

Enhancing Productivity and Nutrient Use Efficiency of Tomato by Humic Acid Based Multinutrient Complex Fertilizers

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Abstract An investigation was carried out to study whether humic acid (HA) multinutrient complex liquid fertilizers such as Groflow 45H commercial™ (a liquid HA- NPK complex) and HA-NPK complex (produced in the laboratory) affect yield and nutrient uptake of tomato. There were 10 treatments with three replications was maintained. The treatments include 200 L, 150 L and 100 L Groflow 45H (T_1 – T_3) and HA-NPK complex (T_4 – T_6) per hectare, respectively; inorganic chemical fertilizers (100% recommended dose

of fertilizer, RDF, T_7); HA (2.5 kg ha^{-1} , T_8); combined application of chemical fertilizers and HA (T_9 , i.e. $T_7 + T_8$); and control (no fertilizers, T_{10}). Results indicated that Groflow 45H (200 L ha^{-1}) application showed the highest tomato yield (33.7 t ha^{-1}) followed by chemical fertilizer (100% RDF) plus HA (2.5 kg ha^{-1}) (32.4 t ha^{-1}), HA-NPK complex (200 L ha^{-1}) (31.8 t ha^{-1}) and chemical fertilizer (100% RDF) (31.3 t ha^{-1}). Further HA based fertilizers (HA-NPK complex and Groflow 45H at 200 L ha^{-1}) improved the N, P and K use efficiencies of tomato in the extent of 9.8% and 19.1%; 6.3% and 12.2%; and 10.1% and 21.8%, respectively higher than the chemical fertilizers. Groflow 45H applied at 150 L ha^{-1} were also performed equally as of chemical fertilizers. In view of the better nutrition and higher productivity imparted by the HA based fertilizer, particularly Groflow 45H, could be a suitable organic-mineral fertilizer for sustainable tomato production.

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Introduction

Tomato is one of the most important widely grown vegetables in the world. It is cultivated in almost all parts of India during all the seasons and is adapted to wide range of soil and climatic conditions. It is a cash crop and acts as main raw materials for many food

Table 1. Initial soil properties of experimental field used to investigate the effect of humic acid multinutrient fertilizers on growth and nutrient use efficiency of tomato. EC, electrical conductivity, TOC, total organic carbon.

Soil parameters	Values
pH (soil: water 1:2.5)	7.62
EC (soil: water 1:2.5) (dS m ⁻¹)	0.31
Mechanical analysis	
Sand (%)	69.4
Silt (%)	13.7
Clay (%)	16.9
Textural class	Sandy loam
TOC (g kg ⁻¹)	8.1
Available nitrogen (kg ha ⁻¹)	178
Available phosphorus (kg ha ⁻¹)	14.2
Available potassium (kg ha ⁻¹)	281
Soil subgroup	Typic Haplustept
Soil series	Meharauli Series

Table 2. Basic properties and nutrient composition of HA based fertilizer used in the study.

Product/Property	Groflow 45H	Supa humus 26
Appearance	Black Liquid	Black Liquid
Boiling point	>100°C	>100°C
pH	7.5–8.5	9.5–12.0
Specific gravity	1.39–1.41	1.05–1.15
Solubility in water	Soluble	Soluble
Ingredient/Source	Potassium phosphate, urea and potassium humate	Potassium humate
Composition	14% N, 15% P, 11% K and 1.2% humus (w/v)	7% K and 18% humus (w/v)

processing industries. The average productivity of tomato in India has increased from 14.7 t ha⁻¹ in 1991–92 to 21.2 t ha⁻¹ in 2013–14 [1]. The increase in productivity of tomato has been attributed to introduction of high yielding nutrient response varieties, higher use of chemical fertilizers and adoption of advanced crop management practices. Among these factors, chemical fertilizer is majorly contributed in increasing tomato production. But the major problems associated with the conventional chemical fertilizers are low use efficiencies. For instances nutrient use efficiency by crops hardly exceeds 58% for N, 30% for P, 60% for K and less than 10% for micronutrients [2–4]. This is resulted in loss of costly chemical fertilizer nutrients which otherwise are potential to pollute the soil, water bodies (surface as well as ground water) and atmosphere.

Humic substances are major components of organic matter, often constituting 60 to 70% of the total organic matter. These are produced from a humification process that involves microbial and chemical transformation of organic debris. These organic compounds have the capability of increasing N, P, K, Ca, Mg and Na availability in soil by producing soil organic carbon (SOC), forming organophosphate complexes, increasing cation exchange capacity (CEC), act as anion replacement of H₂PO₄⁻ as well as coating

materials for Fe/Al oxides [5]. These mechanisms of humic acids (HAs) increase nutrient availability and reduce the nutrient loss from the soil. However Indian soils are very low in organic matter. Hence it is generally recommended organic amendments to soil for crop production. Unavailability and low nutrient content of organic resources drive us to modify the existing fertilizer management practices. Many workers across the world have attempted to modify the existing fertilizers for enhancing nutrient use efficiencies. Several modified fertilizers have been developed and some of them were found to be promising [6]. As the modification is cost intensive, the modified fertilizers sometimes were not economically attractive. Therefore, we should look for naturally occurring materials, the employment of which can make the modified fertilizers as economically viable, ecologically sustainable and socially acceptable product.

In this context HA multinutrient complex fertilizers can be promising as these are reported to enhance uptake and utilization of nutrients [7–9], crop quality and soil properties [10]. The HA based fertilizers have enhanced the uptake and utilization of N, P and K by plants compared to inorganic fertilizers in grape [7] and in potato [11]. Komix (an organic HA liquid fertilizer) [8, 12] and Opal HA-202 liquid fertilizer (HA, sodium humate, N, P, K, Ca, Mg, S, Fe and microele-

Table 3. Effect of humic acid based multinutrient fertilizers on fruit yield and dry biomass yield of tomato. Mean values in a given column followed by same letters are not statistically different at $p \leq 0.05$.

Treatments	Tomato	
	Fruit yield (t ha ⁻¹)	Dry biomass yield (t ha ⁻¹)
T ₁ -Groflow 45H (200 l/ha)	33.7 ^a	2.62 ^a
T ₂ -Groflow 45H (150 l/ha)	31.4 ^b	2.32 ^b
T ₃ -Groflow 45H (100 l/ha)	29.2 ^c	1.87 ^d
T ₄ -HA-NPK (200 l/ha)	31.8 ^b	2.44 ^b
T ₅ -HA-NPK (150 l/ha)	29.5 ^c	2.15 ^c
T ₆ -HA-NPK (100 l/ha)	27.6 ^d	1.78 ^{dc}
T ₇ -Chemical fertilizers (100% RD)	31.3 ^b	2.40 ^b
T ₈ -HA (2.5 kg/ha)	25.7 ^c	1.65 ^c
T ₉ -Chem Fert (100% ED)+HA (2.5 kg/ha)	32.4 ^{ab}	2.44 ^b
T ₁₀ -Control	22.7 ^f	1.28 ^f
CD ($p \leq 0.05$)	1.4	0.13

ments) [13] are increased the yield and quality of soybean and pear, respectively. Also it is reported that HA-NPK-Zn compound fertilizer is the best among the fertilizers tested for physiological and composition effects. HA-NPK-Zn complex fertilizers reduce the nitrate nitrogen content and effectively enhanced the fresh weight, superoxide dismutase, peroxidase activities [14].

The chemical fertilizers are one of the costly inputs in agriculture and it is ironical that the nutrient use efficiencies of the conventional chemical fertilizers are very low. The rest of the applied fertilizers are lost causing pollution to soil, water and atmosphere continuum. Therefore, the development of nutrient efficient fertilizers is the need of the hour. In this direction the controlled release liquid fertilizer complexes with organic sources e.g., HA may provide solution to the above issues. The additional advantages using organic source lie on the improvement of soil physical, chemical and biological properties. There information on the effects of humic acid multinutrient complex fertilizer on yield, quality and nutrient use efficiency of crop plants is lacking. Therefore, generation of scientific data on these complex fertilizers is very essential. Therefore, in this investigation, it is aimed to study whether HA multinutrient complex fertilizers influence yield, nutrient content, nutrient up-

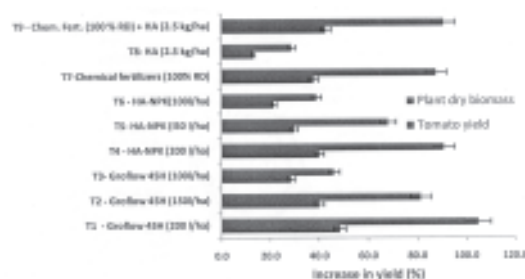


Fig. 1. Percent increase in tomato yield and dry matter yield due to various fertilizer treatments over control.

take and nutrient use efficiency of tomato that grown on an old alluvial sandy loam soil.

Materials and Methods

Experimental site

The field experiment was carried out to examine the effects of HA multinutrient fertilizers on tomato yield and nutrient use efficiency. The experimental trial was performed at New Delhi, India (Latitude: 28°38'23" N, Longitude: 77°09'27" E) on a site with sandy loam old alluvial soil (Inceptisol). The study area falls under semi-arid and sub-tropical climate zone characterized by hot summer and cold winter. Mean annual precipitation was about 650 mm, most of which received during July to September. The average maximum temperature was 35°C and minimum temperature was 4°C. The soil properties prior to the trial are listed in Table 1. The soil belongs to Mehrauli Series of Indo-Gangetic plains with medium fertility category.

Materials used and their properties

The HA multinutrient liquid fertilizer, Groflow 45H and HA as potassium humate (Supa Humus 26) were supplied by Agrichem, Australia and imported to India from Australia. The basic properties and nutrient composition of these products were listed in Table 2. Also by trial and error method adjusting temperature (40°C, 50°C, 60°C, 70°C and 100°C), pH (3, 4, 5, 6, 7, 8 and 9)

and incubation period (1 week and 2 week for aging) HA-NPK complex fertilizers were prepared in the laboratory using Supa Humus 26 as HA source; NH_4Cl as N source and KH_2PO_4 as P and K sources. The nutrient composition of this material was adjusted as of Groflow 45H. After aging dialysis was done and nutrients passed through dialysis bag into the solutions was analyzed to know the amount of nutrients complex with HA. The maximum complexation of nutrients with HA was observed in the treatment combination of temperature 40°C , pH 5 and 2 weeks of aging. Thus prepared material was used in this study to compare its efficacy with that of Groflow 45H.

Experimental design and agronomic management

The randomized block design with three blocks was used. Individual plots were 5 m long and 3 m wide. Seedlings of the tomato cultivar *Pusa Seetal* were transplanted in rows of 90 cm wide and plants within rows spaced 60 cm apart. Treatments consisted of application of 200, 150, 100 L ha^{-1} Groflow 45H (T_1 – T_3) and HA-NPK complex, respectively; chemical fertilizer (100% RDF) (T_7) alone; humic acid 2.5 kg ha^{-1} alone (Supa humus 26, T_8); chemical fertilizers + HA (T_9); and absolute control (without fertilizers, T_{10}). The recommended dose of fertilizer for tomato is 150, 60 and 60 $\text{kg N, P}_2\text{O}_5$ and $\text{K}_2\text{O ha}^{-1}$, respectively. Fertilizer applications were scheduled accordingly to meet the physiological demand of the crops i.e. in four equal split at initial, 30, 60 and 90 days after transplanting (DAT). All the fertilizers used in the study were completely water soluble and were sprayed in soil using pedal operated sprayer. The first irrigation was given after transplanting and followed by 6 irrigations were given at 15 days interval. In order to control weeds, Pendimethylene 30 (0.75 kg ha^{-1}) was applied 3 DAT and one hand weeding at 60 DAT. Tomato fruits were harvested by 3 pickings at 5 days interval and the first picking was done 130 DAT and economic yield was measured in each picking. Plants were uprooted after 145 DAT.

Plant sampling and laboratory analysis

The plant samples were collected from each plot and

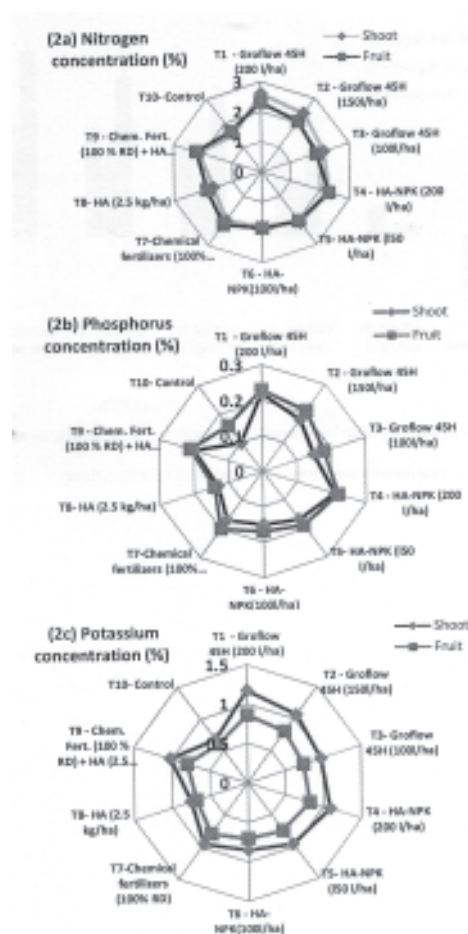


Fig. 2. Nutrients concentration in tomato fruits and shoots as influenced by various fertilizer treatments: (2a) N concentration; (2b) P concentration; (2c) K concentration.

washed by distilled water to remove the dust and air dried. To get a plant dry biomass plants were dried at 60°C in an oven. Then dry biomass were ground, passed through 2 mm sieve and stored for laboratory analysis. N in plant sample was measured following Kjeldahl digestion and distillation method. Plant samples were digested with tri-acid mixture ($10:1:4:: \text{HNO}_3: \text{H}_2\text{SO}_4: \text{HClO}_4$) and the content was extracted with 6 M HCl for P and K analysis [15]. Phosphorus in plant samples were estimated by yellow color method

Table 4. Effect of humic acid based multinutrient fertilizers on uptake of nitrogen (N), phosphorus (P) and potassium (K) by tomato. Mean values in a given column followed by same letters are not statistically different at $p \leq 0.05$.

Treatments	N uptake (kg ha ⁻¹)			P uptake (kg ha ⁻¹)			K uptake (kg ha ⁻¹)		
	Shoot	Fruit	Total	Shoot	Fruit	Total	Shoot	Fruit	Total
T ₁ -Groflow 45H (200 l/ha)	67.9 ^a	85.1 ^a	153 ^a	5.71 ^a	8.79 ^a	14.6 ^a	30.6 ^a	31.9 ^a	62.5 ^a
T ₂ -Groflow 45H (150 l/ha)	55.0 ^{ba}	67.0 ^c	122 ^d	4.25 ^c	6.95 ^d	11.2 ^d	24.5 ^c	26.3 ^c	50.8 ^d
T ₃ -Groflow 45H (100 l/ha)	40.0 ^f	59.8 ^d	99.8 ^f	2.86 ^c	5.62 ^c	8.48 ^f	18.1 ^f	23.5 ^d	41.6 ^f
T ₄ -HA-NPK (200 l/ha)	56.3 ^b	83.7 ^a	140 ^b	5.04 ^b	7.96 ^b	13.0 ^b	26.6 ^b	29.8 ^b	56.4 ^b
T ₅ -HA-NPK (150 l/ha)	45.0 ^c	65.0 ^c	110 ^c	3.64 ^d	5.92 ^c	9.56 ^c	20.6 ^c	24.0 ^d	44.6 ^c
T ₆ -HA-NPK (100 l/ha)	32.4 ^g	54.6 ^c	87.0 ^d	2.61 ^c	4.95 ^f	7.56 ^g	15.0 ^g	20.8 ^c	35.8 ^g
T ₇ -Chemical fertilizers	47.8 ^d	77.2 ^b	125 ^d	4.08 ^c	7.26 ^{cd}	11.3 ^d	22.7 ^d	28.4 ^b	51.1 ^d
T ₈ -HA (2.5 kg/ha)	27.2 ^h	51.5 ^c	78.7 ^h	2.14 ^f	3.97 ^g	6.11 ^h	12.3 ^h	18.6 ^f	30.9 ^h
T ₉ -Chem Fert + HA	52.4 ^c	81.6 ^{ab}	134 ^c	4.79 ^b	7.61 ^{bc}	12.4 ^c	24.7 ^c	29.0 ^b	54.3 ^c
T ₁₀ -Control	19.3 ^f	37.7 ^f	57.0 ⁱ	1.29 ^g	2.61 ^h	3.90 ⁱ	8.7 ⁱ	13.7 ^g	22.4 ⁱ
CD ($p \leq 0.05$)	2.8	4.4	4.6	0.43	0.45	0.59	1.2	1.7	1.9

using spectrophotometer and K by flame photometer.

Nutrient uptake and nutrient use efficiency (NUE) were determined by using the following equations (1) and (2), respectively;

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%)} \times \text{Dry weight (kg ha}^{-1}\text{)}}{100} \text{.....Eq. (1)}$$

$$\text{NUE (\%)} = \frac{[\text{Uptake in treatment (kg ha}^{-1}\text{)} - \text{Uptake in control (kg ha}^{-1}\text{)}]}{\text{Amount of nutrients applied (kg ha}^{-1}\text{)}} \times 100 \text{.....Eq. (2)}$$

Statistics

Data were assessed by analysis of variance (ANOVA) using the software SAS 9.1.3. Duncan's multiple range critical difference tests were used to identify differences between treatment means. The level of significance used was $p \leq 0.05$.

Results and Discussion

Dry biomass and tomato yield

The effect of different kinds of fertilizers, at various

dosage levels, on plant dry biomass and tomato fruit yield is presented in Table 3. The highest dry biomass/matter yield (DMY) was observed in the Groflow 45H (200 L ha⁻¹) treated plot (2.62 t ha⁻¹) which was significantly differ from all the other treatments in the study. There was no significant different among Groflow 45H (at 150 L ha⁻¹), HA-NPK (200 l ha⁻¹), chemical fertilizers (100% RDF) alone and in combination with HA (2.5 kg ha⁻¹) applied plots in case of DMY was concern. Nevertheless further reducing the dose of Groflow 45H to 100 L ha⁻¹ and HA-NPK (150 and 100 L ha⁻¹) and also application of HA (2.5 kg ha⁻¹) alone significantly over-performed the control (1.28 t ha⁻¹) and underperformed the chemical fertilizers (100% RDF) in respect to DMY.

The application of Groflow 45H (200 L ha⁻¹) fetched the highest tomato fruit yield of 33.7 t ha⁻¹ and it was significantly higher than the tomato fruit yield obtained under chemical (31.3 t ha⁻¹) and HA-NPK complex (31.8 t ha⁻¹) fertilizers at their higher dose (Table 3). The gain in tomato fruit yield under Groflow 45H (200 L ha⁻¹) was 48.5% over the control and 10.6% over the chemical fertilizers alone (Fig. 1). All the treatments even HA alone (25.7 t ha⁻¹) showed significantly higher tomato fruit yield when compared to the control (22.7 t ha⁻¹). While the tomato yield under the HA-NPK complex fertilizer (prepared in the laboratory) treated plants did not attain the yield levels of the Groflow 45H treated plants (Table 3). The treatments HA-NPK complex (200 L ha⁻¹), Groflow 45H

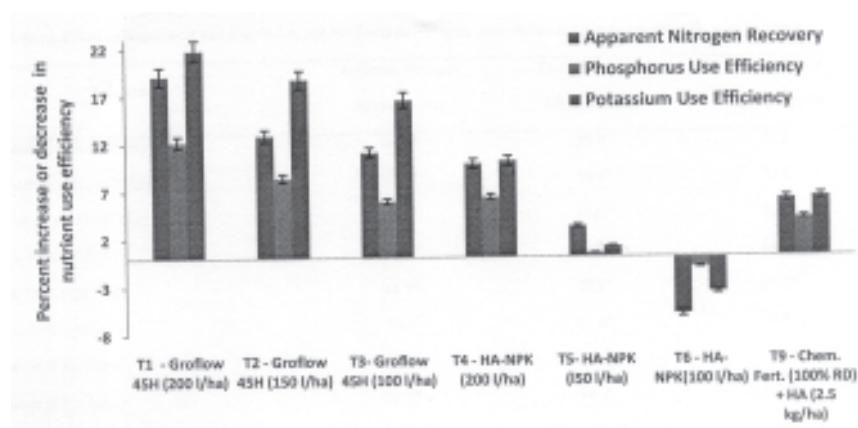


Fig. 3. Percent increase or decrease in nutrient use efficiency of tomato under different humic acid based multinutrient fertilizers over inorganic fertilizers.

(150 L ha⁻¹) and chemical fertilizer did not significantly differ with each other in tomato fruit yield was concern.

Application of HA multinutrient fertilizer the Groflow 45H increased the economic and dry matter yield of tomato when compared to chemical fertilizer alone or combined application of NPK with HA. The application of Groflow 45H at 200 L ha⁻¹ had increased tomato fruit and DM yield to the extract of 48.5% and 2% over the control (unfertilized plants); 10.6% and 17.2% over inorganic chemical fertilizers; 5.8% and 14.1% over chemical fertilizer plus HA, respectively (Fig. 1). The beneficial effect of humic acid based fertilizer on yield and crop growth were also reported in grape [7], apple [8], potato [11] and soybean [12]. The complex fertilizer may slowly release the nutrients and thus reduced the nutrient loss through leaching and thereby increased the availability of nutrient to plants leading higher plant growth and productivity. Though the HA-NPK complex had similar nutritional composition as of Groflow 45H, did not perform at par with it. This might be due to differences in the type and degree of complexation, raw material used, technology adopted and method of preparation of the above two products. Further HA application alone enhanced tomato yield over the control. The humic acids strengthen the root growth and enhance the nutrient

and water uptake and also protect the plant from biotic and abiotic stresses [12]. Apart from these direct effects of HA on plants, the HA mediated improvement in physical, biological and chemical properties of soil could create favorable conditions for plant development and explain the enhanced growth observed. For instance, improving crop yield could be related to improvement of soil physical properties like soil aggregation due to HA [16, 17].

Nutrient content and uptake

The maximum N content was found in Groflow 45H (200 L ha⁻¹) applied tomato plant shoots (2.6%) and fruits (2.31%), which are significantly differ from the other treatments (Fig. 2a). Even Groflow 45H at 150 L ha⁻¹ and the HA-NPK complex at 200 l ha⁻¹ applied plants have showed significantly high N content than the chemical fertilizers (100% RDF) applied plants. Further reducing dosage of Groflow 45H to 100 L ha⁻¹ and HA-NPK complex to 150 and 100 L ha⁻¹ showed lower N content than that of chemical fertilizers (100% RDF). Application of HA alone was also increased the N content from 1.51 to 1.65% in the shoots and from 1.67 to 1.87% in fruits (Fig. 2a). The P content of tomato shoot and fruits were the highest in Groflow 45H (200 L ha⁻¹) treated plants followed by HA-NPK

complex (200 L ha⁻¹), chemical fertilizer (100% RDF) plus HA, Groflow 45H (150 L ha⁻¹) and chemical fertilizer (100% RDF) respectively and they are significantly differed from each other. Even application of HA alone increases the P content in plants and fruits when compared to the control treatment (Fig. 2b). The Groflow 45H (200 L ha⁻¹) applied plants are show the highest K content in their shoots and fruits and the K content of tomato shoot and fruits were 1.17% and 0.86%, respectively. Groflow 45H (150 L ha⁻¹), HA-NPK (200 L ha⁻¹), chemical fertilizer (100% RD) plus HA and chemical fertilizer (100% RD) treated plants are falling in the order of having higher K content in their shoots and fruits after Groflow 45H (200 L ha⁻¹) applied plants (Fig. 2c).

The heighest nitrogen uptake was recorded in Groflow 45H (200 L ha⁻¹) treated tomato (153 kg N ha⁻¹) which is significantly differed from other treatments. The order of N uptake for other treatments is HA-NPK (200 L ha⁻¹), chemical fertilizer (100% RDF) plus HA, Groflow 45H (150 L ha⁻¹) and chemical fertilizer (100% RDF) (Table 4). The nitrogen uptake in the control plot is 57 kg ha⁻¹ and in the HA alone applied plot is 78.7 57 kg ha⁻¹. Groflow 45H (150 L ha⁻¹) treatment is performed as equally as of chemical fertilizer (100% RDF) and there was no significant difference observed between them. The Groflow 45H (200 L ha⁻¹) treated tomato show the highest P uptake of 14.6 kg P ha⁻¹ followed by HA-NPK (200 L ha⁻¹), chemical fertilizer (100% RD) plus HA, Groflow 45H (150 L ha⁻¹) and chemical fertilizer (100% RDF) respectively (Table 4). The former was significantly differed from other treatments. The HA alone applied plants was also showed higher P uptake than the control plants. In case of K also the Groflow 45H (200 L ha⁻¹) applied plants are taken up the highest K (62.5 kg K ha⁻¹) this was significantly differed from other treatments. There were no significant difference observed among HA-NPK (200 L ha⁻¹), chemical fertilizer (100% RDF) plus HA, Groflow 45H (150 L ha⁻¹) and chemical fertilizer (100% RDF). The applied alone also improved the K uptake of the crops over the control (Table 4).

The current investigation revealed that the Groflow 45H application significantly increased N, P and K content and uptake of tomato fruit and shoots when compared to inorganic fertilizers. The results is in consistence with the observation made by others

in grapes and rape [7, 14]. The capacity of humic substances to form complexes permits sequestration of nutrients (Zn, Cu, Fe for example) by formation of metal-humic complexes, thus protecting them from leaching and making them more available for plant uptake [18, 19]. The other indirect effect of humic substances is mainly related to the enhanced nutrient uptake through increased soil cation exchange capacity to check leaching of nutrients especially K, Ca, or NH₄⁺. These mechanisms are primarily responsible for better nutrition leading to improvements in nutrient concentrations of tomato fruits and foliage tissues. It was also reported that the application of humic substances increased macro- and micro- nutrients concentration in plants as well as increased concentration of these nutrients in soil after harvesting [20]. Authors showed that HA application to soil could enhance aggregate stability [21, 22], thus reduces soil erosion and C and N leaching [23, 24]. Humic acid in the fertilizers increased the nutrient availability and the physiological and nutrient composition effects that resulted in higher utilization and accumulation of nutrients in the plants [7]. The plants take more mineral elements due to better developed root systems. The HA based multinutrient fertilizer enhanced uptake and utilization of N, P and K by plants compared to inorganic fertilizers. This was corroborated by the finding of Du et al. [7]. This might be due to higher dry matter yield and nutrient content in the plants treated with Groflow 45H.

Nutrient use efficiency

Apparent nitrogen recovery (ANR) of the conventional chemical fertilizers at 100% RDF was 45.7% for tomato (Table 5). The Groflow 45H (200 L ha⁻¹) treated tomato plants has ANR of 64.8% which was 19.1% higher than the conventional chemical fertilizer (Fig. 3). When chemical fertilizers (100% RDF) are mixed with HA, the ANR was increased from 45.7% to 51.7% for tomato. However this treatment was not significantly different from the Groflow 45H (150 L ha⁻¹) treated plants (Fig. 3). Phosphorus use efficiency (PUE) of Groflow 45H (200 L ha⁻¹) treated tomato plants is 39.9%, which is significantly higher than all other treatments in the study (Table 5). When compared to chemical fertilizers, Groflow 45H (200 L ha⁻¹) showed 12.2% higher PUE (Fig. 3). Also Groflow 45H

Table 5. Effect of humic acid based multinutrient fertilizers on nitrogen, phosphorus and potassium use efficiency by tomato. Mean values in a given column followed by same letters are not statistically different at $p \leq 0.05$.

Treatments	Apparent nitrogen recovery (%)	Phosphorus use efficiency (%)	Potassium use efficiency (%)
T ₁ -Groflow 45H (200 l/ha)	64.8 ^a	39.9 ^a	76.3 ^a
T ₂ -Groflow 45H (150 l/ha)	58.5 ^b	36.1 ^b	73.2 ^a
T ₃ -Groflow 45H (100 l/ha)	56.7 ^b	33.6 ^{bc}	71.0 ^a
T ₄ -HA-NPK (200 l/ha)	55.5 ^{bc}	34.0 ^{bc}	64.6 ^b
T ₅ -HA-NPK (150 l/ha)	48.9 ^{bc}	28.1 ^d	55.6 ^{cd}
T ₆ -HA-NPK (100 l/ha)	39.7 ^f	26.6 ^d	50.8 ^d
T ₇ -Chemical fertilizers	45.7 ^c	27.7 ^d	54.5 ^d
T ₉ -Chem. Fert. + HA	51.7 ^{cd}	31.7 ^c	60.7 ^{bc}
CD ($p \leq 0.05$)	4.7	3.0	5.5

(150 L ha⁻¹) applied plants are performed better than the chemical fertilizers (100% RDF) and as equally as of chemical fertilizers mixed with HA. The HA-NPK (200 L ha⁻¹) was observed to be performing as that of chemical fertilizers alone and mixed with HA in case of PUE was concern. The Groflow 45H (200 L ha⁻¹) applied plants has the highest potassium (K) use efficiency (KUE) 76.3% (Table 5) which was 21.9% higher than chemical fertilizer (Fig. 3). Even Groflow 45H at 150 L ha⁻¹ performed well over chemical fertilizers alone or mixed with humic acids in respect to KUE. The HA-NPK (200 L ha⁻¹) had performed at par with the later as KUE is regarding.

The N, P and K use efficiencies of tomato were increased significantly due to the application of HA multinutrient fertilizer, Groflow 45H as compared to the conventional chemical fertilizers. The result was in consistence with the observation of others in grapes and rape [7, 14]. The HA component of the fertilizer slowly released the nutrients thereby regulating the transport and availability of nutrients in the critical growth stages of the crops for better nutrient absorption and assimilation. As the HA complexes with nutrient elements like N, P and K in the tested HA based fertilizer might have reduced the losses of nutrients thereby increased the fertilizers use efficiency by crops [25]. Humic substances when applied externally might interact with P in soil and could reduce P fixation thus increased P availability to plants

[9]. More specifically, HA likely increased P availability and uptake by inhibiting calcium phosphate precipitation rate, forming phospho-humates, competing for adsorption sites and decreasing the number of adsorption sites by promoting dissolution of metal solid phases via chelation [26]. In support of this, Delgado et al. [27] reported that the utilization efficiency of P fertilizer as mono ammonium phosphate (NH₄H₂PO₄) was increased due to application of commercial HA and fulvic acid compounds. The HA may indirectly influence N and P supply to plants through promoting growth and activity of N mineralizing and P solubilizing organisms in soils [28]. The HA present in the fertilizer might have reduced the K leaching and released fixed soil K, make it available to plants [29]. Though this study had given a gross idea of nutrient use efficiency of HA fertilizers, it could be tagged and studied using isotopic dilution technique to calculate the actual nutrients recovered from fertilizers. Also there is a potential and scope for further improving the HA-NPK complex fertilizer to obtain better NUEs.

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