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Tillage and straw retention in rice-wheat cropping system influences on soil aggregation, aggregate carbon and water balance under irrigated conditions: An overview

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Abstract
Soil organic carbon (SOC) is the most often reported attribute and is chosen as the most important indicator of soil quality and agricultural sustainability. In this review, we summarized how cultivation, residue and tillage management and monoculture affect soil quality, soil organic matter (SOM) and carbon transformation. The results confirm that SOM is not only a source of carbon but also a sink for carbon sequestration. Cultivation and tillage can reduce soil SOC content and lead to soil deterioration. Tillage practices have a major effect on distribution of C and N, and the rates of organic matter decomposition and N mineralization. Proper adoption of tillage and residue can increase or maintain the quantity and quality of soil organic matter, and improve soil chemical and physical properties.

Tillage significantly reduced the proportion of macro-aggregate fractions (>2.00 mm) and thus aggregate stability was reduced by 35% compared with (ridge with no tillage) RNT, indicating that tillage practices led to soil structural change for this subtropical soil. The highest SOC was in the 1.00-0.25 mm fraction (35.7 and 30.4 $mgkg^{-1}$for RNT and CT, respectively), while the lowest SOC was in micro-aggregate (<0.025mm) and silt +clay (<0.053mm) fractions (19.5 and 15.7 $mgkg^{-1}$ for RNT and CT, respectively). Labile C fractions: particulate organic C (POC), microbial biomass C (MBC) and dissolved organic C (DOC) were all significantly higher in NT and ST than in CT in the upper 15 cm. Higher SOC content of 19.44 gkg^{-1} of soil was found in zero tilled residue retained plots followed by 18.53 g kg^{-1} in permanently raised bed with residue retained plots. Whereas, the lowest level of SOC content of 15.86 g kg^{-1} of soil were found in puddled transplanted rice followed by wheat planted under conventionally tilled plots.

Rice transplanted on wide raised beds and transplanted rice under reduced tillage plots consumed more moisture from the deeper profile layer than conventional tillage practice. The wide raised beds plots increased the water use efficiency of 15.12 and 15.78kg grain ha^{-1} mm. The per cent increased in water use efficiency under wide raised beds over conventional tillage was 38.67 and 39.23. The wide raised beds plots increased the water use efficiency of 15.12 and 15.78 kg ha^{-3} and water productivity (1.28 and 1.18kg ha^{-3}). Inland configuration systems, B_{90-4} and 4 cm irrigation at IW/CPE 1.2 displayed significantly higher water use efficiency (2.53; 2.51 and 2.19; 2.18 kg m^{-3}) compared with other treatments. These collected review demonstrated that tillage and straw retention is crucial for improving soil health and sustainability of irrigated farming systems in rice-wheat cropping system.

Keywords: Aggregate stability, aggregate associated n, soil c and n balances, water productivity

Introduction
Globally, soil stores approximately 1,500 PG of carbon in the form of organic carbon. The soil organic carbon (SOC) pool is 2.5 and 2 times the carbon pool in terrestrial vegetation and the atmosphere, respectively (Brown and Lugo, 1982) [6]. Thus, small changes in soil organic carbon can cause dramatic changes in the concentration of atmospheric CO_2 (Jarecki and Lal, 2003) [25]. Before this problem was recognized, the primary purpose of soil tillage was to create suitable soil environmental conditions for crop growth, to conserve soil water, and to promote crop-yield increases (Gao *et al*., 2003) [19]. However, with the increased awareness of the greenhouse effect, soil organic carbon has been found to be easily affected by tillage and fertilization, and various tillage practices were found to exert a significant influence on soil disturbances, aggregate stability, and organic carbon flux rates (Benbi and Senapati, 2010) [4]. Thus, the purpose of soil tillage was no longer limited to increasing crop yields, and a greater consideration was given to the efficacy of enhancing soil carbon preservation and preventing the occurrence of greenhouse effects.

The impact of farmland nutrient losses on environment security is of serious concern. Agriculture management practices, such as conservation tillage and rational fertilization, led to reduce water and soil losses and increase grain yield are potential solution but these approaches require an understanding of complex adaptive traits for climatic factors and environment conditions (Zhang *et al*., 2018). Soil carbon (C) and nitrogen (N) cycling and hydrological processes-the main ecosystem components studied by ecologists and global change scientists-play a key role in agro-ecological systems and can both positively and negatively affect crop production and soil quality (Xia *et al*., 2016) [60]. Thus, the actual impacts of conservation tillage practices on these processes need to be clarified if we want to simultaneously increase crop production and reduce soil nutrient and water losses (Zhao *et al*., 2012) [64]. Conservation tillage including crop straw returning and reducing tillage intensity, is a new approach that has been suggested to benefit agriculture by conserving soil water and reducing seasonal evaporation; in this way, conservation tillage supports sustainable agricultural development (Zhang *et al*., 2018). Previous research has shown that straw returning enhances organic C sequestration and N levels in soil, and is particularly relevant for reducing soil nutrient losses and improving soil properties (Dikgwatlhe *et al*., 2014) [10]. Along with improved soil nutrient contents, several researchers have noted that straw returning to the soil can significantly improve soil moisture by benefiting both infiltration and soil water retention and reducing evaporation from the soil surface (Tan *et al*., 2002). Thus, it has been widely reported that crop straw returning benefits both soil fertility and crop production (Kurothe *et al*., 2014) [30].

Soil organic matter (SOM) is the central indicator of soil quality and health, which is strongly affected by agricultural management (Farquharson *et al*., 2003) [15]. SOM is a major terrestrial pool for C, N, P, and S, and the cycling and availability of these elements are constantly being changed by microbial immobilization and mineralization (Feichtinger *et al*., 2004) [16]. The importance of increased SOM or soil organic carbon (SOC) is its effect on improving soil physical properties, conserving water, and increasing available nutrients. These improvements should ultimately lead to greater biomass and crop yield (Onemli, 2004). There is considerable concern that if SOM or SOC concentrations in soils are allowed to decrease too much, the productive capacity of agriculture will be then compromised by deterioration in soil physical properties and by impairment of soil nutrient cycling mechanisms (Loveland and Webb, 2003) [33]. Long-term experiments are often required to predict soil management impacts on soil carbon storage and provide leading indicators of sustainability, which can serve as an early warning system to detect impairments that threaten future productivity (Clapp *et al*., 2000) [8].

Soil aggregation

Fuentes *et al*. (2009) [17] observed that micro-aggregates (53-250µm) accounted for more than 50% of the total soil and were the predominant water-stable size class in both cropping systems and tillage treatments. The silt and clay fraction (<53 µm) were similar among tillage treatments and soil depth. The proportion of micro-aggregates was lower in NT compared with CT and RT in the 0-to 5-cm depth in both cropping systems and in the 5 to 10 cm in the PN-BB system. Both large and small macro-aggregates (>2000 µm and 250-2000µm, respectively) accounted for the lowest proportion of aggregates with <40% of the total dry soil mass.

In the PN-BB system, total aggregate C concentration of the small macro-aggregates differed in the order NT >RT>CT for the 0-to 5-cm depth. In the same cropping system, micro-aggregate C concentration under NT was greater than under CT and RT in the 0-to 5-cm depth. However, below the 5-cm depth no differences in total aggregate C concentrations were observed in this cropping system. In the PN-BF rotation, similar total aggregate C concentration among tillage treatments was observed in all the soil layers except in the 0-to 5-cm depth where greater micro-aggregate C concentration was observed in NT and CT compared with RT. Differences between cropping system were found in the 0- to 5-and the 5-to 10-cm depths in the NT treatment where greater total macro-aggregate and micro-aggregate C concentrations were observed in the PN-BB system compared with the PN-BF rotation.

Bhattacharyya *et al*. (2013) [5] also found that ZT-B plots had a greater proportion of large macro-aggregates (2-8mm) than CT-F and CT-B plots. Concomitantly, CT-B plots had 20% greater silt? Clay sized fractions than ZT-B plots. The C/M+ W RES plots also had more macro-aggregates and greater MWD than N RES in the 0-5 cm layer. Both tillage and residue retention had significant impacts in the 5-15 cm layer, with similar trends. Neither tillage nor residue retention had significant effects on either aggregates or aggregate-associated N in the 15-30 cm soil layer. Fang *et al*. (2015) [14] also found that the mass of soil aggregates of >5 mm diameter was the greatest followed by 2-5mm, 0.5-1mm, 0.25-0.5mm, and <0.25 mm, and that of 1-2mm aggregates was the lowest. Moreover, smaller aggregates had a higher OC concentration (0.5-1mm, 0.25-0.5mm and <0.25mm) than larger aggregates (>5mm, 2-5mm and 1-2mm) in CF topsoil, and OC concentration decreased with increasing aggregate size in BF topsoil.

Naresh *et al*. (2014) [40] reported that the quantity of fine aggregates (<0.25mm) was much higher than coarse aggregates (>0.25mm). About 5% of the aggregates were larger than 2mm, 7% between 1 and 2mm, 13% between 1 and 0.5 mm, about 20% were in the range of 0.5-0.25mm, and almost 65% of the aggregates had the size smaller than 0.25 mm. Aggregate size distributions were significantly influenced by tillage treatments. Aggregates <25mm in the zero tillage category was significantly higher (4.4%), than conventional tillage (CT) and beds planted wheat (BPW) methods (3.2 and 3.4%, respectively). The zero till methods also had the highest amount of 1 to 2 mm aggregates (5.9%) while the beds planted method contained the lowest amount of this size of aggregates (4.5%). The percentage of the aggregates with other sizes (1 to 0.5, 0.5 to 0.25 and <0.25mm) were similarly influenced by different tillage practices. Some studies generally indicate that no-tillage and reduced tillage systems have positive impacts on conserving soil and water resources by reducing soil erosion, retaining more water in the soil profile, increasing water infiltration and enhancing soil aggregation and stability (Dam *et al*., 2005) [9]. Aggregates in the range >2, 2 to 1,1 to 0.5, and 0.5 to 0.25 mm were all significantly higher in the zero till method compared to other treatments. Bear *et al*. (1994) [2] reported that aggregates ranging from 2 to 0.25mm in size need to be protected by organic carbon binding agents otherwise, under heavy and intensive cultivation, the aggregates would be disrupted.

Wu *et al*. (2019) [58, 59] observed that compared to conventional tillage practices (including T and TS treatments), the percentages of the macro-aggregate fractions under the conservation tillage practices (including NT and NTS treatments) were increased by 41.2-56.6%, with the NTS treatment having the greatest (MWD) under the TS and NTS treatments were 10.68, 13.83 and 17.65% respectively. They were 18.45, 19.15 and 14.12% higher than those under the T treatment, respectively. Zhao *et al*. (2019) reported that the proportion of soil aggregates >2mm notably increased by 26%, with STR compared with CK. Conversely, STR markedly decreased the proportion of soil aggregates, <2mm and >0.25mm by 29%. However, no significant difference was seen in the proportion of soil aggregates <0.25mm and >0.053mm or <0.053mm between two treatments. Soil aggregates >0.053mm were the predominant component of the soil, with aggregates <0.053mm accounting only for a minor proportion of the soil.

Soil aggregate carbon

Zhang *et al*. (2013) [13] also found that the 0-5 and 5-10cm depths, NT and RT had significantly higher total soil C concentration than that of MP-R and MP+R in all aggregate size fractions. However, in the 10-20cm depth, conservation tillage system reduced total C concentration in the macro-aggregate fraction (>250μm) but not in the micro-aggregate and silt plus clay fractions. The greatest change in aggregate C appeared in the large macro-aggregate fractions where aggregate-associated C concentration decreased with depth, especially under the NT system. On the other hand, total C concentrations of the micro-aggregates and silt plus clay fractions were relatively stable. In the 0-5 cm depth, the >2000μm fraction had the largest C concentration under NT, whereas the <53μm fraction had the lowest C concentration under the MP-R treatment. Similar trend was also observed in the >2000μm and 25-2000μm fractions (23 vs. 24g C kg^{-1} aggregates) in the 5-10cm depth.

The large macro-aggregate (>2000μm) had relatively lower C concentration than that in the >250-2000μm fraction in the 10-20cm depth. However, Total C stored in macro-aggregates (>250μm) was 73% higher in RT and 33% higher in NT compared to the average across both MP treatments. In the 10-20 cm depth, soil C stored in the >2000, and 250-2000μm fractions did not differ among the RT, NT and MP+R treatments. The largest C stock occurred in the 53-250μm fraction, following the order of MP+R>RT>MP-R>NT. Du *et al*. (2013) [13] reported that the NT system did affect the SOC stock distribution in the soil profile but not the total quantity. Tillage regimes obviously influenced soil aggregation distribution in the soil profile. In the upper 0.00-0.05 and 0.05-0.20m layers, the NT system improved the formation level of the >2mm aggregate but reduced the formation level of <0.053mm aggregates, compared to the MP system, suggesting that mechanical operation reduced large-macro-aggregate formation and disrupted soil macro-aggregates into individual particles.

In the 0.00-0.05m layer, SOC concentration in macro-aggregates showed the order of NT+S>MP+S = NT-S>MP-S, whereas the NT system was superior to the MP system. However, the NT system significantly reduced the SOC concentration in the 2.00-0.25mm fraction in the 0.05-0.20m layer. A similar trend was observed in the 0.25-0.053mm fraction in the 0.20-0.30m layer. Across all the soil layers, there was no difference in the <0.053 mm fraction between NT-S and MP-S, as well as between NT+S and MP+S, indicating that the NT system did not affect the SOC concentration in the silt +clay fraction. In average across the soil layers, the SOC concentration in the macro-aggregate was increased by 13.5% in MP+S, 4.4% in NT-S and 19.3% in NT+S, and those in the micro-aggregate (<0.25mm) were increased by 6.1% in MP+S and 7.0% in NT+S compared to MP-S. For all the soil layers, the SOC concentration in all the aggregate size classes was increased with straw incorporation, by 20.0, 3.8 and 5.7% under the MP system, and 20.2, 6.3 and 8.8% under the NT system. The higher proportion of >2mm aggregates and lower proportion of <0.053mm aggregates under NT systems might be the result of the higher soil hydrophobicity, low intensity of wetting and drying cycles, higher soil C concentration or the physical and chemical characteristics of large macro-aggregates making them more resistant to breaking up (Vogelmann *et al*., 2013) [57].

Zheng *et al*. (2018) [51] observed that the SOC storage in macro-aggregates under different treatments significantly decreased with soil depth. However, no significant variation was observed in the micro-aggregate associated C storage with depth. SOC storage increased with aggregate size from 1±2 to >2mm and decreased with a decrease in aggregate size. The SOC storage in macro-aggregates of all sizes from 0-30cm depth was higher in the ST treatment than in other treatments. From 30-60cm, trends were less clear. SOC storage in micro-aggregates showed the opposite trend, with significantly higher levels in the CT treatment from 0-30cm, and no significant differences between treatments below this depth.

Song *et al*. (2019) [51] revealed that the aggregate-associated C content within varied aggregate sizes was significantly higher in the topsoil than in the subsoil. The order was as follows: small macro-aggregates>micro-aggregates>large macro-aggregates, with average values of 25.14 gkg^{-1}, 23.34 gkg^{-1}, and 20.54 gkg^{-1}, respectively. In contrast to the topsoil, the variation in aggregate -associated C in the subsoil was smaller between the different aggregate sizes. The average contents under the different treatments were from 10.42-11.77 gkg^{-1}. Under the same tillage conditions, the aggregate-associated C contents under straw return and organic fertilizer were higher than those under single chemical fertilizer. No-tillage coupled with straw return (T_8) had the highest aggregate-associated C in all treatments. The associated C contents of large and small macro-aggregates and micro-aggregates were 25.04%, 28.55%, and 18.12% higher, respectively, than those under conventional tillage (T_1), which had the lowest aggregate-associated C. In contrast to the topsoil, the aggregate-associated C contents in the subsoil showed the trend of conventional tillage >rotary tillage >no-tillage. Without straw return and organic fertilizer, the average contents of aggregate-associated C were 11.60 gkg^{-1}, 10.83 gkg^{-1} and 10.33g kg^{-1}, respectively, under the T_1, T_4, and T_7 treatments. T_1 was significantly greater than T_4 and T_7. Under the same tillage, the application of organic fertilizer and straw return increased the content of aggregate-associated C in the subsoil. The decrease in macro-aggregates in conventional tillage might be due to the destruction of large particles, resulting in the oxidation of previously protected SOC [Yang *et al*., 2015] [14].

Labile soil organic carbon fractions

Huggins *et al*. (2014) [24] revealed that in addition to less C inputs than CC, SS accelerated rates of SOC decomposition. Tillage effects on SOC were greatest in CC where CP had 26% and NT 20% more SOC than MP, whereas SOC in SS was similar across tillage treatments. Up to 33% of the greater SOC under CC for CP and NT, compared with MP, occurred below tillage operating depths. Gu *et al*. (2016) [21] revealed that SOC concentration in all treatments decreased with soil depth. The significant differences of SOC among treatments were solely at depths of 0-40 cm, where soil physicochemical properties changed. Further changes would have occurred following activity by microorganisms. Average SOC content at depths of 0-40cm in ST and GT were 6.26 g kg^{-1} and 6.59 gKg^{-1} respectively, significantly higher than that of 5.44 g kg^{-1} in CK. The use of ST and GT increased SOC by 15.15% and 21.14% respectively. In the course of the growing season, SOC concentrations in all treatments presented substantial changes with seasons. The maximum SOC was recorded in the dry and cold season, and the minimum in the warm and wet season.

Ou *et al*. (2016) [45] reported that the tillage systems obviously affected the distribution of soil aggregates with different sizes. The proportion of the >2 mm aggregate fraction in NT+S was 7.1% higher than that in NT-S in the 0.00-0.05m layer. There was no significant difference in the total amount of all the aggregate fractions between NT+S and NT-S in both the 0.05-0.20 and 0.20-0.30m layers. NT+S and NT-S showed higher proportions of >2mm aggregate and lower proportions of <0.053mm aggregate compared to the MP system for the 0.00-0.20m layer. The proportion of >0.25 mm macro-aggregate was significantly higher in MP+S than in MP-S in most cases, but the proportion of <0.053 mm aggregate was 11.5-20.5% lower in MP+S than in MP-S for all the soil layers.

Gu *et al*. (2016) [21] also found that compared to the control without cover (CK), ST and GT treatments increased the contents of SOC,LOC, DOC, POC and EOC by 14.73%, 16.5%, 22.5%, 41.5% and 21%, respectively, in the 0-40 cm soil layer, and by 17%, 14%, 19%, and 30%, respectively, in the 0-100 cm soil layer. Guo *et al*. (2016) [22] also found that compared with CT treatments, NT treatments did not affect SOC concentration of bulk soil in the 5-20cm soil layer, but significantly increased the SOC concentration of bulk soil in the 0-5cm soil layer. In comparison with NS treatments, S treatments had not significant effects on SOC concentration of bulk soil in the 5-2cm soil layer, but significantly enhanced the SOC concentration of bulk soil in the 0-5cm soil layer. In the 0-5cm soil layer, NT treatments significantly increased SOC concentration by 5.8%, 6.8%, and 7.9% of bulk soil, >0.25mm aggregate, and <0.25mm aggregate, respectively, compared with CT treatments [Table 1]. NT treatments significantly increased MBC of bulk soil, >0.25mm and <0.25mm aggregates by 11.2%, 11.5% and 20.0%, respectively, compared with CT treatments. DOC concentrations of bulk soil, >0.25mm aggregate, and <0.25mm aggregate under NT treatments were 15.5%, 29.5%, and 14.1% higher than those under CT treatments, respectively. In comparison with NS treatments, S treatments significantly increased SOC concentrations of bulk soil by 12.8%, >0.25mm aggregate by 11.3%, and <0.25mm aggregate by 14.1%. In addition, MBC of bulk soil, >0.25mm aggregate, and <0.25mm aggregate under S treatments were 29.8%, 30.2%, and 24.1% higher than those of NS treatments, respectively. S treatments exhibited 25.0%, 37.5%, and 23.2% higher DOC concentrations of bulk soil, >0.25mm aggregate, and <0.25mm aggregate compared with NS treatments, respectively. In the 0-5 cm soil layer, there were significant interactions of tillage and straw returning on SOC concentration of >0.25mm and <0.25mm aggregates, MBC of bulk soil and <0.25mm aggregate, and DOC concentration of >0.25mm aggregate. This increase in SOC concentration can be attributed to a combination of less soil disturbance and more residues returned to the soil surface under conservation tillage (Dikgwatlhe *et al*., 2014) [10]

Table 1: Changes in SOC fractions within aggregates under different tillage and residue treatments [Guo *et al*., 2016] [22]

Organic C	Soil tractions	CTNS	CTS	NTNS	NTS
SOC (0-5cm sod layer)	Bulk soil	19.60+0.55d	21.29±0.12b	20.33±0.46c	21.75±0.18a
(g kg^{-1})	>0.25mm	19.70+0.10e	21.30±0.10b	20.43±0.06c	23.37±0.06a
	>0.25mm	17.28+0.06d	19.48±0.12b	18.41±0.17c	21.24±0.18a
SOC (5-10cm soil layer)	Bulk soil	17.84+0.56a	18.10±0.20a	17.87±0.87a	18.31±0.17a
(g kg l)	>0.25mm	/	/	/	/
	<0.25mm	/	/	/	/
SOC (10-20cm soil layer) (g kg^{-l})	Bulk soil	15.67±0.47a	15.97±0.41a	15.53±0.41a	15.50±0.20a
	>0.25mm	/	/	/	/
	<0.25mm	/	/	/	/
MSC (0-5cm soil layer) (mg kg^{-l})	Bulk soil	1846±15.84d	2366±38.58b	2024±11.40c	2657±28.71a
(mg k0	>0.25mm	1962±3.68d	2538±27.09b	2173±57.73c	2844±22.90a
	<0.25mm	1517±10.5c	1820±14.42b	1758±11.33b	2245±33.66a
DOC (0-5cm soil layer)	Bulk soil	1.09±0.04d	1.33±0.03b	1.22±0.03c	1.56±0.04a
(g kg^{-l})	>0.25mm	1.05±0.05d	1.43±0.03b	1.34±0.01c	1.66±0.01a
	<0.25mm	0.89±0.03d	1.10±0.02b	1.01±0.02c	1.26±0.02a

Different letters in a line denote significant differences among treatments.

CTNS, conventional intensive tillage with straw removal; CTS, conventional intensive tillage with straw returning; NTNS, no-tillage with straw removal; tillage; NTS, no-tillage with straw returning. SOC, soil organic C; MBC, microbial biomass C; DOC, dissolved organic C.

Naresh *et al*. (2017) [42] reported that the T_3 treatment resulted in significantly increased 66.1%, 50.9%, 38.3% and 32% LFOC, PON, LFON and POC, over T_7 treatment and WSC 39.6% in surface soil and 37.4% in subsurface soil. LFOC were also significantly higher following the treatments including organic amendment than following applications solely of chemical fertilizers, except that the F_5, F_6 and F_7 treatments resulted in similar LFOC contents. Application solely of chemical fertilizers had no significant effects on LFOC compared with unfertilized control plots. Nevertheless, application of F_5 or F_6 significantly increased contents of POC relative to F_1 (by 49.6% and 63.4%, respectively). Krishna *et al*. (2018) [28] reported that the total organic carbon (TOC) allocated into different pools in order of very labile >less labile >non-labile >labile, constituting about 41.4, 20.6, 19.3 and 18.7%, respectively. In comparison with control, system receiving farmyard manure (FYM-10 Mg ha^{-1} $season^{-1}$) alone showed greater C build up (40.5%) followed by 100% NPK+FYM (120:60:40 kg N, P, K ha^{-1} +5 Mg FYM $ha^{-1}season^{-1}$) (16.2%). In fact, a net depletion of carbon stock was observed with 50% NPK (-1.2 Mg ha^{-1}) and control (-1.8 Mg ha^{-1}) treatments. Only 28.9% of C applied through FYM was stabilized as SOC. A minimal input of 2.34 Mg C ha^{-1} y^{-1}

is needed to maintain SOC level. The magnitude of carbon pools extracted under a gradient of oxidizing conditions was as follows: $C_{VL}>C^{LL}>C_{NL}>C_L$ constituting about 41.4, 20.6, and 19.3 and 18.7%, respectively, of the TOC. However, the contribution of VL, L and LL pools to SOC was 51.2, 23.1 and 25.5%, respectively. While active pool ($C_{VL}+C_L$) constituted about 60.1%, passive pool ($C_{LL}+C_{NL}$) represented 39.9% of the TOC. Among the treatments, 100% NPK+FYM (44.4%) maintained a proportionately higher amount of soil C in passive pools. With an increase in the dose of fertilization, on average, C allocation into passive pool was increased (33.0, 35.3, 40.7% and 39.3% of TOC under control, 50% NPK, 100% NPK and 150% NPK treatments, respectively).

Kumar *et al*. (2018) [29] also found that the ZTR (zero till with residue retention) (T_1) and RTR (Reduced till with residue retention) (T_3) showed significantly higher BC, WSOC, SOC and OC content of 24.5%, 21.9%,19.37 and 18.34 gkg^{-1}, respectively as compared to the other treatments. Irrespective of residue retention, wheat sown in zero till plots enhanced 22.7%, 15.7%, 36.9% and 28.8% of BC, WSOC, SOC and OC, respectively, in surface soil as compared to conventional tillage. Simultaneously, residue retention in zero tillage caused an increment of 22.3%, 14.0%, 24.1% and 19.4% in BC, WSOC, SOC and OC, respectively over the treatments with no residue management. Similar increasing trends of conservation practices on different forms of carbon under sub-surface (15-30cm) soil were observed however, the magnitude was relatively lower. Kumar *et al*. (2018) [29] revealed that at the 0-15 and 15-30cm, POC, PON, LFOC and LFON content under ZT and RT with residue retention was greater than under without residue and conventional sown plots, respectively. The decrease in the disruption of soil macro-aggregates under ZT plots permitted a greater accumulation of SOC between and within the aggregates. Thus, less soil disturbance is the major cause of higher POC in the ZT and RT plots compared with the CT plots in the 0-15cm and 15-30 cm soil layers. This phenomenon might lead to micro-aggregate formation within macro-aggregates formed around fine intra-aggregate POC and to a long-term stabilization of SOC occluded within these micro-aggregates. The sequestration rate of POC, PON, LFOC and LFON in all the treatments followed the order 200 kg Nha^{-1}(F_4) >160 kg Nha^{-1} (F_3) >120 kg Nha^{-1}(F_2) >800 kg Nha^{-1} (F_1) >control (unfertilized) (F_0).

Water balance

Tuong *et al*. (1996) [56] reported that bypass flow accounted for 41-57% (equivalent to about 100 mm of water) of the total water applied in the field during land soaking. Water loss throughout the period of land preparation may be much greater than this, because cracks may not close after rewetting and bypass flow may continue until soil is repuddled. This might explain the very high percolation losses during land preparation, accounting for up to 40% of the total water supplied for growing a rice crop. Reducing these losses will contribute greatly to improving water-use efficiency of rice. Straw mulching helped conserve moisture in the soil profile reduced crack development during the fallow period but did not reduce the bypass loss during land preparation. Shallow tillage formed small soil aggregates, which blocked and impeded water flow in the cracks and reduced the amount of water that recharged the groundwater via the bottom of the cracks and crack faces. Water was, therefore, retained better in the topsoil. Shallow surface tillage could reduce about 31-34% of the water input for land preparation, equivalent to a saving of 108-117 mm of water depth and shortened time required for land preparation. Water savings during land preparation may increase the service area of an irrigation system.

Singh *et al*. (2001) [50] evaluated the yield and water use of rice established by transplanting, wet and dry seeding with subsequent aerobic soil conditions on flatland and on raised beds. Transplanted rice yielded 5.5 tha^{-1} and used 360 mm of water for wetland preparation and 1608 mm during crop growth. Compared with transplanted rice, dry-seeded rice on flatland and on raised beds reduced total water input during crop growth by 35-42% when the soil was kept near saturation and by 47% and 51% when the soil dried out to 20 and 40 kPa moisture tension in the root zone, respectively. Tabbal *et al.* (2002) [53] reported that direct-seeded rice required 19 per cent less water than puddled transplanted rice during the crop growth period and increased water use efficiency by 25-48 per cent with continuous standing water conditions. Cabangon *et al.* (2002) compared the water input and water productivity of transplanted and direct-seeded (dry and wet seeded) rice production system and reported that dry-seeded rice had significantly less irrigation water and higher water use efficiency as compared to wet seeded and transplanted rice production system.

Humphreys *et al*. (2008) [23] reported that as the irrigation amounts on the beds were usually less than on the flats (because of the volume limitation of the furrows), use of the same irrigation scheduling rule for beds and flats meant that the beds were usually irrigated slightly more frequently. the total water input (post-sowing irrigation + rain) to wheat on both beds and flats on sandy loam was 353 mm and 383mm and on the loam total input was 407 mm and 428 mm on the beds and flats (fig. 1a and 1b).


(a)


(b)

Fig 1(a): First post-sowing irrigation of conventionally tilled wheat (CTW) in small plots
Fig 1(b): First post-sowing irrigation of wheat on fresh beds (WB) in small plots

(a)

(b)

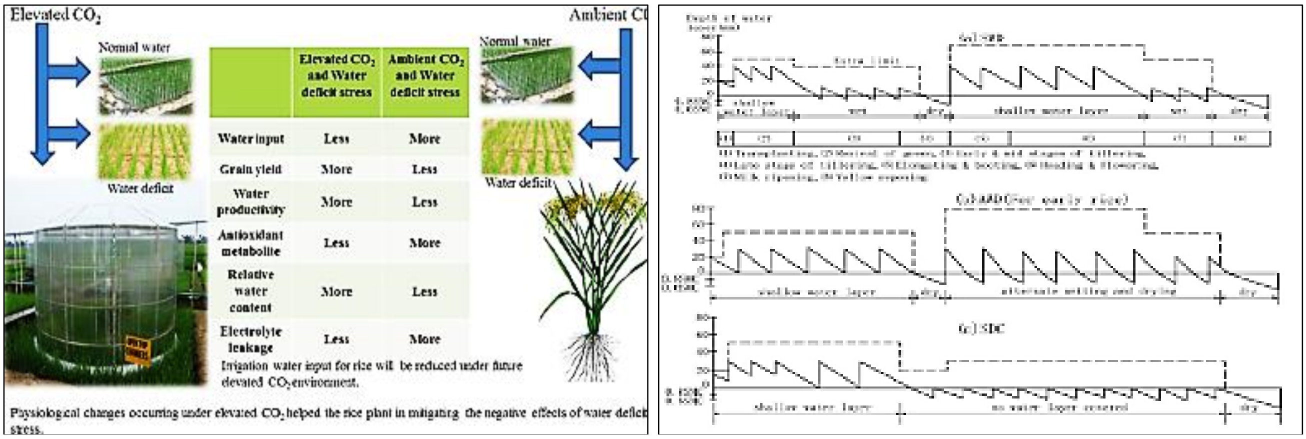
Fig 2(a): Puddled transplanted rice with continuous flooding (PTR-CF)
Fig 2(b): Transplanting of rice on permanent beds (TRB)

Shahid (2011) studied to estimate the change of irrigation water demand in dry-season Boro rice field in northwest Bangladesh in the context of global climate change. The study showed that there will be no appreciable changes in total irrigation water requirement due to climate change. However, there will be an increase in daily use of water for irrigation. As groundwater is the main source of irrigation in northwest Bangladesh, higher daily pumping rate in dry season may aggravate the situation of groundwater scarcity in the region. Naresh *et al*. (2014) [41] also found that numerically, the highest WUE of 15.47 $kgha^{-1}mm^{-1}$ under BPW treatment and the lowest of 13.38 $kgha^{-1}mm^{-1}$ under CT. Conversely, the amount of water used (m^3) to produce 1 kg of wheat grain varied between 2.03m3kg^{-1} in ZT and 2.51 m^3kg^{-1} in CT treatments. During 2010 to 2011, the highest WUE (18.25 $kgha^{-1}mm^{-1}$) was obtained with BPW and the lowest (16.87 $kgha^{-1}mm^{-1}$) with the CT and ZT treatment. Drill seeding of rice and wheat on reduced-till flat land (RT-DSR/RT-DSW) or on raised beds (Bed-DSR/Bed-DSW) saved irrigation or total water use by 62 to 532 mm ha^{-1}, but was less productive than conventional practices; yield loss was high in narrow raised bed planted crops (Naresh *et al.*, 2013) [39]. Although total productivity was less in zero-till drill seeded rice and wheat (ZT DSR/ZTDSW: by 1.08 to 1.3 t ha^{-1}), water savings were high because of lower irrigation water need.

Kadiyala *et al.* (2012) [26] reported that the total amount of water applied (including rainfall) in the aerobic plots was 967 and 645mm compared to 1546 and 1181 mm in flooded rice system, during 2009 and 2010, respectively. This resulted in 37 to 45% water savings with the aerobic method. Jinsy *et al.* (2015) found that compared to conventional flooded rice, the average water productivity of aerobic rice (0.68 kg m^{-3}) was 60.7 per cent higher. Reddy *et al.* (2010) reported that water productivity was higher under aerobic (0.20 to 0.60 kg m^{-3} of water) than that under transplanted (0.14 to 0.43 kg m^{-3} of water) condition. Aerobic rice could be successfully cultivated with 600-700mm of total water in summer and entirely on rainfall in wet season (Sritharan *et al.*, 2010) [52]. The reduction in irrigation water use varied with type of DSR method, ranging from 139mm (12%) in wet seeding on puddled soil (CT-wet-seeding) to 304-385mm (21-25%) in dry seeding after tillage (CT-dry-seeding) or zero tillage (ZT-dry-seeding), and 474mm (33%) in dry seeding on raised beds (Bed-dry-DSR). In CT-TPR, the field is generally kept continuously flooded. Whereas in Wet-DSR, during the first 10 days, very little or no irrigation is applied and then irrigation is either applied at 2-to 3-day intervals or relatively shallow flooding is maintained during the early part of vegetative growth to avoid submergence of young seedlings, thereby reducing seepage, percolation, and evaporation losses. Moreover, the Wet-DSR crop is harvested about 10-15 days earlier than CT-TPR; therefore, total duration from seed to seed is reduced in this method. In Wet-DSR, the main field is soaked, and the land is prepared 2-3 days prior to sowing. In Dry-DSR, lower water use than that in CT-TPR may be attributed to savings in water used for puddling in CT-TPR and the AWD irrigation method instead of continuous flooding in CT-TPR.

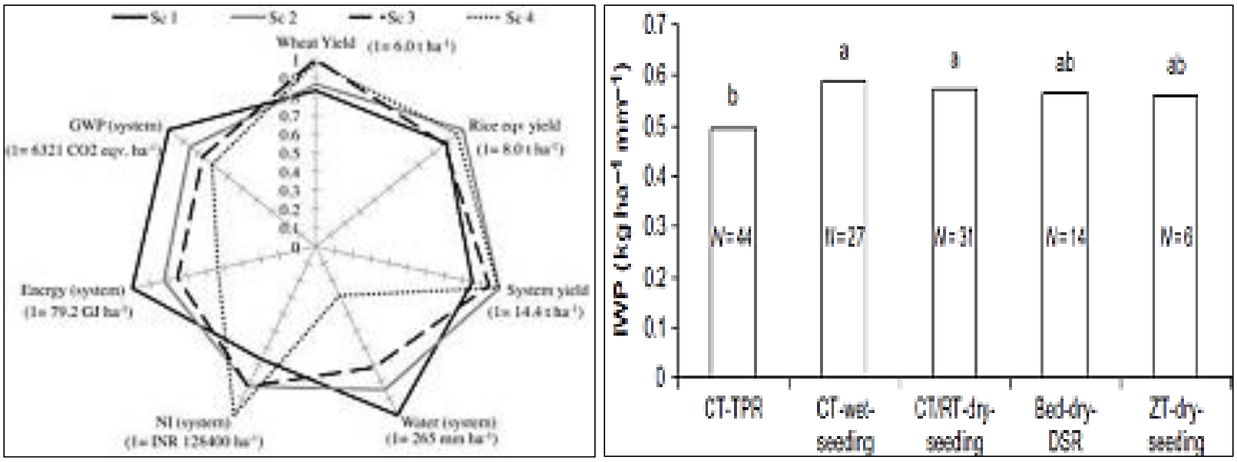
Sandhu *et al*. 2012; Gathala *et al*. (2013) [20] reported that Irrigation water productivity (IWP) was significantly higher in beds to the tune of 13.9% and 13.16% than flat puddled planting. He also revealed that the rice transplanted on beds required 15.4% and 15.3% less irrigation water than that required in puddled plots. The reduction in amount of irrigation water applied in beds may be attributed to the less depth of irrigation water application to beds (5cm) as compared to puddled plots (7.5cm). Naresh *et al*. (2014) [41] revealed that different crop establishment techniques, conventional-tilled puddle transplanted rice (CT-TPR) required 14%-25% more water than other techniques. Compared with the CT-TPR system, zero till direct-seeded rice (ZT-DSR) consumed 6%-10% less water with almost equal system productivity and demonstrated higher water productivity. Similarly, wide raised beds saved about 15%-24% water and grain yield decrease of about 8%. Water productivity of continuous submergence (0.56kg m^{-3}) was lowest as compared to AWD - Flooding to a water depth of 5 cm when water level drops to 10 cm below ground level (0.94 kg m^{-3}) (Kishor *et al.*, 2017) [27].

Shantappa *et al*. (2014) conducted a field experiment at Hyderabad based on the different water levels and noticed that continuous submergence showed significantly higher quantity of water applied (1433mm) than alternate wetting and drying (1151mm) and saturation (960mm). Recommended submergence of 2-5 cm water level as per crop stage consumed more water (1819.7mm) in field experiment on sandy loam soil at Hyderabad than irrigation of 5cm, when water level falls below 5 cm from soil surface in field water tube (1271.7mm), irrigation of 5 cm at 3 days after disappearance of ponded water (1154.7mm) and irrigation of 5 cm, when water level falls below 10cm from soil surface in field water tube treatments were recorded least water consumption (1085mm) among different irrigation regimes (Sathish *et al*., 2017) [47]. The irrigation water applied effective rainfall and seasonal volume of water input varied from 708 to 1390mm, 216 to 300mm and 1048 to 1646mm, respectively on pooled basis. Whereas, the effective rainfall was varied between 238 to 300mm suggesting that the crop in AWD irrigation regimes used large proportion of total rainfall received relative to continuous submergence treatment. Whereas, the total water input amounted to 1056 to 1626mm, 1013 to 1667mm and 1048 to 1646mm in 2013, 2014 and on pooled basis, respectively (Kishore *et al*., 2017). Bouman and Tuong (2007) [7] reported that total (irrigation+ rainfall) water inputs decreased by around 15-30 per cent without a significant impact on yield (Fig. 3-5).



(a) **(b)**

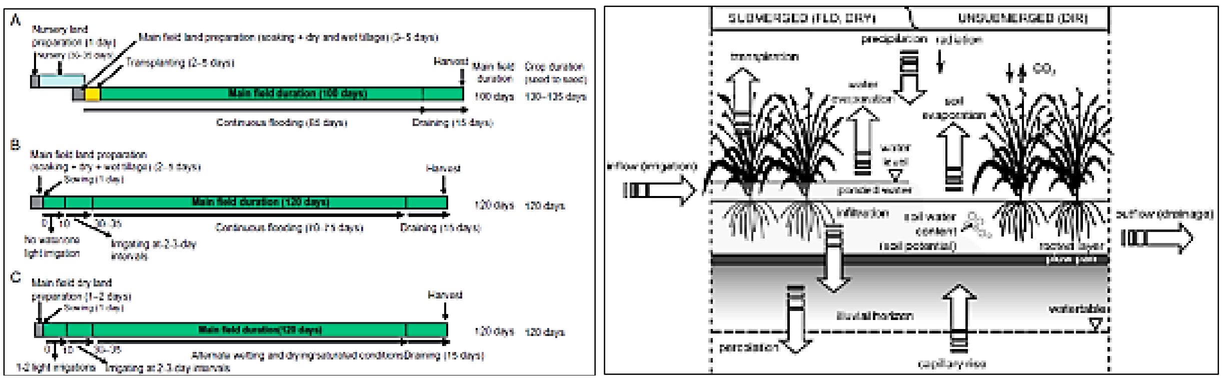
Fig 3: Description of different water efficient regimes (Mao Zhi, 2000)



(a) **(b)**

Fig 4(a): Multiple indicators of long-term performance of different scenarios. Performance metrics included wheat yield, rice equivalent yield in kharif season and system-level yield, irrigation water, net income, energy use, and global warming potential of cropping system

Fig 4(b): Irrigation water productivity (IWP) of major tillage and crop establishment methods in rice



(a) **(b)**

Fig 5(a): Various cultural activities, including irrigation schedules of puddled transplanting (A), direct wet seeding (B), and direct dry seeding (C) modified from Tabbal *et al*., (2002) [53]

Fig 5(b): Water fluxes and storages in flooded (on the left) and aerobic (on the right) rice fields)

Linquist *et al*. (2015) [32] reported about 15% of applied water being lost to percolation and seepage. Furthermore, in cases where AWD is practiced during the wet season a 25.7% reduction in total water use might translate into an even greater reduction in irrigation water use. For example, during a period where the soils are not flooded, a rain event during that time is less likely to result in surface runoff and can delay the time required until irrigation may be needed to re-flood the field (Massey *et al*., 2014) [34]. Nalley *et al*. (2015) [37] revealed that an accounting for the water savings (-27.5% relative to CF) being greater than the reduction in yield (-5.4% relative to CF), water productivity was 24.2% higher in AWD than in CF. Considering only Mild AWD, water productivity was 25.9% higher than CF. With water resources becoming increasingly limited this is an important benefit of AWD. However, depending on the cost of water and rice, higher water productivity does not necessarily indicate that a practice is more economical for a farmer. The economic viability of different AWD treatments and found the lowest profit in the treatment with highest water productivity. Thus, other factors besides water productivity need to be considered. Reduced water use in AWD systems can be attributed, at least in part, to reduced percolation and seepage. Percolation and seepage are significantly reduced in the absence of flood water; however, such losses are highly dependent on the hydrological properties of a given soil. Zhao *et al*. (2015) [61] observed that the total water use of continuously flooded rice in some plots varied up to more than two fold as much between seasons and, in general terms, they attributed this difference to different meteorological occurrences and soil behaviour. Belder *et al*. (2007) [3] reported more than a two-fold variation in water requirements of alternately submerged-non-submerged rice when a deep drain was excavated in order to increase internal drainage and lower the groundwater table. Values of water use efficiencies (evapo transpiration over net water input) and water productivity (grain yield over net water input) were therefore in the order WFL <DFL<DIR. The latter reached a water use efficiency of 0.56 mm mm^{-1} and a water productivity of 0.88 m3 ha^{-1}. Zhang *et al*. (2009) [62] reported an increase in rice yield by 11% (when compared to the CF) when AWD was applied each time the soil matric potential reached 15 kPa at 15-20 cm and yield reduction by 32% under AWD applied each time soil matric potential reached 30 kPa at 15-20cm.

Yin *et al*. (2015) reported that conventional tillage without straw mulching, straw mulching with reduced tillage increased the wheat strip water content in the 0 to 30cm depth by an average of 2.2, 2.0 and 2.4%, and it increased maize strip water content by 8.4, 3.0,and 5.0%, respectively during experimentation. Among the mulching approaches, reduced tillage and straw covering on the soil surface achieved the highest soil water content. From 80 to110 cm soil depth, straw mulching with reduced tillage increased soil water content by an average of 4.2, 6.7 and 9.0% in wheat strips the straw mulching also increased the water content in the maize strips by 5.0 and 3.9%. These results indicate that soil water difference is mainly reflected in the topsoil layer, with straw covering on the soil surface having an overwhelmingly positive effect on water status in the soil profile [Fig.1a]. Averaged over the wheat and maize relay-planting combined with straw standing or covering reduced soil evaporation by 7.5and 8.9% compared to the control. Straw mulching has been proven to be one of the most effective water conservation practices in maintaining soil moisture, reducing water evaporation, and decreasing water consumption (Blaise *et al*., 2005) [1]. An integration of improved farming practices can significantly increase water use efficiency in crop production (Gan *et al*., 2014) [18].

Lamn *et al*. (2015) reported that the full irrigation scenario, based on a fixed irrigation frequency maintained the soil moisture in the root zone at field capacity on a daily basis, since the literature claims this is the optimal status to maximise yield. The irrigation schedule was generated with a fixed time interval and refill to field capacity. Deficit irrigation scenarios with varied field capacity threshold reduce the irrigation dose below the dose at field capacity but keeping the same irrigation frequency, as in full irrigation scenario. Daily generated irrigation doses obtained in full irrigation scenario were reduced by 70, 60, 50, and 40%.

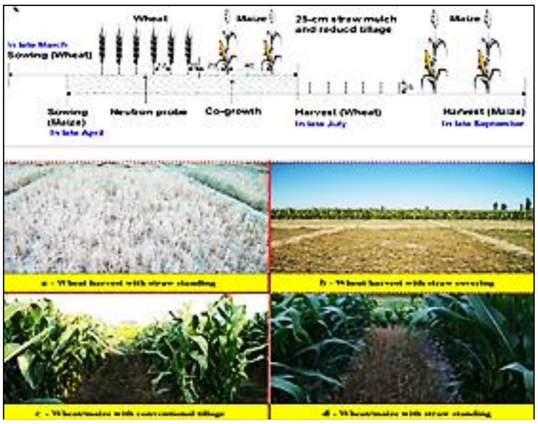
Mekonnen and Hoekstra (2011) [35] revealed that the average water footprint for cereal crops is 1644 m^3 ton^{-1}, but the footprint for wheat is relatively large (1827 m^3 ton^{-1}), while for maize it is relatively small (1222 m^3 ton^{-1}).The average water footprint of rice is close to the average for all cereals together. Sugar obtained from sugar beet has a smaller water footprint than sugar from sugar cane. Besides, the blue component in the total water footprint of beet sugar (20%) is smaller than for cane sugar (27%) and for vegetable oils we find a large variation in water footprints: maize oil 2600 m^3 ton^{-1};cotton-seed oil 3800 m3 ton^{-1}; soybean oil 4200 m^3 ton^{-1}; rapeseed oil 4300 m^3 ton^{-1}; palm oil 5000 m^3 ton^{-1}; sunflower oil 6800 m^3 ton^{-1}; ground-nut oil 7500 m^3 ton^{-1}; linseed oil 9400m^3 ton^{-1}; olive oil 14500 m^3 ton^{-1}; castor oil 24700 m^3 ton^{-1}. Mohd. Suhail (2017) observed that total average WFP consumption of Indian states are much higher for Sorghum (6026), Soybeans (4410), Maize (2537),Barley (2124), Wheat (2100) and Rice (2070) than the global total WFP average of 3048, 2145,1222,1423,1827 and 1673 cubic meter ton^{-1}, respectively. However, spatial variability also estimated among Indian states, Utter Pradesh (28306 m^3ton^{-1}) is the highest total WFP consumer followed by Himachal Pradesh (27889 m3ton^{-1}), Uttarakhand (27809 m^3ton^{-1}), Tamil Nadu (27739 m^3ton^{-1}) Bihar (26960 m^3ton^{-1}), Gujarat (26692 m^3ton^{-1}), Maharashtra (26460 m^3ton^{-1}), Haryana (26337) and Rajasthan (25860 m^3ton^{-1}).

Naresh *et al*. (2017) [43] reported that the water footprint of rice consumption in a nation is calculated by aggregating the water footprints in the regions where the rice consumed in a nation is grown by using a higher spatial resolution. In India water foot print of per unit and total rice production and percolation was 1403 (m^3 ton^{-1}) and 432.9 (billion m^3 yr^{-1}). The per-capita water footprint of rice consumption is quite high in Thailand (547 m^3 $cap^{-1}yr^{-1}$) compared to India (239 m^3 $cap^{-1}yr^{-1}$), with their water footprints related to rice consumption 63,364 and 250, 305 (Mm^3 yr^{-1}), respectively. One cup of coffee needs 140liters of water; 1liter of milk needs 1000liters of water; 1kg of wheat needs 1350liters of water; 1kg of rice needs 3000liters of water and 1 kg maize needs 900liters of water. Ding *et al*. (2018) [11] reported that the grain yield-based WF ranged between 1.08 and 1.80, 0.90 and 1.38, 1.71 and 2.58, 1.94 and 4.28, 1.47 and 2.37, and 1.39 and 1.79m^3 kg^{-1}; whereas the protein yield-based WF ranged between 7.69 and 10.44, 8.27 and 16.47, 3.79 and 7.75, 4.86 and 11.17, 5.09 and 7.42, and 5.51 and10.69m^3 kg^{-1} for spring wheat, barley, canola, sunflower, lentils, and chickpea, respectively. All the WFs of crops generally decreased with time, which could be attributed to precipitation factors.

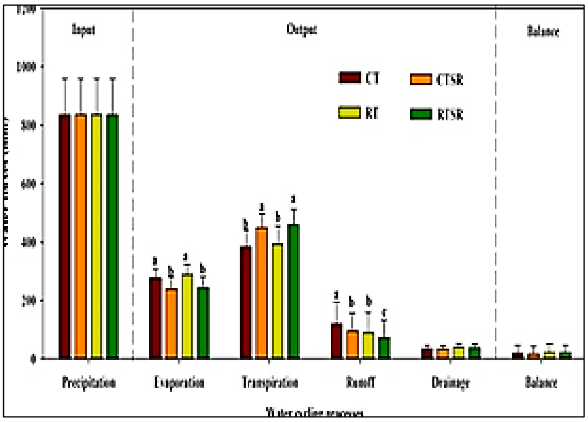
Singh *et al*. (2018) [49] reported that ZT and FIRB practices reduced the system irrigation water requirement by 79-82mm ha^{-1} and 166-168 mm ha^{-1} respectively. Water use efficiency (WUE) (144.6 and 155.4kg ha-cm^{-1}) and water productivity (WP) (4.3 and 4.5 kg m^{-3}) perceived highest under FIRB by using lower total consumptive use of water (35.71 and 35.45 cm) during the respective crop seasons. Thus the consumptive use (CU) was around 6-12%, lower under FIRBS as compared to other crop establishment techniques. Application of irrigation at CRI +IW:CPE =0.75 resulted in highest WUE

(129.0 and 140.0 kg ha-cm^{-1}) and WP (4.2 and 4.4 kg m^{-3}) with minimum water used (37.41 and 36.22 cm) during 2014-15 and 2015-16, respectively in contrast to other two moisture regimes.

Wang *et al*. (2019) [58] also found that the soils under different treatments received the same amount of water input (precipitation 835mm yr^{-1}). No significant tillage effects could be detected on the key soil water processes including evaporation, transpiration, and drainage. Compared with straw removal treatments (CT and RT), straw returning significantly reduced soil water evaporation and surface runoff, but such effects were somehow offset by enhanced transpiration [Fig. 6b]. Straw returning improves the microclimate and strongly reduces water exchange from the soil to the air by promoting plant transpiration at the expense of evaporation from the soil (Dong *et al*., 2018) [12]; this dynamic may have fostered the observed biomass accumulation.



(a)



(b)

Fig 6(a): Field layout of wheat and maize relay-planting

Fig. 6(b): Predicted annual water balance (mm) (0-10 cm soil depth) of the soil-plant system under the CT, CTSR, RT and RTSR treatments

Conclusion

The dynamic processes that influence soil quality are complex, and they operate through time at different locations and situations. Soil organic matter is both a source of carbon release and a sink for carbon sequestration. Cultivation and tillage can reduce and change the distribution of SOC while an appropriate crop rotation can increase or maintain the quantity and quality of soil organic matter, and improve soil chemical and physical properties. No-tillage and straw return in rice-wheat cropping rotation systems is an effective management practice for the formation and stability of soil aggregates. This practice has shown potential to increase the number of water-stable macro-aggregates and micro-aggregates in both the topsoil and subsoil compared to that under conventional tillage. The straw return and application of organic fertilizer increased the cumulative carbon input and increased the aggregate-associated C content. Moreover, straw return is a better option for improving CPC than application of organic fertilizer in maize-wheat cropping rotations.

In irrigated systems, particular attention is to be given to improving quality water services at field level, which includes much improved water supplies in terms of flexibility and reliability, as well as access to sufficient drainage when required. Otherwise, none of the field level options would be effective. Water savings ranged from 12% to 35% depending on type of DSR. Water savings in different types of DSR ranked in the following order: CT wet-seeding <CT-dry-seeding =ZT-dry-DSR <Bed-dry-DSR. Reduces irrigation water loss through percolation due to fewer soil cracks. DSR sowing is more cost effective technology as compared to transplanting. Moreover, water productivity is high in DSR and exceeds corresponding values in transplanting by >25%. The water productivity and water use efficiency of wheat affects significantly with the land configuration and irrigation schedule. The land configuration and irrigation schedule performed consistently better results in $_{B90-4}$ and IW/CPE 0.8 obtained higher water productivity and water use efficiency. With the flexibility and reliability, such an integrated water management approach should be the appropriate answer to rice-wheat cropping system water management that would provide a change to really improve irrigation efficiency and water productivity now and the future.

Conventional tillage in comparison with NT significantly reduced macro-aggregates with a significant redistribution of aggregates-into micro-aggregates. Aggregate protected labile C and N were significantly greater for macro-aggregates, (>2000 and 250-2000µm) than-micro-aggregates (53-250 and 20-53µm) and greater for M than F indicating physical protection of labile C within macro-aggregates. No -tillage and M alone each significantly increased soil aggregation and aggregate-associated C and N; however, NT and M together further improved soil aggregation and aggregate-protected C and N. The distribution pattern of soil microbial biomass associated with aggregates was likely governed by the size of aggregates, whereas the tillage effect was not significant at the aggregate-size scale. Such intelligent approach merits the full attention of all stakeholders and is worthwhile to point out for development.

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