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Influence of Humic Products on Soil Health and Potato Production

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Abstract Since 1900, soil organic matter (SOM) in farmlands worldwide has declined drastically as a result of carbon turnover and cropping systems. Over the past 17 years, research trials were established to evaluate the efficacy of different commercial humates products on potato production. Data from humic acid (HA) trials showed that different cropping systems responded differently to different products in relation to yield and quality. Important qualifying factors included: source; concentration; processing; chelating or complexing capacity of the humic acid products; functional groups (Carboxyl; Phenol; Hydroxyl; Ketone; Ester; Ether; Amine), rotation and soil quality factors; consistency of the product in enhancing yield and quality of potato crops; mineralization effect; and influence on fertilizer use efficiency. Properties of humic substances, major constituents of soil organic matter, include chelation, mineralization, buffer effect, clay mineral-organic interaction, and cation exchange. Humates increase phosphorus availability by complexing ions into stable compounds, allowing the phosphorus ion to remain exchangeable for plants' uptake. Collectively, the consistent use of good quality products in our replicated research plots in different years resulted in a yield increase from 11.4% to the maximum of 22.3%. Over the past decade, there has been a major increase in the quality of research and development of organic and humic acid products by some well-established manufacturers. Our experimentations with these commercial products showed an increase in the yield and quality of crops.

Keywords Humic acids · Humus · Soil organic matter

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Introduction

In his 1840 publication for the British Association for the Advancement of Science, Justus von Liebig clearly theorized that humus is the direct source of carbon for plants (Liebig 1843). Arnon and Stout (1939) proposed the widely used criteria that an essential compound in plants enhances their metabolism. From this thesis, studies of plant nutrition have focused on the function and chemistry of organic elements in plant growth.

Soil is a living system. Soil organic matter (SOM) is derived from the chemical and biological degradation of plant and animal residues in various stages of decomposition and the synthetic activities of microorganisms (Chen and Aviad 1990; Stevenson 1982). The rapid decline of SOM in farmlands over the past century due to carbon turnover and cropping systems has resulted in seriously low levels of SOM in today's soils (Yang et al. 2003).

Soil may be defined as a biological entity similar to a "living tissue with complex biochemical reactions" (Lee and Quastel 1946), in which organic materials are consumed by soil macro- and microorganisms for use as substrate in a metabolic process known as humification.

Humic acids (HA—humic acid, fulvic acid, and humin) are a family of organic molecules made up of very long carbon chains and numerous active radicals such as phenols and other aromatics (Stevenson 1982; Fig. 1). HA are the biological center of soils, possessing properties of chelation, mineralization, buffering, clay mineral-organic interaction, and cation exchange capacity, which are essential to soil health and plant growth (Figs 2, 3, and 4).

Based on our experience and other research findings, the organic carbon content of soil can be an essential and valuable indication of the potential humic chemistry of the soil. The soil carbon level should be an important part of the soil test for the crop production fertility guide.

The objective of this study was to determine the influence of HA on potato yield and quality.

Materials and Methods

Saylor Creek Experiment

Experiment 1 was conducted at Saylor Creek, Idaho, in 1987. At this test site, HA products from different companies in different years were applied in a randomized complete block design with four replications. We established experimental plots in three different farmers' fields. This area is semi-arid with an annual rainfall of 152.4–203.2 mm. The soil in these fields was calcareous with a pH of 8, 8.2 and 8.2 respectively, and organic matter content of 0.9%, 0.9%, and 1.0%, respectively. We used 6% HA from Bio-Tech Company. Irrigation was solid set and we followed the farmers' cultural practices with regard to irrigation, weed and pest management. On April 15, 1987, we planted Russet Burbank cut-seed potatoes by hand spaced 25.4-cm apart. The individual plot was 3.65-m wide and 7.6-m long and included four rows. HA was side-dressed on both sides of the rows. The control

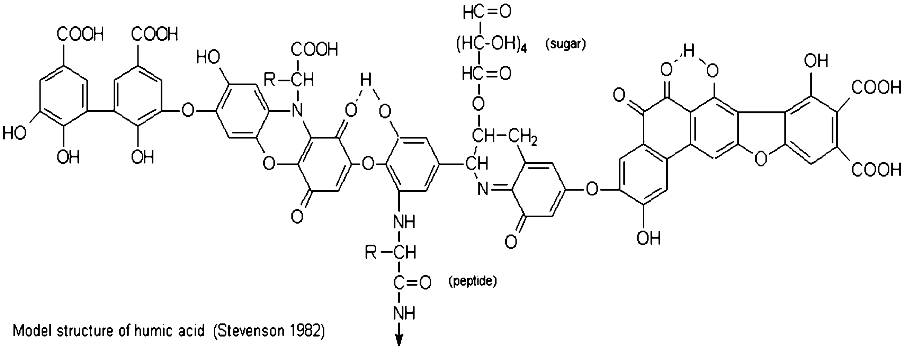


Fig. 1 Model structure of HA (Stevenson 1982)

Fig. 2 Clay-humic association via binding HS to clay by cationic bridges

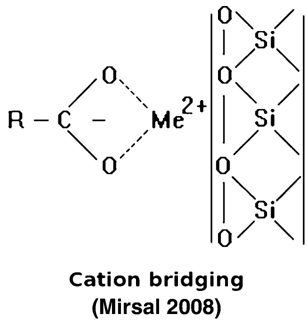


Fig. 3 Clay-humic association via HS adsorption by association with hydrous oxides

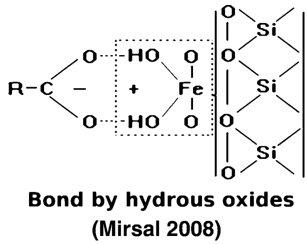
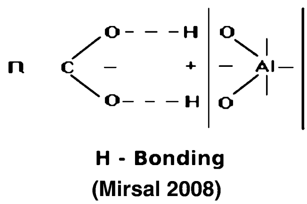


Fig. 4 Clay-humic association via hydrogen bonding



had no HA and was replicated four times. We applied rates of 8.34, 18.69, 37.39, 74.79, and 149.58 l HA ha^{-1} with four replications for all three experiments. On September 29, 1987, we hand-harvested the plots, graded yield, and ran statistical analyses.

Mountain Home Experiment

I selected the 1999 experiment we did at a farmer's field in Mountain Home, Idaho, to explain how HA behave in different soils. The climate is semi-arid with annual rainfall of 152.4–203.2 mm. The soil in this field was calcareous and silt–clay–loam, with soil pH of 8.2 and organic matter content of 1.1%. Individual plots were 3.65-m wide and 7.6-m long and included four rows. We used granular humate (Agri-Plus) and liquid HA (Quantum-H) on the experimental field. On April 16, 1999, we hand-planted cut-seed Russet Burbank potatoes spaced 25.4 cm apart. We side-dressed a different brand of HA (Quantum-H) at a rate of 46.5 and 93 l ha^{-1} with four replications. We top-dressed with 40.48 kg per hectare granular humate (Agri-plus). The irrigation system was solid set, and the farmer followed his own cultural practices for irrigation, pest and weed control. On September 26, 1999, we hand-harvested the plots, graded yield, and ran statistical analyses.

Southeast Idaho Experiment

In 2002, field trials were established in southeast Idaho at the Aberdeen Research and Extension Center (Hopkins and Stark 2003). The objective of this experiment was to evaluate the influence of HA on yield, specific gravity, petiole phosphorous (P), and gross return in Russet Burbank potatoes under different rates of 10-34-0 fertilizer. The soil was Declo sandy loam with a pH that varied from 8.0 to 8.2, and calcareous (4–9% free lime). The P level was optimal (15 to 19 ppm), and organic matter level was 1.1% to 1.2%. Climate was semi-arid with an annual rainfall of 152.4–203.2 mm. The growing season extends from late May to late September. The experimental design was a complete randomized block with five replications. Plots were 3.65-m wide and 12.19-m long, with four rows. Russet Burbank cut-seed potatoes were planted at 30.48-cm seed spacing according to University of Idaho guidelines. The HA source was Quantum-H. Three rates of P were applied with and without added HA in the mark-out band 7.62 cm to the side of the seed piece. The 10-34-0 and HA materials were applied together at a 10:1 volume-to-volume ratio. P status was evaluated by taking petiole samples during mid-tuber bulking. Two 10.67-m sections were harvested from the middle two rows in each plot to determine yield. Tuber quality was determined by size, grade, and specific gravity of each sample. Treatment effects and mean separations were determined by standard analysis of variance procedures using SAS.

Mendota Phosphorus Transformation Experiment

The objective of Dr. Ajwa's experiment in Monterey County near Mendota, California (Ajwa et al. 2006), was (a) to demonstrate organically complexed reacted ammonium phosphate (Actagro organic acid), (b) to compare movement and availability of P fertilizers in the soil, (c) to demonstrate changes in P availability over time, and (d) to study the pattern of P movement in soils relative to the drip tape. The site was selected as representative of the local soil and cropping system. Soil type was clay loam with a pH of 7.8. The average rainfall for this area was 302.8 mm, and the average temperature was 21 °C. Fertilizer treatments were as follows: (a) untreated control; (b) 26.38 kg per ha phosphoric acid; (c) 26.38 kg per ha ammonium polyphosphate; and (d) 26.38 kg per ha organically complexed reacted NH_4 phosphate (Actagro). The experimental design for each treatment was a randomized complete block replicated four times. Final plot size was 1.52 m center to center, 60.97-m long bed. On July 24 and 25, 2006, fertilizers were applied by drip injection with over 6 h of irrigation. Beds were pre-irrigated to ensure high fertigation uniformity and additional irrigation water used after fertigation. Soils were sampled at 1, 2, 14, 28, and 42 days past fertilizer application, following a two-dimensional grid pattern (0–7.62 cm, 7.62–15.24 cm and 15.24–22.86 cm from the drip tape in vertical and horizontal directions). Each cell was 7.62×7.62 cm. A sampling core was used to extract the soil from each grid (Fig. 5).

Results and Discussion

I selected four different studies to illustrate how humic and organic acids behave in different soils and cropping systems.

Saylor Creek Experiment

Our 1988 Saylor Creek Experiment was in calcareous soil with 5–7% free lime. With minimal soil fertility, we used the University of Idaho Fertility Guide for optimal yield. Our stand and vigor evaluation showed that plots treated with HA rated very high (eight out of ten) in comparison with controlled plots (five out of ten). Yield increased as we increased the rate of HA applied. Yield declined when the HA rate applied went over 75 l ha^{-1}. Figure 6 summarizes effects of HA rates on

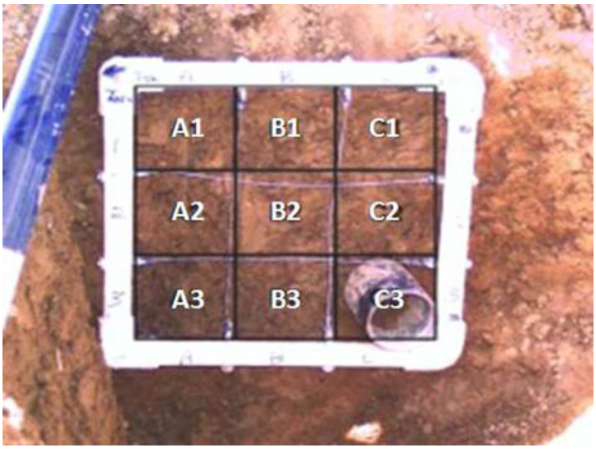


Fig. 5 Soil sampling square. Each square represents an area of 22.86 cm^2

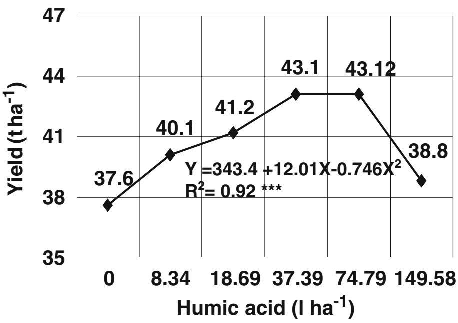


Fig. 6 Effects of HA rate on potato yield at three sites (Sailor Creek)

potato yield at three different sites. We can see from this and other studies we have conducted that HA performs in poor soil with high Ca (3,500 to 5,000 ppm). Due to their strong chelation capacity, complexing capacity, and high cation exchange capacity, HA may enhance fertilizer use efficiency by making P, K, Zn, and Fe more available to the plants. Studies by Chen (1986), Chen and Aviad (1990), MacCarthy and IHSS (1990), and others in humic literature confirm these findings. HA are polydisperse polyanions because of their variable chemical features. HA polymers readily bind clay minerals to form organic–clay complexes. This reaction contributes to the creation of stable humus, which impacts soil physical, chemical, and biological functions.

Mountain Home Experiment

I selected our 1999 study in Mountain Home to illustrate how HA performs in different soil types. Even though humic substances are a good source of energy for beneficial soil organisms, in many experimental cases we do not get significant statistical yield response the first year due to the type of clay minerals soil, cropping system, and rotations. This experiment was conducted in silt–clay–loam soil. In this type of soil texture, we generally need to apply more HA to create organomineral complexes and functionality. As Table 1 indicates, we harvested the potatoes and graded them in different categories. There was no statistical significance between controls in this and other treatments. It is important to note that the following year after our study the grower planted small grains in the same field. The HA-treated area in our experimental plot showed a major yield difference. Because of this response, we recommend that crop consultants and growers do the sieve and hydrometer analysis of soil texture to arrive at the exact percent of clay, silt, and sand content, in order to determine proper HA recommendations.

Southeast Idaho Experiment

The 2002 research conducted at Aberdeen Research and Extension Center in southeast Idaho gives another perspective on HA research. The literature of many studies reveals that HA influences phosphorus (P) use efficiency and prevents calcium phosphate precipitation in calcareous soils. Results of the Southeast Idaho study showed that banded-fertilizer P treatments consistently increased yields compared to zero P

Table 1 Effect of humic acid on tuber yield (t ha^{-1}) at Mountain Home experiment (1999)

Treatments[a]	Size grading					
	0–113.4 g	113.4–220.8 g	226.8–340.2 g	>340.2 g	Culls	Total
Control	10.2[a]	17.9[a]	8.2[a]	5.0[a]	3.4[a]	44.6[a]
Granular humate only (Agri-Plus)	10.7[a]	16.7[a]	8.4[a]	5.5[a]	2.8[a]	45.1[a]
Granular humate only (Agri-Plus) + 46.5 L ha^{-1} liquid humic acid (Quantum-H)	11.5[a]	16.7[a]	7.0[a]	5.0[a]	4.5[a]	44.7[a]
Granular humate only (Agri-Plus) + 93.0 L ha^{-1} liquid humic acid (Quantum-H)	11.0[a]	15.3[a]	6.4[a]	4.2[a]	4.6[a]	41.5[a]

[a] Means followed by the same letter in the same column are not significantly different at the 0.05 level (Newman–Keuls test)

treatments, however, generally the differences were not significant at $P=0.10$. The addition of HA to the fertilizer band tended to increase total yield at both high and low P levels, but differences were generally insignificant at $P=0.10$. Similarly, U.S. No. 1 yields generally increased as P was added at both rates, with a tendency for further yield increases when HA was included in the fertilizer band. The primary effect of P and HA treatments on U.S. No. 1 tuber yields was an increase in tuber size. Even though there was no statistical significance in yield, there was some yield response and this translated to an increase in gross income. Many growers feel that by calculating the gross income, there is enough gain to cover the cost of the HA and the addition of HA improves the long-term quality of their soil as well (Table 2).

Mendota Phosphorus Transformation Experiment

This was a comprehensive study on P fractionation and measurements; however, the main objective of the study was to demonstrate the pattern of P movement in soils relative in the drip tape and to evaluate how the organic acid-complexed P moves in the soil. The results showed that (a) conventional drip-applied P could move 7.6 to

Table 2 Effect of P with and without humic acid on potato yield, specific gravity, petiole P

P_2O_5 treatments (kg ha^{-1})	Humic acid (l ha^{-1})	Tuber yield (t ha^{-1})			Specific gravity	Petiole P (% dwt)	Gross return (US$/ha)
		Total	U.S. No. 1	>283 g			
0	0	44.23	25.26	16.39	1.077	0.24	4523
67.36	0	48.39	29.19	19.87	1.079	0.29	5110
67.36	14	49.85	31.32	20.88	1.080	0.31	5390
134.70	0	49.17	29.3	20.10	1.079	0.30	5187
134.70	28	50.07	31.21	21.67	1.079	0.32	5402
LSD (1%)		5.39	3.71	2.58	0.003	0.03	

P and gross return (Aberdeen Research and Extension)

10.16 cm from the irrigation tape in a clay-loam soil, however (b) organically complexed reacted NH_4 phosphate (Actagro-P) moved twice the distance moved by phosphoric acid or NH_4 polyphosphate. The plants' available P after 42 days was in the order of: organically complexed reacted NH_4 phosphate (Actagro-P) > NH4 polyphosphate>phosphoric acid. This study has excellent implications for P availability in potato production in calcareous soils (Table 3).

Conclusions

By selecting three different experiments in the Saylor Creek study, we showed significant yield response in an average of three different sites. In many other studies we have done, treatments with high-quality humic products resulted in a yield increase from 11.4% to a maximum of 20.3%. The Mountain Home study showed no statistical yield response, but some responses were related to application rate and type of clay minerals in the soil. The southeast Idaho study showed some yield increase, but it was of no statistical significance. However, enhancement of tuber quality and gross income offset the cost of HA and served to improve long-term soil quality as well. The experiment in the Mendota study showed that organically complexed reacted NH4-P fertilizer (Actagro-P) moved twice the distance moved by phosphoric acid or NH_4 polyphosphate. This has significant implications for calcareous soils. Growers have been adapting this type of practice to make P readily available in Idaho soils for potato production and quality.

Our experience over the past 17 years of applied research shows that there have been inconsistencies in results because of the complex nature of HA, lack of valid information on soil total carbon content, lack of understanding of the different soil clay minerals and their organomineral complexes, and HA application rate recommendations of some companies. Our findings and humic research literature illustrate the beneficial effects of HA direct modes of action on plant growth, including: effects on plant cell membranes that result in improved transport of nutritional elements, enhanced protein synthesis, plant hormone-like activity, enhanced photosynthesis, and effects on enzyme activities. Indirect modes of action benefit plant growth through: solubilization of microelements (e.g., Fe, Zn, Mn) and some macro elements (e.g. K, Ca, P), reduction of active levels of toxic elements, and increased microbial populations. Important attributes of HA are their ability to combine soil particles in structural aggregates, to favor mineralization of chemical

Table 3 Treatment list: P transformation in soil, Mendota, CA

P fertilizer treatment	N (kg ha^{-1})	P (kg ha^{-1})
Phosphoric acid	0	26.38
Ammonium P polyphosphate	7.85	26.38
Organically complexed reacted NH_4 phosphate	7.85	26.38
Untreated control (water)	0	0

substances which release SO_4, PO_4, NH_4, and NO_3 and their high cation exchange capacity (Chen 1986).

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