Indian Journal of Weed Science (2022) **54**(1): 18–24
http://dx.doi.org/10.5958/0974-8164.2022.00003.X

RESEARCH ARTICLE

# Weed dynamics and crops productivity as influenced by diverse cropping systems in eastern India

**Rakesh Kumar[1], Narendra Kumawat[2], J.S. Mishra[3]*, Dibakar Ghosh[4], Sonaka Ghosh[1], A.K. Choudhary[1] and Ujjwal Kumar[1]**

Received: 4 January 2022 | Revised: 27 March 2022 | Accepted: 28 March 2022

**ABSTRACT**

The study of weed dynamics in diverse cropping systems helps to formulate the strategies for effective management of weeds. Hence, this study was conducted to assess the effect of diverse cropping systems on weed dynamics and crops productivity in eastern India. The minimum total weed density (4.85 no./m$^2$) and biomass (2.43 g/m$^2$) during rainy season crops was recorded in fodder sorghum-mustard-blackgram systems. In winter crops, the lowest total weed density was observed in soybean-maize system (5.79 no./m$^2$), while the lowest weed biomass (2.26 g/m$^2$) with finger millet-rapeseed (*toria*) system. In summer, soybean-maize, pearl millet-chickpea and sorghum-chickpea were equally effective for reducing weed density and biomass. Weed seedbank analysis revealed maximum grass weed seed density at 0-15 cm depth in foxtail millet-lentil, while minimum with fodder sorghum-mustard-blackgram system. The highest weed seed density of broad-leaved weeds was noted at 0-15 cm depth in maize-pigeonpea and the lowest with conventionally tilled direct-seeded rice (CTDSR)-mustard-blackgram system. It was concluded that diverse cropping systems significantly suppress weed density and biomass in all the seasons.

**Key words:** Cropping systems, Weed flora, Weed management, Weed seedbank, Zero-tillage

## INTRODUCTION

Rice-wheat cropping system (RWCS) is one of the most important agricultural production systems in the world, which cover large extent of area and feeds a vast population (Pan *et al.* 2019). This production system contributes ~40% of rice and wheat in India (Kumar *et al.* 2021). In Indo-Gangetic Plains (IGP), *viz*. India, Bangladesh, Nepal, and Pakistan, rice-wheat system occupies ~13.5 million ha of cultivable land. Productivity of RWCS is decreasing due to decline in factor productivity and increased the problem of various biotic and abiotic stresses (Singh *et al.* 2012). Among biotic stress, weeds are major threat to crop productivity, input-use efficiency, and profitability of any cropping systems.

Soil weed seedbank is the major source of weeds that determines above-ground weed flora composition and density in agricultural fields. Maximum weed seed reserves have been reported in top 0–5 cm soil depth and decreases with increasing soil depth (Mishra and Singh 2012). Continuous cultivation of rice-wheat sequence favoured grassy weeds dominance (Malik *et al*. 2014, Bhatt *et al*. 2016). Adoption of various tillage practices, crop rotations and choice of crop influences type and degree of weed infestation by altering the weed seedbank and species composition (Kumar *et al*. 2013). Retention and incorporation of previous crop residues can play a vital role on weed seed germination by altering the weed seed environment (Nichols *et al.* 2015). Thus, adoption of new crops or changes in RWCS of IGP reduced weed growth as in rice-wheat-greengram sequence (Singh *et al.* 2008) due to creation of an unstable environment for weeds that prevent recurrence of specific annual weed species. Crop rotation strategies may not eradicate troublesome weed species, but they can limit their growth and reproduction (Scherner *et al*. 2018). Hence, this study was conducted to evaluate the role of diverse cropping systems on management of weeds, weed seed dynamics and crops productivity in eastern India.

[1] Division of Crop Research, ICAR RCER Patna, Bihar 800014, India

[2] AICRP on Salt and Salinity Research, Indore, Madhya Pradesh 452001, India

[3] ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482004, India

[4] ICAR-Indian Institute of Water Management, Bhubaneswar, Odisha 751023, India

* Corresponding author email: jsmishra31@gmail.com

## MATERIALS AND METHODS

A study was carried out for five consecutive years from 2016-2020 at the ICAR-Research Complex for Eastern Region, Patna, India, at 25°30'N,85°15'E,52 m above mean sea levels. The annual precipitation was 1168 mm, of which 88% rainfall is received between July and September. Mean annual evaporation was 1573 mm. Soil of experimental site was loamy in texture (50.4, 35.0 and 14.6% sand, silt and clay, respectively) with Typic Haplustept, Fluvisol having pH of 7.5, electrical conductivity of 0.12 dS/m, soil organic carbon content of 6.0 g/kg, $KMnO_4$ oxidizable N of 64.6 mg/kg, Olsen phosphorus of 23.9 mg/kg, $NH_4OAc$ exchangeable potassium of 78.3 mg/kg, and DTPA-extractable zinc of 0.66 mg/kg (0-15 cm soil).

A randomized block design replicated thrice was used. Ten diverse cropping sequences were tested, *viz*. farmers practice (FP) of transplanted rice (TPR)-conventional till (CT) wheat-CT greengram; conventional till-direct-seeded rice (CTDSR)-zero till (ZT) wheat-ZT greengram; CT soybean-ZT maize, CTDSR-ZT mustard-ZT blackgram; CT foxtail millet-ZT lentil; CT pearl millet-ZT chickpea; CT finger millet- ZT rapeseed (*toria*); CT sorghum (grain)-ZT chickpea; CT maize-ZT pigeon-pea and CT sorghum (fodder)-ZT mustard-ZT blackgram. All the rainy season crops were grown in CT, while all winter and summer season crops were grown under ZT, except in farmers' practice. Size of individual experimental plot was 8.0×5.0 m. All the component crops were grown as per the standard crop calendar (**Table 1**). All the rainy season crops were planted during third week of June and harvested by second week of October except for maize and fodder sorghum. During the winter, wheat, oilseed, and pulse crops were sown during 3rd week of October and harvested in March and April. Summer crops (greengram/blackgram) were sown and harvested during first week of April and June, respectively. The observations on weed composition, weed density and biomass were recorded (at 4-5 leaf stage) using quadrats (0.5×0.5 m) placed randomly at four places in each plot.

Weed seedbank studies were undertaken at the end of 5h year rotation by 'seedling emergence' method as described by MacLaren *et al*. (2021). Although this method is time consuming, under-estimate the absolute weed seedbank size, but it provides more accurate estimation of the species composition than seed extraction method. Sampling of weed seedbank was done during June 2020 after harvest of greengram. Soil samples were taken using a 4.0 cm diameter metal core from two depths, 0–15 and 15-30 cm of five places in each plot. All samples of a given depth were bulked to make a composite soil sample per plot. Bulked soil samples were partially air-dried, and clods were broken by the hand. Soil debris and large root fragments were separated from soil samples. Three-kilogram soil sample for each depth per plot was spread on 40.4×30.3×9.5 cm plastic trays with~2 cm soil layer

**Table 1. Crops, varieties, seed rate, fertilization and weed management practices used in crops during different seasons**

| Crops | Varieties | Seeding rate (kg/ha) | Spacing (cm) | Fertilization (kg NPK/ha) | Weed management practices followed during cropping |
|---|---|---|---|---|---|
| *Rainy season* | | | | | |
| Transplanted rice | *Swarna Shreya* | 20 | 20×15 | 120-60-40 | Pretilachlor PE at 2-3 DAT *fb* 1 HW |
| Direct-seeded rice | *Swarna Shreya* | 30 | 20×5 | 120-60-40 | Pendimethalin PE 2-3 DAS *fb* bispyribac-Na at 25-35 DAS and 1 HW at 50-55 DAS |
| Soybean | *Pusa 9712* | 80 | 45×15 | 20-80-40 | Pendimethalin PE at 2-3 DAS *fb* 1 HW at 30-35 DAS |
| Foxtail millet | *Rajendra Kauni* | 10 | 25×10 | 60-40-25 | Atrazine PE at 2-3 DAS *fb* 1 HW at 40-45 DAS |
| Pearl millet | *Proagro 9001* | 5 | 45×15 | 80-40-40 | Atrazine PE at 2-3 DAS *fb* 1 HW at 40-45 DAS |
| Finger millet | *RAU 8* | 5 | 20× 10 | 60-40-25 | Atrazine PE 2-3 DAS *fb* 1 HW at 40-45 DAS |
| Sorghum grain | *CSH 25* | 10 | 45×15 | 80-40-40 | Atrazine PE 2-3 DAS *fb* 1 HW at 50-55 DAS |
| QPM maize | *Shaktiman 5* | 20 | 60×20 | 100-60-40 | Atrazine PE 2-3 DAS *fb* 1 HW at 35-40 DAS |
| Sorghum fodder | *CSH 13* | 30 | 25×5 | 80-40-40 | - |
| *Winter season* | | | | | |
| Wheat | *HD 2967* | 125 | 22.5×5 | 150-60-40 | Pendimethalin PE at 2-3 DAS *fb* total and 2,4-D at 35-40 DAS |
| Pigeonpea | *Pusa 9* | 50 | 30×15 | 20-50-0 | Pendimethalin PE at 2-3 DAS *fb* HW at 40-45 DAS |
| Lentil | *HUL 57* | 35 | 30×10 | 20-50-0 | Pendimethalin PE at 2-3 DAS *fb* HW at 35-40 DAS |
| Chickpea | *Pusa 256* | 80 | 30×10 | 20-50-0 | Pendimethalin PE at 2-3 DAS *fb* HW at 40-45 DAS |
| Rapeseed (*toria*) | *TS 38* | 5 | 30×10 | 60-40-40 | Pendimethalin PE at 2-3 DAS *fb* HW at 30-25 DAS |
| Mustard | *Proagro 5222* | 5 | 30×10 | 80-40-40 | Pendimethalin PE at 2-3 DAS *fb* HW at 35-40 DAS |
| Maize | *S2-945* | 20 | 50×20 | 120-75-50 | Atrazine PE 2-3 DAS *fb* HW at 35-40 DAS |
| *Summer season* | | | | | |
| Greengram | Samrat | 25 | 30×10 | 20-50-0 | Pendimethalin PE at 2-3 DAS *fb* 1 hand weeding at 35-40 DAS |
| Blackgram | Uttara | 25 | 25×10 | 20-50-0 | Pendimethalin PE at 2-3 DAS *fb* 1 hand weeding at 35-40 DAS |

QPM: Quality protein maize; PE: Pre-emergence, HW: hand/manual weeding; DAT: days after transplanting; DAS: days after sowing thickness. Subsequently, these trays were placed in a greenhouse and watered to keep the soil at field capacity. Emerged weed seedlings were identified, counted, and removed until the emergence was nil.

Crop yield of different cropping sequences was converted into rice equivalent yield (REY) by following formula,

$$\text{REY (t/ha)} = \frac{\text{Grain yield of the winter/summer crop} \times \text{MSP of winter/summer crops}}{\text{Price of rice}}$$

Where, MSP is the minimum support price as fixed by the Government of India (GOI).

System rice equivalent yield (SREY) was calculated by adding REY of different crops of a system. All data on weed density and biomass were analysed with 'Statistix 8.1' for analysis of variance (ANOVA). Data were square-root transformed before analysis to reduce heterogeneity of variance.

## RESULTS AND DISCUSSION

### Weed density and biomass during rainy (*Kharif*) season

Data on weed density and biomass recorded during rainy season (**Table 2)** indicated that minimum total weed density was associated with fodder sorghum-mustard-blackgram (4.85 no./m$^2$), while the maximum weed density was with soybean-maize system. Minimum density of *Trianthema portulacastrum* (3.92 and 10.27 no./m$^2$) was recorded in fodder sorghum-mustard-blackgram and pearl millet-chickpea, respectively. While, maximum density of *T. portulacastrum* (58.9 no./m$^2$) was observed in soybean-maize followed by CTDSR-wheat-greengram (43.32 no./m$^2$). Similarly, the lowest density of *Cyperus rotundus* and *Brachiaria ramosa* was recorded with fodder sorghum-mustard-blackgram and CTDSR-wheat-greengram systems. The lowest total weed biomass was observed in fodder sorghum-mustard-blackgram (2.43 g/m$^2$), while the maximum was in soybean-maize (11.57 g/m$^2$). Maximum biomass of *T. portulacastrum*, *C. rotundus*, *B. ramosa* and *C. dactylon* was recorded in soybean-maize, pearl millet-chickpea, soybean-maize, and fodder sorghum-mustard-blackgram (10.29, 6.84, 2.26 ad 1.52 g/m$^2$) systems, respectively. However, the minimum biomass of *T. portulacastrum*, *C. rotundus* and *B. ramosa* was observed in fodder sorghum-mustard-blackgram system. Diverse cropping systems reduced weed density and biomass probably due to greater soil moisture that promoted germination and reduced resistance of soil to seedling emergence. Pan *et al.* (2019) reported that adoption of finger millet + blackgram and finger millet + horsegram system effectively reduced the weed growth and biomass accumulation.

**Table 2. Effect of tillage practice and crop rotation on weed density and dry biomass during rainy season**

| Cropping systems | Weed density (no./m$^2$) | | | | | Weed dry biomass (g/m$^2$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | TP | CR | BR | CD | Total | TP | CR | BR | CD | Total |
| TPR-CT wheat -CT greengram | 18.4 (338*) | 0.71 (0) | 3.67 (13) | 0.71 (0) | 18.74 (351) | 3.32 (10.5) | 0.71 (0) | 1.14 (0.8) | 0.71 (0) | 3.43 (11.3) |
| CTDSR-ZT wheat -ZT greengram | 43.3 (1877) | 5.52 (30) | 10.93 (119) | 0.71 (0) | 45.01 (2026) | 8.13 (65.6) | 2.86 (77.0) | 1.97 (3.4) | 0.71 (0) | 8.79 (76.7) |
| CT Soybean-ZT maize | 58.9 (3471) | 8.91 (79) | 5.43 (29) | 0.71 (0) | 59.83 (3574) | 10.29 (105.4) | 4.89 (23.4) | 2.26 (4.6) | 0.71 (0) | 11.57 (133.4) |
| DSR-ZT mustard-ZT blackgram | 38.8 (1506) | 2.34 (5) | 4.52 (20) | 0.71 (0) | 39.13 (1531) | 6.07 (36.4) | 2.39 (5.2) | 1.30 (1.2) | 0.71 (0) | 6.58 (42.8) |
| CT Foxtail millet-ZT lentil | 31.4 (986) | 7.10 (50) | 0.71 (0) | 0.71 (0) | 32.19 (1036) | 5.34 (28.0) | 4.40 (18.9) | 0.71 (0) | 0.71 (0) | 6.88 (46.9) |
| CT Pearl millet-ZT chickpea | 10. (105) | 9.46 (89) | 0.71 (0) | 0.71 (0) | 13.95 (194) | 1.70 (2.4) | 6.84 (46.3) | 0.71 (0) | 0.71 (0) | 7.01 (48.7) |
| CT Finger millet-ZT rapeseed (*toria*) | 16.89 (285) | 5.70 (32) | 4.74 (22) | 0.71 (0) | 18.42 (339) | 2.92 (8.0) | 3.03 (8.7) | 0.71 (0) | 0.71 (0) | 4.15 (16.7) |
| CT Sorghum (Grain)-ZT chickpea | 24.39 (595) | 3.94 (15) | 0.71 (0) | 0.71 (0) | 24.71 (610) | 5.75 (32.6) | 2.76 (7.1) | 0.71 (0) | 0.71 (0) | 6.34 (39.7) |
| CT Maize -ZT pigeonpea (ZT)-fallow | 25.44 (647) | 1.87 (3) | 1.58 (2) | 0.71 (0) | 25.54 (652) | 5.84 (33.6) | 1.30 (1.2) | 1.14 (0.8) | 0.71 (0) | 6.01 (33.6) |
| CT Sorghum (fodder)-ZT mustard-ZT blackgram | 3.39 (11) | 0.71 (0) | 0.71 (0) | 3.53 (12) | 4.85 (23) | 2.02 (3.6) | 0.71 (0) | 0.71 (0) | 1.52 (1.8) | 2.43 (54.4) |
| LSD (p=0.05) | 1.27 | 0.23 | 0.15 | 0.05 | 1.28 | 0.23 | 0.15 | 0.03 | 0.02 | 0.25 |

*Data were subjected to square root transformation ($\sqrt{x+0.5}$), values in parentheses represent original values; TPR: transplanted puddle rice; CTDSR: conventional till-direct-seeded rice; CT: conventional-till; ZT: zero-till; DSR: direct-seeded rice; TP: *Trianthema portulacastrum*; CR: *Cyperus rotundus*; BR: *Brachiaria ramosa*; CD: *Cynodon dactylon*

### Density and dry matter of weeds during winter (*Rabi*) season

Major weed flora was identified in winter season includes *Solanum nigrum*, *Chenopodium album*, *C. rotundus*, *C. dactylon*, *Ipomoea aquatica*, *Trifolium fragiferum* and *Launaea pinnatifida*. Maximum total weed density was observed in foxtail millet-lentil system (10.91 no./m$^2$), however, minimum weed density was associated with soybean-maize (5.79 no./m$^2$) rotation (**Table 3**). The lowest density of *S. nigrum* was associated with sorghum - chickpea, while the highest with foxtail millet-lentil. This might be due to greater weed seed reserves in the soil of those respective cropping systems in comparison to other cropping sequences (Mishra *et al.*2019). Similarly, the maximum suppression of *C. album* was observed in all other cropping system except TPR-wheat-greengram, CTDSR-wheat-greengram and foxtail millet-lentil systems. Significantly the highest reduction in density of *C. rotundus* was recorded by TPR-wheat-mugbean and foxtail millet-lentil systems in comparison to other systems. Density of *I. aquatica* and *T. fragiferum* were significantly lower in all other cropping system except foxtail millet-lentil and soybean-maize systems, respectively. Significant reduction of *L. pinnatifida* was observed with all cropping system except soybean-maize. A recent meta-analysis on 15 studies covering crop treatment in maize-soybean rotations showed that cover crop helps significantly in reducing weed biomass without changing weed density. Moreover, to achieve 75% reduction in weed biomass, it requires at least 5 mg/ha of cover crop (Sharma *et al*. 2021).

Diverse cropping systems significantly reduced total weed biomass except foxtail millet-lentil, pearl millet-chickpea and fodder sorghum-mustard-blackgram systems. Similarly, diverse cropping systems had significant effect on biomass of *S. nigrum* except TPR-wheat-greengram, foxtail millet-lentil and CTDSR-wheat-greengram. Minimum biomass of *S. nigrum* was recorded in maize-pigeonpea followed by sorghum-chickpea, while maximum biomass of *S. nigrum* was with foxtail millet-lentil followed by CTDSR-wheat-mung. Maximum biomass of *C. album* was observed with TPR-wheat-greengram. TPR-wheat-greengram, foxtail millet-lentil, finger millet-*toria* and soybean-maize significantly reduced biomass of *C. rotundus* compared to other systems. Similarly, biomass of *I. aquatic*, *T. fragiferum* and *L. pinnatifida* was significantly reduced by all cropping system except foxtail millet-lentil, soybean-maize, and pearl millet-chickpea systems. Earlier studies have reported that adapting different crop rotations help in lowering the density of a particular weed/weed density (Zeller *et al*. (2021).

**Table 3. Effect of tillage practice and crop rotation on weed density and biomass during winter season**

| Cropping systems | Weed density ((no./m$^2$) | | | | | | | | Weed dry biomass (g/m$^2$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SN | CA | CR | IA | TF | LP | Others | Total | SN | CA | CR | IA | TF | LP | Others | Total |
| TPR-CT wheat -CT | 7.43 | 3.54 | 0.88 | 0.71 | 0.71 | 1.10 | 1.44 | 8.57 | 2.09 | 1.14 | 0.75 | 0.71 | 0.71 | 0.82 | 0.91 | 2.42 |
| greengram | (59.0*) | (13.0) | (0) | (0) | (0) | (1.00) | (3.0) | (75.0) | (3.90) | (0.80) | (0.07) | (0) | (0) | (0.20) | (0.40) | (5.37) |
| CTDSR-ZT wheat -ZT | 7.16 | 1.39 | 2.83 | 0.71 | 0.71 | 1.94 | 1.52 | 8.58 | 2.28 | 0.87 | 1.18 | 0.71 | 0.71 | 1.04 | 0.90 | 2.71 |
| greengram | (53.0) | (2.0) | (10.0) | (0) | (0) | (6.0) | (2.0) | (73.0) | (4.83) | (0.27) | (1.07) | (0) | (0) | (0.80) | (0.34) | (7.31) |
| CT Soybean-ZT maize | 2.54 | 0.71 | 2.53 | 0.71 | 2.26 | 0.71 | 2.71 | 5.79 | 1.71 | 0.71 | 1.12 | 0.71 | 1.49 | 0.71 | 1.58 | 3.11 |
| | (13.0) | (0) | (8.0) | (0) | (6.0) | (0) | (8.0) | (35.0) | (4.43) | (0) | (0.93) | (0) | (2.03) | (0) | (2.33) | (9.73) |
| DSR-ZT mustard-ZT | 1.25 | 0.71 | 6.23 | 0.71 | 0.71 | 0.71 | 2.06 | 6.73 | 0.91 | 0.71 | 2.32 | 0.71 | 0.71 | 0.71 | 1.11 | 2.60 |
| blackgram | (2.0) | (0) | (40.0) | (0) | (0) | (0) | (4.0) | (46.0) | (0.40) | (0) | (5.53) | (0) | (0) | (0) | (0.81) | (6.74) |
| CT Foxtail millet-ZT | 8.92 | 2.34 | 1.84 | 1.77 | 0.71 | 0.71 | 4.88 | 10.91 | 3.23 | 0.91 | 0.97 | 1.21 | 0.71 | 0.71 | 1.74 | 3.89 |
| lentil | (83.0) | (5.0) | (4.0) | (3.0) | (0) | (0) | (25.0) | (120.0) | (10.73) | (0.35) | (0.47) | (1.10) | (0) | (0) | (2.60) | (15.25) |
| CT Pearl millet-ZT | 2.05 | 0.71 | 8.06 | 0.71 | 0.71 | 2.48 | 1.72 | 9.14 | 0.91 | 0.71 | 4.04 | 0.71 | 0.71 | 1.27 | 0.99 | 4.38 |
| chickpea | (7.0) | (0) | (70.0) | (0) | (0) | (8.0) | (4.0) | (88.0) | (0.40) | (0) | (17.50) | (0) | (0) | (1.40) | (0.62) | (19.92) |
| CT Finger millet-ZT | 1.70 | 0.71 | 4.86 | 0.71 | 0.71 | 0.88 | 2.98 | 6.39 | 0.94 | 0.71 | 1.83 | 0.71 | 0.71 | 0.73 | 1.29 | 2.26 |
| rapeseed (*toria*) | (4.0) | (0) | (24.0) | (0) | (0) | (0) | (4.0) | (43.0) | (0.50) | (0) | (2.87) | (0) | (0) | (0.03) | (1.45) | (4.84) |
| CT Sorghum (grain)-ZT | 1.10 | 0.71 | 7.78 | 0.71 | 0.88 | 0.71 | 0.88 | 7.87 | 0.87 | 0.71 | 3.51 | 0.71 | 0.72 | 0.71 | 0.71 | 3.55 |
| chickpea | (1.0) | (0) | (62.0) | (0) | (0) | (0) | (0) | (64.0) | (0.30) | (0) | (12.10) | (0) | (0.01) | (0) | (0) | (12.42) |
| CT Maize -ZT pigeonpea | 1.18 | 0.71 | 5.64 | 0.71 | 0.71 | 1.70 | 1.39 | 6.28 | 0.82 | 0.71 | 2.98 | 0.71 | 0.71 | 1.13 | 0.84 | 3.25 |
| (ZT)-fallow | (1.0) | (0) | (32.0) | (0) | (0) | (4.0) | (2.0) | (39.0) | (0.20) | (0) | (8.60) | (0) | (0) | (0.77) | (0.23) | (10.16) |
| CT Sorghum (fodder)-ZT | 2.86 | 0.71 | 6.16 | 0.71 | 0.71 | 2.54 | 1.32 | 8.03 | 2.03 | 0.71 | 2.56 | 0.71 | 0.71 | 1.43 | 0.94 | 4.01 |
| mustard-ZT blackgram | (14.0) | (0) | (39.0) | (0) | (0) | (10.0) | (2.0) | (64.0) | (5.13) | (0) | (7.69) | (0) | (0) | (2.30) | (0.50) | (15.63) |
| LSD (p=0.05) | 3.36 | 0.72 | 2.77 | 0.55 | 0.78 | 1.76 | 2.32 | 2.70 | 1.45 | 0.11 | 1.49 | 0.25 | 0.38 | 0.68 | 0.70 | 1.42 |

*Data were subjected to square root transformation ($\sqrt{x+0.5}$), values in parentheses represent original values; TPR: transplanted puddle rice; CTDSR: conventional till-direct seeded rice; CT: conventional-till; ZT: zero-till; DSR: direct-seeded rice; SN: *Solanum nigrum;* CA: *Chenopodium album*; CR: *Cyperus rotundus*; CD: *Cynodon dactylon*; IA: *Ipomoea aquatica*; TF: *Trifolium fragiferum*; LP: *Launia pinnatifida*

### Weed density and biomass during summer

During summer, the lowest total weed density was recorded with soybean-maize system, which was followed by pearl millet-chickpea and sorghum-chickpea, while the maximum density was noticed with TPR-wheat-greengram followed by CTDSR-wheat-greengram and foxtail millet-lentil (13.16, 12.88 and 12.34 no./m$^2$, respectively) systems **(Table 4).** Significantly higher suppression of *C. rotundus* in summer was recorded under sorghum-chickpea followed by pearl millet-chickpea, soybean-maize and TPR-wheat-greengram as compared with other cropping system. The lowest density of *T. portulacastrum* was observed in different cropping systems except TPR-wheat-greengram, CTDSR-wheat-mung and foxtail millet-lentil. Similarly, cropping system significantly reduced density of *S. nigrum* except TPR-wheat-greengram, CTDSR-wheat-greengram and CTDSR-mustard-blackgram systems. Brankov *et al.* (2021) reported that maize-wheat system can reduce weed density in winter season wheat. MacLaren *et al.* (2021) also reported that crop rotation with reduced tillage lowered weed infestation, whereas crop interaction by ZT interaction was unable to reduce weed density.

Soybean-maize, pearl millet-chickpea, finger millet- rapeseed (*toria*) and sorghum-chickpea systems significantly reduced total weed biomass in summer crops (**Table 4**). All cropping systems reduced biomass of *C. rotundus* except CTDSR-mustard-blackgram and fodder sorghum-mustard-blackgram. Similarly, diverse cropping systems had significant effect on biomass of *S. nigrum* except TPR-wheat-greengram and DSR-mustard-blackgram. Maximum biomass of *S. nigrum* was associated with TPR-wheat-greengram and DSR-mustard-blackgram (3.24 and 3.1 g/m$^2$, respectively) in comparison to other treatments. Higher biomass of *T. portulacastrum* was noticed under TPR-wheat-greengram followed by foxtail millet-lentil and CTDSR-wheat-mung (4.59, 3.27 and 3.14 g/m$^2$, respectively). All diverse cropping systems significantly reduced other weeds biomass except CTDSR-wheat-greengram and maize-pigeonpea. Diverse cropping systems significantly reduced the biomass of *C. album* except TPR-wheat-greengram, which had recorded the highest biomass. TPR-wheat-mung, foxtail millet-lentil, finger millet-rapeseed (*toria*) and soybean-maize significantly reduced biomass of *C. rotundus* compared to others cropping systems. Similarly, biomass of *I. aquatic*, *T. fragiferum* and *L. pinnatifida* significantly reduced by diverse cropping systems except foxtail millet-lentil, soybean-maize, and pearl millet-chickpea, respectively, which was maximum biomass. Anderson (2004) reported that weed density could be reduced by utilizing balanced life-cycle intervals in

**Table 4. Effect of tillage practice and crop rotation on weed density and dry biomass during summer season**

| Cropping systems | Weed density (no./m$^2$) | | | | | Weed dry biomass (g/m$^2$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CR | SN | TP | Others | Total | CR | SN | TP | Others | Total |
| TPR-CT wheat -CT greengram | 1.25 (2.0*) | 5.89 (41.0) | 10.92 (125.0) | 2.34 (6.0) | 13.16 (174.0) | 0.78 (0.12) | 3.24 (12.45) | 4.59 (22.59) | 1.09 (0.78) | 5.00 (26.15) |
| CTDSR-ZT wheat -ZT greengram | 4.78 (26.0) | 3.89 (20.0) | 10.10 (103.0) | 4.22 (18.0) | 12.88 (166.0) | 2.23 (4.88) | 2.38 (7.17) | 3.14 (10.04) | 2.62 (6.65) | 4.39 (20.81) |
| CT Soybean-ZT maize | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) |
| DSR-ZT mustard-ZT blackgram | 8.68 (78.0) | 4.17 (22.0) | 0.71 (0) | 4.27 (19.0) | 10.85 (118.0) | 4.45 (19.85) | 3.14 (13.32) | 0.71 (0) | 1.69 (3.12) | 5.05 (28.67) |
| CT Foxtail millet-ZT lentil | 5.25 (40.0) | 1.99 (4.0) | 9.79 (101.0) | 2.67 (7.0) | 12.34 (152.0) | 3.06 (12.77) | 1.50 (1.95) | 3.27 (10.96) | 2.05 (4.63) | 4.32 (18.74) |
| CT Pearl millet-ZT chickpea | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) |
| CT Finger millet-ZT rapeseed (*toria*) | 4.44 (21.0) | 0.71 (0) | 0.71 (0) | 3.72 (17.0) | 6.13 (37.0) | 2.25 (5.42) | 0.71 (0) | 0.71 (0) | 2.01 (4.00) | 2.76 (8.12) |
| CT Sorghum (grain)-ZT chickpea | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) | 0.71 (0) |
| CT Maize -ZT pigeonpea (ZT)-fallow | 5.48 (36.0) | 2.29 (6.0) | 0.71 (0) | 3.83 (16.0) | 7.22 (58.0) | 3.31 (14.31) | 1.90 (3.86) | 0.71 (0) | 2.38 (6.67) | 4.25 (24.17) |
| CT Sorghum (fodder)-ZT mustard-ZT blackgram | 6.39 (41.0) | 2.35 (5.0) | 0.71 (0) | 3.93 (17.0) | 7.92 (62.0) | 3.81 (14.30) | 1.17 (0.98) | 0.71 (0) | 1.90 (3.38) | 3.76 (15.19) |
| LSD (p=0.05) | 3.51 | 2.44 | 2.50 | 2.14 | 2.19 | 2.19 | 1.80 | 1.26 | 1.42 | 2.10 |

*Data were subjected to square root transformation ($\sqrt{x+0.5}$), values in parentheses represent original values; TPR: transplanted puddle rice; CTDSR: conventional till-direct seeded rice; CT: conventional-till; ZT: zero-till; DSR: direct-seeded rice; TP: *Trianthema portulacastrum;* CR: *Cyperus rotundus*; SN: *Solanum nigrum* crop rotation. Different weed management strategies decreased the weed density and biomass, resulting in lower weed-crop competition, which ultimately improved crop productivity.

**Crop yield and system productivity**

Among different rainy and winter crops, the maximum rice equivalent yield was produced by maize and pigeonpea, respectively, whereas during summer season greengram in TPR-ZT wheat-ZT greengram produced the highest rice equivalent yield (**Table 5**). Total system equivalent yield differed among the cropping systems. The maximum system yield was recorded with maize-pigeonpea (22.34 t/ha) cropping system with none of the cropping system was statistically similar to it and it was followed by fodder sorghum-mustard-blackgram, rice-mustard-blackgram and CTDSR-wheat-greengram.

**Economics**

Economic returns obtained from diverse cropping systems revealed the maximum net returns and benefit: cost ratio (BCR) was noted for maize cob- pigeonpeapea (₹ 262902/ha and 3.75), while the lowest with finger millet-toria (₹ 35882/ha and 1.61) (**Table 5**). Expenditure incurred on cereal-based production sequences was higher and could be attributed to excessive tillage operation, and high use of fertilizers, irrigation, and human labours (Kumar *et al.* 2021). Comparatively the lower B: C ratio in cereal-based production system was due to lower returns and higher expenditure involved per unit production.

**Weed seedbank dynamic in diverse cropping systems**

Altogether 14 weed species including grassy and BLW were identified from weed density assessment during rainy season, 11 weed species were identified during winter crop season and 8 weed species were observed during summer **(Table 6).** Maximum weed seed density of grassy weeds at 0-15 cm depth was observed in foxtail millet-lentil (147.37 seedlings/m$^2$) followed by CTDSR-mustard-blackgram and maize-pigeonpea (133.66 and 126.08 seedling/m$^2$, respectively). While minimum weed seed density of grassy weeds (80.9 seedlings /m$^2$) was noticed in fodder sorghum-mustard-blackgram followed byTPR-wheat-mung and DSR-wheat-mung. While maximum weed seed density of grassy weeds (175.78 seedling/m$^2$) was observed with maize-pigeonpea (ZT) and minimum in TPR-wheat-greengram (56.04 seedling/m$^2$) at 15-30 cm of soil depth. Adoption of different tillage techniques may suppress or encourage emergence of weeds, as germination of few weeds is influenced by previously germinated weeds, because of inter-specific competition (Nandan *et al.* 2020). Exposure to light breaks dormancy and eventually increases germination in many species. Generally small seeded species are found to be more sensitive to light than large seeded ones. Eliminating light penetration during tillage can help in reduction of emergence of buried light sensitive species (Singh *et al.* 2012). Maximum weed seed density of broad-leaved weeds (BLW) at 0-15 cm depth (174.29 seedling/m$^2$) was found in maize-pigeonpea followed by sorghum-chickpea (161.95 seedlings/ m$^2$). However, minimum density of BLW at 0-15 cm depth was obtained in DSR-mustard-blackgram (70.24 seedling/m$^2$) followed foxtail millet-lentil (79.86 seedling/m$^2$). At depth of 15-30 cm, the highest weed seed density of BLW was noticed with fodder sorghum-mustard-urd (161.73 seedling/m$^2$) followed by maize-pigeonpea (143.38 seedling/ m$^2$). While the lowest weed seed density of BLW was observed in CTDSR-wheat-mung (44.94 seedling/m$^2$). This might be due to tillage changes vertical distribution of weed seeds in soil profile and soil physical properties, and affects emergence and seed survival of weed through changes in soil conditions and determines weed seedling emergence and species composition (Mishra *et al.* 2019).

**Table 5. Crop yields and economics and system productivity under diverse cropping systems**

| Cropping systems | Crop yield (t/ha) | | | Rice equivalent yield (t/ha) | | | System rice equivalent yield (t/ha) | System net returns (x10$^3$ `/ha) | Benefit: cost ratio |
|---|---|---|---|---|---|---|---|---|---|
| | *Kharif* | *Rabi* | Summer | *Kharif* | *Rabi* | Summer | | | |
| TPR-CT wheat -CT greengram | 4.98 | 5.16 | 1.21 | 4.85 | 5.78 | 4.35 | 14.98 | 104.93 | 1.70 |
| CTDSR-ZT wheat -ZT greengram | 5.31 | 5.48 | 1.01 | 5.35 | 6.13 | 3.63 | 15.11 | 123.01 | 1.91 |
| CT Soybean-ZT maize | 1.86 | 10.51 | - | 3.66 | 9.66 | - | 13.32 | 129.73 | 2.29 |
| DSR-ZT mustard-ZT blackgram | 5.26 | 2.83 | 1.10 | 5.26 | 7.30 | 3.83 | 16.39 | 135.90 | 2.04 |
| CT Foxtail millet-ZT lentil | 1.56 | 2.06 | - | 1.91 | 5.65 | - | 7.56 | 73.56 | 2.20 |
| CT Pearl millet-ZT chickpea | 4.39 | 2.42 | - | 4.04 | 6.87 | - | 10.91 | 121.39 | 2.62 |
| CT Finger millet-ZT rapeseed (*toria*) | 1.64 | 1.51 | - | 2.01 | 3.80 | - | 5.81 | 35.88 | 1.61 |
| CT Sorghum (grain)-ZT chickpea | 4.11 | 2.53 | - | 4.51 | 7.18 | - | 11.69 | 136.51 | 2.76 |
| CT Maize -ZT pigeonpea (ZT)-fallow | 10.31# | 2.81 | - | 12.46 | 9.88 | - | 22.34 | 262.90 | 3.75 |
| CT Sorghum (fodder)-ZT mustard-ZT blackgram | 75.32 | 2.43 | 1.21 | 9.72 | 6.27 | 2.54 | 18.53 | 182.00 | 2.66 |
| LSD (p=0.05) | | | | 0.47 | 0.57 | 0.23 | 1.17 | 11.36 | 0.20 |

TPR: transplanted puddle rice; CTDSR: conventional till-direct seeded rice; CT: conventional-till; ZT: zero-till; DSR, direct seeded rice

**Table 6. Impact of various tillage practice and cropping systems on grasses and broad-leaved weeds seedbank**

| Cropping systems | Weed seed density (emerged weed seedlings/$m^2$) | | | |
|---|---|---|---|---|
| | Grasses | | Broad-leaved weeds | |
| | 0-15 cm | 15-30 cm | 0-15 cm | 15-30 cm |
| TPR-CT wheat -CT greengram | 95.6 (9270) | 56.0 (3146) | 100.9 (10281) | 59.4 (3539) |
| CTDSR-ZT wheat -ZT greengram | 96.2 (9271) | 60.4 (3876) | 81.1 (6629) | 44.9 (2079) |
| CT Soybean-ZT maize | 122.6 (15337) | 150.1 (22697) | 89.5 (9607) | 135.1 (18371) |
| DSR-ZT mustard-ZT blackgram | 133.7 (18764) | 92.6 (10112) | 70.2 (5000) | 57.8 (3371) |
| CT Foxtail millet-ZT lentil | 147.4 (21798) | 111.6 (12472) | 79.9 (6405) | 68.9 (4888) |
| CT Pearl millet-ZT chickpea | 103.8 (11742) | 84.2 (7247) | 80.9 (7472) | 96.3 (10618) |
| CT Finger millet-ZT rapeseed (*toria*) | 110.2 (12528) | 82.6 (6854) | 94.4 (9551) | 101.0 (10281) |
| CT Sorghum (grain)-ZT chickpea | 114.6 (13146) | 76.7 (5899) | 161.9 (29101) | 127.5 (17023) |
| CT Maize -ZT pigeonpea (ZT)-fallow | 126.1 (15955) | 175.8 (31798) | 174.3 (34326) | 143.4 (22023) |
| CT Sorghum (fodder)-ZT mustard-ZT blackgram | 80.9 (6573) | 117.2 (13989) | 92.8 (8708) | 161.7 (30393) |
| LSD (p=0.05) | 36.71 | 40.24 | 65.66 | 55.77 |

TPR: transplanted puddle rice; CTDSR: conventional till-direct seeded rice; CT: conventional-till; ZT: zero-till; DSR: direct-seeded rice

The present study revealed that various diverse cropping systems reduce weed density and manage specific weed flora. Therefore, the best strategy for developing a resilient and sustainable production system is adopting diversified farming as an ecological weed management option. However, farmers are continuing to be reluctant to adopt a diversified cropping system because of requirement of varying skills and higher initial investment.

## REFERENCES


Anderson RL. 2004. Sequencing crops to minimize selection pressure for weeds in the central great plains. *Weed Technology* **18**: 157–164.

Bhatt R, Kukal SS, Busari MA, Arora S and Yadav M. 2016. Sustainability issues on rice-wheat cropping system. *International Soil and Water Conservation Research* **4**: 64–74.

Brankov M, Simi´c M and Dragi¡cevi´ V. 2021. The influence of maize-winter wheat rotation and pre-emergence herbicides on weeds and maize productivity. *Crop Protection* **2021**.

Kumar R, Mishra JS, Mondal S, Meena RS, Sundaram PK, Bhatt BP, Pan RS, Lal R, Saurabh K, Chandra N, Samal SK, Hans H and Raman RK.2021. Designing an eco-friendly and carbon-cum-energy efficient production system for the diverse agroecosystem of South Asia. *Energy* **214**:118860. https://doi.org/10. 1016/j.energy.2020.118860

Kumar V, Singh S, Chhokar RS, Malik RK, Brainard DC and Ladha JK. 2013. Weed management strategies to reduce herbicide use in zero-till rice-wheat cropping systems of the Indo-Gangetic plains. *Weed Technology* **27**: 241–254.

MacLaren C, Labuschagne J and Swanepoel PA. 2021. Tillage practices affect weeds differently in monoculture vs. crop rotation. *Soil Tillage Research* **205**: 104795.

Malik RK, Kumar V, Yadav A and McDonald A. 2014. Conservation agriculture and weed management in south Asia: Prospective and development. *Indian Journal of Weed Science* **46**: 31–35.

Mishra JS and Singh VP. 2012. Tillage and weed control effects on productivity of a dry seeded rice-wheat system on a Vertisol in Central India. *Soil Tillage and Research* **123**: 11–20.

Mishra JS, Kumar R, Kumar R, Rao KK, and Bhatt BP. 2019. Weed density and species composition in rice-based cropping systems as species diversity and reduction of weed seed banks with conservation tillage and crop rotation. *Indian Journal of Weed Science* **51**(2): 116-122.

Nandan R, Singh V, Kumar V, Singh SS, Hazra KK, Nath CP, Malik RK and Poonia SP. 2020 Viable weed seed density and diversity in soil and crop productivity under conservation agriculture practices in rice-based cropping systems. *Crop Protection* **136**: 105210, https://doi.org/ 10.1016/j.cropro.2020.105210

Nichols V, Verhulst N, Cox R and Govaerts B. 2015. Weed dynamics and conservation agriculture principles: A review. *Field Crops Research* **183**: 56–68.

Pan RS, Sarkar PK, Shinde R, Kumar R, Mishra JS Singh AK and Bhatt BP. 2019. Effect of diversified cropping system on weed phytosociology. *International Journal of Chemical Studies* **SP6**: 677-683.

Scherner A, Schreiber F, Andres A, Concenço G, Martins MB and Pitol A. 2018. Chapter 6 pp. 83-98. In: *Rice Crop Rotation: A Solution for Weed Management*. Book: Rice Crop - Current Developments http://dx.doi.org/10.5772/ intechopen .75884

Sharma G, Shrestha S, Kunwar S and Tseng TM. 2021. Crop Diversification for Improved Weed Management: A Review. *Agriculture* **11**: 461. https://doi.org/10.3390/ agriculture 11050461

Singh A, Kaur R, Kang JS and Singh G. 2012. Weed dynamics in rice-wheat cropping system. *Global Journal of Biology, Agriculture & Health Sciences* **1**: 7–16.

Singh A, Singh Y, Singh R, Upadhyay PK, Kumar R and Singh RK.2019. Effect of cultivars and weed management practices on weeds, productivity and profitability in zero-till direct-seeded rice (Oryza sativa). *Indian Journal of Agricultural Sciences* **89**(2):353–359.

Singh RK, Bohra JS, Srivastava, VK and Singh RP. 2008. Effect of diversification of Rice-wheat system on weed dynamics in Rice. *Indian Journal of Weed Science* **40**: 128–131.

Zeller AK, Zeller YI and Gerhards R.2021. A long-term study of crop rotations, herbicide strategies and tillage practices: Effects on *Alopecurus myosuroides* Huds. Abundance and contribution margins of the cropping systems. *Crop Protection* **145**: 105613.