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Ammonium Humate Application Techniques and their Influence on Crop Productivity and Sandy Soil Properties

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ABSTRACT

Ammonium humate (AH) is a substance that applied in agriculture as a fertilizer and soil conditioner. It is created when humic acid, reacts with ammonium hydroxide. So, it is considered a useful tool because it has various advantages for plant growth and development. A field trial was conducted on sandy soil at the Ismailia Agriculture Research Station farm in Ismailia Governorate, Egypt, during the winter season of 2021–2022 to study the influence of three forms of 3% ammonium humate (AH_1, AH_2, and AH_3) and two methods of application (foliar on the plant (M_1) and spraying on the soil (M_2)) on the growth of cultivated crops (wheat, faba beans, and lupine) and some soil properties. Obtained results indicated that adding different forms of AH significantly increased crop productivity, macronutrient total content, and protein percent. The AH_2 form was superior in yield, and the soil application was positive compared to foliar application on the plant. The interaction between AH form and method of application indicated that AH_2M_2 treatment was the best for all tested crop productivity. Macronutrient availability increased with all experiment treatments, and the highest available N values were with the AH_1M_2 treatment. Organic matter content in the soil was highest when different ammonium humate forms were applied to the soil compared to foliar application.

***Keywords*:** Ammonium humate; Application method; Yield production; Soil chemical properties.

INTRODUCTION

In today's agricultural production climate, increasing agricultural product productivity and quality is critical. It can be repaired using inexpensive organic fertilizers and plant growth stimulants (Vinogradova *et al.*, 2015). Organic chemicals known as "biostimulants" are used to promote nutrient uptake, speed growth, improve crop quality, and enhance stress tolerance (Van Oosten *et al*., 2017). Organic components of the soil system account for around 0.5 to 5% of the total mass. According to many soil scientists, agronomists, and farmers, humic acid is an essential portion of organic matter that is highly useful in improving soil conditions and plant growth, as described by Filho *et al*. (2020) and Mutlu and Tas (2022).

Humic acids can be extracted from any material that contains well-decomposed organic matter, such as soil, coal, or compost. It is a necessary component of humic compounds; it is one of the most important organic fertilizers that may be used, broken down, and degraded by living bacteria. Mayans *et al.* (2019) pointed out that humic acids are an essential and fundamental component of soil. It is essential for plant growth due to its unique physical and chemical qualities, which include a very high cation exchange capacity, a huge capacity for storing water, and the ability to complex mineral ions, among others. On the other side, humic material was used as a sustainable natural resource in agricultural production., it has a great influence on the physical, chemical, and biological characteristics of the soil as well as the activities of plant enzymes, root growth, and plant yield (Mauromicale *et al.* 2011). Recently, Liu et al. (2020) found that a humic acid treatment, improves the development of soil macroaggregates and fortifies the soil's physical structure, both of which increase the soil's ability to store water and fertilizer and lengthen the effects of fertilization. Furthermore, a variety of humic acid salts, including potassium, calcium, and ammonium humates, were used to improve soil fertility and encourage plant growth (Buckau *et al*., 2000).

Ammonium humate is a type of organic fertilizer that combines nitrogen and humic acid from nature. According to Pehlivan and Arslan (2006), this complex organic molecule also contains many functional groups, including carboxyl, carbonyl, amino, aldehyde, phenolic hydroxyl, and sulfur-containing groups. By replacing nitrogen, the ammonium nitrogen found in ammonium humate also increases soil fertility (Gupta *et al*., 2010). Ammonium humate can also be used as a soil amendment, a spray, or an inexpensive source of nitrogen that can be administered topically.

However, Zeinali and Moradi (2015) found that foliar application of humic acid led to positive effects on plant growth and improved production. Also, foliar application of humic substances is becoming more common in agricultural practice; the mechanism of potential growth-promoting effects is typically attributed to hormone-like impacts, activation of photosynthesis, acceleration of cell division, increased permeability of plant cell membranes, improved nutrient uptake, reduction of the uptake of toxic elements, and improvement of plant growth (Olk *et al*., 2018). However, Nassar *et al.* (2021) observed that foliar application of humate compounds considerably boosted all morphological traits, yield components, chlorophyll, and nutritional contents. Also, they added that soil additions of both compost and K-humate enhanced the quantities of both

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wheat grain and straw yields, improved their quality, and boosted the usage efficiency of the additional N fertilizer.

The use of humic chemicals with crops has been the subject of several scientific research. According to recent studies (Marenych *et al*., 2019 and Bezuglova *et al*., 2019), humic preparations are increasingly used as plant growth boosters and have a significant influence on plant development and wheat productivity. Additionally, it can promote biomass accumulation and increase agricultural yields (Zhou *et al*., 2019). Furthermore, the addition of humic acid significantly increased the amount of free amino acids, praline, total phenolic content, and carbohydrates compared to the control (Dawood *et al*., 2019).

Recently, Yang *et al*. (2021) reported that the activity of humate substances as hormone-like compounds increases the population and activity of microorganisms, which in turn impacts the physiological processes of plant growth. Humate substances also promote the assimilation of macro- and micronutrients as well as growth regulators. Humate chemicals enhance the seed-filling intensity and water retention. By holding macronutrients and forming organometallic complexes, the chelating agent also holds macronutrients that are thought of as a storehouse or as being more mobile or easily absorbed by plants. This has a positive effect on the growth of seed and straw yields and their characteristics (Rafla, 2012).

Humic acid, in the opinion of Baishu *et al*. (2022), is a synergistic N fertilizer that actively promotes plant development while prolonging fertilizer efficacy and reducing N losses. The stimulation of root growth and development by humic acid leads to an increase in root biomass (Silva *et al*., 2021). Along with that, it can improve root H^+-ATPase activity and increase root nutrient absorption, promoting the development of above-ground crops (Mora *et al*., 2010). At last, Dong *et al*. [2006] established that humic acid inhibits urease activity, delaying the breakdown of urea. This reduces the amount of NH_4^+-N in the soil, which reduces the possibility of NH_3 volatilization and possible nitrification and reduces N losses. Additionally, humic acid aids in lowering soil acidity and increasing P effectiveness (Deng *et al*., 2021 and Yang *et al*., 2021). As a result, humic acid plays a critical role in agricultural output as an N fertilizer synergist.

Wheat (*Triticum aestivum* L.) is one of the most significant grain crops in the world. This is the primary food of many people in many nations, and it provides 80 percent of human protein. As a result, with an expanding country and global population and present food shortages worldwide, one of the most essential and major challenges is the evaluation of methods and strategies that lead to increased production and optimal use of produced wheat (Sary and Hamed, 2021).

The amount needed is greater than what can be produced locally. Additionally, faba bean (*Vicia faba L.*), a strong source of protein in both human and animal meals, is a commonly consumed public food in every country in the globe, including Egypt. Its seeds are also a good source of nutrients, fiber, and carbs (Mahdi *et al*., 2019 and 2021). Due to atmospheric nitrogen's capacity to be fixed, the bean plays a favorable function in crop succession through improving the soil by increasing its organic matter and nitrogen contents (Megawer *et al*., 2017). In the past 10 years, Egypt's faba bean cultivation has declined from 71445 to 32532/ha (FAOSTAT, 2017). This is as a result of faba bean's intense rivalry with other strategic winter season crops such as wheat and clover (El-Kholy *et al*., 2019). However, lupin (*Lupinus termis*) is grown in a variety of environments, and its seeds are more nutritious than those of other legumes (Raza and Jrnsgard, 2005). Since alternative protein sources are becoming more and more necessary (De Ron *et al*., 2017), lupine is a crop that has a lot of potential to be further developed for high-protein production (Lucas *et al*., 2015), as well as for soil phytoremediation and recovery of degraded soils (Quinones *et al*., 2013). In Egypt, lupine seeds have been used as a food source and a healing herb (Shahat *et al*., 2014).

The current study aims to assess impacts of several forms of organic soil amendments (ammonium humate) and their two application procedures on the productivity of wheat, faba beans, and lupine. As well as, protein percentage and total content of macronutrient in their crops were determined. In addition, the chemical composition of the soil and the availability of NPK in sand soil were investigated.

MATERIALS AND METHODS

An experiment was conducted to study the influence of successive additions of three forms of organic soil amendment (ammonium humate) at different forms and methods of application on crop productivity and soil chemical properties.

Ammonium humate preparation

Ammonium humate (AH) was extracted from compost; Table (1) shows the compost analyzed by following the procedure of APHA (2005). Ammonium humate was extracted according to Sanchez-Monedero et al. (2002). In this method, the compost referred to above was treated with 2N NH_4OH. A mixture of 80 g of compost and 800 ml of solution was shaken at 120 rpm under N2 gas atmosphere in sealed bottles for 12 hours, then centrifuged for 15 minutes at 6000 rpm, and the supernatant was collected. The pH was then adjusted to 7.0 with 4 N HNO_3, H_2SO_4, or H_3PO_4 to prepare three forms of ammonium humate AH_1, AH_2, and AH_3, respectively. The analytical properties of three forms of ammonium humate were determined according to Page et al. (1982) as shown in Table (2).

Field experiment

A field trial was conducted in sandy soil at the Ismailia Agriculture Research Station farm in Ismailia Governorate, Egypt. N 30o 36' 56.4" S 32o 14' 23.7". The experiment was carried out during the winter season of 2021, when three crops were cultivated: wheat (*Triticum aestivum* L., cv Giza 168), lupine *(Lupinus termis* L., Giza 1), and faba beans (*Vicia faba* L., Giza 843) under a sprinkler irrigation system. Some physical and chemical characteristics of the studied soil are presented in Table (3). The object of this experiment is to study the influence of successive additions of three ammonium humate forms as organic soil amendments and methods of applications on three crops productivity (Wheat, lupine, and faba beans), along with the effect of these applications on soil chemical properties and macronutrient availability. The statistical design of this experiment was a split-plot design with three replicates, with the dimensions of each plot being 2.0 x 3.0m. The main plots had two methods of application: foliar application on different developing plants (M_1) and application on the soil surface (M_2). The sub-main plots included three forms of ammonium humate as follows: ammonium humate neutralized by HNO_3 (AH_1), ammonium humate neutralized by

H_2SO_4 (AH_2), and ammonium humate neutralized by H_3PO_4 (AH_3). All forms of ammonium humate were applied at a rate of 3% v/v.

Table 1. Chemical analysis of compost utilized.

Physical properties						**Value**
Density Kg m^{-3}						794
Moisture content %						1.93
Chemical properties						Value
pH (1:10)						8.47
EC dS m^{-1} (1:10)						6.26
Organic carbon %						13.69
Organic matter %						23.61
% Total Nutrients		Available Nutrients mg Kg^{-1}				
N	0.812	N	243	Fe	30300	
P	0.39	NH^{4+}	33	Mn	501	
K	1.36	NO^{3-}	210	Zn	70.8	
		P	730	Cu	501	
		K	9700	Cd	Nil-	
				Pd	139	
				Ni	Nil-	

Table 2. Chemical characteristics of the three ammonium humate forms.

Chemical properties	**Ammonium humate forms**		
	AH_1	**AH_2**	**AH_3**
Organic carbon %	1.96	1.97	1.96
Organic matter %	3.39	3.39	3.39
Soluble nutrients %			
N	4.03	2.25	2.25
NH_4^+	2.21	2.21	2.21
NO_3^-	1.82	0.04	0.04
P	46.84 mgL^{-1}	46.92 mgL^{-1}	5.74
K	0.151	0.151	0.151

Table 3. Physical and chemical characteristics of the experimental soil.

Particle size distribution %				
Sand	**Silt**	**Clay**	**Texture class**	
89.20	7.02	3.78	Sandy	
Chemical properties				
pH ((1:25)	EC (dSm^{-1})	O.C %	O.M %	$CaCO_3$ %
7.89	0.105	0.27	0.47	0.32
Soluble cations and anions (meq/100 g soil)				
Cations		Anions		
Ca^{2+}	0.39	CO_3^{2-}	Nil	
Mg^{2+}	0.20	HCO_3^-	0.25	
Na^+	0.4	Cl^-	0.41	
K^+	0.06	SO_4^{2-}	0.38	

Mineral fertilizers were applied at the recommended dose for all three cultivated crops. Phosphorus was added in the form of calcium superphosphate (15% P_2O_5) at a rate of 200 Kg $fed.^{-1}$ basically before sowing, as well as potassium, was added in the form of potassium sulfate (48% K_2O) at rate of 50 Kg $fed.^{-1}$ at each split equal dose at 30 and 60 days from showing. Nitrogen was applied in the form of ammonium nitrate (33% N) at a rate of 360 Kg $fed.^{-1}$. for wheat and added three times at 15, 30, and 60 days from sowing, as well as nitrogen at 60 kg fed^{-1} after 10 days from sowing for lupine and faba bean crops. The normal agricultural practices were carried out during the growing season as recommended

At harvest, plant samples were collected from each plot at the harvested stage after 120 days for wheat, 110 days for faba bean, and 150 days for lupine from planting in one square metre to determine the biological yield and yield component (straw, grains, and weight of 1000 grains for wheat along with 100 seeds for lupine and faba bean) by weight for each crop. All samples were oven dried at 70ºC for 48 h to a constant dry weight, ground, and prepared for digestion using the H_2SO_4 and H_2O_2 methods described by Page *et al.* (1982). Then the digests were subjected to measurements of macronutrients (N, P, and K) and protein percent (%) using the procedure described by Cottenie *et al.* (1982). Grain protein percentage was obtained by multiplying grain N concentration by 5.75 for wheat and by 6.25 for both faba bean and lupine according to the method given in AACC (2000).

Soil samples were obtained from the surface layers (0–30 cm) after the plants were harvested. These samples were then air-dried, and their chemical properties were determined. Page *et al.* (1982) provided techniques for estimating soil pH, organic carbon percentage (OC), organic matter percentage (OM), and calcium carbonate percentage ($CaCO_3$). According to Jackson (1973)**,** total soluble salts were calculated in soil paste (dSm^{-1}) as electrical conductivity (EC). Cottenie *et al.* (1982) presented techniques for determining the soil concentration of accessible macronutrients such as nitrogen (N), phosphorus (P), and potassium (K).

Statistics analysis.

All results obtained in each growing crop were subjected to statistical analysis using MASTATC software, and the means were compared using Duncan's multiple range test ($P < 0.05$).

RESULTS AND DISCUSSION

Yield components of different crops as affected by applied ammonium humate forms and two methods of application

Table (4) shows a summary of how different crops (wheat, faba bean, and lupine) respond to various ammonium humate forms by two application methods on biological yield and yield components (straw, grain, and/or seeds), as well as the weight of 1000 grains of wheat and/or 100 seeds of faba bean and lupine, respectively.

A:- Efficacy of ammonium humate forms: -

Results in Table (4) show that application of all ammonium Humate forms (AH_1, AH_2, and AH_3) significantly increased biological yield, grains and/or seeds, straw yield, and weight of 1000 grains of wheat, 100 seeds of faba bean, and lupine plants compared to control treatment. This study agrees with Khan and Mir (2002), who found that application of ammonium humate increased the wheat grain yield, number of tillers, and weight of 1000 grains. Fan *et al.* (2015) and Liu *et al.* (2019) explain that the growth-promoting effect of ammonium humate can also be attributed to the efficient uptake of essential nutrients via chelate formation, increased root respiratory activity, and an increase in cell membrane permeability, which results in increased moisture and nutrient uptake. Also, humic acid improves crop photosynthetic efficiency by increasing chlorophyll concentration and chloroplast ultrastructure. Humic acid may act as a stressor or alter a plant's metabolism, which can promote the growth and development of roots, as reported by Castro *et al.* (2021).

Also, data presented in Table (4) indicates that the growth parameters studied in this experiment were superior under AH_2 treatment as compared to AH_1 and AH_3 treatments in different tested crops. The increase was reached at 23.7, 52, 17.2, and 3.7 % for biological yield, straw yield, grains yield, and weight of 1000 grains, respectively, for the wheat crop. A similar trend was observed for the faba bean crop, which increased to 26.3, 13.3, 31.2, and 13.3% for biological yield, straw yield, seeds yield, and weight of 100 seeds, respectively. As well as the lupine crop, an increase in yield components reached 41.5, 34.5, 43.7, and 16.1% for the same parameters mentioned previously, respectively. The obtained result may be due to AH_2 treatment content sulphates; this component is crucial because several coenzymes, thioredoxins, and chlorolipids, are present. Sulphur is a crucial component of several chemicals that may play a role in defense mechanisms against infections or in the distinctive flavor and aroma of food plants (Bennett and Walls Grove, 1994). Furthermore, ammonium humate and sulphates are a type of organic fertilizer that combines natural humic acid with nitrogen and is an important humic acid ammonium salt with halophyte nutrition and high-effective organic matter.

Table 4. Response of some yield components of wheat, faba bean and lupine plants to applied ammonium humate forms and two methods of application.

Treatment	Biological yield (Kg fed^{-1})	Percentage increase	Grains or seeds yield (Kg fed^{-1})	Percentage increase	Straw yield (Kg fed^{-1})	Percentage increase	weight of 1000 grains or 100 seeds (g)	Percentage increase
				Wheat				
Control	6460_{B}	–	1203_{B}	–	5257_{B}	–	61.17_{A}	–
AH_1	7509_{A}	16.2	1664_{A}	38.3	5845_{AB}	11.2	62.90_{A}	2.8
AH_2	7988_{A}	23.7	1828_{A}	52.0	6160_{A}	17.2	63.45_{A}	3.7
AH_3	7277_{A}	12.6	1537_{A}	27.8	5740_{AB}	9.2	62.92_{A}	2.9
M_1	6872_{B}	6.4	1459_{B}	21.3	5413_{B}	3.0	62.9_{A}	2.8
M_2	8310_{A}	28.6	1893_{A}	57.4	6417_{A}	22.1	63.3_{A}	3.5
				Faba bean				
Control	5455_{B}	–	1479_{A}	–	3976_{B}	–	80_{B}	–
AH_1	6133_{AB}	12.4	1653_{A}	11.8	4480_{B}	12.7	88.6_{A}	10.8
AH_2	6890_{A}	26.3	1675_{A}	13.3	5215_{A}	31.2	90.6_{A}	13.3
AH_3	5987_{AB}	9.8	1491_{A}	0.8	4515_{B}	13.6	85.3_{A}	6.6
M_1	6240_{A}	14.4	1550_{A}	4.8	4690_{A}	18.0	87.0_{A}	8.8
M_2	6434_{A}	17.9	1650_{A}	11.6	4783_{A}	20.3	89.0_{A}	11.3
				Lupine				
Control	5804_{B}	–	1371_{C}	–	4433_{C}	–	31.0_{B}	–
AH_1	8066_{A}	39.0	1976_{A}	44.1	6090_{AB}	37.4	35.0_{A}	12.9
AH_2	8214_{A}	41.5	1844_{A}	34.5	6370_{A}	43.7	36.0_{A}	16.1
AH_3	6798_{B}	17.1	1548_{B}	12.9	5250_{BC}	18.4	34.0_{AB}	8.1
M_1	7689_{A}	32.5	1809_{A}	31.9	5880_{A}	32.6	34.6_{A}	11.6
M_2	7695_{A}	32.6	1769_{A}	29.0	5927_{A}	33.7	35.6_{A}	14.8

Ammonium humate forms (AH) Foliar application (M_1) Soil application (M_2)

B: - Efficacy of methods application.

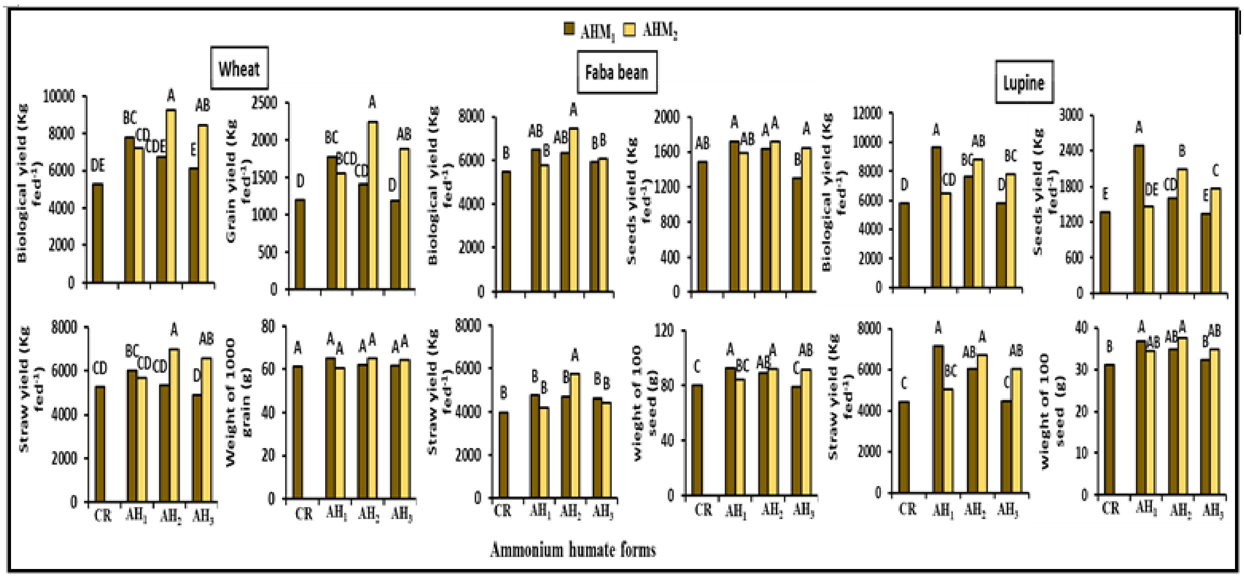
Results in Table (4) also reveal that application of all ammonium humate treatments (AH_1, AH_2, and AH_3) applied on the soil (M_2) was better than foliar application of these treatments on the plant (M_1) of all tested crops. Again, application of AH forms on the soil led to an increase in the growth parameters of all tested crops as compared to the control treatment. The highest percentage increase was recorded (57.4, 11.6, and 29.0%) in grains and/or seeds for wheat, faba bean, and lupine, respectively. This results in good agreement with those of Mir *et al.* (2002) who reported that the addition of ammonium humate to the soil increased the biological yield and grains yield of wheat plants. The increase in grains yield in wheat may be related to the more efficient uptake of nutrients by plants due to the addition of ammonium humate. The effect of ammonium humate on grains yield is due to an increase in the permeability of the plant cell and the promotion of an active uptake of water.

Said-Al Ahl *et al.* (2016) added that foliar sprays of humic acid enhanced plant growth, yield, and quality in a number of plant species due to their action on different physiological and metabolic processes. growth stimulation and enhancement of crop yield. In this connection, Mahdi *et al.* (2021) found that treating the soil with potassium humate significantly enhanced all growth characteristics of faba bean plants as compared to those that were not treated. This result could be explained by the fact that it has many of the components necessary for fostering plant life, enhancing potential growth, enhancing photosynthesis, and accelerating up cell division.

C: - Efficacy of interaction between ammonium humate forms with two methods of application on yield components.

Fig. (1) shows the response of different crop yields to applied ammonium humate by two methods of application. In general, results show that application of ammonium humate forms with two methods of application increased all growth parameters of all tested crops (wheat, faba bean, and lupine) under experiment conditions as compared to control treatment. Also, the obtained results in Fig. (1) revealed that the best treatment was AH_2M_2, which increased the growth parameters (straw, grains, and/or seeds) of all studied crops as compared to other treatments.

The observed results are in excellent accord with Abdel-Baset *et al.* (2020), who found that the application of 3% ammonium humate on the soil followed by the application of 3% ammonium humate and 3% potassium humate on the leaves of crops boosted all growth parameters. Recently, Abdel-Mawgoud *et al.* (2007) demonstrate that humic acid boosts food uptake, cell division, photosynthesis, respiration, the production of nucleic acids and enzymes, as well as the total dry weight of the plant. Moreover, application of humic acid to foliage and soil increased auxin, cytokinin, and gibberellin levels in plants. Likewise, humic acid is a hormone-like substance; its auxin-like activity stimulates cell division and cell elongation. Also, Meganid *et al.* (2015) verified that humic substances can have a good impact on faba bean biomass, both fresh and dry. An increase in CO_2 absorption and photosynthetic rate might be the cause of humic acids' beneficial effects on pigments involved in photosynthesis.



AM **Ammonium humate forms** **AHM** **Interaction Ammonium humate forms and application methods**

Fig. 1. Interaction between ammonium humate forms and two methods of application on some yield components of wheat, faba bean and lupine crops under sand soil conditions.

Total amount of macronutrients and percentage of protein in various planted crops as affected by applied ammonium humate forms and two methods of application

A:- Efficiency of ammonium humate forms.

Data in Table (5) demonstrate how the use of various ammonium humate formulations affects the status of total macronutrient content (N, P, and K) in straw, grain, or seed of various farmed crops (wheat, faba bean, and lupine). Results showed that evaluated crops responded favorably to administered AH forms when compared to control treatments. In comparison to other types of AH treatments, AH_2 treatment often enhances N, P, and K total content in grains, seeds, and straw of wheat and faba bean crops. The lupine crop showed a notably distinct pattern, with the AH_1 treatment appearing to be superior to AH_2 and AH_3, particularly in the seeds. The greatest percentage increase was in N, P, and K were found in wheat grain (88.6, 87.5, and 43.8%, respectively), while similar percentage increase in straw were found for faba bean straw (62.3, 66.1, and 60.8%, respectively), and lupine straw (91.9, 61.6, and 57.5%, respectively). The obtained result may be due to the fact that the addition of ammonium humate increased the growth of plants, as mentioned previously, which led to an increase in the absorption, transfer, and content of N, P, and K in both grain or seed and straw of the studied plants (Nardi *et al.*, 2002). In addition, Ibrahim and Ali (2018) found that humic compounds are important for nutritional absorption. Both directly and indirectly, this use may have an impact on the nutrient status of faba bean plants. Also, Mahdi *et al.* (2021) pointed out that soil treated with HA had much higher levels of N, P, and K than soil not treated with HA. The presence of hydrophilic and hydrophobic areas that encourage surface activity is connected to this. As a result, the humic compounds interact as carriers of nutrients with the cell membrane structures (Garca *et al.*, 2016).

Furthermore, data in Table (5) demonstrated that the application of ammonium humate forms (AH_1, AH_2, and AH_3) improved the protein percentage in wheat, faba bean, and lupine crops compared to controls. The AH_1 ammonium humate form was superior in all plants that were investigated. This result could be explained by the AH_1 form's high nitrogen content, which resulted in a higher protein percentage. This result is due to the role of nitrogen in supporting a photosynthetically active wheat canopy, ensuring grain yield, and producing storage protein in the plants. These findings correspond with those of Abdel-Baset *et al.* (2020), who found that a 3% ammonium humate treatment boosted protein content. However, it is worth noting that the protein content of the lupine seed was higher than that of the wheat plant. This may be due to the higher N content in the lupine seed than in the grain wheat plant, which had a role in producing storage protein. This is in line with the findings of Kalembasa *et al.* (2020), who claimed that legumes have a significant potential to raise the amount of C and N in the seeds. Low C:N ratios in crop wastes and deep-rooting species (like lupine) both encourage the process of mineralization, or the immobilization of those elements in the soil.

B:- Efficiency of methods application.

Data in Table (5) illustrated that all treatments by two methods of application increased the N, P, and K total content in straw, grain, or seed of wheat, faba bean, and Lupine crops, respectively, as compared to the control treatment. Results also showed that, in contrast to foliar treatment (M_1), soil application (M_2) of various ammonium humate forms increased the overall content of macronutrients (N, P, and K) in the various crop components under study. Moreover, protein percentage had no effect on M_1 compared to M_2 method application, which increased protein percentage in all studied crops as compared to either control or foliar AH application. The percentage increase in protein content reached 20.6, 29.5, and 5.2% for Wheat, Faba bean, and Lupine, respectively. This results in good agreement with Denre *et al.* (2014), who found that humic substances promote the conservation of mineral nutrition in the plant. In contrast, Azam *et al.* (2016) reported that high N and P content were also observed in the treatments with foliar application of humic acid on plants. Similar results were obtained by, Abou El-Khair *et al.* (2010) they found that, humic acid increased N, P and K contents in different plant organs.

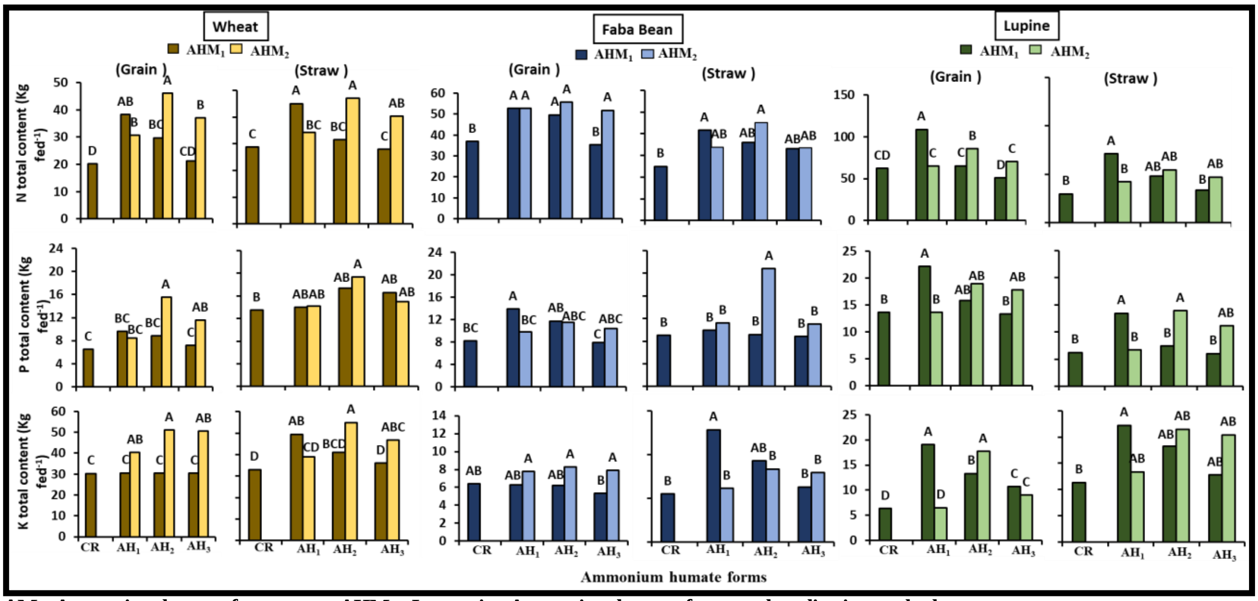
Table 5. Effect of ammonium humate forms and two methods of application on macronutrients total content and protein % in wheat, faba bean and lupine crops

Treatment	Total content of macronutrients (Kg fed^{-1})												Protein (%)	Percentage increase
	Grain or seed						Straw							
	N	Percentage increase	P	Percentage increase	K	Percentage increase	N	Percentage increase	P	Percentage increase	K	Percentage increase		
							wheat							
Control	20.1_{C}	–	6.5_{B}	–	13.29_{B}	–	28.7_{B}	–	13.5_{B}	–	33.0_{B}	–	9.62_{C}	–
AH_1	34.4_{AB}	71.1	9.11_{B}	40.2	13.87_{AB}	17.6	39.6_{A}	38.0	14.07_{B}	4.2	44.1_{A}	33.6	11.96_{A}	24.2
AH_2	37.9_{A}	88.6	12.19_{A}	87.5	14.73_{A}	43.8	39.2_{A}	36.6	18.34_{A}	35.9	47.9_{A}	45.2	11.95_{A}	24.3
AH_3	29.1_{B}	44.8	9.36_{AB}	44.0	14.46_{A}	35.6	34.1_{AB}	18.8	15.78_{AB}	16.9	41.4_{A}	25.5	10.81_{B}	12.4
M_1	29.7_{A}	47.8	8.53_{B}	31.2	13.48_{B}	5.8	34.8_{B}	21.3	16.0_{A}	18.5	42.2_{A}	27.9	11.6_{AC}	20.6
M_2	37.9_{A}	88.6	11.84_{A}	82.2	15.23_{A}	59.0	40.5_{A}	41.1	16.2_{A}	20.0	46.9_{A}	42.1	11.6_{AC}	20.6
							Faba bean							
Control	36.99_{C}	–	8.69_{C}	–	6.38_{A}	–	24.91_{B}	–	9.02_{B}	–	5.48_{B}	–	15.6_{C}	–
AH_1	52.65_{A}	42.3	11.82_{A}	36.0	7.03_{A}	10.2	37.98_{A}	52.5	10.56_{B}	17.1	9.50_{A}	73.4	20.08_{A}	28.7
AH_2	52.62_{A}	42.3	11.58_{AB}	33.3	7.24_{A}	13.5	40.44_{A}	62.3	14.98_{A}	66.1	8.81_{A}	60.8	19.70_{AB}	26.3
AH_3	43.51_{B}	17.6	9.14_{BC}	5.2	6.60_{A}	3.5	33.26_{AB}	33.5	9.91_{B}	9.9	7.01_{AB}	27.9	18.32_{B}	17.4
M_1	45.8_{A}	23.8	11.16_{A}	28.4	6.75_{B}	5.8	36.8_{A}	47.7	9.3_{B}	3.1	7.9_{B}	44.2	18.5_{B}	18.6
M_2	53.0_{A}	43.3	10.54_{A}	21.3	7.98_{A}	25.1	37.4_{A}	50.1	13.3_{A}	47.5	8.9_{A}	62.4	20.2_{A}	29.5
							Lupine							
Control	62.4_{C}	–	13.7_{A}	–	6.32_{D}	–	29.5_{B}	–	6.25_{B}	–	11.3_{B}	–	24.8_{B}	–
AH_1	86.8_{A}	39.1	17.9_{A}	30.7	15.5_{A}	102.5	56.6_{A}	91.9	10.1_{A}	61.6	17.8_{AB}	57.5	27.5_{A}	10.9
AH_2	75.5_{B}	21.0	17.5_{A}	27.7	12.8_{B}	145.3	51.3_{A}	73.9	10.7_{A}	71.2	19.9_{A}	76.1	25.6_{B}	3.2
AH_3	68.5_{C}	6.6	15.6_{A}	13.9	9.86_{C}	56.0	40.3_{AB}	36.6	8.62_{AB}	37.9	16.6_{AB}	46.9	24.9_{B}	0.4
M_1	74.9_{A}	20.0	17.1_{A}	24.8	14.4_{A}	127.9	51.0_{A}	72.9	8.99_{A}	43.8	17.8_{A}	57.5	25.5_{A}	2.8
M_2	73.6_{A}	18.0	16.8_{A}	22.6	11.1_{A}	75.6	47.9_{A}	62.4	10.61_{A}	69.8	18.4_{A}	62.8	26.1_{A}	5.2

Ammonium humate forms (AH) **Foliar application (M_1)** **Soil application (M_2)**

C:- Efficiency of interaction between ammonium humate forms with two methods of application on macronutrients total content and protein percentage.

Fig. (2) revealed that Applied ammonium humate forms and two application methods increased N, P, and K total content in variety crops (wheat, faba bean, and lupine) compared to the control treatment. In comparison to other treatments, application of AH_2M_2 often enhanced N, P, and K total content in grains, seeds, and straw for wheat and faba bean crops. In contrast, the AH_1M_1 treatment for the lupine crop was typically the best one for increasing the overall content of N, P, and K in both seeds and straw.

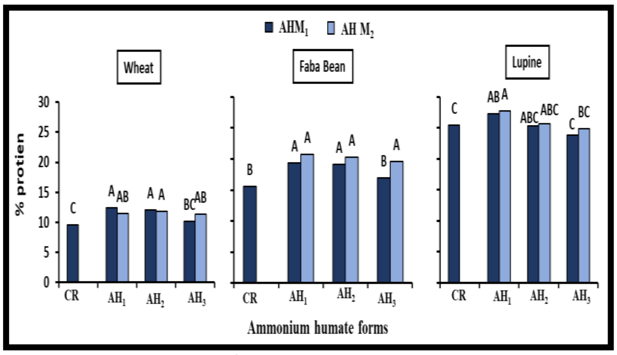


AM **Ammonium humate forms** **AHM** **Interaction Ammonium humate forms and application methods**

Fig. 2. Interaction between ammonium humate forms and two methods of application on some nutrient content in straw and grain or seeds of wheat, faba bean and lupine plants under sand soil conditions.

Obtained results in agreement with Barakat *et al.* (2015), who discovered that humate substance application on the soil had a substantial positive influence on leaf N, P, and, K contents, when compared to the control treatment. this enhancing effect can be discussed on the basis that humate substance addition increases soil organism activity by preventing nutrient ions from leaching, and increases mineral entry into root cells by increasing cell permeability. According to Abd El-Rheem *et al.* (2020), the application of humate substances increased N, P, and K content in plants by boosting nutrient absorption and transfer.

Fig. (3) showed that effect of interaction between ammonium humate forms and two methods of application on protein percentage in grains or seeds for wheat, Faba bean, and lupine crops under sand soil conditions. The results revealed that interaction between ammonium humate forms and two methods of application significantly increased protein content in grain of all studied crops compared to control. Also, the content of protein in lupine grain was higher than in other plant types. This might be explained by the fact that when lupine and faba bean plants are grown, bacterial growth can be supplemented with carbohydrates. As a result, the bacteria fix atmospheric N_2 into NH_4^+ in the soil, which is then transformed into amino acids and used by the plant to synthesize proteins for growth and development (Russel, 2008). These results in good agreement with Barakat *et al.* (2015) who reported that significant higher contents of protein in dry seeds were obvious as a result of humate substance application. Moreover, Abd El-Rheem *et al.* (2020) added that humic acids are compounds that may have various biochemical effects either at the cell wall, membrane level, or in the cytoplasm, such as, enhancing protein synthesis.



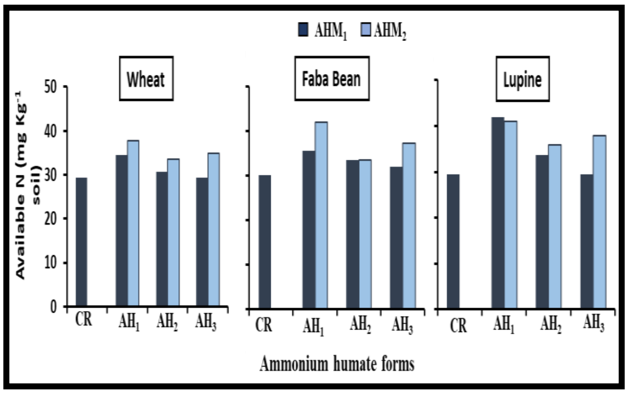
AM Ammonium humate forms
AHM Interaction Ammonium humate forms and application methods

Fig. 3. Interaction between ammonium humate forms and two methods of application on protein% in grains or seeds of wheat, faba bean and lupine plants under sand soil condition.

Efficiency of ammonium humate forms and two methods of application on Macronutrients availability in soil, pH and OM%.

Nitrogen availability

The date in Fig. (4) represents the effect of different ammonium humate (AH) forms with two methods of application (M_1 and M_2) on N availability in sand soil. The obtained results make it clear that the available N increased under all experimental treatments as compared to control. This may be due to applied ammonium humate forms, which contain a high level of organic matter and nitrogen, along with the mineralization of organic material in the soil (Chidankumar and Chandraju, 2009) and the presence of ammonium with humic acid. In addition, the application of AH_1 form with two methods of application (M_1 and M_2) was superior to other treatments. This may be attributed to the application of nitric acid and ammonium with humic acid, which chelated N and kept it available in the soil. Moreover, the highest values of available N content in the soil were observed when ammonium humate was added to the soil compared to its foliar application on the plant.



AM Ammonium humate forms
AHM Interaction Ammonium humate forms and application methods

Fig. 4. Nitrogen availability in soil after wheat, faba bean and lupine crops harvested as affected by ammonium humate forms with two methods of application.

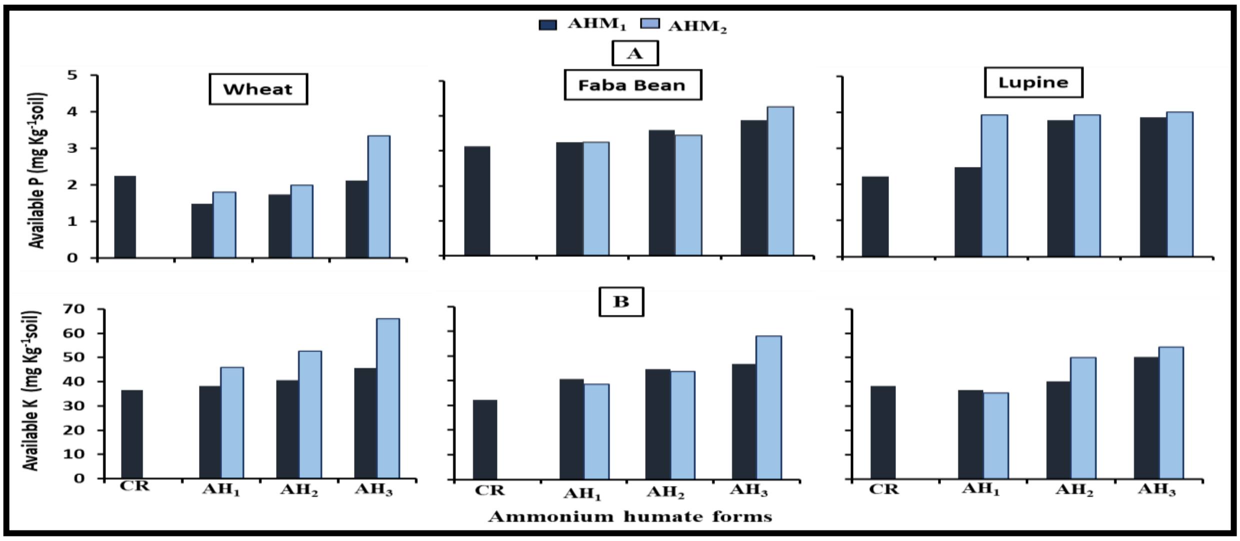
Also, results presented in Fig. (4) showed that there is a slight increase in the soil available N content after harvesting both faba bean and lupine as compared to wheat crops this may be attributed to faba bean and lupine cultivations enhances soil fertility by adding substantial amounts of N into the soil matrix through N_2-fixation by rhizobium bacteria, which colonize the root nodules. Gonzalez *et al.* (1992) hypothesized that the rise in available N might be caused by humic materials increased microbial activity. The observed increase in nitrogen availability may have also been influenced by the humic chemicals' capacity to inhibit nitrification and slow urease activity. This stops the loss of N through vital pathways like leaching and volatilization. The boost in the amount of nitrogen that is easily available might also be brought on by the addition of N from the mineralization of native nitrogen brought on by an increase in microbial activity.

Humic acid has recently been described by Abdel-Baset *et al.* (2020) as improving soil structure, altering the physical properties of soil, and possibly promoting the formation of soil macroaggregates, which increase soil water holding capacity and aid in the chelation of soil NH_4^+-N and NO_3 -N leaching. According to Sun *et al.* (2019), NH3 volatilization typically accounts for 10%–60% of all N losses in agriculture and is the primary mechanism for fertilizer N losses. Making them accessible to plants helps with protein synthesis, enzymatic activity, plant root respiration, photosynthetic density enhancement, and plant chlorosis correction.

Phosphorus and potassium availability

Figs. (5 A and B) showed that application of ammonium humate treatments using M_1 and M_2 procedures, according to the results, enhanced the amount of available P and K in the soil when compared to a control treatment. The findings might be attributed to the phosphorus and potassium that were released during the decomposition of the organic matter, as well as the organic acids that were produced, which sustain and enhance the P and K availability in the soil. Moreover, humic acid, a commercially available organic fertilizer, includes the majority of the components that boost soil fertility and nutrient availability, promoting plant growth and production. In addition, phosphoric acid combined with ammonium humate was used in the AH_3 treatment, which had the maximum phosphorus content in the soil when compared to other treatments. Yang *et al*. (2021) found similar results, demonstrating that humic acid converts soil P to an exchangeable form, thereby preventing P from attaching to metal elements. Similar results were also reported by Awwad et al. (2020), who showed that the addition of potassium humate increase the available nitrogen, phosphorus and potassium in soil as compared to control and improved the soil fertility status at different soil layers.

Moreover, applied AH on the soil (M_2) increased the available P and K content in all treatments as compared with foliar application on the plant (M_1). Data in Fig. (5A) also revealed that the highest content of available P in soil was recorded after the faba bean crop was harvested, where it reached 4.26 mg Kg^{-1} in soil compared to other tested crops. However, the current data showed that the highest content of available K in soil was observed after wheat crop was harvested, where it reached 66.05 mg Kg^{-1} compared to other plants. In addition, Awwad et al. (2020) who reported that humic acid released the fix K from the soil.

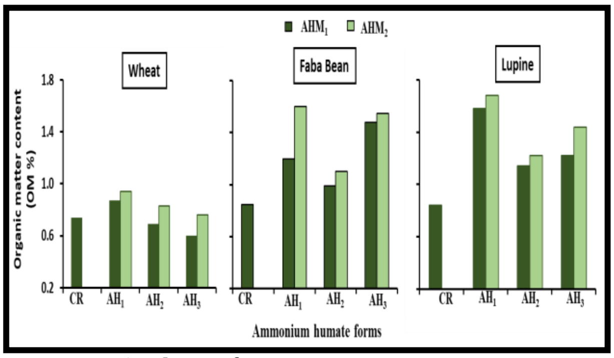


AM **Ammonium humate forms** **AHM** **Interaction Ammonium humate forms and application methods**

Figs. 5A & B. Phosphorus and potassium availability in soil after wheat, faba bean and lupine crops harvested as affected by ammonium humate forms with two methods of application.

Organic matter (OM%)

Organic matter is widely regarded as a vital component of a healthy soil. It is an important part of the soil's physical, chemical, and biological fertility. Data in Fig. (6) indicate that all experimental treatments increased the soil organic matter content compared to control. In addition, AH_1 treatment with different methods (M_1 and M_2) was superior compared with other treatments. The highest values of OM content in the soil were observed when ammonium humate was added to the soil compared to its foliar application on the plant. The obtained result was in agreement with Zhuo *et al*. (2012), who found that the addition of ammonium humate increased soil organic matter. Also, Sharif *et al*. (2002) explained that humic substances contribute up to 85–90% of soil organic matter and can improve soil properties such as aggregation, water holding capacity, microbial growth, organic matter mineralization, and the solubility and availability of micronutrients. It may be worth mentioning that organic matter in soil cultivated with leguminous crops (faba bean and lupine) was higher than in soil cultivated with wheat crops. This may be due to the major advantages of legumes include the amount of nitrogen fixed into the soil and the high quality of the organic matter released to the soil in term of C/N ratio. Some legume species have also deep root systems, which facilitate nutrients solubilization by root exudates and their uptake/recycling as well as water infiltration in deeper soil layers (Stagnari *et al*., 2017).



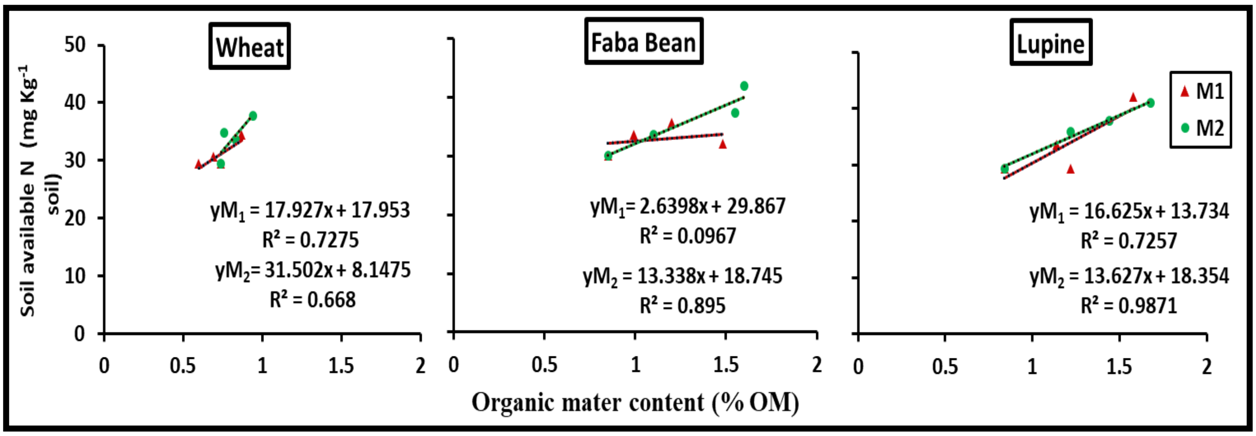
AM **Ammonium humate forms**
AHM **Interaction Ammonium humate forms and application methods**

Fig. 6. Organic matter content in soil after wheat, faba bean and lupine crops harvested as affected by ammonium humate forms with two methods of application.

Correlation between OM % and N availability in soil as affected by applied ammonium humate forms and methods of application

Fig. (7) represented a liner correlation between OM% and N content in the soil as affected by applied ammonium humate forms (AH_1, AH_2 and AH_3) and two methods of application after yield crops were harvested (wheat, faba bean and lupine). This relationship shows a strong positive correlation between OM% and N content in the soil, where R^2 values range from 0.668 to 0.987. Moreover, soil application of all treatments showed a stronger correlation than foliar application of all treatments in different soil samples. As observed by Clinton *et al.*

(1995), humic compounds can incorporate nitrogen into their structure either directly through chemical reactions or indirectly through microbial activity and the ensuing degradation of microbial biomass. According to several publications, N may be attached to organic matter in soil and an increase in soil nitrogen levels might speed up the conversion of organic matter.

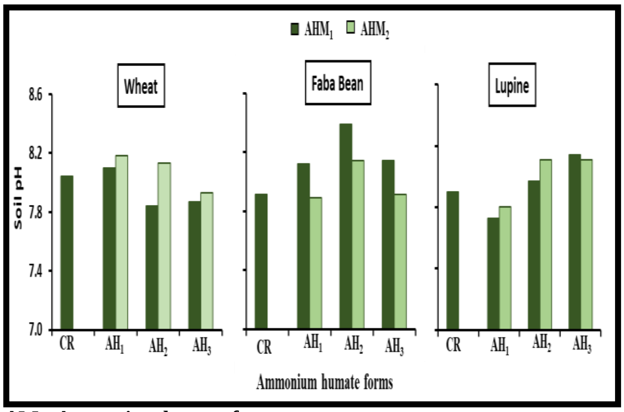


Foliar application (M1) **Soil application (M2)**

Fig. 7. Correlation between organic matter percentage and N availability in soil after wheat, faba bean, and lupine yields harvested as affected by ammonium humate forms and methods of application.

Soil pH

Soil pH is the single soil parameter that reveals a comprehensive picture of the medium for plant growth, including nutrient supply trends, the fate of added nutrients, soil aeration, soil mineralogy, and the region's final meteorological conditions (Zhao *et al.*, 2011). Obtained results in Fig. (8) revealed that pH values increased in soil under all treatments as compared to control this may be attributed that the pH of ammonium humane preparing which was 7. The minimum soil pH (pH 7.73) was found under the ammonium humate (AH_1) treatment with two methods of application (M_1 and M_2) after lupine was harvested. Considering the dissociation of the acidic functional groups, Ceppi *et al.* (1999) observed that humic substances constitute a heterogeneous combination of polyacidic molecules with a significant buffering capacity over a broad pH range. According to Garca-Gil *et al*. (2004), most mechanisms that regulate the optimal delivery of nutrients to crops work within a restricted pH range, making the buffering capacity of soil of great practical consequence in most of these activities.



AM Ammonium humate forms

AHM Interaction Ammonium humate forms and application methods

Fig. 8. Soil pH after wheat, faba bean and lupine crops harvested as affected by ammonium humate forms with two methods of application.

CONCLUSION

Ammonium humate (AH) is a substance that is frequently applied in agriculture as a fertilizer and soil conditioner. This special ingredient is a useful tool because it has various advantages for plant growth and development. It is a helpful chemical for improving soil structure, boosting soil fertility, and promoting microbial activity. It provides numerous advantages for plant growth and development. We can improve production, minimize the demand for synthetic fertilizers, and promote sustainable and environmentally friendly farming practices by using (AH) in agricultural practices. In this study, different forms of (AH) significantly increased crop productivity compared to control treatments. The (AH) that adjusted the pH to 7.0 with H_2SO_4 (AH_2) was found to be superior in yield components for all tested crops. The soil application method (M_2) was positive compared to foliar application (M_1). The interaction between AH forms and application methods revealed that AH_2M_2 treatment was the best for all tested crop productivity. The total macronutrient content in wheat, faba bean, and lupine showed a similar trend, with AH_2M_2 treatment increasing the protein percentage in wheat and faba bean grain or seed, respectively. Macronutrient availability increased under all experiment treatments. Organic matter content in the soil was highest when different ammonium humate forms were applied to the soil (M_2) compared to foliar application. Overall, the addition of ammonium humate forms to the soil increased yield productivity, total macronutrient and protein content, soil fertility, and soil chemical properties, particularly OM% and pH.

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تقنيات إضافة هيومات الأمونيوم وتأثيرها على إنتاجية المحاصيل وخصائص التربة الرملية

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الملخص

تعتبر هيومات الأمونيوم (AH)مادة تستخدم في الزراعة كسماد ومحسن للتربة. يتم انتاجها عندما يتفاعل حمض الهيوميك مع هيدروكسيد الأمونيوم. لذلك، فهي تعتبر مادة مفيدة لأنها تتمتع بمزايا مختلفة لنمو النبات وتطوره. أجريت تجربة حقلية في تربة رملية في مزرعة محطة البحوث الزراعية بالإسماعيلية - محافظة الإسماعيلية - مصر. ولقد نفذت التجربة خلال الموسم الشتوي 2021-2022 و`ذلك لدراسة تأثير إضافة ثلاثة أشكال مختلفة من هيومات الأمونيوم (AH_1، AH_2، AH_3). تم تطبيق طريقتين للإضافة، الرش على النبات (M_1) والاضافة الارضية (M_2) على نمو محاصيل مختلفة (قمح و فول و ترمس) وكذلك بعض صفات الأراض تحت الدراسة . أشارت النتائج التي تم الحصول عليها إلى أن إضافة الصور المختلفة من هيومات الامونيوم أدى إلى زيادة كبيرة في إنتاجية المحصول، والمحتوى الكلي من المغذيات الكبرى، ونسبة البروتين فى المحاصيل المختبرة. كانت هيومات الامونيوم المضاف لها حامض الكبريتيك AH_2 متفوقاً في مكونات المحصول، كما اظهرت النتائج حدوث زيادة معنوية عند الاضافة الارضية M_2 مقارنة بالرش الورقي M_1. أوضح التفاعل بين اشكال AH وطريقة الاضافة أن المعاملة AH_2M_2 كانت ايجابية لإنتاجية المحاصيل المختبرة. اظهرت النتائج ايضا زيادة في محتوى العناصر الكبرى (N,P and K) في التربة بالمقارنة بالكنترول. حيث اعطت المعاملة AH_1M_2 أعلى قيمة نيتروجين الميسر وكان محتوى المادة العضوية في التربة أعلى عند إضافة الصور المختلفة من هيومات الأمونيوم إلى التربة بالمقارنة بالرش الورقي.