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IMPACT OF HUMIC ACID AND CHEMICAL FERTILIZER APPLICATION ON GROWTH AND GRAIN YIELD OF RAINFED WHEAT (*TRITICUM AESTIVUM* L.)

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ABSTRACT: The high cost of inorganic fertilizer, use of natural fertilizer resources for increasing crop production on sustainable basis has become imperative. Two field experiments were conducted to study the potential of humic acid (HA) as a low-cost natural fertilizer and to determine its effect on the yield of rainfed wheat crop (*Triticum aestivum* L. cv. Naseer) at the research farm of Arid Zone Research Institute, Dera Ismail Khan during two successive winter seasons, 2007-08 and 2008-09. The treatments consisted of HA alone (3 kg ha^{-1} or 1.5 kg ha^{-1}) and in combination with full (60:40 kg ha^{-1}) and half (30:20 kg ha^{-1}) the recommended rates of NP fertilizers. Results showed that in the first growing season (2007-08), the combination of 3 kg ha^{-1} HA with half (30:20 kg ha^{-1}) rate of NP produced the highest grain yield (1314 kg ha^{-1}) and increased the yield by 46.9% over the control. In the second growing season (2008-09), application of 3 kg ha^{-1} HA alone produced significantly ($P<0.05$) higher grain yield (2999.9 kg ha^{-1}) and increased the yield by 24% over the control and saved 100% cost of the chemical fertilizer. Results suggested that HA applied alone at 3 kg ha^{-1} or in combination with half (30:20 kg ha^{-1}) rate of NP fertilizers appeared to be the most economical rate to obtain the maximum yield of wheat under the rainfed conditions of Dera Ismail Khan. HA has great potential as a low cost natural fertilizer to improve soil fertility on sustainable basis.

Key Words: Triticum aestivum; Rainfed; Grain Yield; Humic Acid; Chemical Fertilizer; Pakistan.

INTRODUCTION

Yield of dry land crops are limited, both by water supplies and nutrient availability. Fertilizer application not only increases wheat yields by correcting nutrient deficiency, but also enhances the utilization of stored water (Singh et al., 1975). The goal of using nutrients efficiently in wheat crops now-a-days is the primary objective of agriculture, because of the detrimental environmental effects associated with improper fertilizer management and its excessive use (Van de Geijn et al., 1994). The sole use of chemical fertilizers (e.g. N, P, and K) may cause deterioration in soil physical, chemical and biological properties. The high cost of chemical fertilizer and unavailability at the time of application further aggravates the economic conditions of farmers. This calls for a search for an alternative best fertilizer source/ sources those are economical.

Humic acid (HA) is the active constituent of organic fertilizers (Stott and Martin, 1990; Mackowiak, 2001; Karakurt et al., 2009), and its application may represent an alternative to conventional soil fertilization and a prompt source of N, especially in semi-arid conditions.

HA can be used as a cheap organic fertilizer source to improve plant growth and yield, and enhance stress tolerance, as well as to improve soil physical properties and complex metal ions (Piccolo et al., 1992; Hayes and Wilson, 1997; Padem et al., 1997; Atiyeh et al., 2002; Serenella et al., 2002; Zandonadi et al., 2007). In addition, the presence of humic molecules raises the

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effect of NPK fertilization on plants (Pollhamer, 1993; Chen et al., 2001). Humic substances in soil increase nutrient absorption by augmenting the availability of nutrients in addition to improvement of the physical structure of soil (Benedetti et al., 1996; Akinremi et al., 2000; Chen et al., 2001; Cimrin and Yilmaz, 2005). On the other hand, organic matter in soil has been reported to provide the compounds which affect root growth and the distribution of nutrients absorbed by plants (Lobartini et al., 1997). Bohme and Thi Lua (1997) reported that HA had beneficial effects on the nutrient uptake by plants, and was particularly important in the transportation and availability of micro-nutrients in plants.

The integrated use of organic nutrient sources with inorganic fertilizer has been shown to increase the potential of organic fertilizer (Heluf, 2002; Ahmad et al., 2006); improve the efficiency of inorganic fertilizer (Guar and Geeta, 1993) and to improve soil fertility and productivity of agricultural systems (VanLauwe et al., 2002). This may not only help in recycling of organic waste causing environmental pollution but also conserve a rich pool of nutrient resources, which can reduce the sole dependence on chemical fertilizers (Ghosh and Sharma, 1999). So, their use could be reduced up to a certain level. Such practice may also enable the farmers to reduce the use of expensive inorganic sources of fertilizers up to a certain level and get practically realizable yield potentials in a cost-effective and sustainable manner.

The objectives of this study were to ascertain the potential of HA as a low-cost natural fertilizer to improve soil fertility on sustainable basis and determine the extent to which the yield of wheat is affected by applying HA alone and in combination with full (60:40 kg ha^{-1}) and half (30:20 kg ha^{-1}) the recommended dose of NP chemical fertilizers.

MATERIALS AND METHODS

Field experiments were conducted during the *rabi* (winter) growing season of 2007-08 and 2008-09 at the Arid Zone Research Institute, Dera Ismail Khan farm (Pakistan, latitude 32° 4' N, longitude 71° 2', altitude 173 m). Before starting the experiments, soil samples were collected and analysed for various physico-chemical properties according to standard procedures. The soil is characterized by a clay texture (Table 1) with low levels of organic matter and a low cation exchange capacity. Its profile is uniform but showed low amounts of N, P and K relatively high (alkaline) soil pH but average salinity (Table 1). The climate of the study area is arid, subtropical and continental. Because of low humidity, continental location and scarce vegetation, there are great seasonal and daily variations in temperature and amount of precipitation. The average rainfall range is 180-300 mm and the area depends largely on rainfall for rainfed (*barani*) agricultural crop production. A conventional meteorological station placed on the field site recorded climatic data throughout the sowing season (Figure 1).

In each growing season, the soil was treated with: a non-fertilized control (T1), a crop fertilized with 3 kg ha^{-1} HA (T2) + 1.5 kg ha^{-1} HA (T3); a crop fertilized with 3 kg ha^{-1} HA + 30:20 kg ha^{-1} NP chemical fertilizers (T4); 1.5 kg ha^{-1} HA + 30:20 kg ha^{-1} NP chemical fertlizers (T5), and 60:40 kg ha^{-1} recommended rate of NP chemical fertilizer alone (T6). These rates were applied to the experimental plots at sowing time. The HA was thoroughly mixed with soil and then broadcasted as fertilizer.

The experiment was laid out in randomized complete block design with three

Table 1. Soil physical and chemical properties of the experimental area

Parameter	2007-08	2008-09
pH	8.1	8.2
EC (dSm^{-1})	4.6	3.9
Organic matter (%)	0.7	0.8
Available P (mg kg^{-1})	7.1	7.8
Available K (mg kg^{-1})	110.0	112.0
Clay (%)	56.0	54.0
Silt (%)	36.0	37.0
Sand (%)	8.0	9.0
Texture	clay	clay

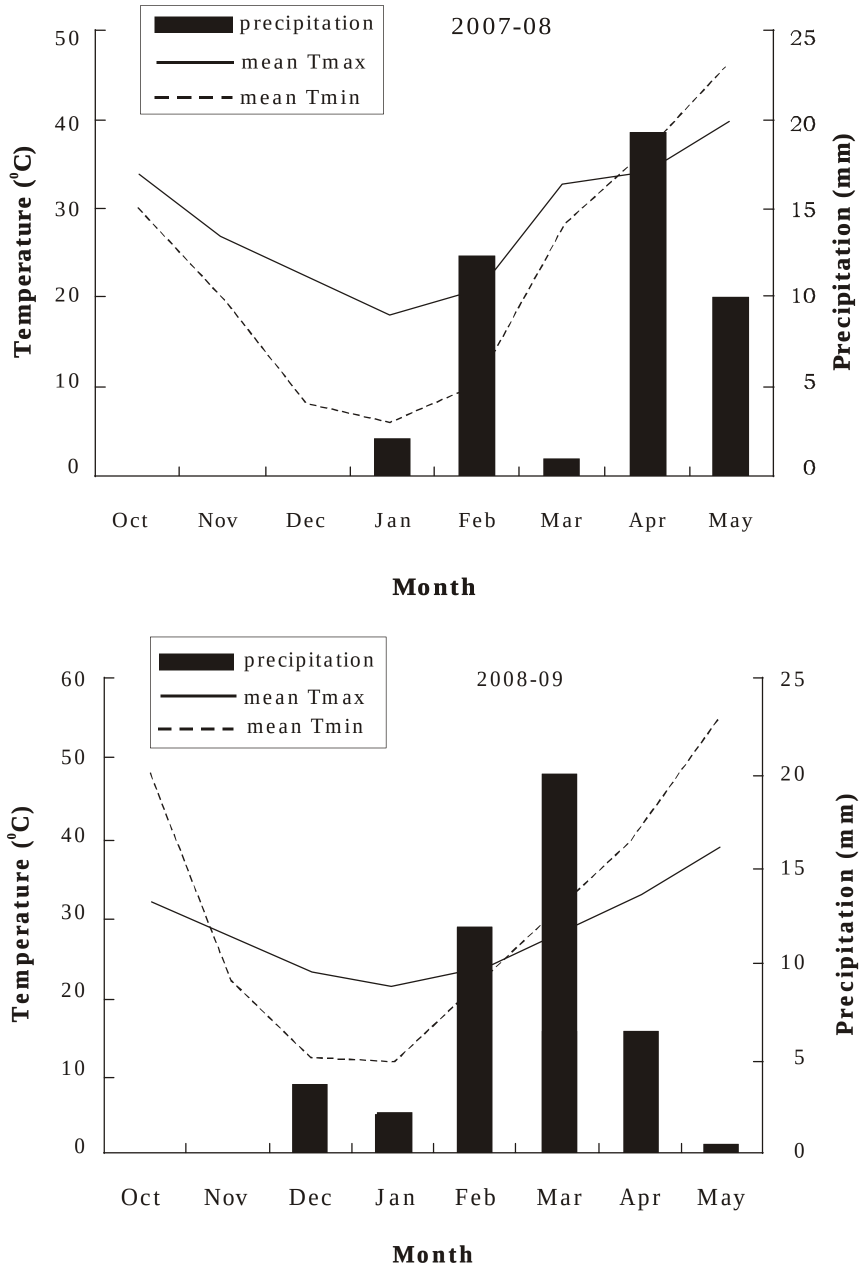

Figure 1. Total rainfall for each month decade, and averaged maximum (Tmax) and minimum (Tmin) temperatures as recorded by a field meteorological station at Arid Zone Research Institute, Dera Ismail Khan, Pakistan

replications having a plot size of 1.8m x 5m (6 rows, 30 cm apart). Prior to seeding, the rotavator was used in all treatments to prepare the uniform seed bed for better seed germination. The wheat cultivar Naseer was sown @ 100 kg ha^{-1} on November 18 in both growing seasons. Pre-sowing irrigation was applied to obtain uniform and optimum plant stand and later, the crop was totally dependent on rainfall up to maturity. Standard cultural practices were applied homogeneously through all plots in both years.

The crop was harvested at physiological maturity. Data on yield components and grain yield from all treatments were obtained on the four central rows in each plot. Statistical analysis was performed using the GLM procedure from SAS (SAS Institute Inc., 2004). Data from both years were pooled and subjected to analysis of variance (ANOVA) to compare the effects of HA treatments. The means were separated using Fisher's LSD test at the 5% level of significance.

RESULTS AND DISCUSSION

Plant Height

The results revealed that different levels of HA and chemical fertilizers alone, or in combination, significantly ($P<0.05$) affected the plant height of the crop in both seasons as compared with the control (Table 2). The plant height was significantly higher in the 2007-08 growing season than in the 2008-09. In 2007-08 the maximum increase in plant height (67.9 cm) was recorded in plots that received 3 kg ha^{-1} HA + 30:20 kg ha^{-1} NP chemical fertilizers. This treatment was at par with 1.5 kg ha^{-1} HA + 30:20 kg ha^{-1} NP and followed by the full recommended rate (60-40 kg ha^{-1}) of NP chemical fertilizers, yielding plant heights of 67.9 and 67.7 cm, respectively. During 2008-09 a maximum plant height (102.6 cm) was recorded after application of 3 kg ha^{-1} HA alone, followed by 100.8 cm plant height after application of 1.5 kg ha^{-1} HA (Table 2). However, there were non-significant ($P>0.05$) differences between these two treatments of HA. The minimum plant height (i.e. 59.9 and 90.2 cm) was recorded in control plots during both seasons (Table 2). These results suggest that HA application has a stimulating effect on shoot growth (Goatley and Schmidt, 1990).

Number of Tillers per Plant

The results showed an increase in number of tillers per plant among all treatments except in the control plots during both the seasons (Table 2). But generally, application of 3 kg ha^{-1} HA+ 30:20 kg ha^{-1} NP chemical fertilizer produced the maximum number of tillers (i.e. 2.2 and 2.5) in 2007-08 and 2008-09, respectively. These

Table 2. Effect of HA and chemical fertilizer application on wheat yield and yield components during 2007-08 and 2008-09

Treatment	Plant height (cm)	No of tiller plant^{-1}	Spike length (cm)	Grains spike^{-1}	1000 grain weight (g)	Grain yield (kg ha^{-1})	Yield increase (% over control)
2007-08							
T 1	59.9 d	1.5 b	7.6 d	44.7 c	25.2 d	894.4 e	-
T 2	62.3 c	1.9 a	7.96 cd	48.0 b	27.7 c	1108.0 d	23.9
T 3	64.8 b	1.9 ab	8.3 bc	48.0 b	28.3 bc	1192.0 c	33.3
T 4	67.9 a	2.2 a	8.7 ab	50.0 ab	29.3 a	1314.0 a	46.9
T 5	67.9 a	1.9 a	8.7 ab	49.7 ab	28.7 ab	1179.0 c	31.8
T 6	67.7 a	2.2 a	8.9 a	50.3 a	29.0 ab	1236.0 b	38.2
LSD (0.05)	1.3	0.5	0.5	2.0	0.9	36.2	
2008-09							
T 1	90.2 d	1.6 b	7.5 c	32.8 d	43.0 b	2412.2 c	-
T 2	102.6 a	2.5 a	8.7 a	35.8 b	44.7 a	2999.9 a	24.4
T 3	100.8 ab	2.2 a	8.2 b	34.4 c	43.0 b	2536.6 bc	5.2
T 4	97.9 de	2.5 a	8.7 a	36.8 a	44.9 a	2965.5 a	22.9
T 5	98.5 be	2.2 a	8.5 ab	35.3 bc	43.4 b	2625.5 b	8.8
T 6	97.9 c	2.2 a	8.7 a	35.9 abc	44.4 a	2963.5 a	22.9
LSD (0.05)	2.3	0.4	0.4	1.0	0.9	165.8	

Means followed by the same letters do not differ significantly at P<5%

results appeared to be at par with the highest (60:40 kg ha$^{-1)}$ rate of NP chemical fertilizers. However, the results further showed that there were non-significant differences among treatments with HA and chemical fertilizer (NP), applied either alone or in combination during both seasons, 2007-08 and 2008-09 (Table 2).

Days to Heading and Maturity

The results revealed that days to heading and maturity were affected by the two growing seasons (Figure 2). There were non-significant (P>0.05) differences among the treatments for days to heading in 2007-08. However, results for 2008-09 showed a significant (P<0.05) variation for days to heading. Minimum (97.7) days to heading was recorded by 1.5 kg ha^{-1} HA + 30:20 kg ha^{-1} NP and 60:40 kg ha^{-1} NP chemical fertilizers (Figure 2a). However, these results were statistically non-significant from the rest of the treatments, except for HA at 1.5 kg ha^{-1} and control treatments, which recorded maximum days to heading i.e. 99.7 and 100 days, respectively. The results for days to maturity were non-significant in both growing seasons, though days to maturity were slightly higher in 2007-08 than in 2008-09 (Figure 2b).

Spike Length

The results for spike length ranged from 7.6 to 8.9 cm in 2007-08 (Table 2). The length of spike increased in plots that received a full recommended rate of chemical fertilizers (60:40 NP kg ha^{-1}), which appeared at par with HA applied @ 1.5-3 kg ha^{-1} combined with half 30:20 kg ha^{-1} of NP chemical fertilizers. During 2008-09, maximum (8.7 cm) spike length was recorded with the highest rate 60:40 kg ha^{-1} of NP which was at par with the other treatments except with the lowest 1.5 kg ha^{-1} rate of HA (Table 2). The control plots recorded the lowest spike length during both the seasons.

Grains per Spike

The results for number of grains per spike ranged from 44.7 to 50.3 during 2007-08. Among the treatments, the full recommended 60:40 kg ha^{-1} rate of NP chemical fertilizers significantly (P<0.005) gave the maximum (53.3) grains per spike with at par values (49.5 and 50.0) grains per spike observed with 1.5 kg ha^{-1} HA + 30:20 kg ha^{-1} HA , and 3 kg ha^{-1} HA + 30:20 kg ha^{-1} NP. HA applied alone at the rate of 1.5 and 3 kg ha^{-1} did not differ significantly for one or the other and produced 48 grains per spike (Table 2). During 2008-09, grains per spike significantly (P<0.005) increased with the application of HA and chemical fertilizer over the control. The grains ranged from 32.8 to 36.8 per spike (Table 2). The maximum 36.8 grains per spike was recorded with the combined application of 3 kg ha^{-1} HA + 30:20 kg ha^{-1} NP. However, this was followed by statistically non-significant 35.9 grains per spike with a full 60:40 kg ha^{-1} recommended rate of NP fertilizers. In both seasons, minimum (44.7 and 32.8) grains per spike were noted in control treatments, respectively (Table 2). Concerning the positive effect of HA on number of grains per spike, Shuixiu and Ruizhen (2001) mentioned that HA used as a soil treatment at the seeding stage significantly increased the seeds per plant in soybean plants.

1000-grain Weight

The 1000-grain weight was significantly (P<0.05) affected by different treatments during both seasons (Table 2). The grain weight was overall significantly higher in the second growing season than in the first. The 1000-grain weight ranged from 25.2g to 29.3g during 2007-08. The maximum (29.3g) 1000-grain weight was recorded in the treatment that received 3 kg ha^{-1} HA + 30:20 kg ha^{-1} NP; this did not differ significantly with the treatment of HA at 1.5 kg ha^{-1} + 30:20 kg ha^{-1} NP and recommended 60-40 kg ha^{-1} rate of NP chemical fertilizers by producing 28.7g to 29.0g 1000-grain weight, respectively. The lowest (25.2g) 1000-grain weight was recorded in control treatments. During 2008-09 the 1000-grain weight ranged from 43.1g to

44.9g, but the maximum (44.9g) 1000-grain weight was recorded with 3 kg ha^{-1} HA + 30:20 kg ha^{-1} NP treatment. This was followed by the non-significant (44.7g and 44.4g) 1000-grain weight at 3 kg ha^{-1} HA alone and 60:40 kg ha^{-1} recommended NP rate, respectively. The lowest (43.0g) 1000-grain weight was recorded in the control and the plots, where the lowest rate of 1.5 kg ha^{-1} HA was applied (Table 2). These results are in line with Delfine et al. (2005), who reported that application of humic acid caused a transitional production of plant dry matter with respect to the unfertilized control. Similarly, Albuzio et al. (1994) found that humic substances increased the dry

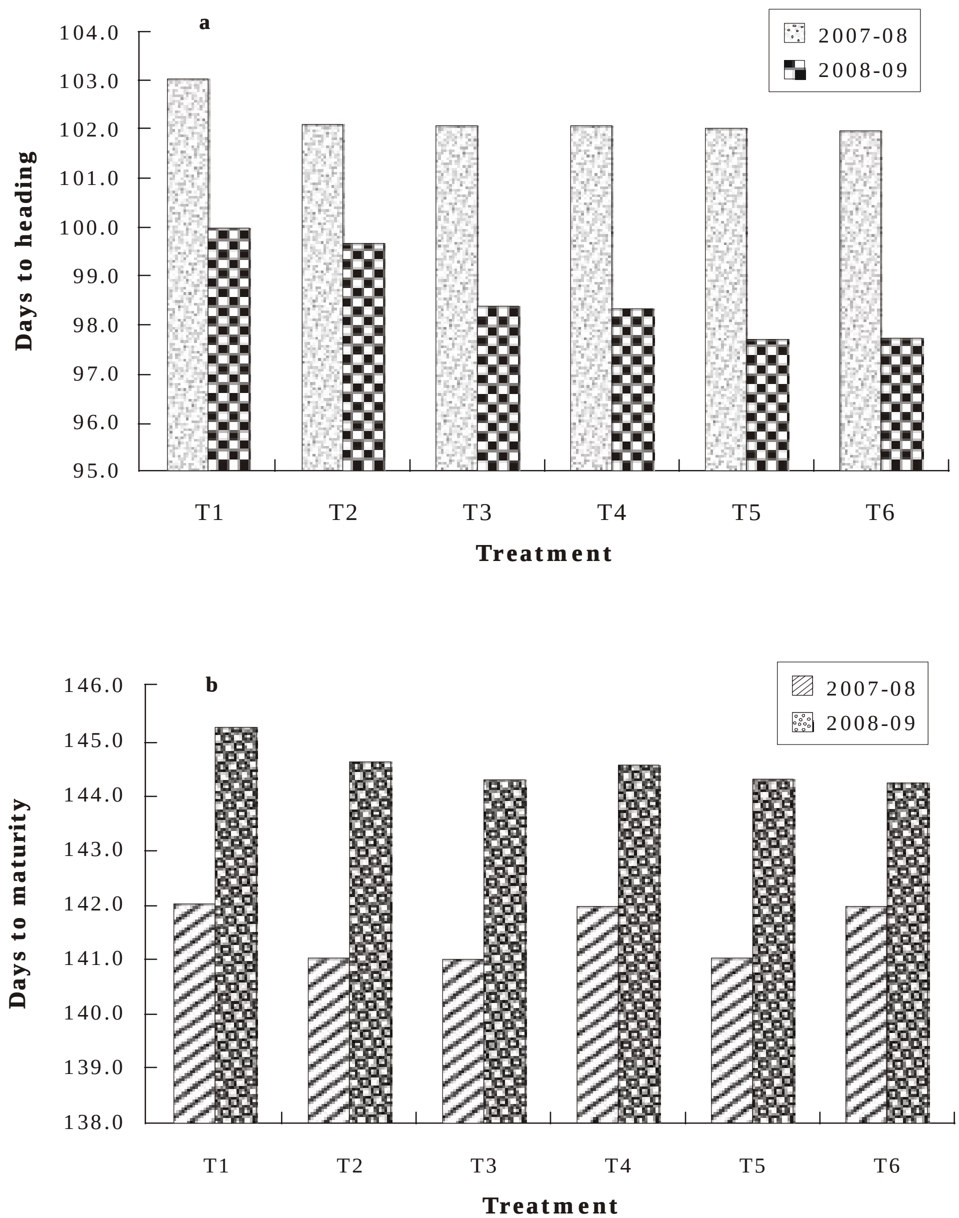

Figure 2. Effect of HA and chemical fertilizer application on (a) days to heading and (b) days to maturity of rainfed wheat during 2007-08 and 2008-09

matter yields of oat seedlings.

Grain Yield

In wheat grain yield was significantly ($P<0.05$) increased by application of HA and NP chemical fertilizers compared with control treatment during both growing seasons. The grain yield during 2007-08 ranged from 894.4 to 1314.0 kg ha^{-1}. The maximum (1314.0 kg ha^{-1}) grain yield was obtained from the treatment with 3 kg ha^{-1} HA + 30:20 kg ha^{-1} NP (Table 2). These results are in line with Benedetti et al. (1996), who studied the effects of HA application alone and mixed with compound mineral fertilizer (NPK-HA) on growing lettuce and maize in the field and pots. The production of both crops was increased by the NPK-HA treatment, which was higher than HA alone. The second highest grain yield (i.e. 1236 kg ha^{-1}) was obtained from a full 60:40 kg ha^{-1} recommended rate of NP chemical fertilizer, while the lowest grain yield (894.4 kg ha^{-1}) was noted in control plots (Table 2).

The grain yield during 2008-09 ranged from 2412.2 to 2999.9 kg ha^{-1}. The yield was significantly increased with the application of organic (HA) and chemical fertilizer (NP), as compared with control plots. The highest grain yield (2999.9 kg ha^{-1}) was obtained from the HA treatment 3 kg ha^{-1} alone, with an increase of 24% over control plots (Table 3). But the said treatment was at par with the same rate of HA but in combination with 30:20 kg ha^{-1} NP and a full 60-40 kg ha^{-1} rate of NP fertilizer. The lowest grain yields (2412.2 and 2536.6 kg ha^{-1}) were recorded in the control and 1.5 kg ha^{-1} HA treatments, respectively.

The results showed that in the first growing season (2007-08), the combination of 3 kg ha^{-1} HA with half (30:20 kg ha^{-1}) the rate of NP produced the highest grain yield, 1314 kg ha^{-1}, and increased the yield by 46.9% over the control. In the second growing season (2008-09), application of 3 kg ha^{-1} HA alone produced statistically significant ($P<0.05$) maximum grain yield, (2999.9 kg ha^{-1}), and increased the yield by 24% over the control and saved 100% the cost of chemical fertilizer. These results might be due to the positive effect of these HA treatments on the yield components of wheat as described earlier. Hai and Mir (1998) reported an 8% to 44% increase in yield of different crops with the application of HA in different ecological zones of Pakistan. Similarly, Sharif et al. (2002) found significant increase of 20-69% wheat yield over control under field conditions.

The grain yield was significantly higher in 2008-09 than in 2007-08, regardless of the treatments (Table 2). Differences between years were often relevant due to weather conditions (Figure 1). Production varies greatly from season to season, and is also caused by rainfall variability. Weather conditions differed between the two seasons (Figure 1). The total amount of precipitation was lower in the first growing season and showed much less spring rainfall (February-April 2008, 65 mm); conversely, the precipitation was relatively well distributed throughout the experimental period during the second growing season and higher in the spring (February-April 2009, 79 mm). Differences in temperature were less pronounced throughout both the growing seasons. However, in 2007-08 the maximum mean temperature was higher (33 ^{o}C) in March as compared with lower mean maximum temperature (28 ^{o}C) in 2008-09 (Figure 1). Wheat crops responded to water deficit through changes in various physiological and metabolic processes (Chandrasekar et al., 2000). The relatively drier weather conditions during the grain filling stage in 2007-08 may have favoured faster senescence of the photosynthetic organs and reduced final grain yield (Yang et al., 2000). When there was sufficient rain (spring 2008-09) to ensure little or no water stress, the crops had a higher yield potential due to the vigorous vegetative growth stimulated by the HA applied at 3 kg ha^{-1} in combination with 30-20 kg ha^{-1} rate of NP fertilizers.

The results strongly suggested that HA applied alone at 3 kg ha^{-1} or in combination with half (30:20 kg ha^{-1}) the rate of NP fertilizers appeared to be the most economical rate to obtain a maximum yield of wheat under the rainfed conditions of Dera Ismail Khan, Pakistan.

It is therefore, concluded the effect of the applied HA on plant growth after two years of study is persistent. The application of HA at 3 kg ha^{-1} alone or in combination with a half rate 30:20 kg ha^{-1} of NP chemical fertilizers is the optimum for getting the most profitable and economical yield of wheat under rainfed conditions. Addition of HA alone or with combination with chemical fertilizers to soil increased grain yield of wheat 24-46.9% over the control and saved almost 50-100% of high-cost chemical fertilizer per hectare for wheat crop production. HA has great potential as a low-cost natural fertilizer to improve soil fertility on a sustainable basis.

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LITERATURE CITED

Ahmad, R. Naseer, A. Zahir, A. Ashad, M. Sultan, T. and Ullah, M.A. 2006. Integrated use of recycled organic waste and chemical fertilizers for improving maize yield. Intern. J. Agric. and Biol. 8: 840–843.

Akinremi, O.O. Janzen, H.H. Lemke, R.L. and Larney, F.J. 2000. Response of canola, wheat and green beans to leonardite additions. Canadian J. Soil Sci. 80: 437-443.

Albuzio, A. Concheri, G. Nardi, S. and Agnola, G. 1994. Effect of humic fractions of different molecular size on the development of oat seedlings grown in varied nutritional conditions. In: Senesi, N. and Mianoms, T.M. (eds.) Humic Substances in the Global Environment and Implications on Human Health. Amsterdam, The Netherlands. Elsevier Science p.199-204.

Atiyeh, R.M. Edwards, C.A. Metzger, J.D. Lee, S. and Arancon, N.Q. 2002. The influence of humic acids derived from earthworm-processed organic wastes on plant growth. Bioresource Technol. 84: 7–14.

Benedetti, A. Figleolia, A. Izza, C. Canale, S. and Rossi, G. 1996. Some thoughts on the physiological effects of HA; interaction with mineral fertilizer, Agrochimica, 40: 229–240.

Bohme, M. and Thi Lua, H. 1997. Influence of mineral and organic treatments in the rhizosphere on the growth of tomato plants. Acta Horticulturae, 450: 161-168.

Chandrasekar, V. Sairam, R.K. and Srivastava, G.C. 2000. Physiological and biochemical responses of hexaploid and tetraploid wheat to drought stress. J. Agron. and Crop Sci. 185: 219–227.

Chen, Y. Magen, H. and Clapp, C.E. 2001. Plant growth stimulations by humic substances and their complexes with iron. Proc. International Fertilizer Society, York, UK. 470:1-14.

Cimrin, K.M. and Yilmaz, I. 2005. Humic acid applications to lettuce do not improve yield but do improve phosphorus availability. Acta Agriculturae Scandinavica, Section B, Soil and Plant Science, 55: 58–63.

Delfine, S. Tognetti, R. Desiderio, E. and Alvino, A. 2005. Effect of foliar application of N and humic acids on growth and yield of durum wheat. Agronomy for Sustainable Development 25(2):183–191.

Ghosh, A. and Sharma, A.R. 1999. Effect of combined use of organic manure and nitrogen fertilizer and the performance of rice under flood prone lowland conditions. J. Agric. Sci. 132: 461–465.

Goatley, J.M. and Schmidt, R.E. 1990. Antisenescence activity of chemicals applied to Kentucky bluegrass. J. Am. Soc. Hort. Sci. 115: 57–61.

Hai, S.M. and Mir, S. 1998. The lignitic coal derived HA and its prospective utilization in Pakistan's agriculture and industry. Sci. Tech. and Dev 17: 32-40.

Hayes, M.H.B. and Wilson, W.S. 1997. Humic substances, peats and sludges; health and environmental aspects. Royal Society of Chemistry. Cambridge, UK. p. 172–496.

Heluf, G. 2002. Soil and Water Management Research Program Summary Report of Research Activities. Alemaya Research Center, Alemaya University. p. 95–98.

Karakurt, Y. Unlu, H. and Padem, H. 2009. The influence of foliar and soil fertilization of humic acid on yield and quality of pepper. Acta Agriculturae Scandinavica, Section B, Soil and Plant Science 59: 233–237.

Lobartini, J.C. Orioli, G.A. and Tan, K.H. 1997. Characteristics of soil humic acid fractions separated by ultrafiltration. Communications in Soil Science and Plant Analysis, 28: 787–796.

Mackowiak, C.L. Grossl, P.R. and Bugbee, B.G. 2001. Beneficial effects of humic acid on micronutrient availability to wheat. Soil Sci. Soc. Am. J. 65: 1744-1750.

Padem, H. Ocal, A. and Alan, R. 1997. Effect of humic acid added foliar fertilizer on seedling quality and nutrient content of eggplant and pepper. Acta Horticulturae, 491: 241–246.

Piccolo, A. Nardi, S. and Concheri, G. 1992. Structural characteristics of humic substances as regulated to nitrate uptake and growth regulation in plant systems. Soil Biology and Biochemistry, 24: 373-380.

Pollhamer, Z. 1993. Effect of humic acid, fulvic acid and NPK fertilizer on the quality of winter wheat varieties on chemical-free soil (in Hungarian). Novenytermeles, 42:447–455.

SAS Institute Inc. 2004. SAS 9.1.3 Help and Documentation, Cary, NC: SAS Institute Inc.

Serenella, N. Pizzeghelloa, D. Muscolob, A. and Vianello, A. 2002. Physiological effects of humic substances on higher plants. Soil Biology & Biochemistry, 34: 1527–1536.

Sharif, M. Khattak, R.A. and Sarir, M.S. 2002. Wheat yield and nutrients accumulation as affected by humic acid and chemical fertilizer. Sarhad J. Agric. 18:323-329.

Shuixiu, H. and Ruizhen, W. 2001. A study on the effect of KOMIX, humic acid containing organic fertilizer, on spring soybean. Acta Agriculturae Universitatis Jiangxiensis, 23: 463-466.

Singh, R. Singh, Y. Prihar, S.S. and Singh P. 1975. Effects of N fertilization on yield and water use efficiency of dryland wheat as affected by stored water and rainfall. Agron. J. 67: 599-603.

Stott, D.E. and Martin, J.P. 1990. Synthesis and degradation of natural and synthetic humic materials in soils. In: Mac Carthy. P. (ed.) Humic Substances in Soil and Crop Sciences, Madison. p. 37-63.

Van de Geijn, S. Vos, J.C. Groenwold, J. Goudriaan, J. and Leffelaar, P.A. 1994. The Wageningen Rhizolab – a facility to study soil-root-atmosphere interactions in crops. I. Description of main functions. Plant and Soil, 161: 275-287.

Van Lauwe, B. Diels, J. Aihou, K. Iwuafor, E.N.O. Lyasse, O. Sanginga, N. and Merckx, R. 2002. Direct interaction between N fertilizers and organic matter: evidence from trials with ^{15}N-labelled fertilizer. In: Van Lauwe, B. Diels, N. Sanginga, N. and Merckx R. (eds.) Integrated Plant Nutrient Management in sub-Saharan Africa: From Concept to Practice, Wallington, UK.: CAB International in association with IITA p.173-184.

Yang, J. Zhang, J. Huang, Z. Zhu, Q. and Wang, L. 2000. Remobilization of carbon reserves is improved by controlled soil-drying during grain filling of wheat. Crop Science, 40: 1645–1655.

Zandonadi, D.B. Canellas, L.P. and Facanha, A.R. 2007. Indolacetic and humic acids induce lateral root development through a concerted plasmalemma and tonoplast H+ pumps activation. Planta, 225:1583–1595.