Impact of Crop Establishment Methods and Weed Management Practices on Productivity and Profitability of Rice-Wheat System in Indo Gangetic Plains

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ABSTRACT

Declining productivity of rice-wheat system in Indo–Gangetic Plains poses risk to conventional practices because of high production cost and low input use efficiency. Four crop establishment methods (CEM) and four weed management practices (WMP) were compared in a 2–year study to determine the productivity and profitability of rice-wheat system. Growth, yield traits and yields of rice was uninfluenced by CEM. Zero tillage rice (ZTR)–zero tillage wheat (ZTW) exhibited highest improvement in mean wheat yield, system productivity and profitability by 7.5%, 4.0% and 16.0% respectively over conventional tillage rice (CTR)–conventional tillage wheat (CTW). CTR–ZTW recorded minimum total weed density and biomass in system. Post emergence application of
1. INTRODUCTION

Rice-wheat system occupies 13.5 million hectares in Indo-Gangetic Plains (IGP) of India, Bangladesh, Nepal and Pakistan. It is a vital for food security and livelihood for millions of rural and urban poor [1]. Challenges associated with conventional production system include declining factor productivity and shrinking profits due to increased in the energy demand and labour costs. Manual rice transplanting in random geometry after puddling is a traditional practice require more tillage, water, capital and energy, deteriorates soil health and creates unfavourable conditions for succeeding crops [2]. Puddling laterization formation of hard–pan at shallow depths, deteriorates soil physical properties, inhibits root elongation, and reduces yield of succeeding wheat [3]. Conventional broadcast seeding method requires rigorous field preparation results delay in wheat planting. Planting after mid November reduces 1–1.5% yield for each day delay [4]. Wheat grown after conventional tillage rice (CTR) yield 8% less than un–puddled direct seeded rice (DSR) [5].

Intensive conventional tillage leads gradual decline in soil organic matter through accelerated oxidation and burning of crop residues. Resource conservation technologies (RCT’s) such as zero tillage (ZT) improve soil health, water use, crop productivity and profitability [6,7]. Reduced till direct seeded rice (RTDSR) saves 34% labour requirement and 29% cost involved in transplanting operation [8,9]. ZT saves cost involved in field preparation and advances wheat sowing by 10–15 days [10]. Maximum benefit derived when rice–wheat grown with ‘double ZT’ system [11,12]. High water, labour and energy requirement demands a shift from conventional to DSR. Irrigation requirement is reduced in zero tillage wheat (ZTW) than conventional tillage wheat (CTW) as it utilizes residual water more effectively [13,14]. Higher root mass and depth in ZTW prevents lodging. Roots become surface feeder in CTW due to sub-surface compaction [15]. During 2008, the area under zero or reduced tillage wheat touched 1.76 million hectares with 0.62 million practicing farmers. The full realization of potential benefits of ZT will depend on reduction of tillage in succeeding rice crop [16]. Reluctance in adoption of ZT in rice-wheat by farming community is mainly associated with management of weeds. Successful implementation of RCT’s largely depends on weed management. Intensive tillage disturbs vertical distribution of weed seeds in soil by several ways. Interaction of tillage, environment, timing and weed management practices (WMP) adopted ascertain the weed flora. Crop establishment methods are location specific needs evaluation across diverse agro-climatic conditions [17]. Based on these, a 2–year study was carried out at Varanasi, Uttar Pradesh to evaluate the impact of CEM and WMP in rice–wheat system of IGP. Precisely, we monitored indexes to assess system productivity, profitability and net returns.

2. MATERIALS AND METHODS

2.1 Study Site and Climatic Condition

A two years investigation conducted during rainy and winter seasons of 2012–13 and 2013–14 at Agricultural Research Farm (25°27’ N, 82°99’ E), Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India. The experimental site falls under semi-arid to sub-humid received total annual rainfall of 698.6 mm during first year and 952.7 mm during second year. Rainfall received between June to September was 615.8 mm (88.1%) and 673.4 mm (70.7%) while from October to March 82.8 mm (11.9%) and 279.3 mm (29.3%) during first and second year, respectively. Mean maximum temperature of 28.8°C and 27.9°C and minimum temperature of 18.3°C and 19.3°C prevailed during year 1 and 2, respectively. The experimental field soil was calcosols with pH of 7.31 and 7.28, 0.42% and 0.44% organic carbon content [18], 206.59 and
209.24 kg ha\(^{-1}\), available nitrogen [19], 25.10 and
25.86 kg ha\(^{-1}\) available phosphorus [20] and
219.60 and 221.30 kg ha\(^{-1}\) available potassium
[21] during first and second year, respectively.

### 2.2 Experimental Design and Crop Management

Experiment was laid out in split plot design replicated thrice. Four CEM assigned to main
plots and four WMP in sub plots consisting 16 treatment combinations in a 2–year rice-wheat
cropping system (Table 1). Cultivar HUR 105 used to raise transplanted and direct seeded rice
adopting uniform seed rate of 30 kg ha\(^{-1}\). Nursery sown on 25 and 20 June during 2012 (year 1)
and 2013 (year 2), respectively and ZTR and RTDSR were also sown same day. Twenty eight
day old seedlings were randomly transplanted same day. Twenty eight

Table 1. Treatment details of Crop Establishment Methods (CEM) and Weed Management
Practices (WMP)

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Rice – wheat system</th>
<th>Tillage practices/CEM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main plots</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEM(_1)</td>
<td>CTR–CTW</td>
<td>2 ploughing (cultivator), 1 planking fb wet tillage/pludding twice (rotavator)</td>
</tr>
<tr>
<td>CEM(_2)</td>
<td>CTR–ZTW</td>
<td>--do--</td>
</tr>
<tr>
<td>CEM(_3)</td>
<td>RTDSR–ZTW</td>
<td>2 ploughing (cultivator), 1 planking</td>
</tr>
<tr>
<td>CEM(_4)</td>
<td>ZTR–ZTW</td>
<td>No tillage, drill seeding</td>
</tr>
</tbody>
</table>

| **Sub plots** | | |
| WMP\(_0\) | Weedy check–weedy check | No weed management |
| WMP\(_1\) | Weed free–weed free | 2 HW (20 & 40 DAS/DAT) pendimethalin at 1 kg ha\(^{-1}\) + metsulfuron at 4 g ha\(^{-1}\) + NIS (0.25%) at 30–35 DAS |
| WMP\(_2\) | Pendi fb bis–sulf + met | 2 HW (20 & 40 DAS) sulfosulfuron at 25 g ha\(^{-1}\) + NIS (0.25%) at 30–35 DAS |
| WMP\(_3\) | Bis + azim–clod + car | bispyribac at 25 g ha\(^{-1}\) + azimsulfuron at 35 g ha\(^{-1}\) + NIS (0.25%) at 20 DAS/20 DAT | clodinofop at 60 g ha\(^{-1}\) + carfentrazone at 20 g ha\(^{-1}\) + NIS (0.25%) at 30–35 DAS |
2.3 Measurements and Observations

Total weed density (no. m\(^{-2}\)) and biomass (g m\(^{-2}\)) in rice and wheat recorded at 20, 40 and 60 DAS/DAT. An area of 0.25 m\(^2\) randomly selected at two places in each net plot to count weed population expressed as no. m\(^{-2}\). Collected weeds were first sun dried for two days then dried in a hot air oven at 70\(^\circ\)C till constant weight and expressed as g m\(^{-2}\). Growth parameters i.e. plant height, no. of tillers m\(^{-2}\) and dry matter accumulation at harvest of rice and wheat; yield attributing characters of rice (panicles m\(^{-2}\), panicle length and grains panicle\(^{-1}\)) and wheat (no. of spikes m\(^{-2}\), spike length, grains spike\(^{-1}\)) were recorded from five randomly selected plants hill\(^{-1}\) in each plot. 1000 grain weight of rice and wheat were worked out on different CEM and WMP treatments with CEM and WMP check (WMP\(_0\)). Data revealed that grain yields obtained in rice and wheat were significantly influenced by CEM (Tables 2 and 3) during both the years.

WMP (WMP\(_1\), WMP\(_2\) and WMP\(_3\)) failed to exert any significant difference on yield attributes, grain and straw yields, and harvest index. Above all WMP proved significantly better over weedy check (WMP\(_0\)). In general, hand weeding claimed the highest values for above parameters and produced significantly greater panicle length (both years) than herbicides use (WMP\(_2\) and WMP\(_3\)). Hand weeding (WMP\(_1\)) was significantly superior over WMP\(_2\) but produced comparable grain yield (2012–13) with WMP\(_3\). WMP\(_3\) and WMP\(_2\) gave 53.9% and 52.1% higher mean grain yield over WMP\(_0\).

CEM and WMP interacted significantly with respect to rice grain yield during both years (Table 4). Data reveals that grain yields obtained in order of RTDSR > CTR, respectively with all WMP except WMP\(_0\). In general, treatment combinations with CEM and WMP\(_1\), WMP\(_2\) and WMP\(_3\) found statistically similar. This response emphasize that all these weed

3. RESULTS

3.1 Rice Growth Parameters, Yield Attributes and Yield

Rice growth parameters, yield attributes and yield found unaffected by CEM but were significantly influenced by WMP (Table 2). However, higher values recorded under ZTR. Two hand weeding (WMP\(_1\)) proved most effective in respect to plant height, number of tillers m\(^{-2}\) and dry matter at harvest over other WMP. Herbicide combinations pendimethalin fb bis and bis plus azim (WMP\(_2\) and WMP\(_3\)) stood equal in controlling weeds resulted superior growth parameters than weedy check. Combination of pre emergence (PE) and post emergence (POE) applied herbicides (pendi fb bis) or POE (bis + azim) shown similar results.

Yield attributes i.e. panicles m\(^{-2}\), panicle length, grains per panicle, 1000 grain weight, grain and straw yields, and harvest index found unaffected by different CEM (Tables 2 and 3) during both the years.

WMP (WMP\(_1\), WMP\(_2\) and WMP\(_3\)) failed to exert any significant difference on yield attributes, grain and straw yields, and harvest index. Above all WMP proved significantly better over weedy check (WMP\(_0\)). In general, hand weeding claimed the highest values for above parameters and produced significantly greater panicle length (both years) than herbicides use (WMP\(_2\) and WMP\(_3\)). Hand weeding (WMP\(_1\)) was significantly superior over WMP\(_2\) but produced comparable grain yield (2012–13) with WMP\(_3\). WMP\(_3\) and WMP\(_2\) gave 53.9% and 52.1% higher mean grain yield over WMP\(_0\).

CEM and WMP interacted significantly with respect to rice grain yield during both years (Table 4). Data reveals that grain yields obtained in order of ZTR > RTDSR > CTR, respectively with all WMP except WMP\(_0\). In general, treatment combinations with CEM and WMP\(_1\), WMP\(_2\) and WMP\(_3\) found statistically similar. This response emphasize that all these weed

2.4 Economic and Statistical Analysis

Economic analysis of treatments was done for individual years by taking into account prevailing prices of inputs and produce. The cost of land preparation, fertilizers, herbicides, weeding, labour, irrigation, harvesting, threshing and winnowing for rice–wheat were worked out on per hectare basis. Gross returns calculated based on minimum support price fixed for rice (Rs 1250 during 2012–13; Rs 1310 during 2013–14) and wheat (Rs 1350 during 2012–13; Rs 1400 during 2013–14). Cultivation cost subtracted from the gross returns to know net returns. System profitability ($ ha\(^{-1}\) day\(^{-1}\)) was worked out by dividing system net returns with 365 days. Analysis of variance (ANOVA) performed on growth parameters, yield attributes, grain and straw yields and, total density and biomass of weeds in rice and wheat. Costat software for split plot design used to determine differences among the treatments. The differences between means were compared using LSD test at $P < 0.05\) [22]. Graphs were prepared by microsoft excel program.
Table 2. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on growth and yield attributes of rice at harvest

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Plant height (cm)</th>
<th>No. of tillers m(^{-2})</th>
<th>Dry matter (g m(^{-2}))</th>
<th>No. of panicles m(^{-2})</th>
<th>Panicle length (cm)</th>
<th>Grains panicle(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CEM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTR (CEM(_1))</td>
<td>110.38</td>
<td>110.95</td>
<td>368.25</td>
<td>369.92</td>
<td>1720.50</td>
<td>1722.42</td>
</tr>
<tr>
<td>CTR (CEM(_2))</td>
<td>110.94</td>
<td>111.30</td>
<td>369.58</td>
<td>371.17</td>
<td>1721.75</td>
<td>1725.00</td>
</tr>
<tr>
<td>RTDSR (CEM(_3))</td>
<td>109.64</td>
<td>110.00</td>
<td>382.67</td>
<td>385.67</td>
<td>1689.75</td>
<td>1716.75</td>
</tr>
<tr>
<td>ZTR (CEM(_4))</td>
<td>112.02</td>
<td>112.67</td>
<td>388.50</td>
<td>393.83</td>
<td>1719.00</td>
<td>1836.00</td>
</tr>
<tr>
<td>S Em±</td>
<td>1.08</td>
<td>0.81</td>
<td>5.28</td>
<td>5.74</td>
<td>38.60</td>
<td>42.37</td>
</tr>
<tr>
<td>LSD ((P = 0.05))</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td><strong>WMP</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WMP(_0)</td>
<td>100.21</td>
<td>100.73</td>
<td>296.67</td>
<td>301.50</td>
<td>1387.75</td>
<td>1436.42</td>
</tr>
<tr>
<td>WMP(_1)</td>
<td>116.69</td>
<td>116.95</td>
<td>408.25</td>
<td>410.50</td>
<td>1884.25</td>
<td>1914.42</td>
</tr>
<tr>
<td>WMP(_2)</td>
<td>112.08</td>
<td>112.92</td>
<td>400.83</td>
<td>402.42</td>
<td>1767.42</td>
<td>1803.33</td>
</tr>
<tr>
<td>WMP(_3)</td>
<td>113.90</td>
<td>114.32</td>
<td>403.25</td>
<td>406.17</td>
<td>1811.58</td>
<td>1846.00</td>
</tr>
<tr>
<td>S Em±</td>
<td>0.70</td>
<td>0.66</td>
<td>3.11</td>
<td>2.52</td>
<td>18.82</td>
<td>17.09</td>
</tr>
<tr>
<td>LSD ((P = 0.05))</td>
<td>2.04</td>
<td>1.92</td>
<td>9.08</td>
<td>7.36</td>
<td>54.92</td>
<td>49.87</td>
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<tr>
<td>Interaction</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

LSD, Least significant difference; NS, non-significant; S Em±, standard error of mean
Table 3. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on rice yields

<table>
<thead>
<tr>
<th>Treatments</th>
<th>CEM</th>
<th>CTR (CEM₁)</th>
<th>CTR (CEM₂)</th>
<th>RTDSR (CEM₃)</th>
<th>ZTR (CEM₄)</th>
<th>CTR (CEM₁)</th>
<th>CTR (CEM₂)</th>
<th>RTDSR(CEM₃)</th>
<th>ZTR (CEM₄)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM</td>
<td></td>
<td>22.55</td>
<td>22.56</td>
<td>4895</td>
<td>4915</td>
<td>6635</td>
<td>6648</td>
<td>42.25</td>
<td>42.29</td>
</tr>
<tr>
<td>CTR (CEM₁)</td>
<td></td>
<td>22.55</td>
<td>22.56</td>
<td>4901</td>
<td>4925</td>
<td>6650</td>
<td>6662</td>
<td>42.25</td>
<td>42.30</td>
</tr>
<tr>
<td>CTR (CEM₂)</td>
<td></td>
<td>22.45</td>
<td>22.48</td>
<td>4759</td>
<td>4809</td>
<td>6495</td>
<td>6563</td>
<td>41.73</td>
<td>41.76</td>
</tr>
<tr>
<td>RTDSR (CEM₃)</td>
<td></td>
<td>22.56</td>
<td>22.57</td>
<td>4873</td>
<td>4996</td>
<td>6580</td>
<td>6752</td>
<td>42.12</td>
<td>42.48</td>
</tr>
<tr>
<td>ZTR (CEM₄)</td>
<td></td>
<td>0.04</td>
<td>0.03</td>
<td>64</td>
<td>72</td>
<td>88</td>
<td>89</td>
<td>0.22</td>
<td>0.28</td>
</tr>
<tr>
<td>S Em±</td>
<td></td>
<td>0.04</td>
<td>0.03</td>
<td>64</td>
<td>72</td>
<td>88</td>
<td>89</td>
<td>0.22</td>
<td>0.28</td>
</tr>
<tr>
<td>LSD (P = 0.05)</td>
<td></td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Table 4. Interaction effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on grain yield of rice

<table>
<thead>
<tr>
<th>Treatments</th>
<th>CTR (CEM₁)</th>
<th>CTR (CEM₂)</th>
<th>RTDSR (CEM₃)</th>
<th>ZTR (CEM₄)</th>
<th>CTR(CEM₁)</th>
<th>CTR (CEM₂)</th>
<th>RTDSR(CEM₃)</th>
<th>ZTR (CEM₄)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMP₀</td>
<td>3740</td>
<td>3744</td>
<td>2966</td>
<td>3227</td>
<td>3757</td>
<td>3783</td>
<td>3033</td>
<td>3533</td>
</tr>
<tr>
<td>WMP₁</td>
<td>5360</td>
<td>5366</td>
<td>5487</td>
<td>5517</td>
<td>5377</td>
<td>5380</td>
<td>5500</td>
<td>5532</td>
</tr>
<tr>
<td>WMP₂</td>
<td>5216</td>
<td>5224</td>
<td>5240</td>
<td>5346</td>
<td>5240</td>
<td>5245</td>
<td>5310</td>
<td>5440</td>
</tr>
<tr>
<td>WMP₃</td>
<td>5263</td>
<td>5270</td>
<td>5343</td>
<td>5403</td>
<td>5287</td>
<td>5292</td>
<td>5393</td>
<td>5480</td>
</tr>
<tr>
<td>S Em±</td>
<td>97</td>
<td>105</td>
<td>283</td>
<td>98</td>
<td>112</td>
<td>308</td>
<td>327</td>
<td></td>
</tr>
<tr>
<td>LSD (P = 0.05)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at P < 0.05; LSD, Least significant difference; NS, non-significant; S Em±, standard error of mean

LSD, Least significant difference; NS, non-significant; S Em±, standard error of mean
management practices are equally effective irrespective of CEM. Weedy check plots produced higher yields under CTR than ZTR and RTDSR. Weed suppression due to puddling operation and impounded water is obvious. Application of bis + azim in ZTR gave highest grain yield while minimum recorded with weedy check in RTDSR.

3.2 Total Biomass and Density of Weeds in Rice

Total biomass (Fig. 1) and density (Fig. 2) of weeds significantly varied due to CEM and WMP during both the years. Minimum values noted in CTR (CEM₁ and CEM₂) while significantly highest values with RTDSR at 20, 40 and 60 DAT. ZTR exhibited slightly higher but comparable values with CTR. During initial growth (20 DAS/DAT) PE and POE of pendim persons/bis (WMP₃) and at later phase (40 and 60 DAS/DAT) POE combination of bis + azim (WMP₄) most effectively reduced total biomass and density of weeds during both years.

3.3 Wheat Growth Parameters, Yield Attributes and Yield

Various CEM caused significant differences in plant height and dry matter accumulation of wheat at harvest however, tillers m⁻² remained unaffected during both years (Table 5). Different ZTW plots (CEM₁, CEM₂ and CEM₃) exerted similar effect and recorded significantly greater plant height and dry matter accumulation over conventional practice (CTW). Such findings indicate that adoption of conventional CEM for both crops in a rice–wheat system reduces growth of wheat plants. However, ZTW grown after ZTR led to greater plant height and dry matter accumulation fb RTDSR. Growth parameters viz. plant height, tillers m⁻² and dry matter accumulation at harvest varied significantly by WMP. Highest values for above parameters noted with WMP₁ closely followed and at par with WMP₂ and WMP₃. However, significantly taller plants produced by WMP₁ over other WMP.

Yield attributes and yields had significant differences because of CEM except harvest index. Spikes m⁻², spike length and grains spike⁻¹ significantly reduced by conventional till broadcasted wheat (CTW) grown after CTR (CEM₄) than rest CEM. Yield attributes of all zero till wheat plots (CEM₂, CEM₃ and CEM₄) observed at par (Table 5) irrespective of CEM followed in rice (CTR, RTDSR and ZTR).

Adoption of double zero till in rice–wheat system (CEM₄) produced highest 1000 grain weight, grain and straw yields of wheat (Table 6). Mean grain yield of wheat under CEM₄ was 7.5% higher over CTW (CEM₁). Yield attributes, grain and straw yields followed the order CEM₄ > CEM₃ > CEM₂ > CEM₁ during both years.

Yield attributes, grain and straw yields also differed significantly due to WMP during both years (Tables 5 and 6). Application of clodinofop at 60 g ha⁻¹ + carfentrazone at 20 g ha⁻¹ + NIS (0.25%) (WMP₄) was next best treatment after weed free (WMP₁) recorded highest yield attributes (spikes m⁻², spike length, grains spike⁻¹ and 1000 grain weight), grain and straw yields. The sulfosulfuron 25 g ha⁻¹ + metosulfuron 4 g ha⁻¹ + NIS (0.25%) (WMP₅) ranked third in overall performance. Although, above WMP could not vary significantly and proved superior to weedy check only (WMP₀). Similar pattern noted for harvest index during both years. WMP₃ and WMP₅ produced mean grain yield 23.5% and 22.6% higher over WMP₀.

3.4 Total Biomass and Density of Weeds in Wheat

Crop establishment methods had significant effect on total biomass (Fig. 3) and density (Fig. 4) of weeds at 20, 40 and 60 DAS during both the years. ZTW after ZTR (CEM₄) caused significant and effective reduction in total biomass and density of weeds than other CEM at all stages (Figs. 3 and 4). On contrary, CTW–CTR (CEM₁) recorded significantly highest total biomass and density of weeds during both years.

WMP exerted significant effect on total biomass and density of weeds at 20, 40 and 60 DAS with highest values recorded in weedy check plots (Fig. 3 and 4). Values for above parameters were significantly lowest with use of sulf + met (20 DAS). Similar response recorded with clod + car at 40 and 60 DAS. Total biomass and density of weeds were comparatively higher during first year (2012–13) than second year (2013–14).

3.5 Economic Analysis of Rice–wheat System

Rice–wheat system (CEM₄) registered highest gross return, net return and B: C ratio among various CEM during both years (Fig. 5), while lowest values recorded with CTR–CTW (CEM₁). Economic analysis followed the order CEM₄ > CEM₃ > CEM₂ > CEM₁. Double ZT (ZTR–ZTW)
Fig. 1. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on total weed biomass in rice
Fig. 2. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on total density of weeds in rice
Fig. 3. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on total biomass of weeds in wheat.
Fig. 4. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on total density of weeds in wheat
enhanced mean net return (16\%) and benefit: cost ratio (38.3\%) over CTR–CTW (CEM\(_1\)). Among WMP, use of bis + azim in rice and clod + carf in wheat (WMP\(_2\)) recorded highest gross return, net return and B: C ratio. Application of pendi fb bis in rice and sulf + met in wheat (WMP\(_3\)) was next best treatment during both years. Net return followed the order WMP\(_3\) > WMP\(_2\) > WMP\(_1\) > WMP\(_0\) while the benefit: cost ratio order was WMP\(_2\) > WMP\(_3\) > WMP\(_0\) > WMP\(_1\).
3.6 System Productivity and Profitability

System productivity did not differ due to CEM during 2012–13 (Fig. 6). During 2013–14, double ZT (CEM4) resulted highest system productivity but was superior only to conventional planting (CEM1). Other methods (CEM2 and CEM3) gave almost similar system productivity. Conventional planting of rice and wheat (CEM1) lowered system productivity by 2.3%, 1.7% and 4.7% than CEM2, CEM3 and CEM4, respectively in second year (2013–14). ZTR–ZTW (CEM4) recorded highest system productivity during both years (Fig. 6) with 15.9% higher mean profitability than CEM1.

After weed free (WMP1), the second highest system productivity recorded with WMP3 (bis + azim in rice and clod + carf in wheat) at par with WMP2 (pendi fb bis in rice–sulf + met in wheat) during both years of study (Fig. 6). WMP3 and WMP2 produced 37.3% and 36.1% higher mean system productivity over WMP0, respectively. WMP3 gave highest system profitability fb WMP2 and the lowest was with WMP0. The increment in mean system profitability by WMP3 and WMP2 was to the extent of 39.2% and 38.7% over weed free check (WMP0). Statistically WMP3 and WMP2 provided equivalent system productivity but both were superior to weed free check (WMP0).

4. DISCUSSION

4.1 Rice Growth Parameters, Yield Attributes and Yield

Rice growth parameters, yield attributes and yield were higher with ZTR. Similar or high yield attributes and yield by ZTR in comparison to CTR reported by earlier researchers [23,24]. Higher weed control efficiency under combination of pre emergence (PE) and post emergence (POE) applied herbicides (pendi fb bis) or POE (bis + azim) confronted minimum weeds competition for moisture, nutrient, light and space. [25-27] reported that application of pendimethalin (PE) fb bispyribac or azimsulfuron or bis + azim (POE) at 15–20 DAS yielded similar to weed free condition.

4.2 Total Biomass and Density of Weeds in Rice

Crop establishment in rice is most critical since influences total density and biomass of weeds. Effective weed killing by puddling operation and continued submergence of ± 5 cm water reduced total density and biomass of weeds in CTR. [28] reported minimum weed density in transplanted rice than dry DSR. Herbicides (WMP2 and WMP3) exhibited similar capability to reduce total density and biomass of weeds at 20, 40 and 60 DAS during both years. However, the combination bis + azim were most promising; bispyribac controlled annual grasses effectively while perennial grasses, sedges, broad leaf weeds were controlled by azimsulfuron. [26,27] also reported that application of tank-mix bispyribac 25 g ha⁻¹ with azimsulfuron 20 g ha⁻¹ provided excellent control of complex weed flora.

4.3 Wheat Growth Parameters, Yield Attributes and Yield

Favourable climatic conditions during second year enhanced growth, yield attributes, grain and straw yields of wheat. Cumulative effect of rainfall and prevalence of low temperatures during February to March (data not shown) favoured spike and grain development. Delayed planting of CTW after CTR (CEM1) results poor crop performance. However, early harvesting of DSR plots (ZTR and RTDSR) facilitated timely planting of ZTW (CEM1 and CEM3) than in CTR plots which in turn increased wheat yields. Late harvesting of transplanted rice is attributed to transplanting shock [29]. Yield decrement of 1% reported in IGP for each day delay in wheat sowing after optimum time i.e. November 15 [4]. Timely sown crop received congenial soil and canopy temperature for favourable root and shoot growth which enhanced light interception and dry matter production, tillers, grains ear⁻¹ and 1000 grain weight finally converted into higher yield by ZTW than CTW. [30,31] reported higher yields of ZTW sown after DSR than CTW. Application of clod + carf at 30–35 DAS manifest superior growth, yield attributes, and yields due to higher weed control efficiency which reduced competition for moisture, nutrients, light and space. These results are in conformity with [32,33].

4.4 Total Biomass and Density of Weeds in Wheat

Residue retained on soil surface might have reduced germination of weed seeds and their growth; absence of inter-row soil disturbance caused minimal and late emergence of weeds. Similar findings were reported by [34,35]. Repeated ploughing in CTW caused surfacing of weed seeds and facilitated conditions for higher weed emergence. These results are similar to...
Table 5. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on growth and yield attributes of wheat at harvest

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Plant height (cm)</th>
<th>No. of tillers m²</th>
<th>Dry matter (g m⁻²)</th>
<th>No. of spikes m²</th>
<th>Spike length (cm)</th>
<th>Grains spike⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTW (CEM₁)</td>
<td>84.05</td>
<td>84.55</td>
<td>418.33</td>
<td>423.75</td>
<td>1135.75</td>
<td>1143.17</td>
</tr>
<tr>
<td>ZTW (CEM₂)</td>
<td>88.15</td>
<td>88.58</td>
<td>432.42</td>
<td>436.83</td>
<td>1288.42</td>
<td>1292.92</td>
</tr>
<tr>
<td>ZTW (CEM₃)</td>
<td>88.73</td>
<td>88.95</td>
<td>435.33</td>
<td>439.58</td>
<td>1291.08</td>
<td>1296.25</td>
</tr>
<tr>
<td>ZTW (CEM₄)</td>
<td>90.83</td>
<td>91.39</td>
<td>442.33</td>
<td>447.67</td>
<td>1302.50</td>
<td>1311.25</td>
</tr>
<tr>
<td>S Em±</td>
<td>1.30</td>
<td>1.11</td>
<td>3.98</td>
<td>4.70</td>
<td>30.68</td>
<td>24.29</td>
</tr>
<tr>
<td>LSD (P = 0.05)</td>
<td>4.49</td>
<td>3.85</td>
<td>NS</td>
<td>NS</td>
<td>106.17</td>
<td>84.05</td>
</tr>
</tbody>
</table>

WMP

<table>
<thead>
<tr>
<th>Treatments</th>
<th>1000 grain weight (g)</th>
<th>Grain yield (kg ha⁻¹)</th>
<th>Straw yield (kg ha⁻¹)</th>
<th>Harvest index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTW (CEM₁)</td>
<td>41.06</td>
<td>41.12</td>
<td>4374</td>
<td>4413</td>
</tr>
<tr>
<td>ZTW (CEM₂)</td>
<td>42.00</td>
<td>42.05</td>
<td>4569</td>
<td>4616</td>
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<tr>
<td>ZTW (CEM₃)</td>
<td>42.07</td>
<td>42.12</td>
<td>4607</td>
<td>4671</td>
</tr>
<tr>
<td>ZTW (CEM₄)</td>
<td>42.46</td>
<td>42.54</td>
<td>4678</td>
<td>4765</td>
</tr>
<tr>
<td>S Em±</td>
<td>0.24</td>
<td>0.22</td>
<td>58</td>
<td>59</td>
</tr>
<tr>
<td>LSD (P = 0.05)</td>
<td>0.82</td>
<td>0.75</td>
<td>200</td>
<td>204</td>
</tr>
</tbody>
</table>

WMP

<table>
<thead>
<tr>
<th>Treatments</th>
<th>1000 grain weight (g)</th>
<th>Grain yield (kg ha⁻¹)</th>
<th>Straw yield (kg ha⁻¹)</th>
<th>Harvest index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMP₀</td>
<td>39.47</td>
<td>39.52</td>
<td>3844</td>
<td>3932</td>
</tr>
<tr>
<td>WMP₁</td>
<td>43.02</td>
<td>43.07</td>
<td>4876</td>
<td>4901</td>
</tr>
</tbody>
</table>

LSD, Least significant difference; NS, non-significant; S Em±, standard error of mean.
<table>
<thead>
<tr>
<th>Treatments</th>
<th>1000 grain weight (g)</th>
<th>Grain yield (kg ha⁻¹)</th>
<th>Straw yield (kg ha⁻¹)</th>
<th>Harvest index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMP₂</td>
<td>42.54</td>
<td>42.60</td>
<td>4734</td>
<td>4801</td>
</tr>
<tr>
<td>WMP₃</td>
<td>42.56</td>
<td>42.64</td>
<td>4773</td>
<td>4831</td>
</tr>
<tr>
<td>S Em±</td>
<td>0.18</td>
<td>0.16</td>
<td>52</td>
<td>49</td>
</tr>
<tr>
<td>LSD (P = 0.05)</td>
<td>0.52</td>
<td>0.47</td>
<td>153</td>
<td>142</td>
</tr>
<tr>
<td>Interaction</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

LSD, Least significant difference; NS, non-significant; S Em±, standard error of mean
that of [36]. Combined effect of CEM and WMP adopted from first year seems more pronounced during second year. Further, the weather prevailed during second year was more congenial resulted higher vigour which smothered weeds to a greater extent. Application of clod + carf at 30–35 DAS minimized total density and biomass of weeds at 40 and 60 DAS. Actually efficient control of grassy weeds by clodinofop and other complex weed flora done by carfentrazone. Previous studies by [32,33] also reported similar findings.

4.5 Economic Analysis of Rice–wheat System

Transplanted rice traditionally grown in IGP is labour and energy intensive often delays planting of succeeding wheat crop. Hence, ZT may save time and energy to the considerable extent. These findings are duly supported by other workers [10,12,17]. Technology adoption in modern agriculture largely depends on its economic viability and increased cost of CEM may lower economic returns [37]. Conservation tillage facilitates reduction in labour and eliminates several operations. Maximum reduction in tillage operations occurs with double zero tillage system (CEM$_4$) which evinced its economic feasibility in terms of gross return, net return and benefit: cost ratio over conventional till rice–wheat system (CEM$_1$). Such response is obvious because of better yields, significant saving of labour and reduced cost of cultivation. These findings are in agree with [1,38], [39] recommended replacement of conventional till rice-wheat system with zero tillage method to save labour, energy and for effective weed control. Use of herbicides (WMP$_3$) in rice – wheat system exhibited highest gross return, net return and benefit: cost ratio due to efficient weed control and higher system productivity.

4.6 System Productivity and Profitability

Double ZT provide stable and higher yield over CTR [1,40]. Further, steady increase in rice and wheat grain yield noticed with early maturity of crops. Lower system productivity of conventional method was due to delay in rice harvest and subsequent late planting of wheat resulted heat stress at later phase of crop. Effective CEM caused lesser weed density and dry weight resulted higher system productivity. Continuous severe weed competition caused inferior performance by weedy check. Appropriate herbicides for rice–wheat system ensued efficient control of complex weed flora contributed higher economic yield of crops. Findings of [26,27] in rice and [32,33] in wheat are in same line. Continuous ZT gives significantly higher system yields than continuous conventional or rotational tillage regardless of weed control methods [39].

5. CONCLUSION

Rice–wheat cropping system plays crucial role in economy and food security of several South Asian countries including India. Findings of two years study indicate the usefulness of the new technologies of crop establishment. Double zero till is the most promising option to address the emerging challenges in rice–wheat systems of IGP. In nutshell, it is concluded that adoption of double zero tillage enhances system productivity, profitability and is superior over conventional till rice-wheat system (farmers practice). Hence, zero tillage crop establishment method be adopted in rice–wheat system with application of bispyribac at 25 g ha$^{-1}$ + azimsulfuron at 35 g ha$^{-1}$ + NIS (0.25%) at 20 DAS in rice and clodinofop at 60 g ha$^{-1}$ + carfentrazone at 20 g ha$^{-1}$ + NIS (0.25%) at 30–35 DAS in wheat to achieve higher yield, system productivity and profitability in the Indo Gangetic Plains.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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3. Boparai BS, Singh Y, Sharma BD. Effect of green manuring with Sesbania aculeate on physical properties of soil and on growth of wheat in rice-wheat cropping systems in a


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