12. Conservation agriculture in intensive rice-based cropping systems in the Eastern Gangetic Plain

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1. Related practices

Conservation agriculture, rice straw residue retention, strip tillage

2. Description of the case study

In this case study the results of long-term research on carbon (C) sequestration potential and life cycle analysis to estimate greenhouse gas emissions under conventional tillage (CT) and strip planting (SP) in combination with low residue (straw) retention and increased residue retention in rice-based cropping systems of the Eastern Gangetic Plain are presented.

In the Eastern Gangetic Plains (EGP), farmers are beginning to follow Conservation Agriculture (CA) practices to grow dry season crops but for rice they follow the traditional soil puddling for rice establishment. Accordingly, the benefits accrued by following zero tillage or strip planting are lost by the puddling of wet soil. The non-puddled transplanting of rice, a novel practice of rice crop establishment, involves minimal soil disturbance so that CA can be practiced in rice-based cropping systems. For rice, first the soil is strip-tilled, for example with a two-wheeled tractor operated Versatile Multi-crop Planter (VMP) (Haque *et al.*, 2016), then the land is soaked overnight, and finally rice seedlings were transplanted within the strip.

Verification of the benefits of the CA system in the EGP (two locations of northwestern Bangladesh) involved long term studies on carbon (C) sequestration potential and life cycle analysis to estimate greenhouse gas (LCA GHG) emissions under conventional tillage (CT) and strip planting (SP) in combination with low residue (straw) retention (LR, business-as-usual/current practice) and increased residue retention (HR) in Calcareous Brown

Floodplain soil (Alipur, Durgapur, Rajshahi) and Grey Terrace soil (Digram, Godagari, Rajshahi). The cropping systems studied were mustard-irrigated rice-monsoon at Alipur and wheat-jute-monsoon rice at Digram site. The novel establishment practices increased total organic carbon (TOC) in 0-30 cm of soil by 26 percent (19.4 t/ha to 24.5 t/ha). That is, after 5 years, practicing SP for upland/dry season crops and non-puddling for rice accumulated an additional 5.1 t TOC/ha. The rice transplanted after non-puddling of soil with residues retained at a minimal rate decreased CO_2eq emissions by 31 percent for the actual LCA GHGs emissions and by 20 percent for the total LCA GHGs emissions in comparison with conventional puddled transplanting. By contrast, non-puddling with increased residue retention reduced the actual LCA GHG emissions by 16 percent in comparison with the current conventional practices. The accurate estimation of improvement in actual LCA GHG emissions depended on the long-term assessment of increases in soil TOC.

3. Context of the case study

The EGP covers about 34.6 million ha of mostly low-lying alluvial plains in Eastern India, Nepal, and Bangladesh. Most of the agricultural land grows a monsoon season crop of wetland, rainfed rice. This is followed in the dry season by mostly irrigated fields crops such as wheat, maize, mustard and irrigated rice (Boro). Then in the early wet season, another crop such as jute may be grown with irrigation to supplement rainfall. Presently in the EGP, the cropping intensity is around 200 percent. However, the intensification occurs at the cost of soil health. The present case study is conducted in the Subtropical climate of the EGP. The climate is favorable for quick decomposition of soil organic matter (SOM) which is a major impediment for SOM enrichment (Ross, 1993). On the top of that, farmers employ excess tillage for dry season/upland crop establishment and puddle the soil for rice crop establishment that accelerates SOM degradation (Alam *et al.*, 2018; Alam, Biswas and Bell, 2016). Over time, the breakdown of soil structure caused by puddling of soils creates a plough layer that hardens when dry at 10-20 cm soil depth leading to shallow rooting depth, waterlogging risk and soil crack development in the dry season. Preparation of the rice-puddled lands for upland/dry season crops requires applying extra tillage, excess labor and fuel that incur farm income losses (Sharma, Datta and Redulla, 1988; Sharma, Tripathi and Singh, 2005). Soil degradation and yield stagnation have been reported in many studies conducted in the Indo-Gangetic Plains (Alam *et al.*, 2017; Kukal and Aggarwal, 2003). The puddled soil for rice in a rice-based system has downsides in terms of methane (CH_4) emissions, while upland crops under intensive tillage emits increased N_2O and CO_2 (Pathak *et al.*, 2011). However, Xu *et al.* (2013) saw the potential for carbon sequestration in paddy soils with improved management, while Lal (2004), Wang, Li and Alva (2010), Alam, Biswas and Bell, (2016) and Das *et al.* (2013) proposed that sequestration of SOC as an effective option for restoration of degraded soil structure, enhancement of soil fertility and emission mitigation from rice soils. The case study relates to the Sub-Tropical/Tropical moist zone (according to the IPCC climate zones on the active Ganges floodplain and Meghna estuarine floodplain) on the following soils: Calcareous Brown Floodplain (Aeric Eutrochrept) and Grey Terrace soils (Aeric Albaquepts) (USDA-SCS, 1975).

4. Possibility of scaling up

The adoption of CA is being replicated in different parts of the EGP including in Bangladesh. Based on the larger number of on-farm trials over a three-year period in four districts of Bangladesh, Haque and Bell (2019) reported that strip-based non-puddled transplanting of rice provided similar or greater yield, reduced cultivation cost and increased gross margin by 69 percent for Boro rice and 67 percent for Aman rice. In the early demonstrated areas, some farmers have adopted non-puddling rice followed by strip planting of dry season crops while retaining moderate level of crop residue. Due to farmers' mindset and preference for soil puddling followed by transplanting of rice seedling, adoption of CA in rice-based systems is slow. The concept of non-puddled rice followed by strip planted dry season crops is relatively new and most farmers, researchers, extension workers and policy planners are not aware on the technology. On the other hand, research and refinement of this technology is still limited while only limited out-scaling actions were undertaken. Intensive research on CA for smallholder farmers in the EGP that reported by Bell *et al.* (2019). Based on that evidence, it can be confidently asserted that the scaling out of CA (non-puddled rice followed by strip planted dry season crop with moderate amount residue retention) in most of the rice-based areas in EGP is possible with the engagement of private sector and farmers. Policy level action for extension, mass propagation, education and advanced research are essential for out scaling of this technology.

5. Impact on soil organic carbon stocks

Strip planting for dry season crops and strip-tilled non-puddled rice transplanting in combination with increased residue retention sequestered more C in soils under rice-intensive cropping systems than the current farmers' practices (intensive dry tillage for upland dry season crops and wet tillage or puddling for rice in combination with residue removal). The accumulated C storage was 10.8 t/ha at Alipur which was 4.26 t/ha higher than business as usual (current practice) in the 0–10 cm soil layer. Similarly, after 13 crops at Digram, the storage was 10.2 t/ha in 0-10 cm depth which was 3.79 t/ha higher than the current farmers' practice. The increased SOC accumulation rate corresponds to 1.2 and 1.1 tC/ha per year at Alipur and Digram, respectively, more than the current practice. In addition to C stock increase in the 0-10 cm soil depth, the C stock increase under the CA-based novel crop establishment practice in the 10-30 cm soil depth was around 0.7 t/ha (i.e. ~0.2 t/ha/yr) more than the current practice after 14 crops at both the sites (Table 49). The adoption of the non-puddled transplanting of rice in the entire EGP could increase the C storage by 131-145 million tons CO_2eq of C in the soils of the rice-based cropping systems.

Table 49. Evolution of SOC stocks after the 5-year experiments

Location	Climate zone	Soil type	Baseline C stock (tC/ha)	Additional C storage (tC/ha)	Duration (Years)	Depth (cm)	Reference
Alipur, Bangladesh	Sub-Tropical/ Tropical Moist[ǂ]	Calcareous Brown Floodplain (Calcareous Alluvium)	6.5	5.1	5	0-30	Alam *et al.* (2018, 2020a)
Digram, Bangladesh		Grey Terrace Soils (High Barind Tract)	6.4	4.6			

[ǂ]IPCC climate zones

6. Other benefits of the practice

6.1. Benefits for soil properties

Besides SOC accumulation, the novel practices had other benefits in terms of soil physical, chemical and microbial properties. Soil bulk density (BD) at both the sites was reduced significantly relative to current farmers' practice. The lowest BD at both Digram and Alipur was recorded in the strip planted rice soil which was 0.12 g/cm^3 lower than the current farmer's practice. In case of soil porosity, residue retention combined with the CA practice increased porosity values by 4.3-4.6 percent relative to the current practices.

The pHs of soils were slightly higher at both the sites (Alipur and Digram) than the current practice. The pHs of the soils was around 6.4 under current farmer's practice which after 14 crops at Alipur was increased to 6.8 and at Digram increased to 6.7 under the novel CA practice.

After 13-14 crops, minimal soil disturbance combined with residue retention recorded the highest increase in total nitrogen (N) in soils of both the case-study sites. The CA soils recorded 0.33 g N/kg at Alipur and 0.27 gN/kg at Digram more total N than the conventionally managed soil after growing 13-14 crops.

Similarly, response of microbial activities (microbial biomass carbon- MBC) were positive to strip tilled non-puddled rice practice. At Alipur and Digram, the non-puddled rice soils recorded higher amounts of MBC than the business as usual (farmers') practice. The non-puddled practice had 43-49 mg/kg higher MBC than the current farmers' practice.

Previous research on the same sites recorded increased water holding capacity and plant available water content in soils but reduced soil penetration resistance under the CA practice (Islam, 2016).

6.2 Minimization of threats to soil functions

Table 50. Soil threats

Soil threats	
Nutrient imbalance and cycles	The strip tilled non-puddled transplanting of rice and strip planting of dry season crops sequesters C and N in soils by slowing their in-season turnover, decreasing gaseous emissions and by improving the synchrony between crop N demand and N availability in soils (Alam *et al.*, 2018, 2020a).
Soil acidification	The current practice in the case-study areas intensifies acidification of soils in the EGP (Bangladesh) (BARC, 2018). After 5 years, the non-puddled rice practice followed by strip planting with increased residue retention showed increase in pH by 0.4, relative to current farmer's practice (Alam *et al.*, 2018, 2020a), indicating that, over time, the practice has potential to reverse the acidification process.
Soil biodiversity loss	The modified crop establishment practices in line with CA principles increased MBC which might be due to diversified microbes in soil (Alam *et al.*, 2020b). Similarly, Rathore *et al.* (2017) related the increased microbial activity with the diversified microbiome and increased abundance in soil under the minimal soil disturbance with increased residue retention.
Soil compaction	The strip tilled non-puddled transplanting of rice and strip planting of dry season crops reduces soil compaction in the surface soil. Studies at Alipur and Digram, Rajshahi, Bangladesh (Islam, 2016) and at Baliakandi, Rajbari, Bangladesh (Salahin, 2017) showed reduced soil compaction due to practicing CA.

6.3 Increases in production (e.g. food/fuel/feed/timber)

The higher grain yields and higher net return for crops in rice-based cropping systems were recorded in strip planting and strip tilled non-puddled rice transplanting practice (in combination with residue retention) compared to the practices farmers currently use (Bell *et al.*, 2019; Islam, 2016; Salahin, 2017) In the first two years, there was no significant variation in rain-fed rice yield using non-puddled transplanting relative practices farmers currently use. Thereafter, significantly higher grain yield of rain-fed rice in non-puddled transplanting was recorded following strip planting with minimal soil disturbance.

6.4 Mitigation of and adaptation to climate change

Strip planting for dry season crops and non-puddled transplanting of rice in combination with increased residue retention after five years decreased greenhouse gas emissions. The on-farm emissions results indicated that the CA practice reduced crop production emissions by around 22 percent relative to current farmers' practice. The strip tilled non-puddled rice transplanting in combination with increased residue retention saved 9.1 and 74.8 kg CH_4/ha/season emission relative to current farmers' practice. Similarly, Alam, Bell and Biswas (2019a), Alam, Biswas and Bell (2016) and Pathak *et al.* (2013) stated that CA can reduce net GHG emission through increased SOC sequestration.

The CA-based crop establishment practice is one of the climate-smart agricultural practices (Rahaman, Rahman and Hossain, 2018). Based on the year 2013-2014, Bell *et al.* (2019) showed that with 2.5 percent adoption of CA and mechanized planting in Bangladesh (which is the current CA adoption level in Asia), the estimated potential gain stands to about USD 20 million year^{-1}. Moreover, it was reported in 2017 that the non-puddling (NP) of rice with and without mechanization was gaining momentum in the EGP area which would help them adapt well with the changing climate.

6.5 Socio-economic benefits

Haque and Bell (2019) showed up to 59 percent greater profit from non-puddled rice on farmers' fields in the EGP. From 50 to 94 percent farmers adopting NP of rice in both the irrigated (Boro) and monsoon (T. aman) seasons reported greater net returns even when there were economic losses due to low rice grain prices. Islam, Hossain and Saleque (2014) recorded the lowest benefit cost ratio (1.42) in the puddled transplanting which they attributed to lower yield at the cost of increased inputs (fuel and machinery pass) and labor requirement for land preparation and seedling transplanting. Salahin (2017) also employed non-puddled transplanting of rice and strip planting for dry season crops and recorded 1.29 benefit: cost ratio for zero tillage under non-puddled condition, 1.51 benefit:cost ratio for strip planting under non-puddled condition and 1.31 for conventional puddling. With these economic profits, farmers adopting the practice will have better socio-economic conditions than farmers with their traditional practices.

7. Potential drawbacks to the practice

7.1 Tradeoffs with other threats to soil functions

Table 51. Soil threats

Soil threats	
Soil erosion	In the EGP, soil erosion is not a significant threat.
Nutrient imbalance and cycles	Nutrient stratification concentrates P and K and SOM closer to the soil surface in CA. Less straw for animal feed and as household fuel when crop residues retained in fields.

Soil threats	
Soil acidification	Soil acidification appears to reverse in long term studies (Alam *et al.*, 2018, 2020a).
Soil compaction	Repeated dry tillage and wet tillage in rotation increase soil compaction (Parihar *et al.*, 2016). On the other hand, Islam (2016) reported reduced penetration resistance and thereby less soil compaction in CA-managed soils. Increased residue retention in combination with non-puddled rice followed by strip planting decreased penetration resistance by 14–17 percent at 5–15 cm depth and by 16–18 percent at 0–10 cm depth, compared to puddled rice followed by dry tillage with low residue retention. The SOC sequestration and reduced tractor passes may reduce the soil compaction under the practice (Bogunovic *et al.*, 2017). Non-puddled soil is initially firmer and depending on the soil type may require more force for transplanting rice seedling roots.

7.2 Increases in greenhouse gas emissions

For all crops in the mustard-irrigated rice-monsoon rice cropping system, strip planting for dry season crops and non-puddled transplanting of rice with either low or increased residue retention were the best actual life cycle GHG mitigation options. The novel CA-based establishment practice decreased CH_4 emission by from 4.3 to 10.8 kg per ton of rice equivalent yield (REY) relative to farmers' practice, while the same practice also decreased N_2O emission by 9 kg CO_2eq to 15 kg CO_2eq emission per ton of REY. With the accumulation of soil TOC in CA cropping (3.8 - 4.2 tons CO_2eq/ha) after five years, the life cycle GHG savings with the best mitigation practice for 1 ton of rice-equivalent yield were 46 percent relative to current farmer's practice in the EGP. After accounting for sequestered TOC, the non-puddled rice followed by strip planting reduced net CO_2eq life cycle GHG emission by 0.25 ton for each ton of rice equivalent production (mustard-irrigated rice-monsoon rice system) relative to farmers' current practice (Alam, Bell and Biswas, 2019a).

7.3 Negative impact on production

The case study did not observe yield reduction of rice either in the short term or longer term (Bell *et al.*, 2019). At both the sites and in other trials, the yields of non-rice crops of the rice-based cropping systems were the same or higher in the CA practice compared to conventional practice.

8. Recommendations before implementing the practice

The following recommendations should be followed to get good results in this practice:

1. If strip tillage non-puddling cannot be provided due to excessive wetness of the soil, zero tillage non-puddling method can be applied.
2. Farmers should confirm the availability of the machines or attachments to machines (two-wheel tractor with strip tillage attachment) before implementing the practice.
3. If hands/fingers experience fatigue from repeated manual transplanting of rice seedlings due to firmness of soils, soak the soil for one or two more days.
4. Even if the yield is equal or slightly less in the first year relative to their current practice, farmers should not be discouraged as it may be due to inexperience with the techniques.
5. To get better yield result by establishing rice seedlings in this technique in lowlands, it is recommended to have good drainage system.
6. Fertilizer application should be localized (along the strip) as much as possible.
7. Pre- and post-planting weed management should be satisfactory. Switching between herbicides with different modes of action and hand weeding once in a year could be advised.

9. Potential barriers for adoption

Table 52. Potential barriers to adoption

Barrier	YES/NO	
Biophysical	Yes	- Delay in timely transplanting due to unavailability of machinery (Johansen *et al.*, 2012). - Drudgery during rice seedling transplanting if the non-puddled soils are hard to penetrate. - Plants/seedlings suffer stresses for establishment if the soils are too firm and resist root proliferation - Non-availability of affordable rice planters.
Cultural	No	There are no cultural barriers for adopting the practice.
Social	No	Farmers who use non-puddled transplanting may be discouraged by neighbors and relatives as the practice is unconventional and by drudgery if the non-puddled soils require more effort to place seedling roots in soils. Mindset is the biggest barrier to adopt this technology.
Economic	No	There are no economic barriers for adopting the practice. Indeed, there is generally increased profitability of non-puddled transplanting and CA. However, the cost of machinery for strip tillage is too high for individual farmers, so they have to rely on service providers. However, the hire cost of the strip tillage is lower than for conventional land preparation and puddling.

Barrier	YES/NO	
Institutional	Yes	The government extension services still favor full tillage, and subsidies for machinery support full tillage machinery rather than those for minimum tillage. Finance institutions are unfamiliar with minimum soil disturbance and hence do not have loan packages to support adopting CA practice.
Legal (Right to soil)	No	There are no legal barriers for adopting the practice.
Knowledge	Yes	Knowledge gap of farmers, researchers, extension workers and policy makers.
Natural resource	No	Increased infiltration in light textured, upland soils may lead to requirement of additional irrigation for rapidly-draining soils and/or yield reduction of irrigated rice (Boro).
Other	Yes	- Delay in transplanting, prolonged inundation and seedling mortality may happen due to lack of drainage in lowland rice. - Early monsoon rain may not allow CA equipment (e.g. zero tillage drill) to enter the field - Altered efficacy of herbicides for control of weeds.

Photos

Photo 30. Two-wheel tractor with Versatile Multi-crop Planter (VMP), sowing through standing residue retained at higher rate at Digram, Rajshahi (top) and low rate (bottom) at Alipur, Durgapur, Rajshahi, Bangladesh

Photo 31. Germination of strip planted mustard and non-puddled rice seedling transplanting at Alipur, Durgapur, Rajshahi, Bangladesh

Photo 32. Performance of non-puddled transplanted rice at Alipur, Durgapur, Rajshahi, Bangladesh

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