Effect of different tillage and residue management practices on growth and yield of corn cultivation in Thailand

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Abstract: The tillage and residue management during soil bed preparation need to be in appropriate manner for sustainable farming practice. The effects of tillage and residue management methods on corn cropping were studied on loamy soil in Bangrakum district, Phitsanulok Province, Thailand. The effects of five commonly used tillage methods: subsoiler tillage (ST), three methods of conventional tillage (CT1, CT2 and CT3), no-tillage (NT), as main factors and two corn residue management methods; burned (R1) and unburned (R2), as sub-factors were studied in a randomized strip plot configuration. Tillage treatment showed significant effect on physical and chemical soil properties, plant growth and development, grain yield, total aboveground biomass and most importantly the weed emergence and density, while the two crop residue management methods did not show significant differences. The improvement in plant development and grain production was found to be due to the increased tilled depth and thus the ST was the most effective tillage method for improving soil physical properties and to increase corn production; corn growth, biomass and grain yield. ST showed higher total grain yield than CT1, CT2, CT3 and NT approximately 35%, 101%, 88%, 216%, respectively. It could be concluded that ST as the best and sustainable method of soil management for corn cropping while having typical weeding and fertilization practices.

Keywords: Tillage, no-tillage, randomized, emergence, compaction, subsoiler, biomass

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1 Introduction

Tillage is one of important activities in the crop production system that optimizes the conditions of soil bed environment for seed germination, seedling establishment and crop growth. Ever since primitive societies learned to manipulate soil by simple tools, cultivation has been an essential component of farming (FAO, 1995). The choices relating to tillage methods are strongly affected by the other components of the cropping system. Thus, the selection of tillage method is very important for cultivation. A proper tillage can alleviate soil related constraints while improper tillage may lead to a range of degradation processes, e.g., deterioration in soil structure, accelerated erosion, depletion of soil organic matter and fertility and disruption in cycles of water, organic carbon and plant nutrient (Lal, 1995).

Soil compaction is generally defined as an increase of the natural density of soil at a particular depth (Singh and Malhi, 2006; Qin et al., 2006). The density increase translates soil into less pore space, less water available for plant, slower water transport, and decreased root has ability to penetrate the compacted zone as it seeks out water and nutrients or can reduce the formation of lateral roots (Singh and Malhi, 2006). Similarly, the bulk density increases due to compaction can serve to retard or divert the flow of water, resulting in pond or excessive runoff. These factors can limit yields and inhibit effective site management for many crops (Rooney, 2004). Philips and Kirkham (1962) and Morris (1975) reported corn yield reductions of 10 to 22% due to compaction. For each 1 kg m^{-3} increase in bulk density, a decrease in corn grain yields of 18% relative to the yield was observed

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on a non-compacted plot by Canarache et al. (1984). Duiker (2004) reported around 15% yield reduction in corn during first five years of heavy machinery use which created compaction in top soil layer. Saini and Lantagne (1974) observed 22% potato yield reduction caused by the same bulk density increase. Wolkowski et al. (2008) reported that compacted soil could reduce crop yield by 50% due to reduced aeration, increased resistance to root penetration, poor internal drainage, and thus limited availability of plant nutrients. Murdock et al. (2008) conducted seven year period of research on soil compaction effect for corn and soybean rotation and reported that the recovery of compaction effect took seven years under no-tillage condition and it was four years when sub-soiled in the first year. Conversely, proper tillage can lead to better spatial distribution of roots, improving the nutrient and water uptakes, hence improved productivity and there are evidences of weed control positively affecting the yield (Singh and Malhi, 2006; Nakamoto et al., 2006).

However, the choice of the most appropriate type of tillage depends on physical factors, such as soil properties, rainfall regime, climate, drainage conditions, rooting depth, soil compaction, erosion hazards, cropping systems, and social-economic factors, including farm size, availability of inputs, and marketing and credit facilities (FAO, 1995). Researchers have emphasized the benefits of conservation agriculture and adoption at the farm level, which is associated with lower labor and farm power inputs, more stable yields and improved soil nutrient exchange capacity (FAO, 1995). Use of correct tillage methods may contribute to higher profits, crop yields, soil improvement and protection, weed control and optimum use of water resources since tillage has a direct impact on soil and water quality (Hanna et al., 2009). Therefore, site-specific knowledge on prevailing tillage systems is required for planning and evaluating the best alternative strategies to increase crop productivity.

The common tillage practices in farmlands of Thailand are mostly with disc ploughs and harrows. Three or four-discs plough systems at primary tillage and seven-discs harrow system at secondary tillage is the common practice. In primary tillage, ploughing is done one to two times up to the depth of 15-20 cm followed by harrowing as secondary tillage. Under certain circumstances, this could result in an excessive compaction of soil at the depth range of 30 to 50 cm and resulting in lower yields. Due to handling difficulties most farmers burn the residues of the previous crop on the field after harvesting or before land preparation. These practices need thorough investigations incorporating all the constraints in the operations.

2 Materials and methods

2.1 Study site

Phitsanulok province in Thailand lies between 16°31'27" and 17°44'31" N latitudes and between longitudes 99°52'27" and 101°04'34" in the Northern region and covers some 10,815.854 square kilometers of area. The statistics at Bangrakum climatology station showed average annual rainfall of 1,003.3 mm from the year 1994 to 2003 and the average temperature of 33.4ºC (TMD, 2004). Most corps in Phitsanulok province are suitable to grow in the low land paddy field areas, covering an area of 0.24 million ha or approximately 70.2% of the total arable lands. In terms of upland field crops, corn is the main crop covering around 12.3% of the total lands. The annual production of corn in the province is 172,900 tons with 4.14 ton $(ha)^{-1}$ of average yield (DOAE, 2004). The soil in the experimental site was classified as loamy soil (47% sand, 37% silt and 16% clay). Soil texture was determined by hydrometer and the particle size methods according to the USDA (United States Department of Agriculture) standard system (Ketter et al., 2001). Low soil fertility and acidic level was observed in the experimental area; organic matter, N, P, K, Ca, Mg were found to be 1.3%, 0.04%, 45, 90, 480 and 160 ppm respectively. Recommended irrigation and fertilizer application schedules were followed uniformly over all field plots. No herbicides were used in order to investigate the effect of compaction treatment on weed emergence, hence on the crop growth and yield.

2.2 Experimental design

This experiment was designed with two factors, five treatments of different tillage methods, subsoiler tillage (ST), three models of conventional tillage (CT1, CT2 and

CT3), no-tillage (NT), and two treatments on the different corn residue management; burnt (R1) and unburn (R2) corn residue conditions. The experimental layout of this study was arranged as a strip-plot design. The tillage methods arranged as horizontal factor while corn residue management as the vertical factor, with ten treatments and three replications. The experiment consisted of 30 sub-plots of 7 m width and 30 m length in each sub-plot. The plots were arranged in randomized manner having two-meter corridor between each other and three-meter gap between each replication for easy movement of tractor during tillage. The border row of upper and bottom sides in the experimental field was kept as four meters allowing the space for turning the tractor.

2.3 Tillage treatments

Tillage practices, which are typical to corn growers in Thailand, were carried out after the chosen residue management was completed. Experimental fields were plowed (primary tillage) with different tillage implements according to the different treatments (Table 1). Secondary tillage was practiced after ten days, and the corn seeds were planted. Tillage treatments were conducted under dry condition before rain.

Table 1 Details of tillage treatments used

Tillage	Description
1. ST	First plowing by a subsoiler with depth of 50 cm followed by moldboard plow with average depth of 30-35 cm. Secondary tillage is with a rotary harrow.
2. CT1	Primary tillage by moldboard at depth 25-30 cm. Secondary tillage by rotary harrow.
3. CT2	This is common practice by Thai farmers to prepare seedbed. Primary tillage is carried out by using three discs plows to a depth of 25-30 cm. Secondary tillage by seven-disc harrow.
4. CT3	Using seven-disc plow with a depth of 10 – 15 cm for plowing and harrowing.
5. NT	In this treatment, the corn seeds were directly planted into the field

2.4 Data collection and analysis

Soil properties such as soil bulk density, cone penetration resistance, soil moisture content, and soil electrical conductivity were measured for each plot from three replications. In-situ measurements, data and soil sample collection, and laboratory analyses were done using standard instruments and following standard procedures (Bowels, 1986; Kettler et al., 2001). Composite soil sampling from 0 to 45 cm depth was carried out for four times; before the tillage practice to determine the initial soil condition, one day after planting (for soil penetration resistance), and 15 days after planting, and at harvesting period. In addition, a field survey was conducted for collecting data that relate with agronomic parameters; dry weight of weeds, both of board leaf and grass weeds (oven dried for 24 h at 103ºC), plant height, stem diameter (at one inch above ground), plant population, number of ear per plant and number of ear per planting area during the crop growing season until harvesting. Corn crop was manually harvested 120 days after planting.

Data collected after harvesting were, number of kernels per ear, number of rows per ear, number of grains per row, ear girth, ear height, per-plant total aboveground biomass, per-area total aboveground biomass, per-plant grain yield and per-area grain yield. Statistical analyses were carried out using the SPSS computer software, and analysis of variance (ANOVA) was conducted to determine the significant differences at less than the 5% level. The least significant difference (LSD) test was performed to separate mean values.

3 Results and discussion

3.1 Tillage and crop residue management effect on soil Electrical Conductivity (EC)

The mean of soil EC at 15 days after planting were found significantly affected by the four tillage treatments against no-tillage (ST, CT1, CT2, CT3 and NT of 113.9^a, 110.1^a, 110.1^a, 106.1^a, and 82.4^b mS m^{-1} respectively, and before tillage the corresponding values were 78.3, 76.4, 77.9, 77.7 and 75.1, no significantly different) however, there was no significant effect on EC due to the residue management method and also no interaction was observed between tillage methods and corn residue management methods. The results indicated that ploughed soil, which had the high volume of macro pores, would have resulted in the higher rate of soil EC.

3.2 Tillage and crop residue management effect on soil Bulk Density (BD)

Significant differences in BD was observed (Table 2) for the different tillage methods between each soil depth at 15 DAP and at harvesting. In general, the BD was significantly higher in the no-tillage (NT) than in the tilled conditions. Rasmussen (1999), Olaoye (2002), Sonkam (2001) and Qin et al. (2006) observed similar trends, especially the no-tillage showing high bulk density in the topsoil. However, only the ST plots showed soil bulk density less than 1.40 g cm^{-3}, which was within the critical soil BD limit for root penetration and crop growth according to FAO (1995).

Table 2 Comparison of mean soil BD (g cm^{-2}) at three depth layers 15 DAP and during harvesting

Tillage practice	15 DAP			Harvesting time		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
ST	1.24^c	1.15^c	1.31^b	1.32^c	1.35^c	1.38^b
CT1	1.25^c	1.34^b	1.64^a	1.32^c	1.52^b	1.73^a
CT2	1.28^c	1.33^b	1.62^a	1.32^c	1.51^b	1.71^a
CT3	1.38^b	1.63^a	1.63^a	1.42^b	1.74^a	1.76^a
NT	1.50^a	1.61^a	1.62^a	1.52^a	1.73^a	1.77^a

Note: The values with the same letter or with no letter are not significantly different by LSD ($p \leq 0.05$).

Among the tilled systems, the greater soil BD was observed in the treatment of CT3, at depth of 0-15 cm. In contrast, ST treatment, even at the deepest soil layer showed lower soil BD value than the other tillage treatments. The difference in these values may be due to the different ways of soil failure by tools and the operating depth. In addition, regardless of tillage treatment, the soil BD showed increasing trend with depth. No significant difference in soil BD was found due to residue management method and the combination treatment effects between tillage methods and corn residue management at each soil depth range. However, the BD at harvesting time was higher than at 15 DAP, probably as a result of the consolidation of soil due to irrigation and intermediate weeding operations, which involves mechanical manipulation of topsoil.

3.3 Tillage and crop residue management effect on soil Moisture Content

The effect of tillage systems and residue management practices on gravimetric water content in three depths, 0-15, 15-30 and 30-45 cm, was monitored after planting in two times; measured 15 DAP and at harvesting. At 15 DAP, soil moisture content shown significantly different only in the 0-15 cm depth (Table 3).

Table 3 Comparison of mean soil moisture content (%) at three depth layers 15 DAP and during harvesting

Tillage practice	15 DAP			Harvesting time		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
ST	19.1^a	20.3	22.6	17.1	22.9^a	23.6^a
CT1	18.9^a	20.7	21.3	16.9	20.4^b	19.1^b
CT2	16.8^b	20.5	22.6	16.9	20.5^b	18.6^b
CT3	16.9^b	20.9	22.2	16.5	18.4^c	19.4^b
NT	15.3^c	21.2	22.1	16.3	18.2^c	19.3^b

Note: The values with the same letter or with no letter are not significantly different by LSD ($p \leq 0.05$).

The ST and CT1 treatments showed significantly higher moisture content than other tillage treatment because both of these treatments might have created better soil conditions with better pulverization, soil pores at deeper layers for preserving infiltrated moisture than other tillage methods resulting less evaporation from surface soil layer. In general the soil moisture content found to be increasing with the increase of soil depth. There was no interaction observed between tillage and corn residue management methods due to two residue management methods at each depth and at 15 DAP or harvesting times.

3.4 Tillage and crop residue management effect on soil Penetration Resistance (PR)

Soil PR as a function of depth for tillage and residue management methods is given in Figure 1. The variation of PR well correlated with the trends (Singh and Malhi, 2006) observed for soil BD. The residue management methods did not interact significantly with the tillage method on this property and also no significant differences were observed among the residue management treatments. Both at seeding and harvesting times, significantly different soil PR values due to different tillage methods were observed at each soil depth range. The ST treatment showed the lowest value of the PR in the 15-45 cm layer, less than 2 MPa. It was not at critical state for normal root and shoots growth, which was significantly different to other tillage methods. Conversely, the NT treatment showed the highest value of soil PR at the 0-15 cm soil depth, as well as deeper layers. A similar trend was confirmed by Tapela and Colin (2002), which indicated that the mean soil PR for the no-till was higher than the chisel and moldboard treatments. Gill et al. (1996) reported significant reduction in soil strength (cone index) due to deep tillage causing deeper and denser rooting than conventional tillage.

Two horizons could be clearly seen in the PR soil profiles in Figure 1. The first horizon at depth 15 cm, ST, CT1 and CT2 treatments having more or less similar, but lower PR levels and CT3 showing moderate and NT with the highest PR levels, gradually increasing from the surface. The second horizon at depth 30 cm, where except ST, other treatments showing similar PR levels. The difference in soil PR value under different tillage methods may have lead to differences in total dry matter production as a result of pore spaces preserving moisture at deeper layers. The lowest value of soil PR under ST may also have attributed to better root development, deep root proliferation (Muhammad et al., 2012).

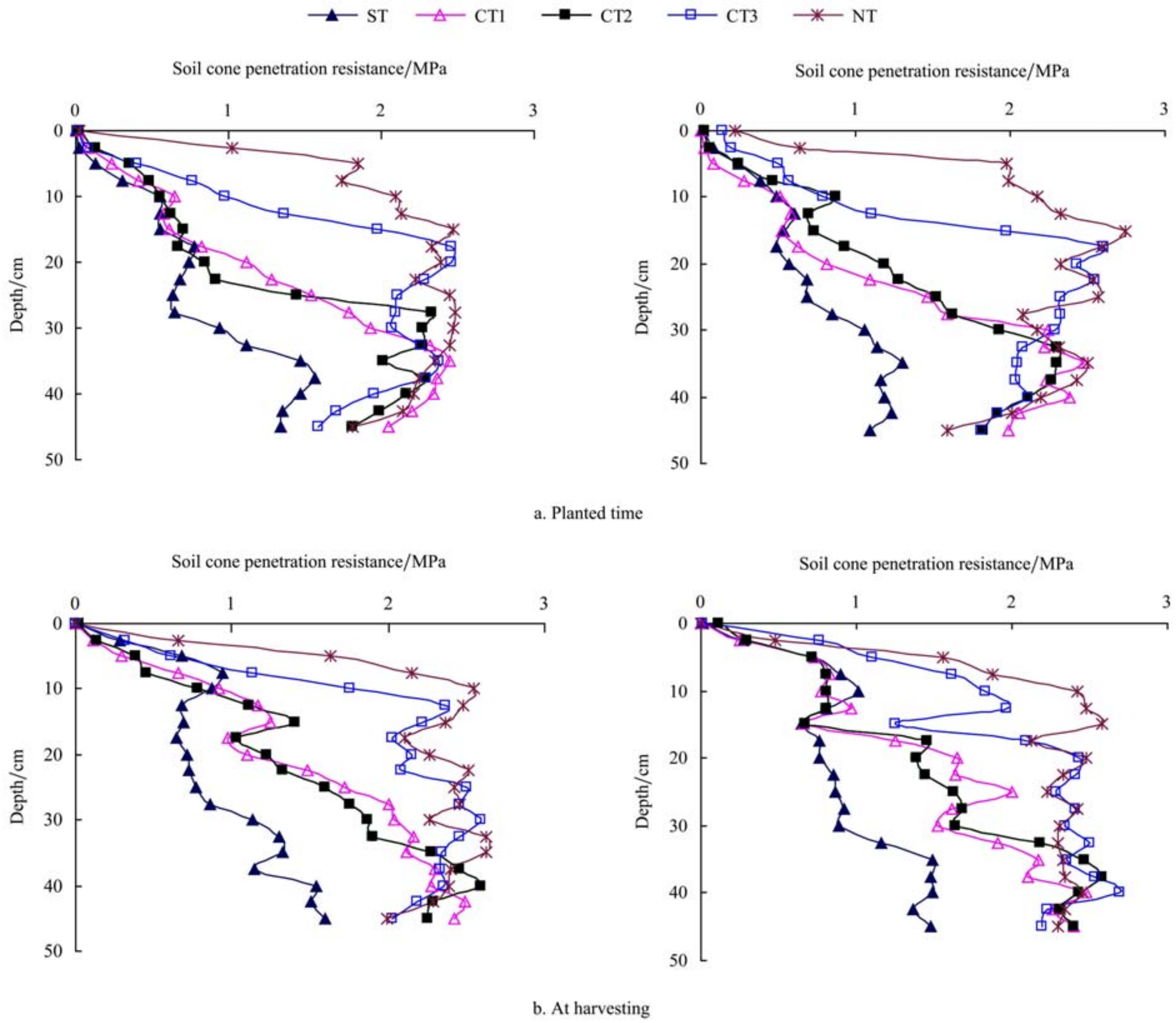
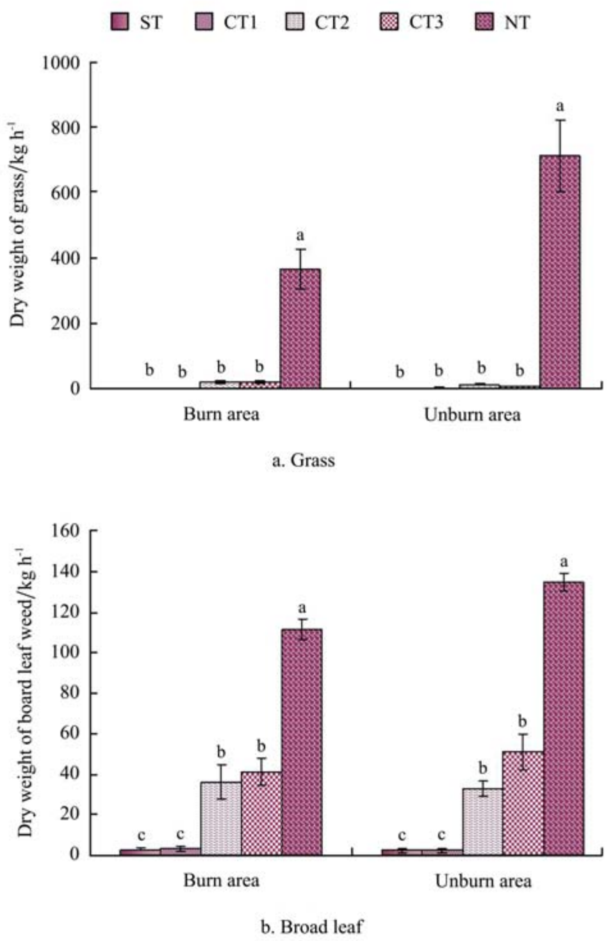


Figure 1 Average soil PR of experimental site with five tillage methods and two methods of residue management

3.5 Tillage and crop residue management effect on Weed Density

The different weed species were observed during the experiment. The grass weeds and broad-leaf weeds were present in the field (Figure 2). The amount of dry weight of grass weeds and board-leaf weeds were significantly higher under no-tillage method (NT). In contrast, significantly lower amounts of dry weight of grass and board leaf weeds were observed in the plots under ST and CT1 treatments (Figures 2 and 3), which used moldboard plow for primary tillage. This may be due to the ability of moldboard plow to turn over and cover crop residues and weeds. These results were in line with the results of McKYES, (1985), Blaise and Ravindran (2003) who also observed the reduced tillage treatment (no-tillage) had significantly higher grassy weeds and more board leaf weeds than under the conventional tillage. This high weed density can compete with corn for water and plant nutrients. Especially at the initial growth stage this may be crucial, as the quickly grown corn canopy shade can further prevent the emergence of weeds. In contrast, quickly emerged weeds can hinder the growth of corn crop (Figures 2 and 3). Bowen (1981), Keeling and Abernathy (1989), Blaise and Ravindran (2003), and Nakamoto et al. (2006) indicated that severe weed population pressure was revealed to reduce overall yield in the conservation tillage system.

The combined effect of tillage methods and residue management on dry weight of grasses was found significantly different. Burnt residue condition had lower grasses dry weight than un-burn residue condition. In contrast, the dry weight of board-leaf weeds was not significantly different between tillage and residue management methods, and also not significantly different between two residue management methods.



Note: Bar indicates the standard deviation about the mean. The values with the same letter or with no letter are not significantly different by LSD ($p \le 0.05$).

Figure 2 Weed emergence, weed density and weed type with respect to different tillage treatments

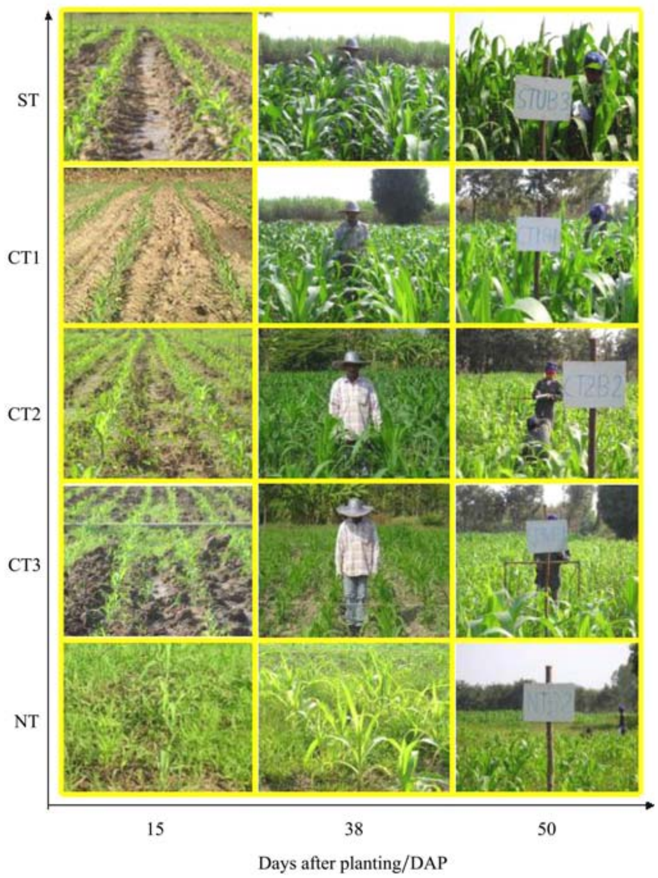


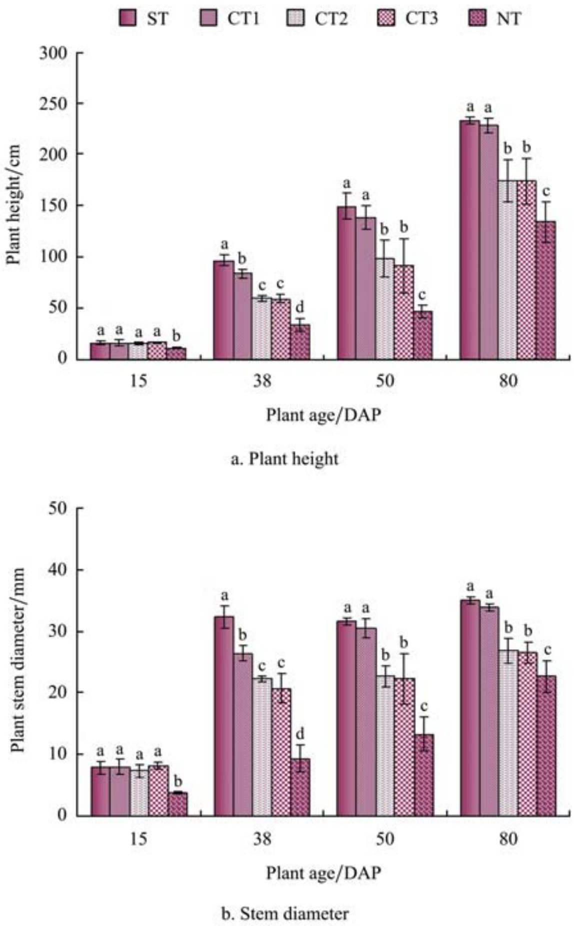
Figure 3 Comparison of height and growth of corn crop and weed emergence density at 15, 38 and 50 days after planting (DAP) for tillage treatments ST, CT1, CT2, CT3 and NT

3.6 Tillage and crop residue management effect on Plant Population

Plant population was obtained at different phonological stages in order to evaluate the treatment effect. The plant populations among tillage methods at the early vegetative stages (measured at 15 DAP) were not significantly different, however, the population at 38, 50 and 80 DAP showed a significant reduction (25%, 8 to 6 plants m^{-2}) in the plant population in NT plots. It showed a decreasing trend with the time. The reason for lower corn population in NT was due to the retarded growth at initial stage mainly affected by the competition by weeds (Figure 3). The results reported here serve to emphasize the potential of soil management practices with appropriate tillage methods in order to avoid crop losses from the water scarcity and logging problem in the study area through soil moisture conservation. The residue management did not show any significant effect on the plant population.

3.7 Tillage and crop residue management effect on plant growth parameters

During the growing periods, both height and stem diameter seemed affected by the tillage method. The plant growth was significantly higher in the tilled treatments (Figures 3 and 4) than in NT treatment. Among tillage treatments, ST showed vigorous plant growth in terms of height and stem diameter than that of the other treatments. The consistent crop growth trend during the growing periods was ST > CT1 > CT2 > CT3 > NT, clearly indicating the correlation with the tillage method and the depth, which led to preserve moisture and proper aeration for root development while retarding the weed emergence. The results tallied with the findings of Gill et al. (1996) on no-tillage against deep tillage with mulching. However, across the residue management methods, the plant growth was not significantly different and no significant interaction between the tillage and residue management methods was observed.



Note: Bar indicates the standard deviation about the mean. The values with the same letter or with no letter are not significantly different by LSD ($p \leq 0.05$).

Figure 4 Plant growth influenced by tillage methods

3.8 Tillage and crop residue management effect on Ear Characteristics

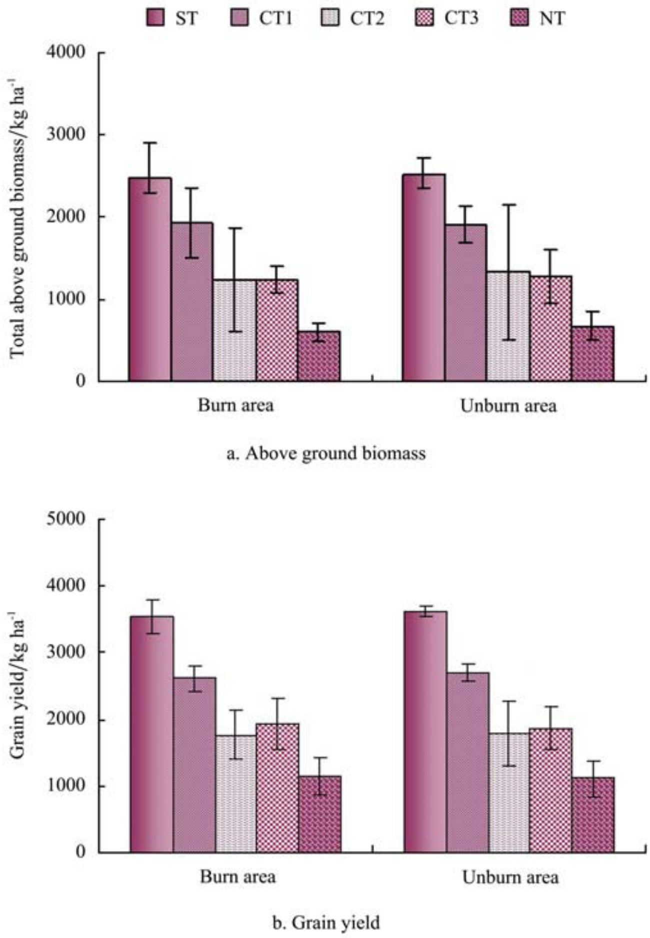
Ear characteristics taken for evaluating the effect by selected treatments were 100 kernel weight, number of kernels per ear, ear length, ear girth, number of rows per ear, number of grain per row, number of ears per planting area and number of ears per plant. The trends obtained were correlated with the growth parameters. ST showed the best results while NT showed the significantly poorer results than the other treatments. However, the major ear characteristics did not show any significant interactions between the tillage and corn residue management methods, and also no significant difference was found between two corn residue management methods.

3.9 Tillage and crop residue management effect on aboveground biomass and yield

Significant differences were found in the total aboveground biomass, both total and vegetative, among tillage treatments. ST showed (Figure 5) significantly higher biomass accumulation and grain yield than the other treatments approximately 29, 100, 105 and 211% more above ground biomass and 35, 101, 88, 216% more grain yield compared to CT1, CT2, CT3 and NT respectively. There was a noticeable difference in the plant population and growth parameters due to different tillage treatments. The ST treatment showed the highest value of corn dry matter and grain yield probably due to the deep root proliferation, less competition by weeds and higher plant population.

On the other hand, the lower grain yields of NT, when compared with the other tillage methods may be partly due to water loss, high evaporation at surface layer, low percolation due to increasingly higher soil strength at deeper layers, causing lower root development with high intensity of weed competition. The result tallied with FAO (1995), which reported that chiseling and sub soiling had increased yield of corn in northern Nigeria. Zorita (2000) reported an increase in vegetative growth and grain yield due to deep tillage on formerly no-tillage plots. Arora et al. (1991) also reported that the deep ploughing to 30 cm depth had resulted a significant increase in corn grain yield and root length index.

However, in this experiment, the aboveground biomass, both total and vegetative, and grain yield did not show significant interactions among the tillage methods and corn residue management methods. No significant differences were observed between two residue management methods.



Note: Bar indicates the standard deviation about the mean. The values with the same letter or with no letter are not significantly different by LSD ($p \leq 0.05$).

Figure 5 Growth and yield

3.10 Recommendations for tillage practice under local conditions

Table 4 shows the recommended tillage practices for cone cropping in Thailand considering the typical soil types and conditions. This is subjected to change as per the specific soil types and conditions in some areas, lower cycle frequency for soils with higher clay etc. This tallies with the recommendation by DOAE of Thailand. Mainly due to economic reasons the usual practice by most farmers is ST followed by CT2 or CT3 with harrowing.

Table 4 Recommended tillage practices for corn under local conditions

Year	Tillage Method
Year one	For crop 1: Subsoiler tillage (ST) followed by one of the conventional tillage methods; CT1, CT2 or CT3 For crop 2: one of the conventional tillage; CT1, CT2 or CT3
Year two	Both crops 1 and 2, one of the conventional tillage; CT1, CT2 or CT3
Year three	Both crops 1 and 2, one of the conventional tillage; CT1, CT2 or CT3
Year four	Same as year one, depending on soil conditions and repeat the cycle

Note: ST = Subsoiler tillage with depth 50 cm; CT1 = Mouldboard plow + 7 discs rotary harrow; CT2 = 3 discs plow + 7 discs harrow; CT3 = 7 discs plow+7 discs harrow (all 20-30 cm depth).

4 Conclusions

This study indicated that sufficiently deeper ploughing would be more effective in improving corn and biomass yields than shallow ploughing. Deep ploughing by ST seemed to have improved deeper root development and enabled the crop to exploit soil moisture reserves and nutrients preserved in different soil horizons. Thus, the poor vegetative growth and low yields in the no-tillage plots was caused by insufficient tillage and consequently by the quick weed emergence and competition with higher weed density. Deep tillage seemed to help deep-submerge of weed-seeds preventing their germination. Low density of weed observed in plots ST, CT1 and the highest weed density in plot NT could be the best justification for this phenomenon.

The cost effectiveness of the choice of tillage method should be well evaluated and made aware to corn farmers, as slightly lower tillage cost may not be the plus factor when considering the cost for heavy weed attack and subsequent lower yields. Proper and deep soil tilth can help better root development, momentary growth of the crop, and canopy at the initial stage, and help defeating the weed competition and subsequently higher yields. It was recommended to investigate the quantified effect on other typical corn growing soil types, residue management by mulching, spatial development of root systems, and corresponding cost-benefit situation for additional tillage verses weeding under specific local conditions.

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