

Effects of Nitrohumic Acids Derived from Low Grade Coal of Sarawak on Aggregate Stability of Loamy Sand and Clay Loam

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ABSTRACT

Humic acids are commonly used to improve the aggregate stability of soils; however, it is not popular in this region. In this paper, low grade coal from Mukah was used as the source of nitrohumic acids and the effects of the nitrohumic acids on the aggregate stability of loamy sand (83.5% sand, 16.4% clay) and clay loam (31% sand, 37% clay) were investigated. Nitrohumic acids were prepared with nitric acid pretreatment and extracted with acid base fractionation. On loamy sand and clay loam, six application rates of nitrohumic acids (0.00, 0.05, 0.10, 0.50, 1.00 and 10.00 g/kg) and 5 wetting and drying cycles were used to assess the changes in the aggregate stability. Results showed that the aggregate stability of loamy sand was improved with nitrohumic acids amendment. For a clay loam sample, the aggregate stability was instead reduced. Nevertheless, there was an upper limit (0.10 g/kg) where the aggregate stability was improved or alleviated. In conclusion, the effect of nitrohumic acids on aggregate stability is dependent on soil type.

Keywords: Nitrohumic acids, low grade coal, aggregate stability, loamy sand, clay loam

INTRODUCTION

Soil structure is an imperative factor in determining soil productivity. Under intensive cropping, soils usually experience progressive depletion in organic matter content resulting in reduced infiltration rates, increased slaking and crusting, accelerated runoff erosion and consequently poor crop productivity (Piccolo *et al.* 1997). Conventionally, organic residues are incorporated as soil conditioners to improve organic matter status. However, for undecomposed residues, a large quantity is needed to obtain significant improvements (Piccolo *et al.* 1997). Some synthetic polymers such as polyacrylamides and polyvinyl alcohols are found to function similarly (Gabriels 1990; Bryan 1992; Sojka and Lentz 1994). Nevertheless, these synthetic conditioners are found to be easily degraded by microorganisms, thus frequent applications are required imposing extra cost; they are therefore less favorable (Gruła *et al.* 1994). Humic sub-

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stances have been well established as a potential soil conditioner, and are regarded as better than the manure and synthetic conditioners. Fortun *et al.* (1989) reported that humic substances improved and prolonged aggregate stability at low application rate, performing better than the bulk farmyard manure. In addition, Rausa *et al.* (1989) reported that they are free from pollutants and are highly reactive towards soil components due to the presence of acidic functional groups; the polycondensed aromatic structure renders them more resistant to microbial attack.

Today, humic acids have become commercially available in the form of inexpensive soluble salts, referred to as sodium or potassium humates. These humic acid products have been well accepted by the agriculture community elsewhere. In Malaysia, they are less commonly used as these products are imported; therefore, they are relatively higher in selling price than other soil conditioners. However, the possibility of producing humic acids from indigenous sources will make the products better known. In Sarawak, abundance of low grade coal was discovered in Mukah, serving as a potential source of humic acids. A preliminary study revealed that the regeneration process with nitric acid prior to extraction produced humic acids with high yields, low ash content and high acidic functional groups (Sim *et al.* 2006). Research on the effect of the locally produced humic acids to improve the aggregate stability is limited. This paper reports on the potential of the nitrohumic acids derived from the low grade coal of Mukah in improving the aggregate stability of two soil textures: loamy sand and clay loam.

MATERIALS AND METHODS

Soil Samples

Topsoil was collected from the construction site located at 10th mile of Kuching, lying between latitudes 24° 59' N and 25° 11' N, and longitudes 19° 27' E and 19° 44' E. The construction site covers approximately 22 hectares of land and was at the clearing stage of preparation for construction of a hostel for the Malaysian Airforce. The soil samples were predetermined with field textural analysis and the classifications were confirmed with soil textural classification system developed by the U.S. Department of Agriculture (Soil Survey Staff 1999). The soil samples were subjected to analyses that included pH, particle size, moisture content and organic matter content. The particle size analysis was performed according to the pipette method (Dewis and Freitae 1970). The soil organic matter was expressed on an oven-dry weight basis and determined by the combustion of samples at 800°C for 2 hours (Allen 1989). Soil pH was measured with a pH metre on a suspension of soil in water (1:1).

Preparation of Nitrohumic Acids

Nitrohumic acids are referred to as humic acids prepared with nitric acid pre-treatment prior to acid base fractionation. They were prepared from low grade

coal of Mukah. The coal sample was ground and sieved through a 50 μm sieve prior to chemical treatment and extraction procedure. The coal sample was pre-treated with 10 % nitric acid prior to extraction. One gram of coal sample was added to 5 mL of nitric acid at 70°C for 2 hours with continuous stirring. The nitrated coal was filtered, washed with distilled water and oven-dried at 60°C. The extraction method described by Swift (1996) was adopted with modifications. Ten gram of coal sample was added to 100 mL of KOH (0.5M) and heated at 70°C for 2 hours. The supernatant was filtered through a 50 μm sieve and the coal residue was washed with distilled water until the wash water was clear. The coal residue was dried at 105°C and weighed. The supernatant was acidified with concentrated H_2SO_4 to pH 1-2 and allowed to stand overnight. The precipitated nitrohumic acids were separated by centrifugation at 6,000 rpm for 15 minutes. The nitrohumic acids were washed with distilled water and centrifuged. The gel-like nitrohumic acids were oven-dried at 60°C and stored in desiccators (International Humic Substances Society 1983; Dick *et al.* 2002).

Characterisation of Nitrohumic Acids

The nitrohumic acids were subjected to analyses that included moisture content, ash content, acidic functional groups content, FTIR and UV/Vis spectroscopy. Moisture content was determined by drying the samples at 105°C overnight while ash content was determined by combustion of the samples at 800°C for 2 hours. Total acidity was measured using the barium hydroxide method and the carboxyl groups were determined by using calcium acetate method (Stevenson 1982). Phenolic content was calculated as the difference between total acidity and the carboxyl groups. FTIR spectra of the samples were recorded on KBr pellets (2 mg nitrohumic acids and 100 mg KBr) using FTIR spectrophotometer. For UV-Vis analysis, approximately 5.0 mg of nitrohumic acids were dissolved in 25 mL of 0.05 mol L⁻¹ NaHCO₃ solutions with pH adjusted to 8-9 with 0.1 M NaOH to assist solubility. Absorbance at 465 nm and 665 nm were recorded. The E_4/E_6 value was calculated based on the ratio of absorbance at 465 nm and 665 nm.

Preparation of Humic Acids Solution

Five nitrohumic acid stock solutions were prepared separately by dissolving 0.005 g, 0.010 g, 0.050 g, 0.100 g and 1.000 g of nitrohumic acids in 30 mL of distilled water. Sodium hydroxide at 0.1M was added dropwise until the pH stabilised at 7.0. The final volumes were made up to 50 mL. A control of distilled water was also prepared simultaneously.

Aggregate Stability Determination

The nitrohumate solutions were mixed with 100 g of 2-5 mm air-dry aggregates to yield the following treatment rates: 0.00, 0.05, 0.10, 0.50, 1.00 and 10.00 g/kg. Lanyon (2001) reports that soil aggregates of 2-5 mm are the most stable fraction to withstand the wetting and drying cycles. The soil samples amended with

nitrohumic acids were homogenised and incubated for 14 days at 25°C prior to continuous wetting and drying cycles.

Aggregate stability of the soil samples was measured by wetting and drying procedure (Kemper and Rosenau 1986). The incubated soil samples were air-dried and sieved to obtain 1-2 mm aggregates. Three grams of the 1-2 mm aggregates were weighed and distributed in a 0.5 mm mesh sieve and placed into a 10 L beaker containing water until the level of 20 mm height above the base of screen. The aggregates were allowed to sit overnight and agitated 20 times on the following day. The 0.5 mm sieve was removed and oven-dried at 105°C for 2 hours. The aggregate stability was calculated according to the following equation:

$$\text{Aggregate stability (\%)} = \frac{W_R - S_W}{3.00 - S_W} \times 100$$

where W_R = total weight of aggregates retained on 0.5 mm sieve.

S_W = weight of 2.0 to 0.5 mm sand.

The procedure was repeated for 2, 3, 4 and 5 cycles in duplicates.

Statistical Analysis

Analysis of variance with repeated measurements at 95% confidence level was employed to analyse the significant differences between the aggregate stability of soils (loamy sand and clay loam) with and without application of nitrohumic acids. The analysis was performed as a split plot design for repeated measurements in a completely randomised design with Statistica 6.0.

RESULTS AND DISCUSSION

Properties of Soils and Nitrohumic Acids

Table 1 summarises the general properties of the loamy sand and clay loam samples. The loamy sand was dominated by sand fraction, while the clay loam had a rather balanced fraction of sand, silt and clay. According to Brown (2006), clay loam is the soil material with the most evenly distributed sand, silt, and clay fractions, with 27 to 40% clay and 20 to 45% sand (Schut 1997). Soil erodibility is a measure of erosion index, EI; lower EI value indicates better stability (Piccolo *et al.* 1997). The experimental results indicate that loamy sand is potentially more susceptible to erosion than clay loam. In addition to the mineralogical properties, soil physical and chemical properties such as organic matter content, moisture content, and pH are other important parameters influencing soil erodibility (Brady and Weil 1996). Chaney and Swift (1984) found a highly significant correlation between the aggregate stability and the organic matter content, moisture content and pH. Greater stability was reported with increased soil moisture and decreased pH. Soil moisture functions bind the soil particles, hence improving the stability, while lower pH reflects the presence of Al and Fe

TABLE 1
Soil properties

Properties	Loamy sand	Clay loam
Sand, %	83.5	31.0
Silt, %	0.0	31.0
Clay, %	16.4	37.0
Aggregate stability, %	43	18
Soil moisture, %	0.50 ± 0.04	0.56 ■ 0.02
Organic matter, %	0.38 ± 0.05	0.10 ■ 0.03
EI (sand + silt/ OM + clay)	4.97	1.67
pH	4.59	4.76

TABLE 2
Characterisation of nitrohumic acids

Properties	
Moisture content, %	14.92 ■ 0.13
Ash content, %	2.99 ■ 0.02
Total acidity, meq g ⁻¹	19.25 ■ 1.58
-COOH, meq g ⁻¹	7.70 ■ 1.75
Phenolic OH, meq g ⁻¹	11.55 ■ 2.37
E ₄ /E ₆	4.92 ■ 0.09

in the soil solution that contributes to the formation of organic matter complexes. Despite the relationships, the organic matter content, moisture content and pH of both soils were statistically similar ($p > 0.05$).

Table 2 summarises the characteristics of the nitrohumic acids. The acidic functional groups of the nitrohumic acids were comparatively higher than the acidic functional groups content of the humic acids prepared without nitration process (Sim *et al.* 2006). Typically, nitration process results in enrichment of carboxyl groups, leading to the formation of humic acids with a variety of aliphatic dicarboxylic acids, benzene carboxylic acids, hydroxybenzoic acids and nitro compounds (Chambury *et al.* 1945). The acidic functional groups upon contact with soil aggregates react quickly with polyvalent cations (Ca²⁺, Mg²⁺, Al³⁺) found on surfaces of clay particles to form well described humus polyvalent metal-clay complexes (Greenland 1977; Theng 1982), thus demonstrating an improved aggregate stability.

Effects of Nitrohumic Acids Pre-treatment on Response to Wetting and Drying Cycles

Table 3 summarises the aggregate stability of the loamy sand and clay loam upon 5 wetting-drying cycles, with the superscript indicating the percentage of aggregate stability relative to the controls (referred to as the aggregate stability of soils without application of humic acids for loamy sand and clay loam respec-

TABLE 3
Aggregate stability of loamy sand and clay loam upon 5 successive wetting-drying cycles (superscript values are the percentages of aggregate stability relative to the controls)

Application rates (mg/kg)	Cycle				
	1	2	3	4	5
Loamy sand					
0.00	56.5 ⁽¹⁰⁰⁾	56.2 ^(99.5)	55.7 ^(98.6)	54.5 ^(96.5)	54.0 ^(95.6)
0.05	58.7 ^(103.8)	58.3 ^(103.2)	57.9 ^(102.5)	57.7 ^(102.1)	57.0 ^(100.9)
0.10	63.2 ^(111.7)	62.4 ^(110.4)	61.5 ^(108.8)	61.2 ^(108.3)	60.5 ^(107.1)
0.50	57.4 ^(101.6)	56.8 ^(100.5)	55.9 ^(98.9)	55.0 ^(97.3)	54.7 ^(96.8)
1.00	52.3 ^(92.6)	51.7 ^(91.5)	51.3 ^(90.8)	51.0 ^(90.3)	50.7 ^(89.7)
10.00	69.0 ^(122.1)	68.0 ^(120.4)	67.2 ^(118.9)	62.8 ^(115.2)	62.0 ^(109.7)
Clay Loam					
0.00	16.6 ⁽¹⁰⁰⁾	16.4 ^(98.8)	16.0 ^(96.4)	15.7 ^(94.6)	15.3 ^(92.2)
0.05	11.8 ^(71.1)	11.4 ^(68.7)	10.8 ^(65.1)	10.4 ^(62.7)	10.2 ^(61.4)
0.10	9.9 ^(59.6)	8.5 ^(51.2)	8.2 ^(49.4)	7.9 ^(47.6)	7.4 ^(44.6)
0.50	10.5 ^(63.3)	10.0 ^(60.2)	9.7 ^(58.4)	9.2 ^(55.4)	9.0 ^(54.2)
1.00	12.0 ^(72.3)	11.3 ^(68.1)	11.0 ^(66.3)	10.7 ^(64.5)	10.2 ^(61.4)
10.00	16.5 ^(99.4)	15.4 ^(92.8)	15.0 ^(90.4)	9.9 ^(59.6)	8.2 ^(49.4)

tively). Successive wetting and drying cycles consistently reduced the aggregate stability of both soils. According to Utomo and Dexter (1982), wetting and drying cycles create planes of weakness which allow the soils to break up into smaller aggregates upon the impact of mechanical stress by the wetting up and further agitation by the wet sieving procedure.

Application of humic acids on the aggregate stability of loamy sand and clay loam demonstrated different observations. Loamy sand showed an improved aggregate stability with increasing amounts of nitrohumic acids up to 0.10 g/kg. At 1.00 g/kg, aggregate stability was disrupted before improvement was resumed with the treatment of 10.00 g/kg of nitrohumic acids. Statistical analysis implied that cycles and application rate had significant effects on the aggregate stability with p -value 0.043 and 0.000, respectively. However, no apparent interaction effect (p -value 0.575) was found between both factors on the aggregate stability of the samples. Inconsistent improvements in aggregate stability with humic acids was similarly reported by other studies. Piccolo *et al.* (1997) reported that there was an upper limit beyond which beneficial effects of humic substances failed. The aggregate stability decreased at application rates > 0.10 g/kg suggesting that higher rates of humic substances can penetrate the clay domain and form complex chelates with the polyvalent cations inside the intercrystalline domains, resulting in displacement of the less strongly bound clay particles (Theng 1982). Durgin and Chaney (1984) further investigated the

dispersive effect of humic substances, indicating that high molecular weight aromatic and aliphatic polycarboxylic acids were able to disperse kaolinite by offsetting the positive charge on the edges of clay particles and promoting clay dispersion. The improved aggregate stability at 10.00 g/kg after the reduction in the aggregate stability at 1.00 g/kg could be explained with the reduced dispersive effect as Jastrow and Miller (1998) showed that the amounts of dispersed clays decreased with the increase in aggregate stability.

For clay loam samples, application of nitrohumic acids failed to improve the aggregate stability. The aggregate stability was gradually reduced with increasing amounts of nitrohumic acids to 0.10 g/kg. Further increases in application rate demonstrated an improved aggregate stability, however, it was not better than the control. Statistically, the cycles and application rate both demonstrated significant effects on the aggregate stability with p -values calculated at 0.036 and 0.00, respectively. Clay loam consists of a considerable amount of clay fraction, and is thus anticipated to be more susceptible to dispersive effect. Visser and Caillier (1988) suggest that humic acids are 140 times more effective in dispersing fine clay fraction (< 0.6 mm) and 1.2 times for coarse clay (0.6-20 mm). The apparent dispersion effect of humic acids on clay soil was evident in another study; Fortun *et al.* (1989) concluded that humic fraction increased the aggregate stability of sandy loam more efficiently than clay soil.

The overall results indicate that the aggregate stability of the loamy sand is improved with nitrohumic acids amendment, but not for clay loam. Indirectly, it suggests that aggregate stability of soils that are more susceptible to erosion could possibly be better improved with nitrohumic acids. Mbagwu and Piccolo (1989) reported similar observations that natural fragile soils benefited more from the amendment with humic acids than the more stable one. Nevertheless, it did not imply that the humic acids could not function to improve the aggregate stability of clay loam. *Fig. 1* illustrates the average aggregate stability of both soils after 5 consecutive wetting and drying cycles. For loamy sand, as revealed by Piccolo *et al.* (1997), there was an upper limit for the beneficial effect of humic substances

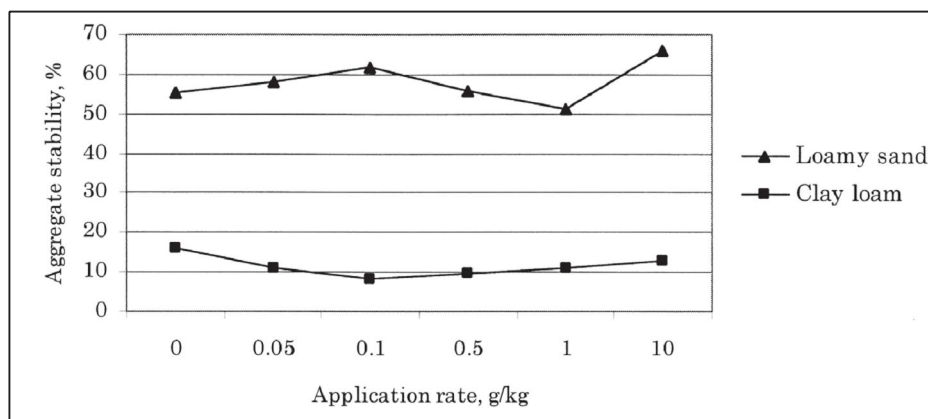


Fig. 1: Average aggregate stability of loamy sand and clay loam after 5 consecutive wetting and drying cycles.

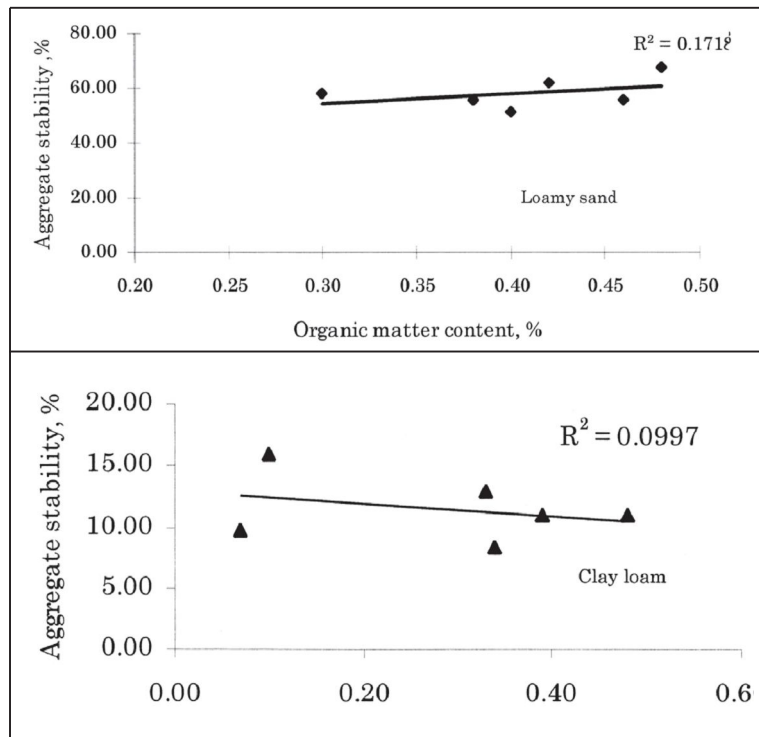


Fig. 2: Regression analysis of organic matter content and aggregate stability for loamy sand and clay loam

to be observed. For clay loam, on the other hand, the upper limit appeared to be the state where dispersive effect took place most significantly; beyond which aggregate stability indicated progressive improvement. The aggregate stability is predicted to improve further with application rates at > 10.00 g/kg as evidenced by Jastrow and Miller (1998) who reported an increase in aggregate stability with decreased amounts of dispersed clays.

Soil Organic Matter and Aggregate Stability

The relationship between organic matter content and aggregate stability has been discussed extensively. Contradictory results are often reported by researchers. Kay and Angers (1999) reported that a minimum of 2 % organic matter content is necessary to maintain structural stability; Boix-Fayos *et al.* (2003) showed that a threshold of 3-3.5 % organic matter content had to be attained to achieve increases in aggregate stability. However, Macrae and Mehuys (1987) and Perfect and Kay (1990) failed to find a significant correlation between aggregate stability and soil organic matter content. A regression study was performed to investigate the relationship between soil organic matter content and aggregate stability; insignificant correlation with R^2 value at 0.172 and 0.099 were attained for loamy sand and clay loam, respectively (Fig. 2).

FTIR was employed to investigate the association between nitrohumic acids and soils. Practically, no observable difference was noted from the spectra for soils amended with and without nitrohumic acids (spectra not shown). This does not indicate failure of the incorporation of nitrohumic acids onto soil particles but inappropriateness of the technique. Relative to the soil samples, a very low amount of humic acids was added ranging from 0.005 to 1% in aggregate stability study. Debosz *et al.* (2002) support the postulation that the effects of organic matter on soil properties are more likely to be attributed to quality and not quantity.

CONCLUSION

Nitrohumic acids sourced from the low grade coal of Sarawak could be employed to improve the aggregate stability of soils, particularly erosion susceptible soils. Nevertheless, there was an upper limit where the beneficial effects could be observed; beyond which the dispersive effect took place resulting in decreased aggregate stability. The more stable soils, clay loam samples in this study, failed to demonstrate improvements in the aggregate stability upon nitrohumic acids amendment. This is likely because the soils consisted of significant amounts of clay fractions which are more susceptible to clay dispersion effect. As a whole, the effects of nitrohumic acids on the aggregate stability are dependent on soil type.

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REFERENCES

- Allen, S.E. 1989. *Chemical Analysis of Ecological Materials*, pp. 15-16. London: Blackwell Scientific.
- Boix-Fayos, C., A. Calvo-Cases, A.C. Imeson and M.D. Soriano-Soto. 2003. Influence of soil properties on the aggregation of some Mediterranean soils and the use of aggregate size and stability as land degradation indicators. *Catena* **44**: 47-67.
- Brady, N.C. and R.R. Weil. 1996. *The Nature and Properties of Soils*. New Jersey: Prentice Hall.
- Brown, R.B. 2006. *Soil Texture*. Florida: Institute of Food and Agricultural Science, University of Florida.
- Bryan, R. 1992. The influence of some soil conditioners on soil properties: laboratory tests on Kenyan soil samples. *Soil Technol.* **5**: 225-247.
- Chambury, H.B., J.W. Eckerd, J.S. Latorre And C.R. Kinney. 1945. Chemistry of N in humic acids from HNO₃-treated coal. *J. Am. Chem. Soc.* **67**: 625-628.
- Chaney, K. And R.S. Swift. 1984. The influence of organic matter on aggregate stability in some British soils. *J. Soil Sci.* **35**: 223-230.

- Debosz, K., S.O. Petersen, L.K. Kure and P. Ambus. 2002. Evaluating effects of sewage sludge and household compost on soil physical, chemical and microbiological properties. *Appl. Soil Ecol.* **19**: 237-248.
- Dewis, J. and F. Freitae. 1970. *Physical and Chemical Methods of Soil and Water Analysis*, pp. 39-57. Rome: FAO
- Dick, D.P., A.S., Mangrich, S.M.C., Menezes, and B. Pereira. 2002. Chemical and spectroscopical characterization of humic acids from two South Brazilian coals of different ranks. *J. Braz. Chem. Soc.* **13**: 177-82.
- Durgin, P. B. and J.B. Chaney. 1984. Dispersion of kaolinite by dissolved organic matter from Douglas-fir roots. *Can. J. Soil Sci.* **64**: 445-455.
- Fortun, C., A. Fortun and G. Almendros. 1989. The effect of organic materials and their humified fractions on the formation and stabilisation of soil aggregates. *Sci. Total Environ.* **81-82**: 561-568.
- Gabriels, D. 1990. Application of soil conditioners for agriculture and engineering. In *Soil Colloids and Their Associations in Aggregates*, ed. M.F. De Boodt, M. Hayes and A. Herbilliom, pp. 557-565. New York: Plenum Press.
- Greenland, D. J. 1977. Interactions between humic and fulvic acids and clays. *Soil Sci.* **111**: 34-41.
- Grula, M.M., M.L. Huang and G. Sewell. 1994. Interactions of certain polyacrilamides with soil bacteria. *Soil Sci.* **158**: 291-300.
- International Humic Substances Society. 1983. Outline of extraction procedures. In *Proc. 1st International Humic Substances Society Conference*, ed. R..S. Swift. IHSS Press.
- Jastrow, J. D. and R.M. Miller. 1998. Soil aggregate stabilisation and carbon sequestration: feedback through organomineral associations. In *Soil Processes and the Carbon Cycle*, ed. R. Lal, J.M., Kimble, R.F. Follett and B.A. Stewart, pp. 207-223. Boca Raton: CRC Press.
- Kay, B. D. and D.A. Angers. 1999. Soil structure. In *Handbook of Soil Science*, ed. M.E. Summer. A-229 - A-276. Boca Raton, USA: CRC Press.
- Kemper, W.D. and R.C. Rosenau. 1986. Size distribution of aggregates. In *Methods of Soil Analysis, Part I*, ed. A. Klute, pp. 425-442. ASA-SSSA, Madison: Wiley Internaional.
- Lanyon, D.M. 2001. Coalescence of a water stable soil. PhD Dissertation, Department of Civil and Environmental Engineering, The University of Melbourne. pp. 33-48.
- Mbagwu, J.S.C. and A. Piccolo. 1989. Changes in soil aggregate stability induced by amendment with humic substances. *Soil Technol.* **2**: 49-57.
- Macrae, R. J. and G.R. Mehuys. 1987. Effects of green manuring in rotation with corn on the physical properties of two Quebec soils. *Biol. Agric. Hort.* **4**: 257-270.
- Perfect, E. and B.D. Kay. 1990. Relations between aggregate stability and organic components for a silt loam soil. *Can. J. Soil Res.* **70**: 731-735.
- Piccolo, A., G. Pietramellara, and J.S.C. Mbagwu. 1997. Use of humic substances as soil conditioners to increase aggregate stability. *Geoderma* **75**: 567-277.

- Rausa, R., V. Calemma and E. Girardi. 1989. Humic acids by dry oxidation of coal with air under pressure. Analytical and spectroscopical characteristics. In *Proc. Int. Conf. Coal Sci., Tokyo, Vol. I*, pp. 237-240. Tokyo: IAES
- Schut, P. 1997. *Soil Texture*. Canada: Agriculture and Agrifood Canada,
- Sim, S.F., S. Lau, N.C. Wong, J. Asing, M.F. Md Nor and A.S. Mohd Pauzan. 2006. Characterization of the coal derived humic acids from Mukah, Sarawak as soil conditioner. *J. Braz. Chem. Soc.* **17**: 582-587.
- Soil Survey Staff. 1999. *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys* (2nd ed.). Washington, D.C.: US Department of Agriculture Soil Conservation Service.
- Sojka, R.E. and R.D. Lentz. 1994. Time for yet another look at soil conditioners. *Soil Sci.* **158**: 233-234.
- Stevenson, F.J. 1982. *Humus Chemistry Genesis, Composition, Reactions*. New York: John Wiley & Sons.
- Swift, R.S. 1996. Organic matter characterization. In *Methods of Soil Analysis Part 3: Chemical Methods*, ed. D.L. Sparks. SSSA and ASA. Madison: Wiley International.
- Theng, B.K.G. 1982. Clay-polymer interaction: summary and perspectives. *Clays Clay Miner.* **30**: 1-10.
- Utomo, W.H. and A.R. Dexter. 1982. Changes in soil aggregate water stability induced by wetting and drying cycles in non-saturated soil. *J. Soil Sci.* **33**: 623-637.
- Visser, S. A. and M., Caillier. 1988. Observations on the dispersion and aggregation of clays by humic substances, I. dispersive effects of humic acids. *Geoderma* **42**: 331-337.