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## Economic analysis of different greenhouse gas mitigation technologies in rice–wheat cropping system of the Indo-Gangetic Plains

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**To reduce the greenhouse gas (GHG) emission from rice and wheat cultivation several mitigation options have been suggested. However, economic impact of these technologies has been poorly documented. In the present study economic analysis of some emerging GHG mitigation technologies for rice–wheat system of the Indo-Gangetic Plains has been carried out. The experiment consisted of six combinations of wheat–rice crop rotation using eight treatments, including conventionally tilled wheat (CTW), zero tilled wheat (ZTW), transplanted puddled rice (TPR), dry direct seeded rice (DSR), intermittent wetting and drying (IWD), application of rice straw (RS) with ZTW and use of neem oil-coated urea (NOCU) in TPR and ZTW. Cost of various inputs and income from grain and straw were used for computing the benefit to cost (B : C) ratio in the different treatments. ZTW showed higher yield and B : C ratio compared to CTW along with reduction in fuel consumption during tillage operation. In spite of lower yield under DSR and IWD, saving of water, labour and energy in these treatments lowered the cost of cultivation and enhanced B : C ratio similar to TPR. Application of rice straw and NOCU also showed positive impact on crop yield. B : C ratio of rice–wheat system ranged from 1.62 to 1.86 in the first year and from 1.86 to 2.16 in the second year. B : C ratio was significantly higher in all the treatments in the experimented rice–wheat system compared to conventional system, i.e. CTW–TPR. The ZTW + RR – DSR (WR5) showed highest B : C ratio followed by ZTW + DSR (WR4) in both the seasons.**

**Keywords:** Economic analysis, greenhouse gases, mitigation technology, rice–wheat system.

THE rice–wheat cropping system (RWCS) of the Indo-Gangetic Plains (IGP) is crucial for food security in Southeast Asia. This system covers 13.5 m ha of land with high concentration in Indian IGP (10.5 m ha). The Indian IGP occupies about 53% of the total area under RWCS, produces about 50% of the total food grains and feeds almost 40% of the population of our country<sup>1,2</sup>.

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Recently, concerns have been raised regarding the stagnation and, in some cases, decline in the productivity and sustainability of this system along with greenhouse gas (GHG) emission<sup>3,4</sup>. This has been mainly reported due to continuous practice of conventional methods of rice and wheat cultivation. Conventionally, rice is transplanted on puddled, water-saturated anaerobic soil prepared by repeated wet tillage (puddling) and the field is submerged with water during crop growth. While wheat seed is sown on intensively tilled, well-aerated soil. Anaerobic rice field is a major source of CH<sub>4</sub>, while application of nitrogenous fertilizer leads to emission of N<sub>2</sub>O from both the crops. The intensive tillage in both crops, frequent irrigation requirement in rice and mechanized harvesting and threshing consume high amounts of energy and emit significant amount of CO<sub>2</sub>. Agriculture is the largest anthropogenic source of CH<sub>4</sub> (77%) and N<sub>2</sub>O (60%) in India<sup>4</sup>. TPR contributes about 3.32 Mt of CH<sub>4</sub> and about 0.14 Mt of N<sub>2</sub>O is emitted from rice, wheat and other crops due to application of nitrogenous fertilizer<sup>5</sup>. Furthermore, repeated tillage and puddling have an adverse impact on the soil. Frequent tilling opens the soil, breaks soil clods and aggregates, enhances oxidation of soil organic matter and makes the soil vulnerable to erosion<sup>6,7</sup>.

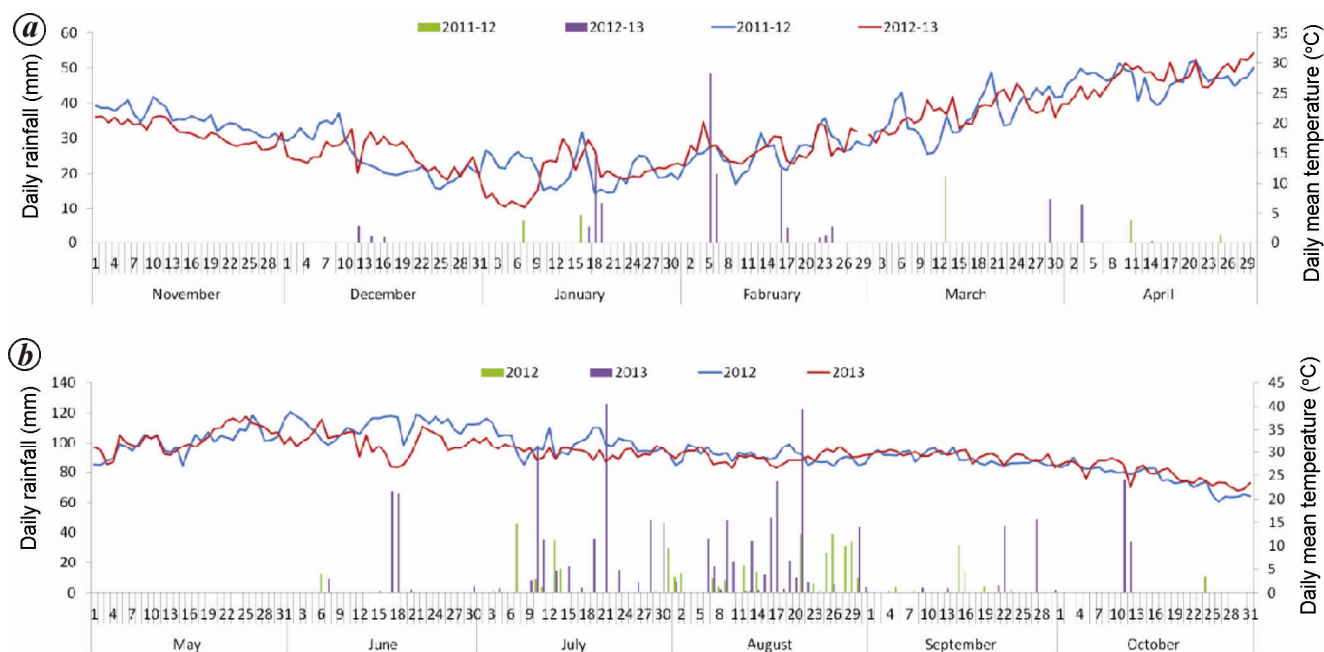
To deal with the aforesaid problems, several rice-wheat cultivation technologies that have proved to be resource efficient and low carbon are becoming popular. Some of these technologies include: (a) zero tilled sowing for reduction in CO<sub>2</sub> emission due to low fossil-fuel consumption and increased soil carbon sequestration; (b) direct seeding of rice and intermittent wetting and drying in transplanted puddled rice for reducing CH<sub>4</sub> emission, and (c) use of nitrification inhibitors for reducing N<sub>2</sub>O emission, etc. These technologies have been frequently reported to reduce GHG emission and global warming potential (GWP) in many countries and parts of India<sup>8-17</sup>. However, their economic analysis is poorly reported. The economic analysis of these technologies must be evaluated to assess their suitability for farmer's income, wider adaptability and identification of major cost factors for further refinement of these technologies. The present study focuses on economic analysis of some important GHG mitigation technologies in RWCS and identifies major cost factors responsible for low income.

A field experiment on GHG mitigation technologies in RWCS system was conducted at the experimental farm of Indian Agricultural Research Institute (IARI), New Delhi for two consecutive years (2011-2013). The experimental site comes under tranche Indo-Gangetic alluvial tract and is located at 28°40'N lat. and 77°12'E long., at an altitude of 228 m amsl. The climate of the region is subtropical, semi-arid type with annual rainfall of 750 mm, about 80% of which occurs from June to September. The average temperature during wheat experimental season was 18.5 ± 5.9°C and 18.3 ± 5.8°C in 2011-12 and 2012-13 respectively, while during rice season it was 30.5 ± 4.3°C

and 29.2 ± 2.8°C in 2012 and 2013 respectively (Figure 1). The 2011-12 period was drier cropping season due to scarce rainfall, while 2012-13 was wet due to high and uniform rainfall (Figure 1). During wheat season (November-April), there was about 43 and 176 mm total rainfall in 2011-12 and 2012-13 respectively, while during rice growing season (June-October) it was 494 and 1349 mm in 2012 and 2013 respectively. The soil of the experimental site is Typic Ustochrept and loam (46% sand, 33% silt and 21% clay) in texture with bulk density 1.38 g cm<sup>-3</sup>, pH 8.1, electrical conductivity 0.48 dS m<sup>-2</sup>, organic-C 0.46%, total N 678 kg ha<sup>-1</sup>, available P 18.45 kg ha<sup>-1</sup> and available K 284 kg ha<sup>-1</sup>.

The experiment consisted of six combinations of rice-wheat rotation developed by permutation of eight treatments including conventionally tilled wheat (CTW), zero tilled wheat (ZTW), transplanted puddled rice (TPR), dry direct seeded rice (DSR), intermittent wetting and drying in TPR (IWD), application of rice straw (RS) in ZTW and use of neem oil-coated urea (NOCU) in TPR and ZTW (Table 1). The experiment was carried out in randomized block design (RBD) on block of 6 × 8 m dimension with three replications. The treatments differed in tillage operation, irrigation management, source of nitrogen and application of rice residue, while other inputs and management were similar. For TPR and IWD treatments, the field was prepared by disc ploughing and harrowing twice each on aerobic soil condition followed by puddling of wet soil and transplanting of 30-day-old seedlings on puddle soil. In DSR and CTW treatments, direct sowing of seed on tilled soil prepared by disc ploughing, and harrowing twice each followed by planking, while in ZTW tilling of whole land was avoided and seed sowing was done with minimum disturbance to soil with zero till turbo-seeder. There was no ponding of water in DSR, except on the day when irrigation was provided, whereas in TPR a ponding depth of 5 ± 1 cm was maintained up to physiological maturity. In IWD irrigation was provided when depth of ponded water receded up to the surface of the soil. In wheat total five irrigations were given in all treatments. Urea was applied in all treatments, except in rice and wheat treatments of the WR6 system in which NOCU was applied (Table 1). The rice straw was applied only in ZTW treatment of WR5 system at the rate of 4 t ha<sup>-1</sup> followed by seed sowing.

The experiment was started with sowing of wheat (HD-2894) on 15 November 2011 at the rate of 100 kg seed ha<sup>-1</sup> followed by rice (PRH-10) on 26 June 2012 at the rate of 20 kg seed ha<sup>-1</sup> for TPR and 30 kg seed ha<sup>-1</sup> for DSR. In the next cropping season, the same package and practices were adopted while sowing of wheat was done on 17 November 2012 and rice on 22 June 2013 respectively. Sowing of seed in nursery for TPR and sowing of DSR in the field was done on the same date. Recommended dose of fertilizers (120 kg N + 80 kg P<sub>2</sub>O<sub>5</sub> + 60 kg K<sub>2</sub>O in wheat and 120 kg N + 60 kg



**Figure 1.** Temporal variation in daily mean temperature and rainfall during rice-wheat cropping seasons: (a) wheat and (b) rice.

**Table 1.** Wheat-rice system treatments

Wheat rice system	Wheat treatment	Rice treatment
WR1	CTW	TPR
WR2	ZTW	TPR
WR3	ZTW	IWD
WR4	ZTW	DSR
WR5	ZTW + RS	DSR
WR6	ZTW + NOCU	TPR + NOCU

CTW, Conventionally tilled wheat; ZTW, Zero tilled wheat; TPR, Transplanted puddled rice; IWD, Intermittent wetting and drying; DSR, Dry direct seeded rice; RS, Rice straw; NOCU, Neem oil-coated urea.

$P_2O_5 + 40 \text{ kg } K_2O + 10 \text{ kg } Zn$  in rice) was applied in both the crops. In all treatments P, K and Zn fertilizers were applied as basal dose, while split application was adopted for nitrogenous fertilizer. Weedicide and insecticide were applied in all treatments of rice, while need-based management was done in wheat treatments. In all treatments of rice, spraying of Pendimethalin at the rate of  $1750 \text{ ml ha}^{-1}$  was done three days before transplanting in TPR and three days before sowing in DSR, followed by spraying of Nomini gold at the rate of  $25 \text{ ml ha}^{-1}$  after 25 days of sowing in DSR. Need-based hand-weeding was also done. In rice treatments, Furadan and Cartap were applied respectively, at 25 and 40 days after sowing or transplanting at the rate of  $20 \text{ kg ha}^{-1}$ . Wheat was harvested on 11 April 2012 and 2013, while rice was harvested on 16 and 20 October in 2012 and 2013 respectively.

Crop yields were determined from the total plot area. The grains were separated from the straw, dried and

weighed. Grain moisture was determined immediately after weighing and subsamples were dried in an oven at  $65^\circ\text{C}$  for 48 h. Straw was also dried in an oven at  $65^\circ\text{C}$  for 48 h and final dry weight was recorded. The operational cost of cultivation was calculated by taking into account the cost of inputs (seed, fertilizers, biocide, diesel and electricity) and the hiring charges of services for various farm operations like land preparation, irrigation, fertilizer application and harvesting. Gross income was the minimum support price offered by the Government of India for rice and wheat in the respective year plus income from selling of residue obtained from market survey. A market survey during the respective crop season was carried out for obtaining the price of all the inputs and hired services for calculating the cost of cultivation. Data obtained were finally analysed by SPSS (version 17), IBM, USA. One-way ANOVA with Duncan's Multiple Range Test (DMRT) at 5% level of significance was carried out to test whether the differences between means were statistically significant. The formulae used for economic analysis were as follows:

$$\begin{aligned} \text{Total cost of cultivation (Rs ha}^{-1}\text{)} \\ = \{ \text{Inputs cost (seed cost} \\ + \text{fertilizer cost + biocide cost} \\ + \text{energy cost)} \\ + \text{cost of hiring services (human and machine)} \\ + \text{miscellaneous cost (@10\% of total cost)} \} \text{Rs ha}^{-1}. \end{aligned}$$

$$\begin{aligned} \text{Cost of energy (Rs ha}^{-1}\text{)} \\ = \{ \text{Diesel consumed by tractor (l ha}^{-1}\text{)} \\ \times \text{total duration of tractor operation (h ha}^{-1}\text{)} \} \end{aligned}$$

$$\begin{aligned} & \times \text{price of diesel (Rs l}^{-1}\text{)}\} \\ & + \{\text{Electricity consumed by electric pump for} \\ & \text{irrigation (kWh h}^{-1}\text{)} \times \text{total duration of pump} \\ & \text{operation (h ha}^{-1}\text{)} \times \text{electric charge (Rs kWh}^{-1}\text{)}\}. \end{aligned}$$

$$\begin{aligned} \text{Gross income (Rs ha}^{-1}\text{)} \\ = \{ & \text{Total grain yield (kg ha}^{-1}\text{)} \\ & \times \text{minimum support price of grain (Rs kg}^{-1}\text{)}\} \\ & + (\text{total straw yield (kg ha}^{-1}\text{)} \times \text{market price of} \\ & \text{straw (Rs ha}^{-1}\text{)}). \end{aligned}$$

$$\begin{aligned} \text{Benefit cost ratio (B : C)} \\ = \text{Gross income (Rs ha}^{-1}\text{)}/\text{total cost (Rs ha}^{-1}\text{)}. \end{aligned}$$

The productivity ranged from 9140 to 9960 kg ha<sup>-1</sup> and 9540 to 10,120 kg ha<sup>-1</sup> among different WR systems in first and second year of experiment respectively (Table 2). Among different systems, WR6 (ZTW + NOCU – TPR + NOCU) showed about 5% significantly higher yield than WR1 CTW–TPR system. The system productivity was in the order WR6 > WR2 > WR3 > WR1 > WR5 > WR4 (Table 2). The difference in system productivity was attributed to difference in wheat and rice yield under different treatments. Grain yield under ZTW treatment was higher compared to CTW treatment; however differences were non-significant (Table 2). On an average about 5% higher yield was obtained under ZTW treatment compared to CTW treatment in both the seasons. This may be due to increased input use efficiency in ZTW compared to CTW. Mehla *et al.*<sup>18</sup> reported 15.4% yield gain under NT in on-farm trials in Haryana. This gain was mainly attributed to timely sowing and enhanced efficiency of fertilizer and water, and to a significant reduction in weed population<sup>18</sup>. Erenstein and Laxmi<sup>19</sup> reviewed on-station trials across the Indian IGP and reported higher wheat yields under ZT in the range 1–12%; however, it varied in different parts of the IGP<sup>19</sup>. There was significantly higher yield (8.5%) under ZTW + RS (WR5) compared to CTW, showing positive impact of application of RS on yield of ZTW. The higher yield under ZTW with residue mulch has also been reported by many workers<sup>20–22</sup>. The increased yield under ZTW with straw mulching has been mainly attributed to its role in conserving initial soil moisture and preventing weed growth<sup>21</sup>. In rice treatments, on an average there was about 11% and 3.5% significantly lower yield in DSR (WR4 and WR5) and IWD (WR3) treatments respectively, compared to conventional TPR treatments (WR1 and WR2) in the first season. However, in the next season differences were low (7.3% and 2%) due to uniform and high rainfall (Table 2). In several studies in northwest India, yield under DSR has also been reported lower than TPR<sup>23–25</sup>. The cause for this yield is generally unknown, but water-deficit stress is a possible factor, as rice yield generally declines as the soil dries below saturation<sup>26</sup>. Yadav *et al.*<sup>25</sup> reported that dry DSR and TPR gave simi-

lar yield when irrigation was scheduled daily or at 20 kPa, while yields of both TPR and DSR declined under higher water deficit stress (40 and 70 kPa irrigation thresholds), but more in DSR. The application of NOCU urea in ZTW and TPR treatments of WR6 system also showed beneficial impact by increasing wheat yield by about 6.5% and rice yield by about 1%; however, difference was significant in wheat and insignificant in rice (Table 2). The application of nitrification inhibitors has been reported to enhance nitrogen (N) use efficiency, extend the time of N availability for plant uptake and thus increase yield<sup>27</sup>. Kumar *et al.*<sup>28</sup> reported in a soil incubation experiment that the meliacins content in neem oil directly affected the nitrification inhibition. So nitrification inhibition property of NOCU in the present study might lead to increase in N use efficiency by slowing down N release and inhibiting loss through denitrification, thus resulting in an increase in yield. Similar results have been reported subsequently by many researchers in the country<sup>29,30</sup>.

In both the crops, the cost for hiring human services was highest followed by fertilizer and seed purchasing (Figure 2). Contribution of human labour, fertilizer and seed in total operational cost ranged from 41% to 44%, 27% to 30% and 13% to 15% respectively, in wheat treatments and 44.5–53%, 13–15% and 9–16% respectively, in rice treatments in the first season (Figure 2). In the second season it ranged from 38% to 45.5%, 27.5% to 32.5% and 13% to 15% respectively, in wheat treatments and 41% to 49%, 15% to 17.5% and 10% to 17% respectively, in rice treatments. On an average, the total cost of cultivation was significantly lower in ZTW (WR2, WR3 and WR4) (8%), ZTW + RR (WR5) (15%) and ZTW + NOCU (WR6) (6%) treatments compared to CTW (WR1) treatment in both the seasons (Table 3). This was mainly due to difference in human labour and diesel consumption during tillage requirement (Figure 2). Among rice treatments, DSR (WR4 and WR5) showed significantly lower (14% and 12% in the first and second season respectively) cost of cultivation than TPR (WR1 and WR2) treatment, IWD also showed lower (5%) cost of cultivation than TPR, however, difference was insignificant (Table 3). This is mainly due to difference in human labour and irrigation requirement (Figure 2). Among WR systems, WR5 (ZTW + RR – DSR) followed by WR4 (ZTW + DSR) showed lowest cost of cultivation and reduced the total cost by about 15% and 10% respectively, compared to WR1 (CTW–TPR) (Table 3).

The estimation of input saving from different treatments showed about 58% saving of diesel consumed during tillage operation in ZTW compared to CTW treatments (Table 4). Application of RS on ZTW treatment (WR5) saved human services by about 22% compared to other treatments. This reduction was mainly due to less weed infestation in RW-applied ZTW field. Among rice treatments, DSR (WR4 and WR5) and IWD (WR3) saved

**Table 2.** Grain and straw yield of different treatments

System*	Wheat						Rice						Wheat-rice									
	Grain		Straw		2012-13		Grain		Straw		2012-13		Grain		Straw		2012-13		Grain		Straw	
	2011-12	2012-13	2012	2013	2011-12	2012-13	2011-12	2012-13	2012	2013	2011-12	2012-13	2011-12	2012-13	2012	2013	2011-12	2012-13	2012	2013	2012	2013
WR1	4520a	4530a	7120	7100	4910bc	5180b	9130	9130	9130	9130	9430ab	9710ab	9430ab	9710ab	16250	16230	9430ab	9710ab	16250	16230	16250	16230
WR2	4770ab	4790bc	8000	8100	5100c	5260b	9440	9440	9440	9440	9870bc	10050bc	9870bc	10050bc	17440	17540	9870bc	10050bc	17440	17540	17440	17540
WR3	4740ab	4710ab	7450	7330	4830b	5110b	8530	8530	8530	8530	9570abc	9820abc	9570abc	9820abc	15980	15860	9570abc	9820abc	15980	15860	15980	15860
WR4	4720ab	4760bc	6900	7450	4420a	4780a	7310	7310	7310	7310	9140a	9540a	9140a	9540a	14210	14760	9140a	9540a	14210	14760	14210	14760
WR5	4910b	4940c	8660	8710	4460a	4860a	7440	7440	7440	7440	9370a	9800abc	9370a	9800abc	16100	16150	9370a	9800abc	16100	16150	16100	16150
WR6	4810b	4850bc	7850	7910	5150c	5280b	9520	9520	9520	9520	9960c	10130c	9960c	10130c	17370	17430	9960c	10130c	17370	17430	17370	17430

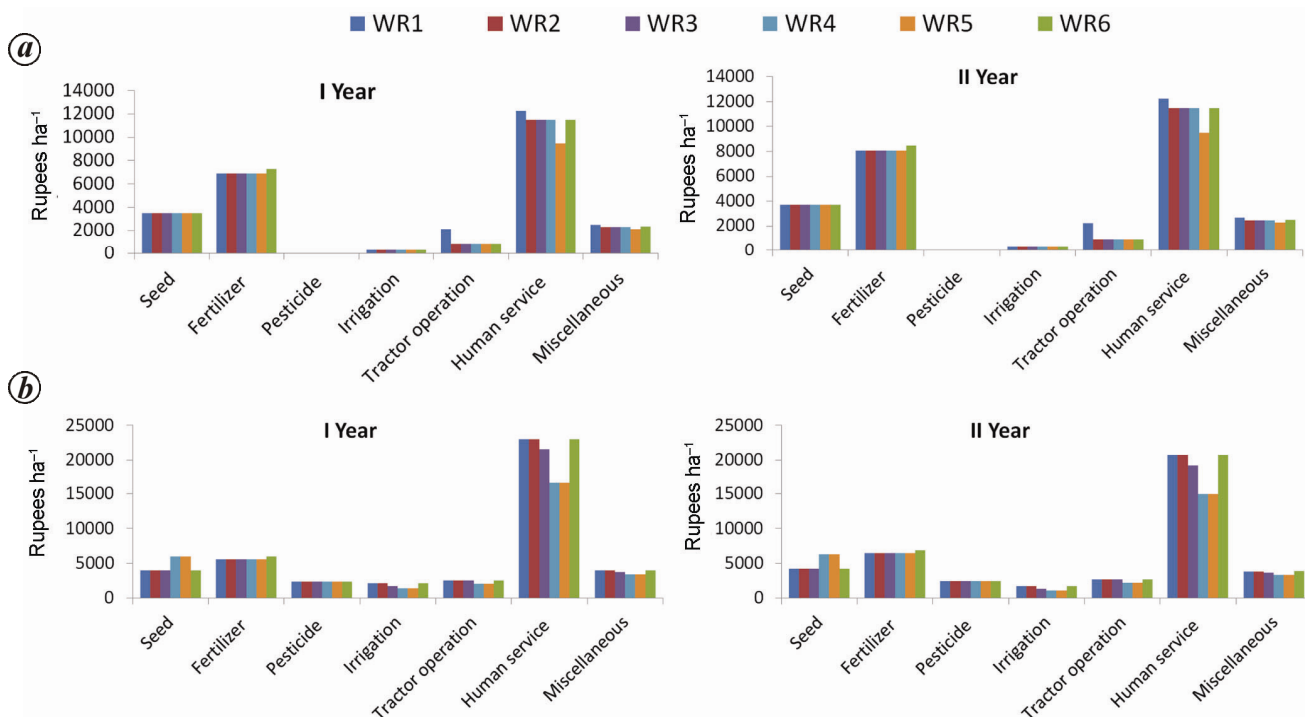
According to DMRT (Duncan's multiple range test) mean followed by different letter(s) in a column is significantly different ( $P \geq 0.05$ ).

\*WR1, CTW-TPR; WR2, ZTW-TPR; WR3, ZTW-IWD; WR4, ZTE-DSR; WR5, ZTW + RR - DSR; WR6, ZTW + NOCU - TPR + NOCU.

**Table 3.** Cost of cultivation and net income under different treatments

System*	Cost						Net income						B : C									
	Wheat		Rice		2012-13		Wheat		Rice		2012-13		Wheat		Rice		2012-13		First year		Second year	
	2011-12	2012-13	2012	2013	2011-12	2012-13	2011-12	2012-13	2012	2013	2011-12	2012-13	2011-12	2012-13	2012	2013	2011-12	2012-13	2012	2013	2012	2013
WR1	27561c	29234c	43538bc	42049c	29171a	34406a	14753b	27211abc	206a	2.18a	1.34a	1.65a	2.06a	2.18a	1.62a	1.86a	2.06a	2.18a	1.62a	1.86a	1.62a	1.86a
WR2	25404b	26933b	43538bc	42049c	34636b	40507b	17000d	28275bc	2.36b	2.50b	1.39a	1.67a	2.36b	2.50b	1.75b	2.00b	2.36b	2.50b	1.75b	2.00b	1.75b	2.00b
WR3	25404b	26933b	41472b	39941b	34083b	39157b	15779c	28391c	2.34b	2.45b	1.38a	1.71a	2.34b	2.45b	1.75b	2.01b	2.34b	2.45b	1.75b	2.01b	1.75b	2.01b
WR4	25404b	26933b	37649a	36866a	33651b	39874b	14643b	27000ab	2.32b	2.48b	1.39a	1.73a	2.32b	2.48b	1.77b	2.05b	2.32b	2.48b	1.77b	2.05b	1.77b	2.05b
WR5	23204a	24793a	37649a	36866a	38747c	44945c	13641a	26314a	2.67c	2.81c	1.36a	1.71a	2.67c	2.81c	1.86c	2.16c	2.67c	2.81c	1.86c	2.16c	1.86c	2.16c
WR6	25837b	27426b	44000c	42510c	34631b	40818b	17129d	28082bc	2.34b	2.49b	1.39a	1.66a	2.34b	2.49b	1.74b	1.99b	2.34b	2.49b	1.74b	1.99b	1.74b	1.99b

According to DMRT mean followed by different letter(s) in a column is significantly different ( $P \geq 0.05$ ). WR1-WR6, same as in Table 2.



**Figure 2.** Share of factors in total cost of cultivation: *a*, wheat; *b*, rice. WR1, CTW-TPR; WR2, ZTW-TPR; WR3, ZTW-IWD; WR4, ZTE-DSR; WR5, ZTW + RR – DSR; WR6, ZTW + NOCU-TPR + NOCU.

**Table 4.** Human and machine energy consumed during farm operations

Inputs	Crop	Season	WR1	WR2	WR3	WR4	WR5	WR6
Irrigation (number ha <sup>-1</sup> )	Rice	I	34	34	28	23	23	34
		II	25	25	19	16	16	25
	Wheat	I	5	5	5	5	5	5
		II	5	5	5	5	5	5
Pump duration (h ha <sup>-1</sup> )	Rice	I	595	595	490	402.5	595	402.5
		II	437.5	437.5	332.5	280	280	437.5
	Wheat	I	87.5	87.5	87.5	87.5	87.5	87.5
		II	87.5	87.5	87.5	87.5	87.5	87.5
Electricity consumed by pump (kWh ha <sup>-1</sup> )	Rice	I	4284	4284	3528	2898	2898	4284
		II	3150	3150	2394	2016	2016	3150
	Wheat	I	630	630	630	630	630	630
		II	630	630	630	630	630	630
Tractor duration (h ha <sup>-1</sup> )	Rice	I	14.5	14.5	14.5	12	12	14.5
		II	14.5	14.5	14.5	12	12	14.5
	Wheat	I	12	5	5	5	5	5
		II	12	5	5	5	5	5
Diesel consumed by tractor (l ha <sup>-1</sup> )	Rice	I	53.25	53.25	53.25	44.5	44.5	53.25
		II	53.25	53.25	53.25	44.5	44.5	53.25
	Wheat	I	44.5	18.75	18.75	18.75	18.75	18.75
		II	44.5	18.75	18.75	18.75	18.75	18.75
Human services (no. ha <sup>-1</sup> )	Rice	I	92	92	86	67	67	92
		II	83	83	77	60	60	83
	Wheat	I	49	46	46	46	38	46
		II	49	46	46	46	38	46

32.5% irrigation water and as a result 17.5% electricity consumed in pumping water for irrigation compared to TPR in the first season and 56% and 24% respectively, in the second season. DSR also saved 16.5% diesel during tillage operation over TPR in both the seasons due to avoidance of puddling operation. DSR and IWD treatments also saved human services by 27% and 6.5% respectively, in the first season and 28% and 7% respectively, in the second season compared to TPR treatments. The difference in saving of labour and diesel between seasons was mainly due to difference in irrigation application.

The B : C ratio in wheat treatments ranged from 2.06 to 2.67 in the first season and 2.18 to 2.81 in the second season (Table 3). All the ZTW treatments showed significantly higher B : C ratio than CTW treatment in both the seasons. Among these, ZTW + RR treatment had the highest B : C ratio. In ZTW, higher B : C ratio was due to saving of diesel consumption during tillage operation as ZTW required energy for opening of furrow only, while CTW required energy for tilling the whole land<sup>31</sup>. There was insignificant difference in B : C ratio among rice treatments; it ranged from 1.32 to 1.39 in the first season and 1.65 to 1.73 in second season (Table 3). There was lower yield under DSR and IWD treatments; however, saving of water, labour and energy in these treatments decreased the cost of cultivation and B : C ratio was at par with TPR. The saving of these inputs under DSR and ZTW has also been reported by Bhushan *et al.*<sup>32</sup>. The B : C ratio was significantly higher in all WR systems (WR2, WR3, WR4, WR5 and WR6) compared to conventional system, i.e. CTW-TPR (WR1). WR5 (ZTW + RR - DSR) showed highest B : C ratio followed by ZTW + DSR (WR4) in both the seasons. The B : C ratio of the systems ranged from 1.62 in WR1 to 1.86 in WR4 in the first year, and 1.86 to 2.16 in the second year (Table 3). The B : C ratios of different WR systems were in order of WR1 ≤ WR6 < WR2 ≤ WR3 < WR5 ≤ WR4 in both the years.

The results indicate that DSR, IWD, ZTW, application of NOCU and RS which have been reported to reduce GHG emission and GWP also reduce cost of cultivation and enhance B : C ratio compared to conventional methods. This benefit is mainly gained due to significant saving of limited resources like diesel, water and labour. The promotion of these technologies in the farmer's field can be viewed as a potential alternative for conventional TPR-CTW system to reduce GHG emission and save scarce resource without much effect on the economy.

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## Clay dispersion induced by changes in some soil properties in undulating salt-affected landscapes of southern Karnataka, India

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**Effect of sodicity on clay dispersion in salt-affected black soils of the Kabini canal command area in Chamrajnagar district, southern Karnataka was studied. Forty-eight soil samples were collected from nine soil profiles and analysed for physical and chemical properties. The clay dispersion ranged from 0.57% to 62.1%. High positive and negative correlations with exchangeable sodium and exchangeable calcium respectively, with clay dispersion were recorded, which can be predicted better with exchangeable sodium and available soil water. Based on clay dispersion value, 2%, 27% and 71% soils are dispersive, intermediate dispersive and non-dispersive respectively. Based on exchangeable sodium percentage, 50, 21 and 29 soils are dispersive, intermediate dispersive and non-dispersive respectively. Application of gypsum and organics reduces the clay dispersion in surface soil. Sub-surface drainage will be more effective. Construction of soil and water conservation structures with pile foundation; providing cement lining for soil stabilization in normal construction; providing drainage lines for the structures; construction after refilling with non-dispersive soil will save the structures in salt-affected soils.**

**Keywords:** Clay dispersion, sodicity, sub-surface effect, surface effect.

SOIL quality declines when the primary particles in soil aggregates start dispersing and soil becomes structurally weak and is prone to erosion. Clay particles are negatively charged; these negative charges are balanced by cations such as Ca<sup>2+</sup>, Mg<sup>2+</sup>, K<sup>+</sup> and Na<sup>+</sup>. When sodium is dominant, the clay particles are weakly bound to each other so that the soil aggregates disperse easily in wet condition. In salt-affected soils, dispersive soils are developed much

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