# Preservation of Organic Matter as Affected by Various Clay Contents in an Acid Soil : Beneficial Impact on Groundnut Yield

*Kestabilan Bahan Organik Tanah yang Diakibatkan oleh Berbagai Kandungan Liat pada Tanah Masam : Dampak Menguntungkan pada Hasil Kacang Tanah*

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## ABSTRACT

Systematic study on the effect of various clay contents on organic C dynamic and groundnut yield *(Arachis hypogea)* in upland acid soils has not received any attention. The objectives of the study were: (i) to assess the capability of various soil clay contents to preserve organic C, (ii) and to relate the effects of soil clay fraction and organic C on groundnut yield of an acid soil (Ultisol). The soil clay content was artificially adjusted to 15, 30, 45, 60 and 75%. Each soil clay percentage was thoroughly mixed with finely ground rice straw at the rate equals to 0.5, 1, 2, 3, 4, and 5% of organic C. The soil was then transferred into a pot and planted with corn (*Zea mays*) for the first 6 months and followed by groundnut for further 6 months. The experiment was arranged in a split plot design with three replications under glasshouse conditions. Results for the first 6 months have been published elsewhere. Hence, results for the last 6 months were presented here. Soil clay was the major factor responsible for the preservation of organic C as indicated by (i) the increased soil organic C with increasing clay fraction, and (ii) the low mineralization rate as shown by $CO_2$-C: total C ratio from low to high 75<60<45<30<15% soil clay. It is observed that every 15% clay increment could preserve another 0.3% organic C for the period of 12 months. The increased soil organic C could linearly increase groundnut yield for 15 and 30% clay and quadratic yield for 45 and 60% clay. The maximum grain yield was 25.7-27.6 g pot$^{-1}$ (equals to 2.9-3.1 t ha$^{-1}$), which was obtained at 30-45 % clay containing 1.8-1.9% soil organic C.

*Keywords : Acid soil, Organic C preservation, C-clay association, Groundnut yield*

## ABSTRAK

Studi secara sistematis mengenai pengaruh berbagai kandungan liat pada dinamika C organik dan hasil kacang tanah (*Arachis hypogea)* pada lahan kering masam belum dilakukan. Tujuan penelitian ini adalah mengkaji kemampuan berbagai kandungan liat untuk mengawetkan C organik, dan pengaruh kandungan liat dan C organik pada hasil kacang tanah pada tanah masam (Ultisol). Kandungan liat tanah diatur secara buatan pada taraf 15, 30, 45, 60 dan 75% dengan menggantikan tanah secara proporsional dengan pasir. Tiap persentase liat dicampur secara merata dengan jerami padi yang telah digiling halus pada takaran setara 0.5, 1, 2, 3, 4 and 5% C organik. Tanah kemudian dipindahkan ke dalam pot dan ditanami jagung pada 6 bulan pertama kemudian diikuti dengan kacang tanah pada 6 bulan berikutnya. Percobaan disusun menurut rancangan petak terpisah dengan tiga ulangan dalam rumah kaca. Hasil penelitian pada 6 bulan pertama telah dipublikasikan sehingga dalam tulisan ini disajikan hasil penelitian pada 6 bulan terakhir. Faktor yang berperan utama dalam pengawetan C organik adalah besarnya kandungan liat seperti yang ditunjukkan oleh (i) total C organik yang meningkat secara linear dengan peningkatan persentase liat, dan (ii) tingkat mineralisasi C yang rendah seperti terlihat pada nisbah $CO_2$-C: total C yang meningkat dari 75 < 60 < 45 <30 < 15% liat. Setiap peningkatan liat 15% mampu mengawetkan tambahan 0,3% C organik dalam waktu 12 bulan. Peningkatan C organik tanah secara linear meningkatkan hasil kacang tanah pada 15 dan 30% liat, dan secara kwadratik pada 45 and 60% liat. Hasil kacang tanah maksimum adalah 25,7-27,6 g pot$^{-1}$ (setara 2,9-3,1 t ha$^{-1}$), yang diperoleh pada kandungan liat 30-45% dan C organik 1,8 -1,9%.

*Kata kunci : Tanah masam, Pengawetan C organik, Asosiasi C organik-liat, Kacang tanah*

## INTRODUCTION

Clay and organic matter colloids are two soil constituents that control major chemical, physical and biological processes and their interaction may result in a longer benefit impact on soil properties and crop yields. The interaction between these two soil components refers to the inter-molecular interactions between organic and inorganic substances that alter the rate of degradation of those organic or synthesis of new organic compounds (Sollins *et al.*,1996).

Generally, there is a positive correlation between organic C and clay content (Parton *et al.*, 1987; Hassink and whitmore, 1997). Stevenson (1994), using data from various soils, showed that about 52 to 98% of the C in the soils examined was associated with clay. This evidence confirms that the clay fraction of soils has the high capacity to preserve organic C. The effect of mineral fraction on quantity and quality of organic matter (OM) in soils

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is due partly to adsorption on clay surfaces by which a large part of the OM is protected from microbial decomposition (Oades, 1988) and another part to physical inaccessibility of OM within pore of microaggregates (Tisdall and Oades, 1982; Sollins *et al.*, 1996). Accessibility refers to the location of organic substances as it influences their access by microbes and enzymes (Sollins, 1996). Recently, Anda *et al.* (2008b) measured surface area, pore sizes and mineral composition (shown by XRD, DTA and SEM) of three Oxisols and reported that Stabilization of SOM in soil occurred through physical protection in the mesopores and cation bridging between OM and mineral surfaces. They also reported the less crystalline and smaller clay size particles play an important role in SOM stabilization.

The mechanism underlying stabilization of soil organic matter (SOM) is not entirely understood. Christensen (1996) reviewed organomineral complexes and reported that mechanisms responsible for stabilization of SOM include chemical recalcitrance, chemical stabilization and physical protection. Similarly, Sollins *et al.* (1996) concluded from their review on mechanisms and factors control stabilization and destabilisation of SOM that the stability of the organic C is the results of three factors: recalcitrance, interactions and accessibility.

Skjemstad *et al.* (1996), using $^{13}C$ NMR with CP/MAS to study chemistry and nature of protected C in Argixeroll, Hapludoll, Kandiustox and Pellustert at 0-10 cm depth, reported that the mechanism of long-term protection of SOM against microbial decomposition is physical incorporation into microaggregates that are able to withstand physically disruptive forces. In addition, Mayer (1994) reported that stabilisation of organic matter occurred through adsorption into small pores (<8-nm width) where slower condensation reactions can occur because of exclusion of faster, competitive biological reactions (hydrolytic enzymes).

Carbon mineralisation as measured by $CO_2$ evolution decreased with increasing clay content in whole soil, suggesting that the potential turnover time of SOM was greater in coarse textured soils than in fine textured soils (Hassink *et al.*, 1993; Franzluebbers and Arshad, 1997). Turnover time for C in clay, silt and sand is 59, 6 and 4 years, respectively (Christensen, 1996). The turnover time also depends on organic matter pool in soils. The minimum turnover times of active pool, slow pool and passive pool are 0.5, 10, and 500 years, respectively (Parton and Rasmussen, 1994).

Under natural condition, upland acid soils can generally contain clay fraction ($< 2 \mu m$) ranged from 30 to 85% (Feller *et al.*, 1992; Anda *et al.*, 2008a). At present, however, no attempt has been made to systematically assess to what extent the capability of acid soils at different clay contents to preserve organic C at a similar C application rate and to relate the effect of soil mineral and organic C interactions on crop yields. The objectives of the study were (i) to assess the capability of various soil clay contents to preserve organic C, (ii) and to relate the effects of soil clay fraction and organic C on groundnut yield of an acid soil (Ultisols).

## MATERIALS AND METHODS

### Soil preparation

The acid soil used in this study was an Ultisols taken from Jambi, Sumatera, where Ultisols are the major soils and are mainly used for plantation and food crops. The bulk soil was taken at 0-20 cm depth, dried, ground and passed through a 2 mm sieve. Total clay in an initial soil was calculated using percentage of clay content obtained from particle size analysis (75% clay; Anda *et al.*, 2005). The sand was taken from the river with the assumption that all organic C has been washed out, hence it would not introduce any addition of organic C when it was used to adjust soil clay content. The soil of 8 kg pot$^{-1}$ was used and the clay fraction was adjusted into 5 levels (15, 30, 45, 60, and 75%) by substituting a portion of the initial soil with sand. The amount of sand to be added to a given

treatment was determined on a weight basis.

The rice straw was collected from a rice field, dried, chopped (2 cm) and then finely ground in order to obtain a homogenous material. The rates of organic C-derived rice straw treatments were 0.5, 1.0, 2.0, 3.0, 4.0, and 5.0%. The amount of rice straw added to adjust soil organic C to a given application rate was calculated as the amount of organic C needed to achieve a given rate of soil organic C and then subtracted by the initial organic C in adjusted clay percentage.

### Glasshouse experiment

The soil clay fractions at 15, 30, 45, 60 and 75% of 8 kg soil prepared as described previously were thoroughly mixed with finely ground rice straw according to a given organic C treatment. Organic C rates consisted of 0.5, 1.0, 2.0, 3.0, 4.0, and 5.0% and designated as O0, O1, O2, O3, O4, and O5, respectively. The exceptions were clay at 75, 60, and 45%. The rice straw was not added at O0 - O2 rates for 75% clay, O0 - O1 for 60% clay and O0 for 45% clay. This is due to the initial organic C content was already similar to the rates of C treatments, even slightly higher for the 75% clay. All other organic C rates were well adjusted according to a given treatment in each clay percentage. After mixing of given rice straw treatment within each clay percentage, the soil was transferred into a black plastic pot and the water content was brought up to 80% water holding capacity. The basal treatments were 150 kg urea, 100 KCl, 150 kg SP-36 ha$^{-1}$ ,and the amount of lime was 1.5 times exchangeable Al. The experiment was arranged in a split plot design where 5 clay percentages as main plots and 6 organic C rates as subplots with three replications. During the first six months, the pot was grown with maize of pioner cultivar and the results have been reported by Anda *et al*. (2005). For the next six months, the pot was

grown with groundnut, singa cultivar, of 2 seeds

pot$^{-1}$. Thinning was performed after two weeks and left one seedling pot$^{-1}$ behind. After harvesting, the groundnut yield was oven dried at 105$^{o}$C for 24 h and then weighed. Duncan multiple range test (DMRT) was used to determine the difference between treatments. We reported the preservation of organic C derived rice straw for a period of 12 months.
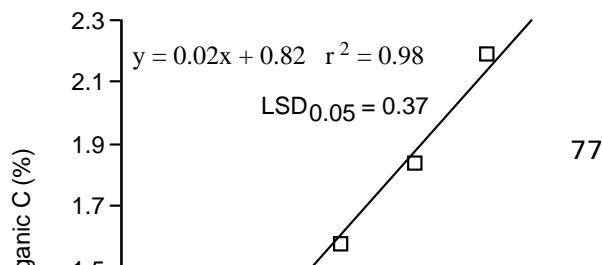
### Soil analyses

Soil was sampled after groundnut harvesting. Total organic C analysis was performed using a wet Walkley and Black method (Nelson and Sommer, 1982) and total N using Kjeldhal method (Bremner and Mulvaney, 1982). $CO_2$ measurement was performed as described by Van De Werf and Verstraete (1987).

### RESULTS AND DISCUSSION

### Effect of clay percentage and organic C-rice straw on soil organic C

The results of the experiment on organic C changes and corn yield for the first six months have been reported by Anda *et al*. (2005); and we present here the results on organic C changes after 12 months and its effect on groundnut yield. The effect of different amounts of clay percentages in preserving soil organic C during a period of 12 month experiment is given in Figure 1. There was a consistent and significant increase in total soil organic C as clay content increased, which is revealed by a positive linear correlation, $Y = 0.02x +0.82$ ($r^2 = 0.98$), between soil organic C and amount of soil clay. This suggests that the clay fraction was a major factor responsible for preservation of organic matter (OM) in the soil. The regression equation indicated that every 15% soil clay increment could preserve another 0.3% organic C.

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The capability of each soil clay to preserve organic C was also assessed using the ratio of organic C in different soil clay percentages (Table 1). The ratio consistently decreased from the high soil clay fraction to the low ones. For example, the values of ratios between 75, 60, 45, and 30% against 15% clay are 2.2, 1.6, 1.4, and 1.2, respectively at a corresponding 3% C-rice straw application rate. This indicates that the amount of organic C substrate physically protected by soil matrices was regularly decrease from the higher to lower clay contents due to reduction of microbial accessibility in the former. The clay fraction as fine particles could fill soil pores, resulting number and size of soil pores to decrease, thereby limited a pathway of various microbes.

Furthermore, the ratio between total organic C

within different clay percentages indicated that the ratio was much higher at the lower rate C application compared to the higher rate, suggesting that most of the C at the lower application rate was adsorbed into mineral surfaces since the sites for adsorption were still available. At the high C organic application rate, adsorption sites may adsorb more organic C and at the same time some organic C was less protected and exposed to microbial decomposers. Mikutta *et al*. (2004) who prepared synthetic hydrous Al oxide, gibbsite and coated with dissolved organic matter (DOM) and polygalacturonic acid (PGA) under laboratory conditions found that organic matter occurred in micropores and small mesopores. Similar results have been reported by other workers (Kahle *et al*., 2002; Mayer *et al*., 2004).

The effect of organic C application rates on total soil organic C after 12 months in different clay percentages is given in Figure 2. The increased rate of C-rice straw applications significantly increased total soil organic C in all soil clay percentages. This can be seen from a positive linear correlation between rates of C treatments and total soil organic C, where determination coefficient is mostly more than 94%.

Generally, total soil organic C significantly increased at an O3 application rate for 15, 30 and 45% clay and at an O4 C application rate for 60 and 75% clay compared to O0, O1, and O2 application rates. The organic C content in soil at

Table 1.   Ratio of soil organic C within different soil clay percentages

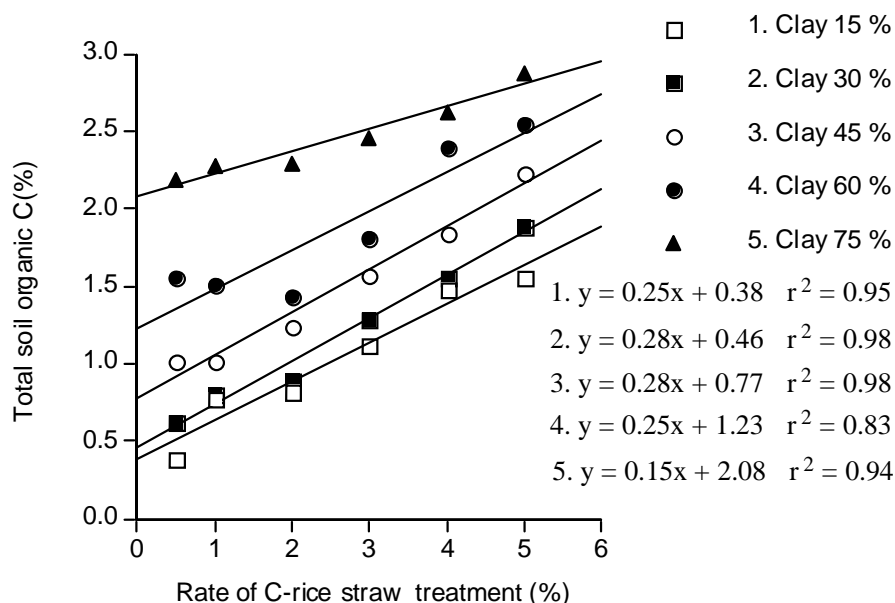| C-rice straw treatment | Organic C ratio in different soil clay pecentages | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
|  | 75:15 | 60:15 | 45:15 | 30:15 | 75:30 | 60:30 | 45:30 | 75:45 | 60:45 | 75:60 |
| O0 | 5.6 | 4.0 | 2.6 | 1.6 | 3.5 | 2.5 | 1.6 | 2.2 | 1.5 | 1.4 |
| O1 | 2.9 | 2.0 | 1.3 | 1.0 | 2.8 | 1.9 | 1.3 | 2.2 | 1.5 | 1.5 |
| O2 | 2.8 | 1.7 | 1.5 | 1.1 | 2.5 | 1.6 | 1.4 | 1.8 | 1.2 | 1.6 |
| O3 | 2.2 | 1.6 | 1.4 | 1.2 | 1.9 | 1.4 | 1.2 | 1.6 | 1.2 | 1.4 |
| O4 | 1.8 | 1.6 | 1.2 | 1.0 | 1.7 | 1.5 | 1.2 | 1.4 | 1.3 | 1.1 |
| O5 | 1.9 | 1.6 | 1.4 | 1.2 | 1.5 | 1.3 | 1.2 | 1.3 | 1.1 | 1.1 |

**Figure 2. Relationship between total soil organic C and rate of C-rice straw application at different soil clay fractions**

O0, O,1 and O2 treatments for 75% clay should be maximum, i.e., 0.5, 1.0, and 2.0%, respectively with respect to organic C rate treatments. However, it is not the case, instead the total soil organic C contents were higher than organic C treatments (O0-O2 rates). A similar case occurred for O0 and O1 rates at 60% clay and at O0 for 45% clay. As described in an experiment method, the higher organic C contents in all those clay fractions than the rate of C treatments were due to the fact that the initial soil organic C was high.

In this study, the existing clay content (75% clay) is already similar to the highest clay percentage treatment rate, hence no sand substitution was made. For 60% clay treatment rate, the addition of sand to lower a clay fraction from 75 to 60% was still insufficient to lower the organic C of initial soil to the desired levels: 0.5% for O0, 1%C for O1 and 2% for O2 rates. Other C treatment rates within 45, 60 and 75% clay fractions are all well adjusted according to a desired organic C rate. The ideal effect of organic C treatment rates on total soil organic C was clearly shown by soil clay contents at 15 and 30%, where all rates of organic C treatments were well adjusted according to a desired rate. A rice straw treatment at O2 significantly increased total soil organic C compared to O0 and O1 rates.

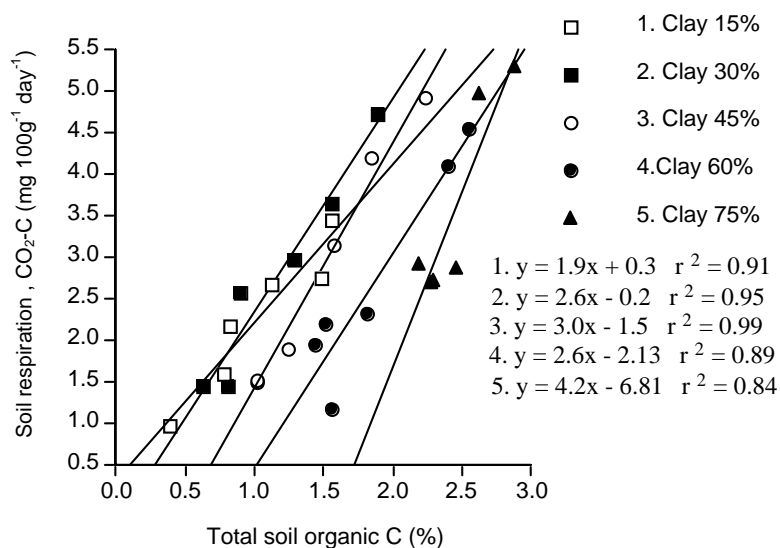**Effect of soil clay and organic C applications on $CO_2$ evolution**

The rate of organic C decomposition was determined from each soil clay percentage at the time of groundnut harvesting. Evolution of $CO_2$ as an indication of microbial activity to decompose organic matter was significantly higher at 75% clay compared to 15% clay (Table 2). However, $CO_2$ evolution from 30, 45 and 60% soil clay were all statistically similar and were not significantly different compared to 75 and 15% clay. The higher $CO_2$ evolution from 75% clay compared to 15% clay does not mean that organic C decomposition rate is faster in the former than the latter, but it is mainly due to a higher substrate (organic C) in 75% clay than 15% clay.

The rate of $CO_2$ evolution from each of soil clay percentage indicated a positive linear correlation with total soil organic C (Figure 3). This suggests

**Table 2.** **The effect of soil clay fractions on soil $CO_2$-C evolution at different C-rice straw application rates**

| C-rice straw treatment | Soil clay (%) | | | | |
|---|---|---|---|---|---|
| | 15 | 30 | 45 | 60 | 75 |
| | ............................. mg $100g^{-1}$ $day^{-1}$ ............................. | | | | |
| O0 | 0.96 d | 1.43 d | 1.48 c | 1.71 b | 2.91 b |
| O1 | 1.59 cd | 1.44 d | 1.52 c | 2.19 b | 2.69 b |
| O2 | 2.16 bc | 2.57 c | 1.90 c | 1.95 b | 2.71 b |
| O3 | 2.66 ab | 2.97 bc | 3.13 b | 2.31 b | 2.86 b |
| O4 | 2.74 ab | 3.65 b | 4.19 a | 4.10 a | 4.96 a |
| O5 | 3.45 a | 4.72 a | 4.92 a | 4.54 a | 5.28 a |
| Mean | 2.26 A | 2.80 AB | 2.86 AB | 2.80 AB | 3.57 B |

In a column, means followed by a similar small letter are not significantly different at 5% level by Duncan multiple range test (DMRT). Means in a row followed a similar capital letter are not significantly different at 5% level by LSD (0.89).



Legend:
- 1. Clay 15%
- 2. Clay 30%
- 3. Clay 45%
- 4. Clay 60%
- 5. Clay 75%

1. $y = 1.9x + 0.3$   $r^2 = 0.91$
2. $y = 2.6x - 0.2$   $r^2 = 0.95$
3. $y = 3.0x - 1.5$   $r^2 = 0.99$
4. $y = 2.6x - 2.13$   $r^2 = 0.89$
5. $y = 4.2x - 6.81$   $r^2 = 0.84$

**Figure 3.** **Relationship between $CO_2$-C evolution and total soil organic C at different soil clay percentages**

that amount of organic matter decomposition not only controlled by the amount of clay fractions as mentioned previously, but also by the amount of substrate availability in the soils. As the availability of substrate (organic C in organic matter) increases the mineralization rate increases, even at the highest soil clay content. Interestingly, determination coefficient of all regression equations indicated that 84 to 99 percent of the variation of $CO_2$ evolution was accounted for by total soil organic C.

The comparison of organic C decomposition rates between clay percentages can not be interpreted directly from $CO_2$ measurement at the end of the experiment because the total soil organic C content was different between clay percentages at any corresponding C treatment rate. As shown previously, the magnitude of $CO_2$ evolution was not only controlled by clay fraction, but also by the amount of organic C in soils. As the $CO_2$ measurement was carried out only at the end of

**Table 3.** The effect of C-rice straw application rate on soil $CO_2$-C: total C ratio within different soil clay percentages

| C-rice straw treatment | Soil clay (%) | | | | |
|---|---|---|---|---|---|
| | 15 | 30 | 45 | 60 | 75 |
| O0 | $2.46 \times 10^{-3}$ | $2.27 \times 10^{-3}$ | $1.47 \times 10^{-3}$ | $1.10 \times 10^{-3}$ | $1.33 \times 10^{-3}$ |
| O1 | $2.06 \times 10^{-3}$ | $1.80 \times 10^{-3}$ | $1.50 \times 10^{-3}$ | $1.45 \times 10^{-3}$ | $1.19 \times 10^{-3}$ |
| O2 | $2.63 \times 10^{-3}$ | $2.86 \times 10^{-3}$ | $1.53 \times 10^{-3}$ | $1.36 \times 10^{-3}$ | $1.18 \times 10^{-3}$ |
| O3 | $2.38 \times 10^{-3}$ | $2.30 \times 10^{-3}$ | $1.99 \times 10^{-3}$ | $1.28 \times 10^{-3}$ | $1.17 \times 10^{-3}$ |
| O4 | $1.86 \times 10^{-3}$ | $2.35 \times 10^{-3}$ | $2.27 \times 10^{-3}$ | $1.72 \times 10^{-3}$ | $1.89 \times 10^{-3}$ |
| O5 | $2.23 \times 10^{-3}$ | $2.50 \times 10^{-3}$ | $2.21 \times 10^{-3}$ | $1.78 \times 10^{-3}$ | $1.83 \times 10^{-3}$ |

**Table 4.** The effect of soil clay content and C-rice straw application rate on total soil N content

| C-rice straw treatment | Soil clay (%) | | | | |
|---|---|---|---|---|---|
| | 15 | 30 | 45 | 60 | 75 |
| | ...................................... % ...................................... | | | | |
| O0 | 0.04 d | 0.07 c | 0.14 d | 0.17 c | 0.24 bc |
| O1 | 0.08 cd | 0.07 c | 0.15 cd | 0.18 c | 0.24 bc |
| O2 | 0.09 bc | 0.08 c | 0.16 bcd | 0.19 c | 0.24 bc |
| O3 | 0.10 abc | 0.12 b | 0.18 bc | 0.20 bc | 0.27 abc |
| O4 | 0.12 ab | 0.15 ab | 0.19 ab | 0.23 ab | 0.28 ab |
| O5 | 0.13 a | 0.18 a | 0.22 a | 0.24 a | 0.30 a |
| Mean | 0.09 C | 0.11 C | 0.17 B | 0.20 B | 0.26 A |

In a column, means followed a similar small letter are not significantly different at 5% level by Duncan multiple range test (DMRT). Means in a row followed a similar capital letter are not significantly different at 5% level by LSD (0.04)

experiment, the interpretation of $CO_2$-C: C total ratios would only valid for the last situation of experiment. However the ratios, at least, gave the idea of the high clay content to slowdown OM decomposition. The higher the ratio, the more is organic C decomposed to produce $CO_2$ and the lesser is organic C preserved.

The $CO_2$-C: C total ratios at different soil clay percentages, receiving a similar rate of C-rice straw were in the order of magnitude 15>30>45>60>75% clay (Table 3). This indicates that amount of $CO_2$ evolution decreased as the clay content increased. Although the substrate C is highly physically protected from microbial decomposers at a high amount of clay fractions in soils, the data also do not rule out that the high decomposition rate occurs as the high organic C substrate available, i.e, when a high rate of organic C applied. This is due to soil matrices, especially a clay fraction, have a limit of maximum potential capability to protect organic C. Once most sites at soil matrices for substrate binding have been saturated, through coating with organic matter, a further increase of organic matter addition could not all be accommodated but some will remain be exposed and subjected to microbial decomposition to produce more $CO_2$. In this study, visual evidence of high organic matter content may be referred to soil color. With increasing rice straw application, the soil color became darker. For example, the soil color was dark brown (10 YR 3/3) at 3 to 5% organic C treatment rates compared to dark yellowish brown (10 YR 4/4) at 2% C rate, as measured by Munsell Soil Color Chart.

### Effect of clay percentage and organic C-rice straw on soil organic N

The effect of rice straw rates on total soil N content in different soil clay percentages is given in Table 4. The total soil N is significantly higher at

Table 5.  Effect of soil clay contents and C-rice straw application rates on groundnut yield

| C-rice straw treatment | Soil clay (%) | | | | |
|---|---|---|---|---|---|
| | 15 | 30 | 45 | 60 | 75 |
| | ................................. g pot$^{-1}$ ................................... | | | | |
| O0 | 8.17 c | 12.50 c | 16.58 b | 19.36 cd | 15.99 c |
| O1 | 10.84 bc | 15.63 bc | 19.22 b | 16.82 d | 20.71 b |
| O2 | 10.28 bc | 18.20 b | 19.15 b | 17.86 cd | 20.13 b |
| O3 | 13.20 b | 24.43 a | 24.44 a | 21.58 bc | 22.08 ab |
| O4 | 18.13 a | 25.07 a | 25.65 a | 26.05 ab | 25.55 a |
| O5 | 22.17 a | 27.60 a | 25.14 a | 25.17 a | 23.86 ab |
| Mean | 13.80 B | 20.57 A | 21.70 A | 21.14 A | 21.39 A |

In a column, means followed a similar small letter are not significantly different at 5% level by Duncan multiple range test (DMRT). Means in a row followed a similar capital letter are not significantly different at 5% level by LSD (4.0)

75% clay compared to all other clay percentages. The comparison between 45 and 60% soil clay showed that the total soil N was not significantly different, but they have significantly higher total N compared to 15 and 30% clay. The higher total N for soils with a high clay percentage compared to soil with low clay can not solely be explained by the differences in amount of clay percentage, but also and more importantly by the differences of total N to be mineralized although they receive a similar rate of organic C for each clay fraction. These differences are due to the changes in total soil N as a consequence of adjustment of soil clay fractions using sand. Those differences can not be compensated by rice straw, since the rate of rice straw application was based on soil organic C content and not on N.

The interaction between soil N and clay fractions indicated total N significantly increased with increasing rate of rice straw applications for each soil clay fraction. The rate of rice straw significantly increased soil N at the O2 rate for 15% clay and at the O3 for 30 and 45% clay fractions compared to a control treatment (O).

### Groundnut yield

The effect of clay percentages and C-rice straw treatments on groundnut yield is shown in Table 5. There were no significant differences in yields obtained at 30, 45, 60 and 75% soil clay but those soil clay have significantly higher yields compared to a 15%. It appears that the suitable soil clay content for growing and production of groundnut is $\geq$ 30%. Groundnut yield at 15% soil clay was 13.8 g pot$^{-1}$, which was equal to 1.5 t ha$^{-1}$. The yields at 30, 45, 60, and 70% soil clay range from 20.6-21.7 g pot$^{-1}$, equivalent to 2.3-2.4 t ha$^{-1}$. The effect of C-rice straw treatments within each soil clay percentage indicated that groundnut yields significantly increase at all organic C rates compared to a control treatment (O0) for 75% soil clay. For soil clay fractions at 30 and 45%, rice straw treatment at O3, O4, and O5 rates showed the groundnut yields were not significantly different but they were significantly higher compared to O0, O1, and O2 rates. The maximum yields could be achieved at O5 rate within 15 and 30% clay and at O4 rate for 45, 60, and 75% clay fractions.

In order to observe in more detail of the effect of organic C on groundnut yields, the correlation was made between yields and total soil organic C. This correlation is different to effect of rates of C-rice straw treatments on groundnut yield (Table 5). The former would provide direct relationship between yield and amount of organic C content in soils, whereas the latter can provide the effect of C application rates after 12 months.
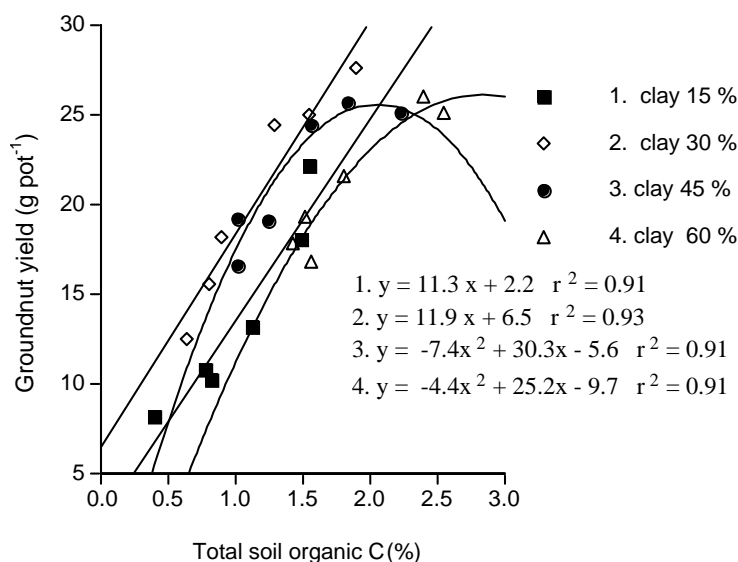
**Figure 4. Relationship between total soil organic C and groundnut yield at different soil clay fractions**

The relationship between groundnut yields and total soil organic C is given in Figure 4. The relationships are linear for 15 and 30% clay, and quadratic for 45 and 60% soil clay. This indicates that the maximum yields due to the increase of soil organic C content have been achieved for 45 and 60% clay, whereas the maximum yields at 15 and 30% soil clay have not yet achieved. The highest yield in this study was 27.6 g pot$^{-1}$, equivalent to 3.1 t ha$^{-1}$, which was obtained at 1.9% C and 30% soil clay. This was followed by 25.7 g pot$^{-1}$ or 2.9 t ha$^{-1}$ obtained at 1.8% C and 45% soil clay.

Since the groundnut yield has achieved maximum value at 45 and 60%, it is reasonable to point out that a good condition for groundnut production is soil having clay content of 30-45% with at least 1.5% C (optimum yield for 45% clay) or clay content may be higher than 45% but soil organic C content should at least 2.0% (optimum yield for 60% clay). The lower organic C level needed at 30-45% clay than the 60% clay is due to less surface sites to adsorb organic C and that 1.5% C may be sufficient for aggregate formation to promote a friable soil condition that allows groundnut pods to develop well. On the other hand, the higher organic C level needed at high soil clay content due to large surface sites, adsorbing organic C to promote soil friable properties needed by pods for maximum development.

The relationship between groundnut yield and total soil N content indicated a similar pattern to relationship between groundnut yield and soil organic C, where the linear correlation was obtained for 15 and 30% clay and quadratic relationship for 45 and 60% clay (Figure 5). The maximum yield of 27.6 g pot$^{-1}$ was obtained at 0.17% N content at 30% clay, followed by about 26.0 g pot$^{-1}$ at 0.20% N which is obtained at about 45 and 60% clay. It seems that the 0.2% soil N is sufficient to support optimum yield of groundnut in this study.

**CONCLUSIONS**

1. The proportion of soil clay content is the major factor responsible for the preservation of organic C as indicated by (i) total soil organic C linearly increased with increasing clay fraction, (ii) the
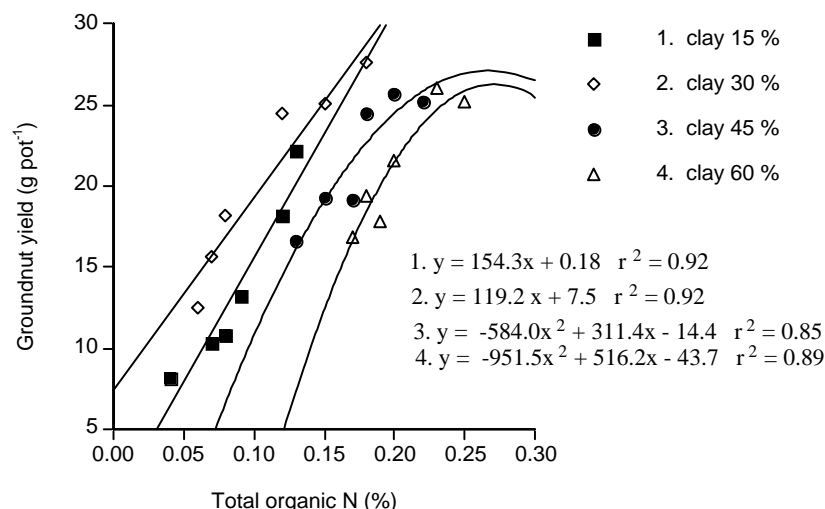
1. $y = 154.3x + 0.18 \quad r^2 = 0.92$
2. $y = 119.2x + 7.5 \quad r^2 = 0.92$
3. $y = -584.0x^2 + 311.4x - 14.4 \quad r^2 = 0.85$
4. $y = -951.5x^2 + 516.2x - 43.7 \quad r^2 = 0.89$

**Figure 5. Relationship between groundnut yield and total soil N at different soil clay percentages**

higher ratio of total C in 75 against 15% clay fraction compared to C ratio in 30 against15%, (iii) and the low ratio of C: total C of higher soil clay fractions than the lower soil clay. Regression equation indicates that every 15% clay increment could protect another 0.3% organic C.

2. The increased rate of organic C applications significantly increased total soil organic C in all clay fractions. The increased rates of soil organic C significantly increased groundnut yield within each soil clay fraction. The highest grain yield was 3.1 t ha$^{-1}$, which was achieved at 30% clay having 1.9% organic C, followed by 2.9 t ha$^{-1}$ at 45% clay with 1.8% organic C.

3. The implications of the study are the high groundnut yield could be achieved by building up soil organic C and that organic matter could be applied once with high rate per year for soils having finer texture since organic matter could be preserved, whereas for soils having a coarser texture (<30% clay) it should be applied periodically with lower rate to minimize C loss.

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