep percolation losses, all of which may induce low water use efficiency (Al-Omran et al. 2004). The arid climate of Egypt is characterized by high evaporation rates (1,500–2,400 mm $year^{-1}$) and scant precipitation (5–200 mm $year^{-1}$) (Robaa 2008), which leaves the River Nile as the predominant fresh water supply. Consequently, effective management practices should therefore be developed and implemented in order to simultaneously improve the fertility and quality of Egyptian soils, maximize water use efficiency, and increase crop production in order to meet the food demands of the growing population.

Several approaches have been investigated to increase the water use efficiency and maintain the productivity in the sandy soils in Egypt. One method, the combined application of soil conditioners and mineral fertilizers, is increasingly gaining recognition as an appropriate means for increasing fertility in depleted soils, particularly in arid regions (Vanlauwe et al. 2010). A more traditional and common approach for improving the water holding capacity and fertility of sandy soils is to incorporate organic residues (e.g. green manure, farmyard manure, crop residues) into the plough layer in order to increase the soil organic matter content; however, large amounts of residue must be applied to significantly improve the water holding capacity and fertility of sandy soils. In addition, organic residues can be a source of both plant and human pathogens, and weed seeds.

It is well known that biogenic wastes, including sewage sludge, can be a good source of plant nutrients, and these types of materials show promise as organic fertilizer sources for sandy soils (Ahmed et al. 2003). However, the application and utilization of some types of organic waste has the potential to cause environmental problems, such as the introduction of pathogenic bacteria and parasites, and soil loading of toxic organic compounds and heavy metals (Badawy 2003; El-Motaium and Abo El-Seoud 2007). Furthermore, sandy soils are prone to leaching; therefore, application of organic wastes to soils with a high sand content presents a risk of groundwater contamination (Abdel-Shafy et al. 2008).

Previous studies have indicated that surface mulching with bitumen emulsions, particularly when using hydrophobic material prepared from local Egyptian bitumen, can improve fertility of sandy soil. Bitumen emulsion has been shown to protect soil against wind and water erosion, reduce evaporation, increase the preserved moisture below the mulch layer, modify soil temperature, increase plant growth and nutrient uptake, and stimulate soil biological activity (El-Hady 1999; El-Hady et al. 2008). However mulching with bitumen can be expensive, and application to a virgin soil will cause a lot of environmental problems (Muratova et al. 2003).

Due to the expense and insufficient longevity of synthetic polymers as soil conditioners, natural soil amendments offer promise as an alternative material to improve the chemical and physical properties of sandy soils (Al-Omran et al. 2004).

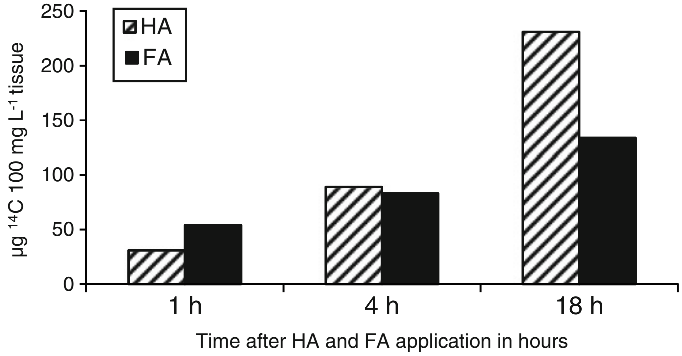

Fig. 27.1 Uptake of ^{14}C-humic acid (HA) and fulvic acid (FA) by pea roots after 1, 4 and 18 h (Modified from Vaughan 1986)

The use of natural deposits may provide a cost-effective means of increasing soil productivity, especially in the areas where these materials are abundant. The application of tafla (particular type of clay deposits formed in Upper Egypt) and other clay deposits has been shown to improve the water holding capacity of sandy soils and increase crop yield (Thabet et al. 1994). Nevertheless, salt accumulation at the soil surface has been attributed to the application of tafla or other clay deposits, especially with low water quality types, which characterized with high salinity levels (Al-Omran et al. 2005).

Of the different natural amendments that have been investigated for use as soil conditioners, humic substances (HS) are among the most effective (Piccolo et al. 1997). The term HS is a general descriptor for a family of organic molecules composed and includes humic acids (HA), fulvic acids (FA), and humin (Stevenson 1982). Early research on the effect of HS on plant growth relied on color changes in plant tissue to serve as an indicator of HS uptake (Prat 1963). More recently, ^{14}C-labeled HS has been used to investigate plant uptake (Vaughan and Ord 1981). In his intensive work, Vaughan (1986), excised roots (25–35 mm long) from 2-day old peas (*Pisum sativum*), and found that HA and FA concentration in roots increased with time (Fig. 27.1), thus indicating that HS could be directly absorbed by plants.

Due to the numerous reported benefits of HS in promoting sustainable agricultural systems, intensive investigation should be conducted to determine the role of HS in maintaining water holding capacity and fertility in sandy soils. In general, sandy soil requires frequent, albeit light, irrigation applications near the cultivated plant, and drip irrigation can be an effective means of meeting these requirements. Consequently, the application of HS by fertigation through drip irrigation systems could be an efficient technique in order to obtain maximum crop yield and quality in sandy soils, especially for economic crops.

Potato (*Solanum tuberosum* L.) is a major food crop in many countries, ranking fourth among the world's various agricultural products in production volume, following wheat, rice and corn (Fabeiro et al. 2001). Thus, it is an important crop in the global economy and the fight against world hunger. In Egypt, the amount of land allocated for potato production represents about 20% of the total cultivated area (Kabeil et al. 2008a). Potato farming was introduced to Egypt during the 1800s, and large scale cultivation began during the First World War, when British colonial officials encouraged its production to feed their troops (International Year of Potato 2008). Export of Egyptian grown potatoes is a significant source of revenue, as potato represents over half of Egypt's net exports. The harvest season in Egypt coincides with winter in the United States and Europe; therefore, exporters are able to internationally market Egyptian potatoes to areas where seasonal production has ceased due to snow cover and cold temperatures.

Potato production on newly reclaimed desert land is highly profitable, and crop yields in reclaimed areas are greater those obtained in the traditional production areas of the Nile Delta and Nile Valley. Increased yield in reclaimed soil is primarily due to a reduction in most common diseases, especially Brown Rot disease, which negatively affects potato production in the Nile Delta and Nile Valley (Kabeil et al. 2008b). Farms on newly reclaimed land tend to be owned by large corporations involved in potato export and processing, and are of greater size and more technologically advanced than farms in traditional production areas. In addition, large corporate farms have sufficient resources to purchase certified seeds, utilize crop rotation practices, and install modern irrigation systems, all of which can help reduce the occurrence of disease and increase crop yields (Pautsch and Abdelrahman 1998).

To obtain maximum tuber yield on sandy, low-fertility, native Egyptian soil, large amounts of mineral fertilizer are normally applied to potato fields. However, modern crop production systems require efficient, sustainable, and environmentally sound fertilizer management practices. Consequently, the adequate rates, appropriate sources and efficient methods of application are important strategies for maintaining the nutrient supply potential of soils (Fageria and Baligar 2005). On the other hand, the agricultural practices in the Nile Delta and valley had been changed under the completion of the Aswan High Dam in 1964. Perennial, furrow irrigation replaced basin flooding, and multiple cropping replaced the single crop per year resulting in shorter fallow periods (Lenney et al. 1996). Therefore, soil fertility declined due to intensive cultivation practices coupled with a lack of systematic nutrient replacement and a loss of the alluvium deposits (Metz 1991). For this reason, modern strategies should be taken in order to increase soil organic matter content, and to compensate the continuous depletion of nutrients. In this chapter we will focus on some case studies of research done in Egypt in order to evaluate the effects of HS application on potato growth and yield.

27.2 Characteristics of Humic Substances

Characterized by long carbon chains with numerous active radicals, such as phenols and other aromatics, HS has an advantage over other natural and synthetic soil amendments as a longer-term soil conditioner. This is primarily due to the refractory

Table 27.1 Elemental composition and atomic and E_4/E_6 ratios of humic acids extracted from different compost materials (Modified from Taha and Modaihsh (2003))

	Elements concentration(%)				Atomic ratio			
Source of HA	C	H	N	O	C/N	C/H	O/H	E_4/E_6
Khaldia	53.68	5.40	5.65	35.27	11.08	0.83	0.41	6.50
Sanbest	50.55	4.45	4.90	40.10	12.04	0.95	0.56	7.90
Yanbost	46.91	4.16	6.34	42.59	8.63	0.94	0.64	5.70
Al-Kharj	44.16	4.41	7.49	43.94	6.88	0.83	0.62	6.40
Al-Enzy	44.09	5.42	4.01	46.48	12.83	0.68	0.54	5.30
Bostan	51.23	6.38	7.63	34.76	7.83	0.67	0.34	4.60

nature of chemical structure of HS, which provides more resistance to microbial attack than simpler, less condensed compounds. Based on published and unpublished data, characteristics of HS introduced it to be an effective source for increasing water and nutrients supply potentials of soil, and stimulating plant growth and yield.

Taha (1985) carried out some physical and chemical measurements on HA isolated from an Egyptian alluvial soil at the Experimental Station of Mansoura University. Humic acid was extracted and purified according to the method reported by Sonbol and El-arquan (1977). The elemental analysis indicated that the extracted soil HA contained 51.43% C, 3.55% H, 3.37% N, 0.37% S and 41.28% O. These data revealed that the extracted HA seems to be in a humified state as a result of the climatic conditions of Egypt, which characterized with little precipitation and high temperature (Robaa 2008). The visible spectra of the isolated HA indicated that it had a red-brown color, which give an indication that it is in a more oxidized state.

Results also showed that HA contents of COOH, phenolic OH and total carbonyl groups were relatively high; however, the alcoholic OH groups content were low. Infra Red (IR) spectroscopy of the studied HA showed strong absorption band at 3,600–3,100 cm^{-1} (H-bonded OH groups); 2,970–2,840 cm^{-1} (aliphatic C-H stretching); 1,700 cm^{-1} (carboxyl and carbonyl of carboxylic acids); 1,600 cm^{-1} (C=C of breathing bands COO^- and quinone groups); and 1,400 cm^{-1} (OH deformation of aliphatic C-H and COO^- groups). The IR spectra of HA-ions complexes showed increasing absorption bands for COO^- at 1,600 and 1,400 cm^{-1}, which explained to be caused by bonding of the ions to the carboxylate or phenolic OH groups.

Another investigation carried out by Taha and Modaihsh (2003) to study some physicochemical characteristics of HAs extracted from different compost materials. The used commercial compost materials were Khaldia (Slaughterhouse wastes compost), Sanbest (Slaughterhouse wastes and crop residues compost), Yanbost (crop residues compost), Al-Kharj (farmyard manure compost), Al-Enzy (farmyard manure and crop residues compost) and Bostan (sludge compost). Humic acid was extracted from different compost materials using 0.1 M NaOH according to Kononova (1966). The obtained data showed that carbon, hydrogen and nitrogen of the studied HAs were affected by the origin of the HAs (Table 27.1). The C/H and O/H values for HA extracted from Yanbost compost were higher than other HAs. Humic acids extracted from Sanbost and Al-Enzy composts have the lowest value of E_4/E_6 ratio indicating a higher degree of aromatic condensation and low aliphatic structure. The IR spectra of the studied HAs showed a broad similarity among the different HAs. The intensities of the absorption band vary slightly among different HAs. They differed mainly in the ratios of the number of functional groups, and the degree of polymerization. On the other hand, HA extracted from sludge (Bostan) contained the highest percentage of aliphatic carbon, associated with polysaccharides structures.

Another unpublished data obtained from the Fertilizers Development Center, El-Delta Fertilizers Plant, Egypt demonstrated the chemical analysis of HS extracted from composted crop residues. Humic substances were extracted using KOH 0.1 M (1:7 w/v). Potassium hydroxide was used instead of other conventional sodium-extractants to increase the benefit of the product from its potassium content. Humic substances fractionation was carried out according to Kononova (1966). Data revealed that HS product contained 14.8% humic acid and 3.5% fulvic acid. The Cation Exchange Capacity (CEC) of HS was 440 meq/100 g. The pH value of HS product was 7.7 and the EC value was 0.97 dSm^{-1}. Macronutrient concentrations were 3.9, 0.13 and 3.22% for N, P and K, respectively; however micronutrients concentrations were 248, 436 and 216 mg kg^{-1} for Zn, Fe and Mn, respectively.

The aforementioned characteristics of HS, which carried out on different origins of HS in Egypt, showed a high ability toward water and nutrients binding as a result of their functional groups. On the other hand, the chemical analysis of HS showed an appropriate content of different plant nutrients. Therefore, HS application to the Egyptian soils could be an effective source for maintaining soil fertility parameters, and promoting plant growth and yield.

27.3 Using HS as a Treatment for Potato Diseases

Early blight, which caused by the fungal pathogen *Alternaria solani* is one of the most common diseases affecting potato plants (Waals et al. 2004; Pasche et al. 2005). In the Noubareia region of Egypt, severe infection with late and early blight diseases has been recorded (El-Gamal et al. 2007). Early blight can affect both leaves and tubers of potato, forming lesions and leading to decreases in potato yield if left uncontrolled. Fungicide application is the predominant means employed to control blight in potato production systems; however, intensive use of agrochemicals in conventional cropping systems has caused irreversible effects on soil and water ecosystems, including pollution of surface and fresh water reserves, and endangering food safety. To circumvent these issues, there have been recent efforts directed at the development of new approaches for controlling plant diseases that are effective, reliable, and safe for the environment.

Abd-El-Kareem (2007) reported that bean plants that had been treated with HA had higher resistance against root rot and Alternaria leaf spot, and improved bean yields. Also, sulfur (S) has been used in organic farming systems to control plant diseases, and can be used as a preventive fungicide (Scherm and Savelle 2001). Sulfur prevents fungal spores from germinating; therefore, it must be applied before the disease develops for effective results. It is well known that soil microorganisms are a crucial factor in the soil S cycle. However, the low organic matter content in sandy soils will affect the efficiency of S in such soil conditions as the low organic matter content will leads to less microbial growth and activity, which would decrease S cycling rates.

Abd-El-Kareem et al. (2009) believed that the integrated applications of HA and S could be an effective remedy for early blight disease of potato plants. For this purpose, greenhouse and field experiments were carried out in El-Nubareia district, Behera Governorate of Egypt, which has a characteristic sandy loam textured soil. For the greenhouse portion of the experiment the effects of different concentrations of HA and S on the severity of early blight infection of potato plants was evaluated. Potato plants (cv. Nigola) were grown in plastic pots (30 cm diameter) under greenhouse conditions (23–25°C) and experimental treatments included the application of HA at rates of 6.0 and 8.0 mL L^{-1}, the application of S at rates of 3 and 4 gL^{-1}, and the integrated application of both HA and S (HA+S). Depending on the particular treatment received, potato plants at the 4–5 compound leaf stage were sprayed with HA, S, or HA followed by S application 3 days later. After 5 days of treatment, plants were inoculated with early blight by spraying potato plants with spore suspensions (10^6 spores ml^{-1}) of *A. solani*. The severity of early blight was based on the percent of the leaf area infected, and rated on a scale of 0–4, according to method of Cohen et al. (1991). The obtained results indicated that all of the HA, S, and HA+S treatments significantly reduced the disease severity ($p<0.05$). The highest reduction in disease severity was obtained with the integrated application of HA at 8 mL L^{-1} and S at 4 gL^{-1}, which was effective for reducing blight severity by 89%, as compared to control treatment. While single treatments of HA and S reduced early blight severity by 54–60%, respectively. Thus, the combined effect of the two treatments was notably improved over only HA or S application alone.

Plant chitinases are induced as a result of the presence of pathogenic infections, as well as by abiotic agents (Yun et al. 1997). *In vitro* studies have shown that chitinases possess antifungal activity and cause lysis of hyphal tips (Leah et al. 1991). Consequently, an increase in plant chitinase activity could serve as a mean of protecting growing potato plants from early blight and other fungal pathogens. Results from this study showed that all of the foliar applications under investigation increased the chitinase activity of potato plants as compared with the control treatment. The chitinase activity of the control treatment was 2.5 units mL^{-1}. Although the conventional treatment of S as a preventive fungicide in organic farming systems increased chitinase activity by up to 64%, the application of HA at both 6 and 8 mL L^{-1} resulted in chitinase activity that was 124% higher than the control. Therefore, the application of HA was more effective at increasing plant chitinase activity than S. Furthermore, the combined application of HA+S did not record a significant increase in chitinase activity as compared with the application of HA alone.

The same treatments in pot experiments were applied under field conditions to study their effect against early blight disease as compared with the application of Ridomil-plus fungicide at 2 gL^{-1}. Field experiments were conducted under natural infection in plots (4×10 m) each comprised of 8 rows (40 holes/row) in a randomized complete block design with 3 replicates (plots) for each treatment. Results from the field studies show clearly that foliar application of all HA and S treatments significantly reduced the severity of early blight during both growing seasons. The most effective treatments were the integrated treatments of HA+S, which reduced the severity of early blight to more than 90% as compared with 72% with Ridomil-plus fungicide.

The role of HA in mitigating early blight disease may be due to an enhancement of the natural resistance by plants against diseases and pests. Experimental results from the greenhouse portion of this study indicated that the highest increase in chitinase activity was obtained from HA application. B-1,3-glucanases and chitinases are responsible for the hydrolysis of B-1,3-glucan and chitin, respectively, which are the major components of fungal cell walls (Mohammadi et al. 2001). On the other hand, HA has been reported to stimulate plant growth by increasing the rate of cell division, optimizing the plant uptake of nutrients and water (Delgado et al. 2002), and stimulating soil microorganisms (Garcia et al. 2004). Thus, while the specific mechanism by which HA increases disease resistance is not clear, this study does indicate that application of HA and a combination of HA and S can decrease the severity of early blight on potato plants and increase the yield of potato tubers produced.

27.4 Effect of Humic Substances Application on Potato Tuber Yield

The role of HS in stimulating the growth and yield of plants has been attributed to both direct and indirect effects. It has been demonstrated that HS can directly affect plant growth by inducing an increase in the absorptive surface area of roots via an ordered remodeling of the root morphology (Schmidt et al. 2007). In addition, HS has been shown to stimulate the proliferation of lateral roots, along with the activation of plasmalemma and vacuolar H^+-ATPases and tonoplast H^+-PPase (Zandonadi et al. 2007). Furthermore, it has recently been shown that HS can interact with root organic acid exudates to influence the root area, primary root length, the number of lateral roots, and lateral root density (Canellas et al. 2008). There have also been reports revealing that HS are able to enhance the respiration rate and increase the permeability of cell membranes in higher plants (Vaughan and Malcom 1985; Samson and Visser 1989). In addition to their role in stimulating enzyme activity and hormone-like activity (Piccolo et al. 1992; Nardi et al. 1994), a number of studies have demonstrated that the two main fractions of HS found in soil, HA and FA, can assist in controlling plant diseases by inhibiting the growth of some soil-borne phytopathogenic fungi (Loffredo et al. 2007).

Indirectly, HS can improve both yield and quality characteristics of crops by enhancing soil enzyme activity and promoting the growth and activity of microorganisms in the rhizosphere. Increased microbial numbers following HS application is primarily due to the role of HS in creating soil conditions that favor microbial replication (Sellamuthu and Govindaswamy 2003). Improved aggregate stability is a cornerstone for success in the reclamation of sandy soils, as it is a crucial factor involved in protection against soil erosion. Fortun et al. (1989) reported that when HS extracted from farmyard manure was applied to soil, that soil aggregation was improved and aggregate stability was increased, as compared to soil that received bulk farmyard manure, even when higher rates of manure than HS were applied.

Several experiments carried out in Egypt to investigate the effect of HS on potato tubers yield. Selim et al. (2009a) carried out a field experiment to examine the effect HS application through fertigation system on increasing water use efficiency of potato grown under sandy soil conditions. The arid climate of Egypt, which marked with high evaporation, requires a modification for drip irrigation system to decrease evaporation losses. Therefore, authors compared the efficiency of subsurface drip irrigation system with the conventional surface irrigation system. The experiment was carried out in the winter growing season between November and February, when the average temperature was 17.4°C, and the average precipitation was 20.3 mm. The soil was sandy in texture (*Entisol-Typic Torripsamments*), with a field capacity of 10.7%, pH of 8.4, and a total $CaCO_3$ content of 5.36%. The soil was not classified as saline (EC = 0.31 dSm^{-1}), and the water used for irrigation was considered to be acceptable quality, with a salinity value of 0.43 dSm^{-1}. Results obtained from this study indicated that HS increased tubers yield under both surface and subsurface drip irrigation systems. Humic substances application at rate of 120 kg ha^{-1} was more efficient than 60 kg ha^{-1} on stimulating tubers yield quantity. Humic substances application through surface drip irrigation system led to increase potato tubers yield over the control treatment by 2.82% and 29.10%; however, this increment was 4.43% and 17.98% in case of subsurface drip irrigation system following the application of HS at rates of 60 and 120 kg ha^{-1}, respectively.

The rapid growth of population of Egypt and the rapid urbanization are causing an imbalance between water supply and demand. There are two ways to overcome this problem, the first of which is by increasing the efficiency with which current water needs are met (e.g. more crop per drop), and secondly by increasing the use of non-conventional water resources, such as saline agriculture drainage water/brackish groundwater, reclaimed wastewater, and the conjunctive use of surface and groundwater (Ragab et al. 2005). Ezzat et al. (2009) conducted a study in order to evaluate the effects of the application of HS on water use efficiency, potato growth, and tuber yield in the North Nile Delta of Egypt under deficit irrigation conditions. Irrigation water was applied at rates of 2,000, 4,000 and 6,000 m^3 ha^{-1} by a drip irrigation system for two growing seasons. The optimum irrigation requirement of potato is 6,000 m^3 ha^{-1}.Potassium humate (K-humate) served as the source of HS, and it was applied as powder additives beside potato seeds. The soil was classified as a clay loam in texture. The highest marketable yield quantity was obtained from the irrigation rate of 4,000 m^3 ha^{-1} with K-humate application (30.1 Mg ha^{-1}). However, the obtained yield of the irrigation requirement of 6,000 m^3 ha^{-1} was 26.9 Mg ha^{-1}. This means that it could be possible to decrease the irrigation quantity to about 67% from the recommended irrigation requirement in case of K-humate application. The irrigation rate of 2,000 m^3 ha^{-1} was associated with the lowest marketable yield quantity (18.2 m^3 ha^{-1}). However, K-humate application increased

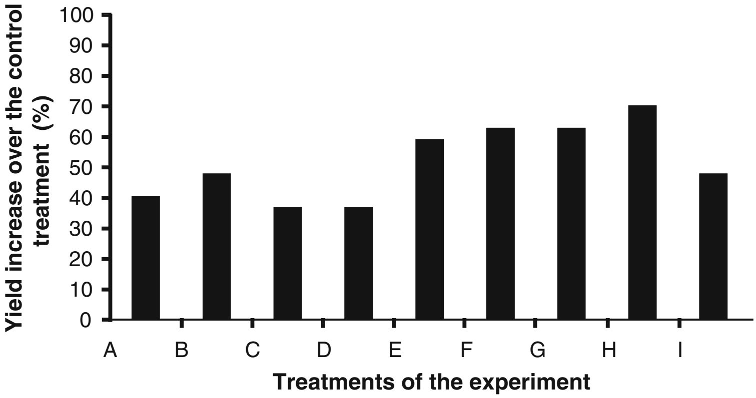

Fig. 27.2 Yield increase in potato yield over the control treatments with different remediation treatments of humid substances (HA) and sulfur (S): (A) HA at 6 mL L^{-1}, (B) HA at 8 mL L^{-1}, (C) S at 3 gL^{-1}, (D) S at 4 gL^{-1}, (E) HA at 6 mL L^{-1} + S at 3 gL^{-1}, (F) HA at 6 mL L^{-1} + S at 4 gL^{-1}, (G) HA at 8 mL L^{-1} + S at 3 gL^{-1}, (H) HA at 8 mL L^{-1} + S at 4 gL^{-1} and (**I**) redomil-plus at 2 gL-1

the marketable yield quantity by about 33%. On the other hand, the lowest irrigation treatment (2,000 m^3 ha^{-1}) was associated with the highest yield of potatoes that were considered to be unmarketable. Thus, application of K-humate led to an increase in the quantity of marketable tubers and improved tuber quality as compared to plots that did not receive K-humate. These results were attributed to increased membrane permeability of plants, which would, promote greater nutrient uptake, and accelerate the net rate of photosynthesis by increasing the concentration of photosynthetic pigments in the plant leaves (Zhang et al. 2003).

Potato plants are attacked by several plant pathogens causing serious diseases during the growing season, this consisted approximately 19% of crop loss (El-Mougy 2009). Early blight, caused by *Alternaria solani* is a very common disease of potato, and is found in most potato growing areas. Values in the literature for measuring crop losses due to early blight vary enormously from 5% to 78% (Waals et al. 2004; Pasche et al. 2005).

Abd-El-Kareem et al. (2009) carried out field experiments in El-Nubareia district, Behera Governorate, of Egypt to examine the effect of the combined application between HA and Sulfur (S) on early blight disease of potato plants. Treatments of the experiments were the application of HA at concentrations of 0.6 and 0.8 mL L^{-1} and S at concentrations of 3 and 4 gL^{-1} solely or in combination as compared with the fungicidal application of Redomil-plus at concentration of 2 gL^{-1}. The control treatment was left untreated. Data presented in Fig. 27.2 illustrated that HA and S treatments either alone or in combination increased potato yield as compared with the control treatment (without spraying). The combined application of HA at 8 mL L^{-1} + S at 4 gL^{-1} was the most efficient treatment for increasing potato yield (70.4% increase over the control treatment). On the other hand the conventional fungicidal remediation of early blight disease by Redomil-plus at concentration of 2 gL^{-1} led to an increase

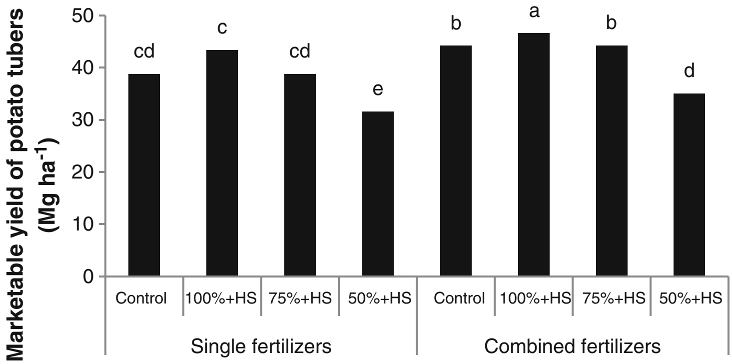

Fig. 27.3 The effect of fertigation with HS and different rates of single and combined NPK fertilizers on the marketable yield of potato tubers (Mg ha^{-1})

in potato yield by 48.1% over the control treatment. Therefore, the combined application of HA and S could be considered as an efficient method for early blight disease of potato. This method is low in cost and friendly with the environment.

A theory behind why fertigation has become the state of the art in plant nutrition in arid environments is that nutrients can be applied in the correct dosage and at the required time appropriate for each specific growth stage (Hebbar et al. 2004; Badr et al. 2010). However, the irrigated agricultural areas are particularly susceptible to groundwater pollution because irrigated crops are abundantly fertilized and the sandy soils are not able to protect plant nutrients against leaching (Vázquez et al. 2006).

Selim et al. (2009b) conducted a study in to evaluate the effect of co-application of HS with either single nutrient or mixed NPK fertilizers via a drip irrigation system to potato planted in a sandy soil. The experimented soil was sandy in texture (*Entisol-Typic Torripsamments*) with a calcium carbonate content of 6%. Treatments of the experiment were assigned in a split plot design with 3 replicates. Fertilization was applied by fertigation through a drip irrigation system, and two forms of mineral fertilizers (single and combined fertilizers) were the main treatments. Sub treatments were the application of HS with 50%, 75% or 100% of the recommended mineral fertilizer rate with HS application in addition to the control treatment (100% of the recommended mineral fertilizer without HS application). Results indicated that application of HS through the fertigation system significantly increased the total marketable yield of potato tubers (Fig. 27.3). The highest marketable yield of potato tubers was obtained from the co-application of HS with 100% of the recommended fertilization rate of NPK. This increment in potato yield is primarily attributed to the enhancement of fertilizer use efficiency, which decreased the leaching of nutrients from the rooting zone, and increased plant nutrient uptake.

27.5 Effect of Humic Substances Fertigation on Potato Tubers Quality

Good-quality potatoes are firm, relatively smooth, and without any defects, sprouts and unfavorable colors. However, these factors may vary according to the degree of maturity, harvest time, variety, and storage conditions. The first quality judgment made by a consumer is by its visual appearance. In this context tubers size and color are the most important appearances attributes, which influence consumers' acceptability (Nourian et al. 2003).

The most important problems, which face potato growers in Egypt is the lack of water supplies and the low fertility in most land resources. The lack of water availability is one of the most important constraints to potato yield, and an adequate water supply is required from planting until maturity. The primary effect of drought or water stress on potato is yield and size reduction. Water deficit during early plant growth can increase the occurrence of spindled tubers, which is more noticeable in oval than in round tuber varieties (El-Ghamry and El-Shikha 2004). Furthermore, growth during drought conditions followed by irrigation may result in tuber cracking or tubers with "hollow hearts"; therefore, water supply and scheduling have important impacts on potato growth, yield and tuber quality (Lutaladio et al. 2009). On the other hand, because most of soils in Egypt are characterized by low fertility standards, Egyptian potato growers typically add large amounts of mineral fertilizers in order to obtain maximum crop yield, particularly when planting in sandy soils. However, modern agricultural production practices require efficient, sustainable, and environmentally sound fertilizer management practices. Consequently, important strategies for maintaining the nutrients supply potential of soils require that fertilization should be conducted at adequate rates, with appropriate sources, and by efficient methods of application.

Tuber size is rated as the most important characteristic of potato quality according to the grower's preference. This finding was reported by Govinden (2006) after his investigation about potato tuber characteristics preferred by growers. He also mentioned that more than two-thirds of the growers preferred large or extra-large tubers. In this respect, Mahmoud and Hafez (2010) demonstrated that humic acid application through drip irrigation system increased potassium fertilizer use efficiency as a result of decreasing its leaching under sandy soils conditions. This was associated with increasing tubers weight and diameter (Figs. 27.4 and 27.5). Potassium fertilization treatments were applied as K-sulfate at rates of 80, 160 and 240 kg ha^{-1}. Humic acid (HA) treatments were added through drip irrigation systems in 5-equal portions at rates of 0, 2.5 and 5 kg ha^{-1}. The experimental soil was sandy in texture, with a field capacity of 16.5%, EC of 1.7 dSm^{-1}, and pH of 8.2.

According to Johnson (2003), potassium has two roles in the functioning of plant cells. First, it has an irreplaceable part to play in the activation of enzymes which are fundamental to metabolic processes, especially the production of proteins and sugars. Thereafter, it has a vital role in a process called carbohydrate metabolism. This process converts simple sugar to more complex sugar and starch. Second, potassium is

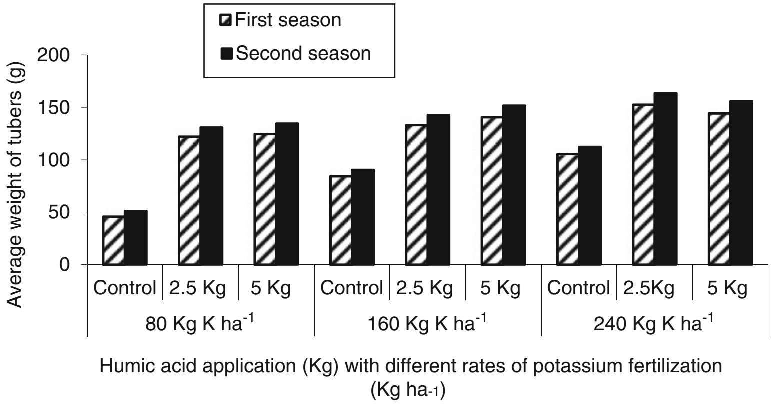

Fig. 27.4 Average tuber weight as a result of HA application with different potassium fertilization levels

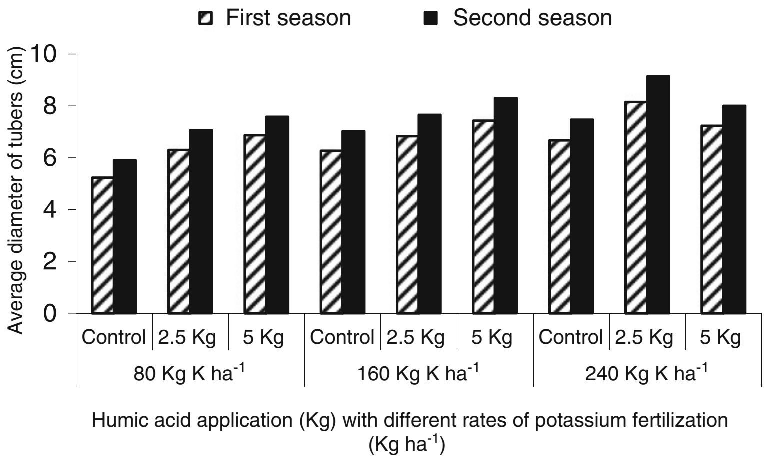

Fig. 27.5 Average tuber diameter (cm) as a result of HA application with different potassium fertilization levels

the "plant-preferred" ion for maintaining the water content in plant cells as it creates conditions that cause water to move into the cell (osmosis) through the porous cell wall. These two important functions are responsible for increasing tubers size and its starch content.

Specific gravity has been used as an important criterion of potato quality because of its close relationship to dry matter content and the rapidly of its measurement (Schark et al. 1956). High specific gravity of potato, which characterized by high starch content, is better suited for baking, frying, mashing and chipping. However, low specific gravity, which characterized by low starch content, is more suited for boiling and canning (Robinson et al. 2006).

According to Selim et al. (2009b), there was no significant effect on specific gravity of potato tubers, however; starch content increased significantly due to HS application. In this study humic substances were applied at 120 kg ha^{-1} through fertigation system with 50%, 75% or 100% from the mineral fertilization dose. The increment of starch content in potato tubers were 1.37%, 16.65% and 3.19% over the control treatment (application of the recommended dose of mineral fertilization without HS application) with mineral fertilization rates of 50%, 75% and 100% from the mineral fertilization dose. Results obtained from this study revealed also that protein content of potato tubers increased significantly as a result of HS application through fertigation system. When HS were applied with 50%, 75% and 100% from the recommended fertilization dose, protein content increased by 14.17% and 5.48% over the control treatment with 75% and 100% from the recommended fertilization dose, respectively. However, the fertilization level of 50% from the recommended dose reduced protein content by 6.68% less than the control treatment.

According to Selim et al. (2009a) starch content of potato tubers increased due to HS application through surface and subsurface drip irrigation systems. Mean values of starch content in potato tubers were 13.01%, 13.98% and 14.61% with HS levels of 0, 60 and 120 kg ha^{-1}, respectively. Authors revealed that there was no significant difference between the control treatment (without HS application) and the application level of 60 kg ha^{-1}; however, the application level of 120 kg ha^{-1} led to a significant increase in starch concentration in potato tubers. Also there was a significant increase in Total Soluble Solids (TSS) concentration in potato tubers as a result of HS application through fertigation system. Total Soluble Solids concentrations were 5.10%, 5.24% and 5.47% with HS application levels of 0, 60 and 120 kg ha^{-1}.

27.6 Effect of Humic Substances Fertigation on Nutrients Concentration in Potato Tubers

Potassium (K) is a crucial element for optimal potato production, which is unlike the specific nutrient requirements of most other vegetable crops. Potassium is important to potato, as it strengthens stems and thus helps to prevent lodging, increases tuber yield, size and quality, increases specific gravity and starch content, and improves fry color and storage quality (Ibrahim et al. 1987; Omran et al. 1991). Furthermore, K can reduce the susceptibility of potato to black spot bruise, decreased the occurrence of darkening after cooking, and lower tuber sugar content. It also allows the crops to adapt to environmental stress viz. salinity stress (Akram et al. 2009), water stress (Kanai et al. 2011), and promotes tolerance of plants against insect infection and increases resistance to fungal disease (Kettlewell et al. 1990; Menzies et al. 1992).

Sandy soils are characterized by low clay content and small buffer capacity and the application of K fertilizers can result in localized increases in K concentration in the soil solution, as there is not sufficient clay mineral surface area to bind ionic K^+ .

Under these conditions, soluble K can be leached through the soil profile by rainfall or irrigation water. In arid and semi-arid regions, the leaching of K is enhanced by the presence of calcite and gypsum (Jalali and Rowell 2003).

The primary aim of the study done by Mahmoud and Hafez in 2010 was to maximize the productivity of potato by increasing K use efficiency under sandy soil conditions. The application of HA beside different potassium fertilization levels led to increase potassium concentration in potato tubers. The highest concentration of K in potato tubers was associated with the application of K-fertilizer rate of 240 kg ha^{-1} with HA at 5 kg ha^{-1}. However, the lowest concentration was associated with the application level of 80 kg ha^{-1}. The mean values of K concentration in potato tubers as affected by HA application were 1.4%, 1.66% and 1.58% with 0, 2.5 and 5 kg ha^{-1}, respectively. The application of HA likely decreased K^+ leaching due to the influence of functional groups commonly present in HA, including carboxyl, phenol and hydroxyl, which contributed in K^+ binding by HA (Wang and Huang 2001). Furthermore, HA could have had a stimulating effect on plant physiological properties, thereby increasing K uptake. According to Samson and Visser (1989), HA can induce an increase in the permeability of biomembranes for electrolytes, resulting in increased uptake of K. Humic acid application not only increased K concentration in potato tubers, but also increase N and P concentrations. The mean values of N concentrations were 1.35%, 1.73% and 1.86%; however, P concentrations were 0.66, 0.77 and 0.75 with the application of HA at rates of 0, 2.5 and 5 kg ha^{-1}, respectively.

Magnesium (Mg) is a very important element in potato nutrition system. It is a vital constituent in the chlorophyll molecule that regulates photosynthesis. In addition, it acts as an activator for many enzyme systems involved in carbohydrate metabolism and synthesis of nucleic acids and helps in translocation of sugar. High rates of K and ammonium-N (NH_4^+-N) application reduce the uptake of Mg. It is evident that high concentration of these cations in soil solution interferes with Mg^{2+} uptake by plants (Marschner 1995). The fertilization programs used in Egypt rarely include Mg supplementation due to sufficient levels of Mg present for potato production in these soils; however, under these conditions, the presence of an excess of fertilizer K and N will lead to a decrease in Mg uptake by potato plants. Moreover, Mg has a pronounced role in the activation of nitrate reductase, which is one step in the pathway responsible for nitrate assimilation into amino acid compounds (Morgan et al. 1972). Therefore, Mg has an indirect effect on alleviating NO_3^- accumulation in potato tubers, and increasing tuber protein content (Herraera and Johnson 1997). In addition, the chelating power of HA in soil could increase plant Mg uptake by protecting Mg^{2+} ions from leaching, forming insoluble Mg-carbonates, or competing with K^+ or NH_4^+ ions for plant uptake.

Awad and El-Ghamry (2007) conducted a study in order to investigate the effects of HA on the activity of soil microorganisms and Mg availability to potato grown in an alluvial soil. The experimented soil was clayey in texture (*Clayey, Superactive, Mesic, Vertic Xerofluvents*) with a pH value of 7.8, and calcium carbonate content of 3.48%. Potato pieces (cv. Spunta) were planted in the fall of 2005 and 2006. Potato plants were fertilized with mineral N, P and K fertilizers at rates of 425, 80 and 200 kg ha^{-1} as a control treatment. Humic acid and Mg were applied alone or in combination with the aforementioned fertilization doses. Humic acid at rate of 100 mL (1:500 w:v) was applied to soil directly beside growing potato plants at 28, 44, and 60 days after planting. While Mg was applied in the form of magnesium sulphate (0.5%) as foliar spraying at 7 and 9 weeks after planting. Cultivation practices for potato production were carried out according to the recommendations of the Egyptian Ministry of Agriculture (Egyptian Agricultural Research Center 2003). The obtained results from this study indicated that HA application also influenced the NO_3^- concentration of potato tubers, revealing that HA application either alone or in combination with Mg, resulted in a reduction in NO_3^- concentration in potato tubers as compared with the control treatment. The mean values of NO_3^- concentrations in potato tubers were 67, 60, 36 and 45 mg kg^{-1} with the treatments of control, humic acid, Mg and (humic acid+Mg), respectively. As mentioned before, Mg has a role in stimulating nitrate reductase, and would therefore increase the rate of NO_3^- assimilation into amino acids in potato tubers. On the other hand, it has been shown that HA can have an inhibitory effect on the activity of urease enzyme, which could potentially decrease the efficiency of NH_3 utilization by potato plants. This is confirmed with results obtained by Thorn and Mikita (1992), using ^{15}N and ^{13}C NMR techniques. They detected that ^{15}N-labeled ammonia was incorporated into humic acid in the laboratory incubation and that the average N content of humic acid increased from 0.88% to 3.17%. It was also found that the concentration of nutrients in both potato tubers was affected by application of HA, likely by directly increasing plant nutrient uptake, and by increasing the nutrient availability in the root zone. The most efficient treatment was the combination of HA, and Mg, showed a synergistic effect. It led to increase N, P and K concentration in potato tubers more than 20% as compared with the control treatment. The binding power of HA can protect NO_3^- ions from leaching following irrigation. This binding power is also able to play a definite role in liberating the fixed K by expanding silicate clays (Tan 1978). Humic acid can increase P availability by complexing with soil minerals and forming stable organo-mineral compounds, decreasing P fixation as apatite and other mineral-phosphates, and allowing P to remain exchangeable for plant uptake (Seyedbagheri 2010).

Because the transport of micronutrients to the plant roots occurs *via* diffusion, low soil moisture content will reduce micronutrient uptake (Hu and Schmidhalter 2005). In a deficit irrigation experiment, Ezzat et al. (2009) examined the role of HS application on mitigating the harmful effect of water stress. Deficit irrigation treatments (2,000 and 4,000 m^3 ha^{-1}) were compared with the optimum irrigation requirement of potato plants (6,000 m^3 ha^{-1}). Results illustrated in Fig. 27.6 revealed that HS application led to increase micronutrients concentration in potato tubers. Humic substances structure presents a variety of potential sites for binding of trace metals. Binding could be occurred through: (1) a water bridge; (2) electrostatic attraction to a charged COO- group; (3) formation of coordinate linkages and ring structures; and (4) formation of chelate structures, such as those with COO- and phenolic OH- site combinations (Shenker and Chen 2005).

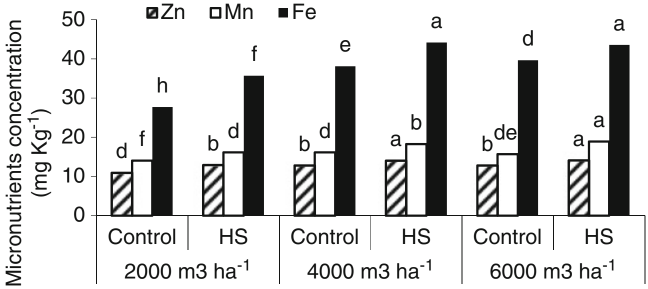

Fig. 27.6 Effect of HS application under different irrigation levels on micronutrients concentration in potato tubers (mg kg^{-1})

27.7 Effect of Humic Substances Fertigation on Soil Fertility After Harvesting

Most of soils of Egypt are considered sandy soils, which characterized with low fertility limits. On the other hand, extensive and frequent cropping under the conditions of an unsustainable irrigation water management and of improper agricultural practices in the Nile Valley and in the Delta have resulted in a depletion and a deficiency in many nutrient elements. This situation has been exacerbated after the construction of the High Dam, which sharply decreased the annual additions of the fertile sediments to the soils. Consequently, all Egyptian soils are poor in their content of organic matter, total nitrogen, and other nutritive elements (Hussein 2011). Humic substances properties (e.g. chelation, mineralization, buffer effect, clay mineral-organic interaction, plant nutrients content and cation exchange) encourage potato growers to use it a conditioner in the sustainable cultivation system (Seyedbagheri 2010). According to Selim et al. (2009a) the application of HS by fertigation increased the level of macro- and micronutrients that were retained in soil after potato harvesting ($p < 0.05$), as shown in Table 27.2, and was likely due to an improvement of the nutrient supply potentials of those sandy soils (Suganya and Sivasamy 2006).

27.8 Conclusion

Due to resistant against microbial attack, numerous active radicals and high content of plant nutrients, HS could be considered as an efficient soil conditioner in the modern potato cultivation systems. According to the aforementioned case studies, HS application led to increase water and nutrients supply potentials of soils. Consequently, it could be possible to decrease amounts of irrigation water and mineral fertilizers application. This will lead to provide huge amounts of irrigation

Table 27.2 The effect of humic substances (HS) applied by fertigation through surface and subsurface drip irrigation systems on soil nutrient concentration following potato harvest

		Macronutrients			Micronutrients		
		N	P	K	Fe	Mn	Zn
Irrigation method and HS application rate		mg kg^{-1}					
Surface drip irrigation	None	47	6.67	200	3.15	1.16	0.93
	60 kg ha^{-1}	48	7.25	226	3.38	1.30	1.11
	120 kg ha^{-1}	50	8.65	253	3.67	1.74	1.25
Subsurface drip irrigation	None	47	6.76	203	3.35	1.27	0.96
	60 kg ha^{-1}	49	8.24	245	3.46	1.5	1.13
	120 kg ha^{-1}	53	9.22	256	3.87	1.87	1.28
Mean values as affected by HS application rate							
	None	47^{b}	6.72^{b}	201^{c}	3.25^{b}	1.22^{c}	0.94^{c}
	60 kg ha^{-1}	48^{b}	7.75^{b}	235^{b}	3.42^{b}	1.40^{b}	1.12^{b}
	120 kg ha^{-1}	52^{a}	8.94^{a}	254^{a}	3.77^{a}	1.81^{a}	1.27^{a}

Mean values followed by the same letter within treatments are not significantly different ($p < 0.05$) according Duncan's multiple range test (Duncan 1955)

water, protecting environmental resources from the excessive mineral fertilization and decreasing the cultivation costs and labor. Furthermore, application of HS led to enhance potato quality characteristics without significant reduction in tubers yield. Therefore, it is recommended to add humic substances through drip irrigation systems in the newly reclaimed sandy soils. Also it is suggested to use HS as organic conditioner in the alluvial soils of the Nile Delta and Valley. Taking into account the motivation of the induced resistant of potato plants due to HS spraying, future studies should be undertaken in order to investigate the role of HS spraying against common potato diseases. This was evident in the enhancement of chitinase activity following HS spraying.

References

Abd-El-Kareem F (2007) Induced resistance in bean plants against root rot and Alternaria leaf spot diseases using biotic and abiotic inducers under field conditions. Res J Agric Biol Sci 3:767–774

Abd-El-Kareem F, Abd-El- Latif FM, Fotouh YO (2009) Integrated treatments between humic acid and sulfur for controlling early blight disease of potato plants under field infection. Res J Agric Biol Sci 5:1039–1045

Abdel-Shafy HI, Guindi KA, Tawfik NS (2008) Groundwater contamination as affected by long-term sewage irrigation in Egypt. I. In: Baz A et al (eds) Efficient management of wastewater. Springer, Berlin/Heidelberg, pp 53–63

Adriansen HK (2009) Land reclamation in Egypt: a study of life in the new lands. Geoforum 40:664–674

Ahmed AH, Rehan MG, Shaheien AH, Awad SS (2003) Effect of sewage sludge, phosphorine inoculation, and cultivars on growth, yield, and elemental composition of pea under newly reclaimed soil. Mansoura Univ J Agric Sci 28:6465–6485

Akram MS, Ashraf M, Akram NA (2009) Effectiveness of potassium sulfate in mitigating salt-induced adverse effects on different physio-biochemical attributes in sunflower (*Helianthus annuus* L.). Flora 204:471–483

Al-Omran AM, Falatah AM, Sheta AS, Al-Harbi AR (2004) Clay deposits for water management of sandy soils. Arid Land Res Manag 18:171–183

Al-Omran AM, Sheta AS, Falatah AM, Al-Harbi AR (2005) Effect of drip irrigation on squash (*Cucurbita pepo*) yield and water-use efficiency in sandy calcareous soils amended with clay deposits. Agric Water Manag 73:43–55

Awad EM, El-Ghamry AM (2007) Effect of humic acid, effective microorganisms and, magnesium on potatoes in clayey soil. J Agric Sci Mansoura Univ 32:7629–7639

Badawy SH (2003) Comparison of Cd, Cu, Ni, and Zn partitions in soils of long term fertility experiments receiving sewage sludge. Mansoura Univ J Agric Sci 28:703–718

Badr MA, Abou Hussein SD, El-Tohamy WA, Gruda N (2010) Nutrient uptake and yield of tomato under various methods of fertilizer application and levels of fertigation in arid lands. Gesunde Pflanz 62:11–19

Canellas LP, Teixeira LRL, Dobbss LB, Silva CA, Medici LO, Zandonadi DB, Fraçana AR (2008) Humic acids crossinteractions with root and organic acids. Ann Appl Biol 153:157–166

Cohen Y, Gisi U, Mosinger E (1991) Systemic resistance of potato plants against *Phytophthora infestans* induced by unsaturated fatty acids. Physiol Mol Plant Pathol 38:255–263

Delgado A, Madrid A, Kassem S, Andreu L, Campillo M (2002) Phosphorus fertilizer recovery from calcareous soils amended with humic and fulvic acids. Plant Soil 245:277–286

Duncan DB (1955) Multiple range and multiple F test. Biometrics 11:11–44

Egyptian Agricultural Research Center (2003) Cultivation and production of potato. In Arabic. Ministry of Agriculture & Land Reclamation, Egypt

El-Gamal G, Abd-El-Kareem NF, Fotouh YO, El- Mougy SN (2007) Induction of systemic resistance in potato plants against late and early blight diseases using chemical inducers under greenhouse and field conditions. Res J Agric Biol Sci 3:73–81

El-Ghamry AM, El-Shikha DM (2004) Effects of different irrigation systems and nitrogen fertilizer sources on potato growth and yield. J Agric Sci Mansoura Univ 29:6393–6410

El-Hady OA (1999) Twenty five years of research with asphalt emulsions for soils reclamation, conditioning, fertilization, remediation and conservation. In: The 3rd international conference on petroleum and environment. Fac Petroleum and Mining Eng. Suez Canal Univ. EPRI, VEA and ISA, Cairo, 4–6 Dec, pp 295–300

El-Hady OA, Ghaly NF, Wanas Sh E (2008) Hydrophobic-hydrophilic combination for sandy soil conditioning and plantation. 1-Growth response and water and fertilizers use efficiency by casuarina trees. Am-Eurasian J Agric Environ Sci 4:332–342

El-Motaium RA, Abo El-Seoud MA (2007) Irradiated sewage sludge for production of fennel plants in sandy soil. Nutr Cycl Agroecosyst 78:133–142

El-Mougy NS (2009) Effect of some essential oils for limiting early blight (*Alternaria solani*) development in potato field. J Plant Prot Res 49:57–62

Ezzat AS, Saif Eldeen UM, Abd El-Hameed AM (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

Fabeiro C, de Santa M, Olalla F, de Juan JA (2001) Yield and size of deficit irrigated potatoes. Agric Water Manag 48:255–266

Fageria NK, Baligar VC (2005) Enhancing nitrogen use efficiency in crop plants. Adv Agron 88:97–185

Fortun A, Fortun C, Ortega C (1989) Effect of farmyard manure and its humic fraction on the aggregate stability of sandy-loam soil. J Soil Sci 40:293–298

Garcia JC, Plaza C, Senesim N, Brunetti G, Polo A (2004) Effects of sewage sludge amendment on humic acids and microbiological properties of a semiarid Mediterranean soil. Biol Fertil Soil 39:320–328

Govinden M (2006) Potato tuber characteristics preferred by growers. MSIRI occasional report no. 34

Hebbar SS, Ramachandrappa BK, Nanjappa HV, Prabhakar M (2004) Studies on NPK drip fertigation in field grown tomato (*Lycopersicon esculentum* Mill.). Eur J Agron 21:117–127

Herraera R, Johnson C (1997) Involvement of magnesium and ATP in the regulation of nitrate reductase activity in *Sinapis alba*. Phytochemistry 44:11–16

Hu Y, Schmidhalter U (2005) Drought and salinity: a comparison of their effects on mineral nutrition of plants. J Plant Nutr Soil Sci 168:541–549

Hussein IA (2011) Desertification process in Egypt. In: Brauch HG et al (eds) Coping with global environmental change, disasters and security, hexagon series on human and environmental security and peace. Springer, Berlin/Heidelberg

Ibrahim FN, Ibrahim B (2003) Egypt: an economic geography. I.B. Tauris, Bodmin

Ibrahim SA, El-Zawily AI, Zayed EA (1987) Effect of NPK level and ratio on growth, yield and chemical composition of potato plants grown in sandy loam soil. Egypt J Soil Sci 27(2):131–144

International Year of Potato. New Lights on a hidden treasure (2008) An end-of- year review. Food and Agriculture Organization of the United Nation, Rome

Jalali M, Rowell DL (2003) The role of calcite and gypsum in the leaching of potassium in a sandy soil. Exp Agric 39:379–394

Johnson AE (2003) Understanding potassium and its use in agriculture. European Fertilizer Manufacturers Association, Brussels

Kabeil SS, Amer MA, Matarand SM, El-Masry MH (2008a) *In planta* biological control of potato brown rot disease in Egypt. World J Agric Sci 4:803–810

Kabeil SS, Lashin SM, El-Masry MH, El-Saadani MA, Abd-Elgawad MM, Aboul-Einean AM (2008b) Potato brown rot disease in Egypt: current status and prospects. Am-Eurasian J Agric Environ Sci 4:44–54

Kanai S, Moghaieb RE, El-Shemy HA, Panigrahi R, Mohapatra PK, Ito J, Nguyen NT, Saneoka H, Fujita K (2011) Potassium deficiency affects water status and photosynthetic rate of the vegetative sink in green house tomato prior to its effects on source activity. Plant Sci 180:368–374

Kettlewell PS, Bayley GL, Domleo RL (1990) Evaluation of late season foliar application of potassium chloride for disease control in winter wheat. J Fertil Issue 7:17–23

Kononova MM (1966) Soil organic matter, 2nd edn. Pergamon Press, Oxford

Leah R, Tommerup H, Svendsen I, Mundy J (1991) Biochemical and molecular characterization of three barley seed proteins with antifungal properties. J Biol Chem 266:1564–1573

Lenney MP, Woodcock CE, Collins JB, Hamdi H (1996) The status of agricultural lands in Egypt: the use of multitemporal NDVI features derived from landsat TM. Remote Sens Environ 56:8–20

Loffredo E, Berloco M, Casulli F, Senesi N (2007) In vitro assessment of the inhibition of humic substances on the growth of two strains of *Fusarium oxysporum*. Biol Fertil Soils 43:759–769

Lutaladio N, Ortiz O, Haverkort A, Caldiz D (2009) Sustainable potato production, International Year of the Potato. FAO, Rome

Mahmoud AR, Hafez MM (2010) Increasing productivity of potato plants (*Solanum tuberosum*, L.) by using potassium fertilizer and humic acid application. Int J Acad Res 2:83–88

Marschner H (1995) Mineral nutrition of higher plants, 2nd edn. Academic, London

Menzies J, Bowen P, Ehret D, Glass ADM (1992) Foliar applications of potassium silicate reduce severity of powdery mildew on cucumber, muskmelon, and zucchini squash. J Am Soc Hortic Sci 117:902–905

Metz HC (1991) Egypt. A country study. Library of Congress, Washington

Mohammadi M, Roohparvar R, Torabi M (2001) Induced chitinase activity in resistant wheat leaves inoculated with an incompatible race of *Puccinia striiformis* f. sp. *tritici*, the causal agent of yellow rust disease. Mycopathologia 154:119–126

Morgan MA, Jackson WA, Volk RJ (1972) Nitrate absorption and assimilation in ryegrass as influenced by calcium and magnesium. Plant Physiol 50:485–490

Muratova A, Hübner T, Narula N, Wand H, Turkovskaya O, Kuschk P, Jahn R, Merbach W (2003) Rhizosphere microflora of plants used for the phytoremediation of bitumen-contaminated soil. Microbiol Res 158:151–161

Nardi S, Panuccio MR, Abenavoli MR, Muscolo A (1994) Auxin-like effect of humic substances extracted from faeces of *Allolobophora caliginosa* and *A. rosea*. Soil Biol Biochem 26:1341–1346
Nourian F, Ramaswam HS, Kushalappa AC (2003) Kinetics of quality change associated with potatoes stored at different temperatures. Lebensm Wiss U Technol 36:49–56
Omran MS, Taysee M, El-Shinnawi MM, El-Sayed MM (1991) Effect of macro– and micronutrients application on yield and nutrients content of potatoes. Egypt J Soil Sci 31:27–42
Pasche JS, Piche LM, Gudmestad NC (2005) Effect of the F129L Mutation in *Alternaria solani* on fungicides affecting mitochondrial respiration. Plant Dis 89:269–278
Pautsch GR, Abdelrahman AH (1998) Effects of Egyptian economic reforms: the horticultural sector. Food Policy 23:199–210
Piccolo A, Nardi S, Concheri G (1992) Structural characteristics of humic substances as related to nitrate uptake and growth regulation in plant systems. Soil Biol Biochem 24:373–380
Piccolo A, Pietramellara G, Mbagwu JSC (1997) Use of humic substances as soil conditioner to increase aggregate stability. Geoderma 75:267–277
Prat S (1963) Permeability of plant tissues to humic acids. Biol Plant 5:279–283
Ragab R, Malash N, Abdel Gawad G, Arslan A, Ghaibeh A (2005) A holistic generic integrated approach for irrigation, crop and field management. 1. The SALTMED model and its calibration using field data from Egypt and Syria. Agric Water Manag 78:67–88
Robaa SM (2008) Evaluation of sunshine duration from cloud data in Egypt. Energy 33:785–795
Robinson JG, Thompson A, Preston D (2006) Potatoes from garden to table. NDSU Extension Service, North Dakota State University, Fargo
Samson G, Visser SA (1989) Surface-active effects of humic acids on potato cell membrane properties. Soil Biol Biochem 21:343–347
Schark AE, Peterson CE, Carlin F (1956) The influence of variety on the specific gravity-mealiness relationships of potatoes. Am Potato J 33:79–83
Scherm H, Savelle AT (2001) Control of peach scab with reduced midseason fungicide programs. Plant Dis 85:706–712
Schmidt W, Santi S, Pinton R, Varanini Z (2007) Water-extractable humic substances alter root development and epidermal cell pattern in *Arabidopsis*. Plant Soil 300:259–267
Selim EM, Mosa AA, El-Ghamry AM (2009a) Evaluation of humic substances fertigation through surface and subsurface drip irrigation systems on potato grown under Egyptian sandy soil conditions. Agric Water Manag 96:1218–1222
Selim EM, El-Neklawy Soad AS, El-Ashry M (2009b) Beneficial effects of humic substances fertigation on soil fertility to potato grown on sandy soil. Aust J Basic Appl Sci 3:4351–4358
Sellamuthu KM, Govindaswamy M (2003) Effect of fertiliser and humic acid on rhizosphere microorganisms and soil enzymes at an early stage of sugarcane growth. Sugar Technol 5:273–274
Seyedbagheri M (2010) Influence of humic products on soil health and potato production. Potato Res 53:341–349
Shenker M, Chen Y (2005) Increasing iron availability to crops: fertilizers, organo-fertilizers, and biological approaches. Soil Sci Plant Nutr 51:1–17
Sonbol HA, El-arquan MY (1977) Dynamics of mineralization and humification of rice straw. J Agric Sci Mansoura Univ 2:136–143
Stevenson FJ (1982) Humus chemistry: genesis, composition, reactions. Wiley-Inter-Science, New York
Suganya S, Sivasamy R (2006) Moisture retention and cation exchange capacity of sandy soil as influenced by soil additives. J Appl Sci Res 2:949–951
Taha AA (1985) Study of physic-chemical properties of humus and its complexes. PhD thesis, Fac Agri Mansoura Univ, Egypt
Taha AA, Modaihsh AS (2003) Chemical and spectroscopic measurements on the humic acid extracted from some organic composts. J Agric Sci Mansoura Univ 28:5073–5082
Tan KH (1978) Effects of humic and fulvic acids on release of fixed potassium. Geoderma 21:67–74
Thabet EMA, Abdallah AAG, Mohammed ARAG (1994) Productivity of onion grown in reclaimed sandy soil using Tafla as affected by water regimes and nitrogen levels. Ann Agric Sci 39:337–344

Thorn KA, Mikita MA (1992) Ammonia fixation by humic substances: a nitrogen-15 and carbon-13 NMR study. Sci Total Environ 113:67–87

Vanlauwe B, Bationo A, Chianu J, Giller K, Merckx R, Mokwunye U, Ohiokpehai O, Pypers P, Tabo R, Shepherd K (2010) Integrated soil fertility management operational definition and consequences for implementation and dissemination. Outlook Agric 39:17–24

Vaughan D (1986) Effetto delle sostanze umiche sui processi metabolic delle piante. In: Burns RG, Dell'Agnola G, Miele S, Nardi S, Savoini G, Schnitzer M, Sequi P, Vaughan D, Visser SA (eds) Sostanze Umiche effetti sul terreno e sulle piante. Ramo Editoriale degli Agricoltori, Roma, pp 59–81

Vaughan D, Malcom RE (1985) Influence of humic substances on growth and physiological processes. In: Vaughan D, Malcom RE (eds) Soil organic matter and biological activity. Kluwer, Dordrecht, pp 37–76

Vaughan D, Ord BG (1981) Uptake and incorporation of 14C-labelled soil organic matter by roots of *Pisum sativum* L. J Exp Bot 32:679–687

Vázquez N, Pardo A, Suso ML, Quemada M (2006) Drainage and nitrate leaching under processing tomato growth with drip irrigation and plastic mulching. Agric Ecosyst Environ 112:313–323

Waals JE, Korsten L, Slippers B (2004) Genetic diversity among *Alternaria solani* isolates from potatoes in South Africa. Plant Dis 88:959–964

Wang FL, Huang PM (2001) Effects of organic matter on the rate of potassium adsorption by soils. Can J Soil Sci 81:325–330

Yun D, Bressan RA, Hasegawa P (1997) Plant antifungal proteins. Hortic Rev 14:39–87

Zandonadi DB, Canellas LP, Fraçana AR (2007) Indolacetic and humic acids induce lateral root development through a concerted plasmalemma and tonoplast H^+ pumps activation. Planta 225:1583–1595

Zhang X, Ervin EH, Schmidt RE (2003) Physiological effects of liquid applications of a seaweed extract and a humic acid on creeping bentgrass. J Am Soc Hortic Sci 128(4):492–496