


## Article

# Response of Rice to Tillage, Wheat Residue and Weed Management in a Rice-Wheat Cropping System

Bisheshwor P. Pandey<sup>1</sup> and Tanka P. Kandel<sup>2,\*</sup> <sup>1</sup> National Wheat Research Program (NWRP), Rupandehi, Nepal; bisheshworpandey2009@gmail.com<sup>2</sup> Noble Research Institute, LLC, Ardmore, OK 73401, USA

\* Correspondence: tanka.kandel@okstate.edu

Received: 23 September 2020; Accepted: 2 November 2020; Published: 7 November 2020



**Abstract:** In Nepal and elsewhere in the Indo-Gangetic plains where rice-wheat is a major crop rotation, interest in conservation practices such as direct-seeding of rice on zero-tilled soil and retention of crop residue is increasing. However, the use of herbicide is increasing in the region due to a shortage of labor and its ease of operation compared to manual weeding. This field experiment was conducted to identify the response of rice to tillage and planting systems, level of wheat residue retention and weed managements under rice-wheat cropping system. This study was conducted during three growing seasons of rice (June through November) in 2014, 2015 and 2016 at the National Wheat Research Program (NWRP), Rupandehi, Nepal. The experiment was conducted in a split-split plot design. Tillage and planting systems were the main plots where rice was either transplanted on puddled field managed with conventional tillage (CT) or direct seeded on zero till (ZT) soil. The level of residue retention was the sub-plot which included three levels of residue retention as whole (WR), partial (PR) or no (NR) retention. Forms of weed management were the sub-sub plots with manual weeding (MW) compared with chemical weeding (CW) through the application of bispyribac-sodium. Each treatment combination consisted of three replicated units. Averaged across the years, grain yield of rice under the CT system ( $4.8 \text{ t ha}^{-1}$ ) was significantly higher than ZT ( $4.4 \text{ t ha}^{-1}$ ). Increased level of wheat residue retention increased grain yield consistently in all three years. Grain yield was not influenced by systems of weed management. The following conclusions were drawn from the results: (i) rice grain yield might decrease under a direct-seeded ZT system more than the conventional system, (ii) wheat residue retained in the field can increase rice grain yield significantly, and (iii) application of bispyribac-sodium could be equally effective as manual weeding for weed control in both tillage/planting systems of rice.

**Keywords:** tillage; wheat residue; weed management; grain yield

## 1. Introduction

Rice (*Oryza sativa* L.) is a principal source of food for more than half of the world population, and ranks third as an agricultural commodity after sugarcane and maize [1]. Rice contributes one-fifth of total caloric intake by human beings making it an important grain. More than 90% of rice worldwide is grown and consumed in Asia [2]. In Nepal, rice is the first most important cereal crop with 1.36 million hectares of cultivated area with a productivity of  $3.15 \text{ t ha}^{-1}$  in 2016 [3].

Rice-wheat (*Triticum aestivum* L.) is a major crop rotation in the Indo-Gangetic Plains (IGP) of South Asia that spreads over 13.5 million ha in Bangladesh, India, Nepal and Pakistan [4]. As both crops exhaustively uptake large amounts of nutrients and most of the nutrients in the plants are removed from the fields as harvested crop, the double cropping system heavily depletes soil nutrients [5,6]. However, if crop residues are retained in the soil, a large proportion of nutrients taken from the soil are retained in the ecosystem which might help to maintain the fertility of the soil [7]. Additionally,

the retained residue can increase soil organic carbon and overall soil health [8,9]. Rice and wheat residue in the region are traditionally used for feeding animals. However, in recent decades, a large volume of crop residue is left in during mechanical harvesting which is burned to ease planting of following crop. However, burning crop residues is not a sustainable practice since it generally accelerates the loss of soil carbon, increases emissions of CO<sub>2</sub> and increases air pollution [10].

Traditionally, lowland rice in Nepal and elsewhere in the IGP is transplanted into puddled field soil after repeated ploughing. Puddling reduces percolation loss of water, controls weeds, eases planting of seedlings and decreases the loss of soil carbon as carbon dioxide [11–13]. However, conventional tillage practices for puddling can destroy soil aggregates, form plough pan in the subsurface layers, and may increase the loss of soil and nutrients as runoff [14]. Also, puddling is a labor- and cost-intensive practice which may increase the cost and reduce profits [15]. Therefore, as an alternative to conventional puddling, there is increased interest in direct seeded rice as it might contribute to reducing the cost of cultivation while conserving water, soil and other resources incurred in cultivation [13,15].

Weed management is a major challenge for no-till direct seed rice cultivation but the availability and use of herbicides in the IGP are increasing rapidly which may increase the adoption of direct seeded rice cultivation [13]. Farm sizes in Nepal are generally very small (less than one hectare) which makes it feasible to manually weed rice and wheat crops. However, in recent decades a large portion of the working population has emigrated creating a labor shortage in the farming sector. The labor shortage and ease of operation has increased exponential use of herbicide use in the country. However, the effectiveness and management options of herbicide in comparisons to manual weeding is scarcely evaluated.

Many field studies were conducted in the IGP during the last two decades to understand tillage, residue and weed managements on the yield of wheat grains [13,16,17]. However, field trials were mostly conducted in India and Pakistan. Thus, the influence of tillage systems, residue retention and weed managements on growth, yield and yield attributes of rice in the Southern Nepal, which is considered as a grain bowl of the country, are scarce. Therefore, this field study was conducted to compare tillage systems (zero and conventional tillage), rice residue retention (whole, partial and no-retention), and forms of weed management (manual and chemical) on yield and yield attributes of rice. These hypotheses were tested in this study: (i) direct seeded rice on zero-tilled soil would produce similar yield as transplanted rice on conventionally tilled puddled field, (ii) rice yield would increase with increased level of wheat residue retention, and (iii) herbicide application will be equally effective as manual weeding in rice.

## 2. Materials and Methods

### 2.1. Study Area and Environmental Materials

A field experiment was conducted at the research farm (27°31'49'' N, 83°27'36'' E and 82 m above sea level) of the National Wheat Research Program (NWRP) in Bhairahawa, Nepal. The climate is of sub-tropical type with three distinct seasons as summer, rainy and winter. Detailed descriptions of soil physical and chemical properties are given elsewhere [18]. In brief, the texture is classified as silt loam to silty clay loam. Total soil organic matter content was 2.5% and total N content was 0.14%. The soil was mildly alkaline, with an average soil pH of 7.9. This study site lies within C-block of the NWRP farm map [18].

The field experiment was conducted over three main rice growing seasons (June through November) of Nepal during 2014, 2015 and 2016 which are defined as Year-1, Year-2 and Year-3, respectively in the following descriptions.

### 2.2. Experimental Design and Crop Management

The experiment was designed as nested split-split plots in a completely randomized design. Tillage and planting systems were the main plots where rice was either transplanted on puddled field

managed with conventional tillage (CT) or direct seeded on zero till (ZT) soil. Main plots were split into sub-plots at three levels of wheat residue management treatment as whole (WR), partial (PR) and no (NR) residue retention. In WR management, all aboveground residues of wheat were chopped, stored in bags, and later used as mulching material during the vegetative stage of rice. In PR management, the bottom 20 cm of the wheat plant was left in the field. In NR management, all wheat residue was removed. Forms of weed management were the sub-sub plots with manual weeding (MW) was compared with chemical weeding (CW) with application of bispyribac-sodium. Thus, there were a total of 12 treatment combinations with 3 replicated plots (4m × 4m) in each combination.

Wheat was harvested in April in all the three years of study. After wheat harvest, rice (cv. Sabitri) was transplanted/sown at 0.2 m × 0.2 m spacing. Sabitri cultivar was released in 1979 and recommended for Terai and the inner Terai region of Nepal. Two to three seedlings per hill were transplanted in the CT system. Rice was sown/transplanted in an east–west row direction. The number of rows per plot were 20. Grain yield was determined on the central 12 lines comprising a net plot area of 9.6 m<sup>2</sup>.

Timelines of field operations during the rice cultivation are presented in Supplementary Table S1. The plots were irrigated 3–5 times in each study year. In each irrigation event, all plots were flooded with water till the water height reaches up to 5–7 cm above the soil surface. All plots received inorganic fertilizer at the rate of 100:30:30 kg N: P: K (nitrogen, phosphorus, potash) ha<sup>−1</sup> at transplanting/sowing of rice as urea (46:0:0 N:P:K), di-ammonium phosphate (18:46:0 N:P:K) and muriate of potash (0:0:60 N:P:K). Half a dose of the N and full doses of P and K fertilizers were applied during transplanting/sowing of rice. The remaining half dose of N was applied as urea by equally splitting at 25 and 45 days after transplanting/sowing. Glyphosate (1 kg active ingredient ha<sup>−1</sup>) was sprayed in ZT plots prior to sowing of rice. Weeds in CW plots were controlled with spraying bispyribac-sodium (Nominee gold®, PI Industries, Gurgaon, India) at the rate of 0.025 kg active ingredient ha<sup>−1</sup> during the crop growing period of rice.

### 2.3. Measurement of Plant Growth and Yield Traits

Heading and physiological maturity was recorded on marked 50 plants. A particular stage was supposed to be completed while 75% of the observed plants show the characteristics of that phase and number of days were counted from the date of soaking the rice seed in water for sprouting in CT. In ZT, phenological stages were counted from the date of sowing. Plant height and panicle length and number of grains per panicle were measured from 10 randomly selected plants per plot at physiological maturity. Number of effective tillers per square meter were counted at physiological maturity stage from 1m<sup>2</sup> areas in each plot. After final harvesting, the crop was sun dried, threshed, cleaned and grain was sun dried again. Grain yield was adjusted at 14% moisture since the grain was sun dried instead of oven drying. Thousand grain weight was determined by weighing 1000 grains resulted from each plot.

### 2.4. Statistical Analysis

Effect of tillage, residue and weed managements and their interactions were analyzed by analysis of variance (ANOVA) using a PROC GLIMMIX procedure in SAS software (version 9.3, Cary, NC, USA). Each dependent variable were analyzed with tillage system as the main factor, residue retention as the split factor, and weed control method as a split-split factor. All data for each measurement were combined across years, and years were treated as repeated measurement applying the autoregressive term AR(1). Block was treated as random variable with two- and three-way interactions with tillage and residue retention treatments. Measurements of plant height, panicle length and number of grains per panicle taken on multiple plants per plot were averaged prior to statistical analysis. Results are presented for each year and averaged across years since year × treatment interactions were significant for most of the measurements. Mean separation to compare treatments, years, and treatments for each year was done by least significant difference (LSD) method at the 5% probability level using the simulation option available in the LINES statement of PROC GLIMMIX.

### 3. Results

Monthly temperature and precipitation of the three rice growing seasons in comparison to long-term data are presented in Supplementary Figure S1. Whereas total precipitation during rice growing season in Year-1 (1234 mm) and Year-3 (1684 mm) were close to the long-term average precipitation (1550 mm), Year-2 (870 mm) was particularly dry. Average maximum temperature during the rice growing season remained between 33.0 to 34.5 °C while average minimum temperature ranged between 23.2 to 24.9 °C. Average minimum temperature in Year-3 during August–November were particularly higher than in the previous years.

#### 3.1. Plant Height and Tiller Numbers

Averaged across the year, plant height was not influenced by tillage systems (Tables 1 and 2). However, plant height was influenced by residue retention rate as WR retention management had the tallest and NR management had the shortest plants in all year (Tables 1 and 2). Averaged across three years, the method of weed management did not affect plant height of rice but plants at MW management were slightly taller than CW management in Year-2.

**Table 1.** Significance (*P*-values) of the effects of year, tillage, residue and weed managements and their interactions on yield and yield attributes of rice. The *P*-values are presented with bold fonts if analysis of variance showed significance difference ( $P < 0.05$ ). TGW: 1000 grain weight.

Effect	Plant Height	Tiller Number	Days to Heading	Days to Maturity	Ear-Head Length	TGW	Grain/Ear-Head	Grain Yield
Year	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.01</b>
Tillage	0.20	0.05	0.09	0.08	<b>0.03</b>	<b>0.02</b>	<b>0.03</b>	<b>0.02</b>
Residue	<b>0.00</b>	<b>0.05</b>	<b>0.01</b>	<b>0.01</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>
Weed	0.08	0.25	<b>0.01</b>	0.06	<b>0.03</b>	0.08	<b>0.04</b>	0.19
Year×Tillage	0.30	<b>0.03</b>	0.17	<b>0.03</b>	<b>0.00</b>	0.15	<b>0.00</b>	0.48
Year×Residue	<b>0.00</b>	0.54	<b>0.00</b>	<b>0.04</b>	0.23	0.58	0.22	0.90
Year×Weed	0.08	0.30	0.52	<b>0.02</b>	0.90	0.83	0.29	0.84
Tillage×Residue	0.86	0.50	0.26	0.45	0.92	0.44	0.94	0.52
Tillage×Weed	0.72	0.84	0.19	0.54	0.95	0.33	0.75	0.93
Residue×Weed	0.93	0.89	0.31	0.96	0.74	0.50	1.00	0.86
Tillage×Residue×Weed	0.99	0.90	0.69	0.96	0.70	0.46	0.98	0.64
Year×Tillage×Residue	0.31	0.83	<b>0.03</b>	0.60	<b>0.01</b>	0.75	0.58	0.67
Year×Tillage×Weed	0.56	0.80	0.98	0.19	0.99	0.55	0.95	0.89
Year×Residue×Weed	0.60	0.99	0.66	0.81	0.71	0.91	0.98	0.96
Year×Tillage×Residue×Weed	0.96	0.98	0.98	0.79	0.79	0.85	0.75	0.88

**Table 2.** Effects of different tillage, crop residue and weeding management on plant height and tiller numbers of rice. Different lowercase letters within a column indicate significant difference with a treatment. Different uppercase letter within a row for annual mean values (last row) indicate significant difference among the study years.

Treatment	Plant Height (cm)				Effective Tiller Number m <sup>-2</sup>			
	Year-1	Year-2	Year-3	Avg.	Year-1	Year-2	Year-3	Avg.
Tillage practice								
Conventional (CT)	98.4	105.5a	106.0	103.3	261.4a	329.8a	289.8a	293.7
Zero tillage (ZT)	97.6	104.1b	104.8	102.1	244.5b	288.8b	271.2b	268.2
Rice residue management								
Whole retention (WR)	98.8a	106.4a	106.6a	103.9a	261.4a	326.1a	286.8	291.4a
Partial retention (PR)	98.0ab	104.9b	105.2b	102.7b	251.3ab	304.5b	280.2	278.6ab
No retention (NR)	97.2b	103.0c	104.4b	101.5c	246.3b	297.3b	274.5	272.7b
Weed management								
Manual (MW)	98.1	105.4a	105.7	103.1	257.0	316.3a	282.2	285.2
Chemical (CW)	97.9	104.3b	105.1	102.4	248.9	302.3b	278.8	276.7
Annual mean	98.0C	104.8B	105.4A		253.0C	309.3A	280.5B	

Tillage system significantly affected effective tiller number in individual years as CT system had significantly more effective tillers than in ZT system in individual years but the influence was not

significant while averaging across the years (Tables 1 and 2). Wheat residue management significantly affected effective tillers per square meter of rice in Year-1 and Year-2 as WR management produced significantly greater tiller numbers than NR management (Tables 1 and 2). Weed management method did not influence tillage number (Tables 1 and 2). Averaged across the treatments, plants had the lowest number of effective tillers in Year-1 and the highest in Year 2.

### 3.2. Days to Heading and Maturity

Averaged across three years, tillage did not influence days to heading, but influenced slightly in Year-1 and Year-2 (Tables 1 and 3). The effect of wheat residue management on days to heading was significant as plants in WR and PR managements reached heading stage earlier than in NR managements. Weed management significantly affected the occurrence of heading of rice in as earlier heading stage was recorded under MW than CW. Although, statistically significantly, the difference in heading stage across various managements were less than 3 days within a year.

**Table 3.** Days to heading and physiological maturity of rice under different tillage, crop residue and weeding managements. Different lowercase letters within a column indicate significant difference with a treatment. Different uppercase letter within a row for annual mean values (last row) indicate significant difference among the study years.

Treatment	Days to Heading				Days to Maturity			
	Year-1	Year-2	Year-3	Avg.	Year-1	Year-2	Year-3	Avg.
Tillage practice								
Conventional (CT)	112.0b	113.3b	109.3	111.5	140.8	140.4b	139.1b	140.1
Zero tillage (ZT)	112.4a	113.8a	109.4	111.9	141.2	141.1a	140.1a	140.8
Rice residue management								
Whole retention (WR)	111.7b	113.0b	108.3c	111.0b	140.5b	140.1c	138.6c	139.7b
Partial retention (PR)	112.0b	113.4b	109.3b	111.6b	140.9ab	140.7bc	139.7b	140.4ab
No retention (NR)	112.9a	114.3a	110.6a	112.6a	141.5a	141.4a	140.4a	141.1a
Weed management								
Manual (MW)	111.9b	113.1b	108.9b	111.3b	140.9	140.3b	139.2b	140.1
Chemical (CW)	112.5a	114.0a	109.8a	112.1a	141.1	141.1a	139.9a	140.7
Annual mean	112.2B	113.6A	109.4C		141.0A	140.7B	139.6C	

Averaged across three years, tillage did not influence days to maturity, but influenced slightly in Year-2 and Year-3 (Tables 1 and 3). Wheat residue management significantly affected days to maturity of rice in all three years. In general, plants reached physiological maturity earlier with increasing level of residue retention. Days to maturity was significantly affected by weed management in Year-2, Year-3 but influence of weed management was not significant when data were averaged across three years.

### 3.3. Yield Attributes of Rice at Harvest

Panicle (ear-head) length was significantly affected by tillage systems in all the three experimental years as ZT had significantly longer panicles than CT (Tables 1 and 4). Wheat residue management significantly affected panicle length of rice in all three years as WR management resulted in longer panicles than NR management. Likewise, weed management had significant influence on panicle length as longer panicles were recorded under MW management than CW management in all three study years.

**Table 4.** Length of ear-head and number of grains/ear-head of rice under different tillage, crop residue and weeding managements. Different lowercase letters within a column indicate significant difference with a treatment. Different uppercase letter within a row for annual mean values (last row) indicate significant difference among the study years.

Treatment	Length of Ear-Head (cm)				No. of Grains/Ear-Head			
	Year-1	Year-2	Year-3	Avg.	Year-1	Year-2	Year-3	Avg.
Tillage practice								
Conventional (CT)	21.0b	21.2b	21.6b	21.3b	113.4b	157.2	121.4	130.7b
Zero tillage (ZT)	21.4a	21.7a	22.5a	21.9a	119.9a	158.9	122.5	133.8a
Rice residue management								
Whole retention (WR)	21.8a	21.9a	22.7a	22.1a	121.1a	163.9a	125.4a	136.8a
Partial retention (PR)	21.1b	21.5a	22.1b	21.6b	116.7b	157.6b	122.0ab	132.1b
No retention (NR)	20.6c	21.0b	21.4c	21.0c	112.3c	152.7c	118.5b	127.8c
Weed management								
Manual (MW)	21.3a	21.6a	22.2a	21.7a	118.2a	158.9	122.9	133.4a
Chemical (CW)	21.0b	21.3b	21.9b	21.4b	115.2b	157.2	121.0	131.1b
Annual mean	21.2C	21.5AB	22.0A		116.7C	158.1A	122.0B	

Tillage system significantly influenced number of grains per panicle in Year-1 and averaged across three years (Tables 1 and 4) as more grains per panicle were recorded under a ZT system. Wheat residue retention rate significantly affected the number of grains per panicle in all the individual years and averaged across three years as WR management resulted in the highest number of grains per panicle and NR management had the lowest number of grains per panicle. Weed management significantly influenced the formation of number of grains per panicle in Year-1 and averaged across three years as MW resulted higher number of grains per panicle than.

The weight of 1000 grains was significantly higher under ZT system than in CT system in all the three experimental years and averaged across the years (Tables 1 and 5). Weight of 1000 grains was significantly influenced by wheat residue retention rate in all the individual years and averaged across three years as WR management resulted the highest 1000 grain weight of rice and NR management resulted in the lowest 1000 grain weight. Overall, weed management did not influence the weight of 1000 grains of rice but 1000 grain weight of rice from MW management was greater than that from CW management.

**Table 5.** Weight of 1000 grains of rice under different tillage, crop residue and weeding managements. Different lowercase letters within a column indicate significant difference with a treatment. Different uppercase letter within a row for annual mean values (last row) indicate significant difference among the study years.

Treatments	Year-1	Year-2	Year-3	Avg.
Tillage practice				
Conventional (CT)	21.6b	19.0b	22.1b	20.9b
Zero tillage (ZT)	22.0a	19.9a	22.8a	21.6a
Rice residue management				
Whole retention (WR)	22.3a	20.1a	23.2a	21.8a
Partial retention (PR)	21.8b	19.4b	22.4b	21.2b
No retention (NR)	21.4b	18.9c	21.8c	20.7c
Weed management				
Manual (MW)	22.0a	19.6	22.6	21.4
Chemical (CW)	21.6b	19.4	22.3	21.1
Annual mean	21.8B	19.5C	22.4A	



### 3.4. Grain Yield

Grain yield was significantly affected by the tillage system all the three experimental years and averaged across three years as higher yield was recorded under CT system than in ZT (Tables 1 and 6). Wheat residue management significantly affected the grain yield of rice in all the individual years and averaged across three years as WR management produced the highest yield and NR management produced the lowest yield. Grain yield was not influenced by weed managements.

**Table 6.** Grain yield of rice ( $\text{t ha}^{-1}$ ) under different tillage, crop residue and weeding management practices. Different lowercase letters within a column indicate significant difference with a treatment. Different uppercase letter within a row for annual mean values (last row) indicate significant difference among the study years.

Treatments	Year-1	Year-2	Year-3	Avg.
Tillage practice				
Conventional (CT)	4.8a	4.6a	5.0a	4.8a
Zero tillage (ZT)	4.3b	4.3b	4.5b	4.4b
Rice residue management				
Whole retention (WR)	4.9a	4.7a	5.1a	4.9a
Partial retention (PR)	4.6b	4.5ab	4.8ab	4.6b
No retention (NR)	4.3b	4.2b	4.4b	4.3c
Weed management				
Manual (MW)	4.6	4.5	4.9	4.7
Chemical (CW)	4.5	4.4	4.7	4.5
Annual mean	4.6AB	4.4B	4.8A	

## 4. Discussion

In this study, we evaluated the influence of tillage system, wheat residue retention rate and method of weed control on growth, yield attributes and grain yield of rice cultivated in the southern plains (Terai) of Nepal under rice-wheat cropping systems. Grain yield of rice cultivated under conventional tillage system was significantly greater (10%) compared to the direct seeded rice in zero-tilled soil. The results on decreased yield of direct seeded rice than transplanted rice in the puddled field under a conventional tillage system aligned with the results from studies in the IGP [4,8,15]. Although the rice grain yield was decreased only by 10%, the system might be more profitable than the conventional puddling-based transplanting methods [15]. Even though the results indicated minimal difference (albeit significant) between the two tillage/planting systems, the adoption of direct seeded rice planting mostly depend on availability of machineries for direct seeding on zero tilled soils. Therefore, stakeholders in Nepal should focus on increasing availability, use and training of direct seeded rice. Our results indicated that the lower number of effective tillers were the main reason for lower yield of direct seeded rice compared to the transplanted rice on puddled soil. Therefore, future research should also focus on the selection and breeding of rice varieties that have higher tiller forming ability under no-till, no-puddling conditions.

The key finding of this study is that an increased level of residue retention under rice-wheat cropping system can increase grain yield and improve yield attributes. These results also align with results from most of other studies in the IGP [19,20]. The lack of significant interaction effects of tillage and residue management on grain yield and other variables indicated that residue retention can improve performance of rice yield under both conventional and zero-tilled direct seeded systems of rice production. The results corroborate findings from the previous studies in the region as yields of rice and wheat were increased irrespective of tillage systems when residues were retained in the field [19–21]. The results are encouraging since the deterioration of soil productivity, increased straw burning and increased cost of cultivation due to external fertilizer inputs are a great concern in the IGP. Our results thus recommend to retain as much straw of rice and wheat as possible under rice-wheat

based cropping systems in the region. Although this study was limited to three years, greater positive effects of residue retention can be expected in the long term due to continued increase of carbon in the soil and improved soil health. Indeed, a previous study has documented significant increase of soil health parameters such as soil organic carbon and soil aggregate stability by coupling dry-seeded system and residue retention [21]. Therefore, the concerned stakeholders in Nepal should promote adoption of residue retention practices in rice-wheat cropping system.

Our results showed a similar effect of both methods of weed managements on rice yield. The method of weed control had no significant interaction with systems of tillage system and residue retention rate on any measured variables. This indicated that the herbicide can work effectively not only for transplanted rice under the puddled field method, but also for direct seeded rice. The results are encouraging since farmers' adoption of direct seeded rice in the region is constrained by higher weed infestation and greater cost of production in manual weeding [22]. Previously, Singh et al. [23] tested the effectiveness of bispyribac-sodium in Haryana, India, and found bispyribac-sodium as one of the most effective herbicides. Our results thus corroborate findings from the previous study in the IGP. Although application of bispyribac-sodium proved to be an effective alternative to manual weeding in this study, resistance to the herbicide is expected when a single herbicide is applied over the years. Further studies are required for effectiveness of other herbicides, resistance, application methods, residual effects and environmental effects in the region as the application of herbicides is a new but popular practice under rice-wheat rotation in the region.

## 5. Conclusions

The results in this study indicated direct seeded rice on zero-tilled soil can decrease grain yield than transplanted rice on puddled soil. Similarly, the results showed positive impacts of wheat residue retention on yield and yield attributes of rice grain yield. Yield of rice grain was improved with increasing level of retention of wheat residues. Therefore, retention of all wheat residues of wheat in the field is recommended for rice production in the southern Terai of Nepal. Our results also concluded that bispyribac-sodium herbicide application can be equally effective as a manual method of weed control under both transplanted and direct seeded rice.

**Supplementary Materials:** The following are available online at <http://www.mdpi.com/2073-4395/10/11/1734/s1>: Figure S1: Mean monthly values of (a) total precipitation (b) maximum daily temperature, and (c) minimum daily temperature in the study area during the growing seasons of three study years during 1985–2015 (long-term)., Table S1: t Timeline of field operations during the study periods.

**Author Contributions:** Conceptualization, B.P.P.; methodology, B.P.P.; software, B.P.P. and T.P.K.; validation, B.P.P. and T.P.K.; formal analysis, B.P.P. and T.P.K.; investigation, B.P.P.; resources, B.P.P.; data curation, B.P.P. and T.P.K.; writing—original draft preparation, B.P.P.; writing—review and editing, T.P.K.; visualization, B.P.P. and T.P.K.; supervision, B.P.P.; project administration, B.P.P.; funding acquisition, B.P.P. All authors have read and agreed to the published version of the manuscript.

**Funding:** This study was funded by Nepal Agricultural Research Council (NARC).

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. FAOSTAT. *FAO Statistical Service*; United Nations Food and Agriculture Organization: Rome, Italy, 2012.
2. Evans, L.T. *Feeding the Ten Billion: Plants and Population Growth*; Cambridge University Press: Cambridge, UK, 1998; 247p.
3. Ministry of Agriculture Development. *Statistical Information on Nepalese Agriculture 2015/2016*; Agri Statistics Section, Monitoring, Evaluation and Statistics Division, Ministry of Agricultural Development, Singha Durbar: Kathmandu, Nepal, 2017.
4. Ladha, J.K.; Fischer, K.; Hossain, M.; Hobbs, P.; Hardy, B. *Improving the Productivity and Sustainability of Rice-Wheat Systems of the Indo-Gangetic Plains: A Synthesis of NARS-IRRI Partnership Research*; IRRI Discussion Paper 40; IRRI: Los Banos, PL, USA, 2000; p. 31.



5. Singh, Y.; Singh, B. Efficient Management of Primary Nutrition in the Rice-Wheat System. In *The Rice-Wheat Cropping Systems of South Asia: Efficient Production Management*; Kataki, P.K., Ed.; Food Products Press: New York, NY, USA, 2001; pp. 23–85.
6. Subehia, S.K.; Sepehya, S. Influence of Long-Term Nitrogen Substitution through Organics on Yield, Uptake and Available Nutrients in a Rice-Wheat System in an Acidic Soil. *J. Indian Soc. Soil Sci.* **2012**, *60*, 213–217.
7. Nandan, R.; Singh, V.; Singh, S.S.; Kumar, V.; Hazrab, K.K.; Nath, C.P.; Poonia, S.; Malik, R.K.; Bhattacharyya, R.; McDonald, A. Impact of conservation tillage in rice—Based cropping systems on soil aggregation, carbon pools and nutrient. *Geoderma* **2019**, *340*, 104–114. [[CrossRef](#)] [[PubMed](#)]
8. Sharma, S.; Thind, H.S.; Sidhu, H.S.; Jat, M.L.; Parihar, C.M. Effects of crop residue retention on soil carbon pools after 6 years of rice-wheat cropping system. *Environ. Earth Sci.* **2019**, *78*, 296. [[CrossRef](#)]
9. Sapkota, T.B.; Jat, R.K.; Singh, R.G.; Jat, M.L.; Stirling, C.M.; Jat, M.K.; Bijarniya, D.; Kumar, M.; Singh, Y.; Saharawat, Y.S.; et al. Soil organic carbon changes after seven years of conservation agriculture in a rice-wheat system of the eastern Indo-Gangetic Plains. *Soil Use Manag.* **2017**, *33*, 81–89. [[CrossRef](#)]
10. Sahai, S.; Sharma, C.; Singh, S.K.; Gupta, P.K. Assessment of Trace Gases, Carbon and Nitrogen Emissions from Field Burning of Agricultural residue in India. *Nutr. Cycl. Agroecosyst.* **2011**, *89*, 143–157. [[CrossRef](#)]
11. Humphreys, E.; Meisner, C.; Gupta, R.; Timsina, J.; Beecher, H.G.; Lu, T.Y.; Singh, Y.; Gill, M.A.; Masih, I.; Guo, Z.J.; et al. Water savings in rice wheat systems. *Plant. Prod. Sci.* **2005**, *8*, 242–258. [[CrossRef](#)]
12. Saharawat, Y.S.; Singh, B.; Malik, R.K.; Ladha, J.K.; Gathala, M.; Jat, M.L.; Kumar, V. Evaluation of alternative tillage and crop establishment methods in a rice-wheat rotation in North Western IGP. *Field Crops Res.* **2010**, *116*, 260–267. [[CrossRef](#)]
13. Singh, Y.; Singh, V.P.; Singh, G.; Yadav, D.S.; Sinha, R.K.P.; Johnson, D.E.; Mortimer, A.M. The implications of land preparation, crop establishment method and weed management on rice yield variation in the rice-wheat system in the Indo-Gangetic plains. *Field Crops Res.* **2011**, *121*, 64–74. [[CrossRef](#)]
14. Kirchhof, G.; Priyono, S.; Utomo, W.H.; Adisarwanto, T.; Dacanay, E.V.; So, H.B. The effect of soil puddling on the soil physical properties and the growth of rice and post-rice crops. *Soil Tillage Res.* **2000**, *56*, 37–50. [[CrossRef](#)]
15. Bhushan, L.; Ladha, J.K.; Gupta, R.K.; Singh, S.; Tirol-Padre, A.; Saharawat, Y.S.; Gathala, M.; Pathak, H. Saving of water and labor in a rice-wheat system with no-tillage and direct seeding technologies. *Agron. J.* **2008**, *99*, 1288–1296. [[CrossRef](#)]
16. Akbar, N.; Jabran, K.; Ali, M.A. Weed management improves yield and quality of direct seeded rice. *Aus. J. Crop. Sci.* **2011**, *5*, 688.
17. Khaliq, A.; Matloob, A.; Hussain, A.; Hussain, S.; Aslam, F.; Zamir, S.I.; Chattha, M.U. Wheat Residue Management Options Affect Productivity, Weed Growth and Soil Properties in Direct-Seeded Fine Aromatic Rice. *Clean Soil Air Water* **2015**, *43*, 1259–1265. [[CrossRef](#)]
18. Khadka, D.; Lamichhane, S.; Thapa, B.; Rawal, N.; Chalise, D.R.; Vista, S.P.; Lakhe, L. Assessment of soil fertility status and preparation of their maps of national wheat research program, Bhairahawa, Nepal. In Proceedings of the Second National Soil Fertility Research Workshop, Khumaltar, Lalitpur, Nepal, 24–25 March 2015; pp. 330–340.
19. Singh, S.; Ladha, J.; Gupta, R.; Bhushan, L.; Rao, A.; Sivaprasad, B.; Singh, P. Evaluation of mulching, intercropping with Sesbania and herbicide use for weed management in dry-seeded rice (*Oryza sativa* L.). *Crop. Prot.* **2007**, *26*, 518–524. [[CrossRef](#)]
20. Jat, R.K.; Sapkota, T.B.; Singh, R.G.; Jat, M.L.; Kumar, M.; Gupta, R.K. Seven years of conservation agriculture in a rice-wheat rotation of Eastern Gangetic Plains of South Asia: Yield trends and economic profitability. *Field Crops Res.* **2014**, *164*, 199–210. [[CrossRef](#)]
21. Choudhury, S.G.; Srivastava, S.; Singh, R.; Chaudhari, S.K.; Sharma, D.K.; Singh, S.K. Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice-wheat cropping system under reclaimed sodic soil. *Soil Tillage Res.* **2014**, *136*, 76–83. [[CrossRef](#)]

22. Farooq, M.; Siddique, K.H.M.; Rehman, H.; Aziz, T.; Lee, D.-J.; Wahid, A. Rice direct seeding: Experiences, challenges and opportunities. *Soil Tillage Res.* **2011**, *111*, 87–98. [[CrossRef](#)]
23. Singh, V.; Jat, M.L.; Ganie, Z.A.; Chauhan, B.S.; Gupta, R.K. Herbicide options for effective weed management in dry direct-seeded rice under scented rice-wheat rotation of western Indo-Gangetic Plains. *Crop. Prot.* **2016**, *81*, 168–176. [[CrossRef](#)] [[PubMed](#)]

**Publisher’s Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).