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Effect of Different Tillage Practices and Two Cropping Patterns on Soil Properties and Crop Productivity

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A FIELD experiment compared five tillage practices, wide raised beds (WRB), narrow raised beds (NRB) both after soil plowing, no-tillage with beds (NTRB), no-tillage (NT) and conventional tillage (CT) through two cropping systems, the sole corn (*Zea mays* L.) and sole soybean (*Glaycine max* (L.) Merr.) and the intercropping of corn and soybean on irrigation water economy, soil physical and chemical properties and yield and yield attributes were done. Soil sustainability was quantifying for each tillage system using rating index. The results generally showed that raised beds tillage reduced the applied amounts of irrigation water and increased irrigation water productivity compared to conventional and no-tillage under the two cropping systems. Width of the beds has a significant effect on soil properties and yield and its attributes. Wide beds (WRB) improved soil properties (reduced the bulk density, increased porosity and available water content of the soil) which increased yield and its attributes of the two cropping systems followed by narrow raised bed system as compared to the other tillage systems. Significant difference between wide raised bed tillage and conventional tillage was found for the studied parameters. The sustainability index indicated that wide raised bed tillage was highly sustainable tillage system, whereas, the other studied tillage systems had less sustainability.

Keywords: Raised bed tillage, Conventional tillage, No-tillage, Cropping patterns, Soil properties, Corn, Soybean, Yield, Yield attributes, Sustainability index

Seedbed preparations are crucial for crop establishment, growth and ultimately yield (Atkinson *et al*., 2007). Tillage practices profoundly affect soil physical properties; therefore, it is essential to select a tillage practice that sustains the soil physical properties which are important for maintaining soil quality and for favorable conditions for crop growth (Jabro *et al*., 2009 and Mulumba & Lal, 2008). Soil quality is the integrated effect of management on most soil properties that determine crop productivity and sustainability (Anikwe and Ubochi, 2007). Tillage methods increase irrigation efficiency and enhance the effectiveness of drainage systems as it is capable of influencing soil structure (Jabro *et al*., 2009). Iqbal *et al*. (2005) and Ghazanfar *et al*. (2010) also found that tillage has an impact on water consumption by changing soil hydrological properties, water evaporation and also by affecting the water consumption of plants. Gill (2012) concluded that soil tillage influences agriculture sustainability of soil through its effect on soil processes, soil properties and crop growth. Since new tillage practices are needed for sustainable agriculture management system, raised beds have been proposed as a conservation tillage system (Morrison *et al*., 1990). Raised beds encourage the benefits of minimum tillage in soil physical properties and it is effective in reducing compaction of the crop zone and managing crop residues on the bed which lead to rapid vegetative growth of crops (Talukder *et al*., 2002, Peries *et al*., 2004 and Boulal *et al*., 2012). Raised beds increased fertilizer use efficiency, reduced weed infestation and reduced seed rate without sacrificing yield (Hobbs *et al*., 2000). Bhushan *et al*. (2008) and Gathala *et al*. (2011) also found that permanent raised beds reduced the adverse impact of excess water on crop production and improved water distribution. Fahong *et al*. (2004) indicated that a change from growing crops on the traditional furrows to the raised bed offers more effective control of irrigation water and drainage. However, Hassan *et al*. (2005) found that on coarse-textured loamy sand similar corn yield on raised bed and conventional systems were obtained due to high rate of infiltration. Wu (2006) recommended that as the environment becomes drier and grain yield lowers, beds should be wider and as the environment improves and grain yield increases, beds can be narrowed. Yuan *et al*. (2005) found that soil water content in 0.80 m wide beds was higher than that in traditional flat fields. The advantages of intercropping are effective use of available resources, efficient use of labour, increased crop productivity, and food security (Li *et al*., 2001). Panhwar *et al*. (2004) found that intercropping of soybean in maize rows did not show any adverse effect on plant height, 1000-grain weight as well as on grain yield of maize. The concept of sustainability emphasizing increased and stabilized production and conserving natural resources (FAO, 1989). Quantification of sustainability is essential to assess the impact of management systems on soil (Ikemura and Manoj, 2009). The aim of this study was to (i) assess the variation in irrigation water productivity under different tillage systems and two cropping systems (ii) quantify the sustainability of the soil under the different tillage systems and (iii) compare raised bed tillage systems with conventional and no-tillage systems with two cropping systems (sole and intercropping of corn and soybean) on crop yield of corn and soybean.

Materials and Methods

A field experiment was conducted at Research Station of Agriculture College, Cairo University during the two growing summer seasons of 2012/2013 and 2013/2014. A randomized complete block design with three replicates was used.

Management practices and cropping systems

The tillage practices involved wide width (100 cm) raised bed (WRB), narrow width (70 cm) raised bed (WRB) with soil loosening, no-tillage with 100cm beds (NTRB), conventional tillage (CT) and no-tillage on flat field (NT).

Raised beds were formed by hand with 15cm high, flat tops about 70 and 100 cm wide and a spacing of 70 cm. The sub plot size was (5.5×7.0 m). The flat planting treatment followed traditional practices, with furrows. Seeds of soybean (Giza 22) and corn (hybrid single cross 123) were sown on top of the raised beds at 14 May and 5 June and at 18 May and 10 June of the first and second season, respectively. The cropping systems were planted for each tillage system as follows:

1- Intercropping corn with soybean, each crop planted in alternation with the other crop using 1:1 intercropping system where, the two crops were planted on both sides.
2- Pure stand of corn and pure stand of soybean were planted in rows. The two crops were planted in one side of the bed and the furrow.

The distance within beds and furrows was 20 cm, with one plant / hill for corn and 10 cm apart with two plants per hill for soybean.

Soil sampling and analysis

The physical and chemical properties of the experimental soil site (Table 1) were determined before tillage in the two seasons by taking soil samples at 0-10, 10-20 and 20-30cm soil depths. At maturity, the determination of bulk density (Bd), total porosity (TP), field capacity (FC), wilting point (WP) and soil hydraulic conductivity (Ks) were done according to Klute (1986). The difference between soil moisture at saturation and field capacity was calculated to assess the effective porosity (θ_e) and the difference between soil moisture at field capacity and wilting point was calculated to assess plant available water capacity (AWC). Soil organic matters (OM), electric conductivity (EC) in extracts of saturated soil pastes and pH in suspension of 1:2.5 soil water were determined according to Page *et al.* (1982). The mean of the two seasons was taken into consideration as there was no significant difference found between the two seasons.

TABLE 1. Physical and chemical properties of the experimental soil site before tillage (average of the two seasons) .

Soil depth (cm)	Clay %	Silt %	Sand %	Texture class	ECe dS/m	pH 1:2.5	Bd g.cm^{-3}	OM %	FC %	WP %	AWC %	Ks cm.h^{-1}
0-10	26.0	32.7	41.3	Loam	1.97	7.97	1.23	2.26	38.79	20.27	18.52	2.57
10-20	24.7	30.6	44.7	Loam	1.85	8.02	1.26	1.82	39.34	19.87	19.47	1. 52
20-30	19.2	26.5	54.3	S.Loam	1.06	8.15	1.35	1.03	32.45	15.49	16.96	2.98

Fertilization regime

All treatments of corn and soybean were fertilized with nitrogen at rate of 120 and 15 kg N /fed. in the form of urea (46.5 %N) at planting and phosphorus fertilizer in the form of calcium superphosphate (15.5% P_2O_5) at the rate of 200 and 150 kg P_2O_5/ fed. before planting, respectively. Soybean seeds were inoculated with powder (*Bradyrhizobium japonicum* L.) at sowing time.

Irrigation water applied and irrigation water productivity

The quantity of irrigation water applied for each treatment was measured by digital flow meter and the irrigation water productivity (IWP) was calculated according to James (1988) as follows:

$$\text{IWP} = \frac{Y}{Wa}$$ where:

Y = total grain yield, kg/fed.

Wa = total applied water, m^3/fed.

Soil sustainability index

Soil sustainability index was calculated for the studied tillage practices according to Lal (1994). The sustainability index was obtained by adding critical levels proposed by Lal (1994) for each soil physical and chemical property within a depth, separately for each tillage practice (Table 2). The critical levels ranged from none to extreme on a scale of one to five. Cumulative rating (CR) for the different tillage systems (Table 3) ranged from sustainable (CR<20) to unsustainable (CR >40) (Lal, 1994).

Harvesting

Sole and intercropped soybean and corn crops were harvested at September 12^{th} and 29^{th} of the first season and 14^{th} and 25^{th} of the second one, respectively. A central area of 2×2 m was harvested for seed yields and its attributes. For sole and intercrop corn, yield attributes were: number of ears/plant, ear weight/plant and grain weights/ plant. Soybean attributes were: number of pods/plant, number of branches/plant and seed weight/plant.

Statistical analysis

The data were subjected to analysis of variance techniques according to Gomez and Gomez (1984). The L.S.D. test at 5% probability level was used to test the significance of the differences among means.

جدول 2

TABLE 3. Sustainability of management system in relation to the cumulative ratings (CR) based on above 11 indicators.

Sustainability	RWF	CR
Highly sustainable	1	<20
Sustainable	2	20-25
Sustainable with high input	3	25-30
Sustainable with another land use	4	30-40
Unsustainable	5	>40

RWF- Relative weighting factors

Results and Discussions

Irrigation water amounts and irrigation water productivity

The effect of studied tillage practices and cropping systems on irrigation water amounts (IWA) and irrigation water productivity (IWP) is shown in Fig. 1. The highest amounts of irrigation water (2466.24, 2421.3 and 2652.08 m^3/fed.) were recorded with conventional treatments (CT) whereas; the lowest amounts of irrigation water (2210.46, 2146.62 and 2382.36 m^3/fed.) were recorded with wide raised bed treatments (WRB) for sole corn, sole soybean and intercropping corn/soybean systems, respectively. The wide and narrow raised beds were effective in reducing irrigation water amounts compared to CT. A significant difference between each of WRB and NRB and CT was found under all cropping patterns. The amounts of irrigation water applied for raised bed with no-tillage (NTRB) were also lower than CT. However, no significant difference was found among NTRB, NT and CT under all cropping systems. These results are in agreement with Choudhury *et al.* (2007) and Ram-Singh *et al.* (2012). Moreover, under all tillage practices, the highest amount of irrigation water was recorded with intercropping system followed by sole corn and sole soybean, respectively. The increase of irrigation water amounts with intercropping system may be due to the increased plant population compared to sole stand of corn and soybean. Intercropping system under wide raised beds (WRB), narrow raised beds (NRB) and no-tillage raised beds (NTRB) saved irrigation water amounts by 10.2%, 8.3% and 5.8%, respectively compared to CT.

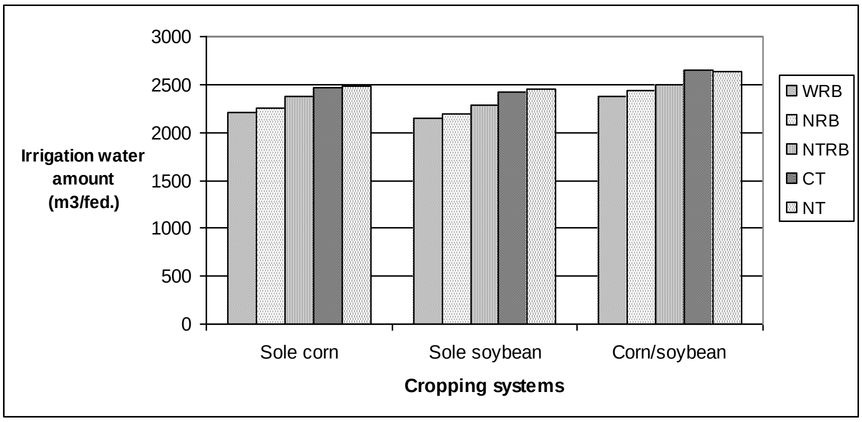

Fig. 1. Irrigation water amounts (m^3/fed.) of the cropping systems under different tillage systems (LSD 5%= 142.06).

Concerning irrigation water productivity (IWP) as an important index for the assessment of water saving, (Fig. 2), the IWP under all cropping systems followed the order of WRB > NRB > NTRB > CT > NT. The raised beds recorded higher IWP compared to CT and NT. The wide raised bed significantly increased water productivity compared to the other tillage practices under the studied cropping systems. The NRB was also effective in increasing IWP compared to both NTRB and NT. A significant difference was found between NRB and each of NTRB and NT under all cropping systems. These results revealed that the lowest irrigation water amounts were associated with the highest IWP and the WRB have potential for higher IWP. These results are in agreement with Jat *et al.* (2005). The intercropping system also increased water productivity than sole corn and sole soybean.

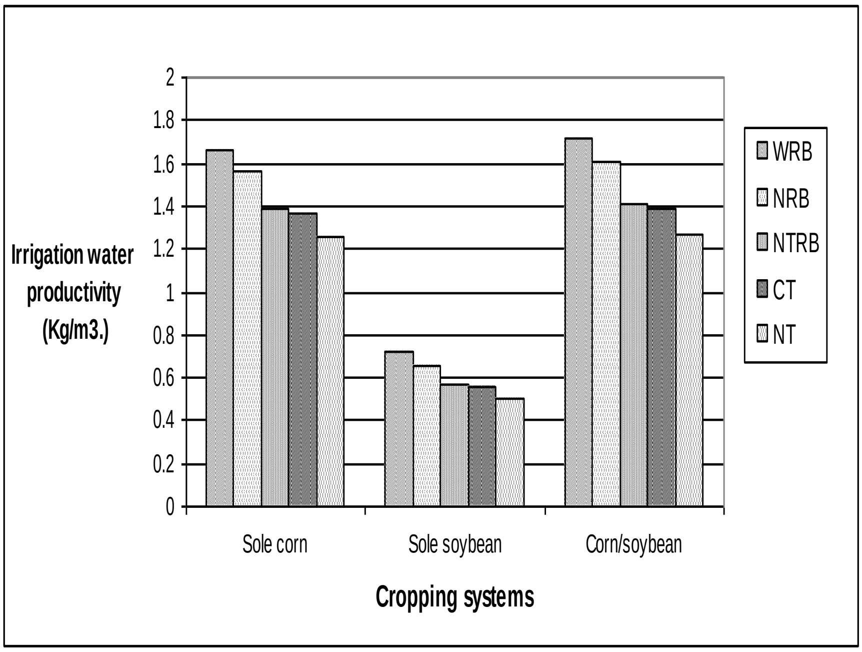

Fig.2. Irrigation water productivity (kg.m^{-3}) of the cropping systems under different tillage systems (LSD 5%=0.07).

Soil properties of different tillage systems

The impact of different tillage systems on soil bulk densities (Bd) measured at the end of the field experiment for the 0-30cm depth is given in Fig. 3. Wide and narrow raised bed recorded the lowest Bd values compared to CT, whereas, both NTRB and NT recorded higher Bd values compared to CT. A significant difference among raised bed treatments was found as compared to CT.

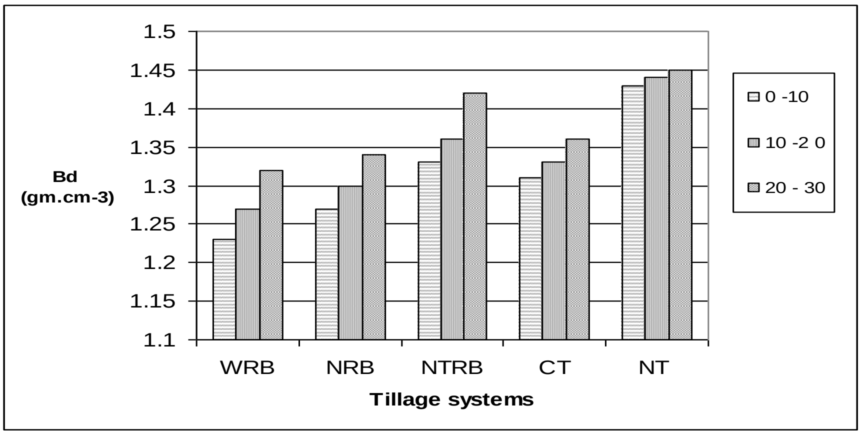

Fig.3. Soil bulk density (Bd) as affected by tillage systems.
(LSD 5%=0.05)

The total porosity of the soil as affected by tillage practices is shown in Fig. 4. Minimum total porosity was recorded with no-tillage treatments (NT) followed by raised bed with no-tillage (NTRB), whereas, the highest total porosity was recorded with wide raised bed treatments (WRB) followed by narrow raised bed treatments (NRB) compared to CT. A significant difference in total porosity between each of WRB and NRB and CT was found. The improvement in Bd and porosity in beds might cause favorable conditions for roots, consequently increased yield of corn and soybean of the different cropping systems.

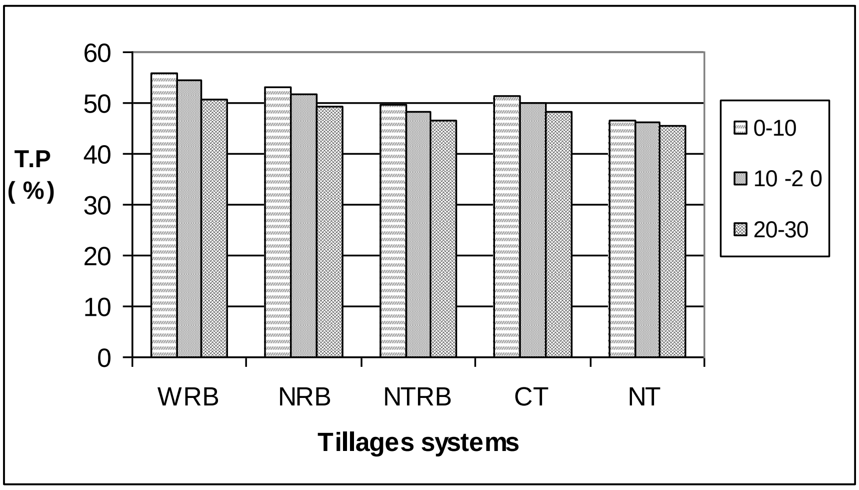

Fig. 4. Total porosity (TP) % as affected by tillage systems.
(LSD 5%=2.23).

Tillage practices also affected field capacity (FC), wilting point (WP) and consequently available water capacity (AWC) of the soil. The wide raised bed tillage (WRB) maintained the highest available water capacity (AWC) values followed by narrow raised bed tillage (NRB) as compared with CT. On the other hand, NTRB increased AWC than NT. The only significant difference between bed tillage practices and CT was found with WRB. Regarding soil hydraulic conductivity (Ks), raised bed (WRB and NRB) increased Ks significantly as compared to the other tillage. Hamza and Anderson (2005) reported that soil bulk density, porosity and water movement in the soil, depend on method of tillage. The increase in Ks values with these tillage treatments suggests greater porosity and better pore continuity. These results are in agreement with Elder and Lal (2008). The decrease in Ks under NT and NTRB may be due to the higher Bd with less pore space that reduced water movement and decreased Ks. The results concluded that raised bed tillage system produced the most favorable soil physical properties. Sotomayor – Ramirez *et al.* (2006) indicated that soil physical properties improved under raised bed systems.

TABLE 4. Wilting point (W.P), field capacity (F.C.), available water capacity (AWC) and hydraulic conductivity (Ks) as affected by different tillage systems at different soil depths.

Tillage practice	Soil properties											
	WP %	FC %	AWC %	Ks $cm.h^{-1}$	WP %	FC %	AWC %	Ks $cm.h^{-1}$	WP %	FC %	AWC %	Ks $cm.h^{-1}$
	Soil depth (cm)											
	0-10				10-20				20-30			
WRB	17.69	37.82	20.13	11.77	18.77	38.70	19.93	11.10	15.95	34.64	18.69	9.56
NRB	18.62	37.79	19.17	11.25	19.48	38.81	19.32	10.37	15.91	34.10	18.19	8.74
NTRB	18.20	36.10	17.90	3.76	18.91	37.50	18.59	2.67	14.51	32.26	17.75	1.89
CT	18.47	37.16	18.69	5.27	19.28	38.20	18.92	4.58	14.76	33.16	18.40	3.72
NT	16.37	33.45	17.08	1.96	18.06	34.46	16.40	1.40	14.35	30.91	16.56	0.80
LSD%												
WP	1.67											
FC	1.65											
AWC	1.42											
Ks	1.88											

Chemical properties of the soil

Soil chemical properties at the end of the field experiment are presented in Table 5. Organic matter content, electric conductivity and pH of the soil were influenced by the different tillage practices. The highest OM content was recorded with NT, whereas, the lowest OM content was obtained with NRB followed by WRB as compared to the other tillage systems at all depths. A significant difference between each of WRB and NRB in respect to CT was recorded. The data also showed that the lowest and the highest EC and pH values were recorded with NT and WRB, respectively. The soil pH was more uniform throughout the different depths of all tillage systems. No significant difference was found in EC or pH among raised bed tillage treatments.

TABLE 5. Soil pH , electric conductivity (EC) and organic matter (OM) as affected by tillage systems at different soil depths.

Tillage practices	Soil depth (cm)								
	0-10			10-20			20-30		
	Soil properties								
	pH 1:2.5	ECe dS/m	OM %	pH 1:2.5	ECe dS/m	OM %	pH 1:2.5	ECe dS/m	OM %
WRB	8.25	2.36	1.98	8.30	2.03	1.49	8.20	1.38	0.91
NRB	8.20	2.29	1.90	8.25	1.98	1.43	8.17	1.30	0.83
NTRB	8.15	1.94	2.40	8.20	1.76	1.87	8.15	1.14	1.21
CT	8.24	2.13	2.34	8.28	1.91	1.82	8.19	1.18	1.16
NT	8.12	1.84	2.49	8.17	1.63	1.94	8.09	1.07	1.24
LSD 5%									
pH	ns								
ECe	0.23								
OM	0.27								

Evaluation of soil sustainability

Soil physical and chemical properties have been proposed to quantitatively assess sustainability of the soil management practice. The study relates changes in soil properties under different soil tillage practices with soil sustainability using rating index. The rating index uses critical limits of soil physical and chemical properties on the basis of limitations to crop production (Lal, 1994). Rating index ranged from one to five for the relative weighting factor for each soil properties. The lower limit of one for a soil property indicated no limitation and the upper limit reflected a severe constraint. The cumulative ratings values (CR) calculated for the different tillage practices at the studied three depths are given in Table 6. The CR values ranged from 17 to 22, 19 to 23 and 22 to 24 for the first layer, the second layer and the third layer of the studied tillage practices, respectively. The tillage practices followed the order of wide raised bed< narrow raised bed< conventional tillage <raised bed with no-tillage <no-tillage. These results showed that the lowest CR value was obtained with wide raised bed tillage (WRB) whereas; the highest CR value was obtained with the no-tillage system. These results revealed that the CR values obtained for wide raised bed (WRB) is less than 20, therefore, the WRB tillage is considered highly sustainable tillage practice. Therefore, wide raised bed tillage is an efficient management practice for soil sustainability. On the other hand, the CR values of the other tillage systems (narrow raised bed, raised bed with no-tillage, conventional tillage and no– tillage) were more than 20, therefore, these tillage practices are sustainable tillage practices. These results indicated that sustainable production of crops depends on tillage system.

TABLE 6. The calculated cumulative ratings (CR) for the studied tillage systems.

Tillage systems	Soil depth (cm)			
	0-20	20-40	40-60	Mean
WRB	17	19	22	19.3
NRB	19	22	22	21.0
NTRB	21	21	24	22.0
CT	21	22	22	21.7
NT	22	23	23	22.7

Yield and yield attributes

The effect of tillage systems on sole corn, sole soybean, intercropping corn and intercropping soybean yields are illustrated in Fig. 5. Yields attributes of the two cropping systems are given in Table 7. Generally, the data revealed that seed yields and yield attributes of corn and soybean were influenced by tillage and cropping systems. The higher corn and soybean yields and yield components (no. of ears/ plant, ear weight and seed weight/plant) were obtained under raised bed with soil loosening (WRB and NRB) compared to CT under sole and intercropping corn and soybean. These results are in agreement with Hassan *et al*. (2005) and Zang *et al*. (2012). There was no significant difference between WRB and NRB in yields and yield attributes of corn and soybean of the two cropping systems. Holland *et al*. (2007) explained that the significant increase in yields with raised beds may be due to the improvement of air filled porosity and available water capacity which leads to better root environment under raised bed, also wide and narrow raised bed might provide more water for the growth of the crops by maintaining greater soil water content than conventional tillage. Therefore, the highest seed yield was connected with the tillage system that had the highest available water capacity. A significant difference between wide raised bed tillage (WRB) and both CT and NT was found with corn yield of sole and intercropping systems, whereas no significant difference was found with soybean yield of both sole and intercropping systems. The yields and yield attributes of corn and soybean of all cropping systems were lower under raised bed with no-tillage (NTRB) treatments than CT treatments. However, yield of corn and soybean of the two cropping systems were higher under NTRB treatments than NT treatments, the difference between them was not significant. The data also showed that corn and soybean yields and its attributes were higher with sole system than intercropping system. The results concluded that raised beds tillage with soil loosening may therefore be an option for increasing productivity of corn and soybean crops. L

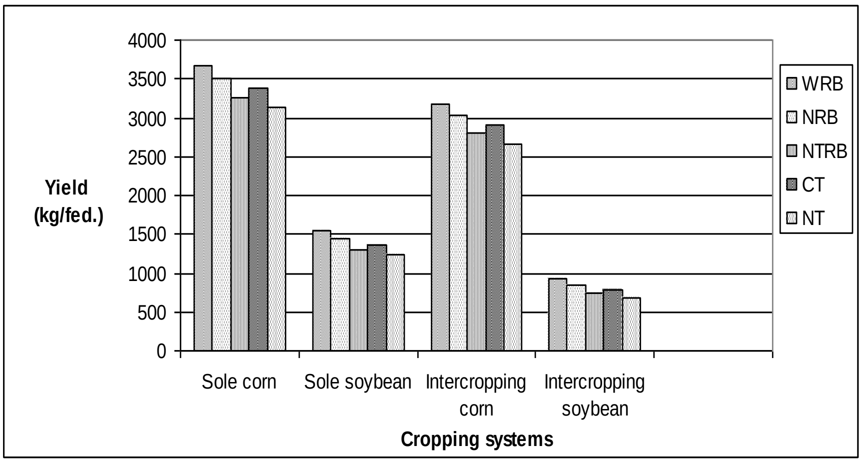

Fig.5. Seed yields (Kg/fed.) of the two cropping systems as affected by different tillage systems (LSD 5%= 192.64).

TABLE 7. Yield attributes of sole corn, sole soybean and intercropping corn / soybean as affected by tillage systems

Tillage system	Sole system						Intercropping system					
	Corn			Soybean			Corn			Soybean		
	No .of ears/plant	Ear weight	seed weight/plant	No. of pods	No. of branches	Seed weight/plant	No. of ears/plant	Ear weight	Seed weight/plant	No. of pods	No. of branches	Seed weight/plant
WRB	1.36	334.40	305.79	74.83	5.69	27.79	1.32	317.05	286.19	65.15	5.18	23.31
NRB	1.32	326.76	295.49	72.50	5.29	26.52	1.27	312.73	280.91	63.21	4.81	22.16
NTRB	1.26	307.18	281.49	66.70	4.64	25.16	1.22	294.39	267.14	57.82	3.99	20.87
CT	1.31	319.12	277.39	70.18	5.17	26.37	1.25	302.58	261.63	60.11	4.39	22.19
NT	1.17	288.19	261.95	64.10	4.08	24.45	1.12	273.69	246.29	53.82	3.64	19.21
LSD 5%	0.05	14.86	16.54	4.14	0.91	1.32	0.06	12.53	17.26	4.16	0.89	2.84

Conclusion

Modern management practices should be applied for sustainable agriculture and better crop production. The results revealed the superiority of raised bed tillage with soil loosening over conventional and no-tillage practices. Wide and narrow raised beds were associated with the increase of irrigation water productivity and the increase in available moisture capacity, total porosity, saturated hydraulic conductivity and the decrease of bulk density of the 0-30 cm soil layer compared to CT. They also provided significant increase in yields of corn and soybean and its attributes with the studied cropping systems as compared to conventional and no-tillage systems. The advantage of raised bed can be explained by the improvement of physical and chemical properties of the soil. Sustainability index indicated that wide raised bed tillage is highly sustainable whereas, narrow raised bed tillage is sustainable tillage practices.

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تأثير طرق خدمة مختلفة ونظامين للزراعة على خواص التربة وأنتاجية المحصول

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أجريت التجربة الحقلية فى محطة التجارب الزراعية، كلية الزراعة، جامعة القاهرة خلال موسمى 2013/2014 و2012/2013 لمقارنة خمسة نظم مختلفة لخدمة التربة هى نظام المصاطب العريضة (100 سم عرض) (WRB)، المصاطب الضيقة (70 سم عرض)) (NRB وذلك بعد حرث التربة، نظام عدم الخدمة مع المصاطب (100 سم عرض) (NTRB)، نظام عدم الخدمة بدون مصاطب (NT)ونظام الخدمة التقليدية (CT) مع نظامين للزراعة هما الزراعة المنفردة للذرة الشامية والزراعة المنفردة لفول الصويا والزراعة المحملة للذرة الشامية مع فول الصويا بنظام 1 : 1 وأثر هذة المعاملات على إنتاجية مياه الرى وخواص التربة الفيزيائية والكيميائية و المحصول وبعض مكوناته. وتم حساب دليل إستدامة الزراعة فى التربة تحت نظم الخدمة المختلفة بإستخدام دليل Rating index. ولقد أظهرت النتائج أن نظام المصاطب قد أدى الى نقص كمية مياه الرى المضافة وزيادة إنتاجية المياه بالمقارنة بنظام الخدمة التقليدية ونظام عدم الخدمة لنظامى الزراعة المتبعة. وقد تفوق نظام الزراعة على مصاطب بعد حرث التربة على نظام الزراعة على مصاطب بدون حرث للتربة. وأثر أيضا عرض المصطبة على خواص التربة المدروسة والمحصول ومكوناتة حيث أدت الزراعة على المصاطب العريضة إلى تحسن واضح فى خواص التربة الطبيعية والكيميائية وتوفير مياه الرى مما أدى الى تحسن إنتاجية التربة من محصولى الذرة وفول الصويا ويلي نظام المصاطب العريضة القاعدة المصاطب الضيقة وذلك بالمقارنة بباقى نظم الخدمة المدروسة لكل من نظام الزراعة المنفردة والتحميل. وقد أكد دليل أستدامة زراعة التربة تفوق نظام المصاطب العريضة على باقى نظم الخدمة المدروسة فى المساهمة فى إستدامة الزراعة لهذة الأرض.