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AGRICULTURAL APPLICATION RESULTS OF HUMIC ACID IN CROP PRODUCTION: A REVIEW

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Abstract
The technology of using humic acid substance in agricultural application is a completely unexplored area that is expected to expand in the future, in addition to expecting excellent application for this technology in the field of fertilizer manufacturing, reduce the quantities of chemical fertilizers add to the soil, decreasing the rates of pollution with their residues, and preserving the environment. So this review study came to highlight the impact of humic acid application as one of the importance humic substances on different field crops production, through its essential role in improving plant nutrition and soil fertility, and it's characterized by its low price, ease of use, and lack of environmental pollution and crops products. Humic acid contributes to improving many soil biological, physical, chemical and organically properties compared to chemical fertilizers, which have positive influence on crop growth and production, therefore application of humic acid in crop fertilization it is possible to decrease chemical fertilizers application even partially, with reduce cultivation cost and enhance role in mitigation of harmful impacts of abiotic stress causes by drought, high temperatures and salinity. In this literature review has been summarized the impact of humic acid application on various field crops traits such seedling and crop growth, crop productivity, seeds quality, and nutrients uptake and availability in the soil, when humic acid applied in any method by seeds soaking, soil application and foliar application.

Keywords: Humic substances, crops growth and production, plant nutrition.

Introduction

In spite of the effectiveness of common chemical fertilizers, their wide uses, and their importance in rising agricultural production and improving its quantity and quality, they are nevertheless economically costly and cause environmental pollution (Raheem, 2023), as well as health damage to humans, animals and plants. In order to decrease employ of chemical fertilizers, the trend has become towards using organic compounds to complement or completely replace chemical fertilization (AL-Saray, 2019), this is to improve plant growth and reduce harmful environmental impacts. The most important of these organic compounds are humic substances that are produced naturally in consequence of disintegration of organic matter from plant and animal waste, and which contain compounds of varying molecular weight, such as humic acid, fulvic acid and humin (Mahdi, 2019). Humic substances are able to remain available in the soil for crop in excess a long period because it's resistant to biodegradation (Farid et al., 2021).

Humic acid is one of the organic acids produce naturally, and it consider one of humic substances resulting of biological and chemical disintegration of organic matter by the microorganisms biological activities, it is contain carbon, nitrogen and oxygen in varying proportions, resulting in the formation of substances with different molecular weights (Mohammed, 2020). Humic acid is one of major constituents of humic substances plays a significant role in plant nutrients and water absorption, and their ability to be transported in plant tissues (Abo-Hegazy and Badawy, 2022). The efficacy of humic acid is like to the effectiveness of inside plant's natural hormones, and this reflect on increase growth and efficiency of the plant, and then leading to increase production and improve quality (Eldardiry, et al., 2015). Humic acid as a complementary source of polyphenols enters the plant, which work as a respiratory chemical intermediary this leads to an enhance plant's biological effectiveness, as increases effectiveness of enzymatic system and accordingly increases cell division (Rastghalam et al., 2011).

Humic acid increases the formation of chlorophyll, sugars, amino acids and protein, and helps in the photosynthesis process. Its role is similar to that of auxins in cell division, which encourages plant growth. Humic acid is a part of the humic substance and it is safe, highly soluble in water, fast acting and leaves no harmful impacts on plants. It has a positive role in increasing plant growth and yield (Najafivafaet al., 2015), whether by soaking plants seeds in it, soil application or foliar spraying. It stimulates root growth and the plants resistance to drought, high temperatures and salinity. The intention of this literature review is for review the impact of humic acid substance application on growth, yield and its components, seeds quality and plant's vegetative parts in addition to seeds uptake of mineral elements of different field crops.

Humic acid impact on root and seedling growth

Aydine et al. (2012) confirmed that foliar application of humic acid increased significantly root and shoot dry weight in saline soil for *Phaseolus vulgaris* L. Also in Turnip (*Brassica rapa* L.) crop with humic acid (Humic acid 80% concentration) foliar application at level 0.04% the root fresh and dry weight, and root length significantly increased comparing to 0 and 0.02% humic acid level (El-Sherbeny et al., 2012). Humic acid have a positive influence on roots development and increase biological nitrogen fixation in legume crops, Rezazadeh et al. (2014) revealed that humic acid foliar application with 150 ppm following 40 days from planting time significantly increased plant roots growth, roots number, nodules number, roots dry weight, and nitrogen fixation percentage in root's nodule by 6.1% compared to 0 and 75 ppm humic acid application in Cowpea. Al-Dulaimi (2020) found that humic acid (Humic acid 85% concentration) soil application at 24 kg ha^{-1} caused a greater seedling field establishment per meter square in triticale (X. *Triticosecale wittmack*) crop compared to 0, 8, and 16 kg ha^{-1}. Kadhim and Hamza (2021) concluded that maize seeds pre-soaked before sowing in 1 ml L^{-1} of humic acid concentration for 18 hours improved significantly field emergence and seedling vigor comparing with seeds pre-soaked in distilled water only or Citric acid or Ascorbic acid.

Humic acid impact on crop growth traits

Humic acid increase nutrient availability to the growing plant and rate of photosynthesis which increase plant height and branches plant^{-1} in Mustard (*Brassica compestris* L.) when used humic acid (58% humic acid concentration) by soil application before sowing at rates 3.17, 6.35 and 9.35 kg acre^{-1} compared with control treatment (Rajpar et al., 2011). It was reported by Moulla et al. (2015) that humax (contain 60% humic acid) foliar application at 2 g L^{-1} increased significantly plant's: height, dry weight, No. leaves, leaf area and leaf area index in Snap bean - Tema (*Phaseolus vulgaris* L.) and they recommended by using foliar spray method than soil application for humax substance. Jasim and Mohsin (2015) found that spraying of liquid humic acid at 1 mM as complementary fertilizer increased leaf chlorophyll content (SPAD) in Mung bean (*Vigna radiate* L. Wilczek) compared to no humic acid spraying. Fouda (2017) presented that humic acid foliar application caused a significant augment in faba bean plant's fresh and dry weight, leaves chlorophyll a, b and a+b mg g^{-1} content, flowers number and pod setting percentage compared to no humic acid application. Al-Dulaimi and Al-Jumaili (2017) documented that humic acid soil application with 3 kg ha^{-1} lead to significant superior in plant length, primary branches for every plant, leaf area, plants fresh and dry weight, leaves chlorophyll content and flowers sitting percentage in compared to 0 or 2 kg ha^{-1} humic acid application in *Phaseolus vulgaris* L. crop. Broad bean plant's height and branches number increased with humic acid foliar application of 3 ml L^{-1} compared to 0 or 1.5 ml L^{-1} observed by Abead et al. (2018). On the other hand Al-zubaidy and Al-Bawee (2018) found that humic acid foliar application of 2 ml L^{-1} significantly gave highest plant's leaf area, dry weight and flowers number of broad bean compared to 0 and 1.5 ml L^{-1}.

Al-Tayyar and Abdullah (2019) stated that humic acid (85% humic acid concentration) soil application at 16 kg ha^{-1} for wheat crop in begging of tillering stage significantly increased tillers number m^{-2}, while plant dry weight (g m^{-2}) increased significantly with humic acid application at 8 kg ha^{-1} compared to without humic acid application. Whereas, Mraee and Khder (2020) remarked that humic acid (85% humic acid concentration) soil application at 16 kg ha^{-1} in seed germination stage and 35 days after sowing date for sorghum crop significantly increased plant's height, tillers number and leaf area compared with 0 and 8 kg ha^{-1} application of humic acid. Similar results obtained by Al-Dulaimi (2020) with soil humic acid application at 24 kg ha^{-1} in triticale crop. Humic acid application on soil at 40 kg ha^{-1} recorded earliness flowering and first pod appearance, highest leaves chlorophyll a, b and a plus b content, highest plant height, branches $plant^{-1}$ and plant leaf area in broad bean compared to 0 and 20 kg ha^{-1} (Al-azee, 2019). Similar results in increasing broad bean growth traits observed by Al-Obaidi et al. (2021) with 4 kg ha^{-1} humic acid soil application compared with without humic acid application.

Significant increase for plant height, tillers number m^{-2}, flag leaf area, plant dry weight (gm^{-2}), relative growth rate also crop growth rate was noticed with the foliar application of 2 m L^{-1} humic acid at tillering and flowering stage compared to 0 and 1 ml L^{-1} in wheat (Baqir and Zeboon, 2019). Also Mahdi (2019) found that 20 ml L^{-1} humic substance (65% humic acid and 15% fulvic acid) foliar application at two wheat growth stages tillering and booting increased significantly plant height, flag leaf chlorophyll content, flag leaf area, and plant dry weight g m^{-2} compared to 0, 5 and 10 ml L^{-1}. The enhancement impact of humic acid foliar application at 5% concentration on broad bean crops noticed by Dawood et al. (2019) in plant fresh weight and carotenoid pigment compared to control treatment. Al-Gzal et al. (2019) obtained an important increase in forage sorghum plant's stem diameter, height, tillers $plant^{-1}$, leaves $plant^{-1}$, plant leaves percentage and dry forage yield with humic acid soil application of 12 kg ha^{-1} compared with 0 and 6 kg ha^{-1}.

Abd-Elaziz et al. (2019) opined that humic acid foliar application at 1000 and 2000 mg L^{-1} on broad bean plants produce significant augment for plant's height, branches number as well as fresh mass compared to control treatment. Similar results were remembered in broad bean by Abo-Hegazy and Badawy (2022) with foliar application of humic acid 3 g L^{-1} in compare with 0 and 1.5 g L^{-1} applied with humic acid and Awaad et al (2020) with potassium humate soil application at 10 kg fed^{-1} compared to 0 and 5 kg fed^{-1}. While foliar application of 1 and 2 ml $^{-1}$ humic acid

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(Humic acid 80% concentration) at two plant growth stages four true leaves appearance and beginning silk appearance with a third of nitrogen fertilizer recommendation in maize (100 kg urea ha^{-1}) recorded significant highest in plant height, ear height, plant leaves number, plant's leaves area, plant's leaves area index, chlorophyll content in leaves, crop growth rate and dry weight for plant compared with control treatment which included complete nitrogen fertilizer recommendation for maize 300 kg ha^{-1} urea was obtained by AL-Saray (2019). On the other hand Taha et al. (2019) pointed that humic acid soil application at 24 k g h a^{-1} had a great role in increasing maize plant height, ear height, stem diameter, leaves plant^{-1}, and leaf are index also led to significant decreasing for days up to 75% male and female flowering than 0 and 12 k g h a^{-1}. Similar results in broad bean plant's height and branches number obtained by 25 k g h a^{-1} humic acid (99% humic acid concentration) soil application compared to control treatment.
Abdel Nabi and Obaid (2019) suggested that humic acid foliar application with 4 g L^{-1} to broad bean crop improved number of leaves and flowers per plant as well as plant vegetative fresh weight, while concentration at 2 g L^{-1} of humic acid improved plant leaf area than control treatment. Al-Jobouri (2020) study results showed that humic acid (99% humic acid concentration) soil application at 24 k g h a^{-1} led to earliness significantly in days to 50% male and female flowering for *Zea maize* L., and significantly increased plant height, ear height, plant leaves area in addition to plant dry weight than 0, 8 and 16 kg ha^{-1} of application humic acid. Application 8 g L^{-1} humic acid (72% humic acid concentration) on soil led to significant augment for faba bean photosynthetic pigments leaves content (chlorophyll a, b, and a with b plus carotenoid) and proline than control treatment (El-Kamar, 2020). Plant's leaves number, height, fresh weight and leaves weight significantly increased by humic acid (as potassium humate) foliar application at 4 g L^{-1} with one or double doses compared without application of humic acid for broad bean (Hamza et al., 2020). Similar findings obtained by Jasim and Alghrebawi (2020) with foliar humic acid application by 1-2 g L^{-1} in increasing broad bean leaf area index and plant height compared to 0 and 3 g L^{-1} .
Nayyef and Hammadi (2021) observed that sunflower crop growth responding to high concentration of humic acid foliar application by 500 ml L^{-1} which increased significantly leaves area and leaves chlorophyll a content by analogical to 0 and 250 ml L^{-1} humic acid concentration. On the other hand soil appliance of potassium humate substance (humic acid 65% + fulvic acid 25% + K_2O 10%) at rate 50 kg ha^{-1} caused an important increase in faba bean plants fresh plus dry weight, branches number, leaves number, shoot length, photosynthetic pigments in leaves (chlorophyll a, b, and carotenoid) compared to no potassium humate application (Mahdi et al., 2021).

Humic acid impact on crop seed yield and its components

Humic acid had a potential to increase seed yield in many crops. Humic acid soil application at 6.35 k g acre^{-1} increased significantly seed yield in mustard (Rajpar et al., 2011), and foliar application increased significantly seed yield of faba bean (Fouda, 2017). Soil application of at 16 k g ha^{-1} humic acid increased significantly grains spike^{-1} and 1000 grain weight, while application of 8 k g ha^{-1} humic acid increased significantly wheat grain yield (Al-Tayyar and Abdullah, 2019). Abead et al. (2018) observed significant positive response with foliar application of 3 m L^{-1} humic acid for plant pods number, pod's seeds number, weight of 100 seed, and broad bean seed yield compared to 0 and 1.5 m L^{-1}. Highest spike length, spikes m^{-2}, grains $spike^{-1}$, harvest index and grain yield of wheat were recorded by foliar application 20 ml L^{-1} humic acid, while highest 1000 grain weight and biological yield was recorded at applied 10 ml L^{-1} humic acid compared to 0 and 5 ml L^{-1} of humic acid concentration (Mahdi, 2019). Whereas, 1000 mg L^{-1} humic acid foliar application induced significant boost in good seed percentage and total seed yield also decreased poor seed percentage of broad bean compared to control treatment documented by Abd-Elaziz et al. (2019).

Humic acid Foliar application with 1 - 2 ml L^{-1} plus a third of nitrogen fertilization (100 kg ha^{-1} urea) from recommended fertilizer for maize significantly resulted in the highest average length of ear, rows of ear, grains of row, grains of ear, 500 grain weight and total grain yield compared to addition the complete nitrogen fertilizer recommendation for maize 300 kg ha^{-1} urea, this indicates that using of humic acid gives a potential to reduce nitrogen fertilizer addition rate in amount 200 kg ha^{-1} urea and consequently reducing costs and environmental pollution (AL-Saray, 2019). Very important increases for yield and its components were recorded by humic acid soil application to broad bean & 12 k g ha^{-1} (Rafiq and Al-Jobouri, 2019), at 25 kg ha^{-1} (Alwan et al., 2019), at 40 kg ha^{-1} (Al Azzi and AL-Obaidy, 2019), at 4 kg ha^{-1} (Al-Obaidi, 2020), at 10 kg fed^{-1} (Awaad et al., 2020), at 50 kg ha^{-1} (Mahdi et al., 2021), to maize at 24 kg ha^{-1} (Taha, 2019), (Al-Jobouri and Al-Jobouri, 2020) and to triticale at 24 kg ha^{-1} (Al-Dulaimi, 2020).

Baqir and Zeboon (2019) found that wheat biological yield increased significantly with humic acid foliar spraying of 2 ml L^{-1} compared to 0 as well as 1 m l L^{-1} humic acid concentration. Abdel Nabi and Obaid, (2019) stated that humic acid foliar application with 2 or 4 g L^{-1} induced important increase in pods number of plant, pod weight, plant seed yield plus total seed yield of broad bean comparing with control treatment. Jasim and Al-Amiri (2020) concluded that broad bean seed and biological yield significantly increased with plants spraying of 3000 mg L^{-1} humic acid compared to 0, 1000 and 2000 mg L^{-1}. Sorghum weight of 1000 grain, head length and grain yield of plant significantly increased with humic acid soil application & 16 k g ha^{-1} compared to 0 as well as 8 kg ha^{-1} was reported by Mraee and Khder (2020). Increasing faba bean seed yield plus its components with foliar application by humic acid at 4 g L^{-1} was reported by Hamza et al. (2020) and at 8 g L^{-1} was reported by El-Kamar, (2020).

Al-Rawi and Al-Dulaimi (2021) recommended to adoption of 24 kg humic acid ha^{-1} by soil application to maize because it's significant exceeding in length of ear, rows of ear, grains of row, weight of 500 grain and grain yield for two growing season compared to without humic acid application. Nayyef and Hammadi (2021) obtained significant increase in seeds $disc^{-1}$, 1000 seed weight, plant's seed plus biological yield in sunflower with foliar application at 500 ml L^{-1} humic acid compared to 0 and 250 ml L^{-1} humic acid concentration. El-Mashhdany (2021) noticed that 4 ml humic acid L^{-1} soil application significantly caused an increase in plant $capsules^{-1}$, seeds $capsule^{-1}$, plant plus total seed yield, biological yield, harvest index and straw yield of flax in two locations compared to 0 and 2 ml L^{-1} humic acid concentration. Broad bean crop foliar application with 3 g humic acid L^{-1} had a positive significant impact in pods of plant, seeds of plant, seed index, seed yield of plant, seed yield per area, biological yield as well as harvest index compared to 0 and 1.5 g humic acid L^{-1} concentration (Abo-Hegazy and Badawy, 2022).

Humic acid impact on crop seed quality

For enhancing the crop seed quality nutrients are required. Many studies showed that humic acid application gave better quality of crop seeds. Rajpar et al. (2011) observed significant higher oil content of mustard seeds (21.8%) with 6.35 kg humic acid acre^{-1} soil application. El-Sherbeny et al. (2012) illustrated that humic acid application at 0.06% on turnip plants significantly increased total carbohydrate (29.02%) and lipids content (25.32%) in turnip seeds; also they detected that humic acid application led to highest values of total unsaturated fatty acids in seeds oil except Erucic acid which was not found in the seeds oil for plants treated with 0.02% humic acid. Fouda (2017) found significantly higher Ash (4.57%), total carbohydrates (54.46%) and crude protein (16.48%) content of faba bean seeds and significant decrease in crud fiber with humic acid application in comparison to control treatment. Significant enhance in faba bean seed's protein content was claimed by Abead et al. (2018) with humic acid foliar application at 3 ml L^{-1} compared with 0 and 1.5 ml humic acid L^{-1} concentration. Dawood et al. (2019) noticed significant increase in the free amino acids (129.60 mg g^{-1}), proline (32.26 mg g^{-1}), total phenolic content (24.20 mg g^{-1}) and total carbohydrate (42.15 %) in faba bean seeds when plants treated with humic acid foliar at 5% concentration comparing with no humic acid applied.

The highest protein yield of faba bean was obtained with soil application at 4 k g fed^{-1} potassium humate (humic acid 67.25% + fulvic acid 15.73% + K_2O 12.60%) than 0 and 2 kg fed^{-1} (El-Kholy et al., 2019). AL-Saray (2019) presented that foliar application of 2 ml humic acid L^{-1} plus a third of nitrogen fertilization (100 kg ha^{-1} urea) from recommended fertilizer for maize induced significant increase of grains protein percentage (12.54% and 13.05%) and oil percentage (7.82% and 7.90%) at two growing season respectively, compared to complete nitrogen fertilizer recommendation for maize 300 kg ha^{-1} urea. Taha (2019) indicated to significant increase of grains oil and protein content percentage and yield of oil and protein with high soil application of 24 k g humic acid ha^{-1} in maize crop compared with 0 and 12 kg ha^{-1}. Similar results also obtained by Al-Jobouri (2020) in maize and Al-Obaidi (2020) in broad bean seeds protein content with 4 k g humic acid ha^{-1} by soil application. Also Al-Dulaimi (2020) found that soil application of 24 k g ha^{-1} humic acid resulted significant boost in grain's specific weight (kg hl^{-1}), grains content in protein and starch percentage for triticale crop.

Hamza (2020) recorded highest protein content in faba bean seeds by foliar application of 4 g humic acid L^{-1} over control treatment. El-Mashhdany (2021) opined that soil application of 4 ml L^{-1} humic acid to *Linum usitatissimum* L. led to obtain a highest oil yield over 2 and 4 ml humic acid L^{-1} foliar application in addition to control treatment. Abo-Hegazy and Badawy (2022) remarked significant boost in Ash (4.34%), crude protein (29.91%), crud fiber (6.18%) and carbohydrate (65.23%) of faba bean seeds when the plants treated with 3 g humic acid L^{-1} compared to 0 as well as 1.5 g L^{-1}. On the other hand soil application with 40 kg ha^{-1} caused high protein content (27.4%) in broad bean seeds documented by AL-Azee et al (2023).

Humic acid impact on Nutrient uptake and elements availability in soil after harvesting

El-Sherbeny et al. (2012) mentioned that humic acid spray at 0.06% concentration revealed significantly higher N (%), P (%), Fe (ppm) and Mn (ppm) uptake in turnip crop leaves, while 0.04% concentration of humic acid recorded higher K (%), Ca (%), Zn (ppm), and Cu (ppm) uptake in turnip crop leaves compared to 0 and 0.02% concentration. Plant's content of No_3, N, and P

increased significantly in bean when sprayed with humic acid reported by Aydin et al. (2012). Jasim and Mohsin (2015) observed that liquid humic acid foliar application at 1 mM as complementary fertilizer improved N, P, K and Ca % uptake for Mung bean plants compared to no humic acid application. Faba bean crop sprayed by humic acid enhanced leaves and seeds N, P and K % uptake, also improved available soil N, P and K (ppm) in compared with no humic acid used (Fouda, 2017). Nitrogen (%) uptake by maize plants (in leaves) significantly increased with foliar application of 2 ml humic acid L^{-1} plus a third of nitrogen fertilization (100 kg ha^{-1} urea) from recommended fertilizer for maize compared to complete nitrogen fertilizer recommendation for maize 300 kg ha^{-1} urea (AL-Saray, 2019).
Application of 8 g L^{-1} humic acid on soil and faba bean plants recorded the highest seeds content in macro elements N, P and K (%) in addition to micro elements Mn, Fe and Zn (mg kg^{-1}) over control, also humic acid application increased significantly available soil's macro elements (N-P-K mg kg^{-1} soil) in addition to micro elements (Fe-Zn-Mn mg kg^{-1} soil) after harvesting documented by (El-Kamar, 2020). Similar results were obtained for the macro elements N, P, K by soil application of 10 k g humic acid fed^{-1} as potassium humate in broad bean seeds content and soil availability of these elements after harvesting compared to 0 as well as 5 k g potassium humate fed^{-1} application (Awaad et al., 2020). Hamza et al. (2020) found highest faba bean seeds content of N, P and K % at 4 g L^{-1} foliar spray with humic acid contrast to control treatment. Farid et al. (2021) pointed to significant raise in soil availability of N and P in addition to faba bean plants uptake at soil application of humic substance (10 ml humic acid kg^{-1} soil plus 10 ml fulvic acid kg^{-1} soil). Soil application at 50 kg potassium humate ha^{-1} enhanced nutrient uptake for faba bean plant leaves after 50 days from sowing by achieve significant augment in leaves content of N, P, K and Ca, whereas Na content in leaves was declined than control treatment (Mahdi et al., 2021). AL-Azee et al. (2023) obtained maximum Nitrogen and Phosphorus uptake by broad bean leaves and seeds through soil application of 40 kg humic acid ha^{-1}.

Conclusions

It has been well showed by the all different studies on different crops in different area that humic acid substance can improve crop growth, yield and yield components, seed quality, nutrient uptake by any methods applied, such seeds soaking, soil or foliar application, and then it is possibility to partially dispense with the chemical fertilizer use in the first stage, and almost completely dispense with it in the second stage in order to enable sustainable agriculture and reduce environmental pollution and harm to human, animal and plant health.

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