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# EXPLOITING THE NATURAL RESOURCE - LIGNITE HUMIC ACID IN AGRICULTURE - A REVIEW

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## ABSTRACT

**Humic acid typically contains heterocyclic compounds with carboxylic, phenolic, alcoholic and carbonyl fractions extracted from lignite with high molecular weight. Humic acid has been extracted from various sources such as lignite, peat, coal, farmyard manure, coirpith besides natural persistence in soil. Humic acid plays a vital role in enhancing the nutrient uptake of crop by acting as a chelate in mobilizing nutrients. Prevents losses of degradation and leaching of nutrients and thus reduces the use of inorganic fertilizers besides increasing the efficiency of the applied fertilizers. Presence of growth promoting substances such as auxins and gibberellins had been reported in humic acid and it plays an important role in enhancing the enzymatic activities of the plants. The resistance in the plants found to be increased by the humic acid application. The soil fertility would be improved by mobilising the unavailable form of nutrients to the available form. The humic acid application at optimal rates has been reported to enhance the yield of various crops.**

Rational use of natural resources of humus such as from peat and lignite is urged by the scientific community. Humic acid typically contains heterocyclic compounds with carboxylic, phenolic, alcoholic and carbonyl fractions extracted out from lignite with high molecular weight. Humic acid is insoluble in water, thus manufactured in the commercial form of potassium humate with a production potential of 30t/annum by Neyveli Lignite Corporation (Khungar and Manoharan, 2000). Humic acid has been extracted from various resources such as lignite, peat, coal, farmyard manure, coir pith etc., besides natural persistence in the soil. The labile and humified organic matter will have a strong impact on soil fertility and desirable influence on soil physio-chemical properties. Organic matter becomes a vital part in both crop production and soil fertility but what type is best is the arising question. The answer is humus, which is the well decomposed organic matter derived from microbial action. Renowned organic scientist Schnitzer (2000) reported that the term total humic substances (humic acid + fulvic acid + humin) are also synonymous with soil organic matter. The major advantages of humic acid in agriculture are, it plays a vital role in enhancing the nutrient uptake of crop by acting as a chelate agent in mobilizing nutrients, prevents losses of degradation and leaching of nutrients, improves the water retention capacity, porosity, aggregates stability, cation exchange capacity, reduces the use of inorganic fertilizers, helps in building up of organic matter and favourable microbial population of the soil, develops resistance to the plants through reduced aminoacid synthesis by diverting free aminoacid to protein, synthesis of phenols and indole compounds from the aromatic amino acids, enhanced the levels of organic matter solubilises silica associated with higher concentration of silica in plants improving plant resistance to pest and disease (Kowalski and Davies, 1982) and promotes growth due to growth promoting substances possibly IAA or its precursors and gibberellins like substances in humic acid (Casenova De Sanfilippo, 1990). Keeping in view the advantages or significance of humic acid in agriculture and its role in

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organic agriculture, this review was drafted for the reference of planners, scientists and farmers.

**Physico - chemical properties of humic acid**

All humic acid found to have one atom of oxygen for every two atoms of carbon and about one hydrogen for every atom of carbon and the same trend was observed in lignite humic acid (Chandrasekaran, 1992). Singhal and Pramod Kumar (1992) studied infrared spectra of humic acid and indicated the preponderance of oxygen containing functional groups with high molecular weight contained methyl, methylene, ketonic and ester groups. Sanjibkar (1998) revealed that viscosity measurement of humic acid molecules at higher concentration behaved like uncharged polymers and at lower concentration molecules were expanded and behaved like charged polymer. Humic substances consisted of protein, carbohydrates, organic acids, fats, waxes, resins etc, COO-groups, aromatic, C=C and H- bonded quinone with NH deformation frequency (Hasmot saikh and Parthakumar Chandra, 1999). Sujana Reddy and Chandrasekhar Rao (2000) indicated that humic acid behaved like weak acids using potentiometric titrations. Lal and Mishra (2000) reported that contribution of phenolic hydroxyl group in total acidity of humic acid was more than of carboxylic group. Cross polarization matric angle spinning CP-MAS-C-NMR spectroscopy isolated humic acid with higher oxygen content and lower C, H, N when treated with NPK + blue green algae and in contrast with NPK and farm yard manure was observed by Prasad and Singh (2000). Santhi *et al.* (2001) quantified CEC of humic acid and was 400 Cmol (p+)/kg. Lobartini *et al.* (1992) observed that humic acid fraction from lignite contain larger N content compared to non-lignite humate and also showed humic acid similar to mollisols. Humic acid fraction has been derived from organic matter order sediments such as lignite lenses or older lignite source (Ivanovich *et al.*, 1996). Madhumita Das *et al.* (2000) ranked humic acid under natural condition maximum in the order of sal = teak = pine > agroforestry > fallow > dariyfarming > horticulture > pasture.Humic material is mainly lipids and was more effective in stabilizing soil aggregates and depends on its incubation period (Dinel *et al.*, 1991). Singhal and Pramod Kumar (1992) studied the prescence of C-C, C-OH and C-O-C of glucoside and polymeric substances on humic substance which gave loose structure and responsible for enhanced water holding capacity. Whiteley (1993) observed waterstable aggregates in soil by addition of lignite humic acid. Larger number of functional groups of humic acid particularly carboxyl and phenolic OH groups possessed a metal binding activity, which promoted nutrient assimilation and plant metabolism (Concheri *et al.*, 1996). igher molecular weight of humic acid favoured the physical adsorption due to entrophy reactions (Basak and Ghosh, 1999). Schnitzer (2000) opined that humic acid substances were good chelating agents having large surface per unit weight and an excellent dispersants and depending upon pH it acts as oxidizing and reducing agent. Manojkumar *et al.* (2002) observed that at higher humate concentration the trend of specific surface area was Zn > Co > Cu > Al and mineral ion humate interaction was significantly different for montmorillonite and kaolinite clays.

**Physiological role of humic acid**

Humic acid contains growth promoting substances and indirectly helps in promoting growth and yield of crops by decreasing IAA oxidase activity and promoting metabolic activities consequently accelerates growth and yield of crops. Humic acid readily available from Leonardite, a naturally oxidized form of lignite which contains auxin like substances and promoting growth of crops (O' Donnell, 1973).

Dell' Agnola and Nard (1987) and Casenova De Sanfilippo *et al.* (1990) observed that stimulatory effect of $NO_3$ uptake was due to gibberellins and auxin like constituents in humic acid and also existence of growth promoting substances. Albuzi *et al.* (1986) postulated that humic acid fractions stimulated the activities of nitrate reductase enzyme about 65 per cent over control and nitrate uptake enhanced at a concentration of 100 mg/l after an incubation period of 16 hours to increase the enzymatic activity in barley seedlings. Application of humic acid 25 - 250 mg/l accelerated chlorophyll synthesis and carotenoids and showed inhibitory effect at higher concentration in *Rhapanus sativus* (Singhvi, 1991). Peng Zheng Ping *et al.* (2001) observed that humic acid effectively enhanced the chlorophyll content and made the blade thickened, glossy dark green and further reduced that $NO_3$ - N, and increased the $NRA^{ase}$ activity in cabbage. Hydroxy proline formation enhanced by a mechanism which rendered more ferrous ion for proline hydroxylation and stimulated enzyme required for hydroxyl proline process in *Beta vulgaris* (Vaughan and Ord, 1983). Maggioni *et al.* (1987) reasoned that humic acid increased the nutrient uptake via an enzymatic activities of $K^+$ and $Mg^{2+}$ + $ATP^{ase}$. Nardi *et al.* (2000) observed water soluble constituent stimulated nitrate uptake, $K^+$ stimulated activity in oat root microsomes and $H^+$ extrusion from root but decreased ATP concentrations. Irrespective of molecular weight humic acid promoted enzymatic activity by stimulating invertase and peroxidase activity (Concheri *et al.*, 1996). Sumukh Das (2001) reported that permeability of plant membranes increased resulting in higher metabolic activity due to increased nutrient availability and enzymatic activity. Humic acid increased the root respiration activity, thereby resulted in higher root length and dry weight in maize and gourd (Mirsanavosmidova, 1960). Mylonas and Mc Cants (1980) stated that humic acid application intensified the respiration, enhanced protein synthesis and nucleic acids and acted as hydrogen carrier and removed oxygen deficiency. Higher levels of OD phenols in plants retarded IAA oxidase activity and promoted the plant growth by IAA (Mato *et al.*, 1971). Cacco and Agnola (1984) reported that plant growth regulatory activity of soil humic complexes was due to direct action and inhibition of IAA oxidase activity. Mallikarjuna Rao *et al.* (1987) recorded higher OD-phenol values by humic acid, which retarded IAA oxidase activity. Quinone is the most important constituent of humic aid contributed higher dry matter and also helped in transformation of trypsine to P hydroxyphenyl acetic acids and tryptophan to IAA (Raina and Goswami 1988). Ferretti *et al.* (1991) studied an increase in endogenous hormone concentration in the tissues as humic acid inhibited IAA oxidase in maize. Young and Chen (1997) determined polyphenolic compound, which induced auxin activity by humic application.

**Influence of humic acid on crop growth**

Humic acid enhanced plant growth by increasing the adsorption of ion facilitating chelation of micronutrients and also contains growth promoters. The interaction of glycine with humic acid 10 mg/l in white solution brought out a substantial increase (5.1. per cent) in tomato roots (Ivanohelanova and Sladky, 1967). Poapst *et al.* (1970) reported that higher concentration of humic acid retarded stem elongation as it blocked the uptake of gibberllic acid. Vaughan and Lanehan, (1976) reported that Enhanced growth of roots and shoots of wheat under axenic condition and microbial degradation was not necessary for humic acid as it has direct effect on biochemical process. Mylonas and Mc Cants (1980) recorded higher root length by 30 and 35% for 75 and 100 ppm of humic acid, whereas, at higher concentration decreased the root length in tobacco seedlings. Humic acid application at 30 kg/ha resulted in higher dry matter and root shoot ratio in sorghum (Mallikarjuna Rao, 1987). Raina and Goswami (1988) observed that the growth rate at 5, 10 and 20 ppm of humic acid was 75.0, 79.1 and 37.1 per cent, respectively in maize and increased root length and dry matter *Pisum sativum* seedlings (Sensi *et al.*, 1990). Humic matter treated roots were longer and with very few hairs (Nardi *et al.*, 1994). Harper *et al.* (1995) reported that toxic effect of Al on root elonglation was negated by forming complexes of aluminium with organic ligands. Humid acid application in soybean resulted in 96, 92 and 72% variations for shoot, root and nodules and reduced the nodule number, increased the nodule dry weight and N (Das, 1996). Concheri *et al.* (1996) opined that humic acid fraction supplementation increased the plant root hairs over control.

**Effect of humic acid on crop yield**

Humic acid plays a vital role in enhancing the crop productivity at optimal dose which varies among the crop, soil and environment. Sodium humate spraying at 10 ppm thrice on soybean showed 24% increased yield whereas, at 50 ppm only 14.5% increased yield and tomato 109 and 104 per cent respectively, for 10 and 50 ppm (Varshney and Gaur, 1974). Humic acid applied to the soil at 7.5 t/ha gave the highest yield in cabbage, however, aerial application of humic acid was very harmful (Suwandi and Nurtika 1987). Swayamprabha *et al.* (1989) recorded significantly higher number of pods/plant, shelling percentage and 100 kernal weight by application of 20 kg humic acid/ha along with gypsum at 200 kg/ha at flowering phase. Humic acid along with compound fertilizer application gave better yield in wheat, maize, cotton, rape and sesame than DAP and chemical fertilizer application alone (Xui *et al.*, 1994). Chellaiah and Gopalaswamy (1995) reported that application of 2% DAP and 0.5% humic acid gave the highest yield over control in rice fallow sesame. Vasudevan *et al.* (1997) recorded higher yield in sunflower by applying recommended dose of fertilizers, 2 kg boron, 4 kg zinc and 5 litres humic acid/ha over control without humic acid. Singaravel *et al.* (1998) accounted higher seed yield in sesame over control by humic acid application at 20 kg/ha. Mishra and Srivastava (1998) stated the oat yield increased for 100 mg humic acid application on carbon basis over control and showed detrimental effect at higher concentration (200 mg). Application of 10 kg/ha of humic acid along with 0.3 per cent foliar spraying and 0.1 per cent root dipping was effective as humic acid application at 20 kg/ha in augmenting rice yield along with NPK fertilizers over control (Sathyabama, 2001). According to Balasubramanian *et al.* (2002) humic acid soil application 20 kg/ha along with rhizobium increased the pod number, seed index and yield (8.25 q/ha) over control (4.8q/ha) and rhizobium inoculation alone (6.75q/ha) in soybean. Application of humic acid from aqueous source showed one per cent increased crop yield, whereas, humic substance from lignite yielded significantly higher (Rozenbaha *et al.*, 2002). Seed soaking with 1.5 per cent humic acid and foliar spraying of humic acid (0.5%) improved crop growth and yield in summer irrigated cotton (AICCIP, 1994). Solaiappan *et al.* (1995) reported that seed soaking in one per cent humic acid solution recorded significantly higher plant height, sympodial branches and bolls per plant over control and also observed significantly higher seed cotton yield over control under upland condition. Yang-An-Min *et al.* (1999) recommended 415 and 1085 mg/kg HA-K of foliar application or root injection of 74.7 mg kg HA-K to produce a unit yield of 1.9 t/ha. Chellaiah and Gopalaswamy (2000) reported that 2% DAP and 1% humic acid spraying produced higher seed cotton yield over control.

**Effect of humic acid on nutrient uptake**

Most of the research works in humic acid failed to find out the influence of plant growth under limited nutrient conditions and restricted under laboratory condition. Nishita *et al.* (1973) observed that increased N and K concentrations in barley seedlings and reduced B, $C_s^{137}$, Na, Sr, Ba by humic acid application with a modified Neubeaur method. Dormaur (1975) reported that total nutrient uptake decreased in lower concentration (1 mg/l) of humic substance, increased at optimum concentration (5 mg/l) and when concentration further increased reduced nutrient uptake in *Phaseolus vulgaris*. Humic acid application enhanced the K uptake in tobacco (Mylonas and Mc Cants 1980) and in tomato (Guminiski *et al.*, 1983). Addition of the natural complexing agent humic acid in solution containing Cd, suppressed the adsorption of Cd in corn roots (Tyler and Bride, 1982). The contents of N, P, K, Ca, Mg, Fe and Zn in sugarcane leaf blade were enhanced by humic acid application (Saravanan, 1989). Similar increase in nutrient contents in maize was reported by (Raina and Goswami (1988). Fegbenro and Agboola *et al.* (1993) reported that 1280 mg/l humic acid addition in tomato seedlings increased the shoot accumulation of P, K, Ca, Mg, Fe, Mn and Zn as well as increased accumulation of N, Ca, Fe, Zn and Cu in roots and showed as positive correlation of electrolyte leakage with humic acid. Highly significant positive relationship was obtained between humic acid on nutrient uptake and yield of fingermillet, maize and cowpea in long term experiment (Santhi *et al.*, 2001). Balasubramanian *et al.* (2002) reported that humic acid enhanced the rhizobium activity in soybean.

**Effect of humic acid on soil fertility**

The soil is the most important natural resource and the presence of organic matter that distinguishes soil from a barren mass of rock particles to become a living system. Decrease in soil fertility, increase in soil acidity, deletion in organic matter and humus content result in poor crop yield and quality. Soil organic matter is a quite important as a source of CEC in plain soils. The beneficial effect of humified materials on the physical and chemical properties of soil and nutrient uptake by plant has been increasingly recognized. Application of fulvic acid for saline sodic soil augmented Zn solubility by thousand fold due to enhanced soil diffusion and chelating properties (Milap Chand *et al.*, 1980). Tan (1980) stated that at pH 7.0, humic acid was capable of dissolving silica, aluminium and potassium from minerals by chelation and complex reactions or both. Lignite humic acid application added to alkaline soil dissclved the fixed P such as tricalcium photosphate or fluarapatite (Martinez, 1984). Samirpal and Sengupta (1985) observed an increased K availability due to release of fixed K by humic acid application and also increased Fe, Mn and Zn in soil. Humic acid form nitro-organo complexes which are attributed to slow release of nitrogen (Mallikarjuna Rao *et al.*, 1987). Tan and Binger (1986) opined that humic acid addition chelated aluminium thus rendered it inactive from aluminium phosphate. On an average organic matter could contribute 49% CEC and 19% specific surface area of fractionized materials in soil (Thompson *et al.*, 1989). Chandrikavaradachari *et al.* (1991) stated that exchangeable cations played an important role in complexation of humic acid by the clay minerals. Stevenson (1991) opined that humic acid forms complex formation which made the nutrition in available form to the plant. Flocculation value of Na-montmorillonite found to be increased with increasing concentration of humic acid at all pH levels. Humic acid may be activated by reacting peat with ammonia resulting in sustained release of ammonia (Abbes *et al.*, 1994). David *et al.* (1994) suspected that at low pH, humic acid complexes with Fe in solution making more P availability. Schnitzer (2000) stated that humic acid maintained adequate soil structure by acting as a binding agent in the formation of soil aggregate, ensuring satisfactory drainage and aeration, protected from erosion and played a major role in water retention. Humic acid occupies an intermediate position in soil organic matter which persists in soil for a prolonged period so as to the crop plants unlike fulvic acid which are interchangeable from one form to another form in soil. Moreover, humic acid extracted from lignite, coal, FYM, coirpith possessed same structure and properties like naturally occurring humic acid in soil thus should have more residual influence on the succeeding crop.

**Role of humic acid in organic agriculture**

Organic manures play critical and prominent role in sustained productivity of crops in the tropical soils under intensive cultivation. As the source of organic manures is dwindling day by day there are great needs to search out the alternatives. Many researchers in developed countries extensively studied the importance of humic acid on crop growth and yield and it is now in commercial utilization. But most of the studies on humic acid were conducted in controlled and pot culture conditions and as nutrient solutions in various crops. Whereas, the main contribution of humus towards soil fertility is largely indirect through its influence on improving physiochemical and biological properties. Thus the researchers should focus on the field performance of humic acid. Moreover the mass extraction of humic acid from various organic sources are also found to be costlier.

## CONCLUSION

From the foregoing review, it could be inferred that humic acid application along with recommended inorganic fertilizers and organic manures plays a greater role in plant bio-chemical and physiological activities and soil fertility, consequently resulting in better growth and yield of crops. On the other hand, if humic acid was applied at higher level it hampers the growth and yield of crops. Thus optimum dose should be applied. Moreover there is limited work has been done about the influence of different forms of humic acid on crop growth.

**Future line of work**

Humic acid extracted from the lignite has many advantages in increasing the crop yield, quality and as well as it take cares the soil fertility. Long term research on the influence of lignite humic acid on crop yield and soil fertility would be fruitful. Soil physical properties influenced by the humic acid should be studied in depth and the influence of lignite humic acid should be studied for the perennial trees and fruit crops with its long-term benefits. The researchers should be focused on studying the feasibility of including lignite humic acid as one of the components in organic agriculture.

## REFERENCES

Abbes, C. *et al.* (1994). *Soil Biol. Bio. Chem.*, **26**: 1041-1051.
Albuzi, A. *et al.* (1986). *Can. J. Soil. Sci.*, **66**: 731-736.
All India Co-ordinated Cotton Improvement Project (1994). Annual Progress Report, Coimbatore Centre, pp. 20-22.
Balasubramanian, O. *et al.* (2002). *Indian. J. Agric. Chem.*, **33**(1): 11-15.
Basak, U.K. and Ghosh, S.K. (1999). *J. Indian Soci. Soil Sci.*, **47**(2): 200-205.
Cacco, G. and Agnola, G.D. (1984). *Can. J. Soil. Sci.*, **64**: 225-228.
Casenova De Sanfilippo *et al.* (1990). *Biol. Plantarum*, **32**(5): 346-351.
Chandrasekaran, S. (1992). *Indian. J. Agric. Chem.*, **25**: 129-141.
Chandrikavaradachari *et al.* (1991). *Soil Sci.*, **151**(1): 220-227.
Chellaiah, N. and Gopalaswamy, N. (1995). *Agric. Sci. Digest*, **15**(4): 171-173.
Chellaiah, N. and Gopalaswamy, N. (2000). *Madras Agric. J.*, **87**(4-6): 267-270.

Concheri, G.S. *et al.* (1996). *Plant Soil,* **179**: 65-72.
Das, A. (1996). *J. Indian Soci. Soil Sci.,* **44**(4): 788-790.
David, P.P. *et al.* (1994). *J. Plant Nutrition,* **17**(1): 173-184.
Dell' Agnola G. and Nard, S. (1987). *Biol. Fertil. Soils.,* **4**: 115-118.
Dinel, H. *et al.* (1991). *Soil Sci.,* **151**: 146-155.
Dormaur, J.F. (1975). *Can. J. Soil Sci.,* **55**: 111-118.
Fegbenro, J.A. and Agboola, A.A. (1993). *J. Plant Nutrition,* **16**(8): 1465-1483.
Ferretti, M.R. *et al.* (1991). *Can. J. Soil Sci.,* **71**: 239-242.
Guminiski, S. *et al.* (1983). *J. Exp. Bot.,* **16**: 151-152.
Harper, S.M. *et al.* (1995). *Plant Soil,* **171**: 189-192.
Hasmotsaikh and Parthakumar Chandra (1999). *J. Indian Soci. Soil Sci.,* **47**(2): 206-211.
Ivanohelanova and Sladky, Z. (1967). *Biol. Plantarum,* **9**(4): 276-284.
Ivanovich, M. *et al.* (1996). Symposium at the American Chemical Society's National Meeting, Chicacogo, USA, 220-243.
Khungar, S.C. and Manoharan, V. (2000). *Fertil. News,* **45**(8): 23-25.
Kowalski. R. and Davies, G.F. (1982). *Plant Soil,* **68**: 139-141.
Lal, J.K. and Mishra, B. (2000). *J. Res.,* **12**(2): 179-185.
Lobartini, J.C. *et al.* (1992). *Sci. Total Environment,* **113**(1): 1-15.
Madhumita Das *et al.* (2000). *Ann. Agric. Res.,* **21**(2): 216-222.
Maggioni, A., *et al.* (1987). *Sci. Total Environ.,* **62**: 355-363.
Mallikarjuna Rao *et al.* (1987). *Curr. Sci.,* **56**: 1273-1276.
Manjokumar *et al.* (2002). *J. Indian Soci Soil. Sci.,* **50**: 213-216.
Martinez, M.A. *et al.* (1984). *Soil Sci.,* **138**(4): 257-261.
Mato, M.C. *et al.* (1971). *Soil Biol. Biochem.,* : 258-288.
Milap Chand *et al.* (1980). *Plant Soil,* **55**: 17-24.
Mirsanavosmidova (1960). *Biol. Plantarum,* **2**(2): 152-164.
Mishra, B. and Srivastava, L.L. (1998). *J. Indian Soc. Soil. Sci.,* **36**: 83-89.
Mylonas, V.A. and Mc Cants, C.B. (1980). *Plant Soil,* **54**: 485-490.
Nardi, S. *et al.* (1994). *Soil Biol. Biochem.,* **26**: 1341-1346.
Nardi, S. *et al.* (2000). *Soil Sci. Soc. Amer. J.,* **64**: 639-645.
Nishita, H. *et al.* (1973). *Plant Soil,* **39**: 161-176.
O'Donnell, R.W. (1973). *Soil Sci.,* **116**: 106-112.
Peng Zheng Ping *et al.* (2001). *J. Hebci Agric. Univ.,* **24**(1): 24-27.
Poapst, P.A. *et al.* (1970). *Plant Soil,* **32**: 367-372.
Prasad, B. and Singh, K.N. (2000). *J. Indian. Soc. Soil Sci.,* **48**(2): 377-378.
Raina, J.N. and Goswami, K.P. (1988). *J. Indian. Soc. Soil Sci.,* **36**: 264-268.
Rozenbaha *et al.* (2002). *Analytica - Chemica. Acta.,* **452**(1): 105-114.
Samirpal and Senugpta, B. (1985). *Plant Soil.,* **88**: 71-91.
Sanjibkar, (1998). *Indian Agric.,* **42**(4): 273-277.
Santhi, P.*et al.* (2001). *J. Indian Soci. Soil Sci.,* **49**(2): 281-289.
Saravanan, A. (1989). M.Sc. (Ag.) Thesis. Annamalai University.
Sathyabama, K. (2001). Ph.D. Thesis. Tamil Nadu Agricultural University. Coimbatore.
Schnitzer, M. (2000). *Adv. Agron.,* **68**: 3-54.
Sensi, N. *et al.* (1990). *Plant Soil,* **127**: 41-47.
Singaravel, K. *et al.* (1998). *J. Indian Soc. Soil Sci.,* **46**(1): 145-146.
Singhal, R.M. and Pramod Kumar (1992). *J. Indian. Soc Soil Sci.,* **40**: 837-839.
Singhvi, N.R. (1991). *Acta Botanica India,* **19**: 97-99.
Solaiappan, U. *et al.* (1995). *Indian J. Agron.,* **40**(1): 156-157.
Stevenson, F.J. (1991). *Organic Matter – Micronutrient reactions in soil.* Soil Sci. Soc. Am., Madison.
Sujana Reddy, K. and Chandrasekhar Rao, P. (2000). *J. Indian Soc. Soil Sci.,* **48**(3): 596-598.
Sumukh Das (2001). *Pestology,* **25**(3): 51-53.
Suwandi and Nurtika, N. (1987). *Buletin - Penelitian - Hortikulture,* **15**(2): 213-218.
Swayamprabha, K. *et al.* (1989). *National Seminar on "Humic Acids in Agriculture".* Annamalai University,Tamil Nadu, India, pp. 175-181.
Tan, K.H. (1980). *Soil Sci.,* **129**(1): 5-11.
Tan, K.H. and Binger, A. (1986). *Soil Sci.,* **141**: 20-25.

Thangavelu, R. and Ramabadran, R. (1993). *Madras Agric. J.*, **80**: 575-580.
Thompson, M.L. *et al.* (1989). *Soil Sci.*, **148**: 250-256.
Tyler, L.D. and Bride, M.C. (1982). *Plant Soil.*, **64**: 259-262.
Varshney, T.N. and Gaur, A.C. (1974). *Curr. Sci.*, **43**: 95-97.
Vasudevan, S.N. *et al.* (1997). *Indian J. Agric. Sci.*, **67**(3): 110-112.
Vaughan, D. and Lanehan, D.J. (1976). *Plant Soil*, **44**: 445-449.
Vaughan, D. and Ord, B.G. (1983). *Plant Soil*, **73**: 27-34.
Whiteley, M. (1993). *Soil Tech.*, **6**(4): 321-327.
Xui, S.C. *et al.* (1994). *J. Hebci. Agric. Univ.*, **17**(1): 24-27.
Yang-An-Min *et al.* (1999). *China Cottons*, **26**: 12-14.
Young, C.C. and Chen, L.F. (1997). *Plant Soil*, **195**: 143-149.