CHAPTER 5
DISCUSSION

Sugarcane in Northeast Thailand is planted on an area about one third of production area of whole Kingdom (0.43 million hectare of whole Kingdom's cane area 1.2 million hectare) (Office of agricultural economics, 2005). Majority of sugarcane areas in Northeast is sandy soil. Sandy soil in Northeast Thailand occurred by sandstone weathering. Hence, eighty percent of Northeast region is sandy soil and three fourth are classified in order Ultisol and Oxisol (Maneewan *et al.*, 1988). Korat soil series (Oxic Paleustults) is a major series in Northeast with 20.05 percent of whole region (Keerati-Kasikorn, 1984) and about eighty percent under sugarcane cropping (Land Development Department, 2002).

1. Soil properties before amendment

The experimental site was located in middle terrace about three kilometers far from Yang river, Kalasin province. Soil is classified in Korat soil with brown color (7.5 YR 5/2) in topsoil and light brown (7.5 YR 6/4) in subsoil. The physical soil properties consisted of 1.54 g cm^{-3} of bulk density, 81.55 percent sand, 11.01 percent silt and 7.44 percent clay on loamy sand texture. The chemical soil properties had 0.43 percent of organic matter, pH 5.56, available phosphorus 20.45 ppm, exchangeable potassium 0.14 $cmol_c$ kg^{-1}, 0.79 $cmol_c$ kg^{-1} of calcium, 0.2 $cmol_c$ kg^{-1} of magnesium and CEC 4.33 $cmol_c$ kg^{-1}.

The soil properties in this present site were medium range of Korat soil series properties when compared with previous data of Keerati-Kasikorn (1984). The soil color was lighter gray in topsoil and lighter brown in subsoil due to high depletion of organic matter in sugarcane cropping system. The texture had high sand fraction due to alluvium genesis and located not far from river. The chemical soil properties consisted of slightly low organic matter content due to agricultural usage without organic material amendments and moderate pH. The higher available phosphorus was investigated due to fertilizer application with high phosphate in sugarcane plantation. The lower potassium content than previous data was found caused by high potassium removal by sugarcane cropping system. The slightly low calcium and magnesium contents shown is caused by sugarcane consumption without calcium and magensium supplementation (Calcino, 2000) and moderate CEC with kaolinite clay mineral dominant (Suddhiprakarn *et al.*, 1985). However, this soil is deficient in exchangeable potassium, organic matter, CEC and improper texture with high sand fraction for sugarcane production.

2. Properties of amendment materials

Organic and clay material amendment in degraded Korat sandy soil was aimed at improving improper soil properties and enhance crop growth and yield. The properties of clay soil (CS) in this experiment contained higher N, P, K and CEC than bentonite clay properties as reported by Puttaso (2003) but similar to particle size distribution (%sand, %silt and %clay content). In clay soil amendment expected to improve K, Ca, Mg and CEC with higher clay fraction of high activity clay mineral. The filter cake (FC) had great chemical properties (N, P, K, Ca and Mg) especially P that was similar in the other works like Sruttaporn and Sangsila (1988) and Anakawech (1997) but lesser in C/N ratio and organic matter. However, filter cake amendment was expected to improve soil bulk density, aggregate stability, organic matter, available phosphorus and CEC. The cattle manure (CM) properties varied with source and keeping methods when compared with previous works but similar in chemical properties with high potassium and magnesium (Dobermann and Fairhurst, 2000 and Saskatchewan Soil Conservation Association, 2000). Cattle manure amendment was expected to improve bulk density, aggregate stability, potassium, organic matter and CEC. The bagasse properties were similar with result of Anonymous (1998) especially for C/N ratio but bagasse of Mitr Kalasin Sugar Mill contained higher potassium content. Nevertheless, bagasse amendment is expected to improve soil organic matter and CEC. The data presented in Table 3 compared the chemical properties of four materials and found the best material was filter cake (highest nutrients content with proper C/N ratio) followed by cattle manure (high nutrients and organic matter content). The third appropriate material was clay soil (CS) with medium nutrients contents and highest CEC. The final appropriate material was bagasse (BG). Bagasse had highest C/N ratio and lower nutrient content especially high lignin, coupled with low bulk density and during decomposition process it releases acetic acid which affects on germination and growth (Anonymous, 1998). However, in tropical light-textured soils influence to organic decomposition rate is faster with high temperature increasing the application of organic materials requires large quantities and regular addition. In addition, high-activity clay has been shown to permanently increase CEC in soil and provide positive yield benefits (Noble *et al.*, 2001; Noble *et al.*, 2003 and Noble *et al.*, 2004) but the rate of application should be considered on sugarcane production.

3. Soil properties and plant growth after amendment

The properties of soil, sugarcane growth, yield component and plant nutrient concentration after amendment with different materials are explained basicd on application method (broadcast and banding).

3.1 Broadcast method

3.1.1 Physical soil properties

The soil bulk densities fluctuated during experimental period due to cultivation practices such as fertilization and manual weeding and data recording disturbance. However, at harvest (12 months) the bulk density significantly decreased in clay soil @ 25 and 75 t ha^{-1} at 0-30 cm depth and also decreased at 30-60 cm soil depth in clay soil @ 25 t ha^{-1} and cattle manure after amendment. The incorporation depth of ploughing was approximately 30 cm which affected more loosing of topsoil and dense at subsoil. In case of clay material amendment there is a trend to improve soil bulk density by cementing and forming soil granulation with cohesive force which influenced to increased soil porosity (Brady, 1984 and Stevenson, 1994). The bulk density after amendment increased in subsoil as reported by Qongqo and van Antwerpen (2000) due to cultivation practices with heavy machinery depression. Nevertheless, in high organic matter content materials i.e. filter cake and bagasse it could not reduce soil bulk density as expected. Jongrauysub *et al.* (2001) and Paul (1974) found filter cake amendment increased bulk density caused by wax which got struck in soil pore and reduced soil porosity. In addtion, bulk density in control was stable due to no nutrient addition in soil for providing more microbial activity and forming cementing agent for soil particles binding like in other treatments.

Particle size distribution significantly increased clay fraction only at 0-30 cm depth in all treatments at 12 months after planting. This would have been the effect of land preparation during furrowing process which earthes up subsoil which contained higher clay content to the upper layer. However, broadcasting of clay soil @ 25 and 75 t ha^{-1} had higher clay content than other treatments at both soil depths at harvest. The calculation of increasing clay content after amendment of clay @ 25 t ha^{-1} was 7.49 percent, clay @ 50 t ha^{-1} was 7.54 percent and clay @ 75 t ha^{-1} was 7.58 percent respectively. The clay content in soil samples got higher clay content than probable calculation that sometime is due to irregular distribution by broadcast in sampling site. However, in this trial we found high activity clay amendment could attract with clay particle by adhesion force and forming soil granulation as relationship between clay fraction in soil and degree of aggregation ($r = 0.43^*$) as shown in Appendix 40. Cohesiveness between clay particles is the ultimate internal binding force within microaggregates (Hillel, 1998). The new cultivation field with organic and clay material incorporated could claim soil aggregates better than control and chemical fertilizer application (Turchenek and Oades, 1978 and Baldock *et al*., 1991). The data supported this statement also found at two and a half year that particle size distribution collected at 0-30 cm soil depth differed in sand, silt and clay content. The clay percentage in organic and clay material amendments were still higher than control and chemical fertilizer application.

The mean weight diameter, degree of aggregation and aggregate stability increased after planting but not significant difference during experimental period. Soil aggregation is formed with the extensive network of roots which permeates the soil and tends to enmesh soil aggregates. Water uptake by roots causes differential dehydration, shrinkage, and opening of numerous small cracks. Moreover, root exudations and the continual death of roots and particularly of root hairs promote microbial activity, which results in the production of humic cements (Metting, 1993). Nevertheless, the root exudates released unchelated polyvalent cations into the soil solution which strengthened bonds between organic matter and clay and increased the aggregate stability (Pojasok and Kay, 1990). Because these binding substances are transitory, being susceptible to further microbial decomposition, organic matter must be replenished and supplied continually for aggregate stability to be maintained in the end (Huang and Schitzer, 1986). However, in the present study we found organic and clay material amendment, higher MWD, degree of aggregation and aggregate stability than control and chemical fertilizer. Organic products may further promote aggregate stability by reducing wettability and swelling. The concentration of organic carbon generally decreased as the particle size increased (Turchenek and Oades, 1978). The finer particles contained high concentratoons of alkyl-C, which appeared to be intimately associated with humic materials and clay materials. The alkyl-C probably consisted of highly degraded organic materials and some materials synthesize by microorganisms (Baldock *et al.*, 1990). Organic matter in sandy soils was protected by adsorption to clay minerals or encrustation by clay minerals (Hassink *et al.*, 1993). Similarly, the present work, we found the positive correlation between degree of aggregation and percentage of clay (r = 0.43*). This indicates degree of aggregation increased with increasing clay content in soil as the above statements by Baldock, 1990 and Hassink *et al.*, 1993. Otherwise, there was positive correlations found in relationship between MWD and CCS (r = 0.40*), degree of aggregation and CCS (r = 0.38*), aggregate stability and number of tiller per stool (r = 0.40*). Hunsigi (1993) has said that for better yield potential, sugarcane requires a crumb soil structure.

The soil moisture was influenced by rainfall intensity but high significant difference between treatments at both soil depths at 12 months after planting. The highest moisture of soil was found in cattle manure plots and the lowest in bagasse application plots. However, after amendment with chemical fertilizer, clay soil @ 25 and 75 t ha^{-1} and cattle manure also had significant effect on soil moisture. The moisture of above treatments significantly increased with the influence of bulk density, organic matter and crop growth parameters changed. Similar, in this experiment, we found a negative correlation between soil moisture and bulk density (r = -0.60**) (Appendix 40). The volume of pore spaces as well as soil solids determines bulk density that soils with high proportion of pore space to solids have lower bulk densities (possible to store more water) than more compact and less pore space soil (low moisture storage) (Brady, 1984). Treatments, which decreased soil bulk densities i.e. cattle manure, clay soil @ 25 and 75 t ha^{-1}, increased soil moisture. In addition, there was positive correlation of soil moisture with stalk height and purity (r = 0.42* and 0.35*). The moisture of soil was used for nutrient transportation. The increased moisture content in soil influences to increase plant nutrient uptake with higher availability for elongation and ripening (Hogarth and Allsopp, 2000).

3.1.2 Chemical soil properties

The pH of soil (1:5 H_2O) decreased in all plots of broadcasting trial. The pH differed among treatments at 8 and 12 months after planting. Filter cake and bagasse broadcasted plots had less pH than control at both soil depths. This was due to decomposition process of filter cake and bagasse release acetic acid which can reduce pH of soil (Anonymous, 1998 and Kingston, 1999). Nevertheless, pH of soil in plots amended with clay soil and cattle manure were higher than control and chemical fertilizer plots due to higher pH in materials as shown in Table 3. Cattle manure and clay soil amendments had higher pH than other materials, especially clay soil amendment contained high exchangeable calcium which can increase pH of soil (Miller and Roy, 1990). However, the pH of soil at two and a half year differed among treatments at both soil depths. The maximum pH increment was found only in cattle manure plot due to the highest pH value in material. Similarly Vityakon *et al.* (1988) and Kogram *et al.* (2002) have reported enhanced pH by cow manure and chicken manure application and attributed it to manures having high value of pH. In this trial, we found positive correlation between pH and stalk length ($r = 0.35^*$) and pH affected nutrients availability for growth promotion (Brady, 1984).

The electrical conductivity among treatments was different from before planting only at 12 month after planting. The application of filter cake had highest electrical conductivity and the lowest was found in clay soil @ 75 t ha^{-1}. The electrical conductivity increased at both soil depths after amendment with all treatments which was caused by soil pH and nutrients level changes. There was a negative correlation between the electrical conductivity and pH of soil ($r = -0.40^*$). The electrical conductivity was determined by the amount of total soluble salts which composed of cations e.g. sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) and the anions e.g. chloride (Cl^-), sulfate (SO_4^{2-}) and bicarbonate (HCO_3^-). The encouragement of high levels of the exchangeable base such as calcium, magnesium, potassium and sodium will contribute toward a reduction in acidity and an increase in alkalinity. Therefore, the correlation between EC and pH should be positive toward exchangeable base of reduction in acidity and increase in alkalinity (Brady, 1984).

However, there was positive correlation between electrical conductivity with tiller density, purity, millable cane, cane yield and sugar yield (r = 0.36*, 0.36*, 0.39*, 0.37* and 0.37* respectively). The higher electrical conductivity caused by increasing cation (K, Ca and Mg) which enhances sugarcane growth (Brady, 1984).

The organic matter content at 0-30 cm soil varied during experimental period which dropped 4 months after planting and rose at 8 months and decreased again at 12 months after planting. At 30-60 cm soil, the organic matter dropped at 4 months and increased continuously till 12 months after planting except in control. These results are due to decomposition of old organic materials (low organic matter content) which were still left after land preparation and easier to decompose within 4 months then decomposing of new materials later (8 months) especially in cattle manure (slow release) and bagasse (high C/N ratio) including root decay. The process of organic material decomposition was completed within 12 months (decreased value). At 30-60 cm soil, the continuos rising trend of organic matter was caused by slower decomposition rate than upper layer which simulater temperature and depth of incorporation only in the upper 30 cm layer. In all treatments except in clay soil @ 75 t ha^{-1}, we found organic matters were significant changed due to its mineralization to inorganic compound for sugarcane uptake. In clay soil @ 75 t ha^{-1}, organic matter did not change due to organo-clay complex tight attraction (Brady, 1984) and delay mineralization of organic material which were left after land preparation. However, the maximum organic matter after amendment was found in cattle manure and filter cake application at both soil depths. Vityakon *et al.* (1988) also found the soil organic matter increased with increasing rate of applied cow manure in Chinese kale grown and Leaungvutirog *et al.* (2002) stated that the application of compost animal manure could raise soil organic matter content in Mab Bon, Tha Yang, Satuk and Renu series for super sweet corn cultivation. The organic carbon content of the soil treated with cow slurry was higher than the untreated soil (Ugolini *et al.*, 2002). Kogram *et al.* (2002) also found chicken manure application enhanced soil organic matter on cassava production. Otherwise, in this present work found the relationship between organic matter and CEC was positive correlated with r = 0.51** (Appendix 42). This caused negative charge of humic acids i.e. carboxyl and phenolic hydroxyl groups that can adsorb cation more tightly (Brady, 1984).

Otherwise, from this experiment we found a negative correlation between organic matter and brix (r = -0.38*). Positive correlation of organic matter with tiller density, plant height, stalk weight, millable cane, cane yield and sugar yield (r = 0.62**, 0.43**, 0.50**, 0.65**, 0.49** and 0.44* respectively) were found in this trial. These were similar to Abayomi (1987) who found the increased yield by addition of nitrogen is due to a higher tiller number and to yield attributes like stalk length, stalk diameter and number of millable canes, available phosphorus with number of tiller per stool, plant height, millable cane, cane yield and sugar yield (r = 0.56**, 0.40*, 0.38*, 0.38* and 0.35* respectively).

Available phosphorus in soil after sugarcane planting changed during experimental period. Broadcasting with filter cake had a clear increasing trend of available phosphorus due to high phosphorus content in filter cake (Table 3). This present work, we found available phosphorus correlates with organic matter content in soil (r = 0.61**). The main cause of complexs of relatively strong bonds between phosphates and humic components (Weir and Soper, 1963; Levesque and Schnitzer, 1967; Levesque, 1969; Sinha, 1971). Prasad (1976) asserted that filter cake is more effective than triple super phosphate and a level of 20 t ha^{-1} of filter cake can improve the yield and quality of cane. In addition, the observation by Ng Kee Kwong and Deville (1988) supported the inference that filter cake is superior to triple super phosphate. Chapman (1996) recommended one filter mud application to each crop cycle of a plant crop and five ratoons that provides enough phosphorus required by sugarcane for the whole crop cycle. In general, a mill mud application will supply sufficient N for half a crop, P for six crops, K for one crop, Ca for six crops, Mg for four crops, and S for two crops.

Exchangeable potassium in soil after broadcasting with various materials changed but significantly differed among treatments only at 8 and 12 months after planting. The maximum values were recorded in filter cake, cattle manure and bagasse which had higher potassium content in materials (Table 3). The beneficial effects of the organic nutrient sources are due to their increased availability of phosphorus, potassium or micronutrients (Avnimelech, 1986 and Bouldin, 1988) or better root development (Kumazawa, 1984). The exchangeable potassium increased after amendment with chemical fertilizer, clay soil @ 75 t ha^{-1} and cattle manure.

High potassium level in conventional chemical fertilizer and cattle manure enhanced exchangeable potassium. Clay soil generated negative charge with increasing clay particle and could attract more cation (Miller and Roy, 1990). In this experiment a positive correlation between potassium and organic matter (r = 0.42*) was found as shown in Appendix 42. This was caused by charge development on soil organic matter which is predominately negative. The principal functional groups of organic matter involved in negative charge development are carboxylic and phenolic acids (Brady, 1984). Interaction of cations with soil organic matter involves several different bonding mechanisms. Basic nutrient cations (Ca, Mg and K) interact predominantly viz., electrostatic attraction with soil organic matter (Duxbury *et al.*, 1989). In this trial a negative correlation between exchangeable potassium and CCS (r = -0.35*) and a positive correlation between exchangeable potassium and stalk weight (r = 0.35*) were found. From the results of BSES potassium application recommended rates could not increased cane yield or CCS (Hogarth and Allsopp, 2000). Potassium helps plants use other nutrients and water more efficiently, synthesis and translocation of proteins and carbohydrates that can enhance sugarcane photosynthesis and growth (Hunsigi, 1993).

Exchangeable calcium increased only at 4 months after planting and decreased at both soil depths in all treatments except in control which reduced from 4 months onward till 12 months at 0-30 cm soil. The increment of exchangeable calcium in soil during initial period was due to low calcium uptake in early growth period and increaseduring the grand growth period (152-288 days) (Coale *et al.*, 1993). Exchangeable calcium in soil decreased in all treatments except clay soil @ 75 t ha^{-1} due to clay material contained higher calcium (Table 3) resulting inncreased CEC and calcium in soil. In work we found a negative correlation between calcium and sand particle percentage (r = -0.43*). This is related to another positive correlation found between calcium and CEC (r = 0.35*) as presented in Appendix 42. Finer-textured soils tend to have higher cation exchange capacities than sandy soil (Brady, 1984). There were relationships of exchangeable calcium with stool density, stalk length and purity (r = 0.49**, 0.36* and 0.35* respectively). Calcium is essential for the growth and development of spindle, leaves and roots. Calcium plays an important role in nitrogen metabolism (Hogarth and Allsopp, 2000).

Exchangeable magnesium after broadcast application with different materials fluctuated. The trend of exchangeable magnesium increased at 4 months relative to before planting and then dropped continuously. These results relate with magnesium requirement which low in early stage and higher during the grand growth period (Coale *et al.*, 1993). In the control, chemical fertilizer and bagasse amendments exhibited lower exchangeable magnesium content in soil due to low magnesium in their composition and more magnesium take up for growth utilization. So, organic and clay material amendments can improve exchangeable magnesium with CEC improvement. The positive correlations between magnesium and clay particle percentage, CEC, organic matter and pH (r = 0.66**, 0.62**, 0.49** and 0.37* respectively) were found as shown in Appendix 42. The charge in clays comes from ionizable hydrogen ions and isomorphous substitution. The increased negative charge with increasing clay particle can attract more cation (magnesium) and increase CEC. Interaction of cations with soil organic matter involves several different bonding mechanisms. Basic nutrient cations (Ca, Mg and K) interact predominantly viz., electrostatic attraction with soil organic matter (Duxbury *et al.*, 1989). The increased exchangeable magnesium in soil can replace and neutralized the exchangeable H^+ and $Al(OH)_2^+$ and hence, increases pH of acidic soils (Miller and Roy, 1990). The relationship between exchangeable magnesium and brix (r = -0.35*) was found. In addition, positive correlations of exchangeable magnesium with tiller density, number of tiller per stool, stalk diameter and stalk weight (r = 0.42*, 0.36*, 0.42* and 0.62**) were also found. Magnesium is an essential constituent of chlorophyll where photosynthesis takes place to underpin sugar production and other growth processes (Hogarth and Allsopp, 2000).

Cation exchange capacity (CEC) at 0-30 cm soil increased 4 months after planting and then decreased continuously. The main cause being furrowing which earthes up subsoil containing higher clay fraction and CEC turn to upper layer soil. However, this varied after rainy season when clay illuviated to lower layers. The amendment of organic and clay material were still higher in CEC than control and conventional chemical fertilizer application. Cation exchange capacity at 30-60 cm dropped at 4 months (except in clay soil @ 50 t ha^{-1}) then increased at 8 months and dropped at 12 months (except in clay soil @ 50 and 75 t ha^{-1}). This showns the effect of clay soil on increasing CEC and organic materials to maintain CEC of soil when compared with chemical fertilizer and control. However, the present work, we found the effect of leaching and illuviation process during 8 to 12 months (peak of rainfall) which leached and percolated organic matter and clay particle through runoff and illuviation processes. Otherwise, the relationship between CEC and clay fraction was found with correlation coefficient 0.51**. The charge in clay comes from ionizable hydrogen ions and isomorphous substitution. Ionizable hydrogen ions are hydrogens from hydroxyl ions on clay surfaces. The –Al-OH or –Si-OH portion of the clay ionizes the H and leaves an unneutralized negative charge on the oxygen (-Al-O^- or –Si-O^-). The second source of charge on clay particles is the substitution of one ion for another of similar size and often with lower positive valence (Miller and Roy, 1990). The positive correlation between CEC with stool density (r = 0.37*) was found from this trial. CEC can be thought of as the ability of soil to hold onto positively charged nutrients that are potentially available for plant use (Hogarth and Allsopp, 2000).

3.1.3 Growth parameters

The germination in broadcast clay soil treatments were reduced by increasing rate of application. This was mainly due to available moisture as it decreases releasing for use in germination of seed sett. However, the germination of all treatments was able to catch up with each other and it was at the same level after two months. As for the stool density, although the actual number in each plot is difficult to identify, the trend was that maximum stool density in cattle manure followed by clay soil @ 75 t ha^{-1} and chemical fertilizer. This trend was partly supported by the data of tiller density which exhibitated the maximum in cattle manure followed by clay soil @ 75 t ha^{-1} and filter cake. It is likely that the differences in stool and tiller density were the influence of the treatment was observed that same variety, planting method and germination exhibitated similar stool and tiller density (Hogarth and Allsopp, 2000). The parameter related to sugarcane elongation i.e. plant height and stalk length were found to be highest in clay soil @ 75 t ha^{-1}. Cattle manure also produced taller plant and clay soil @ 25 t ha^{-1} produce high value of stalk length. The stalk diameter did not differ between treatments due to genetic control. Similarly stalk weight did not differ among treatments. The brix of sugarcane juice also did not differ because of same weather condition in same variety. The cumulation of commercial cane sugar was similar in all treatments but in all materials amendment there was more CCS than control. Maximum millable cane was found in filter cake followed by cattle manure and clay soil @ 75 t ha^{-1}. The millable cane and stalk weight parameters have effect on cane yield with maximum cane yield in cattle manure followed by filter cake and clay soil @ 75 t ha^{-1}. Maximum sugar yield found in cattle manure followed by filter cake and clay soil @ 75 t ha^{-1} respectively. Cane yield is affected by variation in environment and genotype and environment interaction. Thus, the study of relationship between agronomic triats and its direct effect on cane yield. The above characters were classified into three groups in which 14 agronomic traits were correlated with cane yield as represented by the diagram in Figure 73.

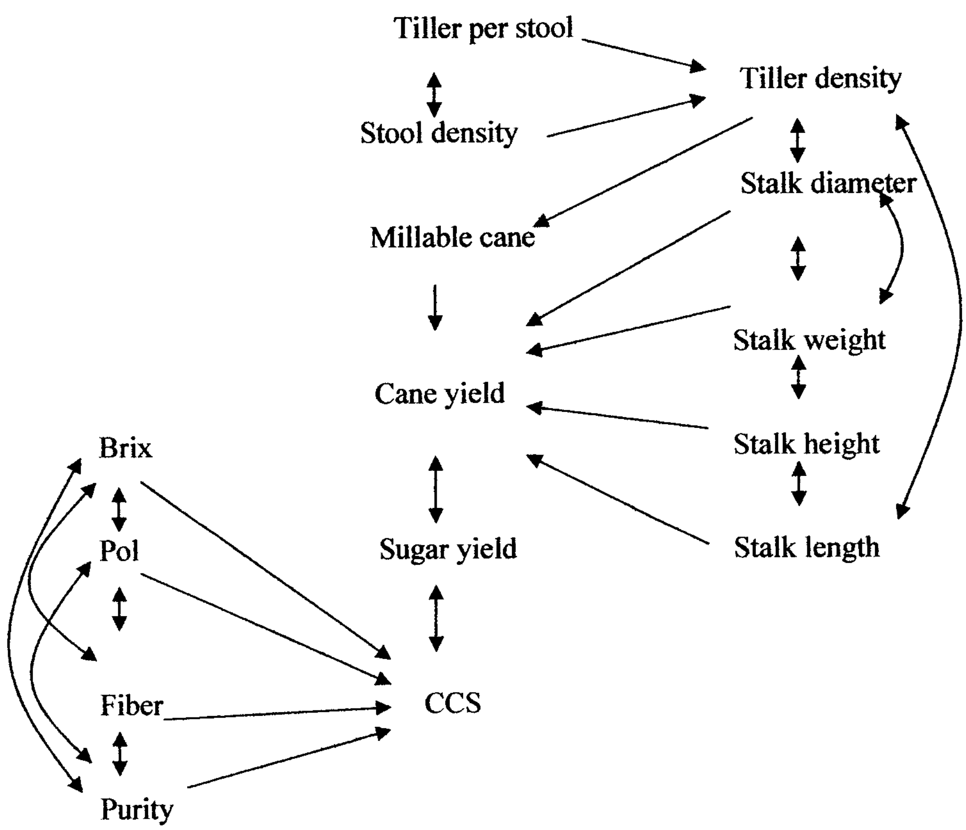

Figure 73 Relationship between 14 agronomic triats and cane yield

This present work found positive relationship of tiller density, stalk length, stalk weight with stalk height (r = 0.58**, 0.62** and 0.51** respectively) as shown in Appendix 44. The relationship of stalk height, stalk length and stalk diameter with stalk weight were positive with correlation coefficient 0.51**, 0.74** and 0.61** respectively. The strong positive relationship of tiller density, cane yield and sugar yield with millable cane were found with correlation coefficient 0.87**, 0.73** and 0.71** respectively. There was a strong correlation of tiller density, stalk length, stalk height, stalk weight, and sugar yield with cane yield (r = 0.68**, 0.48**, 0.83**, 0.45** and 0.98** respectively) and between sugar yield and C.C.S. (r = 0.35*). This indicates that tiller density and millable cane affected cane yield in the experiments as previously studied by Serivichayaswadi *et al.* (1997). The agronomic traits affecting cane yield can be arranged in the order of stalk height, tiller density, stalk length and stalk weight, respectively. Serivichayaswadi *et al.* (1997) stated the most effective agronomic trait on cane yield was tiller density followed by stalk length and stalk diameter in that order. The relationship of brix, pol, fiber, purity and CCS with sugar yield varied -0.28^{ns}, 0.10^{ns}, -0.14^{ns}, 0.46** and 0.35*. Thus, sugar yield was positively correlated with purity and CCS as commented by Serivichayaswadi *et al.*, 1997. Otherwise, brix was related with pol and purity (r = 0.64** and -0.45**) (Appendix 45). The germination with high population tend to have more stool density and with closer stool influences low tiller number per stool. In case of high tiller density, cane competes for light intensity for photosynthesis process that tend to increase stalk elongation i.e. plant height and stalk length than horizontal growth i.e. stalk diameter (Hunsigi, 1993).

The significant differences in stool biomass parameters was fresh and dry weight of stalk and dry weight of root ($P<0.1$). The maximum fresh and dry weights of root were found in clay soil @ 50, 75 t ha^{-1} and filter cake applications and maximum dry weight of root found in clay soil @ 50 t ha^{-1}.

The above relationship between soil properties and growth parameters were used to simulate a model for cane yield prediction using stepwise regression analysis. The selected independent factors from significantly correlation coefficient on clay yield i.e. bulk density, electrical conductivity, organic matter, phosphorus in leaf, potassium in leaf, calcium in leaf, magnesium in leaf, tiller density, stalk height, stalk length and stalk weight. The factors affecting yield were stalk height and tiller density as in model 1 and 2 below.

$$\text{Yield} = -35.49 + 0.34 \text{ stalk height} \quad ; r^2 = 0.69^{**} \qquad (1)$$

Yield = -28.58 + 0.27 stalk height + 0.07 tiller density ; $r^2 = 0.75^{**}$ _______ 2

In addition, the plant height and tiller density was related with soil properties as follow

Plant height = 707.65 + 6.51 (Moisture) + 2.00 (Avai. P) – 308.839 (BD) ; r^2=0.73**

Tiller density = 1.43 + 0.003 (Avai. P) + 2.95 (Aggregate stability) ; r^2=0.45**

The higher soil moisture and available phosphorus effected higher plant height. In contrary, with higher bulk density decreased plant height. Tiller density can be increased by increasing available phosphorus and aggregate stability as the stated by Hunsigi (Hunsigi, 1993). Treatments, which can reduce soil bulk density, increase soil moisture, available phosphorus and aggregate stability, can increase cane yield. Phosphorus is required for early growth stage for rooting, tillering and internode elongation. Vomacil (1957) indicated that a high BD has a significant influence on mechanical impedance and root growth with a consequent reduction in water availability and root aeration. Ricaud (1977) showed that there was a severe reduction in cane yield in sandy soils of Louisiana due to soil compaction. This is confirmed by Monteith and Banath (1965) who stated that as BD increased, mechanical impedance became dominant and controlled root growth. Mechanical strength reduced the foliar concentration of nutrients and their accumulation in the plant (Trouse and Humbert, 1961). In the studies of Juang and Uehara (1971) soil compaction reduced P (90%) and K (50%) uptake by cane as well as reducing the dry weight of roots. Through reducing aggregate size, as soil loses their structure, they are more susceptible to slaking and dispersion, which reduces infiltration and provides greater resistance to root growth (Hogarth and Allsopp, 2000). Good soil moisture and tilth are important to achieve good germination and emergence (Hunsigi, 1993) and positive correlated with stem elongation (Hogarth and Allsopp, 2000).

3.1.4 Plant nutrient

Plant nutrient concentration in third visible dewlap leaf differed for total phosphorus, total potassium, total calcium and total magnesium. The maximum total phosphorus was found in filter cake application caused by highest phosphorus content as shown in Table 3. However, Reuter and Robinson (1997) reported the critical level of nutrient content in sugarcane leaf is total nitrogen 1.8 percent, total phosphorus 0.19 percent, total potassium 0.90 percent, total calcium 0.13 percent and total magnesium 0.12 percent. Otherwise, from the reported of Calcino (2000) who found critical levels of total nitrogen of 1.8%, total phosphorus 0.19%, total potassium 1.11%, total calcium 0.20% and total magnesium 0.08%. Hence, plant nutrient concentration in leaf were deficient in nitrogen and phosphorus in all treatments. Calcium and magnesium were deficient in the control. Otherwise, phosphorus in plant was related with organic matter and phosphorus in soil (r = 0.46** and 0.67**) as shown in Appendix 48. The maximum total potassium in leaf found in control and chemical fertilizer application caused by the negative correlation with calcium, magnesium, CEC and pH in soil (r = -0.44*, -0.48**, -0.39* and -0.50** respectively). The more calcium in soil is accompanied by reduced uptake of potassium due to antagonism (Hunsigi, 1993). The maximum total calcium in plant found in clay soil @ 25, 75 t ha^{-1} and filter cake application caused by more calcium, electrical conductivity and magnesium in soil (r = 0.37*, 0.41* and 0.38* respectively). Maximum total magnesium in leaf was found in cattle manure application due to the correlation with calcium, CEC and organic matter in soil (r = 0.56**, 0.43* and 0.55** respectively).

3.2 Banding method

3.2.1 Physical soil properties

The bulk density of soil fluctuated due to many factors like cultivation practices, disturbance by data recording process and root growth. However, the bulk density of soil did not differ among treatments at both soil depths. The bulk densities at 0-30 cm after banding with organic materials (filter cake, cattle manure and bagasse) were lesser than control. Greenland and Dart (1972) pointed out the benefits of organic matter in agricultural systems compared to control. At 30-60 cm soil depth, only cattle manure amendment had lesser bulk density than control. The decreasing bulk density at 0-30 cm soil but increased at 30-60 cm was caused by land preparartion with ploughing depth of 30 cm. This resulted the soil loose at 0-30 cm and compact at 30-60 cm. Futhermore, in this present work we found the negative correlation between bulk density and organic matter (r = -0.40*). It showed with increasing of organic matter which can reduce soil bulk density with organic matter supplied directly, or indirectly through microbial action, the major soil aggregate-forming granulation and increases both air and available water content in sandy soils (Miller and Roy, 1990).

Particle size distribution at 12 months and 2.5 years after banding did not significant differ between treatments at both soil depths. From the graph in Figure 26 illustrates no increment of clay centent at 0-30 cm soil but higher at 30-60 cm soil, especially in clay soil and organic materials banded (more than chemical fertilizer and control by 1-5%). This was caused by banding amendment which were applied at the basic of furrow (about 40 cm depth) so more clay content at 30-60 cm depth. In addition, the banding of organic and clay material with irregular distribution in furrow within different depths depends on furrow depth which was the main cause of variation. However, in this experiment we found clay fraction signicantly increased in clay soil @ 25 and 50 t ha^{-1} and consistent clay fraction in organic amendment. This shows that clay particle can react with organic matter to form organo-clay complex with van der Waals forces, electrostatic bonding and hydrogen bonding. Organic products may further promote aggregate stability by reducing wettability and swelling. Some of the organic materials are inherently hydrophobic, or become dehydrated, so that the organo-clay complex may have a reduced affinity for water. Some inorganic materials also can serve as cementing agents. Cohesiveness between clay particles is ultimate internal binding force within microaggregates (Hillel, 1998). The relationships between soil properties and growth parameters from this experiment supported the above statement with negative correlation of %sand content with number tiller per stool and CCS (r = -0.45** and -0.35*), %clay content with germination, stool density, tiller density, stalk length, millable cane and cane yield (r = -0.41*, -0.39*, -0.36*, -0.41* and -0.35* respectively). Positive correlations were found in relationship of %sand content with germination, stool density and millable cane (r = 0.37*, 0.38* and 0.36* respectively), %silt content with number of tiller per stool, CCS and purity (r = 0.39*, 0.41* and 0.39* respectively) and %clay content with number of tiller per stool (r = 0.49*). The above relationships were constructed from the data received from all treatments. There were some treatment effect on germination directly i.e bagasse before influenced to soil properties, which is not direct relationship. However, the possible relationship should be considered such as correlation between clay and germination which also found in broadcast application.

Clay soil amendments were applied at high rate which can absorb water within their particle and are difficult to release for seed sett availability during germination stage (Brady, 1984). Therefore, the application of clay soil in sugarcane production should have sufficient moisture content in soil.

The mean weight diameter, degree of aggregation and aggregate stability did not differ at both soil depths after banding with various materials. This was caused by non incorporation of materials, hence no more surface area for attachment with soil particles and cementing with low binding force. However, after amendment with organic and clay material the MWD, degree of aggregation and aggregate stability were higher than control and conventional chemical fertilizer application. From this present work we found a positive correlation between MWD and degree of aggregation (r = 0.80**) (Appendix 49). This caused organic matter in soil contains mainly o-alkyl C (hemicellulose, cellulose and proteins) which is slow decomposion rate with contain mainly aromatic-C (lignin) and highly recalcitrant alkyl-C (waxes and fatty acids) (Baldock *et al.*, 1992). Organic matter in sandy soils was protected by adsorption with clay minerals or encrustation by clay minerals (Hassink *et al.*, 1993). The relationship between soil properties and growth parameters is present in Appendix 50 and 56. Negative correlations were found in the relationship of MWD and stool density (r = -0.40**), degree of aggregation and stool density (r = -0.38*), aggregate stability with stool density, tiller density, millable cane, cane yield and sugar yield (r = -0.43**, -0.44**, -0.38**, -0.41** and -0.36** respectively). This was not the direct effect of aggregate properties on growth parameters due to bagasse amendment which affected on germination and influenced other parameters e.g. stool density before having effect on soil properties.

The soil moisture is a parameter which fluctuates with rainfall. Only at 30-60 cm soil at 4 and 8 months after planting the moisture of soil was significantly different among treatments. The highest moisture was measured in bagasse application, caused mainly by the high fiber content in bagasse which can hold more moisture in soil during rainy season but quickly losses during dry season. However, at harvest (12 month) the soil moisture in clay soil, filter cake and cattle manure plots increased higher than control at both soil depths. Those materials can improve moisture-retaining properties of sandy soils (Stevenson, 1994).

3.2.2 Chemical soil properties

The pH of soil (1:5 H_2O) was significantly different among treatments after amendment at both soil depths. Futhermore, pH of soil increased at 0-30 cm after banding of clay soil @ 75 t ha^{-1} and bagasse due to high calcium content in these materials with 37.44 and 37.50 $cmol_c$ kg^{-1} respectively. The adsorbed acidic aluminium ions are replaced with calcium ions from the material and released H^+ are neutralized by the carbonates or hydroxides added as lime (Miller and Roy, 1990). However, the pH of soil decreased at 12 months after planting in all treatments especially in control and conventional chemical fertilizer except in clay soil @ 75 t ha^{-1}. This showed clay soil could increase pH of soil according to high calcium content in its component. The present experiment we found the relationship of pH with clay fraction, exchangeable calcium, exchangeable magnesium and CEC in soil (r = 0.41*, 0.85**, 0.50** and 0.72** respectively) (Appendix 51). The increasing of soil pH was caused by more basics cation adsorption (Brady, 1984).

The electrical conductivity in all treatments increased after planting especially at 0-30 cm soil. The maximum increase of electrical conductivity was recorded in cattle manure application where its electrical conductivity was highest (Table 3). The increase of electrical conductivity in all treatments was related to exchangeable potassium with the correlation coefficient 0.64** (Appendix 51). The increase of cation in soil solution and activity of the cation influenced to increasing conductivity of soil solution (Foth and Ellis, 1996). Otherwise, from this trial found a positive relationship between electrical conductivity with soil moisture (r = 0.47**) showing that more soil moisture can solute more cation into the soil in available form (Foth and Ellis, 1996). The effect of electrical conductivity on growth parameter in this trial we found a positive correlation between EC and stalk height (r = 0.45**). The high cation content (i.e. potassium, calcium and magnesium) when electrical conductivity increased it can enhance sugarcane growth (Hogarth and Allsopp, 2000).

The organic matter contents at 12 months of both soil depths increased from before planting. However, the organic matter in soil differed among treatments only at 30-60 cm soil. The application of clay soil @ 50 t ha^{-1}, bagasse @ 12.5 t ha^{-1} and clay soil @ 75 t ha^{-1} had high organic matter at 30-60 cm soil. The organic matter in above treatments increased by organo-clay complex in clay soil amendment. Especially in bagasse application which had high organic carbon content (Table 3) which can increase soil organic matter. Organic matter in sandy soils was protected by adsorption with clay minerals or encrustation by clay minerals (Hassink *et al.*, 1993). In addition, banding trial of present work found the positive correlation between organic matter and CEC in soil (r = 0.37*) (Appendix 51). The anions of phenolic and carboxylic group of humic acid were constructed after amendment with organic material which can increase CEC in soil (Stevenson, 1994 and Foth, 1996). The relationship between chemical soil properties and growth parameters are presented in Appendix 56. There was a positive correlation between soil organic matter and plant height (r = 0.40*). Organic matter can influence on soil fertility, soil structure and the ability of a soil to act as a buffer against sharp pH changes. Organic matter contributes substantial amounts of nitrogen and sulfur due to microbial breakdown processes, storage for phosphorus, potassium, calcium and magnesium, as it generally has a high CEC which enhanced sugarcane growth (Hunsigi, 1993 and Hogarth and Allsopp, 2000).

Available phosphorus increased in all treatments except control. The maximum available phosphorus found in filter cake, bagasse and clay soil @ 75 t ha^{-1} due to the materials consisted of higher phosphorus content as data presented in Table 3. Bagasse application affected poor germination and against to low phosphorus uptake and leaving more in soil. Nevertheless, there was positive correlation between available phosphorus and soil organic matter content (r = 0.55**) as found by Weir and Soper, 1963; Levesque and Schnitzer, 1967; Levesque, 1969; Hunsigi, 1993 and Sinha, 1971. Otherwise, there was a negative correlation found in relationship between available phosphorus and brix (r = -0.36*) and positive correlation between available phosphorus and plant height (r = 0.63**). Hunsigi (1993) also found increased cane yield following phosphorus dressing is ascribed to a higher number of tillers per bud and height of millable cane.

Exchangeable potassium at both soil depths slightly increased with maximum value in cattle manure application. The cattle manure composed with the highest potassium content when compare with other materials (Table 3). However, bagasse and clay soil amendment also showed higher exchangeable potassium than chemical fertilizer and control. This caused by charge development on soil organic matter is predominately negative. The principal functional groups involved in negative charge development are carboxylic and phenolic acids (Brady, 1984). Interaction of cations with soil organic matter involves several different bonding mechanisms. Basic nutrient cations (Ca, Mg and K) interact predominantly via. electrostatic attraction with soil organic matter (Duxbury *et al.*, 1989). In case of clay soil amendment consisted of charge in clays comes from ionizable hydrogen ions and isomorphous substitution. The increased negative charge with increasing clay particle can attract more cation (magnesium) and higher CEC (Brady, 1984). From banding trial in present work we found the relationship between exchangeable potassium and clay fraction (r = 0.35*). The potassium ions are attached between layers of clay crystals by the same negative charges responsible for the internal adsorption of these and other cations (Brady, 1984). Nevertheless, there were a negative correlation of exchangeable potassium with germination, stool density, fiber and millable cane (r = -0.47**, -0.41*, -0.35* and -0.40*) and positive correlation between exchangeable potassium and number of tiller per stool (r = 0.38*). The application of potash fertilizer at planting should not come in contact or very close to the seed sett, fertilizer can burn resulting in delayed or failed germination of the sett. Root stubbing may also occur (Hogarth and Allsopp, 2000).

Exchangeable calcium in soil increased after amendment especially at 4 months after planting. The highest of increment was found in clay soil at the rate of 75 t ha^{-1} where calcium increased at both soil depths after planting 4 months. That caused from high CEC of clay soil it can absorb more cation than other materials as relation illustrated in this trial between CEC and calcium in soil with correlation coefficient 0.67** (Appendix 51). The electrically charged colloidal surface area will attract mobile substances of opposite charge in the soil water. Cation exchange sites hold Ca^{2+} ion and slow its losses by leaching (Miller and Roy, 1990).

Exchangeable magnesium in soil after amendment was quite stable when compared with control and chemical fertilizer where the values decreased. However, the application of filter cake, clay soil @ 75 t ha^{-1} and bagasse increased exchangeable magnesium. Bagasse banded application had highest magnesium increment at both soil depths at 12 months. Low plant population in bagasse caused reduction of magnesium uptake and left more magnesium content in soil. From this trial there was a positive correlation between magnesium and clay fraction (r = 0.62**) (Appendix 51). The source of negative charge on silicate clays associated with oxygens and hydroxyl groups exposed at the broken edges and flat external surfaces of minerals. The presence of surface and broken-edge OH groups gives the clay particles their electronegativity and their capacity to adsorb cations (Brady, 1984). Magnesium is a structural component of montmorillonite clay. Magnesium deficiencies most often occurs on coarse-textured, acid soils that have low clay content, low CEC and high leaching potential (Foth and Ellis, 1996). The relationship between exchangeable calcium in soil and sugarcane growth parameters in this trial we found a negative correlation between exchangeable magnesium and fiber (r = -0.36*) and a positive correlation between exchangeable magnesium and number of tiller per stool (r = 0.39*). Magnesium is an essential constituent of chlorophyll where photosynthesis takes place to underpin sugar production and other growth processes. Magnesium is needed for movement of phosphorus in plant and is involved in plant respiration and protein synthesis (Hogarth and Allsopp, 2000). Calcino (2000) also showed symptoms of magnesium deficiency are often present in young cane e.g. stooling is weak and cane growth is retarded.

Cation exchange capacity increased in organic and clay material amendment in banding trial. Especially, clay soil application at the rate of 75 t ha^{-1} has had highest CEC at both soil depths due to high CEC in clay soil material with 62.74 $cmol_c$ kg^{-1}. CEC in soil after amendments of clay and organic material in banding method also obtained higher CEC than chemical fertilizer and control. This CEC mainly is influenced by organic matter, kind and amount of clay and pH of soil. In the present experiment found the CEC was related with organic matter and pH of soil with correlation coefficient 0.37* and 0.72** respectively (Appendix 51). Organic matter contributes to the cation exchange capacity, often furnishing 30-70 percent of the total amount. The large available sufaces of humus have many cation exchange sites that adsorb nutrients for eventual plant use (Miller and Roy, 1990). Increasing acidity is associated with decreasing CEC, decreasing supply of available essential plant nutrients, and an increase in the amount of solution H^+ and Al^{3+} (Foth and Ellis, 1996). The exchange acidity of humic substances very wide but the exchange capacity increases markedly with increasing pH. The latter has been attributed to increased ionization of acidic groups, mostly carboxylic group, at the higher pH values (Stevenson, 1994).

3.2.3 Growth parameters

The amendment with various materials in banding application affected seed sett germination, especially in bagasse application. With high fiber and C/N ratio with low density and fluffy characteristic when applied in row caused seed sett not to come in contact with soil and cut off capillary water flow from subsoil to topsoil which setts use for germination. In cattle manure observedlower germination than control at 35 days after planting due to high potassium content in cattle manure which could affect germination. The effect was caused by osmotic desiccation of plant cells and is effectively a salt injury. If the potash is in contact with, or very close to the cane setts, fertilizer burn can result in delayed or failed germination of some of the eyes of the sett. Root stubbing may also occur (Hogarth and Allsopp, 2000). From Figure 46 in this present study we found conventional chemical fertilizer, clay soil with different rates and filter cake did not affect germination. The stool density depends on germination of seed sett and was lowest in bagasse application followed by cattle manure. In contrary, the tiller per stool was highest in bagasse application followed by cattle manure due to low competition with nearby stool. The tiller density was lowest in bagasse application that caused by lowest germination and stool density. The highest tiller density was found in cattle manure followed by clay soil @ 25 t ha^{-1} and filter cake application. The stalk height was highest in filter cake followed by cattle manure and clay soil @ 75 t ha^{-1}. The stalk length from random sampling showed shortest stalk length in bagasse application and appeared like stunted cane. The longest stalk was collected from filter cake followed by clay soil @ 75 and 50 t ha^{-1} respectively. The stalk weight was heaviest in cattle manure, filter cake and bagasse respectively. The stalk diameter was thickest in bagasse, control and cattle manure where low stool density with low competition on growth factors. The brix of cane did not differ between treatments. The commercial cane sugar in various materials banded did not differ. The millable cane was high in clay soil @ 25 t ha^{-1}, filter cake and clay soil @ 75 t ha^{-1}. The lowest millable cane was found in bagasse banded due to low germination. Cane and sugar yield were highest in filter cake, cattle manure and clay soil @ 75 t ha^{-1}.

In the present experiment found relationship of stool density, tiller per stool and tiller density with germination (r = 0.77**, -0.68** and 0.62** respectively) as presented in Appendix 53. The relationship of tiller per stool, tiller density and stalk length with stool density (r = 0.77**, -0.81** and 0.39* respectively). The relationship of tiller density, stalk length and stalk diameter with tillers per stool (r = -0.79**, -0.43* and 0.42* respectively). The relationship of plant height, stalk length and stalk diameter with tiller density (r = 0.32*, 0.54** and -0.41* respectively). The relationship between stalk weight and stalk diameter (r = 0.67**). The positive relationship of germination, stool density and tiller density with millable cane (r = 0.81**, 0.82** and 0.89** respectively). The relationship of germination, stool density, tiller density, plant height and stalk length with cane yield (r = 0.62**, 0.75**, 0.91**, 0.48** and 0.71**). The strong relationship of millable cane and cane yield with sugar yield (r = 0.86** and 0.98** respectively). The stool density, tiller density and millable cane had affect on cane yield as reported by Serivichayaswadi *et al.*, 1997. The agronomic traits affecting cane yield can be arranged tiller density followed by stool density, stalk length, germination and plant height, respectively. Serivichayaswadi *et al.* (1997) stated that the most effective of agronomic trait on cane yield was tiller density followed by stalk length and stalk diameter respectively. The relationship of brix, pol, fiber, purity and CCS with sugar yield was 0.07^{ns}, 0.28^{ns}, -0.25^{ns}, 0.18^{ns} and 0.35^{ns}. Otherwise, brix was related with pol and purity (r = 0.38* and -0.61**) as shown in Appendix 54.

Stool biomass in banding application trial differed only in fresh and dry weight of stalk and root (P<0.1) similar to broadcast application. From this trial the fresh and dry weight of stalk was related to cane yield (r = 0.61**). However, the trend of fresh and dry stalk weight was positive correlation with stalk weight at 12 months after planting (r = 0.46*).

The above relationships were used to simulate the model for cane yield prediction using stepwise regression analysis by selected independent factors from significantly correlation coefficient on cane yield i.e. aggregate stability, phosphorus in leaf, germination percentage, stool density, tiller per stool, tiller density, stalk height, stalk length and stalk diameter. However, the factors affecting yield were tiller density and stalk length as in model 3 and 4 below.

Cane yield = 2.04 + 0.18 (tiller density) ; $r^2 = 0.83^{**}$ ________________ 3

Cane yield = -59.29 + 0.14 (tiller density) + 0.31 (stalk length) ; $r^2 = 0.90^{**}$ _______ 4

In banding method soil properties effect on tiller density and stalk length are simulated in the following models.

Tiller density = 625.55 - 243.38 (AS) - 25.10 (%clay) ; $r^2 = 0.31^{*}$

Stalk length = 272.09 – 5.13 (%clay) ; $r^2 = 0.13^{*}$

The above models showed higher soil aggregate stability and %clay content decreased tiller density. Otherwise, with higher clay content decreased stalk length. However, in bagasse application with low germination which affected stool and tiller density and finally on cane yield. Therefore, the regression analysis for plant growth prediction should be direct effect of material on soil. The appropriate materials for banding application in furrow should not affect germination, enhance tiller density and stalk length.

3.2.4 Plant nutrient

Plant nutrient concentration in third visible dewlap leaf differed for total nitrogen, total phosphorus, calcium and magnesium. The maximum total nitrogen was in cattle manure and filter cake amendments. From the critical level of nutrients of Reuter and Robinson (1997) and Calcino (2000), total nitrogen and total phosphorus in tissue were deficient. Magnesium deficiency was found in control. The nitrogen in plant tissue was related with available phosphorus and exchangeable potassium in soil (r = 0.42** and 0.36*) (Appendix 52). Clement (1901) also found similar positive interaction between N in leaf and potassium in soil. The maximum total phosphorus was found in cattle manure, filter cake and clay soil @ 75 t ha^{-1} applications due to high phosphorus content in those materials as shown in Table 3. From this present work we found relationship of total phosphorus in plant with available phosphorus in soil (r = 0.43*). This is similar to Clement's (1901) report in the phosphorus and growth showed strong positive trends and phosphorus with calcium was slightly positive correlated. The maximum total calcium was found in clay soil @ 50 t ha^{-1}, clay soil @ 75 t ha^{-1} and filter cake application. The calcium in tissue was related with available phosphorus in soil (r = 0.36*) as result of Clement (1901) showed very strong relation between phosphorus in soil and calcium in leaf. The maximum total magnesium was found in filter cake, cattle manure and bagasse application. The magnesium in tissue was related with available phosphorus in soil (r = 0.41*) showes that magnesium is needed for movement of phosphorus in the plant (Hogarth and Allsopp, 2000).

4. Best amendment method and type of ameliorant determination

4.1 Determined by comparing with soil suitability classification index

The soil suitability classification was determined by using standard index of sugarcane requirement as showed in Table 10 (Prammanee, 2001) and compared the index with before planting classification. We used the data at 12 months after planting in each treatment to classify and find out which was more suitable for cane planting than before planting to find the most appropriate material which can improve deficiency in soil properties.

4.1.1 Broadcast trial

From table 11 we found soil is deficient in exchangeable potassium, organic matter, CEC and have had improper texture. Hence, after amendment these properties should be improved. The soil properties after broadcasting with organic and clay material are presented in Table 11. We found bulk density, soil texture, pH, EC, available phosphorus, exchangeable potassium, extractable potassium, organic matter and CEC after treated 12 months did not improve to suitable level. The above properties were suitable for bulk density, pH, EC and available phosphorus and unsuitable in soil texture, exchangeable potassium, magnesium, organic matter and CEC were same as before planting. However, the best indicator in this determination is exchangeable calcium in soil which was suitable at before planting but after planting found it was not suitable in control, conventional chemical fertilizer, filter cake, cattle manure and bagasse. From Table 12, clay soil application with all rates especially @ 75 t ha^{-1} can maintain exchangeable calcium in soil not lower than sugarcane requirement due to clay material contain with highest calcium content as presented in Table 3.

4.1.2 Banding trial

In banding the results were similar to broadcast trial and the suitable soil properties before planting were bulk density, pH, EC, available phosphorus, exchangeable calcium and exchangeable magnesium. After amendment, properties of soil i.e. bulk density, pH, EC, available phosphorus, exchangeable calcium and exchangeable magnesium were still unsuitable for sugarcane planting similar to before planting. However, the best indicator in this was determination also exchangeable calcium that was suitable in soil before planting but after planting found calcium in soil was not suitable in control, conventional chemical fertilizer, filter cake, cattle manure and bagasse. From Table 12 the application of clay soil with all rates especially @ 75 t ha^{-1} can retain exchangeable calcium in soil at sufficient level for sugarcane requirement.

The amendment of organic material, conventional chemical fertilizer and clay soil were better than control. In control, we found unsuitability of available phosphorus at 12 months after planting. From both trials we found no materials can improve all soil properties. In addition, only application of clay soil can maintain exchangeable calcium in soil. The best rate of clay soil can be reconsidered from the calcium level at 12 months that the application rate of clay soil @ 75 t ha^{-1} having highest value. Moreover, the consideration of application method by comparing the superiority of exchangeable calcium in soil after banding clay soil @ 75 t ha^{-1} can maintain exchangeable calcium at both soil depths

Table 11 Soil suitability classification for sugarcane production after organic and clay material amendment in broadcast trial

Properties	Require	Before planting			12 months after planting											
					Control			CF			CS_25			CS_50		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.50	1.60	S	1.35	1.41	S	1.35	1.37	S	1.51	1.52	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	4.39	4.81	S	4.19	4.26	S	5.00	4.98	S	4.91	4.82	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.05	S	0.06	0.07	S	0.07	0.05	S	0.07	0.06	S
Avai. P (ppm)	10-20	25.11	15.79	S	20.23	12.80	S	25.92	13.49	S	32.25	23.67	S	25.92	32.94	S
Exch. K ($cmol_c/kg$)	0.24-0.71	0.13	0.14	U	0.12	0.10	U	0.10	0.12	U	0.12	0.09	U	0.14	0.10	U
Ca ($cmol_c/kg$)	0.55-1.25	0.76	0.82	S	0.17	0.04	U	0.25	0.21	U	0.61	0.45	S	0.71	0.68	S
Mg ($cmol_c/kg$)	0.10-0.25	0.26	0.25	S	0.20	0.23	S	0.15	0.15	S	0.26	0.23	S	0.26	0.31	S
OM (%)	2-4	0.47	0.38	U	0.41	0.34	U	0.44	0.99	U	0.51	0.89	U	0.51	1.00	U
CEC ($cmol_c/kg$)	> 15	4.19	4.47	U	3.88	4.46	U	4.44	3.22	U	4.01	4.39	U	5.06	7.20	U

Remarks: S = Suitable, U = Unsuitable

Table 11 Soil suitability classification for sugarcane production after organic and clay material amendment in broadcast trial (cont.)

Properties	Require	Before planting			12 months after planting											
					CS_75			FC			CM			BG		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.28	1.37	S	1.49	1.57	S	1.32	1.33	S	1.50	1.57	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	5.58	5.14	S	4.55	4.53	S	4.88	5.01	S	4.33	4.59	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.04	S	0.10	0.07	S	0.07	0.06	S	0.07	0.05	S
Avai. P (ppm)	10-20	25.11	15.79	S	23.92	23.47	S	111.32	62.52	S	22.34	15.44	S	22.72	12.79	S
Exch. K ($cmol_c$/kg)	0.24-0.71	0.13	0.14	U	0.08	0.10	U	0.16	0.13	U	0.15	0.16	U	0.10	0.13	U
Ca ($cmol_c$/kg)	0.55-1.25	0.76	0.82	S	0.90	0.58	S	0.40	0.35	U	0.40	0.55	U	0.23	0.36	U
Mg ($cmol_c$/kg)	0.10-0.25	0.26	0.25	S	0.25	0.19	S	0.28	0.27	S	0.29	0.30	S	0.19	0.18	S
OM (%)	2-4	0.47	0.38	U	0.43	0.19	U	0.60	0.59	U	0.48	0.30	U	0.47	0.95	U
CEC ($cmol_c$/kg)	> 15	4.19	4.47	U	5.17	5.60	U	4.98	5.86	U	5.13	5.86	U	4.95	4.74	U

Remarks: S = Suitable and U = Unsuitable

Table 11 Soil suitability classification for sugarcane production after organic and clay material amendment in broadcast trial

Properties	Require	Before planting			12 months after planting											
					Control			CF			CS_25			CS_50		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.50	1.60	S	1.35	1.41	S	1.35	1.37	S	1.51	1.52	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	4.39	4.81	S	4.19	4.26	S	5.00	4.98	S	4.91	4.82	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.05	S	0.06	0.07	S	0.07	0.05	S	0.07	0.06	S
Avai. P (ppm)	10-20	25.11	15.79	S	20.23	12.80	S	25.92	13.49	S	32.25	23.67	S	25.92	32.94	S
Exch. K ($cmol_c$/kg)	0.24-0.71	0.13	0.14	U	0.12	0.10	U	0.10	0.12	U	0.12	0.09	U	0.14	0.10	U
Ca ($cmol_c$/kg)	0.55-1.25	0.76	0.82	S	0.17	0.04	U	0.25	0.21	U	0.61	0.45	S	0.71	0.68	S
Mg ($cmol_c$/kg)	0.10-0.25	0.26	0.25	S	0.20	0.23	S	0.15	0.15	S	0.26	0.23	S	0.26	0.31	S
OM (%)	2-4	0.47	0.38	U	0.41	0.34	U	0.44	0.99	U	0.51	0.89	U	0.51	1.00	U
CEC ($cmol_c$/kg)	> 15	4.19	4.47	U	3.88	4.46	U	4.44	3.22	U	4.01	4.39	U	5.06	7.20	U

Remarks: S = Suitable, U = Unsuitable

Table 11 Soil suitability classification for sugarcane production after organic and clay material amendment in broadcast trial (cont.)

Properties	Require	Before planting			12 months after planting											
					CS_75			FC			CM			BG		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.28	1.37	S	1.49	1.57	S	1.32	1.33	S	1.50	1.57	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	5.58	5.14	S	4.55	4.53	S	4.88	5.01	S	4.33	4.59	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.04	S	0.10	0.07	S	0.07	0.06	S	0.07	0.05	S
Avai. P (ppm)	10-20	25.11	15.79	S	23.92	23.47	S	111.32	62.52	S	22.34	15.44	S	22.72	12.79	S
Exch. K (cmol$_c$/kg)	0.24-0.71	0.13	0.14	U	0.08	0.10	U	0.16	0.13	U	0.15	0.16	U	0.10	0.13	U
Ca (cmol$_c$/kg)	0.55-1.25	0.76	0.82	S	0.90	0.58	S	0.40	0.35	U	0.40	0.55	U	0.23	0.36	U
Mg (cmol$_c$/kg)	0.10-0.25	0.26	0.25	S	0.25	0.19	S	0.28	0.27	S	0.29	0.30	S	0.19	0.18	S
OM (%)	2-4	0.47	0.38	U	0.43	0.19	U	0.60	0.59	U	0.48	0.30	U	0.47	0.95	U
CEC (cmol$_c$/kg)	> 15	4.19	4.47	U	5.17	5.60	U	4.98	5.86	U	5.13	5.86	U	4.95	4.74	U

Remarks: S = Suitable and U = Unsuitable

Table 12 Soil suitability classification for sugarcane production after organic and clay material amendment in banding trial

Properties	Require	Before planting			12 months after planting											
					Control			CF			CS_25			CS_50		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.47	1.57	S	1.47	1.56	S	1.58	1.65	S	1.56	1.56	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	4.76	4.88	S	4.76	5.08	S	5.36	5.03	S	5.04	5.75	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.06	S	0.06	0.05	S	0.05	0.05	S	0.06	0.04	S
Avai. P (ppm)	10-20	25.11	15.79	S	14.46	8.68	U	27.40	19.41	S	17.03	8.91	S	19.70	11.29	S
Exch. K ($cmol_c$/kg)	0.24-0.71	0.13	0.14	U	0.14	0.15	U	0.13	0.14	U	0.14	0.14	U	0.12	0.16	U
Ca ($cmol_c$/kg)	0.55-1.25	0.76	0.82	S	0.30	0.40	U	0.17	0.44	U	0.54	0.53	S	0.55	0.93	S
Mg ($cmol_c$/kg)	0.10-0.25	0.26	0.25	S	0.25	0.25	S	0.17	0.18	S	0.24	0.22	S	0.20	0.20	S
OM (%)	2-4	0.47	0.38	U	0.59	0.40	U	0.60	0.41	U	0.56	0.47	U	0.58	0.53	U
CEC ($cmol_c$/kg)	> 15	4.19	4.47	U	3.54	3.57	U	3.01	3.38	U	4.90	5.00	U	5.34	4.68	U

Remarks: S = Suitable and U = Unsuitable

Table 11 Soil suitability classification for sugarcane production after organic and clay material amendment in broadcast trial

Properties	Require	Before planting			12 months after planting											
					Control			CF			CS_25			CS_50		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.50	1.60	S	1.35	1.41	S	1.35	1.37	S	1.51	1.52	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	4.39	4.81	S	4.19	4.26	S	5.00	4.98	S	4.91	4.82	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.05	S	0.06	0.07	S	0.07	0.05	S	0.07	0.06	S
Avai. P (ppm)	10-20	25.11	15.79	S	20.23	12.80	S	25.92	13.49	S	32.25	23.67	S	25.92	32.94	S
Exch. K ($cmol_c/kg$)	0.24-0.71	0.13	0.14	U	0.12	0.10	U	0.10	0.12	U	0.12	0.09	U	0.14	0.10	U
Ca ($cmol_c/kg$)	0.55-1.25	0.76	0.82	S	0.17	0.04	U	0.25	0.21	U	0.61	0.45	S	0.71	0.68	S
Mg ($cmol_c/kg$)	0.10-0.25	0.26	0.25	S	0.20	0.23	S	0.15	0.15	S	0.26	0.23	S	0.26	0.31	S
OM (%)	2-4	0.47	0.38	U	0.41	0.34	U	0.44	0.99	U	0.51	0.89	U	0.51	1.00	U
CEC ($cmol_c/kg$)	> 15	4.19	4.47	U	3.88	4.46	U	4.44	3.22	U	4.01	4.39	U	5.06	7.20	U

Remarks: S = Suitable, U = Unsuitable

Table 11 Soil suitability classification for sugarcane production after organic and clay material amendment in broadcast trial (cont.)

Properties	Require	Before planting			12 months after planting											
					CS_75			FC			CM			BG		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.28	1.37	S	1.49	1.57	S	1.32	1.33	S	1.50	1.57	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	5.58	5.14	S	4.55	4.53	S	4.88	5.01	S	4.33	4.59	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.04	S	0.10	0.07	S	0.07	0.06	S	0.07	0.05	S
Avai. P (ppm)	10-20	25.11	15.79	S	23.92	23.47	S	111.32	62.52	S	22.34	15.44	S	22.72	12.79	S
Exch. K ($cmol_c$/kg)	0.24-0.71	0.13	0.14	U	0.08	0.10	U	0.16	0.13	U	0.15	0.16	U	0.10	0.13	U
Ca ($cmol_c$/kg)	0.55-1.25	0.76	0.82	S	0.90	0.58	S	0.40	0.35	U	0.40	0.55	U	0.23	0.36	U
Mg ($cmol_c$/kg)	0.10-0.25	0.26	0.25	S	0.25	0.19	S	0.28	0.27	S	0.29	0.30	S	0.19	0.18	S
OM (%)	2-4	0.47	0.38	U	0.43	0.19	U	0.60	0.59	U	0.48	0.30	U	0.47	0.95	U
CEC ($cmol_c$/kg)	> 15	4.19	4.47	U	5.17	5.60	U	4.98	5.86	U	5.13	5.86	U	4.95	4.74	U

Remarks: S = Suitable and U = Unsuitable

Table 11 Soil suitability classification for sugarcane production after organic and clay material amendment in broadcast trial

Properties	Require	Before planting			12 months after planting											
					Control			CF			CS_25			CS_50		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.50	1.60	S	1.35	1.41	S	1.35	1.37	S	1.51	1.52	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	4.39	4.81	S	4.19	4.26	S	5.00	4.98	S	4.91	4.82	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.05	S	0.06	0.07	S	0.07	0.05	S	0.07	0.06	S
Avai. P (ppm)	10-20	25.11	15.79	S	20.23	12.80	S	25.92	13.49	S	32.25	23.67	S	25.92	32.94	S
Exch. K ($cmol_c/kg$)	0.24-0.71	0.13	0.14	U	0.12	0.10	U	0.10	0.12	U	0.12	0.09	U	0.14	0.10	U
Ca ($cmol_c/kg$)	0.55-1.25	0.76	0.82	S	0.17	0.04	U	0.25	0.21	U	0.61	0.45	S	0.71	0.68	S
Mg ($cmol_c/kg$)	0.10-0.25	0.26	0.25	S	0.20	0.23	S	0.15	0.15	S	0.26	0.23	S	0.26	0.31	S
OM (%)	2-4	0.47	0.38	U	0.41	0.34	U	0.44	0.99	U	0.51	0.89	U	0.51	1.00	U
CEC ($cmol_c/kg$)	> 15	4.19	4.47	U	3.88	4.46	U	4.44	3.22	U	4.01	4.39	U	5.06	7.20	U

Remarks: S = Suitable, U = Unsuitable

Table 11 Soil suitability classification for sugarcane production after organic and clay material amendment in broadcast trial (cont.)

Properties	Require	Before planting			12 months after planting											
					CS_75			FC			CM			BG		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.28	1.37	S	1.49	1.57	S	1.32	1.33	S	1.50	1.57	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	5.58	5.14	S	4.55	4.53	S	4.88	5.01	S	4.33	4.59	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.04	S	0.10	0.07	S	0.07	0.06	S	0.07	0.05	S
Avai. P (ppm)	10-20	25.11	15.79	S	23.92	23.47	S	111.32	62.52	S	22.34	15.44	S	22.72	12.79	S
Exch. K (cmol_c/kg)	0.24-0.71	0.13	0.14	U	0.08	0.10	U	0.16	0.13	U	0.15	0.16	U	0.10	0.13	U
Ca (cmol_c/kg)	0.55-1.25	0.76	0.82	S	0.90	0.58	S	0.40	0.35	U	0.40	0.55	U	0.23	0.36	U
Mg (cmol_c/kg)	0.10-0.25	0.26	0.25	S	0.25	0.19	S	0.28	0.27	S	0.29	0.30	S	0.19	0.18	S
OM (%)	2-4	0.47	0.38	U	0.43	0.19	U	0.60	0.59	U	0.48	0.30	U	0.47	0.95	U
CEC (cmol_c/kg)	> 15	4.19	4.47	U	5.17	5.60	U	4.98	5.86	U	5.13	5.86	U	4.95	4.74	U

Remarks: S = Suitable and U = Unsuitable

Table 11 Soil suitability classification for sugarcane production after organic and clay material amendment in broadcast trial

Properties	Require	Before planting			12 months after planting											
					Control			CF			CS_25			CS_50		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.50	1.60	S	1.35	1.41	S	1.35	1.37	S	1.51	1.52	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	4.39	4.81	S	4.19	4.26	S	5.00	4.98	S	4.91	4.82	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.05	S	0.06	0.07	S	0.07	0.05	S	0.07	0.06	S
Avai. P (ppm)	10-20	25.11	15.79	S	20.23	12.80	S	25.92	13.49	S	32.25	23.67	S	25.92	32.94	S
Exch. K ($cmol_c$/kg)	0.24-0.71	0.13	0.14	U	0.12	0.10	U	0.10	0.12	U	0.12	0.09	U	0.14	0.10	U
Ca ($cmol_c$/kg)	0.55-1.25	0.76	0.82	S	0.17	0.04	U	0.25	0.21	U	0.61	0.45	S	0.71	0.68	S
Mg ($cmol_c$/kg)	0.10-0.25	0.26	0.25	S	0.20	0.23	S	0.15	0.15	S	0.26	0.23	S	0.26	0.31	S
OM (%)	2-4	0.47	0.38	U	0.41	0.34	U	0.44	0.99	U	0.51	0.89	U	0.51	1.00	U
CEC ($cmol_c$/kg)	> 15	4.19	4.47	U	3.88	4.46	U	4.44	3.22	U	4.01	4.39	U	5.06	7.20	U

Remarks: S = Suitable, U = Unsuitable

Table 11 Soil suitability classification for sugarcane production after organic and clay material amendment in broadcast trial (cont.)

Properties	Require	Before planting			12 months after planting											
					CS_75			FC			CM			BG		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.28	1.37	S	1.49	1.57	S	1.32	1.33	S	1.50	1.57	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	5.58	5.14	S	4.55	4.53	S	4.88	5.01	S	4.33	4.59	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.04	S	0.10	0.07	S	0.07	0.06	S	0.07	0.05	S
Avai. P (ppm)	10-20	25.11	15.79	S	23.92	23.47	S	111.32	62.52	S	22.34	15.44	S	22.72	12.79	S
Exch. K ($cmol_c/kg$)	0.24-0.71	0.13	0.14	U	0.08	0.10	U	0.16	0.13	U	0.15	0.16	U	0.10	0.13	U
Ca ($cmol_c/kg$)	0.55-1.25	0.76	0.82	S	0.90	0.58	S	0.40	0.35	U	0.40	0.55	U	0.23	0.36	U
Mg ($cmol_c/kg$)	0.10-0.25	0.26	0.25	S	0.25	0.19	S	0.28	0.27	S	0.29	0.30	S	0.19	0.18	S
OM (%)	2-4	0.47	0.38	U	0.43	0.19	U	0.60	0.59	U	0.48	0.30	U	0.47	0.95	U
CEC ($cmol_c/kg$)	> 15	4.19	4.47	U	5.17	5.60	U	4.98	5.86	U	5.13	5.86	U	4.95	4.74	U

Remarks: S = Suitable and U = Unsuitable

Table 12 Soil suitability classification for sugarcane production after organic and clay material amendment in banding trial

Properties	Require	Before planting			12 months after planting											
					Control			CF			CS_25			CS_50		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.47	1.57	S	1.47	1.56	S	1.58	1.65	S	1.56	1.56	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	4.76	4.88	S	4.76	5.08	S	5.36	5.03	S	5.04	5.75	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.06	S	0.06	0.05	S	0.05	0.05	S	0.06	0.04	S
Avai. P (ppm)	10-20	25.11	15.79	S	14.46	8.68	U	27.40	19.41	S	17.03	8.91	S	19.70	11.29	S
Exch. K ($cmol_c$/kg)	0.24-0.71	0.13	0.14	U	0.14	0.15	U	0.13	0.14	U	0.14	0.14	U	0.12	0.16	U
Ca ($cmol_c$/kg)	0.55-1.25	0.76	0.82	S	0.30	0.40	U	0.17	0.44	U	0.54	0.53	S	0.55	0.93	S
Mg ($cmol_c$/kg)	0.10-0.25	0.26	0.25	S	0.25	0.25	S	0.17	0.18	S	0.24	0.22	S	0.20	0.20	S
OM (%)	2-4	0.47	0.38	U	0.59	0.40	U	0.60	0.41	U	0.56	0.47	U	0.58	0.53	U
CEC ($cmol_c$/kg)	> 15	4.19	4.47	U	3.54	3.57	U	3.01	3.38	U	4.90	5.00	U	5.34	4.68	U

Remarks: S = Suitable and U = Unsuitable

Table 11 Soil suitability classification for sugarcane production after organic and clay material amendment in broadcast trial

Properties	Require	Before planting			12 months after planting											
					Control			CF			CS_25			CS_50		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.50	1.60	S	1.35	1.41	S	1.35	1.37	S	1.51	1.52	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	4.39	4.81	S	4.19	4.26	S	5.00	4.98	S	4.91	4.82	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.05	S	0.06	0.07	S	0.07	0.05	S	0.07	0.06	S
Avai. P (ppm)	10-20	25.11	15.79	S	20.23	12.80	S	25.92	13.49	S	32.25	23.67	S	25.92	32.94	S
Exch. K ($cmol_c/kg$)	0.24-0.71	0.13	0.14	U	0.12	0.10	U	0.10	0.12	U	0.12	0.09	U	0.14	0.10	U
Ca ($cmol_c/kg$)	0.55-1.25	0.76	0.82	S	0.17	0.04	U	0.25	0.21	U	0.61	0.45	S	0.71	0.68	S
Mg ($cmol_c/kg$)	0.10-0.25	0.26	0.25	S	0.20	0.23	S	0.15	0.15	S	0.26	0.23	S	0.26	0.31	S
OM (%)	2-4	0.47	0.38	U	0.41	0.34	U	0.44	0.99	U	0.51	0.89	U	0.51	1.00	U
CEC ($cmol_c/kg$)	> 15	4.19	4.47	U	3.88	4.46	U	4.44	3.22	U	4.01	4.39	U	5.06	7.20	U

Remarks: S = Suitable, U = Unsuitable

Table 11 Soil suitability classification for sugarcane production after organic and clay material amendment in broadcast trial (cont.)

Properties	Require	Before planting			12 months after planting											
					CS_75			FC			CM			BG		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.28	1.37	S	1.49	1.57	S	1.32	1.33	S	1.50	1.57	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	5.58	5.14	S	4.55	4.53	S	4.88	5.01	S	4.33	4.59	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.04	S	0.10	0.07	S	0.07	0.06	S	0.07	0.05	S
Avai. P (ppm)	10-20	25.11	15.79	S	23.92	23.47	S	111.32	62.52	S	22.34	15.44	S	22.72	12.79	S
Exch. K (cmol$_c$/kg)	0.24-0.71	0.13	0.14	U	0.08	0.10	U	0.16	0.13	U	0.15	0.16	U	0.10	0.13	U
Ca (cmol$_c$/kg)	0.55-1.25	0.76	0.82	S	0.90	0.58	S	0.40	0.35	U	0.40	0.55	U	0.23	0.36	U
Mg (cmol$_c$/kg)	0.10-0.25	0.26	0.25	S	0.25	0.19	S	0.28	0.27	S	0.29	0.30	S	0.19	0.18	S
OM (%)	2-4	0.47	0.38	U	0.43	0.19	U	0.60	0.59	U	0.48	0.30	U	0.47	0.95	U
CEC (cmol$_c$/kg)	> 15	4.19	4.47	U	5.17	5.60	U	4.98	5.86	U	5.13	5.86	U	4.95	4.74	U

Remarks: S = Suitable and U = Unsuitable

Table 11 Soil suitability classification for sugarcane production after organic and clay material amendment in broadcast trial

Properties	Require	Before planting			12 months after planting											
					Control			CF			CS_25			CS_50		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.50	1.60	S	1.35	1.41	S	1.35	1.37	S	1.51	1.52	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	4.39	4.81	S	4.19	4.26	S	5.00	4.98	S	4.91	4.82	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.05	S	0.06	0.07	S	0.07	0.05	S	0.07	0.06	S
Avai. P (ppm)	10-20	25.11	15.79	S	20.23	12.80	S	25.92	13.49	S	32.25	23.67	S	25.92	32.94	S
Exch. K ($cmol_c/kg$)	0.24-0.71	0.13	0.14	U	0.12	0.10	U	0.10	0.12	U	0.12	0.09	U	0.14	0.10	U
Ca ($cmol_c/kg$)	0.55-1.25	0.76	0.82	S	0.17	0.04	U	0.25	0.21	U	0.61	0.45	S	0.71	0.68	S
Mg ($cmol_c/kg$)	0.10-0.25	0.26	0.25	S	0.20	0.23	S	0.15	0.15	S	0.26	0.23	S	0.26	0.31	S
OM (%)	2-4	0.47	0.38	U	0.41	0.34	U	0.44	0.99	U	0.51	0.89	U	0.51	1.00	U
CEC ($cmol_c/kg$)	> 15	4.19	4.47	U	3.88	4.46	U	4.44	3.22	U	4.01	4.39	U	5.06	7.20	U

Remarks: S = Suitable, U = Unsuitable

Table 11 Soil suitability classification for sugarcane production after organic and clay material amendment in broadcast trial (cont.)

Properties	Require	Before planting			12 months after planting											
					CS_75			FC			CM			BG		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.28	1.37	S	1.49	1.57	S	1.32	1.33	S	1.50	1.57	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	5.58	5.14	S	4.55	4.53	S	4.88	5.01	S	4.33	4.59	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.04	S	0.10	0.07	S	0.07	0.06	S	0.07	0.05	S
Avai. P (ppm)	10-20	25.11	15.79	S	23.92	23.47	S	111.32	62.52	S	22.34	15.44	S	22.72	12.79	S
Exch. K (cmol$_c$/kg)	0.24-0.71	0.13	0.14	U	0.08	0.10	U	0.16	0.13	U	0.15	0.16	U	0.10	0.13	U
Ca (cmol$_c$/kg)	0.55-1.25	0.76	0.82	S	0.90	0.58	S	0.40	0.35	U	0.40	0.55	U	0.23	0.36	U
Mg (cmol$_c$/kg)	0.10-0.25	0.26	0.25	S	0.25	0.19	S	0.28	0.27	S	0.29	0.30	S	0.19	0.18	S
OM (%)	2-4	0.47	0.38	U	0.43	0.19	U	0.60	0.59	U	0.48	0.30	U	0.47	0.95	U
CEC (cmol$_c$/kg)	> 15	4.19	4.47	U	5.17	5.60	U	4.98	5.86	U	5.13	5.86	U	4.95	4.74	U

Remarks: S = Suitable and U = Unsuitable

Table 12 Soil suitability classification for sugarcane production after organic and clay material amendment in banding trial

Properties	Require	Before planting			12 months after planting											
					Control			CF			CS_25			CS_50		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.47	1.57	S	1.47	1.56	S	1.58	1.65	S	1.56	1.56	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	4.76	4.88	S	4.76	5.08	S	5.36	5.03	S	5.04	5.75	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.06	S	0.06	0.05	S	0.05	0.05	S	0.06	0.04	S
Avai. P (ppm)	10-20	25.11	15.79	S	14.46	8.68	U	27.40	19.41	S	17.03	8.91	S	19.70	11.29	S
Exch. K ($cmol_c$/kg)	0.24-0.71	0.13	0.14	U	0.14	0.15	U	0.13	0.14	U	0.14	0.14	U	0.12	0.16	U
Ca ($cmol_c$/kg)	0.55-1.25	0.76	0.82	S	0.30	0.40	U	0.17	0.44	U	0.54	0.53	S	0.55	0.93	S
Mg ($cmol_c$/kg)	0.10-0.25	0.26	0.25	S	0.25	0.25	S	0.17	0.18	S	0.24	0.22	S	0.20	0.20	S
OM (%)	2-4	0.47	0.38	U	0.59	0.40	U	0.60	0.41	U	0.56	0.47	U	0.58	0.53	U
CEC ($cmol_c$/kg)	> 15	4.19	4.47	U	3.54	3.57	U	3.01	3.38	U	4.90	5.00	U	5.34	4.68	U

Remarks: S = Suitable and U = Unsuitable

Table 12 Soil suitability classification for sugarcane production after organic and clay material amendment in banding trial

Properties	Require	Before planting			12 months after planting											
					Control			CF			CS_25			CS_50		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.47	1.57	S	1.47	1.56	S	1.58	1.65	S	1.56	1.56	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	4.76	4.88	S	4.76	5.08	S	5.36	5.03	S	5.04	5.75	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.06	S	0.06	0.05	S	0.05	0.05	S	0.06	0.04	S
Avai. P (ppm)	10-20	25.11	15.79	S	14.46	8.68	U	27.40	19.41	S	17.03	8.91	S	19.70	11.29	S
Exch. K ($cmol_c$/kg)	0.24-0.71	0.13	0.14	U	0.14	0.15	U	0.13	0.14	U	0.14	0.14	U	0.12	0.16	U
Ca ($cmol_c$/kg)	0.55-1.25	0.76	0.82	S	0.30	0.40	U	0.17	0.44	U	0.54	0.53	S	0.55	0.93	S
Mg ($cmol_c$/kg)	0.10-0.25	0.26	0.25	S	0.25	0.25	S	0.17	0.18	S	0.24	0.22	S	0.20	0.20	S
OM (%)	2-4	0.47	0.38	U	0.59	0.40	U	0.60	0.41	U	0.56	0.47	U	0.58	0.53	U
CEC ($cmol_c$/kg)	> 15	4.19	4.47	U	3.54	3.57	U	3.01	3.38	U	4.90	5.00	U	5.34	4.68	U

Remarks: S = Suitable and U = Unsuitable

Table 12 Soil suitability classification for sugarcane production after organic and clay material amendment in banding trial

Properties	Require	Before planting			12 months after planting											
					Control			CF			CS_25			CS_50		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.47	1.57	S	1.47	1.56	S	1.58	1.65	S	1.56	1.56	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	4.76	4.88	S	4.76	5.08	S	5.36	5.03	S	5.04	5.75	S
EC (dS/m)	<1.7	0.02	0.02	S	0.06	0.06	S	0.06	0.05	S	0.05	0.05	S	0.06	0.04	S
Avai. P (ppm)	10-20	25.11	15.79	S	14.46	8.68	U	27.40	19.41	S	17.03	8.91	S	19.70	11.29	S
Exch. K ($cmol_c/kg$)	0.24-0.71	0.13	0.14	U	0.14	0.15	U	0.13	0.14	U	0.14	0.14	U	0.12	0.16	U
Ca ($cmol_c/kg$)	0.55-1.25	0.76	0.82	S	0.30	0.40	U	0.17	0.44	U	0.54	0.53	S	0.55	0.93	S
Mg ($cmol_c/kg$)	0.10-0.25	0.26	0.25	S	0.25	0.25	S	0.17	0.18	S	0.24	0.22	S	0.20	0.20	S
OM (%)	2-4	0.47	0.38	U	0.59	0.40	U	0.60	0.41	U	0.56	0.47	U	0.58	0.53	U
CEC ($cmol_c/kg$)	> 15	4.19	4.47	U	3.54	3.57	U	3.01	3.38	U	4.90	5.00	U	5.34	4.68	U

Remarks: S = Suitable and U = Unsuitable

Table 12 Soil suitability classification for sugarcane production after organic and clay material amendment in banding trial (cont.)

Properties	Require	Before planting			12 months after planting											
					CS_75			FC			CM			BG		
		0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class	0-30 cm	30-60 cm	Class
Bulk density (g/cm^3)	1.1-1.6	1.52	1.56	S	1.48	1.60	S	1.45	1.60	S	1.40	1.55	S	1.38	1.70	S
Textural class	SL to CL	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U	LS	LS	U
pH (1:5 H_2O)	4.0-8.5	5.51	5.62	S	5.82	5.88	S	4.98	5.15	S	4.76	4.98	S	5.75	5.93	S
EC (dS/m)	<1.7	0.02	0.02	S	0.07	0.05	S	0.05	0.04	S	0.10	0.06	S	0.07	0.06	S
Avai. P (ppm)	10-20	25.11	15.79	S	28.04	19.55	S	28.04	19.55	S	42.85	33.64	S	42.85	33.64	S
Exch. K ($cmol_c$/kg)	0.24-0.71	0.13	0.14	U	0.12	0.16	U	0.12	0.13	U	0.16	0.18	U	0.15	0.18	U
Ca ($cmol_c$/kg)	0.55-1.25	0.76	0.82	S	0.81	0.91	S	0.45	0.42	U	0.55	0.45	U	0.68	0.66	S
Mg ($cmol_c$/kg)	0.10-0.25	0.26	0.25	S	0.25	0.27	S	0.23	0.28	S	0.29	0.29	S	0.41	0.40	S
OM (%)	2-4	0.47	0.38	U	0.70	0.48	U	0.74	0.36	U	0.76	0.34	U	0.74	0.53	U
CEC ($cmol_c$/kg)	> 15	4.19	4.47	U	5.93	5.33	U	4.93	3.98	U	4.85	4.16	U	5.30	7.98	U

Remarks: S = Suitable, U = Unsuitable

4.2 Determine by ranking method

To interpret the data a new method in which the scoring 1 as best and 8 as worst was used to rank the treatments. The ranking for each property e.g. bulk density (low = 1 and dense = 8), soil moisture, pH, organic matter, phosphorus, potassium, calcium, magnesium, CEC, millable cane, cane yield and sugar yield (highest value = 1 and lowest = 8). When we sum up scores for each treatment for different properties, those with lowest score should be the best ameliorant.

4.2.1 Broadcast trial

In broadcast trial we ranked each property and the data is presented in Table 13. We found lowest score for cattle manure (total score = 30) followed by filter cake (39) and clay soil @ 50 t ha^{-1}(44). The amendment of cattle manure @ 25 t ha^{-1} was highest for soil moisture, exchangeable potassium, magnesium, cane yield and sugar yield which can be determined by best scrore (1) for the properties. The amendment of filter cake @ 50 t ha^{-1} had highest organic matter, available phosphorus and millable cane. The amendment of clay soil @ 50 t ha^{-1} had highest calcium in soil.

Table 13 The ranking of properties to determine appropriate materials at 0-30 cm soil of broadcasting trial

Treatment	BD	Mois	pH	OM	P	K	Ca	Mg	CEC	Mill cane	Cane yield	Sugar yield	Total
Control	6	7	5	8	8	8	8	7	7	8	8	8	88
CF	3	2	8	6	3	7	6	8	3	5	4	6	61
CS_25	8	4	3	4	2	4	2	4	6	7	6	4	54
CS_50	5	6	2	2	4	3	1	3	2	6	5	5	44
CS_75	1	3	1	7	7	6	3	5	8	3	3	3	50
FC	7	5	7	1	1	2	5	2	4	1	2	2	39
CM	2	1	4	3	5	1	4	1	5	2	1	1	30
BG	4	8	6	5	6	5	7	6	1	4	7	7	66

Remarks: 1 = best and 8 = worst

The data is for 30-60 cm is shown in Table 14. We found the lowest score in cattle manure (total score = 24) with increasing score by filter cake

(42) and clay soil @ 75 t ha^{-1} (44). Cattle manure @ 25 t ha^{-1} had lowest bulk density, highest soil moisture, pH, exchangeable potassium, cane yield and sugar. Filter cake @ 50 t ha^{-1} had highest organic matter, available phosphorus and millable cane.

After summing the scores for different properties within treatment (Table 15) and averaged over both soil depths, we found best ameliorant was cattle manure (first rank at both soil depths), filter cake and clay soil @ 75 t ha^{-1} with average scores 27.0, 40.5 and 47.0 respectively. Control got the last rank at both soil depths as expected with lowest organic matter, available phosphorus, exchangeable potassium, exchangeable calcium, millable cane, cane yield and sugar yield. We determined appropriate material in broadcasting trial was cattle manure @ 25 t ha^{-1} followed by filter cake @ 50 t ha^{-1} and clay soil @ 75 t ha^{-1} respectively.

Table 14 The ranking of properties to determine appropriate materials at 30-60 cm soil of broadcasting trial

Treatment	BD	Mois.	pH	OM	P	K	Ca	Mg	CEC	Mill cane	Cane yield	Sugar yield	Total
Control	8	6	6	8	8	8	8	4	8	8	8	8	88
CF	4	2	8	3	4	5	6	8	7	5	4	6	62
CS_25	3	3	2	7	5	6	5	7	6	7	6	4	61
CS_50	7	8	4	5	2	7	1	1	1	6	5	5	52
CS_75	2	4	3	6	3	4	2	6	5	3	3	3	44
FC	6	7	7	1	1	2	7	3	3	1	2	2	42
CM	1	1	1	2	7	1	3	2	2	2	1	1	24
BG	5	5	5	4	6	3	4	5	4	4	7	7	59

Remarks: 1 = best and 8 = worst

Table 15 The average values ranking in appropriate materials determination of broadcasting trial

Treatment	0-30 cm score	0-30 cm rank	30-60 cm score	30-60 cm rank	Average score	Average rank
Control	88	8	88	8	88.0	8
CF	61	6	62	7	61.5	7
CS_25	54	5	61	6	57.5	5
CS_50	44	3	52	4	48.0	4
CS_75	50	4	44	3	47.0	3
FC	39	2	42	2	40.5	2
CM	30	1	24	1	27.0	1
BG	66	7	59	5	62.5	6

4.2.2 Banding trial

The determination of the best amendment material for improving degraded soil for sugarcane production in banding trial is shown below. The method of scoring and ranking pattern was similar to the broadcasting method.

At 0-30 cm soil we found the best material for soil amendment was filter cake which improved soil bulk density, organic matter, available phosphorus, cane yield and sugar yield (Table 16). Another best material in banding trial was clay soil @ 75 t ha^{-1} which improved pH of soil, calcium CEC and followed by cattle manure which improved soil moisture, exchangeable potassium and exchangeable magnesium in soil.

Table 16 The ranking of properties to determine appropriate materials at 0-30 cm soil of banding trial

Treatment	BD	Mois	pH	OM	P	K	Ca	Mg	CEC	Mill cane	Cane yield	Sugar yield	Total
Control	6	4	7	8	8	8	5	7	7	7	7	7	81
CF	5	7	8	5	5	6	8	8	8	4	5	5	74
CS_25	7	6	2	6	7	4	3	4	3	1	4	4	51
CS_50	8	5	3	7	6	7	2	6	2	5	6	6	63
CS_75	3	3	1	2	4	5	1	3	1	3	3	2	31
FC	1	2	5	1	1	3	4	5	5	2	1	1	31
CM	2	1	6	4	2	1	6	1	6	6	2	3	40
BG	4	8	4	3	3	2	7	2	4	8	8	8	61

Remarks: 1 = best and 8 = worst

At 30-60 cm soil we found the best material for soil improvement was filter cake which improved organic matter, available phosphorus, magnesium, cane yield and sugar yield (Table 17). The second material which appropriate to banding was clay soil @ 75 t ha^{-1} which improved pH of soil, calcium and CEC and followed by clay soil @ 50 t ha^{-1} which can decrease soil bulk density.

Table 19 clearly indicates the superiority of filter cake @ 50 t ha^{-1} followed by clay soil @ 75 t ha^{-1} as most suitable material. Cattle manure @ 25 t ha^{-1} was also effective with lower values.

By combining both amendment methods, we can see that the best materials by broadcast and banding methods are filter cake @ 50 t ha^{-1}, clay soil @ 75 t ha^{-1} and cattle manure @ 25 t ha^{-1}.

Table 17 The ranking of properties to determine appropriate materials at 30-60 cm soil of banding trial

Treatment	BD	Mois	pH	OM	P	K	Ca	Mg	CEC	Mill cane	Cane yield	Sugar yield	Total
Control	7	1	6	8	8	8	5	4	5	7	7	7	73
CF	3	7	7	7	5	7	8	7	8	4	5	5	73
CS_25	4	8	5	5	7	4	4	6	4	1	4	4	56
CS_50	1	4	2	2	6	3	2	8	2	5	6	6	47
CS_75	5	6	1	3	3	6	1	5	1	3	3	2	39
FC	6	5	4	1	1	5	3	1	6	2	1	1	36
CM	8	3	8	6	4	1	7	3	7	6	2	3	58
BG	2	2	3	4	2	2	6	2	3	8	8	8	50

Remarks: 1 = best and 8 = worst

Table 18 The average values ranking in appropriate materials determination of banding trial

Treatment	0-30 cm score	0-30 cm rank	30-60 cm score	30-60 cm rank	Average score	Average rank
Control	81	7	73	7	77.0	8
CF	74	6	73	7	73.5	7
CS_25	51	3	56	4	53.5	4
CS_50	63	5	47	3	55.0	5
CS_75	31	1	39	2	35.0	2
FC	31	1	36	1	33.5	1
CM	40	2	58	6	49.0	3
BG	61	4	50	5	55.5	6

From the above ranking method, we could determine the best method of application by averaging the score for each treatment. The lower scores indicated better application method. From Table 19, best method of application for the best materials are broadcasting of cattle manure @ 25 t ha^{-1}, banding of filter cake @ 50 t ha^{-1} and banding of clay soil @ 75 t ha^{-1}.

Table 19 The average values ranking to determine appropriate application method

Treatment	Broadcast average score	Banding average score
Control	88.0	77.0
CF	61.5	73.5
CS_25	57.5	53.5
CS_50	48.0	55.0
CS_75	47.0	35.0
FC	40.5	33.5
CM	27.0	49.0
BG	62.5	55.5

4.3 Evaluation through cost and benefit analysis

Cost benefit is the prime method for farmer to make a decision for applying new management technique. The cost benefit for the present trial was done by calculating the cost of investment in two parts viz., material and management cost. The materials cost (material cost and transportation cost) viz., conventional chemical fertilizer grade 16-16-8 kgN-P_2O_5-K_2O @ 7.6 Baht kg^{-1}, fertilizer grade 21-0-0 kgN-P_2O_5-K_2O @ 4.6 Baht kg^{-1}, clay soil @ 0.12 Baht kg^{-1}, filter cake @ 0.06 Baht kg^{-1}, cattle manure @ 0.3 Baht kg^{-1} and bagasse @ 0.11 Baht kg^{-1}. The management cost viz., maintenance cost (land preparation, irrigation, planting, weeding and fertilization) @ 3,750 Baht ha^{-1} and harvest cost (harvest and transport) @ 190 Baht ton^{-1}. Hence, the net cost was addition of material and management cost. Profit was calculate using cane price @ 600 Baht ton^{-1} and CCS price (6% of cane price at CCS above 10 that in this case is 36 Baht CCS^{-1} over 10 CCS). Net benefit was calculated from net profit by deducting the cost.

4.3.1 Broadcast trial

The conventional chemical fertilizer in broadcast trial was 16-16-8 kgN-P_2O_5-K_2O @ 156.25 kg ha^{-1} as basal application and 21-0-0 kg N-P_2O_5-K_2O @ 312.5 kg ha^{-1} as top dressing application). From Table 20, the highest net cost was cattle manure @ 25 t ha^{-1} which was 35,999 Baht ha^{-1} and lowest in control with 15,232 Baht ha^{-1}. Maximum net profit of 63,068 Baht ha^{-1} was obtained by cattle manure @ 25 t ha^{-1} broadcasting while the least was in control (36,365 Baht ha^{-1}.) However, highest return on investment or net benefit return was found in filter cake @ 50 t ha^{-1} followed by conventional chemical fertilizer and cattle manure @ 25 t ha^{-1} with values 32,021, 29,967 and 27,069 Baht ha^{-1} respectively. The higher expenditure cost of material in clay soil was mainly due to transportation cost and management cost and for cattle manure was due to expensive material and weeding cost.

Table 20 Cost and benefit analysis in broadcast trial

Treatment	Cost (Baht ha^{-1})		Net cost	Yield	CCS	Profit	Net benefit
	Material	Management	(Baht ha^{-1})	(t ha^{-1})		(Baht ha^{-1})	(Baht ha^{-1})
1. Control	-	15,232	15,232	60.43	12.98	36,365	21,134
2. CF	3,813	21,091	24,904	91.27	13.03	54,871	29,967
3. CS_25 + CF	6,813	20,556	27,368	88.45	13.74	53,205	25,837
4. CS_50 + CF	9,813	20,706	30,518	89.24	13.43	53,667	23,149
5. CS_75 + CF	12,813	23,147	35,960	102.09	13.32	61,374	25,414
6. FC + CF	6,813	23,430	30,243	103.58	13.21	62,264	32,021
7. CM + CF	11,313	24,687	35,999	104.93	13.05	63,068	27,069
8. BG + CF	5,188	18,612	23,799	78.22	13.53	47,059	23,260

4.3.2 Banding trial

The conventional chemical fertilizer in broadcast trial was 16-16-8 kgN-P_2O_5-K_2O @ 156.25 kg ha^{-1} as basal application and 21-0-0 kgN-P_2O_5-K_2O @ 312.5 kg ha^{-1} as top dressing application. From Table 21, the highest net cost was found in clay soil @ 75 t ha^{-1} (30,904 Baht ha^{-1}) and lowest in control (8,048 Baht ha^{-1}). Maximum net profit was obtained by filter cake @ 50 t ha^{-1} banding amounting to 54,272 Baht ha^{-1}, while the lowest net profit was in bagasse (13,699 Baht ha^{-1}). However, maximize net benefit return was found in filter cake @ 50 t ha^{-1} followed by conventional chemical fertilizer and clay soil @ 25 t ha^{-1} with values 27,747, 24,939 and 23,059 Baht ha^{-1} respectively. The expenditure cost of material was highest in clay soil with transportation cost as the key factor followed by cattle manure among the management cost was expensive in weed control.

From both trials in this present work we found similar materials appropriate for soil amendment e.g. filter cake @ 50 t ha^{-1}, conventional chemical fertilizer, cattle manure @ 25 t ha^{-1} and clay soil @ 25 t ha^{-1}. However, the best material in each application method can be determined by deducting the net benefit of control. All treatments in broadcasting method were superior to control especially in filter cake, conventional chemical fertilizer and cattle manure. In banding method in we found filter cake, conventional chemical fertilizer and clay soil @ 25 t ha^{-1} were superior to control. Bagasse, cattle manure, clay soil @ 50 and 75 t ha^{-1} had lower net benefit than control due to low germination in bagasse, high material cost of clay soil and cattle manure. We can conclude that the best method of amendments is broadcasting method with higher net benefit when compared to different methods within treatments and no effect on germination.

The determination of best amendment method from three assessment methods in the present work we found broadcasting method was superior to banding method. The best material was cattle manure @ 25 t ha^{-1}, clay soil @ 75 t ha^{-1} and filter cake @ 50 t ha^{-1} for soil and plant improvement assessment methods but by cost benenfit analysis filter cake @ 50 t ha^{-1}, conventional chemical fertilizer and clay soil @ 25 t ha^{-1} gained more benefit.

Table 21 Cost and benefit analysis in banding trial

Treatment	Cost (Baht ha^{-1})		Net cost	Yield	CCS	Profit	Net benefit
	Material	Management	(Baht ha^{-1})	(t ha^{-1})		(Baht ha^{-1})	(Baht ha^{-1})
1. Control	-	15,585	15,585	62.29	12.98	37,481	21,896
2. ½ CF	2,625	18,211	20,836	76.11	13.03	45,775	24,939
3. CS_25 + ½ CF	5,625	18,718	24,343	78.78	13.74	47,403	23,059
4. CS_50 + ½ CF	8,625	17,924	26,549	74.60	13.43	44,883	18,334
5. CS_75 + ½ CF	11,625	19,279	30,904	81.73	13.32	49,158	18,254
6. FC + ½ CF	5,625	20,899	26,524	90.26	13.21	54,272	27,747
7. CM + ½ CF	10,125	19,368	29,493	82.20	13.05	49,430	19,937
8. BG + ½ CF	4,000	8,048	12,048	22.62	13.53	13,699	1,651

5. General discussion

Soil degradation implies a regression from higher to a lower state; a deterioration in productive capability (FAO, 1983). The sugarcane production without soil improvement practices results in physical degradation (e.g. soil compaction), chemical degradation (e.g. deplet soil fertility and decrease soil organic matter), biological degradation (e.g. reduce microbial activity) and environmental degradation (e.g. soil erosion and soil pollution). A significant part of soil quality (i.e. inherent quality) that involves some important soil properties and attributes (e.g. particle size distribution and mineralogy) are not readily subject to changed by human manipulation and are relatively static. This aspect of soil quality has long been addressed by land resource and soil survey inventories. Other properties and attributes of soil quality (i.e. dynamic quality) that include, for example, organic matter and structural properties (e.g. porosity, permeability and aggregation), can be subjected to relatively rapid change and responsive to soil management (Carter, 2000).

The influence of sugarcane cropping system affects soil degradation viz., (1) High nutrient removal as reported by Calcino (1991) e.g. 136 kg ha^{-1} of nitrogen, 21 kg $ha^{-1}$of phosphorus, 220 kg $ha^{-1}$of potassium, 39 kg ha^{-1} of calcium, 36 kg ha^{-1} of magnesium, 34 kg ha^{-1} of sulfur, 0.09 kg ha^{-1} of copper, 0.47 kg ha^{-1} of zinc, 7 kg ha^{-1} of iron and 3.81 kg ha^{-1} of manganese. (2) Harvest cane to sugar mill and the burning of left over trash either before or after harvest that loss much more soil fertility. (3) The monoculture of sugarcane cropping causes development of pests and diseases, concentrate biotic activity in the soil surface and does not encourage exploration and cycling of biota and nutrients into deeper soil layers. (4) Sugarcane farming system is highly dependent on heavy machinery for land preparation, harvest and transport especially cultivation practices carried out during wet conditions causes soil compaction. (5) The adverse indirect effects of monoculture and using heavy machinery in the sugarcane systems can be linked closely to two practices i.e. excessive tillage and a failure to return adequate quantities of organic matter to the system. Both are inextricably linked, as tillage further degrades an often-deplete organic matter status.

The soil productivity degradation process in conventional chemical fertilizer application occured (1) physical properties degradation due to coarse texture at topsoil which is easy to erode by runoff water, nutrient loss by deep percolation, surface soil crust due to consist of low activity clay mineral after wetting and drying (2) chemical properties degradation (low organic matter content, N, P and K) due to plant removal and organic matter mineralization for plant utilization (3) Biological process was inactive in low soil moisture, acidic soil and low organic carbon content (4) yield decline (poor cover cropping and low nutrient recycling) as illustrated in Figure 74.

Study plot after deforestation about four years was earlier planted with cane that obtained average yield of 62.5 ton ha^{-1} in plant cane and 43.75 ton ha^{-1} in first ratoon cane (that lower than average yield of this region). The average rooting depth during the first ratoon cane was 80 cm. The determination of limiting factor for sugarcane production was compared with productive characteristics index of Prammanee (2001) as presented in Table 1. This experimental area was located on suitable topography characteristic (e.g. altitude, slope and aspect), good rainfall amount and distribution with 1,624 millimeters/annum and 138 rain days/annum and optimum climate for growth and ripening (sunshine and temperature). However, this site had a main problem of poor ratooning ability which is caused by soil fertility problems i.e. acidity, low available phophorus, exchangeable potassium, exchangeable calcium, exchangeable magnesium, organic matter and CEC (pH_{H_2O} 5.56, available phosphorus 20.45 ppm, exchangeable potassium 0.14 $cmol_c\ kg^{-1}$, 0.79

$cmol_c$ kg^{-1} of exchangeable calcium, 0.26 $cmol_c$ kg^{-1} of exchangeable magnesium, 0.43% of organic matter and cation exchange capacity 4.33 $cmol_c$ kg^{-1} respectively). The limitating factors of sugarcane production in this present work found important problems of the soil for sugarcane plantation were texture, exchangeable potassium, organic matter and cation exchange capacity.

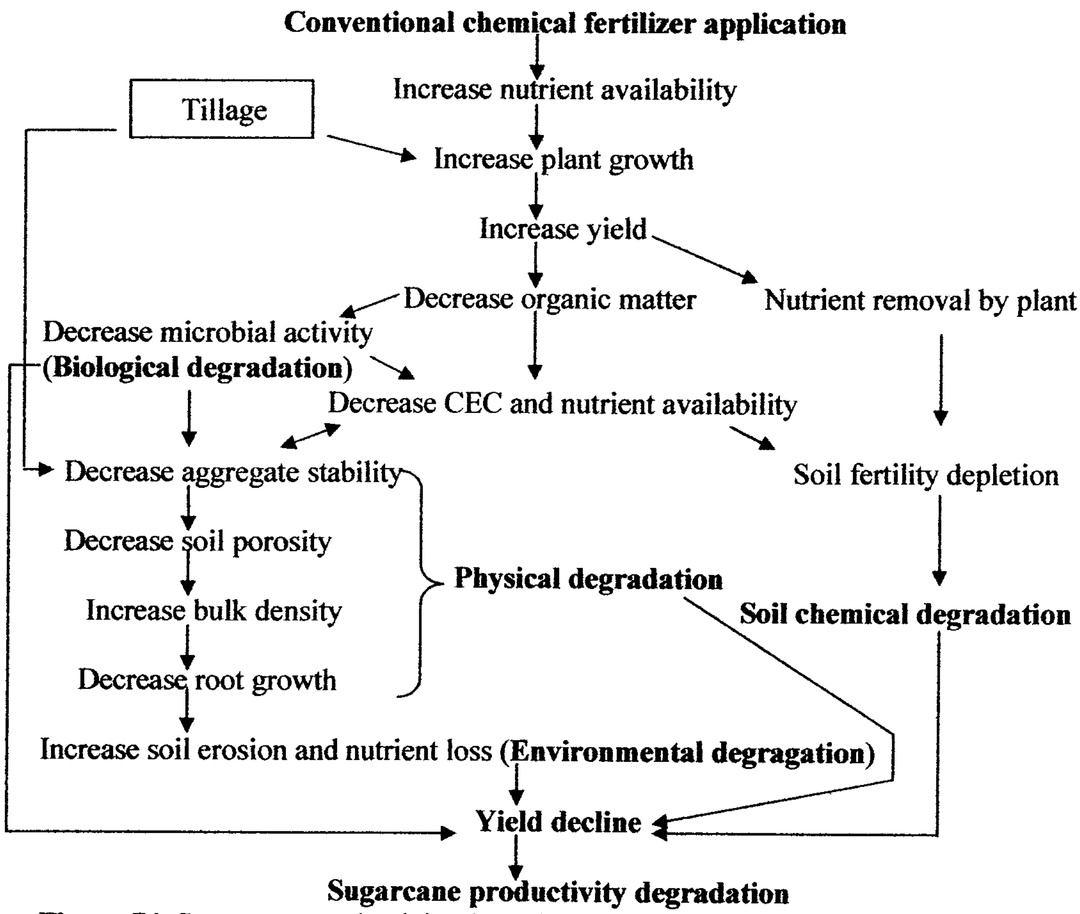

Figure 74 Sugarcane productivity degradation process

The soil dymanic quality (exchangeable potassium, organic matter and cation exchange capacity) can be rehabilitated by soil management techniques. The organic material amendment pointed out the benefits when used e.g. provide nutrients (supplies most of the N and S and half of the P taken up by unfertilized crops), improve nutrient holding capacity, decrease phosphorus fixation, improve physical properties, reduces susceptibility to erosion, improve water retention properties, improve micronutrient availability and prevent their leaching, reduce Al and Mn toxicity, enhance formation of soil aggregation and aeration, control soil temperature

(Greenland and Dart, 1972). In this trial we used local organic waste from sugar industrial and livestock production which generally used for soil improvement e.g. cattle manure and by-product of sugar industry (e.g. filter cake and bagasse). An alternative approach to rehabilitate the soil degradation for sugarcane production was addition of high-activity clay (2:1 clay). The advantage of clay soil amendment was increased CEC, improved nutrient retention properties, increased soil pH, increased microbial activity, increased aggregate stability, increase soil porosity and reduced bulk density (Noble *et al.*, 2001; Noble *et al.*, 2003; Noble *et al.*, 2004; Puttaso, 2003 and Velde, 1992) as process is illustrated in Figure 75.

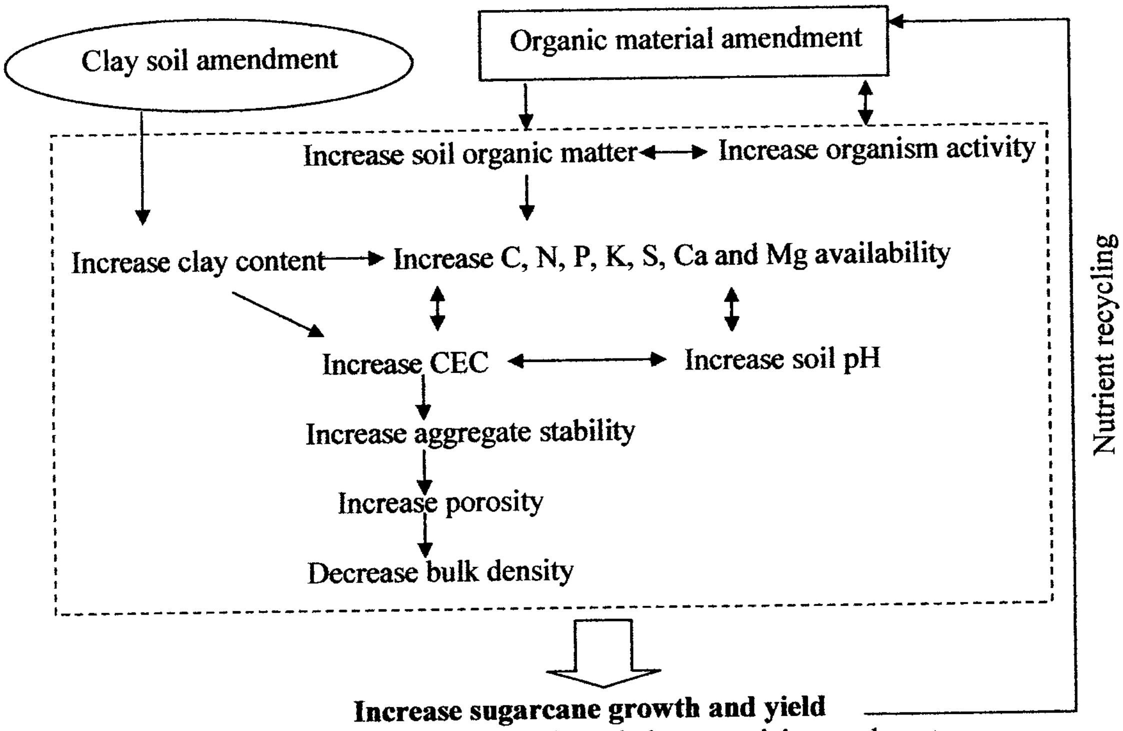

Figure 75 Rehabilitation process in organic and clay material amendment

Rehabilitation capability can be detected by sugarcane growth, plant nutrient concentration and soil properties after amendment. The conventional chemical fertilizer application was used to compare with other treatments for soil improvement determination. From the present work we found yield in clay soil @ 75 t ha^{-1}, filter cake @ 25 t ha^{-1} and cattle manure @ 12.5 t ha^{-1} were higher than conventional chemical fertilizer. Plant nutrient concentration we found (1) total nitrogen and total phosphorus in organic and clay material amendments greater than conventional chemical fertilizer (2) total potassium in organic and clay material amendments lesser than conventional chemical fertilizer (3) total calcium in clay soil and filter cake application were higher than conventional chemical fertilizer (4) total magnesium in filter cake and cattle manure were higher than conventional chemical fertilizer. Soil properties after amendment i.e. (1) bulk density was lesser than conventional chemical fertilizer after using clay soil @ 75 t ha^{-1} and cattle manure (2) soil texture did not differ (3) aggregate stability in organic and clay material amendments were higher than conventional chemical fertilizer (4) soil moisture did not differ (5) soil pH in organic and clay material amendments higher than conventional chemical fertilizer (6) electrical conductivity did not differ (7) organic matter in organic materials (filter cake, cattle manure and bagasse) application were higher than conventional chemical fertilizer (8) available phosphorus after using filter cake @ 50 t ha^{-1} was higher than conventional chemical fertilizer (9) exchangeable potassium in filter cake @ 50 t ha^{-1} and cattle manure @ 25 t ha^{-1} application were higher than conventional chemical fertilizer (10) calcium in all clay soil applications were greater than conventional chemical fertilizer (11) magnesium in all materials was higher than conventional chemical fertilizer (12) CEC in organic and clay material amendments was higher than conventional chemical fertilizer.

The organic and clay material amendments can improve soil dynamic quality (Carter, 2000) that include, physical (i.e. bulk density and aggregation) and chemical properties (i.e. soil pH, organic matter, available phosphorus, extractable potassium, calcium, magnesium and CEC). The significant effect of amendment materials on soil properties in each amendment method can be explained below:

5.1 Soil properties improvement among amendment methods

The banding method shall be practical method for small farmer to implement and for sugarcane planter in big farmer. The effect of materials on soil properties in banding trial improved soil pH, available phosphorus, exchangeable potassium, exchangeable calcium, exchangeable magnesium and cation exchange capacity after amendment. The application of organic and clay material could increase soil pH. Available phosphorus increased in filter cake application. Cattle manure enhanced exchangeable potassium and clay soil influenced to increase exchangeable calcium, exchangeable magnesium and cation exchange capacity.

Broadcasting method will duplicated the effect of organic and clay material at end of crop cycle (about three year with one plant cane and two ratoons cane) in banding trial. At the end of sugarcane cycle in banding trial, plough out and incorporate organic and clay material into the soil. After plough out the organic and clay material should be incorporated like in broadcasting trial. Broadcast can improve bulk density, soil pH, organic matter, available phosphorus, exchangeable potassium, exchangeable calcium, exchangeable magnesium and cation exchange capacity. Cattle manure application can decrease bulk density and increase soil pH, organic matter and exchangeable potassium. Filter cake could increase available phosphorus. Clay soil could increase exchangeable calcium, exchangeable magnesium and cation exchange capacity.

5.2 Limited factors of soil properties improvement

Both of application methods have the same trend in cattle manure, filter cake and clay soil amendments which could improve exchangeable potassium, available phosphorus and cation exchange capacity respectively. However, limiting factors on sugarcane growth in this soil i.e. potassium, organic matter and cation exchange capacity can improve each property after amendment as described below:

5.2.1 Potassium

The first limiting factor in this area was potassium deficiency. Potassium influences translocation, photosynthesis, enzyme system and respiration. Potassium improvement in soil can be managed with fertilization and improved CEC. After the amendments with organic and clay material in this experiment we found greater potassium content in soil due to organic matter and clay particle can fix potassium ion with greater CEC and higher negative charge tend to slow the release in available form (Brady, 1984). On the other hand, potassium concentration in plant was higher comsumption with more potassium availability in soil that plants tend to take up soluble potassium far in excess of their needs. In this trial we confirmed above statement with potassium concentration in sugarcane third visible dewlap leaf in all treatments was in excess than necessary especially in control and conventional chemical fertilizer. Organic matter and clay micelle could retain potassium availability as found the relationship of extractable potassium with organic matter and clay content (r = 0.42* and 0.35* respectively) as shown in Appendix 41. Clay soil involved negative charge with increasing clay particles can attract more cation (Miller and Roy, 1990). This caused by predominately negative charge development on soil organic matter. The principal functional groups involved in negative charge development are carboxylic and phenolic acids (Brady, 1984). Interaction of cations with soil organic matter involves several different bonding mechanisms. Basic nutrient cations (Ca, Mg and K) interact predominantly via. electrostatic attraction with soil organic matter (Duxbury *et al.*, 1989).

Calcino (1991) reported the average amount of potassium removal by one crop of sugarcane 220 kg ha^{-1}. Potassium removal by sugarcane is quite high that the amendment of organic and clay material can maintain potassium in soil and retain availability for a longer time. Otherwise, influence of calcium in clay soil can greatly reduce the level of potassium in soil solution. Futhermore, high calcium levels in the soil solution may reduce potassium uptake (Clement, 1901). This indicates clay soil application can reduce luxury comsumption of potassium and maintain its level deficiently for ratoon crops. In addition, after harvest, 7-12 t ha^{-1} of new trash dry matter was present on the soil surface (Robertson and Thorburn, 2000) which contained potassium 134-229 kgK ha^{-1} accumulated in trash. In unpublished data of Larsen and Mitchell found nutrient return of about 20% in trash blanket system (80% loss through leaching). The potassium return to soil was 27-46 kgK ha^{-1} or about 0.10-0.17 $cmol_c$ kg^{-1} in the year following harvest. The potassium level in soil of all treatments after harvest had ranged 0.08-0.17 $cmol_c$ kg^{-1} and include with potassium in trash blanket was not enough for using in ratoon cane.

The sustainable sugarcane production which retains potassium level in soil can use green cane trash blanket for potassium recycling and addition with regularly application of organic materials containing high potassium level as in cattle manure to improve potassium level and retain potassium availability with high activity clay addition which can increase CEC for potassium adsorption. Nevertheless, the application of potassium fertilizer at planting caused osmotic desiccation of plant cells and its effectively a salting injury. If the potash is in contact with the cane setts, fertilizer burn can result in delayed or failed germination of some of the eyes of the sett and root stubbing may also occur. Hence, careful potassium application should be avoid contact directly with seed sett and should be buried in a band on each side of the row (Hogarth and Allsopp, 2000).

5.2.2 Organic matter

Organic matter builds up from organic material decomposition by microorganisms. The decomposition processes (breakdown of proteins and organic decay) in sugarcane depends on radiation, temperature, fertilization, planting and incorporation of crop residues through cultivation or burning of crop residues. However, fast decomposition rate was found in tropical soil (about 100 days after harvest) (Thorburn *et al.*, 2000). The enzymatic changes of the soil organic matter proceed, simple decomposition products as carbon (CO_2, CO_3^{2-}, HCO_3^-, CH_4 and elemental carbon), nitrogen (NH_4^+, NO_2^-, NO_3^- and gaseous nitrogen), sulfur (S, H_2S, SO_3^{2-}, SO_4^{2-} and CS_2), phosphorus ($H_2PO_4^-$, HPO_4^{2-}) and others (H_2O, O_2, H_2, H^+, OH^-, K^+, Ca^{2+}, Mg^{2+} and etc.). The colloidal nature of humus was emphasized (1) The tiny colloidal humus particles (micelles) are composed of carbon, hydrogen, and oxygen (probably in the form of modified lignins, polyuronides and polysaccharides) (2) The surface area of humus colloids is very high, generally exceeding that of silicate clays (3) The colloidal surfaces of humus are negatively charged, the sources of the charge being carboxylic or phenolic groups. The extent of the negative charge is pH dependent (4) At high pH values the cation exchange capacity of humus far exceeds that of most silicate clays (150-300 $cmol_c\ kg^{-1}$) (5) Humus has low plasticity and cohesion, which helps account for its very favourable effect on aggregate formation and stability (7) Cation exchange reactions with humus are qualitatively similar to those occurring with silicate clays.

The organic matter enhanced after applying cattle manure and filter cake broadcast and banding application with clay soil @ 50 t ha^{-1}, bagasse @ 12.5 t ha^{-1} and clay soil @ 75 t ha^{-1} similar to results of Vityakon *et al.*, 1988; Leaungvutirog *et al.*, 2002; Ugolini *et al.*, 2002; Kogram *et al.*, 2002; Anakawech *et al.*, 1979; Anakawech, 1997; Sruttaporn and Sangsila, 1988; Sillapaprommas *et al.*, 2000; Hunsigi, 1993 and Cerri *et al.*, 1988. From the above characteristics of humus we also found in this experiment as the relationship between organic matter and CEC was a positive correlated with r = 0.51** (Appendix 41). In addition, organic matter in soil was correlated with cane yield as r = 0.49**. The negative charge of humic acids is caused by the acidic carboxyl and phenolic hydroxyl groups that can adsorb cation (Brady, 1984). The organic matter in above treatments increased by organo-clay complex in clay soil amendment and by high organic carbon content in bagasse. Organic matter in sandy soils was protected by adsorption to clay minerals or encrustation by clay minerals (Hassink *et al.*, 1993). Organic matter can influence soil by affecting soil fertility, soil structure, and the ability of a soil to act as a buffer against sharp pH changes. Organic matter contributed substantial amounts of nitrogen and sulfur due to microbial breakdown processes, storage for phosphorus, potassium, calcium and magnesium, as it generally has a high CEC which enhanced sugarcane growth (Hunsigi, 1993 and Hogarth and Allsopp, 2000).

The trash returned after harvest contained 3-5 t C ha^{-1}, 28-55 kg N ha^{-1} and had a C:N ratio of 70-117 (Robertson and Thorburn, 2000). Retention of trash C and N in the soil with 10-20% of cumulative C returns (300-1000 kg C ha^{-1}; organic C) and 40-100% of cumulative N returns (11-55 kg N ha^{-1}). The organic matter under trash blanket in retentive scheme, soil C would be increased by 7-14% after 25 years and soil N would have increased by 8-21% after 35 years. Under non-retentive scheme, soil C would have increased by 1.4-2.6% after 6 years and soil N would have increased by 1.3-3% after 6 years.

Sustainable sugarcane production should build up retentive organic matter which can store complex clay particles (White *et al.*, 2000). The increasing organic matter in soil tends to increase CEC. Otherwise, other parameters affected on CEC e.g. clay content, calcium, magnesium and pH. This indicates the sustainable organic matter management in sugarcane sould be effective with three procedures (1) Liming with dolomite to improve pH, calcium and magnesium in soil and then incorporate with organic material for soil organic matter improvement in land preparation process before planting (2) incorporation with organic materials into soil for soil organic matter and CEC improvement and then addition of clay soil to maintain CEC (increase clay content, increase calcium and magnesium adsorption with clay particles) and (3) combine method that liming with dolomite, organic material incorporation and clay soil application (4) Green cane trash blanket can return nutrients and organic matter accumulating in the soil and reduce soil erosion by reducing raindrop impact on soil surface.

5.2.3 Calcium

Calcium in soil of filter cake and clay soil application was higher than conventional chemical fertilizer as the materials consisted of high calcium content (Table 3). In moderately acid soil in this present study (pH_{H_2O} 5.56) aluminium and hydrogen compounds also account for soil solution hydrogen ions, but again by different mechanisms (Brady, 1984). The alunimum can no longer exist as Al^{3+} ions but is converted to aluminium hydroxy ions by reactions and some of the aluminium hydroxy ions are adsorbed and act as exchangeable cations. In 2:1 type clays, the aluminium hydroxy ions move into the interlayer space of the crystal units and become very tightly adsorbed. In this form they prevent intracrystal expansion and block some of exchange sites. Their removal, which can be accomplished by raising the soil pH, results in the release of these exchange sites. In moderate acid soils, adsorbed hydrogen also contributes to the soil solution hydrogen. The readily exchangeable hydrogen held by the permanent charges. In addition, with the rise in pH, some hydrogen ions have been held tenaciously through covalent bonding by the organic matter and clay are now subject to release.

The calcium increment was found in clay soil at the rate of 75 t ha^{-1} application where calcium increased at both soil depths after amendments. This caused high CEC in clay soil which can absorb more cation than other materials as the relationship between CEC and calcium in soil. In this present work we found a position correlation between calcium and CEC with correlation coefficient 0.67** (Appendix 46). The increasing of calcium in soil increased soil pH as correlation in Appendix 46 ($r = 0.85^{**}$). The application of clay soil clearly increased exchangeable calcium in soil, pH, CEC and calcium concentration in plant. In addition, there was a positive correlation between calcium in plant and yield ($r = 0.56^{**}$). Calcium is essential for the growth and development of spindle, leaves and roots. Calcium plays an important role in nitrogen metabolism (Hogarth and Allsopp, 2000). The calcium concentration in leaf was 0.12-0.16% or 8.4-11.2 kg Ca ha^{-1}. In unpublished data of Larsen and Mitchell found nutrient return about 20% in trash blanket system (80% loss through leaching and plant uptake). Calcium return to soil after harvest was about

1.68-2.24 kg Ca ha^{-1} or 0.02-0.03% Ca in soil. The remaining exchangeable calcium in soil 0.04-0.90 $cmol_c\ kg^{-1}$ after harvest and return calcium from trash to soil about 0.001 $cmol_c\ kg^{-1}$ was sufficient for ratoon crop only in high calcium content (>0.55 $cmol_c\ kg^{-1}$) found in clay soil amendments in this experiment.

The sustainable calcium management for sugarcane production in Oxic Paleustults should apply high CEC and calcium content materials such as clay soil. Otherwise, the calcium in soil can be improved by liming with agricultural lime or dolomite, should be broadcast and incorporated at least 1 month before planting so that it can increase soil pH and tend to increase CEC and cane yield ultimately.

5.2.4 Cation exchange capacity

Cation exchange capacity (CEC) increased in organic and clay material amendments especially in clay soil application at the rate of 75 t ha^{-1} which had highest CEC. Negative charge in clay comes from ionizable hydrogen ions and isomorphous substitution. Ionizable hydrogen ions are hydrogens from hydroxyl ions on clay surfaces. The –Al-OH or –Si-OH portion of the clay ionizes the H and leaves an unneutralized negative charge on the oxygen ($-Al-O^-$ or $-Si-O^-$). The second source of charge on clay particles is the substitution of one ion for another of similar size and often with lower positive valence (Miller and Roy, 1990). The increase of CEC due to increased clay fraction as the relationship between CEC and clay particle content found with a positive correlation (r = 0.51**). Clay soil application had clearly increased CEC. CEC is mainly influenced by organic matter, kind and amount of clay and pH of soil as found in this experiment the CEC was related with organic matter and pH of soil with correlation coefficient 0.37* and 0.72** respectively (Appendix 46). Organic matter contributes to the cation exchange capacity, often furnishing 30-70 percent of the total amount. The large available sufaces of humus have many cation exchange sites that adsorb nutrients for eventual plant use (Miller and Roy, 1990). Increasing acidity is associated with decreasing CEC, decreasing supply of available essential plant nutrients, and an increase in the amount of solution H^+ and Al^{3+} (Foth and Ellis, 1996). The exchange acidity of humic substances vary widely but the exchange capacity increases markedly with increasing pH. The latter has been attributed to increased ionization of acidic groups, mostly carboxylic group, at the higher pH values (Stevenson, 1994).

The modifying effects of adsorbed cations after organic and clay material amendments constructed aggregate stability with higher mean weight diameter and degree of aggregation than conventional chemical fertilizer. The chemical properties of the humus and clay are probably effective in the organization and the later stabilization of the aggregate. Moreover, slime or other viscous microbial products encourage crumb development and exert a stabilizing influence. The adsorption of ions such as calcium, magnesium or aluminium may encourage the individual colloidal particles to come together in small aggregate called fluccules (Brady, 1984 and Hillel, 1996). The organic material amendment can increase soil organic matter which can encourage CEC to adsorb cation by the negative charge of humic acids is caused by the acidic carboxyl and phenolic hydroxyl groups that can adsorb cation such as calcium and form soil aggregate as relationship between organic matter and CEC was correlated with r = 0.51** (Appendix 41). In clay material amendments supplied more 2:1 clay content in soil and phenomenon of the isomorphous substitution was occur. The mechanism of this substitution results of net negative charge in the clay crystal which can adsorb positively charged cation. The increase clay content increased CEC as the relationship with clay particle (correlation coefficient 0.51** as presented in Appendix 41). In addition, we found the positive correlation between degree of aggregation and percentage of clay (r = 0.43*). This indicates degree of aggregation increased with increasing clay content in soil as reported by Baldock, 1990 and Hassink *et al.*, 1993.

The increasing of CEC possibility increases nutrient retention for longer availability and forming aggregate stability. CEC management in soil depended on pH which can be increased with increasing pH, so in moderate acid soil as in this experiment should increase soil pH. In addition, humic acid in soil organic matter and high activity clay content in smectite can enhance CEC. That CEC management to sustain sugarcane production should be supplied regularly with organic materials which can arise from ionization of COOH groups and phenolic OH groups contributing to higher CEC in soil. The application of high activity clay can be developed negative charge from isomorphous replacement, the ionization of OH groups at the edges of clay plates, and pH-dependent charges associated with Al oxides. Liming for the beneficial results to raise soil pH with increased net negative charge and, therefore, increases the capacity of the soil to retain cations.

5.2.5 Interaction

The amendment with organic material will improve soil organic matter which can increase microbial activities and numbers. The increased microbial numbers and activities decomposes organic material faster especially with high temperature in tropical soil. Generally, after organic residue application its initially changes in the chemical by mineralization in the form of carbon and hydrogen containing compounds followed by organisms attack easily decomposable compounds such as sugars and celluloses, releasing CO_2 and H_2O and rapidly increasing their own numbers as well as the quantities of new compounds they synthesize. The original soil organic matter is subjected to some breakdown, CO_2 and H_2O probably being the decomposition products. The decomposition products results from the activity of the soil microorganisms e.g. C, N, P, K, Ca and Mg. As soon as the easily decomposed food is exhausted, microorganism number decline. The remaining microbes attack the more resistant compounds, both those in the original plant material and those that have been synthesized. In time, modified compounds from the original plant materials and new synthesized compounds, all of which are very slowly decomposed, become indistinguishable form the original soil humus. The humic micelles, like the particles of clay, high cation eachange capacity, granulation encouraged, plasticity and cohesion reduced, water holding capacity increased, supply and availability of nutrients. The major agency in the encouragement of granular and crumb type aggregate formation is organic matter, which not only binds but also lightens and expands, making more soil porosity of macropore size and decreased soil bulk density.

The organic matter composited with variable charges. In case of clay soil amendment, the major affect on increased clay content has higher anion to adsorb cation in soil and improve nutrient availability. Aggregate formation is definitely influenced by the nature of the cations adsorbed by clay colloids especially the clay soil content with high calcium may encourage aggregate formation starting with a process of flocculation. Otherwise, chemical binding force of clay particle is probably effective in the organization and stabilization of the aggregate. The increased aggregate stability affects higher macropore and decreases bulk density.

Both organic and clay material amendment in degraded sandy soil of Oxic Paleustults for sugarcane production can improve physical soil properties (aggregate stability, porosity and bulk density), chemical soil properties (C, N, P, K, S, Ca, Mg, CEC, pH and organic matter) and biological soil properties (microbial numbers and activities). All of the above properties can be improve sugarcane yield after amended with organic and clay material.

Both clay and organic matter contribute to the cation exchange capacity of the soil. Because cations are positively charged, they are attracted to surfaces which are negatively charged. The charge on the clay fractions arise from isomorphous replacement, the ionization of OH groups at the edges of clay plates, and pH-dependent charges associated with aluminum oxides. There are two basic types of charge develop on clay mineral surface: permanent and pH dependent. For the organic fraction, the charge arises largely from ionization of COOH groups, although some contribution from phenolic OH is suspected. The retention of cations of organic matter are depending on soil pH (variable charges). Moreover, clay material amendment can improve nutrient retention with higher CEC and form complex with humus. To sustain sugarcane productivity we should increase soil organic matter with organic material amendments and maintain organic matter level with clay soil amendments.

6. Recommendation

The degraded Oxic Paleustults rehabilitation for sugarcane production should

6.1 Soil organic matter increment by organic materials supplement (especially with local organic waste and industrial by-product) should be done. Clay material addition would restore organic matter and retain cation exchange capacity. It could retain nutrient availability especially in high consumption nutrients e.g. potassium and calcium with permanent charge of clay mineral.

6.2 Provide sufficient nutrients at a balanced level with plant removal using split fertilizer application depending on stage of growth and crop nutrient demand.

6.3 Liming with dolomite can increase soil pH, calcium, magnesium, CEC and encourage aggregate stability.

6.4 Green cane trash blanket after harvest can return carbon, nitrogen and other nutrients (e.g. P, K, Ca, Mg) to soil.

6.5 Increase biodiversity by organic matter supplement, avoid herbicide and insecticide (using integrated pest management).

6.6 Control tillage system in land preparation and weeding should be done at the right time with minimum tillage.

6.7 Control traffic in heavy machinery usage by constructing transportation path to reduce soil compaction in field.

6.8 Soil erosion control by reducing unnecessary cultivation practices, green-cane trash blanketing and contour planting on steep slope. Management on time following sequence of sugarcane cropping system avoiding cultivation or growing during storm (prevalent between September and October).

6.9 The cropping system management using fallow or crop rotation with green manuring between crop cycles provide the soil with a break from continous sugarcane, break pest, weed and diseases cycles and allows mineralization of nitrogen and other nutrients that are stored in soil microbes.

However, soil improvement in Oxic Paleustults of Northeast Thailand for sustainable crop productivity was quite difficult due to very coarse texture with high water percolation rate which take clay particle illuviation at subsoil. In addition, type of cover crops should be considered with fibrous root like grass or dense crown cover e.g. forage crop for reduce detachment by rainfall and runoff. In case of sugarcane production we should select fast growth in early growth stage to narrow the interrow space, wide stool shape, broad leaf, good tillering, free trashing and good ratooning ability varieties. Fallow land between crop cycles using crop rotation and green manuring with legume crop should be practiced.

7. New knowledge

Korat degraded sandy soil can be improved for soil pH, organic matter, exchangeable potassium, exchangeable calcium, exchangeable magnesium and cation exchange capacity by organic and clay material amendments which can enhance sugarcane growth and yield. The rehabilitation process of organic materials amendment increased organic matter which is reserve of plant nutrient (nitrogen, phosphorus and potassium) and anion. The anion arise largely from ionization of COOH groups, although some contribution from phenolic OH in organic matter (variable charge). Organic matter can enhance cation exchange capacity which can attract with basic cation nutrients (potassium, calcium and magnesium) by ionic bonding and enhance soil pH. In case of clay soil amendment, the rehabilitation process starts from increased cation exchange capacity with their anion arising from isomorphous replacement, the ionization of OH groups at the edges of clay plates, and pH-dependent charges associated with aluminum oxides (permanent and variable charge). In addition, organic matter can adsorb with clay material. The increment of cation exchange capacity attracts with basic cation nutrients (potassium, calcium and magnesium) by ionic bonding which can enhance soil pH. Both materials can improve nutrient availability for sugarcane growth which can increase sugarcane yield and lead to good ratooning ability.