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Influence of Humic Acid on Nutrient Uptake in Plant, Fruit and Post-Harvest Soil Profile in Okra

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ABSTRACT

Okra is a multi-purpose vegetable crop grown across the country, and its fruits are highly valued for their nutritious profile and mucilage and fibre content. Several reports describe the response of okra to growth-stimulating compounds, among which humic acid (HA), an organic acid with well-documented ability to promote the growth, yield and quality of many food crops, holds particular promise. An experiment was conducted to study the effect of HA on okra plants along with varying doses of farmyard manure (FYM) and recommended fertilizers. The results revealed that treatment T15 (FYM plus 100% RDF along with 0.2% HA) recorded the highest soil organic carbon and available N, P and K status, and the highest N, P and K uptake by plant and fruit tissues. The findings indicate that a lower dose of HA is favourable for improving post-harvest soil nutrient status and nutrient uptake in okra plants and fruits.

Introduction

Vegetables are rich sources of nutrients, and their inclusion in the daily diet supplies protective substances such as vitamins and minerals along with energy sources like carbohydrates, protein and fats. Okra (*Abelmoschus esculentus* (L.) Moench) is a remunerative and indispensable vegetable crop cultivated widely across India, and considerable research attention has been devoted worldwide to its nutrient management and supply.

Humic acids possess the ability to hold water up to seven times their own volume, and this greater water-holding capacity allows plant roots to access the nutrients required for growth and yield more readily (Hartwigsen and Evans, 2000).

Humic substances are also effective in removing excess pesticides from soils low in organic matter, thereby averting soil toxicity hazards. The molecular components of humic acid act in a manner similar to plant growth hormones, and their application can be timed to activate vegetative growth, flowering, fruit set and fruit ripening. Humic acid is widely recognised by soil scientists and agronomists as an important component of healthy, fertile soil (Ravichandran, 2011). The present study was undertaken to determine the effect of humic acid on the post-harvest nutrient status of soil and on nutrient uptake in the plant and fruit tissues of okra.

Materials and Methods

The study on foliar application of humic acid in okra was conducted in the college orchard of Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, U.T. of Puducherry. Treatment details are furnished in Table 1. Initial composite soil samples were collected from a depth of 0–15 cm by the 'V' cut method prior to sowing and analysed for physical and chemical properties, the results of which are presented in Table 2.

The okra variety 'Arka Anamika', released by the Indian Institute of Horticultural Research (IIHR), Bengaluru, was used in the study, and the humic acid was procured from NLC, Neyveli, Tamil Nadu. The experiment was laid out in a Randomized Block Design (RBD) with three replications.

A composite surface soil sample (0–15 cm) representing the entire experimental field was collected by the 'V' cut method both before layout and after harvest. Samples were shade-dried, gently powdered with a wooden mallet, passed through a 2 mm sieve and used for analysis.

Five fruits were collected from tagged plants at peak harvest from each treatment and their fresh weight recorded. The fruits were shade-dried and then oven-dried at 60°C to constant weight, ground in a Willey mill and stored in labelled containers for analysis. Similarly, five plants were randomly selected from each plot after final harvest, shade-dried and oven-dried at 60°C to constant weight, ground in a Willey mill and stored for chemical analysis.

Nutrient uptake by plants and fruits at different growth stages was computed using the formula:

Nutrient uptake (kg ha^{-1}) = [Nutrient content (%) × DMP (kg ha^{-1})] / 100

The analytical procedures employed for soil and plant analysis are presented in Table 3.

Results and Discussion

Effect of foliar application of humic acid on post-harvest soil status

The residual availability of soil nutrients is of considerable benefit to the succeeding crop. Humic acid does not directly contribute significant quantities of nutrients to plants at normal rates of application; however, its indirect effects on soil fertility can be substantial. When adequate humic substances are present in the soil, the requirement for NPK is naturally reduced, and micronutrients, particularly iron, may become more available to plants in the presence of humates. Soils treated with humic acid release more available zinc, since the added zinc is sequestered by humic acid into soluble organic complexes that would otherwise rapidly transform into an insoluble form. Humic acids also form complexes with mineral nitrogen fertilizers, serving as a slow-release nitrogen source (Madumathi, 1987).

The presence of humin in soil improves its water-holding capacity, structure and fertility, among other functions (Pettit, 2012). Addition of humic substances such as humic acids increases soil aggregation, water retention and infiltration rate (Brady and Weil, 2008), and has been shown to improve aggregation across a range of soil textures (Quilty and Cattle, 2011).

From a biological standpoint, humic substances enhance soil fertility by influencing the composition of microbial populations (Calvo *et al.,* 2014). Root proliferation was found to be better with humic acid applied at low concentrations, and this stimulatory effect has been directly correlated with enhanced uptake of nitrogen, phosphorus, sulfur, zinc and iron (Mylonas and McCants, 1980).

Organic carbon (g g^{-1})

The organic carbon status of post-harvest soil, as influenced by the different treatments, is presented in Table 4. Differences among treatments were statistically significant, with values ranging from 0.19 g g^{-1} to 0.43 g g^{-1}. Treatment T15 (FYM plus 100% RDF along with 0.2% HA) recorded the highest organic carbon status at 0.43 g g^{-1}, while T0 (absolute control) recorded the lowest at 0.19 g g^{-1}. This significant improvement in organic carbon with foliar application of 0.2% humic acid and 100% RDF corroborates the earlier findings of Sharma and Mitra (1998). Addition of organic manures provides sufficient carbonaceous material for microbial decomposition, converting it into mineralised organic colloids in addition to enriching soil reserves.

Available N status (kg ha^{-1})

The post-harvest available nitrogen status of soil, as influenced by the treatments, is presented in Table 4. The KMnO4-N status ranged from 66.27 kg ha^{-1} to 112.93 kg ha^{-1}, with significant differences observed between treatments. T15 (FYM plus 100% RDF along with 0.2% HA) recorded the highest available nitrogen status at 112.93 kg ha^{-1}, while T0 (absolute control) recorded the lowest at 66.27 kg ha^{-1}. Govindasamy and Chandrasekaran (1989) observed that ammonia volatilisation with lignite humic acid plus nitrogen was lower than with nitrogen alone, since the addition of lignite humic acid forms complexes with the ammonium ion, preventing volatilisation losses and resulting in higher accumulation of inorganic nitrogen fractions. Nitrogen is a major constituent of proteins, enzymes, chlorophyll and nucleic acids.

Available P status (kg ha^{-1})

The available phosphorus status of post-harvest soil samples is presented in Table 4. The Olsen-P status ranged from 7.62 kg ha^{-1} to 18.39 kg ha^{-1}, with foliar application of humic acid significantly influencing available P. The maximum available P status (18.39 kg ha^{-1}) was recorded in T15 (FYM plus 100% RDF along with 0.2% HA), while T0 (absolute control) recorded the lowest at 7.62 kg ha^{-1}. Lignite humic acid generally improves phosphorus availability in soil, as humic acid forms a protective cover over colloidal sesquioxides, thereby reducing phosphorus sorption. Chelating agents can break the bonds between phosphates and iron or aluminium compounds, releasing phosphate ions into solution. Nitrification retardation due to humic acid in soil has also been reported by Singh *et al.,* (1979). Phosphorus plays a major role in the development of reproductive parts and root formation.

Available K status (kg ha^{-1})

Data on the influence of foliar application of humic acid on post-harvest available potassium status are presented in Table 4. The NH4OAc-K status ranged from 62.67 kg ha^{-1} to 117.67 kg ha^{-1}, with the maximum available potassium recorded in T15 (FYM plus 100% RDF along with 0.2% HA) at 117.67 kg ha^{-1} and the lowest in T0 (absolute control) at 62.67 kg ha^{-1}. Potassium plays a major role in activating enzymes involved in flowering, fruit set and translocation of carbohydrates. The nutrient content in humic acid was in soluble form, and its direct application as a foliar spray is likely to have been absorbed by the plants quickly, accounting for the greater nutrient availability observed in this treatment.

Effect of foliar application of humic acid on nutrient uptake in plant tissue

Humic acids are excellent foliar fertilizer carriers and activators. Their application in combination with trace elements and other plant nutrients, as foliar sprays, can improve the growth of foliage, roots and fruit. Humic acid compounds may exert various biochemical effects at the cell wall, cell membrane or cytoplasmic level, including increased photosynthesis and respiration rates, enhanced protein synthesis and greater plant hormone activity (Ravichandran, 2011).

The stimulative effect of humic acid on plant growth is reflected in enhanced uptake of the major plant nutrients nitrogen, phosphorus and potassium. By forming organo-metal complexes, these organic acids bring about the dissolution of primary and secondary soil minerals, making them available for uptake by plant roots. Chelation of nutrients such as iron, copper, zinc, magnesium, manganese and calcium reduces their toxicity as cations, prevents leaching and increases their uptake rate, while also promoting root growth that enables more effective foraging and translocation of nutrients within the plant system (Pettit, 2012).

In smaller molecular amounts, humic acids act as specific sensitising agents that increase plasma membrane permeability, resulting in increased nutrient uptake; however, since such small amounts cannot be regarded as a primary fertilizer source, this stimulatory effect is observed only in the presence of an adequate supply of major nutrients (Senn and Kingman, 1973).

N uptake in plant sample (kg ha^{-1})

Data on nitrogen uptake by the plant sample, as influenced by foliar application of humic acid, are presented in Table 5. Treatments significantly influenced nitrogen uptake, with values ranging from 4.28 kg ha^{-1} to 39.92 kg ha^{-1}.

Table.1 Treatment details

S. No.	Treatment
T0	Absolute control
T1	FYM + RDF – 0% + Humic acid – 0%
T2	FYM + RDF – 0% + Humic acid – 0.1%
T3	FYM + RDF – 0% + Humic acid – 0.2%
T4	FYM + RDF – 0% + Humic acid – 0.4%
T5	FYM + RDF – 50% + Humic acid – 0%
T6	FYM + RDF – 50% + Humic acid – 0.1%
T7	FYM + RDF – 50% + Humic acid – 0.2%
T8	FYM + RDF – 50% + Humic acid – 0.4%
T9	FYM + RDF – 75% + Humic acid – 0%
T10	FYM + RDF – 75% + Humic acid – 0.1%
T11	FYM + RDF – 75% + Humic acid – 0.2%
T12	FYM + RDF – 75% + Humic acid – 0.4%
T13	FYM + RDF – 100% + Humic acid – 0%
T14	FYM + RDF – 100% + Humic acid – 0.1%
T15	FYM + RDF – 100% + Humic acid – 0.2%
T16	FYM + RDF – 100% + Humic acid – 0.4%

Table.2 Soil properties of the field under study

Property	Value
Physical properties	
Clay (%)	12.40
Silt (%)	4.75
Fine sand (%)	17.46
Coarse sand (%)	64.61
Textural class	Sandy clay loam
Bulk density (g cm^{-3})	1.333
Taxonomical group	Vertic Ustropept
Soil series	Surakudy soil series
Physico-chemical properties	
Soil reaction (pH)	8.01
Electrical conductivity (dS m^{-1})	0.092
Chemical properties	
Organic carbon (g g^{-1})	0.240 (Low)
Available nitrogen (kg ha^{-1})	98.00 (Low)
Available phosphorus (kg ha^{-1})	9.337 (Low)
Available potassium (kg ha^{-1})	85.00 (Low)

Table.3 Methods employed for soil and plant analysis

Analysis	Methodology	Reference
Soil analysis		
Electrical conductivity	ELICO (CM 180) conductivity meter	Jackson (1973)
Soil reaction (pH)	Glass electrode, ELICO (LI 120) pH meter	Jackson (1973)
Bulk density	Cylinder method	Dakshinamoorthy and Gupta (1968)
Texture	International/Robinson's pipette method	Piper (1966)
Organic carbon	Chromic acid wet digestion	Walkley and Black (1934)
Available nitrogen	Alkaline permanganate method	Subbiah and Asija (1956)
Available phosphorus	0.5 M NaHCO3, pH 8.5	Olsen *et al.,* (1954)
Available potassium	Flame photometry, neutral N NH4OAc	Stanford and English (1949)
Plant analysis		
Total nitrogen	Micro-Kjeldahl's method	Bremner (1965)
Total phosphorus	Vanadomolybdate yellow colour method	Piper (1966)
Total potassium	Flame photometric method	Piper (1966)

Table.4 Effect of foliar application of humic acid on post-harvest soil nutrient status

Treatment	Organic carbon (g g^{-1})	N status (kg ha^{-1})	P status (kg ha^{-1})	K status (kg ha^{-1})
T0	0.19	66.27	7.62	62.67
T1	0.24	74.67	8.41	86.00
T2	0.28	85.87	8.97	90.00
T3	0.30	80.27	8.87	91.33
T4	0.28	88.67	8.41	88.00
T5	0.26	87.73	9.38	87.00
T6	0.31	85.87	9.43	94.33
T7	0.31	91.47	10.09	99.67
T8	0.30	94.27	10.94	95.00
T9	0.30	93.33	12.32	99.67
T10	0.31	102.67	13.62	104.00
T11	0.41	109.20	16.99	114.00
T12	0.33	103.60	15.71	102.67
T13	0.31	98.93	12.65	99.67
T14	0.37	106.40	14.15	105.67
T15	0.43	112.93	18.39	117.67
T16	0.40	103.60	15.91	111.67
Mean	0.31	93.54	11.73	96.33
SEd	0.06	4.60	0.53	3.22
CD (0.05)	0.12	9.34	1.08	6.55

Table.5 Effect of foliar application of humic acid on nutrient uptake in plant tissue

Treatment	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})
T0	4.28	1.88	10.54
T1	9.73	2.84	13.34
T2	8.36	2.14	13.96
T3	12.18	3.11	12.69
T4	12.94	3.65	16.20
T5	11.57	3.04	16.28
T6	14.48	3.48	17.96
T7	16.06	3.71	19.17
T8	15.61	3.62	20.13
T9	18.76	3.82	22.92
T10	19.57	4.42	23.98
T11	34.92	7.61	35.34
T12	26.82	6.13	31.01
T13	25.61	5.36	28.56
T14	28.91	6.94	33.34
T15	39.92	9.10	37.67
T16	33.16	7.08	34.67
Mean	19.58	4.58	22.81
SEd	2.92	0.72	2.94
CD (0.05)	5.96	1.47	6.00

Table.6 Effect of foliar application of humic acid on nutrient uptake in fruit tissue

Treatment	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})
T0	11.23	3.36	7.97
T1	19.91	5.12	15.43
T2	25.70	7.38	10.57
T3	22.52	7.48	19.49
T4	24.96	7.41	23.74
T5	26.79	7.27	25.54
T6	33.31	10.24	29.03
T7	32.35	9.85	35.85
T8	40.02	11.33	33.14
T9	41.96	11.59	29.53
T10	46.31	11.79	35.56
T11	46.77	16.17	46.44
T12	43.51	14.79	45.53
T13	41.37	13.89	35.97
T14	47.74	16.97	44.63
T15	52.14	17.62	47.13
T16	49.33	16.06	45.99
Mean	35.64	11.08	31.27
SEd	3.74	1.68	5.17
CD (0.05)	7.62	3.43	10.53

The highest N uptake was recorded in T15 (FYM plus 100% RDF along with 0.2% HA) at 39.92 kg ha^{-1}, while T0 (absolute control) recorded the lowest at 4.28 kg ha^{-1}. This trend is consistent with the findings of Rauthan and Schnitzer (1981) in cucumber, Ping *et al.,* (2001) in brassica, and David *et al.,* (1994) and Adani *et al.,* (1998) in tomato. The principal physiological function of humic acid may lie in its ability to reduce oxygen deficiency in plants, resulting in greater nitrogen uptake (Bhuma, 2001; Kandasamy, 2001). The high ion-exchange capacity of humates may improve utilisation of applied nitrogen by making it more available in the root zone (Tenshia, 2003). The ammonium ion is also reported to form covalent compounds with humic acid, maintaining its mobility in solution and aiding increased uptake; the acidic functionality of humic acid may further stimulate nitrate uptake, and humic substances are known to induce the activity of enzymes such as invertase and nitrate reductase, thereby enhancing nitrogen assimilation (Ferretti *et al.,* 1991).

P uptake in plant sample (kg ha^{-1})

Data on phosphorus uptake by plants are presented in Table 5. Significant differences were observed among treatments, with values ranging from 1.88 kg ha^{-1} to 9.10 kg ha^{-1}. The maximum uptake was recorded in T15 (FYM plus 100% RDF along with 0.2% HA) at 9.10 kg ha^{-1}, while T0 (absolute control) recorded the lowest at 1.88 kg ha^{-1}, on par with T2 (FYM with 0.1% HA) at 2.14 kg ha^{-1}. The nutrients present in humic acid may enhance the synthesis of cytokinin and auxin in root tissues, resulting in better mobilisation of assimilates from the source; similar findings were reported by Ken (2000) in onion.

K uptake in plant sample (kg ha^{-1})

Results on potassium uptake in plant samples are presented in Table 5, with values ranging from 10.54 kg ha^{-1} to 37.67 kg ha^{-1}. The highest K uptake was recorded in T15 (FYM plus 100% RDF along with 0.2% HA) at 37.67 kg ha^{-1}, and the lowest in T0 (absolute control) at 10.54 kg ha^{-1}. Potassium, as a protoplasmic factor, is involved in photo- and oxidative phosphorylation, augmenting the energy required for flower growth. The highest potassium content was recorded in plants sprayed with 0.2% humic acid along with the full dose of inorganic fertilizers, consistent with the findings of El-Gizawy *et al.,* (1992) and Adani *et al.,* (1998) in tomato.

Effect of foliar application of humic acid on nutrient uptake in fruit tissue

N uptake in fruit sample (kg ha^{-1})

Nitrogen uptake by okra fruits, as influenced by foliar application of humic acid, is presented in Table 6, with values ranging from 11.23 kg ha^{-1} to 52.14 kg ha^{-1}. T15 (FYM plus 100% RDF along with 0.2% HA) recorded the highest fruit N uptake at 52.14 kg ha^{-1}, while T0 (absolute control) recorded the lowest at 11.23 kg ha^{-1}.

P uptake in fruit sample (kg ha^{-1})

Data on phosphorus uptake by fruits are presented in Table 6, with values ranging from 3.36 kg ha^{-1} to 17.62 kg ha^{-1}. T15 (FYM plus 100% RDF along with 0.2% HA) recorded the highest fruit P uptake at 17.62 kg ha^{-1}, while T0 (absolute control) recorded the lowest at 3.36 kg ha^{-1}.

K uptake in fruit sample (kg ha^{-1})

Data on potassium uptake by fruit samples are presented in Table 6, with values ranging from 7.97 kg ha^{-1} to 47.13 kg ha^{-1}. T15 (FYM plus 100% RDF along with 0.2% HA) recorded the highest fruit K uptake at 47.13 kg ha^{-1}, while T0 (absolute control) recorded the lowest at 7.97 kg ha^{-1}. These results align with the earlier findings of Umamaheswari (2009) in hot pepper, who attributed the highest nutrient uptake to the ease with which foliar-applied humic acid mobilises cell wall permeability; comparable results in okra were reported by Elayaraja *et al.,* (2014).

In conclusion, Chemical analyses of organic carbon and nutrient status in soil, along with nutrient uptake by plant and fruit tissues, revealed that treatment T15 consistently recorded the highest soil organic carbon and N, P and K status, as well as the highest N, P and K uptake in plant and fruit tissues. Application of FYM plus 100% RDF along with 0.2% HA is therefore recommended for maximising yield and nutrient content in the soil, plant and fruit tissues of okra.

Author Contributions

B. Bavithra: Investigation, formal analysis, writing—original draft. A. Shanthi: Validation, methodology, writing—reviewing. V. Sundaram:—Formal analysis, writing—review and editing. L. Aruna: Investigation, writing—reviewing. J. Jyothsna: Resources, investigation writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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