

Zero — Tillage and Intercropping on a Tropical Alfisol: I Effects on soil Physical Properties

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Abstract

Rapid deterioration of soil physical properties of arable land under continuous cultivation adversely affects crop production in the humid and subhumid tropics. This investigation, which lasted for four consecutive growing seasons, was conducted to determine whether the deterioration can be minimized by a tillage and cropping system that can be readily adopted by the local farmer. The results show that over the four growing seasons, soil bulk density (Db) of the surface (0 - 0.1m) soil increased by 0.10Mg/m³. Intercropping reduced soil compaction rates under conventional tillage (CT) and No-tillage (NT) in the two years while sole crops of maize and melon increased soil compaction in their respective plots under CT. Surface soil of the NT plots retained more water than that of CT plots at saturation and field capacity. Higher saturated hydraulic conductivity (SCH), and improved infiltration characteristics were found under NT. Intercropping with melon was effective in improving soil physical properties under both tillage treatments. The over-all results indicate improvement in soil physical properties under NT and intercropping with continuous cultivation. It further shows the possibility of integration of NT into the subsistence intercropping farming methods practised in this region where fertilizers and weed control chemicals are just gaining popularity.

Introduction

To stop degradation of most tropical soils and maintain productivity under continuous cultivation, NT System of cultivation with crop residue mulches has been advocated (Lal, 1976 and 1984). The fundamental management considerations are to maintain good soil structure through continuous ground cover (Wilson et al, 1982), maintain higher level of soil organic matter (Agboola, 1981), prevent soil exposure and minimization of the physical impact of raindrops and solar radiations (Shelton et al, 1983).

The limitations imposed by mulch availability due to the tropical climate which accelerates rapid decomposition of plant residue left over after the cropping season has made in situ mulching difficult. Mulching therefore has become a time consuming operation and requires planting, cutting, transportation and spread of the mulch materials from neighbour-

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ing fields to the field of use. This in turn has made the adoption of the NT farming method less attractive to the peasant farmer. To reduce this large dependence on mulch, work on NT technique in the tropics, which earlier emphasized sole cropping must look into the areas of intercropping including ground cover intercrops. apart from the acceptability of intercropping to the farmer, such cropping practices have been found to be beneficial in land and resource use efficiency (Wahua and Miller 1978).

There are conflicting reports regarding the effects of tillage practices on soil properties. for example, while Curfs (1976) reported improved soil physical properties under CT, Lal (1976) on the other hand, reported the reverses while Osuji (1984) obtained a progressive superiority of NT over CT in soil physical properties over a period of five years. More research information are needed to resolve some of these contradictions because the susistability of different tillage methods depends largely on soil properties, moisture regimes, availability and rate of decomposition residue mulches on the surface soil.

The objective of the present study was to determine changes in soil physical properties of a tropical alfisol under NT and CT with less dependence on mulch in NT by practising intercropping.

Materials and Methods

The experiments were conducted for 2 years (1983 and 1984) with two growing seasons per year at the Teaching and Research Farm of the University of Ibadan, Ibadan in western Nigeria. Ibadan (7.22°N, 3.58°E) is located at the Northern-fringe of the rain forest zone and has an annual rainfall of between 1,000 and 1,600mm with mean of about 1,270mm. There are two distinct seasons, wet (April to November) and dry (December to March). There are also two growing seasons. The first season, late March to late July, ends in a short dry spell in August while the shorter second growing season begins in late August and ends in December.

Prior to 1952, the history of this site was not known. The field was cleared in 1952 from a bush supporting oil palm, kolanut trees and many other tree species. The area was divided into contour strips and has been subjected to mechanical tillage for upward of 25 years. Different rotations of various crops have been followed. The land had been under fallow for 5 years before this experiment was started. The site has a gently undulating terrain with a slope of 3%. The well drained soil which is derived from fine-grained biotite gnesis and schist parent material belongs to the Iwo Series (Smyth and Montgomery 1962). The texture of the surface layer is loamy sand to (Table 1). Prior to the imposition of the tillage and crop treatments, physical and chemical properties of the soil were determined from three soil pits dug at various parts of the study area. Two tillage treatments were imposed viz:

- (i) **Conventional Tillage:** The plots were ploughed once per cropping season with a small tractor (15 KW) using a mouldboard plough and later harrowed once.
- (ii) **No-tillage:** In this treatment, the existing vegetation was killed with paraquat (1, 1, — dimethyl — 4, 4'bipyridiniumion) at 0.50kg/ha (active ingredient) applied one week before planting. The soil was left undisturbed. A thin layer of mulch, consisting largely of residue vegetation on the plots, was applied to completely cover the soil surface before starting the experiment. After the first season, crop residues left after harvest plus cut bush regrowth from each plot were used as mulch at subsequent planting period.

The crop treatments were as follows:

- (i) Sole maize (*Zea mays*, L.) variety TZPB developed at IITA, Ibadan.
- (ii) Sole melon (*Colocynthus Vulgaris*, L.) local varie of 'egusi' melon. This crop does not require heavy fertilization and it offers complete ground cover about four weeks after emergence.
- (iii) Maize — 'egusi' melon intercrop.
- (iv) Uncropped plot: To eliminate the effects of canopy cover and added fertilizer no crops were grown on the bare plots after the imposition of the tillage treatments. This served as the control.

Planting was done manually. The sole maize and sole melon crops were planted at a spacing of 1m x 1m with two plants per hill for maize and one plant per hill for melon on a plot size 5m x 5m. In the maize - melon intercrop, maize was planted at the usual spacing of 1m x 1m with two plants per hill, then 0.5m away from the maize stand in the same plot, melon was planted at the regular spacing of 1m x 1m with one melon plant per stand. NPK (15-15-15) fertilizer was applied at the rate of 200 kg/ha two weeks after planting. The fertilizer was handed with a hoe in the CT treatments while it was surface applied in NT treatments and covered with residue mulch. At 6 weeks after planting, 50kg/ha of urea was surface applied in all the planted plots.

Three core samples were collected from the centre of each plot using metal cores with an average diameter of 0.65m and a volume of 2.32 litres. Only core samples that were free from any visible defects were chosen for determination of bulk density, saturated hydraulic conductivity and soil moisture retention. The core samples were placed in a trough of water, with the covered end down, and then allowed to saturate by capillarity for 24 hours. Saturated hydraulic conductivity was determined using Klut's (1965) method, soil moisture retention was determined for the high energy moisture range using the tension table (Clement, 1966) while lower energy characteristics were obtained using a pressure plate apparatus (Richards, 1949). Infiltration rates were monitored by the double ring infiltrometer method. The inner ring was 0.3m in diameter and 0.3m deep. The outer ring was 0.5m in diameter and 0.3m deep. These rings were driven into the soil to a depth of 0.15m. A constant water head of approximately 0.05m was maintained in the inner ring using the mariotte bottle technique. Weekly gravimetric soil moisture content at 0-0.1m depth, was determined from three after planting. There were three replications for each of the soil properties determined.

The design of the experiment was Randomised Complete Block (RCB). The data was analysed as a two-factor (Crop and tillage factors) factorial with three replications. The infiltration data was analysed according to Philip's (1957) model in order to compute soil — water sorptivity (S) and transmissivity (A) in the following equation:

$$I = At + St^{1/2} \text{ where}$$

I = cumulative infiltration
 S = Soil — water sorptivity
 A = transmissivity
 t = time

Results and Discussion

The area of maximum impact of the tillage implements (0 - 0.3m) shows a decrease in sand content with depth (Table 1.). The entire profile is gravelly with gravel concentration ranging from 18.7% at the 0.30 — 0.60m depth to 25.4% at the 0 — 0.15m depth. The high Db at the 0.15 — 0.3m depth reflects the gravel and sand content. The soil has good internal drainage characteristics which appear unhindered down to the 1m profile depth. This can be

TABLE 1. SOME SOIL PHYSICAL PROPERTIES OF THE SITE AT IBADAN

| Soil Depth (m) | Sand (%) | Silt (%) | Clay (%) | Textural Class | Gravel Concentration (%) | Bulk Density (Mg/m ³) | Total Porosity (%) | Saturated Hydraulic Conductivity (Ks) (Cm/hr) | Field Capacity 0.01 MPa | Permanent Wilting 1.5MPa (Cm ³ /cm ³) (Cm ³ /Cm ³) |
|----------------|----------|----------|----------|----------------|--------------------------|-----------------------------------|--------------------|---|-------------------------|--|
| 0—0.15 | 73.7 | 20.1 | 6.2 | LS | 25.4 | 1.52 | 42.6 | 32.4 | 0.19 | 0.05 |
| 0.15—0.30 | 77.9 | 17.8 | 4.3 | LS | 23.4 | 1.60 | 39.6 | 25.5 | 0.12 | 0.03 |
| 0.30—0.60 | 75.4 | 18.3 | 6.3 | SL | 18.7 | 1.58 | 40.4 | 21.3 | 0.17 | 0.04 |
| 0.6—1.0 | 71.6 | 16.6 | 11.8 | SL | 20.5 | 1.57 | 40.8 | 20.2 | 0.16 | 0.04 |

1. Loamy Sand
2. Sandy Loam

TABLE 2: MEAN BULK DENSITY (MG/M³) OF THE SURFACE (0-0.1M) AT 1ST WEEK OF STARTING THE EXPERIMENT (APRIL 1983) AND AT THE END OF EACH GROWING SEASON.

| Month | Year | CT | NT | Standard Error | Sole maize | Sole Melon | Mixed Maize + Melon | Bare Plots | Standard Error |
|----------|------|-------|-------|----------------|------------|------------|---------------------|------------|----------------|
| April | 1983 | 1.5a* | 1.48b | 0.019 | 1.43b | 1.54a | 1.46ab | 1.54a | 0.027 |
| July | 1983 | 1.54a | 1.47b | 0.021 | 1.47ab | 1.54a | 1.46ab | 1.54a | 0.031 |
| December | 1983 | 1.57a | 1.45b | 0.020 | 1.49a | 1.53a | 1.52a | 1.54a | 0.028 |
| July | 1984 | 1.60a | 1.46b | 0.016 | 1.51a | 1.55a | 1.53a | 1.57a | 0.073 |
| December | 1984 | 1.63a | 1.44b | 0.040 | 1.56a | 1.56a | 1.56a | 1.61a | 0.057 |

*Only means followed by different letter(s) within a row differ at $P < 0.05$ (Duncan Multiple Range Test (DMRT)).

TABLE 3: EFFECT OF TILLAGE AND INTERCROPPING ON SOIL MOISTURE RETENTION (CM³/CM³) OF THE SURFACE SOIL (0 - 0.1M).

| Treatments | Total Pore Space (OMPa) | | Field Capacity (- 0.005MPa) | |
|---------------------|----------------------------|------------------|--------------------------------|------------------|
| | DECEMBER 1983 | DECEMBER 1984 | DECEMBER 1983 | DECEMBER 1984 |
| | CT | 0.29b* | 0.26b | 0.14a |
| NT | 0.32a | 0.31a | 0.15a | 0.14b |
| Standard Error | 0.13 | 0.11 | 0.02 | 0.04 |
| Sole Maize | 0.32a | 0.28ab | 0.14a | 0.12ab |
| Mixed Naize + Melon | 0.32a | 0.29a | 0.15a | 0.13a |
| Bare Plots | 0.29b | 0.27b | 0.13a | 0.11b |
| Standard Error | 0.12 | 0.14 | 0.013 | 0.05 |

*Only means followed by different letter (s) within column differ at $P < 0.05$ (DMRT).

TABLE 4: INFILTRATION CHARACTERISTICS OF THE SOIL AS AFFECTED BY TILLAGE AND INTERCROPPING AFTER FOUR CROPPING SEASONS (END OF LATE SEASON 1984).

| Treatments | Philip's A | Equation S | Correlation Coefficient |
|---------------------|---------------|---------------|----------------------------|
| CT | 0.63 | 9.11 | 0.94** |
| NT | 0.72 | 14.24 | 0.97** |
| Sole Maize | 0.56 | 6.34 | 0.98** |
| Sole Melon | 0.63 | 8.45 | 0.95** |
| Mixed Maize + Melon | 0.31 | 6.00 | 0.97** |
| Bare Plots | 0.58 | 7.52 | 0.95** |

¹Phillip's equation $I = St^{0.5} + At$ where

I = accumulative infiltration

S = Soil - Water sorptivity

A = TrAnsmisibility

t = Time

**= Significant at the 1% level

| Treatments | December 1983 | December 1984 |
|---------------------|---------------|---------------|
| CT | 24.64a* | 16.35b |
| NT | 24.75a | 25.86a |
| Standard Error | 6.46 | 3.54 |
| Sole Maize | 25.53a | 20.58a |
| Sole Melon | 25.16a | 15.84b |
| Mixed Maize + Melon | 27.19a | 24.88a |
| Uncropped Plots | 23.14a | 15.74b |
| Standard Error | 4.57 | 2.50 |

*Only means followed by different letter (s) within a column differ at $P < 0.05$ (DMRT).

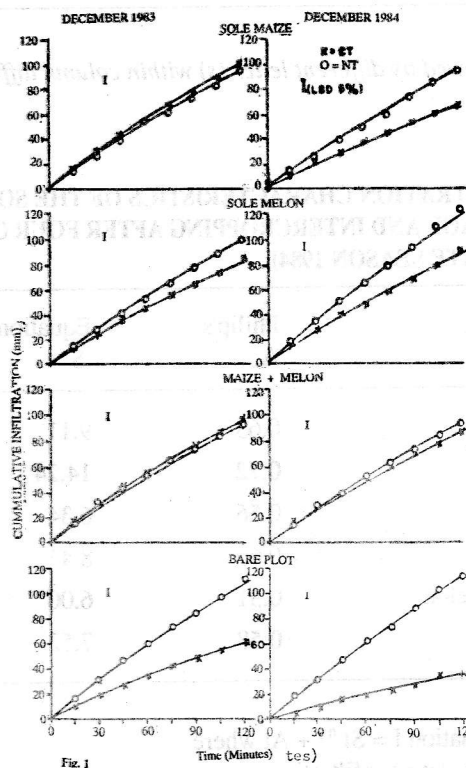


Fig. 1. Effects of Tillage and Cropping treatments on Cumulative Infiltration in 1983 and 1984.

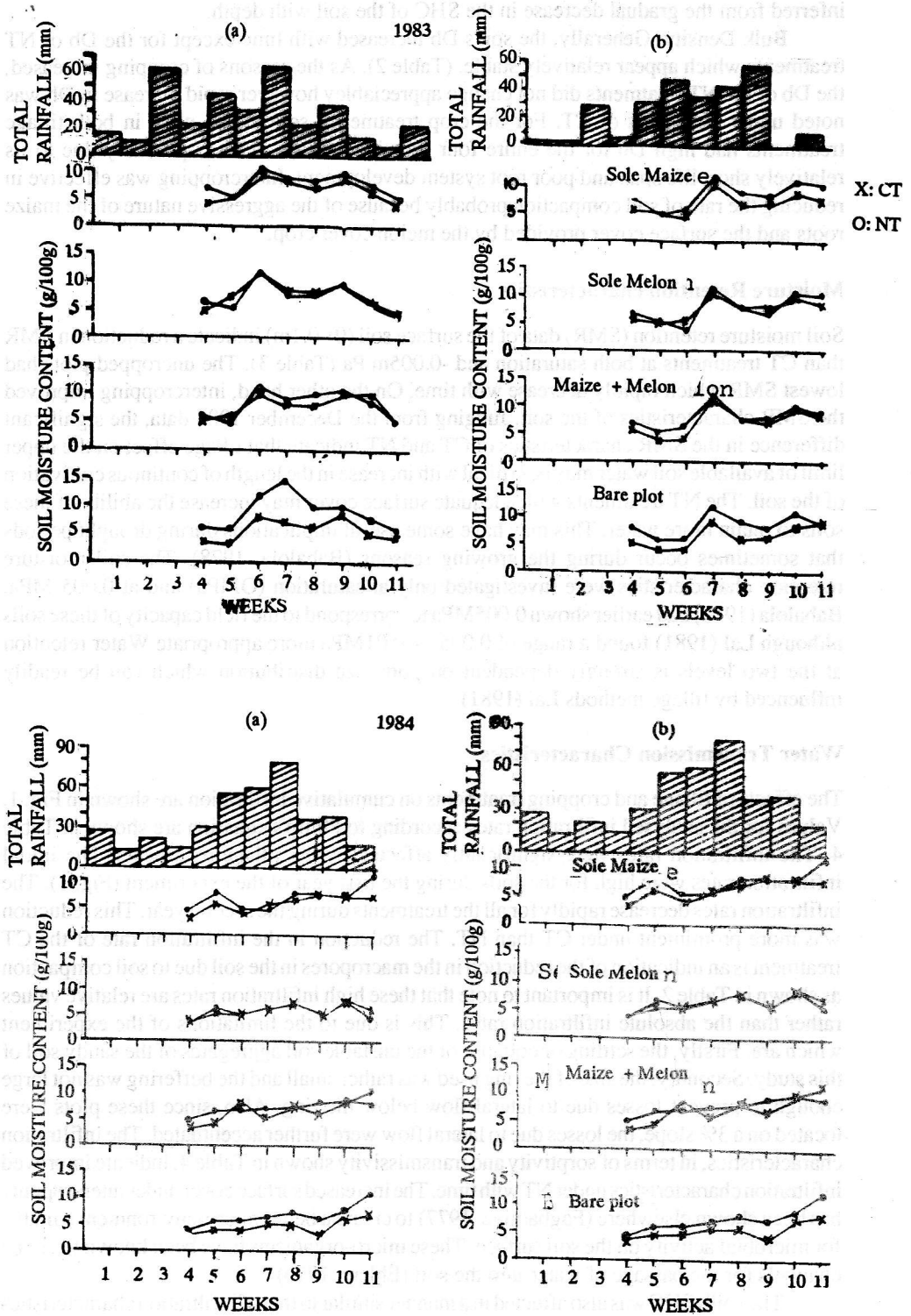


Fig. 2. Changes in soil moisture content at 0-0.1m depths for (a) First and (b) Second growing seasons of 1983 and 1984.

inferred from the gradual decrease in the SHC of the soil with depth.

Bulk Density: Generally, the soil's Db increased with time except for the Db of NT treatments which appear relatively stable. (Table 2). As the seasons of cropping increased, the Db of the NT treatments did not change appreciably however rapid increase in Db was noted under bare plots of CT. For the crop treatments, sole melon plots in both tillage treatments had high Db for the entire four growing seasons. This is probably due to its relatively short life span and poor root system development. Intercropping was effective in reducing the rate of soil compaction probably because of the aggressive nature of the maize roots and the surface cover provided by the melon cover crop.

Moisture Retention characteristics

Soil moisture retention (SMR) data of the surface soil (0 - 0.1m) indicate a reduction in SMR than CT treatments at both saturation and -0.005m Pa (Table 3). The uncropped plots had lowest SMR which rapidly decrease with time. On the other hand, intercropping improved the SMR characteristics of the soil. Judging from the December 1984 data, the significant difference in the SMR characteristics of CT and NT indicate that tillage effect on the upper limit of available soil water may be critical with increase in the length of continuous cultivation of the soil. The NT treatments with adequate surface cover may increase the ability of these soils to retain more water. This may have some useful implications during drought periods that sometimes occur during the growing seasons (Babalola, 1978). The soil moisture retention characteristics were investigated only at saturation (OMPa) and at 0.005 MPa. Babalola (1978) had earlier shown 0.005MPa to correspond to the field capacity of these soils although Lal (1981) found a range of 0.005 — 0.01MPa more appropriate. Water retention at the two levels is strongly dependent on pore size distribution which can be readily influenced by tillage methods Lal (1981).

Water Transmission Characteristics

The effects of tillage and cropping treatments on cumulative infiltration are shown in Fig. 1. Values for the analysed infiltration rates according to Philip's equation are shown in Table 4. The infiltration rates were significantly affected by the tillage treatments. The initial infiltration rates were high for the soils during the first year of the experiment (Fig. 1). The infiltration rates decrease rapidly for all the treatments during the second year. This reduction was more prominent under CT than NT. The reduction in the infiltration rate of the CT treatment is an indication of the reduction in the macropores in the soil due to soil compaction as shown in Table 2. It is important to note that these high infiltration rates are relative values rather than the absolute infiltration rates. This is due to the limitations of the experiment which are: Firstly, the settling or collapse of the unstable soil aggregates of the sandy soil of this study. Secondly, the size of the ring used was rather small and the buffering was not large enough to prevent losses due to lateral flow below the ring. Also, since these plots were located on a 3% slope, the losses due to lateral flow were further accentuated. The infiltration characteristics, in terms of sorptivity and transmissivity shown in Table 4, indicate improved infiltration characteristics under NT with time. The increased surface cover under intercropping has been shown elsewhere (Fagbamiye, 1977) to create a better micro-environment suitable for microbial activity on the soil surface. These micro-organisms have been known to create channels for the passage of water into the soil (Ehlers, 1976).

The soil's SHC was also affected in a manner similar to that of infiltration characteristics

(Table 5). The SHC values are also relative rather than absolute. This might be attributed to problems associated with soil core sampling and the measurement of SHC on Core samples in the laboratory using Klute's (1965) method. The effect of tillage and crop treatments on the soil's SHC was not significant. This is possible due to the texture of the soil (Loamy Sand to Sandy, Table 1), and the land use. As mentioned earlier, these plots have been subjected to CT over a long period of time, at least five years before this experiment began. The overall effects of these tillage operations on the soil over the years will be compaction and destruction of the soil aggregates which possibly account for the initial low SHC obtained on these soils. The data indicates an increase in SHC of the NT treatments over time even though this was not statistically significant in the study. Other workers have made similar observations (Hamblin, 1984, Osuji, 1984). For example, Hamblin (1984) noted that within 3 years of her study, no appreciable differences were noticed between SHC of CT and NT plots. This trend could be altered with increasing years of the tillage practices.

Soil Moisture Content: The changes in surface soil moisture content as affected by tillage and crop treatments at 0 — 0.1m depths for the four growing seasons are shown in figure 2 which also shows cumulative precipitation. The rainfall amount and distribution were adequate in the first growing seasons of 1983 and 1984. This was however not so in the second season of 1983. In the 1984 second season, the total amount of rainfall was quite high and was uniformly distributed. The soil moisture content did not differ significantly between CT and NT in the seasons of adequate rainfall. This indicates that the soil water regime under adequate rainfall is not significantly affected by tillage. During the second season of 1983 when rainfall was low and poorly distributed, the NT plots had higher surface water content than CT plots. A large amount of mulch (between 4 — 6 Mg/ha) has been shown to be needed for improved moisture storage of NT plots. This large quantity of mulch is not always available but with increase in the amount of biomass at the soil surface due to intercropping, the dependence on mulch can be reduced. The ability of the melon crop to conserve soil water not considering its evapotranspirational losses, was shown earlier by Ikeorgu (1984). During intercropping, the melon crop with its shallow root system allows the soil moisture conserved by the melon crop to be tapped and used by the deep rooted crop in the mixture.

Conclusions

Much progress has been made in the humid tropics in understanding the basic principles of tillage practices and their effects on crop yield. However, most recommendations based on particular soil type such as soils of this study have advocated no-tillage with large quantities of mulch (4 - 6Mg/ha) (Ial, 1983). The recommendations are largely based on monocropping which is at variance with the traditional mixed cropping of the local farmer. The results of this study, show the potential of intercropping (with an economically profitable companion crop) in reducing the large dependence on crop residue mulch which can make the NT practice acceptable to the peasant farmer who practise intercropping. Soil bulk density, soil moisture retention and transmission characteristics with surface soil water content were improved under continuous NT. Furthermore, with adequate mulch to entire soil surface at the beginning of cultivation, intercropping melon with maize, can lead to better soil physical conditions under continuous NT.

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