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Nutrient uptake and yield of rice (*Oryza sativa* L.) as influenced by coal-derived potassium humate and chemical fertilizers

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ABSTRACT

An experiment was conducted for two consecutive years to investigate the influence of potassium humate and chemical fertilizers on yield and nutrient uptake of rice. Potassium humate was applied at the rate of 0 (PH_0), 5 (PH_5) and 10 (PH_{10}) mg kg^{-1} soil along with 75 and 100% recommended dose of nitrogen, phosphorous and potassium (NPK). Two doses of zinc, 0 (Zn_0) and 12.5 ($Zn_{12.5}$) mg kg^{-1} were also applied in the form of zinc sulphate. The above treatments were arranged in a Factorial Complete Randomized Design (FCRD) with three replications. Two years experimental results showed that sole and combined application of 10 mg kg^{-1} potassium humate along with 100% NPK and 12.5 mg kg^{-1} zinc sulphate was significantly superior in increasing the yield and nutrient uptake by rice over 75 and 100% of NPK alone.Application of 10 mg kg^{-1} potassium humate along with 100% NPK and 12.5 mg kg^{-1} zinc sulphate recorded highest N, P, K, S and Zn uptake by straw and grain of rice. Thus integrated use of humic acid along with chemical fertilizers is beneficial for increasing productivity and soil health.

Key words: *Potassium humate, chemical fertilizers, rice, yield and nutrient uptake*

INTRODUCTION

India is the second largest producer of rice after China. It plays a major role in India's diet and is central to food security. Due to imbalance use of chemical fertilizers and removal of nutrients from the soil by intensive cropping, majority of the Indian soils have become deficient in nutrients. This has led to sharp decline not only in the crop yield but also in soil organic carbon content (Nayak et al., 2012) which is key to good soil health and sustainability. Potassium humate is concentrated form of humus in the naturally occurring Lignite which is the brown coal that accompanies coal deposits. Ihsanullah & Bakhashwain, 2013 and Kumar et al., 2013 have reported the stimulatory effects of humic substances on plant growth. Addition of humic acid promotes hormonal activity, microbial growth, water holding capacity (WHC), nutrient availability soil organic matter mineralization (Jones et al., 2007) which is the central reason for increased growth and yield response of rice.

Apart from adoption of modern scientific cropping sequences (Roy et al., 2011; Kumar et al., 2016) for sustainable agriculture, a soil management approach should be based on maintaining soil quality, which is only possible by utilization of higher carbon containing organic amendments along with inorganic fertilizers. Relatively poor productivity of rice in India is also linked with low organic carbon content of rice growing soils. Still very little research work has been done in the direction of utilization of coal derived humic acid by cereals crops. Therefore, present study was conducted to investigate the effect of potassium humate and chemical fertilizers on yield and nutrient uptake by rice.

MATERIAL AND METHOD

Pot experiment was conducted in the net house of the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India, during *Kharif* 2009 and 2010. Varanasi is located between 25.14^0 and 25.23^0 N latitude and 82.56^0 and 83.03^0 E longitude and falls in a semi-arid to sub humid climate. The bulk surface soil (0-15 cm) was collected from the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. Potassium humate used for experimentation was obtained from Gangeya Agro India Ltd. Lucknow. Product was manufactured by PranavBio.Tech, Mumbai, India. It contained 70% humic acid, 49.5 % total carbon and 10% potassium with 95% solubility.The soil sample was air-dried under shade and crushed with a wooden roller and passed through sieve having openings of 2 mm diameter, 8 kg of soil was filled in each polythene lined pot. Soil in each pot was puddled manually and 5 seedlings of rice(variety -Malviya 36) were transplanted. After establishment, four hills were maintained. The soil was an alluvial representing an Inceptisol (Typic Ustochrept). The soil had sandy loam texture, 7.9 pH, 0.211 dS/m EC, 4.3 g organic carbon, 185 kg ha^{-1} available N, 17.25 kg ha^{-1} P and 198.85 kg ha^{-1} exchangeable K. The experiment was arranged in factorial completely randomized design with three replications. Potassium humate (PH) was applied in soil at the rate of 0.0, 5.0 and 10.0 mg kg^{-1} soil along with 100% and 75% recommended doses of fertilizers NPK (60, 30, 30 mg kg^{-1}) and 12.5 mg kg^{-1} zinc sulphate was also used. The treatments tested were as follows:- (i) $NPK_{75\%}+ PH_0+Zn_0$ (T_1), (ii) $NPK_{75\%}+ PH_0Zn_{12.5}$ (T_2), (iii)$NPK_{75\%}+ PH_5+ Zn_0$ (T_3), (iv) $NPK_{75\%}+ PH_5+ Zn_{12.5}$ (T_4), (v) $NPK_{75\%} + PH_{10} + Zn_0$ (T_5), (vi) $NPK_{75\%} + PH_{10} + Zn_{12.5}$ (T_6), (vii) $NPK_{100\%} + PH_0 + Zn_0$ (T_7), (viii) $NPK_{100\%} + PH_0 + Zn_{12.5}$ (T_8), (ix) $NPK_{100\%} + PH_5 + Zn_0$ (T_9), (x) $NPK_{100\%} + PH_5 + Zn_{12.5}$ (T_{10}), (xi) $NPK_{100\%} + PH_{10} + Zn_0$ (T_{11}), (xii) $NPK_{100\%} + PH_{10} + Zn_{12.5}$ (T_{12}). The pots were irrigated and 2 cm of standing water was maintained by daily addition of water. At physiological maturity plant samples from each plot were harvested manually and separated into straw and panicles. The dry weight of straw was determined after oven drying at 65°C to constant weight. Panicles were hand-threshed and the filled spikelets were separated from unfilled spikelets with a blower. All unfilled spikelets were counted to determine the number of unfilled spikelets. Grain yield was determined from each plot and adjusted to the standard moisture content of 0.14 g H_2O g^{-1} fresh weight (Kumar et al., 2016, 2017).

Plant analysis

Plant samples were harvested at maturity. The representative grain and straw samples were dried in an oven at 65°C till a constant weight was attained. Dried plant samples were ground by a grinding machine for tissue analysis. Then the ground samples were passed through a 20-mesh sieve and stored in paper bags and finally they were kept in desiccators. Total P were determined by the Vanadomolybdate method, K by flame photometry, total N was analyzed using micro-kjeldahl, S by turbidity method and Zn by using atomic absorption spectrophotometer (Unicam Atomic Absorption Ltd., York street Cambridge), following the procedure outlined in Sparks (1996). Nutrient (N, P, K, S and Zn) uptake in grain and straw of rice were calculated by multiplying dry weight of the respective plant part by the nutrient concentration within the respective plant part.

Statistical analysis

The data were subjected to one-way analysis of variance (ANOVA) using SPSS version 16 software. Duncan's multiple range test (DMRT) was performed to test the significance of difference between the treatments.

RESULT AND DISSCUSION

Effect on rice grain yield

Two year replicated applications of different rates of potassium humate and chemical fertilizers on rice grain yield are shown in (Fig. 1). The highest mean grain yield was obtained from the treatment T_{12} (48.35 g pot^{-1}) followed by T_6 (45.35 g pot^{-1}), which was also significantly higher than T_7 (35.56 g pot^{-1}) and T_1 (29.32 g pot^{-1}). The changes in grain yield values of other pots under combined treatments of potassium humate and chemical fertilizers along with zinc sulphate were also statistically significant. Similar to the first year, the highest value was obtained under the treatment of T_{12} followed by T_6 and the effects of combined treatments of potassium humate with chemical fertilizers on grain

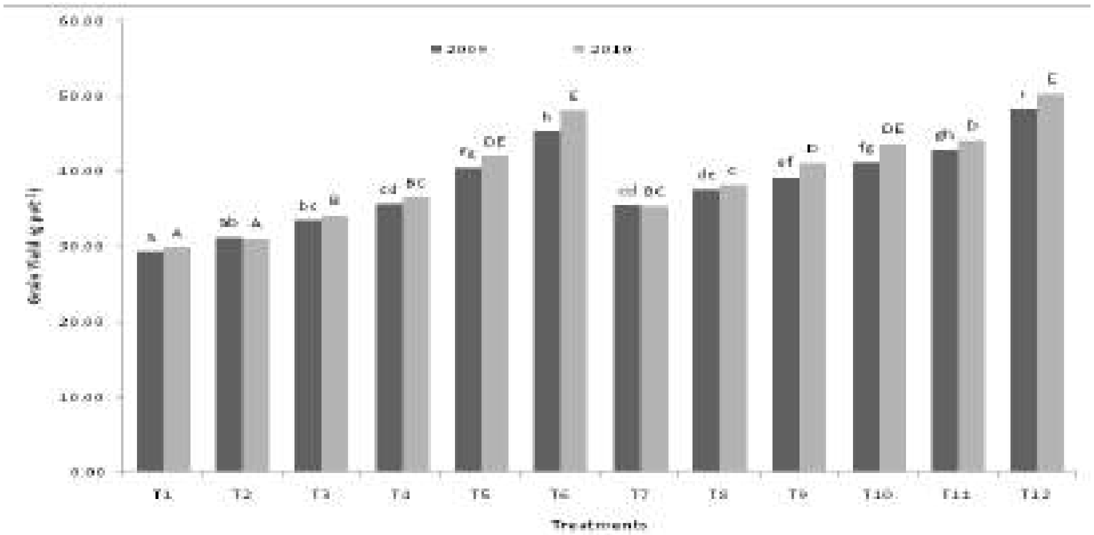

Fig.1. Effect of potassium humate and chemical fertilizers grain yield of rice. Values followed by different letters in a column show significant difference at $p < 0.05$ by Duncan Multi Range Test.

yield were more apparent and gave higher values than treatment $NPK_{75\%}$ (T_1) and $NPK_{100\%}$ (T_7) alone Fig. 1. Highest grain yield after addition of potassium humate in present study reveal that humic acid enhanced the availability of the plant nutrients and improved yield components and yield of rice crop. Khan and Mir (2002) stated that humic acids derived from Pakistani lignite had a beneficial effect on the growth and yield of wheat. Ibrahim and Ramadan (2015) reported that application of Potassium-humate combined with fertilizers to common bean increased yield by 25-35%.

Nitrogen uptake

Application of potassium humate along with inorganic fertilizers significantly affected the nitrogen uptake by grain and straw of rice. The highest nitrogen uptake by rice straw (0.66 and 0.86 g pot^{-1}) and grain (0.78 and 0.87 g pot^{-1}) was recorded under10 mg kg^{-1} of potassium humate along with 100 % NPK and 12.5 mg Zn kg^{-1} (T_{12}) during first and second year respectively and it was significantly higher than T_1 and T_2 (Table 1). Recommended NPK along with FYM resulted in higher nutrient uptake as compared to the recommended rate of NPK alone (Chaturvedi and Chandel, 2005). Dhanasekaran (2011) also reported that the uptake of NPK by cotton was increased with increasing level of HA when applied with NPK. The humic substances work on the metabolism of the plant and the effect is mainly exerted on the cell membrane functions and thus

Table 1. Effect of potassium humate and chemical fertilizers on nitrogen uptake by rice

Treatments	Nitrogen uptake (g pot^{-1})					
	Straw		Grain		Total	
	2009	2010	2009	2010	2009	2010
T_1	0.28±0.01a	0.37±0.01a	0.38±0.02a	0.42±0.02a	0.66±0.03a	0.79±0.03a
T_2	0.34±0.01b	0.42±0.02b	0.43±0.02b	0.46±0.02b	0.77±0.03b	0.88±0.04bb
T_3	0.41±0.02c	0.51±0.02c	0.45±0.02b	0.50±0.02b	0.86±0.03c	1.01±0.04cd
T_4	0.45±0.02d	0.56±0.02d	0.50±0.02c	0.55±0.02c	0.94±0.04d	1.11±0.04e
T_5	0.49±0.02e	0.66±0.03e	0.57±0.02d	0.64±0.03d	1.06±0.04e	1.29±0.05f
T_6	0.56±0.02fg	0.73±0.03f	0.67±0.03e	0.76±0.03e	1.22±0.05gh	1.48±0.06g
T_7	0.34±0.01b	0.46±0.02b	0.44±0.02b	0.48±0.02b	0.78±0.03b	0.93±0.04bc
T_8	0.38±0.02c	0.51±0.02c	0.50±0.02c	0.55±0.02c	0.88±0.04cd	1.05±0.04de
T_9	0.47±0.02de	0.65±0.03e	0.58±0.02d	0.65±0.03d	1.05±0.04e	1.30±0.05f
T_{10}	0.54±0.02f	0.72±0.03f	0.65±0.03e	0.73±0.03e	1.19±0.05f	1.45±0.06g
T_{11}	0.58±0.02g	0.76±0.03f	0.68±0.03e	0.75±0.03e	1.27±0.05gh	1.50±0.06g
T_{12}	0.66±0.03h	0.86±0.03g	0.78±0.03f	0.87±0.03f	1.44±0.06h	1.72±0.07h

NPK = Recommended dose of fertilizer (60:30:30 mg kg^{-1} corresponding to 120, 60, and 60 kg ha^{-1} of N, P_2O_5 & K_2O, respectively) values followed by different letters in a column show significant difference at $p < 0.05$ by Duncan Multi Range Test.

promoting nutrient uptake or plant growth and development by acting as a hormone-like substance. During both the years of experimentation, $NPK_{100\%}$ gave higher N uptake by rice straw and grain, which was significantly higher than $NPK_{75\%}$ alone. The application of 10 mg kg^{-1} of potassium humate along with 100 % NPK and 12.5 mg Zn kg^{-1} (T_{12}) also gave the highest total N uptake (0.1.44 and 0.1.72 g pot^{-1}) which was significantly higher than T_7 and T_1. It has been reported that the incorporation of humic acids into soils stimulated root growth (Cooper et al., 1998).

Phosphorus uptake

The sole application of chemical fertilizers (T_1 and T_7) on P uptake by rice straw and grain was significant during both the years of experiment. This indicates that application of NPK increased P supply and concentration in plant and finally the uptake on P. Higher uptake of P under NPK fertilizers was also observed by Sharma et al. (2012). Combined application of potassium humate alongwith 100 % NPK and 12.5 mg Zn kg^{-1} significantly affected P uptake by rice straw and grain. The highest P uptake by rice straw (0.081 and 0.095 g pot^{-1}) and grain (0.160 and 0.171 g pot^{-1}) was recorded under T_{12} which was significantly higher than T_1 and T_7 during first and second year respectively (Table 2). Combined application of humic acid and 100% NPK recorded the highest P uptake in cotton (Dhanasekaran, 2011). Soil application of humic acid at 100 kg ha^{-1} along with 50% recommended dose of fertilizers improved the availability and uptake of nutrients to greater extent than 100% recommended dose of fertilizers alone (Sarwar et al., 2012). The results point out that use of potassium humate had beneficial effect on P uptake by rice straw and grain. This observation was in tune with the finding of Bama et al. (2003). Humic acid likely increases P availability and uptake by inhibiting calcium phosphate (Ca-P) precipitation rates, forming phosphohumates (Ayuso et al., 1996), competing for adsorption sites and decreasing the number of adsorption sites by promoting dissolution of metal solid phases via chelation (Guppy et al., 2005). Singh et al. (2012) recorded marked variations in concentration and uptake of phosphorus by plants at maturity. They found that sulphur and zinc had significant influence on content and uptake of P as they plays important role in growth and development. Results have clearly shown that the highest P uptake was recorded under 10 mg kg^{-1} of potassium humate with 100 % NPK and 12.5 mg Zn kg^{-1} (T_{12}) which was significantly higher than (T_1) as well as (T_7) during both the years of experimentation (Table 2). Khaled and Fawy (2011) also gave similar report. The increased P uptake was ascribed to formation of humo-phospho complexes, which could be easily assimilable by plants (Szymanski, 1962) and this explains the higher P uptake by rice in the present study.

Potassium uptake

Higher K uptake by rice straw and also by grain was recorded under $NPK_{100\%}$, (T_7) which was significantly higher than those recorded with $NKP_{75\%}$ (T_1). Increase in potassium uptake due to higher doses of N, P and K

Table 2. Effect of potassium humate and chemical fertilizers on phosphorous uptake by rice

Treatments	Phosphorous uptake (g pot^{-1})					
	Straw		Grain		Total	
	2009	2010	2009	2010	2009	2010
T_1	0.035±0.001a	0.039±0.001a	0.056±0.002a	0.059±0.002a	0.090±0.004a	0.098±0.004a
T_2	0.043±0.001b	0.047±0.001b	0.062±0.002b	0.065±0.003a	0.105±0.004b	0.112±0.004b
T_3	0.050±0.002c	0.055±0.002c	0.072±0.003c	0.076±0.003b	0.122±0.005c	0.131±0.005c
T_4	0.055±0.002d	0.060±0.002d	0.082±0.003d	0.087±0.003c	0.136±0.005d	0.147±0.006d
T_5	0.067±0.002f	0.075±0.002g	0.100±0.004f	0.107±0.004e	0.167±0.007f	0.182±0.007ef
T_6	0.072±0.002g	0.084±0.003hi	0.125±0.005g	0.137±0.005f	0.197±0.008g	0.220±0.009g
T_7	0.048±0.001c	0.059±0.002cd	0.071±0.003c	0.073±0.003b	0.118±0.005c	0.132±0.005c
T_8	0.054±0.002d	0.064±0.002e	0.080±0.003d	0.084±0.003c	0.134±0.005d	0.149±0.006d
T_9	0.063±0.002e	0.072±0.002f	0.091±0.004e	0.099±0.004d	0.154±0.006e	0.171±0.007e
T_{10}	0.070±0.002fg	0.081±0.002h	0.100±0.004f	0.110±0.004e	0.170±0.007f	0.191±0.008f
T_{11}	0.076±0.002h	0.085±0.003i	0.133±0.005h	0.141±0.006f	0.209±0.008h	0.226±0.009g
T_{12}	0.081±0.002i	0.095±0.003j	0.160±0.006i	0.171±0.007g	0.241±0.010i	0.266±0.011h

Values followed by different letters in a column show significant difference at $p < 0.05$ by Duncan Multi Range Test.

Table3. Effect of potassium humate and chemical fertilizers on potassium uptake by rice

Treatments	Potassium uptake (g pot^{-1})					
	Straw		Grain		Total	
	2009	2010	2009	2010	2009	2010
T_1	0.53±0.02a	0.53±0.02a	0.065±0.003a	0.077±0.004a	0.60±0.02a	0.60±0.02a
T_2	0.58±0.02b	0.60±0.02b	0.075±0.004b	0.086±0.004a	0.66±0.03b	0.68±0.03b
T_3	0.66±0.03cd	0.71±0.03de	0.085±0.004bc	0.098±0.005b	0.75±0.03c	0.81±0.03de
T_4	0.71±0.03de	0.77±0.03e	0.097±0.005d	0.112±0.006cd	0.81±0.03d	0.88±0.04f
T_5	0.78±0.03fg	0.88±0.04f	0.125±0.006fg	0.144±0.007fg	0.90±0.04ef	1.03±0.04g
T_6	0.82±0.03gh	0.97±0.04g	0.145±0.007h	0.171±0.009i	0.97±0.04g	1.14±0.05h
T_7	0.59±0.02b	0.65±0.03bc	0.094±0.005cd	0.106±0.005bc	0.68±0.03b	0.76±0.03c
T_8	0.64±0.03c	0.70±0.03cd	0.108±0.005e	0.123±0.006d	0.74±0.03c	0.83±0.03ef
T_9	0.74±0.03ef	0.87±0.03f	0.117±0.006ef	0.137±0.007e	0.86±0.03de	1.01±0.04g
T_{10}	0.83±0.03h	0.95±0.04g	0.128±0.006g	0.151±0.008gh	0.96±0.04fg	1.10±0.04h
T_{11}	0.90±0.04i	1.00±0.04g	0.138±0.007h	0.157±0.008h	1.04±0.04h	1.15±0.05h
T_{12}	0.97±0.04j	1.12±0.04h	0.162±0.008i	0.186±0.009j	1.14±0.05i	1.30±0.05i

Values followed by different letters in a column show significant difference at $p < 0.05$ by Duncan Multi Range Test.

fertilizers might be due to an increase in the nutrient content in the plant. The highest potassium uptake by rice straw and grain was recorded under10 mg kg^{-1} of potassium humate with 100 % NPK and 12.5 mg Zn kg^{-1} (T_{12}) and it was significantly higher than T_7 and T_1 (Table 3). Rice being a monocot, could have taken up more of K by virtue of its high root CEC (Tisdale et al., 1997), which was increased due to HA. The mobile nature of K and increase in the root volume would also have resulted in higher K uptake. Increased K content in soil due to HA application would have also contributed to more K absorption by rice. Similar result was also reported by Bama et al. (2003). The content and uptake of K by plants was reported to significantly increase with increasing potassium humate concentration (Rizk and Mashhour, 2008). Keram et al. (2012) also revealed that potassium uptake increased significantly with the application of recommended NPK+Zn @ 20 kg ha^{-1} by wheat as compared to NPK alone. In case of total uptake, aapplication of 10 mg kg^{-1} potassium humate with 100 % NPK and 12.5 mg Zn kg^{-1} (T_{12}) gave highest total K uptake (1.14 and 1.30 g pot^{-1}) which was significantly higher than that observed with (T_1) and (T_7) (Table 3). Bama et al. (2003) also reported that application of humic acid along with recommended dose of fertilizers enhanced potassium uptake in rice crop.

Sulphur uptake

Significantly higher S uptake by straw and grain was recorded in case of 100% recommended dose of NPK (T_7) as compared to 75% recommended doses of NPK (T_1). The highest removal of S by rice straw and grain

Table 4. Effect of potassium humate and chemical fertilizers on sulphur uptake by rice

Treatments	Sulphur uptake (g pot^{-1})					
	Straw		Grain		Total	
	2009	2010	2009	2010	2009	2010
T_1	0.039±0.002a	0.048±0.002a	0.038±0.002a	0.046±0.002a	0.077±0.003a	0.094±0.004a
T_2	0.046±0.002b	0.055±0.002b	0.045±0.002b	0.052±0.002b	0.090±0.004b	0.107±0.004b
T_3	0.061±0.002d	0.072±0.003c	0.051±0.002c	0.060±0.002c	0.113±0.005cd	0.133±0.005c
T_4	0.067±0.003e	0.079±0.003d	0.057±0.002de	0.067±0.003de	0.124±0.005e	0.146±0.006de
T_5	0.082±0.003f	0.098±0.004f	0.071±0.003fg	0.083±0.003fg	0.153±0.006g	0.181±0.007g
T_6	0.088±0.004g	0.108±0.004g	0.086±0.003i	0.102±0.004i	0.174±0.007h	0.210±0.008i
T_7	0.055±0.002c	0.073±0.003cd	0.054±0.002cd	0.062±0.002cd	0.109±0.004c	0.135±0.005cd
T_8	0.060±0.002cd	0.077±0.003cd	0.060±0.002e	0.070±0.003e	0.120±0.005de	0.147±0.006e
T_9	0.069±0.003e	0.085±0.003e	0.067±0.003f	0.080±0.003f	0.137±0.005f	0.165±0.007f
T_{10}	0.078±0.003f	0.096±0.004f	0.074±0.003g	0.088±0.004gh	0.151±0.006g	0.184±0.007g
T_{11}	0.088±0.004g	0.105±0.004g	0.080±0.003h	0.092±0.004h	0.167±0.007h	0.197±0.008h
T_{12}	0.098±0.004h	0.122±0.005h	0.092±0.004j	0.108±0.004j	0.191±0.008i	0.229±0.009j

Values followed by different letters in a column show significant difference at $p < 0.05$ by Duncan Multi Range Test.

was recorded with 10 mg kg^{-1} of potassium humate with 100 % NPK and 12.5 mg Zn kg^{-1} (T_{12}). Treatment T_{10} and T_{11} also produced significantly higher S uptake by rice straw and grain over T_7 and T_1 (Table 4). These effects are considered as an important action of humic acid on plant nutrient acquisition. Another important factor in the uptake of nutrients is the root system of plants. Sulphur and Zinc had significant influence on concentration and uptake as they play important role in growth and development. Humic acid enhanced the uptake of minerals through the stimulation of microbiological activity (Day et al., 2000). Humic substances actually coat mineral surfaces with a membrane-like bi-layer, which aids in the solubilization of otherwise insoluble compounds (Tombacz and Rice, 1999) by dissolving, complexing and chelating the dissolved nutrients. Use of potassium humate also significantly affected the total S uptake at harvesting stage of rice crop. The highest removal of S by rice was recorded with 10 mg kg^{-1} of potassium humate with 100 % NPK and 12.5 mg Zn kg^{-1} (T_{12}) which was significantly higher than other levels, T_1 and T_7, during both the years.

Zinc uptake

In most Zn-deficient soils, the low level of organic matter plays an important role in reduced solubility and uptake of Zn. Increased amount of organic materials in soils can enhance the pool of soluble chelates, which can form readily soluble Zn complexes in soil solution and contribute to enhanced Zn uptake. The application of 10 mg kg^{-1} of potassium humate with 100 % NPK and 12.5 mg Zn kg^{-1}significantly affected the zinc uptake by straw and grain of rice. The highest zinc uptake by rice straw and grain was recorded with T_{12} and was significantly higher than T_7 and T_1 (Table 5). Several studies on the effects of Zn- humic complexes on Zn uptake have been carried out during past years. Kumar and Prasad (1989) studied the effect of Zn-fulvic acid complexes on maize grown in an alkaline, calcareous soil. They found a significant increase in shoot Zn uptake from the fulvic acid fraction of the complexes. Ozkutlu et al. (2006) reported that application of Zn humate enhanced shoot Zn concentration more than two fold in soybean and wheat crop. Total zinc uptake by rice was enhanced significantly by $NPK_{100\%}$ over $NPK_{75\%}$. Application of potassium humate at the rate of 10 mg kg^{-1} with 100 % NPK and 12.5 mg Zn kg^{-1} induced highest total Zn uptake (2.71 and 3.11 g pot^{-1}) which was significantly higher than that caused by T_7 and T_1 (Table 5). These results show the significant efficiency of the specific mechanisms that plants have in order to modify the dynamics of nutrients in the rhizosphere under adverse soil conditions (Uren, 2001). Thus, under Zn deficiency, graminaceous species release in the rhizosphere non-proteinogenic amino acids with the capacity to solubilise non-available Fe, Zn and Cu by the formation of stable complexes that are directly taken up by roots. Similar findings were reported by Chen et al. (2001) in cucumber. The beneficial effect of humic

Table 5. Effect of potassium humate and chemical fertilizers on zinc uptake by rice

Treatments	Zinc uptake (g pot^{-1})					
	Straw		Grain		Total	
	2009	2010	2009	2010	2009	2010
T_1	0.42±0.02a	0.48±0.02a	0.24±0.01a	0.29±0.01a	0.66±0.03a	0.77±0.03a
T_2	0.52±0.02b	0.58±0.02b	0.32±0.01b	0.35±0.01b	0.84±0.03b	0.93±0.04b
T_3	0.66±0.03c	0.74±0.03c	0.41±0.02c	0.46±0.02c	1.07±0.04c	1.20±0.05c
T_4	0.79±0.03d	0.88±0.04d	0.52±0.02d	0.58±0.02e	1.31±0.05d	1.46±0.06d
T_5	0.97±0.04e	1.09±0.04f	0.67±0.03f	0.75±0.03g	1.64±0.07f	1.84±0.07f
T_6	1.23±0.05f	1.43±0.06h	0.92±0.04i	1.05±0.04i	2.15±0.09h	2.49±0.10i
T_7	0.53±0.02b	0.67±0.03c	0.48±0.02d	0.52±0.02d	1.02±0.04c	1.19±0.05c
T_8	0.67±0.03c	0.81±0.03d	0.59±0.02e	0.64±0.03f	1.26±0.05d	1.45±0.06d
T_9	0.84±0.03d	0.96±0.04e	0.65±0.03f	0.73±0.03g	1.49±0.06e	1.70±0.07e
T_{10}	1.03±0.04e	1.21±0.05g	0.77±0.03g	0.87±0.03h	1.80±0.07g	2.07±0.08g
T_{11}	1.31±0.05g	1.46±0.06h	0.83±0.03h	0.89±0.04h	2.14±0.09h	2.36±0.09h
T_{12}	1.62±0.06h	1.91±0.08i	1.09±0.04j	1.20±0.05j	2.71±0.11i	3.11±0.12j

Values followed by different letters in a column show significant difference at $p < 0.05$ by Duncan Multi Range Test.

acid in soil might have prevented the formation of insoluble complexes of zinc and facilitated their uptake by plants.

CONCLUSION

It may be concluded that application of potassium humate@ 10 mg kg^{-1} with 100 % NPK and 12.5 mg Zn kg^{-1} was found to be beneficial in terms of increased uptake of N, P, K, S and zinc in grain and straw of rice as well as yield of rice.

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