

संरक्षण कृषि-आधारित अरहर-गेहूँ फसल प्रणाली में खरपतवारों, गेहूँ की उत्पादकता एवं मृदा के गुणों पर जुताई, फसल अवशेष एवं नाइट्रोजन के प्रभाव

**Tillage, residue and nitrogen effects on weeds, wheat productivity, and soil properties under Conservation Agriculture-based pigeon pea-wheat system**

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ICAR-INDIAN AGRICULTURAL RESEARCH INSTITUTE  
NEW DELHI - 110 012**

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# Tillage, residue and nitrogen effects on weeds, wheat productivity, and soil properties under Conservation Agriculture-based pigeon pea-wheat system

By

**Tarun Sharma**

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Submitted to the Post-Graduate School,  
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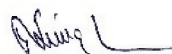
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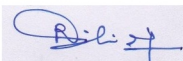
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This is to certify that the thesis entitled “**Tillage, residue and nitrogen effects on weeds, wheat productivity, and soil properties under Conservation Agriculture-based pigeon pea-wheat system**” submitted to the Post-Graduate School, ICAR-Indian Agricultural Research Institute, New Delhi, in partial fulfilment of the requirement for the degree of **Master of Science in Agronomy**, embodies the results of *bona fide* research work carried out by **Mr. Tarun Sharma (Roll no. 21427)** under my guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.

All the assistance and help received during the course of the investigation have been duly acknowledged by him.

Place: **New Delhi**  
Date: **30/10/2022**

**(T.K. Das)**  
Chairman  
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(Tarun Sharma)

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### Introduction

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Wheat [*Triticum aestivum* (L.) emend Fiori & Paol] is a staple food crop of the world grown over 215.9 M ha area (highest among the food grains' crops) with production of 765.76 million tonnes (2<sup>nd</sup> highest after maize) and productivity 3.54 t/ha (3<sup>rd</sup> after maize and rice) (FAOSTAT, 2020). In India, wheat occupies 30.5 million ha area (highest globally), 107.3 million tonnes production (2<sup>nd</sup> after China) and 3.51 t/ha productivity (2<sup>nd</sup> among major growing countries) (USDACIR, 2020). Wheat is the second most important food grain crop after rice in India in terms of area, production and productivity (FAOSTAT, 2020). Globally, wheat is consumed by 2.5 billion people in 89 countries and traded about US\$ 50 billion-worth every year (CGIAR, 2020). Ramadas *et al.* (2019) reported that wheat constituted 36% share in total foodgrains production of India and major share of protein (20%) and calorie intake (19%). Pigeon pea (*Cajanus cajan* L.) is grown over 5.6 and 4.5 million ha area with 4.42 and 3.31 million tonnes production in the world and India, respectively. India constitutes 81% and 74.9% of world's area and production of pigeon pea, respectively (FAOSTAT, 2020). Das *et al.* (2016) viewed that continuous adoption of rice-wheat system has led to depletion of inherent soil fertility, resulting in serious threat to its sustainability in addition to many environmental concerns in the Indo-Gangetic Plains (IGP). Singh *et al.* (2005) reported that over the years wheat grown after pigeon pea produced 11.4-15.1% higher than when wheat was grown after rice. Further, the scope for adoption of pigeon pea-wheat system is widened with the development of short duration varieties of pigeon pea like Pusa Arhar 16 (120 days duration). This has adequately paved the way for diversification/ intensification of the existing rice-wheat cropping system with other non-rice rainy season (~*kharif*) crops like pigeon pea, cotton, maize etc. in the IGP of India.

Conservation Agriculture (CA) is a concept for resource conservation and mitigation of adverse climatic impacts and has higher profitability (Das *et al.*, 2014). It is an environment friendly technology for sustainable crop production that preserves soil and water resources with better economic viability (Zheng *et al.*, 2014). It relies on three major principles: maintenance of permanent vegetative cover or residue mulch on the soil surface; direct planting to minimize soil

disturbance; and diversified crop rotation (FAO, 2012). Farmers worldwide are increasingly adopting CA. In 2018-19, CA was practised globally in 102 countries over an area of 205.4 million ha (M ha), which is 14.7% of the global crop land. In India, the area under CA was around 3.5 M ha in 2018-19 (Kassam *et al.*, 2022). Under conventional tillage (CT) system, wheat is sown by broadcasting/ drilling seed after disking, tilling and planking operations. In this CT system, frequent tillage for seed bed preparation oxidizes organic matter, breaks macro-aggregates into micro-aggregates, which adversely affect soil properties (Roper *et al.*, 2013; Das *et al.*, 2014). Due to less disruption of soil structure and aggregates, soil organic carbon retention in the surface soil layers (0–15 cm) under zero till (ZT) farming has been found to be higher than CT plots (Das *et al.*, 2013). Moreover, soil perturbation by repeated tillage makes soil to serve as a source rather than a sink of atmospheric pollutants, thus, is not sustainable and environment friendly (Busari *et al.*, 2015). Zero till (ZT) technique on the other hand is an ecological approach for soil surface management and seed bed preparation, resulting in less energy requirement, better crop residue management and higher or equal yield (Jain *et al.*, 2007). The ZT-sown wheat with residue retention had about 15% higher wheat grain yield than that of CT wheat plots (Bhattacharyya *et al.*, 2015). Zero tillage reduces energy consumption by reducing energy expenses for tillage, crop establishment, water, labour, and fuel, thus, resulting in more net energy returns, energy ratio and energy productivity compared to CT (Saad *et al.*, 2016). Experiences from several locations in the IGP of India showed that ZT technology could enable farmers to reduce diesel consumption by 50-60 L ha<sup>-1</sup> (Sangar *et al.*, 2005). Therefore, the use of ZT in wheat production has demonstrated agronomic and economic benefits while improving environmental footprints of agriculture across the IGP (Erenstein *et al.*, 2008).

In both CT and ZT agriculture, weeds remained as major biotic constraint/impediment to crop production through their ability to compete for resources and their impact on product quality reduction. A common belief is that, as tillage is reduced in CA, weeds can become a limiting factor in crop production (Das, 2008). While switching over from CT to ZT, weeds might be a major challenge for their severe infestation and dynamics/shift in the initial years of adoption. But, when tillage could be combined with residue mulch and early planting of wheat, the emergence of *Phalaris minor* got reduced by 83-98% compared with normal or delayed planting without residue (Kumar *et al.*, 2012). Considering all these, the Research Gaps identified were: i) the effect of tillage, pigeon pea residue and N management on weed interference/dynamics under CA-based

system is hardly studied; ii) substantial work has been accomplished on tillage and residue management in different crops, but information on N management and its residual effect is scant under CA based pigeon pea-wheat system; and studying interactive effect between crop establishment, residue and N application may be newer dimensions of research in pigeon pea-wheat system under CA. Therefore, it was planned and designed to undertake the research work entitled **“Tillage, residue and nitrogen effects on weeds, wheat productivity, and soil properties under Conservation Agriculture-based pigeon pea-wheat system”** with the following objectives:

1. To evaluate effects of tillage, crop residue and N on weed interference in wheat.
2. To assess crop productivity, profitability and resource-use efficiency under conservation agriculture and N management.
3. To estimate the effects of tillage, crop residue and N management on soil properties across CA practices.

**REVIEW OF LITERATURE**

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Indo-Gangetic Plains (IGP) provides food and livelihood to the burgeoning population of South-East Asia. The IGP of India is referred to as ‘food bowl of India’. India has experienced the Green Revolution in the late 1960s mainly in this region with the introduction of high yielding, input responsive cultivars of rice and wheat. Nawaz *et al.* (2019) viewed that from 1960s-1990s, there had been continuous increase in the adoption of rice-wheat cropping system (RWCS) in the region due to large farm size, increased mechanization, availability of good quality irrigation sources, utilization of fertilizers and pesticides, and assured market of crop produce. Jat *et al.* (2016) reported that indiscriminate use and overexploitation of natural resources, and excessive agrochemicals application imposed a threat to the sustainability of this region and now the productivity has shown stagnated or declining response. The decline in the crop, water, and land productivities, soil health deterioration, greenhouse gas emission due to intensive tillage and residue burning, groundwater table deepening, shift in weed flora, and herbicidal resistance in weeds are serious unsustainability issues threatening the food security of the nation (Bhatt *et al.*, 2021). Conservation agriculture is one of the possible solutions to sustain productivity, combat unsustainability, and to safeguard food security (Lal, 2009; Bhatt *et al.*, 2021). To check soil erosion and conserve soil moisture, conservation tillage was developed in the USA. The concept is primarily based on zero tillage with minimal disturbance of soil, keeping a protective cover of plants and/or plant residues on the soil surface to reduce soil losses, encourage microbial populations, and conserve moisture and nutrients. Conservation agriculture is a concept in support of sustainable land management, environmental protection, and climate change adaptation and mitigation. It involves minimum mechanical soil disturbance, permanent soil cover (at least 30% area covered), and crop diversification (FAO, 2012). It is an innovative resource based-approach for sustainable management of soil, water, nutrients, and energy. Conservation agriculture is cost-effective as it reduces the cost of cultivation, advances wheat sowing by about a week and reduces the *Phalaris minor* infestation. The area sown under wheat adopting zero-till drill has been

progressively increasing and covers more than 2 million ha in North-western plains zone (Sangar *et al.*, 2005).

The existing puddled transplanted rice-based system exerts pressure on natural resources. It requires repeated tillage operations to puddle soil at the expense of non-renewable energy sources, huge groundwater application for land preparation and further stagnation, poor nutrient use efficiency, and greenhouse gases emission (CH<sub>4</sub>). The substitution of rainy season (~*kharif*) rice crop with legumes like short-duration pigeon pea, mungbean, and soybean enhances sustainability and avoids exploitation of natural resources (Ali *et al.*, 2016). The pigeon pea-wheat system (PWS) could be an effective alternative to existing RWCS in the IGP due to various reasons: a) pigeon pea meets nitrogen requirements by biological-N fixation, has high fertilizer use efficiency, b) less NO<sub>3</sub>-N losses to groundwater and hence environmental pollution is minimized, and c) pigeon pea improves soil physical, chemical, and biological properties of soil, and d) wheat production is more in PWS than in conventional RWCS. (Sepat *et al.*, 2015; Singh *et al.*, 2005). Conservation agriculture practices result in improved crop productivity, water-use efficiency, net economic returns, and reduction in global warming potential (Jat *et al.*, 2016; Das *et al.*, 2013; Das *et al.*, 2018). Hence CA-based sustainable intensification can be an important tool to meet the sustainable development goal of “Zero Hunger” and hold the potential to bring in a second Green Revolution in the region. Various researchers have reported the superiority of conservation agriculture-based systems over traditional conventional tillage systems. In this chapter, an attempt has been made to review the research findings related to the study entitled ‘**Tillage, residue, and nitrogen effects on weeds, wheat productivity, and soil properties under Conservation Agriculture-based pigeon pea-wheat system.**’ The review has been presented under the following broad categories:

## **2.1 Weed dynamics and interference**

## **2.2 Crop root growth, productivity, and profitability**

## **2.3 Resource use efficiency (water, and energy)**

## **2.4 Soil properties**

### **2.1 Weed dynamics and interference**

Weeds are the major pest in crop production, roughly accounting for 37% loss of agricultural produce in India (Das, 2008). CA manipulates crop field ecology and disturbs weed habitat, but under the ZT conditions, the major proportion of weed seeds is more in the top soil layers. Due to minimum mechanical soil disturbance and crop diversification, a shift in weed flora or weed composition in a particular area takes place, which makes herbicide selection important and weed control using herbicides mandatory (Soni *et al.*, 2020). The switch from conventional till (CT) wheat to ZT wheat causes a shift in weed dynamics and weed seed recruitment (Singh *et al.*, 2015). Chauhan *et al.* (2006) viewed that weed management under a ZT system is more complicated than CT due to the lack of weed seed burial by tillage and reduced efficacy of soil-applied herbicides. Weed seeds concentrate on soil surface or topsoil layers than sub-soil layers. The recruitment of weed seeds are found more in minimum till than no-till and same fashion in biomass accumulation was observed for rigid ryegrass. The recruitment of seeds requiring light to germinate is more, and are problematic under CA system (Chauhan *et al.*, 2012). Weed management practices like stale seedbed technique, altered sowing time, use of crop residue as mulch, narrow row spacing, high seed rate, competitive cultivars for weed suppression, crop rotation and judicious use of herbicides are integrated weed management options to sustain CA. Chauhan *et al.* (2012) opined that the addition of crop residue as mulch is one of the CA principles, which can suppress emergence and growth of many weed species besides moisture and soil conservation. It gives competitive edge to crop plants over weeds. Wilson (1998) reported that 70-90% of the weed seed bank population consisted of few dominant weed species. The evolution of weed populations takes place in response to agricultural activities. The changes in ecosystem like soil disturbance, crop rotations and fertilization results into change in weed seed bank composition, weed species richness, seed bank abundance and diversity (Hosseini *et al.*, 2014). Under CA systems small-seeded species constitutes major proportion of the weed flora, and seedling recruitments. It is favoured because small-seeded weeds germinate more from top soil layers, from deep soil layer their germination is difficult (Chauhan *et al.*, 2007; Sosnoskie *et al.*, 2006). With the continuous adoption of zero-tillage for years, the shift in weed flora from annual to perennial weeds takes place. The minimum soil disturbance provides the favourable environment for reproduction and spread of underground reproductive organs of perennial weeds (Buhler *et al.*, 1994; Froud-Williams *et al.*, 1981; Triplett and Lytle, 1972). The dynamics in weed flora and weed diversity in CA calls for the integration of efficient weed management strategies for sustainability of CA based cropping systems. These

strategies can include stale seedbed technique, altering crop sowing time, use of crop residues as mulch, selection of weed competitive cultivars, high seeding rates, altered row spacing, proper and judicious use of herbicides, use of preventive measures and crop rotation (Bajwa, 2014; Chauhan and Mahajan, 2012; Kumar *et al.*, 2013). Angiras *et al.* (2010) reported that the populations of *Digitaria sanguinalis*, *Echinochloa colona*, and *Panicum dichotomiflorum* were lowest at 0-10 cm depth under raised bed planting, but at 10-20 cm and 20-30 cm depths under ZT system. Clements *et al.* (1996) studied weed seeds population of common lambsquarters under different till systems, viz. mouldboard plough, chisel plough, ridge-till, and no-till. They found more than 60% of common lambsquarters population was concentrated in top 5 cm soil layer under no-till and chisel plough conditions, whereas was uniformly distributed in soil layers under mouldboard ploughing. Minimizing soil disturbance increased seed decay of *Lolium rigidum* by 48%-60% under no-till system and 12%-39% under minimum tillage (Chauhan *et al.*, 2006). No-till system led to 2-3.8 times lower seedling recruitment and lower biomass accumulation of *Lolium rigidum* than minimum tillage. The reduced recruitment and vigour of weeds under no-till could give competitive edge to crop plants over weeds.

Bajwa (2014) reported that efficient crop rotations like rice-potato-sunflower, rice-potato-wheat, rice-berseem, rice-ghobi sarson could lower weed seed bank and weed dry matter of *Phalaris minor*. These crop rotations could be the potential substitute to existing RWCS in the IGP, where herbicide resistant *Phalaris minor* menace is prevalent. Arif *et al.* (2007) reported significantly higher density and biomass of *Cynodon dactylon* and *Cyperus rotundus* under ZT condition than reduced till or deep tillage plots. In ZT rice, addition of wheat residue mulch @ 5 t/ha led to reduction in weed density by 22 to 76% and endorsed predation of weeds. Kumar *et al.* (2013) observed in ZT wheat that addition of rice residue mulch (6 to 10 t/ha) with early sowing reduced emergence of *P. minor* by over 80%. These non-chemical weed management practices accomplished through turbo happy seeder led to suppression of weeds and enhanced wheat yield. Swanton *et al.* (1999) from a 9-year old study on weed dynamics due to tillage, N levels and cover crops observed the association of *Amaranthus retroflexus* and *Chenopodium album* with CT and *Digitaria sanguinalis* with ZT system, whereas the effect of N levels and cover crop not significant. Bernstein *et al.* (2014) reported that rye cover crop, ZT, early soybean planting, and narrow soybean row-space played a role in contributing to effective season-long weed suppression and, together, comprised a diversified approach to weed management. Weed suppression was

much greater across ZT rye treatments than in the tilled treatment. Velvetleaf recruitment was consistently greater in the CT than ZT rye treatments. In the CT rye treatments, weed emergence peaked early in the season, but in the ZT rye treatments, in the middle or late season. The ZT rye treatments were linked to more diversified summer annual and perennial weed species. Govindasamy *et al.* (2020) found that compared to CT system, the ZT showed higher concentrations of Johnsongrass [*Sorghum halepense* (L.) Pers.], prostrate spurge [*Chamaesyce humistrata* (Engelm. ex A. Gray) Small], waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer], and henbit (*Lamium amplexicaule* L.). Furthermore, when compared to the CT system (H = 0.6, S = 4.2), the ZT system had higher weed diversity (Shannon-Wiener index, H = 0.8) and species richness (S = 6.2). In sandy loam soil over a period of 8-years, Hugo *et al.* (2021) observed that CA-based rotation led to weed species shift with *Commelina benghalensis* L. numbers rapidly increasing after three years, while the population of *Crotalaria sphaerocarpa* DC got more than doubled. New weed species such as *Helichrysum argyrosphaerum* and *Vernonia poskeana* were also observed. The CA-based treatment had significantly higher weed diversity than CT treatments. Pratibha *et al.* (2021) reported a shift in weed species from annual to perennial under ZT, whereas annual weed species were dominant in CT and reduced tillage (RT). After seven years, the CT had much lower weed density and weed biomass than the RT and ZT. In ZT, a shift in weed species was detected as well as greater weed density and biomass in dicots (*Tridax procumbens* L. and *Euphorbia hirta* L.) and a slight decrease in monocots (*Bulbostylis barbata*, *Digitaria sanguinalis* L.). In contrast, Sasode *et al.* (2020) observed that ZT with residue during both the *kharif* and *rabi* seasons as well as exclusively during the *rabi* season, led to reduction in narrow-leaved and broad-leaved weeds by 40 and 19%, respectively. Carter and Ivany (2006) reported that the mouldboard plough (17 species) had a significantly lower weed species diversity than shallow tillage (ST; 21 species) and direct drilling (DD; 22 species). Weed seed population was substantially higher under DD (56 weeds m<sup>2</sup>) and ST (66 weeds m<sup>2</sup>) than under MP (25 weeds m<sup>2</sup>) for the total soil depth sampled (0–20 cm), and was mostly due to variations in the numbers of annual broad-leaved weeds relative to perennial broad-leaved and grasses. Nandan *et al.* (2020) reported that the ZT dry seeded rice - ZT wheat/ maize (ZTDSR-ZT), unpuddled transplanted rice – ZT wheat/maize, unpuddled transplanted rice – ZT wheat/maize, ZT transplanted rice– ZT wheat/maize, and ZT dry seeded rice - ZT wheat/maize (ZTDSR-ZT) systems had superior Shannon-Wiener, Simpson, and evenness indices than CT transplanted puddled rice–CT

wheat/maize system. Ghosh *et al.* (2021) observed that CA- based permanent broad bed with crop residue and 75% RDN led to 34% lower weed density than CT, but the permanent broad bed with residue and 100% RDN had 22% greater maize grain yield and 36% higher net returns than CT. Similarly, Nath *et al.* (2015) observed that ZT with 5 t/ha maize residue retention + 75% N + rest N based on GreenSeeker led to a significant reduction in the population of narrow-leaved, broad-leaved, and total weeds compared to CT and ZT without residue.

## **2.2 Crop root growth, productivity and profitability**

CA-based crop production practices have the capability to increase crop productivity and profitability while improving energy efficiency, greenhouse gases mitigation, and soil health in the IGP of South Asia (Kumar *et al.*, 2013).

### **2.2.1 Root growth**

Conservation tillage improves crop root growth, water, and nutrient use efficiencies, increase crop diversification, crop yield, and ultimately benefits the environment (Das *et al.*, 2018; Ghosh *et al.*, 2019). Martinez *et al.* (2008) observed that ZT system affected root growth in a positive manner, and when compared to CT system, root length density under ZT increased in the top soil layers. Pearson *et al.* (1991) viewed that the impact of tillage on the root growth of wheat may be influenced by length of time from the implementation of ZT system. The roots in the ZT system accumulates in 0-5 cm top soil layer compared to CT (Chan and Mead, 1992; Wulfsohn *et al.*, 1996). However, the opposite trend was observed in lower layers (Chan and Mead, 1992). Pearson *et al.* (1991) found no significant effect of tillage on wheat roots diameter. According to Qin *et al.* (2004), while ZT and CT had no significant influence on root length density (RLD), the average RLD under CT was slightly larger than that under ZT. The tillage strategy had no effect on the mean root diameter (MD), nevertheless, in all settings, the average MD was somewhat greater under ZT than CT.

### **2.2.2 Crop productivity and profitability**

CA promotes the soil biological activity and biodiversity, a better soil structure and cohesion, and a very high natural physical protection against extreme weather events (intense rainfall, wind, dry or wet periods) and therefore reduces the soil erosion (Li *et al.*, 2019; Page *et al.*, 2020). Diversified

crop rotation, including a legume crop under CA, can improve soil fertility, reduce pests/diseases, and increase crop yield stability. Das *et al.* (2014) reported that plots under PBB+R had significantly greater wheat grain yield than ZT flat bed and CT plots. PBB+R plots yielded around 9% and 11% more wheat grain than PNB (4.37 Mg/ha) and CT (4.29 Mg/ha), respectively. The PBB+R plots also had highest net returns (mean values of two years) that was 36 and 13% higher compared with CT and PNB plots. They, therefore, recommended growing cotton–wheat system under permanent beds with residue retention. Kler *et al.* (1992) reported after ten years of continuous ZT rotation with maize, paddy, cotton, and moong bean that wheat grain yields were somewhat higher than in CT. Due to ZT wheat sowing in the NW-IGP, farmers could advance wheat seeding by 2 weeks to get a head start over *Phalaris minor* (Singh *et al.*, 1999). Brar *et al.* (2004) reported from long term experiment that after 25 years wheat yield in maize-wheat sequence remained same in ZT and CT. Similarly, Sharma *et al.* (2012) found wheat yields similar under ZT with rice residue and CT. Gupta *et al.* (2007a) reported that the marginal yield performance of wheat under ZT could be due to various favourable factors under ZT like proper placement of seed in narrow slits made by Zero-Seed Drill, early emergence of wheat seedlings and availability of higher moisture content. Again, Singh (2000) observed ZT had statistically similar plant dry matter, number of effective tillers, ear length, spikelets/spike, test weight, grain and straw yields with that in CT. In contrast, Yadav *et al.* (2005) reported significantly higher (~7.7%) grain yield of wheat under ZT than CT, mainly due to increase in effective tillers, grains/ear, and 1000-grain weight. Tripathi *et al.* (1999) in Mexico observed that raised-beds gave significantly higher grain yield of wheat over conventional flat sowing by reducing lodging (50-60%) and increasing yield attributing characters. Again, He *et al.* (2008) observed that permanent raised beds (PRB) could significantly increase soil water content (7.2–10.7%), soil temperature (0.2–0.98°C) during the wheat-growing period and increased yield slightly with ~18% higher IWUE relative to CT and ZT flat. Shivakumar and Mishra (2001) reported significantly higher shoot number, dry matter accumulation, number of ears and ear weight at harvest but non-significant difference in yield of wheat due to broad-bed furrow and flat-bed sowing. Das *et al.* (2014) reported that PBB+R led to ~9 and ~11% higher wheat grain yield than PNB and CT plots, respectively and highest net returns. Although the system productivity in terms of wheat equivalent yield (WEY) was similar in the plots under PBB+R, PBB, PNB+R, plots under PBB+R led to almost 15 and 13% higher WEY than PBB and PNB+R plots. Similarly, mean water productivity

of the system in the PBB+R treated plots (12.58 kg wheat grain/ha/mm) was 48, 22, 12, 15, 13, 24% higher compared with CT, PNB, PNB+R, PBB, ZT+R and ZT plots, respectively. Several workers (Hobbs *et al.*, 1997; Chauhan *et al.*, 2000; Khatri *et al.*, 2001) reported similar superior performance of the raised bed planting with three rows sown per bed on wheat grain yield and water-use efficiency than CT flat planting. But, Singh *et al.* (2002) found non-significant difference in grain yields between two or three rows per bed in timely-sown wheat. Sayre *et al.* (2005) also reported that no significant differences in wheat yield between CT with straw incorporation and permanent bed system where the residue was not burnt. But, bed planting through confining the traffic to furrow bottoms, provided a natural opportunity to reduce compaction on the beds (Sayre, 2004). On the contrary, in sandy loam soil, Sharma *et al.* (2002) observed inferior performance of wheat grown on raised beds than in CT flat beds mainly due to reduced tillering due to water stress during vegetative stage, however, got compensated by larger grains number per spike and higher grain weight (Bhardwaj *et al.*, 2004; Dhillon *et al.*, 2004; Sikka *et al.*, 2004; Ram *et al.*, 2010). Ghuman and Sur (2001) found that minimum tillage + maize residue mulch in wheat improved the sustainability of the maize–wheat cropping system.

### **2.3 Resource use efficiency (water, energy, nutrients)**

#### **2.3.1 Water**

Agriculture is the largest user of water, which is essential for crop production. Efficient water management and moisture conservation practices improve water productivity. Under CA, zero tillage, improved crop establishment practices, and residue retention boost water productivity while reducing irrigation water demand. Das *et al.* (2018) observed that because of lower irrigation water use and higher productivity, residue retention practices had higher water productivity than residue removal plots. ZT was found to save 20-35% of irrigation water compared to CT in wheat, lowering water use by roughly 10 cm ha<sup>-1</sup> or 1 million L ha<sup>-1</sup> (Gupta and Seth, 2007; Erenstein and Laxmi, 2008). Das *et al.* (2014) found that the ZT permanent broad bed+residue (wheat residue in cotton and cotton residue in wheat) resulted in 48% increase in system water productivity compared to CT plots in a CA-based irrigated cotton-wheat system. Similarly, in a CA-based pigeon pea-wheat system, Das *et al.* (2016) found that the ZT permanent broad bed + residue (wheat residue in pigeon pea and pigeon pea residue in wheat) led to a 27% higher water-use efficiency and 12.4% (~150 mm) lower system water use than the CT-based pigeon pea – wheat

system. Parihar *et al.* (2016a) reported highest system water productivity in a maize-wheat-mungbean system, which increased by 13–28% and 7–30% under permanent beds and ZT, while irrigation water requirement decreased by 40–65 and 60–98 ha-mm, respectively compared to CT.

### 2.3.2 Energy

Sustainable energy management requires a two-pronged approach: first, efficient business energy consumption, and second, utilizing renewable energy sources as a supplement to and replacement for commercial energy sources. Humans, draft animals, engines, tractors, power tillers, and electric motors among other sources, provide direct energy inputs to agricultural production systems. Seeds, organic manures, fertilizers, pesticides, growth regulators, and other indirect energy inputs are needed to accomplish various agricultural operations. Energy consumption has been steadily growing in India to boost agricultural output. However, energy efficiency is steadily falling. Kadleek and Cervinka (2000) found that indirect energy demands for wheat production systems were 92-94% of total consumption with most energy use associated with the use of fertilizers and agro-chemicals. According to Tomar *et al.* (2006), field preparation and crop establishment require about 25-30% of energy. Farmers need as many as 10-12 tillage operations, which include 3–4 disc harrowing and 2 cultivations followed by planking before sowing with seed drill or bed planter. As a result, the fuel required for field preparation and planting for 10-15 h of tractor operation is 65-80 litres per ha compared to merely 6 litres per ha under minimum tillage. Ram *et al.* (2010) reported from a maize-wheat cropping system that the PB (permanent bed) treatment had lowest input energy and energy output/input ratio (13.82), while the ZT+S/ZT (S-straw) treatment had highest output energy (392.04 x 10<sup>3</sup> MJ/ha/year). Gupta *et al.* (2007b) found that ZT had much higher energy consumption efficiency and productivity than CT. Choudhary *et al.* (2006) reported that under ZT practices, input energy consumption was higher with residue application compared with no residue application. Pratibha *et al.* (2015) evaluated the energy efficiency of several tillage strategies in a pigeon pea–castor system and found that in pigeon pea and castor, ZT resulted in reduction in fuel usage by 58 and 81%, respectively, and CT had 30 and 31% higher energy inputs than ZT. Sowing seeds by drilling in rows gave marked greater returns and energy output than broadcast sowing (Sharma and Thakur, 1989). Erenstein and Laxmi (2008) compared studies in rice-wheat systems in the IGP and found a considerable seasonal savings of diesel for land preparation with ZT in the range of 15–60 l/ha with an average of 36 l/ha or 81%

saving across the studies, equating to a CO<sub>2</sub> emission reduction of 93 kg CE/ha/yr. Saad *et al.* (2016) reported that in a maize-wheat-mungbean cropping system, ZT with raised bed (ZTB) with wheat and maize residues (WMR) spent 8% less energy than CT with a flatbed. In soil preparation and irrigation, ZTB saved 91% and 38% of energy, respectively. The cropping under ZT with flatbed resulted in significantly higher crop yield, output energy, and net energy return. On the contrary, the ZTB was more energy-efficient and productive. When compared to no residue treatment, WMR produced the most energy with a 17% increase in output energy. Chaudhary *et al.* (2017) reported that rice sown with a happy turbo seeder had lowest energy input, followed by bed planting, ZT, reduced tillage, CT, direct sowing, and broadcasting. They found that seeding in beds required least irrigation energy. In terms of energy efficiency, these resource-saving methods outperformed traditional practices. Similarly, Parihar *et al.* (2018b) observed that CA-based ZT and permanent bed plots had significantly lower energy use for land preparation (49.7-51.5%) and irrigation (16.8-22.9%), leading to higher energy use efficiency (13.4-17.1%) than CT plots.

### **2.3.3 Partial factor productivity and nutrient uptake**

Singh-Y *et al.* (2021) reported that CA led to enhanced partial factor productivity of N by 34 and 59% in rice and wheat, respectively, and a considerable saving of nutrients over a long run. Similar increase was also reported by Ghosh *et al.* (2020) in productivity, profitability, input-use efficiency including partial factor productivity of N and NPK in direct-seeded rice under a rice-wheat-mungbean system. In a maize-wheat-mungbean system, Ghosh *et al.* (2021) reported that the CA-based treatments with residue retention led to higher nutrients (N,P, and K) uptake than those without residue retention and CT in maize. Lower nutrient uptake in CT practice can be attributed to emergence of more grassy weeds and sedges, intensive tillage operations, nutrient losses, less soil water retention and impaired soil physical, chemical and biological properties. Ghosh *et al.* (2022) also showed similar higher productivity and partial factor productivity of N and P in mungbean under a maize-wheat-mungbean system.

## **2.4 Soil properties**

### **2.4.1 Physical properties**

#### **2.4.1.1 Bulk density (BD)**

Lampurlanes and Cantero-Martinez (2003) opined that tillage is temporary, and after tillage, soil rapidly settles, recovering its former bulk density (BD). Kay and Vanden Bygaart (2002) found across soil textures varying from sandy-loam to clay-loam that BD was greater under ZT than under mouldboard tillage in the top 20 cm of the soil profile. Gwenzi *et al.* (2009) stated that the conversion from CT to MT and ZT had no noticeable effects on BD even after six years. Hu *et al.* (2007) in their four years study at Luancheng, China reported that ZT significantly increased topsoil (0-5 cm) BD, while reduced tillage maintained a lower BD than CT. Ram *et al.* (2010) at PAU, Ludhiana found that soil BD recorded in CT was significantly higher than sequential fresh-bed and permanent bed treatments. In several other studies of the world, BD was not significantly affected by tillage treatment (Dao, 1996; Martinez *et al.*, 2008). Parihar *et al.* (2018a) noticed that BD under ZT and permanent beds decreased by 0.07 and 0.07, 0.11 and 0.12, and 0.07 and 0.09 Mg m<sup>-3</sup> at 0-5 cm, 5-15 cm, and 15-30 cm soil depths, respectively compared to the values measured for CT plots of 1.53, 1.65, and 1.65 Mg m<sup>-3</sup> for the respective depths.

#### **2.4.1.2 Aggregates**

According to Tisdall and Oades (1982), roots and hyphae are the major binding agents for macroaggregates (>0.25 mm), while humic compounds promote microaggregate (<0.25 mm) formation. Agricultural practices influence the quantity and persistence of binding agents, which may lead to aggregate formation or breakdown. Thus, soil aggregation can be used to evaluate agricultural management practices and select those that could optimize crop growth and minimize soil nutrient loss. Beare *et al.* (1994) reported that soil (0 to 5 cm layer) from CT plots had fewer water stable aggregates (WSA) >2 mm (sand-free basis) and lower total C and N concentrations than soil from adjacent plots under ZT for the same length of time (13 years). Greater soil macro-aggregation in ZT systems was due to reduced disturbance normally caused by ploughing has been reported by several authors (Filho *et al.*, 2002; Pinheiro *et al.*, 2004). Wright and Hons (2004) and Bhattacharyya *et al.* (2013a) found that ZT management increased soil aggregation, produced higher concentrations of organic C and N (sand-free basis) in macro-aggregates, and stored more soil organic carbon (SOC) and soil organic nitrogen in the 0 to 15 cm depth than CT (Das *et al.*, 2013). According to Bhattacharyya *et al.* (2013b), plots under ZT with bed planting (ZT-B) exhibited more macro-aggregates (0.25–8 mm) and larger mean weight diameter than CT-B plots in the 0-5 cm soil layer under the maize-wheat system. Plots under ZT-B showed 49% higher

macro-aggregate-associated N stocks than CT-B due to the greater abundance of macroaggregates (38 kg total soil N or TSN ha<sup>-1</sup>). Water stable aggregate distribution indices were higher in soil for ZT maize production than for CT maize production with different tillage practices, highlighting the role of ZT farming in improving soil structure. The soil mean weight diameter for CT was lowest (1.47–1.62) indicating that ploughing had a negative effect, namely, destroying soil structure, increasing the risk of soil erosion, and declining soil quality (Nath and Lal, 2016).

### **2.4.1.3 Soil temperature**

Soil temperature indirectly influences plant growth through its impact on soil physical process, i.e. rate of evaporation, rate of soil aeration, and other chemical and biological processes. The soil thermal properties influencing soil temperature are specific heat capacity, thermal conductivity, thermal diffusivity, and albedo. The thermal conductivity of soil is higher with reduced porosity and depends on its texture sand>loam>clay>peat. Frequently soil temperature regime is modified as a consequence of the tillage system involving residue retention and mulching. Acharya *et al.* (1998) showed the presence of organic residues as mulch in the conservation tillage treatments raised minimum soil temperature, measured at 5 cm depth, by 0.5-2<sup>0</sup>C, compared to no mulch treatment during wheat growth. The maximum temperature under CT treatments however was lowered at this depth by 0.3-2<sup>0</sup>C. Azooz *et al.* (1995) opined that residue on soil surface generally reduces radiant energy inputs, cools the soil. It also reduces heat loss from the soil surface and diurnal soil temperature fluctuations. Soil temperature under ZT was 0.6 °C lower than under MP and 0.7 °C lower than under RT. Shen *et al.* (2018) reported that higher residue coverage caused lower soil temperature; the effect was greater for maize than soybean residue. Residue type had a significant effect on soil temperature in 9 of 15 weekly periods with 0–1.9°C lower soil temperature under maize than soybean residue.

## **2.4.2 Chemical properties**

### **2.4.2.1 Soil pH and electrical conductivity (EC)**

The pH is a basic soil chemical property that influences microbial activity, nutrient availability, and crop performance. Kettler *et al.* (2000) found that the major influence of ploughing on soil pH was more significant for 0-7.5 cm soil depth. Both no-till and sub-till treatments, which usually leave plant residues at or near the soil surface, have lower pH than mould-board ploughing

treatments at all levels. Hulugalle and Entwistle (1997) found that pH was lower under minimal tillage compared with CT, whereas Thomas *et al.* (2007) found no effect of tillage on pH. Similarly, Malhi *et al.* (2011) viewed that tillage and straw management usually had little or no effect on soil pH in any soil layer. The electrical conductivity (EC) was significantly higher in permanent bed straw burnt than in a permanent bed where straw was not burnt (Verhulst *et al.*, 2011). Retention of crop residue on the soil reduced bulk density, enhanced organic C and EC, but reduced the pH of soil (Sushant and Yadav, 2004).

#### **2.4.2.2 Soil carbon**

The chemical properties of the surface layer of soil are generally better under ZT practice than in tilled soil. Adoption of ZT over a longer duration is advantageous to the protection and improvement of the structure and chemical properties of soil, particularly the SOC content (Lal, 1997). Increased mineralization and/or leaching rates may be responsible for the decrease in organic C and total N under tilled plots due to soil structure deterioration after tillage (Busari and Salako, 2015). One of the benefits of ZT has been identified as high carbon sequestration (Lal *et al.*, 2007). Hunt *et al.* (1996) reported that ZT systems improved SOC content in the upper 5 cm soil layer, regardless of soil texture, when compared to mouldboard plough and chisel plough systems. Wang *et al.* (2011) reported ZT system resulted in significant increases in soil N, organic C, and SOM fraction, whereas CT had a negative effect on soil microbial biomass as well as reduced SOC. Dorr *et al.* (2012) observed increased availability of P, Mg, TOC, total N, and mineral N when ZT was used, implying an increase in soil fertility in this system. According to Bhattacharyya *et al.* (2013a), ZT with bed planting and ZT with flat planting practices showed 15% higher TSN concentrations ( $0.63 \text{ g kg}^{-1}$  soil) than CT with bed planting in the 0–5 cm soil layer under a maize-wheat system. Similarly, Das *et al.* (2013) reported that plots with ZT with bed planting and ZT with flat planting had around 28 and 26% larger total SOC stock in the 0–5 cm soil layer than CT with bed planting ( $5.5 \text{ Mg ha}^{-1}$ ) in a maize-wheat-mungbean system. Das *et al.* (2018) reported that CA methods resulted in considerably greater SOC concentration and SOC pool than the CT technique in a maize-wheat cropping system. The maximum SOC pool was recorded under PBB+R, i.e. permanent broad bed with residue retention ( $34.4 \text{ Mg ha}^{-1}$ ), which was 19.4% greater than the CT system ( $28.8 \text{ Mg ha}^{-1}$ ). In this practice, the carbon sequestration potential was found to be  $5.59 \text{ Mg ha}^{-1}$ . Furthermore, the total SOC pool in the 0–30 cm soil layer was improved by 4.5% in residue retention plots compared to residue removal plots. Bhattacharyya

*et al.* (2015) observed that plots under the CA-based rice-wheat-mungbean system (i.e. mungbean residue + direct seeded rice followed by zero tilled wheat with rice residue retention followed by zero tilled relay summer mungbean) had 24% higher labile C pools than conventional rice-wheat system ( $3.1 \text{ g kg}^{-1}$ ). Soil bulk density reduced considerably in the 5–15 cm layer under CA-based plots compared to CT practice. Betrol *et al.* (2007) observed that ZT treatments had higher P, K and organic C concentrations in the superficial 0–0.25 cm soil layer and in runoff sediments than CT.

#### **2.4.2.3 Soil nitrogen**

In CA, optimum N fertilization can increase crop productivity, improve nutrient use efficiency, minimize N leaching losses, and lower  $\text{N}_2\text{O}$  emissions (Yadav *et al.*, 2017). Crop residue retention and the inclusion of legumes as a component of crop diversification for reducing N inputs can help improve food security regardless of whether they contribute to climate change mitigation (Powlson *et al.*, 2016). Schoenau and Campbell (1996) opined that in the early years of some CA systems, there might be an increased need for N, but the N requirement under CA should be expected to reduce over time as a result of organic matter accumulation. Jat *et al.* (2012) observed an increase in fertilizer N-use efficiency under CA practices and reported on its potential importance for reduced GHG emissions. The ZT permanent beds with crop residue would be a superior management choice for soil N enhancement as the management technique has the ability to promote soil aggregation with larger buildup of TSN inside macro-aggregates (Bhattacharyya *et al.*, 2013a).

#### **2.4.3 Soil biological properties**

Enzymes are important activators in biological processes, and also known to have significant roles in soil health and the environment. The majority of enzymatic activity in soil comes from microbial sources, including intracellular, cell-associated, and free enzymes. Soil health is maintained by a unique balance of chemical, physical, and biological (including microbial, notably enzyme activities) components (Das and Varma, 2011). The reduction in physical soil disturbance along with crop residue retention results in habitats with robust and diversified litter generation under ZT. The microbial community would be extraordinarily diversified in this system (Giller, 1996). CA can build a stable soil microbial community with pathogen-suppressing beneficial bacterial and fungal species (Palm *et al.*, 2014). Cookson *et al.* (2008) found that fungal biomass was

reduced as tillage disturbance increased, while bacterial biomass increased. CA has also been related to a rise in the diversity of fungal and bacterial populations, especially when crop rotations are more varied (Wang *et al.*, 2010). Parihar *et al.* (2016b) reported that ZT and crop rotation had a substantial effect on soil microbial biomass carbon (MBC) at the 0-30 cm soil layer. When compared to CT, MBC was found to be 48.9% higher in ZT and 44.9% higher in permanent beds. Nyamwange *et al.* (2021) reported that minimum tillage + mulch + no NPK fertilizer produced highest microbial biomass C and N with an average of 122.3 g g<sup>-1</sup> and 12.73 g g<sup>-1</sup>, respectively, while conventional tillage + no mulch + NPK fertilizer produced the lowest microbial biomass C and N with an average of 82.07 g g<sup>-1</sup> and 4.50 g g<sup>-1</sup>, respectively.

At all soil depths, tillage had a detrimental influence on hydrolase activities (urease, protease-BAA, phosphatase, and  $\beta$ -glucosidase), primarily with the adoption of mouldboard (Roldan *et al.*, 2005). Dehydrogenase, cellulase, xylanase,  $\beta$ -glucosidase, phenol oxidase, and peroxidase enzyme activities were all higher in ZT soils. ZT has tremendous promise for improving soil health and supporting climate change mitigation strategies since it improves both microbial functioning and C storage in soil (Mangalassery *et al.*, 2015). Roldan *et al.* (2005) found that dehydrogenase activity increased in direct proportion to the buildup of crop residues on soil surface (0–5 cm) when ZT adopted. Similarly, Yeboah *et al.* (2016) reported that ZT + residue system led to 16% and 14% higher SOC and 42% and 38% higher soil microbial biomass carbon in 0-30 cm depth, respectively than CT and ZT without residue systems. Also, dehydrogenase, urease, protease, phosphatase, glucosidase activities and aggregate stability were higher in ZT soils than in tilled soils.

## MATERIALS AND METHODS

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The field experiment entitled “**Tillage, residue and nitrogen effects on weeds, wheat productivity, and soil properties under Conservation Agriculture-based pigeon pea-wheat system**” was conducted at ICAR-Indian Agricultural Research Institute, New Delhi, India to evaluate effects of tillage, crop residue and N on weed interference in wheat; to assess crop productivity, profitability and resource-use efficiency under conservation agriculture (CA) and N management; to estimate the effects of tillage, crop residue and N management on soil properties across CA practices. This chapter describes the experimental details, techniques employed and the observations recorded during the course of study.

### 3.1 Experimental site and cropping history

The experiment was conducted at Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi, India (28°35' N latitude, 77°12' E longitude and at an altitude of 228.6 meters above mean sea level) during winter (*~rabi*) 2021-22. The field had a level topography and good drainage system. The experiment was undertaken in the 12<sup>th</sup> year of a long-term experiment on CA entitled “Conservation Agriculture for enhancing productivity and resource-use efficiency in wheat-based systems involving cotton-wheat, pigeon pea- wheat and maize-wheat systems.”

**Table 3.1. Cropping history of the experimental field**

Year	Cropping system	Residue retention
2010-2017	Cotton -wheat	Fixed layout with treatments (mentioned in this study) involving ZT bed-planted (permanent narrow, broad, and flat bed) conditions with cotton residue in wheat and wheat residue in cotton during 2010-2017 under a long-term CA project.
2017-2022 (Current experiment)	Pigeon pea-wheat	Cotton was replaced with pigeon pea and pigeon pea-wheat rotation started in the fixed layout with treatments (mentioned in this study) involving ZT bed-planted (permanent narrow, broad, and flat bed) conditions with pigeon pea residue in wheat and wheat residue in pigeon pea during 2017-2022 under a long-term CA project.

### 3.2 Climate and weather of the experimental site

The climate of Delhi is semi-arid and subtropical with harsh cold winters in December and January and hot, dry summers in May and June (mean maximum temperatures of 40° to 45° C). Sandstorms and ground frost are often associated with summer and winter, respectively. Average annual rainfall is about 710 mm, most of which is received between July and September due to the South-West monsoon and December to February due to the western disturbances. During wheat growth period (*rabi* 2021-22), mean daily Class 'A' open pan evaporimeter reading for the U.S. Weather Bureau varied from as high as 6.7 mm in April to as low as 1.6 mm in January. The pan evaporation was about 598.2 mm. Average wind speed varied from 1.6 kmph in November to 4.2 kmph in April. Mean relative humidity was highest during January (85%) and lowest during the april (41%). Rainfall was recorded 181.5 mm most of which was received during January (84.5 mm) , February (70.9 mm) and March (60.6 mm). The weekly average meteorological data from November 2021 to April 2022 recorded at the Meteorological Observatory of ICAR-Indian Agricultural Research Institute, New Delhi are presented in appendix 1 and graphically represented in Figure 3.1.

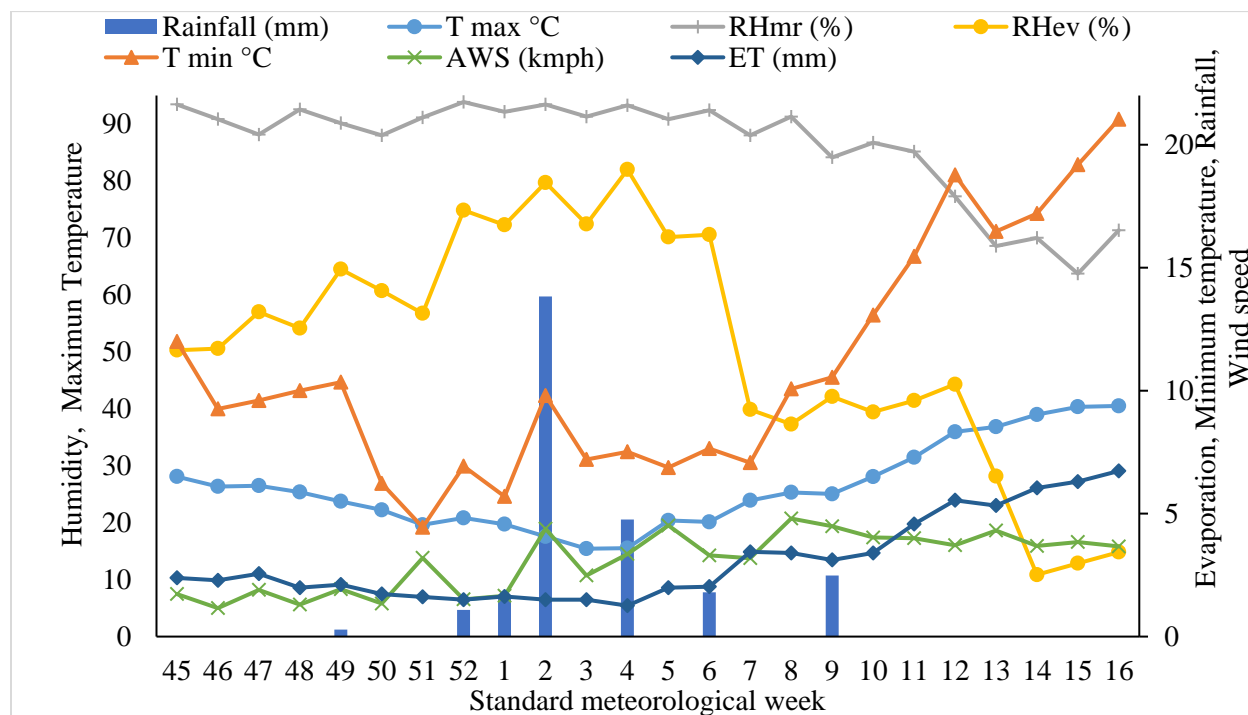


Fig. 3.1 Weather conditions during winter 2021-22

### 3.3 Soil characteristics

Initially after harvesting of pigeon pea and before sowing of wheat crop in November 2021, soil samples were collected from the fixed plots/treatments (0-15 cm depth) using core sampler. Soil samples from each treatment/plot across replications were collected, and composite samples were prepared replication-wise. The soil of experimental field was sandy clay loam in texture (sand 48%, silt 24%, and clay 28%) at 0-15 cm soil depth with the following soil properties (Table 3.2).

**Table 3.2. Initial soil properties of the experimental field (before wheat sowing)**

Treatment	pH	EC (dS/m)	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)
CT	8.32	0.29	0.65	253.7	73.0	436.2
PNB	8.44	0.27	0.70	273.7	79.0	460.1
PNBR	8.22	0.26	0.88	289.0	85.0	506.5
PBB	8.32	0.27	0.74	261.0	79.5	479.1
PBBR	8.10	0.22	0.97	291.7	95.0	599.8
ZTFB	8.27	0.25	0.80	268.0	75.0	458.0
ZTFBR	8.24	0.25	0.93	286.8	83.5	483.8

### 3.4 Treatments and experimental details

The experiment was conducted in a randomized complete block design (RCBD) with three replications. There were seven CA/CT treatments (Table 3.3) continued since 2010 under a long-term CA system. In this study, two levels of N, i.e. 75% and 100% of the recommended dose of N for wheat were imposed in the three CA-based treatments (PNBR, PBBR and ZTFBR) having two crops residue retained on the surface since 2010 to economize N dose in wheat under pigeon pea-wheat system. Thus, total treatments were 10 in this study (Table 3.3).

The CA-based treatments with and without residue were compared with conventional tillage (CT) practice. Different methods of crop establishment (i.e. permanent narrow, broad, and flat beds with and without residue of pigeon pea) along with 75% and 100% recommended doses of N were integrated with residue retention in the CA practices. Each narrow bed (PNB) had 40 cm bed width and 30 cm furrow, while a broad bed (PBB) had 110 cm bed width and 30 cm furrow. The PNB and PBB plots had 12 and 6 raised beds, respectively. Each treatment had 30.0 m long and 8.4 m wide strip ( $\sim 252 \text{ m}^2$ ) for ease of tractor operations for sowing and fertilizer application, harvesting, and anchoring residue). For replications, this strip was sub-divided into three plots of 9.0 m x 8.4

m (~75.6 m<sup>2</sup>) each with a gap/bund of 1.5 m between plots. Bunds were constructed around each plot for irrigation. The layout plan of the experiment is depicted in Figure 3.2.

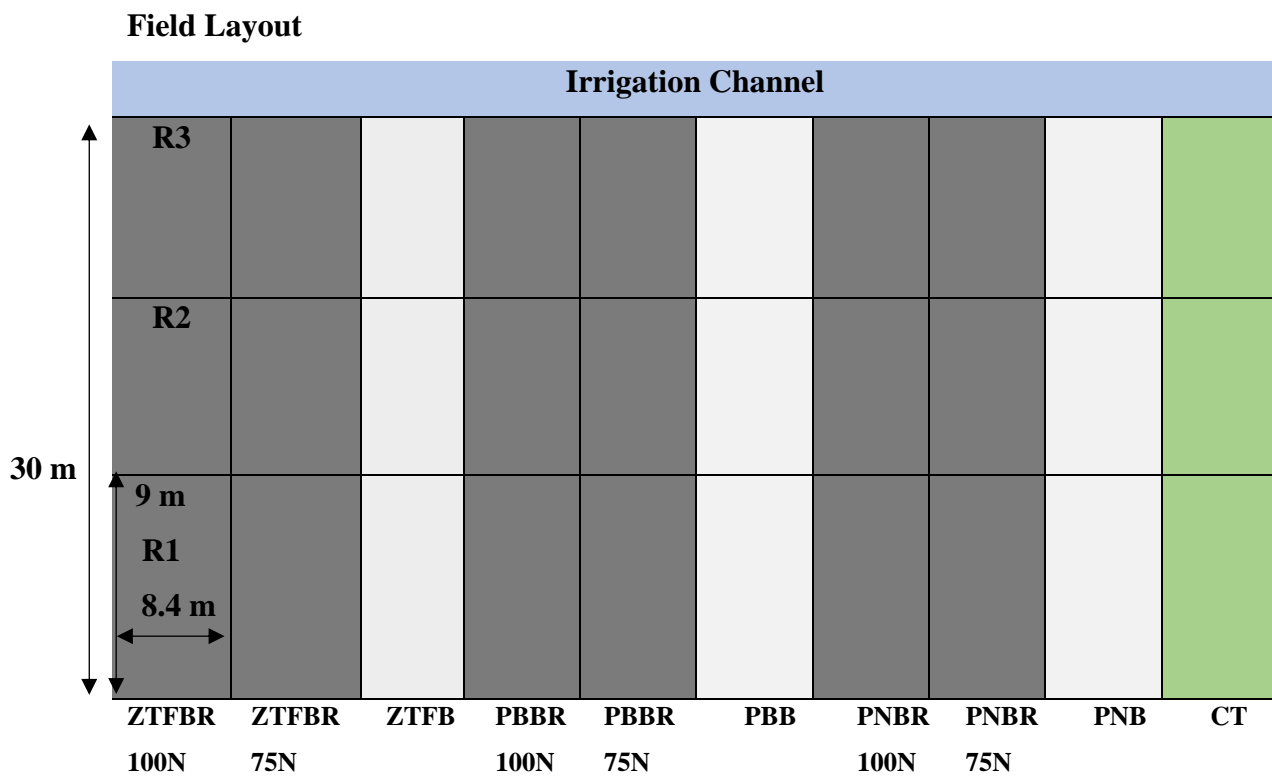
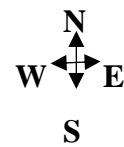
About 40% of pigeon pea residue/stover (above-ground biomass) amounting to 2.8 to 3.2 t/ha (as per the treatments) was retained as anchored residue in the residue retention plots of PNBR, PBBR and ZTFBR. In these residue retention plots, existing/standing pigeon pea plants at maturity were cut manually at about 60 cm height from the base and left *in situ* as anchored residue and quantification of residue was done on dry weight-basis. Extra residue if at all required for 40% residue retention of particular plots was applied uniformly as loose residue. Rest pigeon pea plants (above 60 cm height), which included branches, tender twigs, and leaves were harvested and threshed for estimating grain yield. Also, pigeon pea leaf litter was measured across the treatments/plots (Table 3.3). Similarly, wheat plants were harvested with a combine harvester at 40 cm height from the base of plants for grains, and rest was retained as stubble at the end of season. To quantify the residue load of each plot, an area of 1.0 m<sup>2</sup> was selected in each plot and residue samples from that area was weighed after oven drying.

**Table 3.3. Treatment's code and description**

Treatment code	Treatment details
CT	Conventional tillage with flat-land sowing (farmers' practice) +100% N
PNB	ZT permanent narrow-bed + 100% N
PNBR75N	ZT permanent narrow-bed with residue (R) + 75% N
PNBR100N	ZT permanent narrow-bed with residue + 100% N
PBB	ZT permanent broad-bed + 100% N
PBBR75N	ZT permanent broad-bed with residue + 75% N
PBBR100N	ZT permanent broad-bed with residue + 100%N
ZTFB	ZT flat bed + 100% N
ZTFBR75N	ZT flat bed with residue (ZTFB+R) + 75% N
ZTFBR100N	ZT flat bed with residue ((ZTFB+R) + 100% N

The total residue retention (~total residue biomass input) was estimated by summing up the crop residues retained, leaf litter, and root biomass. For the residue removal (PNB, PBB and ZTFB) and

CT treatments, pigeon pea plants were harvested just above the soil surface at around 3-4 cm heights. A dose of 150 kg N, 26.2 kg P and 33.2 kg K/ha is the recommended dose of N, P, and K for wheat in the IGP of India. Accordingly, the 100%N and 75%N treatments received 150 and 112.5 kg N/ha with a common dose of 26.2 kg P and 33.2 kg K/ha. The full dose of P and K and half dose of N as per the N treatments were applied as basal with the help of a turbo seeder in PBB and ZTFB, bed planter in PNB and seed-cum-fertilizer drill in CT plots. Remaining N was top-dressed in two equal splits after first irrigation (21-25 DAS) and at pre-flowering stage (60-65 DAS).



**Fig. 3.2. Layout plan of the field experiment**

### 3.5 Description of materials used

#### 3.5.1 Wheat variety

Wheat HD 3117 is a late sown variety bred for irrigated, high fertility, and conservation agriculture conditions and released from ICAR-Indian Agricultural Research Institute, New Delhi in 2015. It

is also suited to early sowing (mid-October) and released for Delhi and NCR. The variety has semi-spreading growth habit, dark green leaves and medium lax ear head with medium maturity (108-136 days). Plant height is 84 cm (ranges between 64-105 cm) and yield is 47.8 and 47.9 q/ha under CT and CA, respectively. It is resistant to brown rust, moderately resistant to yellow rust and highly tolerant to Karnal bunt. The grain protein content is ~11.7%.

### **3.5.2 Crop residues**

The CA-based residue retention plots of PNB, PBBR and ZTFBR had about 40% pigeon pea residue/stover (above-ground biomass) as mentioned in Section 3.4 and shown in Photo 1.



Photo 1. Anchored pigeon pea residue with leaf litter in wheat (ZTFBR)

### **3.6 Field operations**

The cultural operations carried out in wheat crop during experimentation have been given below.

#### **3.6.2 Land preparation**

Land preparation was done as per the treatments. In CT plots, one primary tillage using a tractor-drawn disk plough and three secondary tillage operations using cultivator/harrow were done followed by leveling for pulverizing soil for fine tilth. But, the plots were not ploughed in the CA-based PNB, PBB and ZTFB plots with and without residue treatments (Table 3.3).

#### **3.6.3 Fertilizer application**

A dose of 150 kg N, and 112.5 kg N/ha was applied to wheat for 100% and 75% N treatments as mentioned in Section 3.4. Besides, a common dose of 26.2 kg P and 33.2 kg K/ha was applied to both these treatments. For top dressing of N, urea was broadcasted on the soil in all the plots except PNB and PBB plots, where urea was applied only on the beds leaving aside the furrows.

#### **3.6.4 Sowing**

Sowing of wheat was carried out in CT plots by using a tractor-drawn seed-cum-fertilizer drill, in PNB plots by bed planter, and in PBB and ZTFB plots by turbo seeder (Photo 2). Wheat was sown with a seed rate of 100 kg/ha. There were 36 rows of wheat on 12 narrow beds in each plot of PNB (3 rows of wheat spaced at around 13 cm), and 30 rows of wheat on 6 broad beds (5 rows of wheat per broad bed) in each plot of PBB. In CT and CA-based ZTFB and PBB plots, wheat was sown at 20 cm row spacing.



Photo 2. Wheat sowing under ZT with Turbo Seeder on PBB with pigeon pea residue

#### **3.6.5 Gap filling and thinning**

Gap filling and thinning were done after crop germination (10 DAS) to maintain optimum plant population.

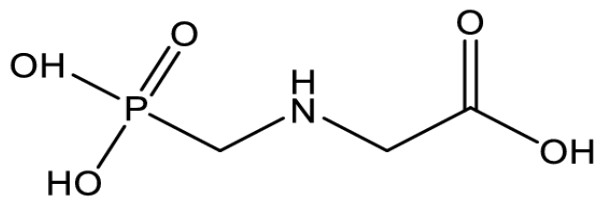
#### **3.6.6 Irrigation**

The depth of irrigation water varied according to moisture content in soil. Six irrigations (including pre-sowing) were applied. Based upon the moisture deficit in soil, and discharge of channel, the irrigation amount and time was scheduled.

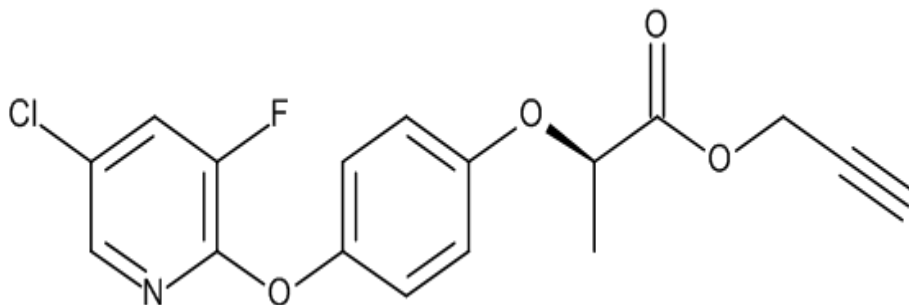
### 3.6.7 Herbicide application

Glyphosate (N-phosphonomethyl glycine) @ 1.0 kg a.i./ha was applied as pre-plant desiccant for pigeon pea stalks and existing weeds. A tank-mix application of clodinafop-propargyl [prop-2-ynyl(R)-2-{4-(5-chloro-3-fluoro-2-pyridyloxy)phenoxy}propionate] + metsulfuron methyl [methyl-2-[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)-amino]carbonyl] amino] sulfonyl] benzoate] (0.060 kg a.i./ ha + 0.005 kg a.i./ha) was done in all the treatments at 30 DAS to control existing weeds. However, there were three fixed plots of 1.0 m x 1.0 m area kept undisturbed and unsprayed with herbicides in each treatment for evaluating the performance of the CA/CT practices towards weed control.

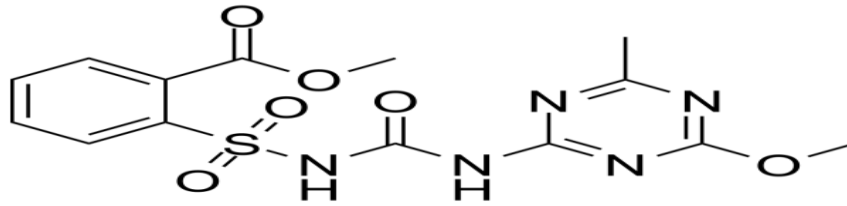
Chemical structures of herbicides used:



Glyphosate



Clodinafop-propargyl



Metsulfuron-methyl

### 3.6.8 Harvesting and threshing

A net plot area of 5 m<sup>2</sup> and 7 m<sup>2</sup> was randomly selected in each plot from three locations for harvesting wheat crop manually from the flat beds and raised beds, respectively. Later a combine harvester was used to cut wheat plants at about 40 cm height above the ground level from rest of the plots/area. Threshing of wheat was done by using a Pullman Thresher. In case of residue removal (PNB, PBB, ZTFB) and CT plots, crop was harvested manually by cutting at the bases of plants at around 3-4 cm heights above soil surface. After threshing, grains were cleaned and grain yield was recorded at 12% moisture. Similarly, straw/stover samples were weighed for straw yields.

## 3.7. Biometric observations

### 3.7.1. Weeds

#### 3.7.1.1 Weed seedling count under fixed plot study (Non-destructive sampling)

Weed seedling count and dry weight were observed from different treatments at 30 and 60 DAS and at harvest. To evaluate the changes in weed flora due to CT and CA-based practices, an area of 1 m × 1 m area was randomly selected across replications of each treatment and kept undisturbed and no herbicide applied all through to appraise the treatments' effects. Weed species were counted periodically from that area, and species-wise, category-wise and total weed population/density were determined.

#### 3.7.1.2 Weed population and dry weight (Destructive sampling)

Species-wise weeds were collected from a quadrat area of 0.25 m<sup>2</sup> (0.5 m × 0.5 m) in each treatment/ plot, counted and grouped as category-wise and total/composite weed populations at 60 DAS. At 30 DAS, an application of the tank-mix of clodinafop-propargyl (60 g/ha) + metsulfuron-methyl (5 g/ha) was made to all treatments to have a broad-spectrum weed control and to provide equal opportunity to all the treatments towards expressing their yield potential. The weeds collected were first sun-dried for three days and then kept in an electric oven at 70<sup>0</sup>C till constant weight for estimating dry weight. As wide variations in data existed across the treatments, therefore, data on weed population and dry weight were transformed through square root [(x+0.5)<sup>1/2</sup>] method before analysis of variance (ANOVA).

### **3.7.2 Wheat crop**

#### **3.7.2.1 Wheat growth parameters**

Wheat growth parameters such as plant height, leaf area index (LAI), tiller number and dry matter accumulation were studied at 30, 60, and 90 DAS. Ten plants were randomly selected and tagged from the central 6 rows of each plot for periodic measurement of plant height. The height of the plants was measured from the ground level to the tip of the topmost leaf. Number of tillers was counted from three fixed 1.0 m row lengths in each treatment plot at 30 and 60 DAS. For leaf area estimation, a 20 cm row length was uniformly selected from three places in each treatment plot and plants were cut from the ground level. Then leaves were detached and leaf area was estimated by using a leaf area meter (Model: LI-COR-3100). For dry matter estimation, plants from the same 20 cm row length selected for LAI measurement, were sun-dried for three days, then oven-dried at 65<sup>0</sup>C for 24 hours till constant weight achieved and dry weight was expressed in g/m<sup>2</sup>.

#### **3.7.2.2 Wheat root growth**

Root samples were collected at 70 DAS from three and five rows, respectively in narrow (PNB) and broad bed (PBB) treatments under both residue retention and removal. In case of flatbed treatments and CT, root samples were taken from three consecutive rows. Root samples were taken using root auger having 7.5 cm diameter from 0-30 cm soil depth and soaked in water containing tray for 30 minutes. Later roots were separated from soil, liquid decanted off through a bigger sieve (5 mm) and a smaller sieve (2 mm). The trapped roots collected in each sieve size were washed with running water and placed into containers. Roots were kept on blotting paper and fresh

weight recorded and then kept in plastic sealed bags for analysis using WinRHIZO software (Himmelbauer, 2004; Guan *et al.*, 2014), which is an image analysis system, specifically designed for automatic root measurement in different forms. It uses a desktop optical scanner as the image acquisition device. Root samples were placed in a transparent tray on the scanner glass and scanned and analysis of the acquired images was carried out using WinRHIZO software. Total root length, surface area, volume and average diameter were recorded. Then the root samples were oven dried at 65°C to a constant weight for 24 hours for dry weight estimation. Then root length density (RLD), root mass density (RMD) and root volume density (RVD) were computed by dividing length, mass and volume of root by the volume of soil collected.

### 3.7.2.3 Lodging score and index

At 120 DAS, wheat crop in the experimental field experienced lodging, which varied across the CA and CT treatments. Therefore, lodging of wheat crop was estimated at 120 DAS. Lodging score (Fischer and Stapper, 1987) and lodging index (Wiersma *et al.*, 1986) were determined using the following formulae:

$$\text{Lodging score} = \frac{(\% \text{ plot area lodged} \times \text{angle of lodging from the vertical})}{90}$$

$$\text{Lodging index} = \frac{(\% \text{ plot area lodged} \times \text{degree of lodging})}{100}$$

where, % plot area lodged =  $\frac{\text{lodged area}}{\text{net plot area}} \times 100$ ; 0° angle from vertical means main stem standing upright; 90° angle from vertical means main stem laid down horizontally; degree of lodging 0 means main stem standing upright, while degree of lodging 100 means main stem laid down horizontally.

### 3.7.2.4 Wheat yield attributes and yield

Number of ear-bearing tillers was counted from three rows of 1.0 m length in each treatment plot at harvest. Twenty ear heads were randomly selected from each replicated plot, threshed manually and number of grains per ear head counted. For estimating grain and straw yield, wheat crop from the net plot area of 5 m<sup>2</sup> and 7 m<sup>2</sup> was harvested manually and threshed after sun-drying for three days in flat bed and raised beds, respectively. Grain weight and straw weight was taken from each treatment and expressed as t/ha. A representative sample of grains was taken from the bulk grains

of each treatment, cleaned and dried to about 12% moisture for moisture adjustment in yield and 1000 grains weight (~test weight).

### **3.8 Economic analysis**

The economic analysis in terms of gross and net returns and net benefit: cost (returns per rupee invested) was worked out on the basis of existing rate of inputs and outputs (Appendix II). Total cost included the cost of various inputs such as seeds, fertilizers, irrigation and various cultural operations such as ploughing, sowing, plant protection measures, harvesting, threshing etc. The rental value of land was also considered in the cost of cultivation. Returns were calculated by using the following formula:

Gross returns (INR/ha) = Value of the grain + Value of straw

Net returns (INR/ha) = Gross returns – Total cost of cultivation

Net benefit: cost =  $\frac{\text{Net returns}}{\text{Total costs of cultivation}}$

### **3.9 Resource-use efficiencies**

#### **3.9.1 Nutrient-use efficiency and uptake**

##### **3.9.1.1 Partial factor productivity (PFP) of nutrients**

Partial factor productivity (PFP) of nutrient is a measure of efficiency of nutrient use. The PFP of nutrients (N, P, K) was calculated by dividing the yield (kg/ha) with total amount of N, P, and K applied individually through fertilizers (kg/ha).

##### **3.9.1.2 N, P, and K concentrations (in wheat grain and straw) and their uptake**

Nitrogen (N) content (%) in grain and straw was determined by modified Kjeldahl method. Phosphorus (P) content in grain and straw was determined by vanadomolybdophosphoric acid yellow colour method. Potassium (K) content in grain and straw was determined by flame photometer method (Jackson, 1973).

Nutrient uptake by grain or straw was calculated by using the following:

Nutrient uptake (kg/ha) =  $[\{\text{Grain/straw nutrient (\%)} \times \text{grain or straw yield (kg/ha)}\} / 100]$ .

#### **3.9.2 Soil moisture and water productivity**

##### **3.9.2.1 Soil moisture**

For estimating the frequency and quantity of water applied, soil samples were collected using tube auger at respective depths and analyzed for soil moisture content using gravimetric soil moisture method by drying the soil at 105°C till the constant weight achieved. Irrigation was scheduled when the available soil moisture at the root zone was depleted by 50%. According to Michael (2008), the depth of irrigation water was determined using the following equation.

$$\text{Soil moisture deficit (mm)} = (\text{SMC}_{fc} - \text{SMC}_{bi}) \times D_i \times \text{BD}$$

Where,  $\text{SMC}_{fc}$  = soil moisture content (%) at field capacity;  $\text{SMC}_{bi}$  = soil moisture content (%) before irrigation;  $D_i$  = depth of root zone (mm);  $\text{BD}$  = bulk density ( $\text{Mg m}^{-3}$ )

### 3.9.2.2 Water productivity

Water productivity (kg grain/ha/mm of water) was calculated following Bhushan *et al.* (2007) and Das *et al.* (2018).

$$\text{Irrigation water productivity (kg grain/ha/mm)} = \frac{\text{Grain yield (kg/ha)}}{\text{Irrigation water applied (mm)}}$$

$$\text{Total water productivity (kg grain/ha/mm)} = \frac{\text{Grain yield (kg/ha)}}{\text{Total water applied (mm)}}$$

Total water applied includes effective rainfall and irrigation water. Effective rainfall was calculated by using standard methods as given by FAO (2010) (Daily rainfall data was collected from a rain gauge located at about 400 m away from the experimental plot). The amount of irrigation water to be applied was determined by measuring the water discharge (m/s) using digital flow meter and wetted area ( $\text{m}^2$ ) of the field channel (Das *et al.*, 2018). Based on irrigation water depth requirement ( $\text{m}^3$ ) and water channel discharge ( $\text{m}^3/\text{s}$ ), the timings for running the irrigation water in each treatment plot were determined during each irrigation period. Before irrigation to the treatment plots, a rating curve was generated, showing the relationship between flow depth and discharge in the main channel. Then, an exponential equation was developed. Afterwards, flow depth was measured at the time of irrigation in the channel using digital flow meter and corresponding discharge was estimated using the rating curve.

### 3.9.3 Energy auditing/budgeting

Energy-use indices were analyzed using the formulae given by Mittal and Dhawan (1988), Singh *et al.* (1997), Saad *et al.* (2016), and Parihar *et al.* (2018b, 2018c). Energy equivalents of different operations used in the experiment are given in Appendix III.

### 3.9.3.1 Input energy

Total input energy was estimated by adding energy equivalents of all inputs. Operation-wise energy was calculated on the basis of input energy consumed in field preparation, sowing, fertilizer application, irrigation, intercultural operation, plant protection, harvesting and threshing. Source-wise renewable and non-renewable energy under direct and indirect energies of inputs, *viz.*, human labour, water, seed, crop residue, diesel, agro-chemicals (pesticides, herbicides), fertilizers and machinery, were also calculated to find out the energy consumed in every crop management practices under CT and CA-based treatments. Grain and straw samples from the net areas were harvested manually, however, mechanized harvesting and threshing were assumed for energy calculation on hectare basis.

### 3.9.3.2 Output energy

The amount of energy produced from wheat grain and straw yields were converted in terms of energy (MJ/ha) using corresponding energy coefficients. The output energy was computed as the sum of the total energy equivalents of grain and straw yields.

### 3.9.3.3 Energy productivity

Energy productivity was estimated by dividing the grain yield (kg/ha) to total input energy (MJ/ha) used.

$$\text{Energy productivity (kg/MJ)} = \frac{\text{Grain yield (kg/ha)}}{\text{Total input energy(MJ/ha)}}$$

### 3.9.3.4 Energy ratio

Energy ratio was calculated by dividing total energy output (MJ/ha) by total energy input (MJ/ha)

$$\text{Energy ratio (MJ /MJ)} = \frac{\text{Total output energy(MJ/ha)}}{\text{Total input energy(MJ/ha)}}$$

## 3.10 Soil properties

### 3.10.1 Physical properties

#### 3.10.1.1 Bulk density

Soil bulk density is a measure of the oven-dry mass per unit volume of bulk soil. It was measured by core auger method with the help of core sampler. The core auger method involves sampling a soil core from a desired depth in its most natural condition using cylindrical core sampler (5 cm

internal diameter and 5.1 cm height) and determining the oven-dry mass of soil per unit volume of core. Bulk density of three layers of soil (0-5 cm, 5-15 cm and 15-30 cm) was determined by core sampler from three randomly chosen areas of each treatment plot. The procedure for determining bulk density was followed as described by Bandyopadhyay *et al.* (2012).

### 3.10.1.2 Soil aggregate analysis

Soil aggregate stability was determined by wet sieving method using Yoder's apparatus. Soil samples from three layers (0-5 cm, 5-15 cm and 15-30 cm) were collected from three random places of each treatment plot and aggregate stability was determined. In this method, the wet sieve shaker was used, which comprises of 4 sets of nested sieves suspended from a bar which is oscillated by a shaft and crank system driven by an electric motor. The sets of sieves were having 20 cm diameter and 5 cm height with sieve openings of 2.0, 0.25, 0.053 and 0 (without openings) diameter at the bottom stacked in descending order. 100g of air dried 4 to 8 mm soil aggregates was transferred onto the top of the nest of sieves. Then the water level in the tank was slowly brought to the level to wet up the aggregates sitting on the top of the first sieve. The aggregates were allowed to gradually wet for 5 minutes by capillary wetting. Then the mechanical oscillator was switched on to move the nest of sieves up and down with a frequency of 30 cycles per minute and a stroke of 3 cm. Sieving was done for 10 minutes. Then the nest of sieves was removed from water and allowed to drain. The contents of each sieve were poured and washed out into a pre-weighed beaker and allowed to settle for 24 hours and the supernatant water was decanted. Then the beakers along with the contents were dried in an oven at 105°C till constant weight is achieved and weight of the dry soil aggregates was estimated. For the determination of primary particles (cankers), 10 ml 5% sodium hexametaphosphate solution was added to aggregates of each size class along with distilled water. It was kept overnight and then sieved through corresponding sieves.

The mean weight diameter of soil aggregates was estimated as follows:

$$\text{Mean Weight Diameter (MWD)} = \frac{\sum(X_i W_i)}{\sum W_i}$$

Where,  $X_i$  = Mean opening of the sieve (e.g. 5, 1.1265, 0.153, 0.0265 for 4.0-2.0, 2.0-0.253, 0.253-0.05 and 0.05-0 mm size classes, respectively)

$W_i$  = Weight of retained aggregates (g);  $n$  = Number of size classes

### **3.10.1.3 Soil temperature**

Soil temperature of the treatments was recorded at 0-5 and 5-15 cm depth using HANNA temperature probe (HI 1762 BL) and thermistor at 7 days interval. The minimum soil temperature and maximum temperature was recorded at 700 h morning and 1400 h afternoon, respectively.

### **3.10.2 Chemical properties**

#### **3.10.2.1 Soil pH, EC, and N, P, and K concentrations**

Soil pH, EC, available N, P, K and organic C from the treatment plots were determined as per Prasad *et al.* (2006). Soil samples from treatment plots were collected from 0-15 cm soil profile with the help of a tube auger at the beginning and end of the experiment. Soil samples collected for each treatment were composited and reduced to about 500 g by quartering process. Then these samples were air dried, ground with the help of wooden pestle and mortar, and passed through 2 mm stainless steel sieve.

Soil pH was measured by using pH meter after making soil-water suspension at 1:2.5. Soil EC was measured with the help of conductivity meter. Available N in soil was estimated by alkaline  $\text{KMnO}_4$  method (Subbiah and Asija, 1956). Available P in soil was determined by using Olsen's reagent (0.5 M  $\text{NaHCO}_3$ , pH 8.5) (Olsen *et al.*, 1954). Available K in soil was estimated by using 1 normal neutral ammonium acetate extraction method and determined by flame photometer (Hanway and Heidel, 1952). Available N, P, and K contents in soil were expressed in kg/ha.

#### **3.10.2.2 Soil organic carbon (%)**

Soil organic carbon (%) was estimated from 0-5, 5-15, 15-30, 30-45 cm soil depths using Walkley and Black method (Walkley and Black, 1934). A 0.5 g dry soil fine enough to pass through 0.25 mm sieve was taken in 500 ml conical flask, 10 ml of  $\text{K}_2\text{Cr}_2\text{O}_7$  and 20 ml of  $\text{H}_2\text{SO}_4$  were added and kept for 30 minutes. A 200 ml water was added to the solution and allowed to cool. A 10 ml orthophosphoric acid and 1 ml phenolphthalein indicator were added to the solution and titrated against 0.5 N ferrous ammonium sulphate (FAS).

#### **3.10.2.3 Total organic carbon concentration (g/kg)**

Total carbon concentration of soil was analyzed after processing of soil sample and passing through 0.25 mm sieve. Around 15 mg sample was taken and analyzed in CHNS analyzer (EuroVector Instruments, EA 3000, Italy). Total soil inorganic carbon was measured titrimetrically

by digesting with HCl and then back titrated with dilute NaOH (Richards 1954). Total organic carbon was then calculated by subtracting the total SIC from total carbon.

#### **3.10.2.4 Soil carbon pools (g/kg)**

Soil active and passive pools were determined as per Chan et al. (2001) method, using 5, 10, 20 ml of concentrated H<sub>2</sub>SO<sub>4</sub> (36N) and 10 ml K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>. This forms three acid-aqueous solution ratios of 0.5:1, 1:1, and 2:1, which corresponds to 12N, 18N, 24N solution, respectively. Active pool is sum of Pool 1 and Pool 2, and passive pool consists of Pool 3 and Pool 4. Different carbon pools were determined as follows:

Pool 1: Organic C oxidizable under 12N H<sub>2</sub>SO<sub>4</sub>.

Pool 2: Difference in Organic C oxidizable under 12N and 18N H<sub>2</sub>SO<sub>4</sub>.

Pool 3: Difference in Organic C oxidizable under 18N and 24N H<sub>2</sub>SO<sub>4</sub>.

Pool 4: Difference in total organic C and organic C oxidizable under 24N H<sub>2</sub>SO<sub>4</sub>.

#### **3.10.2.5 Soil mineral nitrogen (NH<sub>4</sub><sup>+</sup>-N and NO<sub>3</sub><sup>-</sup>-N)**

Mineral nitrogen (NH<sub>4</sub><sup>+</sup>-N and NO<sub>3</sub><sup>-</sup>-N) of fresh soil samples from different treatments taken from 0-5 and 5-15 cm soil depths was estimated by extracting the soil samples with 2M KCl (soil: solution = 1:10) followed by determination of NH<sub>4</sub><sup>+</sup>-N by steam distillation with magnesium oxide (MgO) in a micro-Kjeldahl distillation unit (Keeney and Nelson, 1982). The ammonia (NH<sub>3</sub>) evolved during distillation was absorbed in 2% boric acid (H<sub>3</sub>BO<sub>3</sub>) containing mixed indicator (0.099 g bromocresol green and 0.066 g methyl red dissolved in 100 ml of 95% ethanol). Then it was titrated against standard 0.02 N H<sub>2</sub>SO<sub>4</sub> and NH<sub>4</sub>-N was determined. The sample was further distilled for estimation of NO<sub>3</sub><sup>-</sup>-N after reduction with Devarda's alloy and same procedure was followed.

### **3.10.3 Soil biological properties**

#### **3.10.3.1 Microbial biomass carbon**

Soil microbial biomass carbon (MBC) was determined using chloroform fumigation-extraction method (Vance et al., 1987). Soil samples from 0-5 cm, and 5-15 cm depths were taken at flowering stage of wheat and kept in refrigerator afresh until analysis was done. A 10 g soil sample was taken and fumigated with chloroform for 24 hours in order to kill the soil microbes. Similarly, a non-fumigated sample of same soil was run. The sample was extracted with 0.5M K<sub>2</sub>SO<sub>4</sub>. A 10

ml aliquot was taken and after adding 2 ml K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>, 10 ml concentrated H<sub>2</sub>SO<sub>4</sub> and 5 ml of orthophosphoric acid, the sample was kept on a water bath for 30 minutes and then allowed to cool. Using 2-3 drops of ferroin indicator the sample was titrated against 0.005N Ferrous ammonium sulphate. MBC was determined using following formula:

$$\text{MBC } (\mu\text{g/g soil}) = (\text{EC}_{\text{Fumigated}} - \text{EC}_{\text{Non-fumigated}}) / \text{K}_{\text{EC}}$$

### 3.10.3.2 Dehydrogenase activity

It was estimated from the release of triphenyl formazon (TPF) from the reduction of 2,3,5-triphenyl tetrazolium chloride (TTC) (Casida *et al.*, 1964). A 1.0 g fresh soil was taken and added with 1.0 ml of 3% TTC and incubated for 24 h at 30°C. A 10 ml of methanol was added and intensity of pink colour was measured at 485 nm. The amount of TPF released was estimated from calibration curve of TPF standards of known concentration.

## 3.11 Carbon footprints and indices

### 3.11.1 Carbon footprints

The spatial carbon footprint (CF<sub>s</sub>) and yield scale carbon footprint (CF<sub>Y</sub>) were estimated using equations (Jat *et al.*, 2019; Ghosh *et al.*, 2022). The carbon emission equivalents used in calculations have been given in Appendix III.

$$\text{CF}_s (\text{kg CO}_2\text{-eq/ha}) = \text{CO}_2 + \text{CO}_2\text{-eq}(\text{N}_2\text{O}) + \text{CO}_2\text{-eq}(\text{CH}_4)$$

$$\text{CF}_Y (\text{kg CO}_2\text{-eq/t}) = \frac{\text{CF}_s}{\text{wheat grain yield}(\text{t/ha})}$$

### 3.11.2 Carbon efficiency, carbon sustainability index and carbon efficiency ratio

The C output indicating C fixed by the system was calculated by converting grain, straw and root biomass produced by crops into carbon equivalents (kg C-eq/ha). The below-ground root biomass was estimated from shoot:root of wheat (7.4) and of pigeon pea (5.2) (Bolinder *et al.*, 2007; Das *et al.*, 2016). Total C input was estimated by multiplying total crop biomass (grain, straw/stover, root) with 0.4 (Chaudhary *et al.*, 2017). The following indices were calculated as per Ghosh *et al.*, (2022).

$$\text{Carbon efficiency} = \frac{\text{C output}}{\text{C input}}$$

$$\text{Carbon sustainability index} = \frac{(\text{C output} - \text{C input})}{\text{C input}}$$

$$\text{Carbon efficiency ratio} = \frac{\text{Grain yield (kg C/ha)}}{\text{Carbon equivalent emissions (kg C-eq/ha)}}$$

### **3.12 Statistical analysis**

The data on weed density, weed biomass, crop productivity and profitability, resource use efficiency, soil physical, chemical, and biological parameters were subjected to analysis of variance (ANOVA) and statistical significance of treatment effects for the randomized completed block design using OPSTAT (Sheoran *et al.*, 1998)

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## RESULTS

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The results of the field experiment entitled “Tillage, residue and nitrogen effects on weeds, wheat productivity, and soil properties under Conservation Agriculture-based pigeon pea-wheat system” conducted during *rabi* (winter) 2021-2022 at ICAR- Indian Agricultural Research Institute, New Delhi have been presented in this chapter. The observations recorded on weed interference, crop growth, productivity, profitability, resource-use efficiency (water, energy, and nutrients), and soil physical, chemical, and biological properties were statistically analyzed and the significance of the results were verified. The final results are presented here in the form of Tables and Figures (wherever suitable) for clear understanding of the results.

### 4.1. Weed dynamics and interference in wheat

#### 4.1.1. Weed flora in the experimental wheat field

Weed flora (Table 4.1) in the experimental wheat field comprised of *Phalaris minor* Retz. (grassy weeds); *Chenopodium album* L., *Coronopus didymus* L., *Malva parviflora* L., *Melilotus indica* L., *Parthenium hysterophorus* L., *Sonchus oleraceus* L., *Spergula arvensis* L., *Polygonum aviculare* L. (broad-leaved weeds); and *Cyperus esculentus* L. (sedge). Among them, *P. minor*, *C. didymus*, *S. oleraceus*, *M. parviflora*, and *C. esculentus* were dominant weeds at 30 DAS, whereas *P. minor*, *C. album*, *M. indica*, *P. hysterophorus*, *S. oleraceus*, and *C. esculentus* were dominant at 60 DAS (Table 4.1 and Photo 3-12)

#### 4.1.2. Species-wise and category-wise weed population

Tillage, residue, and N (TRN) management practices significantly influenced weed density at 30, and 60 DAS. It was observed that the density of *P. minor* was significantly higher under PNB (without residue) followed by PBB at 30 DAS (Fig. 4.1). But, a significant reduction in its density was observed under ZTFBR75N and ZTFBR100N. The treatments ZTFB and CT showed significantly higher and lower density of *M. parviflora* at 30 DAS, respectively. The density of *C. didymus* was significantly higher in CT and lowest in ZTFBR75N and ZTFBR100N. *Sonchus oleraceus* and *C. esculentus* densities were found significantly higher in CT (Fig. 4.1). The grassy weed density also differed significantly at 30 DAS due to varied TRN management practices and

was found significantly higher in PNB followed by PBB whereas broad-leaved weeds and sedge densities were found significantly higher in CT (Table 4.2). Hence, the total weed density was found significantly higher in CT and lowest in permanent flat bed with residue retention and 75 and 100% N application (i.e. ZTFBR75N and ZTFBR100N).

Table 4.1. Weed species observed at 30 and 60 DAS across treatments

Scientific name	Common name	Family	Habit	30 DAS	60 DAS
<i>Phalaris minor</i> Retz.	Littleseed canarygrass	Poaceae	Decumbent annual grass herb	Dominant	Dominant
<i>Chenopodium album</i> L.	Common lambsquarter	Chenopodiaceae	Erect annual broad-leaved herb	Less dominant	Dominant
<i>Coronopus didymus</i> (L.) Smith	Swinecress	Brassicaceae	Protracted grown annual broad-leaved herb	Dominant	Less dominant
<i>Malva parviflora</i> L.	Little mallow	Malvaceae	Annual broad-leaved herb	Dominant	Less dominant
<i>Melilotus indica</i> (L.) All.	Yellow sweetclover	Fabaceae	Annual broad-leaved herb	Less dominant	Dominant
<i>Parthenium hysterophorus</i> L.	Parthenium	Asteraceae	Annual much branched broad-leaved herb	Less dominant	Dominant
<i>Sonchus oleraceus</i> L.	Annual sowthistle	Asteraceae	Erect robust milky herb	Dominant	Dominant
<i>Spergula arvensis</i> L.	Corn spurrey	Caryophyllaceae	Prostrate or erect annual narrow-leaf broad-leaved herb	-	-
<i>Polygonum aviculare</i> L.	Prostrate knotweed	Polygonaceae	Annual prostrate broad-leaved herb	-	-
<i>Cyperus esculentus</i> L.	Yellow nutsedge	Cyperaceae	Perennial herb with yellow inflorescence	Dominant	Dominant



Photo 3-12: 3. *Phalaris minor* Retz. 4. *Cyperus esculentus* L. 5. *Coronopus didymus* L., 6. *Melilotus indica* L., 7. *Chenopodium album* L., 8. *Sonchus oleraceus* L., 9. *Parthenium hysterophorus* L., 10. *Malva parviflora* L., 11. *Spergula arvensis* L., 12. *Polygonum aviculare* L.

At 60 DAS, *P. minor* weed density was higher in PBB and statistically similar with those in PNB, PBBR75N, and PBBR100N (Fig. 4.2). *Chenopodium album* density was significantly higher in PBB and at par with CT, PNB, and PNB75N. *Cyperus esculentus* density was significantly higher in CT and comparable with that in PNB. The CT treatment again had significantly higher density of *M. indica* (Fig. 4.2). Bed planting treatments showed infestation of *P. hysterophorus*, which was significantly higher in PBB. But there was hardly any infestation of *P. hysterophorus* found in the flat bed treatments irrespective of tillage, residue retention and N application (ZTFB, ZTFBR75N, ZTFBR100N, CT).

The ZTFB, ZTFBR75N, and ZTFBR100N treatments led to significant reductions in grassy weeds population than other TRN practices, mainly, PBB, which showed significantly higher weed population than others (Table 4.3). PNB had significantly higher broad-leaved weeds density, which was comparable with that in CT. CT resulted in highest sedges and total weed density at 60 DAS. At harvest, PBB had significantly higher grassy weed density, which was comparable with PBBR75N, PNB, and PBBR100N. This treatment also resulted in higher broad-leaved weeds, which was at par with that in PNB100N (Table 4.4). Sedge and total weed densities were significantly higher in CT. The ZTFBR100N, ZTFB, and ZTFBR75N were found more effective in reducing total weed density at harvest.

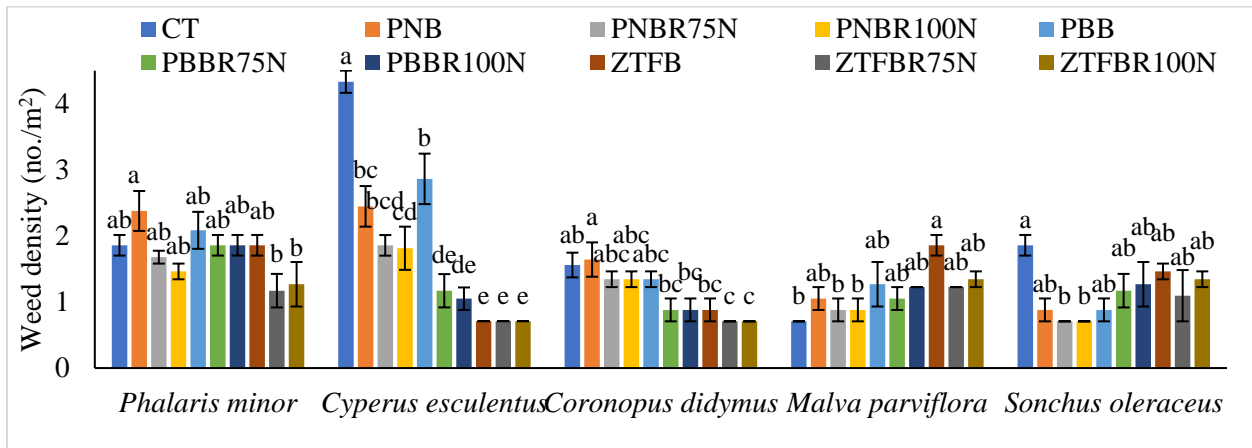


Fig 4.1. Dynamics in weed density of major species observed at 30 DAS across treatments (square-root transformed  $(x+0.5)^{1/2}$  values)

Table 4.2. Category-wise weed density and dry weight in wheat across treatments at 30 DAS (fixed-plot study)

Treatments	Weed density (number/m <sup>2</sup> )				Weed dry weight (g/m <sup>2</sup> )			
	Grassy	BLW	Sedges	Total	Grassy	BLW	Sedges	Total
CT	1.9 (3.0)*	4.6 (20.7)	4.3(18.3)	6.5 (42)	1.1 (0.7)	1.2 (1.0)	0.8 (0.2)	1.6 (2.0)
PNB	2.4 (5.3)	3.4 (11.3)	2.4 (5.7)	4.8 (22.3)	1.5 (1.6)	1.0 (0.6)	0.8 (0.1)	1.7 (2.4)
PNBR75N	1.7 (2.3)	2.3 (4.6)	1.9 (3.0)	3.2 (10)	1.1 (0.7)	0.8 (0.1)	0.7 (0.1)	1.1 (0.8)
PNBR100N	1.5 (1.7)	2.0 (3.6)	1.8 (3.0)	3.0 (8.3)	0.9 (0.4)	0.8 (0.1)	0.8 (0.1)	1.0 (0.5)
PBB	2.1 (4.0)	2.8 (7.6)	2.9 (8.0)	4.4 (19.7)	1.1 (1.1)	0.9 (0.3)	0.8 (0.1)	1.3 (1.2)
PBBR75N	1.6 (2.0)	2.1 (4)	1.2 (1.0)	2.9 (8.0)	1.0 (0.5)	0.8 (0.1)	0.7 (0.1)	1.1 (0.7)
PBBR100N	1.6 (2.0)	2.1 (4)	1.1 (0.7)	2.8 (7.7)	1.0 (0.5)	0.8 (0.2)	0.7 (0.1)	1.1 (0.7)
ZTFB	1.9 (3.0)	3.5 (12)	0.7 (0)	3.9 (15)	0.9 (0.3)	1.1 (0.8)	0.7 (0)	1.3 (1.1)
ZTFBR75N	1.2 (1.0)	1.9 (3.3)	0.7 (0)	2.2 (4.3)	0.8 (0.2)	0.9 (0.2)	0.7 (0)	1.0 (0.4)
ZTFBR100N	1.3 (1.3)	2.1 (4)	0.7(0)	2.4 (5.3)	0.8 (0.1)	0.9 (0.2)	0.7 (0)	0.9 (0.4)
SEm±	0.21	0.25	0.22	0.3	0.07	0.04	0.01	0.08
LSD (P=0.05)	0.63	0.75	0.65	0.9	0.20	0.12	0.03	0.24

\* Data are square-root transformed and the original values are in the parentheses; BLW-Broad leaved weeds

Overall, the dominance of grassy and broad-leaved weeds was higher in ZT plots with or without residue retention, and the sedge density was significantly higher in CT treatment. Both ZTFBR100N and ZTFBR75N treatments were found more effective in reducing overall weed density at 30 and 60 DAS, and at harvest, the next best treatments could be PBBR100N and PBBR75N (Tables 4.2 and 4.3).

Table 4.3. Category-wise weed density and dry weight in wheat across treatments at 60 DAS (fixed-plot study)

Treatments	Weed density (number/m <sup>2</sup> )				Weed dry weight (g/m <sup>2</sup> )			
	Grassy	BLW	Sedges	Total	Grassy	BLW	Sedges	Total
CT	1.6 (2.0)*	3.57(12.3)	11.0 (121)	11.7(135.3)	2.76 (7.5)	1.02 (0.6)	2.41 (5.3)	3.7 (13.4)
PNB	2.1 (4.0)	3.89(14.7)	4.3 (18)	6.1 (36.7)	3.63 (12.8)	2.43 (5.4)	1.20 (0.9)	4.43 (19.1)
PNBR75N	1.6 (2.0)	3.49(11.7)	1.6 (2)	4.0 (15.7)	2.72 (7.1)	2.08 (3.8)	0.8 (0.1)	3.39 (11.1)
PNBR100N	1.5 (1.7)	2.73 (7.0)	0.7 (0)	3.0 (8.7)	2.4 (5.4)	1.04 (0.6)	0.71 (0)	2.52 (6.0)
PBB	2.2 (4.3)	3.13 (9.3)	4.4 (19)	5.8 (32.7)	3.95 (15.3)	2.12 (4.0)	1.32 (1.2)	4.57(20.5)
PBBR75N	1.9 (3.0)	1.87 (3.0)	0.7 (0)	2.5 (6.0)	2.81 (7.5)	0.99 (0.5)	0.71 (0)	2.9 (8.0)
PBBR100N	1.7 (2.7)	2.32 (5.0)	0.7 (0)	2.8 (7.7)	2.54 (6.5)	1.03 (0.6)	0.71 (0)	2.66 (7.0)
ZTFB	1.3 (1.3)	2.04 (3.7)	2.5 (6)	3.4 (11)	2.15 (4.2)	0.8 (0.2)	0.85 (0.2)	2.24 (4.6)
ZTFBR75N	1.2 (1.0)	0.88 (0.3)	0.7 (0)	1.3 (1.3)	1.72 (3.0)	0.75 (0.1)	0.71 (0)	1.73 (3.1)
ZTFBR100N	1.2 (1.0)	0.71 (0)	0.7 (0)	1.2 (1)	1.94 (3.3)	0.71 (0)	0.71 (0)	1.94 (3.3)
SEm±	0.20	0.13	0.18	0.21	0.38	0.06	0.26	0.30
LSD (P=0.05)	0.59	0.38	0.53	0.63	1.01	0.19	0.78	0.90

\* Data are square-root transformed and the original values are in the parentheses; BLW-Broad leaved weeds

The destructive sampling at 60 DAS after a common herbicide treatment (clodinafop-propargyl + metsulfuron-methyl) to all plots revealed that the densities of grassy and broad-leaved weeds were drastically reduced, and their densities across the treatments was non-significant. But, the densities of sedges and total weed were found significantly higher in CT treatment (Table 4.5).

#### 4.1.3. Weed biomass

The TRN management practices significantly influenced weed dry weight at 30 and 60 DAS. At 30 DAS, PNB treatment resulted in significantly higher grassy and total weed dry weight and CT was comparable with it in this regard (Table 4.2). But, at 60 DAS, grassy and total weed dry weight was significantly higher in PBB, and PNB was found comparable with it. Significantly higher weed dry weight of broad-leaved weeds was found in CT at 30 DAS and in PNB at 60 DAS (Table 4.2 and 4.3). Sedge dry weight was significantly higher in CT treatment at 30 and 60 DAS.

The ZTFBR75N and ZTFBR100N treatments were superior in reducing the total weed dry weight at 30 and 60 DAS and found comparable with PNBR100N at 30 DAS. Among the categories of weeds, grassy weeds had highest dry weight at 30 and 60 DAS. Grassy weed dry weight at harvest was significantly higher in PBB, and found comparable with those in PBBR75N, PNB, and PBBR100N (Table 4.4). The same treatment showed higher broad-leaved and total weed dry weight. However, sedge weed dry weight was found highest in CT. The destructive sampling at 60 DAS after a common herbicide treatment (clodinafop-propargyl + metsulfuron-methyl) revealed that there had been a drastic reduction in grassy and broad-leaved weed dry weight, and the dry weights were statistically similar across the treatments. However, the CT treatment had significantly higher sedges and total weed dry weight (Table 4.5).

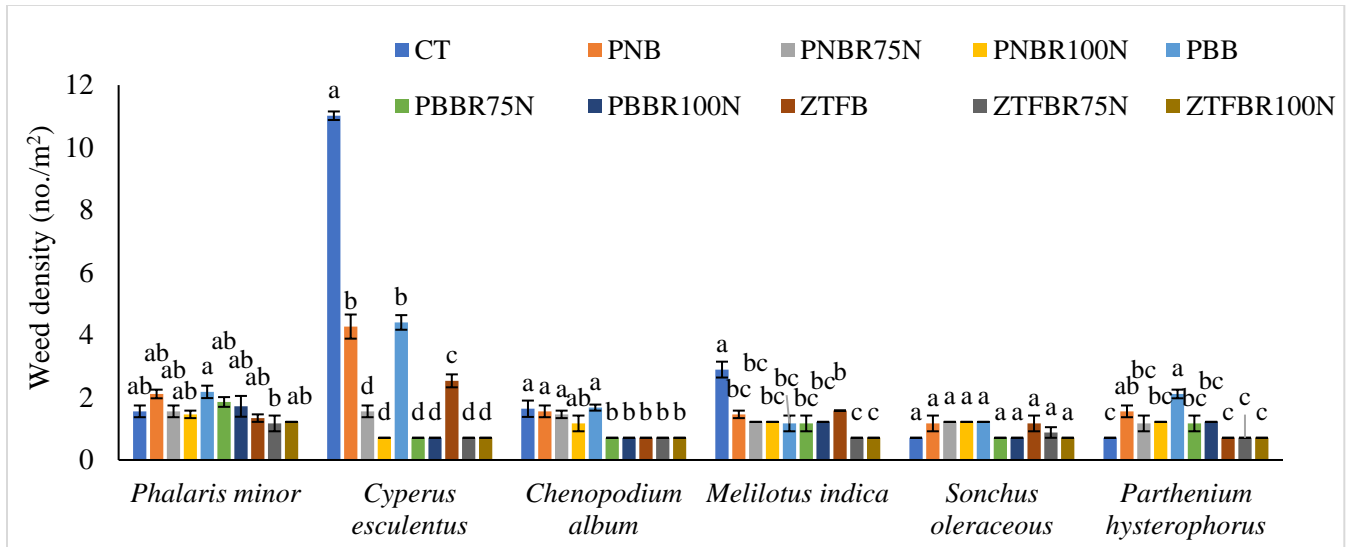


Fig 4.2. Dynamics in weed density (no./m<sup>2</sup>) of major species observed at 60 DAS across treatments (square-root transformed  $(x+0.5)^{1/2}$  values)

#### 4.1.4. Per cent reduction in weed population and dry weight

The TRN management practices influenced weed population and dry weight significantly. Compared to CT, the ZTFBR75N and ZTFBR100N led to 89.7% and 87.3% reduction in weed population, and 78.6% and 81.6% reduction in weed dry weight, respectively (Fig 4.3.). CT treatment had highest weed population, whereas PNB showed highest weed dry weight, which was 23.2% higher than in CT.

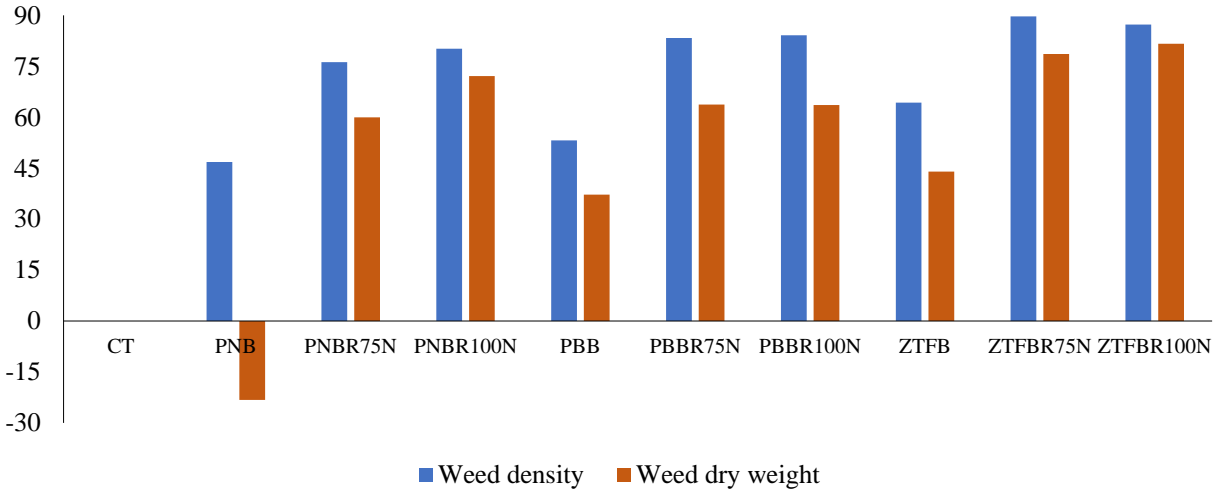


Fig 4.3. Per cent reduction in weed density and dry weight at 30 DAS over CT across treatments

Table 4.4. Category-wise weed density and dry weight in wheat across treatments at harvest (fixed-plot study)

Treatments	Weed density (number/m <sup>2</sup> )				Weed dry weight (g/m <sup>2</sup> )			
	Grassy	BLW	Sedges	Total	Grassy	BLW	Sedges	Total
CT	0.7 (0)*	0.7 (0)	12.0 (148)	12.0 (148)	0.70 (0)	0.71 (0)	1.69 (2.4)	1.69 (2.4)
PNB	3.4 (12.0)	2.1 (4.0)	3.5 (16.0)	5.7 (32.0)	1.29 (1.2)	1.05 (0.6)	0.91 (0.4)	1.61 (2.1)
PNBR75N	2.8 (8.0)	1.9 (4.0)	3.7 (14.7)	5.2 (26.7)	1.05 (0.7)	1.16 (1.0)	0.8 (0.1)	1.44 (1.8)
PNBR100N	2.4 (5.3)	2.7 (6.7)	3.3 (12.0)	4.8 (24.0)	0.95 (0.4)	1.06 (0.6)	0.79 (0.1)	1.28 (1.2)
PBB	4.3 (18.7)	2.7 (6.7)	4.5 (22.7)	6.9 (48.0)	1.5 (1.8)	1.30 (1.2)	0.94 (0.4)	1.97 (3.4)
PBBR75N	4.0 (16.0)	1.7 (2.7)	3.067 (9.3)	5.3 (28.0)	1.49 (1.8)	0.87 (0.3)	0.85 (0.3)	1.64 (2.3)
PBBR100N	3.3 (10.7)	2.0 (4.0)	2.563 (8.0)	4.8 (23.0)	1.28 (1.2)	0.94 (0.4)	0.79 (0.1)	1.48 (1.7)
ZTFB	0.7 (0)	0.7 (0)	0.71 (0)	0.7 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
ZTFBR75N	0.7 (0)	1.3 (1.3)	0.71 (0)	1.3 (1.3)	0.71 (0)	0.76 (0.1)	0.71 (0)	0.76 (0.1)
ZTFBR100N	0.7 (0)	0.7 (0)	0.71 (0)	0.7 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
SEm±	0.37	0.34	0.84	0.61	0.13	0.10	0.10	0.17
LSD(P=0.05)	1.11	1.02	2.52	1.82	0.38	0.31	0.29	0.51

\* Data are square-root transformed and the original values are in the parentheses; BLW-Broad leaved weeds

Table 4.5. Category-wise weed density and dry weight in wheat across treatments at 60 DAS (herbicide treated-plot study)

Treatments	Weed density (number/m <sup>2</sup> )				Weed dry weight (g/m <sup>2</sup> )			
	Grassy	BLW	Sedges	Total	Grassy	BLW	Sedges	Total
CT	0.9 (0.3)*	2.6 (8)	6.1 (38.0)	6.7 (46.3)	0.74 (0.0)	0.96 (0.5)	1.42 (1.5)	1.58 (2.0)
PNB	1.2 (1.0)	2.7 (7.3)	4.2 (17.3)	5.1 (25.7)	0.79 (0.1)	0.97 (0.5)	1.04 (0.6)	1.3 (1.2)
PNBR75N	1.1 (0.7)	2.2 (4.7)	1.2 (1.3)	2.7 (6.7)	0.83 (0.2)	0.86 (0.2)	0.71 (0)	0.97 (0.5)
PNBR100N	0.7 (0)	2.3 (5.0)	0.7 (0)	2.3 (5.0)	0.71 (0)	0.86 (0.2)	0.85 (0.3)	0.99 (0.5)
PBB	1.2 (1.0)	2.2 (5.3)	3.4 (18.7)	4.4 (25.0)	0.81 (0.2)	0.85 (0.2)	0.89 (0.4)	1.07 (0.8)
PBBR75N	1.0 (0.7)	2.3 (6.0)	0.7 (0)	2.4 (6.7)	0.80 (0.2)	0.83 (0.2)	0.71 (0)	0.90 (0.3)
PBBR100N	1.0 (0.7)	2.4 (5.3)	0.7 (0)	2.5 (6.0)	0.78 (0.1)	0.81 (0.2)	0.71 (0)	0.88 (0.3)
ZTFB	0.7 (0)	1.2 (1.3)	1.2 (1.3)	1.7 (2.7)	0.71 (0)	0.73 (0.0)	0.73 (0.0)	0.75 (0.1)
ZTFBR75N	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
ZTFBR100N	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
SEm±	0.17	0.52	0.69	0.79	0.05	0.07	0.09	0.11
LSD (P=0.05)	NS	NS	2.07	2.37	NS	NS	0.26	0.31

\* Data are square-root transformed and the original values are in the parentheses; BLW-Broad leaved weeds

## 4.2. Wheat crop growth

### 4.2.1. Wheat plant height

Tillage, residue, land configuration and N management practices had significant impacts on wheat plant height at 30, 60, and 90 DAS. The CA-based practices significantly increased plant height of wheat compared to CT. Residue retention with 100% and 75% N application had comparable plant height (Table 4.6). Significantly greater plant heights of wheat were obtained under the ZTFBR100N at 30 and 60 DAS. The treatment PNBR100N registered significantly greater plant height at 90 DAS. Greater plant height in residue retained treatments confirmed better growth and beneficial effects of residue retention compared to residue removal treatments and CT (Photo 13-21).

#### 4.2.2. Wheat dry matter accumulation

Dry matter accumulation of wheat plants at 30, 60, and 90 DAS was significantly influenced by TRN practices (Table 4.7). The dry matter accumulation was significantly higher under ZTFBR100N at 30, 60, and 90 DAS and was found comparable with those in all the residue treatments irrespective of N application at 30 and 60 DAS. At 90 DAS, ZTFB also was comparable with ZTFBR100N and all residue treatments in this regard. This ZTFBR100N treatment showed 24%, 37%, and 28% increase in dry weight of wheat over CT at 30, 60, and 90 DAS, respectively.

Table: 4.6. Wheat plant height (cm) across treatments at different growth stages

Treatments	Wheat plant height (cm)		
	30 DAS	60 DAS	90 DAS
CT	25.7	48.9	100.0
PNB	26.2	51.9	102.7
PNBR75N	28.8	52.3	107.3
PNBR100N	30.2	52.3	107.7
PBB	27.0	51.9	103.0
PBBR75N	29.1	52.2	105.0
PBBR100N	30.1	53.3	105.3
ZTFB	27.2	51.8	101.0
ZTFBR75N	30.7	53.7	105.7
ZTFBR100N	31.3	54.1	107.0
SEm±	1.2	0.7	1.0
LSD (P=0.05)	3.7	2.1	3.0



Photo 13. PNB100N at 30 DAS



Photo 14. PBB100N at 30 DAS

Table: 4.7. Wheat plant dry weight ( $\text{g/m}^2$ ) across treatments at different growth stages

Treatments	Plant dry weight ( $\text{g/m}^2$ )		
	30 DAS	60 DAS	90 DAS
CT	36.8	386.7	842.3
PNB	38.1	469.7	940.0
PNBR75N	42.9	474.8	1033.3
PNBR100N	43.8	496.9	1050.0
PBB	38.4	451.6	950.0
PBBR75N	42.1	492.6	1037.5
PBBR100N	44.2	495.8	1057.8
ZTFB	39.8	463.3	983.3
ZTFBR75N	44.7	507.5	1043.3
ZTFBR100N	45.6	529.9	1077.8
SEm $\pm$	1.7	18.82	35.4
LSD (P=0.05)	5.2	56.36	106



Photo 15. ZTFBR100N at 30 DAS



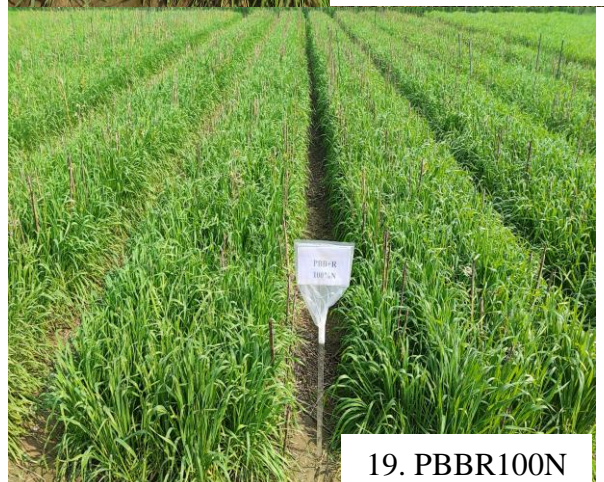
16. ZTFBR75N



17. ZTFBR100N



18. PBBR75N



19. PBBR100N



20. PNBR75N



21. PBBR100N

Photo 16-21. Wheat crop across treatments at 60 DAS

#### 4.2.3. Wheat leaf area index (LAI)

The treatment ZTFBR100N had significantly higher leaf area index (LAI) of wheat at 30 DAS and found comparable with all residue retention plots including both 75% and 100%N levels (Table 4.8). The PBBR100N had significantly higher LAI at 60 DAS and was found comparable with PNBR100N, PBBR75N, and ZTFBR100N in this regard. But, at 90 DAS, the LAI was significantly higher in the PNBR100N, and was comparable with those found in all residue retention treatments and 75% or 100% N application (i.e. PNBR75N, PBBR75N, PBBR100N, ZTFBR75N, and ZTFBR100N). The CA-based residue retention treatments (namely, PNBR75N, PNBR100N, PBBR75N, PBBR100N, ZTFBR75N and ZTFBR100N) showed 28.6-42.9%, 14.6-31.7%, and 32.5-44.1% higher LAI than CT at 30, 60, and 90 DAS, respectively and confirmed better growth in these treatments.

#### 4.2.4. Wheat tillers number

All the CA-based TRN treatments (i.e. PNBR75N, PNBR100N, PBBR75N, PBBR100N, ZTFBR75N and ZTFBR100N) led to significantly higher number of tillers of wheat than CT (Table 4.9). Tillers number was significantly higher in PNBR100N and found comparable with those in PNB, PNBR75N, PBBR75N, and PBBR100N at 30 DAS. At 60 and 90 DAS, PBBR100N resulted in significantly higher tillers per meter row length, and PNB, PNBR75N, PNBR100N,

and PBBR75N were found comparable with it in this regard. The CA-based residue retention treatments showed 20.2-38.4%, 8.8-22.5%, and 18.3-33.7% higher tiller number at 30, 60, and 90 DAS, respectively than CT.

Table: 4.8. Wheat leaf area index (LAI) across treatments at different growth stages

Treatment	LAI		
	30 DAS	60 DAS	90 DAS
CT	0.28	3.09	4.06
PNB	0.30	3.34	4.96
PNBR75N	0.36	3.54	5.58
PNBR100N	0.39	3.88	5.85
PBB	0.31	3.30	4.87
PBBR75N	0.36	3.96	5.54
PBBR100N	0.38	4.07	5.78
ZTFB	0.31	3.22	4.84
ZTFBR75N	0.37	3.64	5.38
ZTFBR100N	0.4	3.77	5.72
SEm±	0.01	0.11	0.28
LSD (P=0.05)	0.04	0.33	0.84

Table: 4.9. Wheat tillers/ meter row length across treatments at different growth stages

Treatments	Wheat tillers/ m row length		
	30 DAS	60 DAS	90 DAS
CT	58.3	92.4	62.9
PNB	74.9	107.3	77.5
PNBR75N	79.7	107.9	79.5
PNBR100N	80.7	108.8	81.0
PBB	73.5	109.2	77.6
PBBR75N	76.0	111.3	80.8
PBBR100N	76.6	113.2	84.1
ZTFB	67.1	99.0	70.5
ZTFBR75N	70.1	100.5	74.4
ZTFBR100N	73.3	103.4	77.0
SEm±	1.9	2.2	2.2
LSD (P=0.05)	5.8	6.5	6.5

#### 4.2.5. Wheat root growth

Tillage, residue and crop establishment method significantly influenced wheat root growth. CA-based residue retention treatments showed better root growth than zero-till without residue treatments and CT (Table 4.10 and Photo 28). Results indicated that root length density, root mass density and root volume density in 0-30 cm soil depth of wheat were significantly higher in CA-based practices (i.e., permanent narrow, broad, and flat beds with residue retention and 75 or 100% N application) compared to CT. The CA-based practices with residue retention achieved 15.13-26.58% higher root length density, 20.9-29.16% higher root surface area density, 38.4-57.3% higher root volume density, and 31.74-50% higher root mass density than CT. The zero-till treatments without residue retention (i.e., PNB, PBB, and ZTFB) also resulted in higher values of these parameters at 0-30 cm soil depth. Among the CA based treatments PNB100N showed significantly higher root length (3015.9 cm), root volume (361.9 cm<sup>3</sup>), root surface area (3.46 cm<sup>2</sup>), root length density (2.76 cm/cm<sup>3</sup>), root surface area density (0.24 cm<sup>2</sup>/cm<sup>3</sup>), root mass density (0.19 × 10<sup>-3</sup> g/cm<sup>3</sup>) and root volume density (2.29 × 10<sup>-3</sup> cm<sup>3</sup>/cm<sup>3</sup>) than others. This treatment also resulted in significantly higher root fresh weight (6.67 g) and dry weight (0.28 g) and the values were statistically similar with those observed in PNB75N, PBB75N, PBBR100N, and ZTFBR100N for root fresh weight and with PNB75N, PBB75N, PBBR100N, ZTFBR75N, and ZTFBR100N for root dry weight.

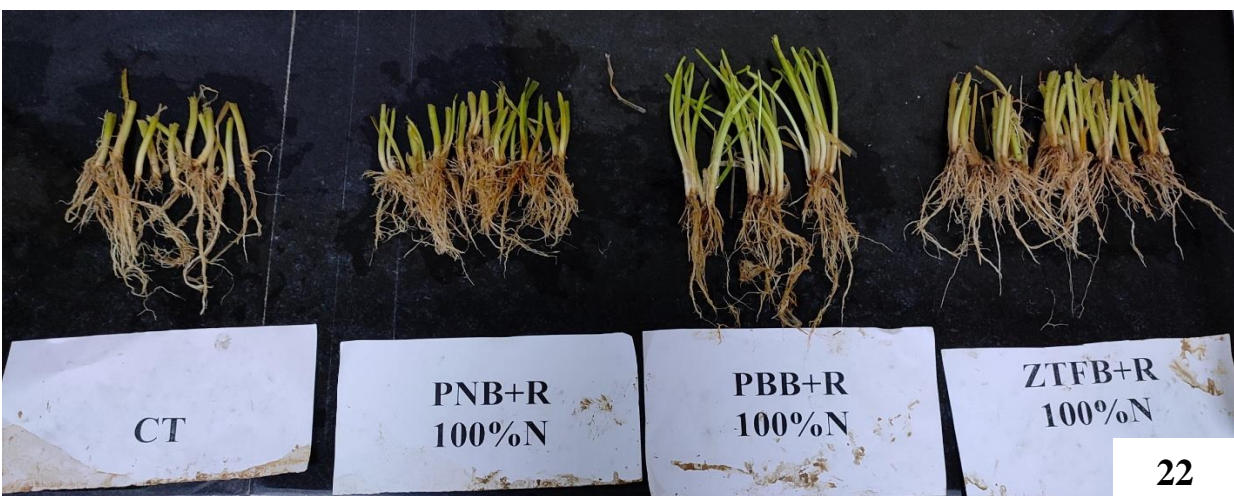


Photo 22. Wheat root growth in CT and residue retention 100%N treatments

Table 4.10. Wheat root growth parameters across treatments at 70 DAS

Treatments	Root length (cm)	Root surface area (cm <sup>2</sup> )	Root volume (cm <sup>3</sup> )	Root fresh weight (g)	Root dry weight (g)	Root length density (cm/cm <sup>3</sup> )	Root surface area density (cm <sup>2</sup> /cm <sup>3</sup> )	Root volume density (cm <sup>3</sup> /cm <sup>3</sup> )	Root dry weight density (mg/cm <sup>3</sup> )
CT	2382.6	256.4	2.2	4.1	0.19	1.58	0.17	1.50	0.13
PNB	2442.9	271.4	2.4	5.3	0.22	1.62	0.18	1.60	0.15
PNBR75N	2918.4	346.8	3.3	6.5	0.27	1.94	0.23	2.20	0.18
PNBR100N	3015.9	361.9	3.5	6.7	0.28	2.00	0.24	2.30	0.19
PBB	2412.7	286.5	2.7	5.2	0.23	1.60	0.19	1.82	0.15
PBBR75N	2782.6	333.1	3.2	6.2	0.27	1.85	0.22	2.11	0.18
PBBR100N	2804.8	346.8	3.4	6.4	0.28	1.86	0.23	2.27	0.18
ZTFB	2382.6	271.4	2.5	4.9	0.20	1.58	0.18	1.63	0.14
ZTFBR75N	2742.5	323.7	3.0	5.8	0.25	1.82	0.22	2.00	0.17
ZTFBR100N	2774.7	331.8	3.2	6.0	0.27	1.84	0.22	2.10	0.18
SEm±	95.2	12.3	0.2	0.3	0.01	0.07	0.01	0.13	0.01
LSD (P=0.05)	282.8	36.5	0.5	1.0	0.03	0.21	0.03	0.39	0.02

#### 4.2.6 Wheat crop lodging

Wheat crop in the experimental field experienced lodging at 120 DAS, the degree of lodging varied across the CA and CT treatments (Fig. 4.4). Therefore, lodging of wheat crop was estimated. Among various TRN management practices, the CA-based residue retention treatments showed lower lodging score (LS) and lodging index (LI) than ZT permanent beds without residue and CT treatments. CT showed significantly higher LS (35.38) and LI (35.75) than other treatments except ZTFB. Usually, bed planting treatments (PNB, PBB) performed better than flat bed (ZTFB, CT) planting treatments, and residue retention with 75%N application resulted in lower LS and LI than 100% N with residue retention. The PNBR75N and PBBR75N treatments had lower lodging

indices (i.e., LS 0.13 & 0.17 and LI 0.14 & 0.18, respectively) and were found superior in reducing lodging of wheat plants at maturity (Photo 29-34).

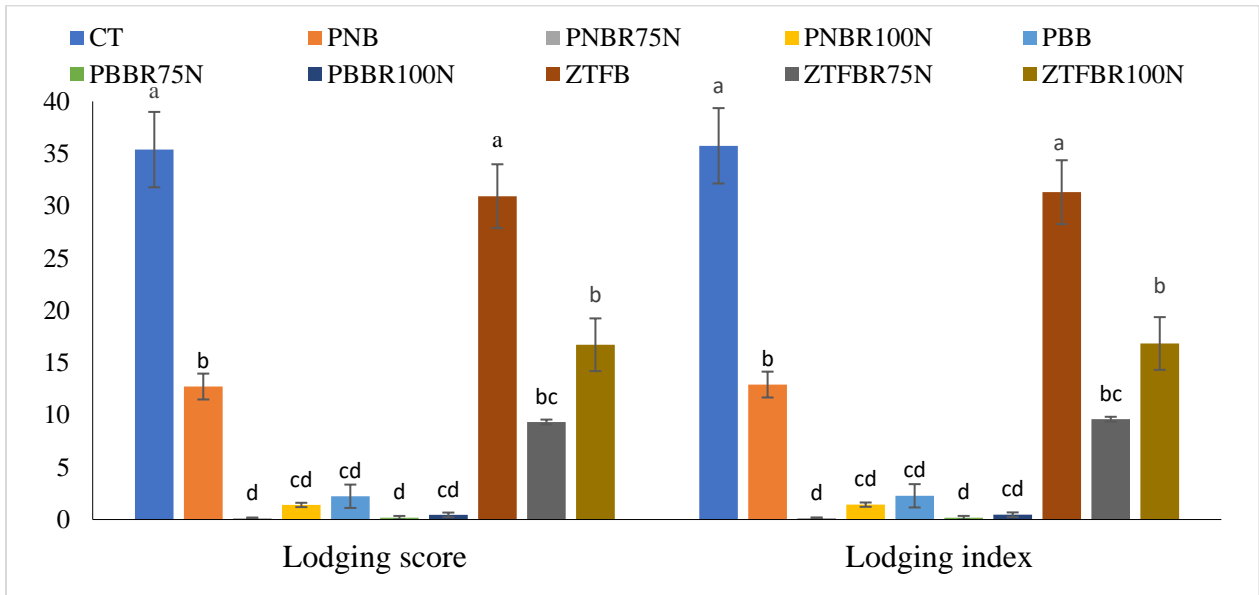
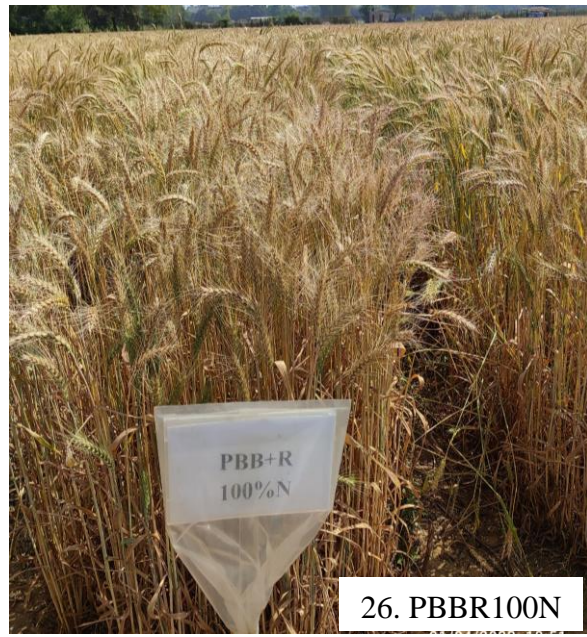


Fig.4.4. Lodging score and lodging index across the treatments at wheat maturity





25. PBBR75N



26. PBBR100N



27. ZTFB



28. ZTFBR75N

Photo 23-28. Lodging in wheat crop across treatments observed at 120 DAS

### 4.3. Wheat productivity and economics

#### 4.3.1. Wheat yield attributes

The yield attributes of wheat such as number of ear-bearing tillers/m row length, number of grains per spike and 1000-grain weight varied significantly due to different tillage, residue, and N management practices. The CA-based practices showed significant improvement in yield attributing characters of wheat (Table 4.11) and the treatments with residue retention were found

superior than without residue. The treatment PBBR100N registered significantly higher number of ear-bearing tillers, and number of grains per spike, but PNBR75N, PNBR100N, and PBBR75N treatments were comparable with it on ear-bearing tillers, and PBBR75N was comparable with it on grains/spike. The PBBR100N and ZTFBR100N resulted in slightly higher (~1%) test weight (~1000 grains weight) than CT, but the values did not differ significantly. The permanent beds with residue retention treatments showed 18.3-33.3% higher EBT, and 5.9-27.6% higher grains/spike compared to CT. These treatments when supplemented with 100% or 75% N resulted in comparable values of yield attributes of wheat, which were however higher than in CT and without residue treatments. Results indicated the positive effects of residue retention towards improving yield attributes in wheat cultivation.

Table: 4.11. Wheat yield attributes across treatments at maturity

Treatments	Ear bearing tillers/m row length	Grains/spike	Test (~1000 grains) weight (g)
CT	60	52.2	40.3
PNB	74	55.3	39.8
PNBR75N	76	58.3	40.5
PNBR100N	77	60.0	40.8
PBB	74	59.2	39.8
PBBR75N	77	64.1	40.5
PBBR100N	80	66.6	40.7
ZTFB	67	53.7	40.3
ZTFBR75N	71	55.3	40.4
ZTFBR100N	73	56.3	40.8
SEm±	2	1.9	0.6
LSD (P=0.05)	6	5.6	NS

#### 4.3.2. Wheat grain, straw, and biological yields and harvest index

Wheat productivity got significantly influenced due to varied tillage, residue, land configuration and N management practices. The zero-till practices improved wheat grain yield up to 8.1-14.9%, straw yield up to 2.8-8.1% and biological yield up to 4.9-10.8% over CT (Table 4.12). Harvest index did not vary significantly among the treatments. Among CA-based practices, ZTFBR100N

led to significantly higher grain yield (5.37 t/ha), straw yield (7.71 t/ha), and biological yield (13.08 t/ha) of wheat. However, all the ZT practices with and without residue retention (PNBR75N, PBBR75N, PBBR100N, ZTFBR75N, ZTFBR75N, PNB, PBB and ZTFB) were found comparable with it in these regards. Among zero-till practices, the treatments with residue retention outperformed the treatments without residue; and 100%N were found comparable with 75%N on yield parameters of wheat. The results of contrast analysis on wheat grain yield showed that the zero-till practices with or without residue retention treatment significantly increased wheat grain yield than that of CT practice (Table 4.13). Also, the residue retention was found superior to residue removal practice. The contrast analysis between 100% N and 75% N application was found to be non-significant indicating the similar yield obtained at these two N levels and a saving of 25%N in wheat (Photo 29-34).

Table: 4.12. Wheat grain, straw, and biological yield and harvest index (%) across treatments

Treatments	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	Harvest Index (%)
CT	4.67	7.14	11.81	39.5
PNB	5.05	7.34	12.39	40.7
PNBR75N	5.21	7.56	12.77	40.8
PNBR100N	5.30	7.65	12.95	40.9
PBB	5.09	7.43	12.51	40.6
PBBR75N	5.26	7.60	12.86	40.9
PBBR100N	5.33	7.68	13.01	41.0
ZTFB	5.11	7.45	12.57	40.7
ZTFBR75N	5.28	7.62	12.90	40.9
ZTFBR100N	5.37	7.71	13.08	41.0
SEm±	0.13	0.11	0.23	0.4
LSD (P=0.05)	0.39	0.32	0.68	NS

Table 4.13. Contrast analysis of yield between various factors

Contrast	Contrast SS	F Value	Pr > F	Significant
ZT vs ZT+R	0.260	6.732	0.018	*
100N vs 75N	0.033	0.852	0.368	NS
CT vs ZT	0.990	25.599	<.0001	**
CT vs ZT-R	0.382	9.884	0.006	**

\*\* - Significant at 1%, \* - Significant at 5%, NS – Non-Significant

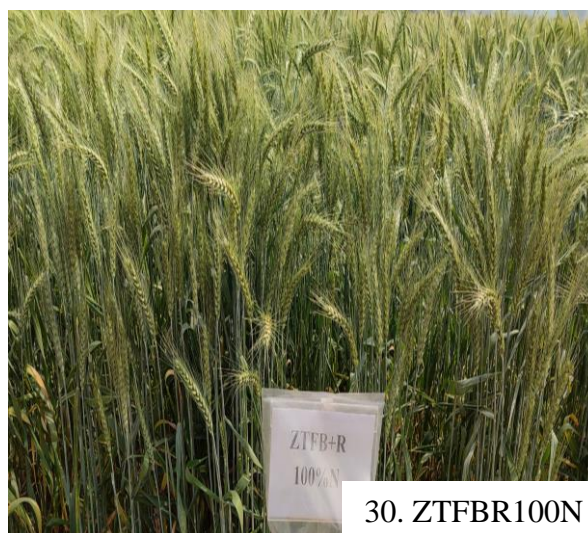




Photo 29-34. Wheat crop across treatments at 110 DAS

#### 4.3.3. Benefit-cost analysis of wheat crop

The cost of cultivation of wheat varied across the treatments due to varying levels of inputs (i.e., tillage, residue, crop establishment practices etc.) required and their variable costs (Table 4.14). The CT wheat incurred higher cost of cultivation than other practices due to higher costs of land preparation. The ZT practices with and without residue retention registered 3.1-15.7% lower cost of cultivation, but 19.4-23.8% higher net returns and 24.6-46.7% higher net benefit:cost (B:C) than CT practice. The ZT practices without residue registered significantly higher net B:C than residue retention treatments. The CA-based practices with residue retention resulted in higher costs but were found to be superior in gaining higher net returns due to enhanced yield. All the CA practices with and without residue retention were comparable with each other and resulted in significantly higher net returns ( $92.7 \times 10^3$  INR/ha) and net B:C (2.01) than CT. The ZTFB, PBB, and PNB (without residue) resulted in significantly higher net B:C (2.31, 2.29 and 2.27) than these treatments with residue retention and CT practice.

#### 4.4. Resource-use efficiency in wheat

##### 4.4.1. Water productivity and use efficiency

Variation in water use was observed among the treatments due to different tillage, land configuration and residue management practices (Table 4.15). Among the ZT permanent bed practices, the treatments with residue retention consumed less water than treatments with no residue. The CT practice had highest irrigation water use (300 mm). The CA-based residue

retention registered 9%-20.6% lower irrigation water use than CT, and thereby increased irrigation and total water productivity. Among CA-based practices with residue retention, PBBR100N registered 20.6% lower irrigation water use (238 mm) than CT, and PBBR75N was comparable with it in this regard. As a result, this treatment resulted in significantly higher irrigation water productivity and total water productivity by 43.8% and 35.9% than CT, respectively. However, it was found comparable with PBBR75N for irrigation water use efficiency and with PBBR75N and PNBR100N for total water productivity. The average total water use in this treatment was 384.5 mm, which was 27.9% lower than in CT.

Table: 4.14. Benefit-cost analysis of wheat production across treatments

Treatment	Cost of cultivation ( $\times 10^3$ INR/ha)	Net returns ( $\times 10^3$ INR/ha)	Net B:C
CT	47.66	75.00	1.57
PNB	40.16	90.90	2.27
PNBR75N	45.67	89.53	1.96
PNBR100N	46.16	91.23	1.98
PBB	40.16	92.03	2.29
PBBR75N	45.67	90.67	1.98
PBBR100N	46.16	92.03	1.99
ZTFB	40.16	92.70	2.31
ZTFBR75N	45.67	91.17	2.00
ZTFBR100N	46.16	92.83	2.01
SE $\pm$	-	3.00	0.07
LSD (P=0.05)	-	9.00	0.21

#### 4.4.2. Energy productivity and use efficiency

The total input and output energy for wheat cultivation varied significantly due to different tillage, residue, land-configuration, and N management practices (Table 4.16 and Fig. 4.5). It was observed that the CA-based ZT practices without residue (~PNB, PBB and ZTFB) consumed considerably lower input energy than those with residue retention, and CT. Among these practices, the lowest input energy was recorded in PBB, which had 14.9% lower input energy than CT. The

Table 4.15. Irrigation water, total water use, and water productivity across treatments

Treatments	Irrigation water applied (mm)	Total water use (mm)	Irrigation water productivity (kg/ha.mm)	Total water productivity (kg/ha.mm)
CT	300	397	15.5	11.7
PNB	259	356	19.5	14.2
PNBR75N	255	352	20.4	14.8
PNBR100N	255	352	20.7	15.1
PBB	246	343	20.6	14.8
PBBR75N	238	335	22.0	15.7
PBBR100N	238	335	22.3	15.9
ZTFB	288	385	17.7	13.3
ZTFBR75N	272	369	19.4	14.3
ZTFBR100N	272	369	19.7	14.6
SEm±	-	-	0.4	0.3
LSD (P=0.05)	-	-	1.3	0.9

highest input energy was recorded in ZTFBR100N. Among residue management practices, 100% N application treatments led to marginally higher input energy compared to 75% N application. However, *vis-à-vis* the CA-based practices with residue retention gave significantly higher output energy than ZT without residue and CT. The ZTFBR100N resulted in significantly higher output energy (by 14.1%) than CT (Table 4.16). The treatment PBB registered significantly higher energy productivity (0.29 kg/MJ) and energy ratio (9.86) and was comparable with PNB and ZTFB in these regards. The CA-based residue retention practices led to lower energy productivity than ZT without residue and CT due to energy incurred in residue retention constituted about 67.6-70.9% of total energy input (Fig. 4.5).

Table 4.16. Energy input, energy output, energy productivity, and energy ratio across treatments

Treatments	Total input energy ( $\times 10^3$ MJ/ha)	Total output energy ( $\times 10^3$ MJ/ha)	Energy productivity (kg/MJ)	Energy ratio
CT	20.58	162.53	0.23	7.90
PNB	17.73	170.98	0.28	9.64
PNBR75N	61.51	176.26	0.08	2.87
PNBR100N	63.79	178.79	0.08	2.80
PBB	17.51	172.69	0.29	9.86
PBBR75N	59.20	177.57	0.09	3.00
PBBR100N	61.47	179.73	0.09	2.92
ZTFB	18.23	173.44	0.28	9.52
ZTFBR75N	78.68	178.14	0.07	2.26
ZTFBR100N	80.95	180.67	0.07	2.23
SEm $\pm$	-	-	0.01	0.15
LSD (P=0.05)	-	-	0.02	0.44

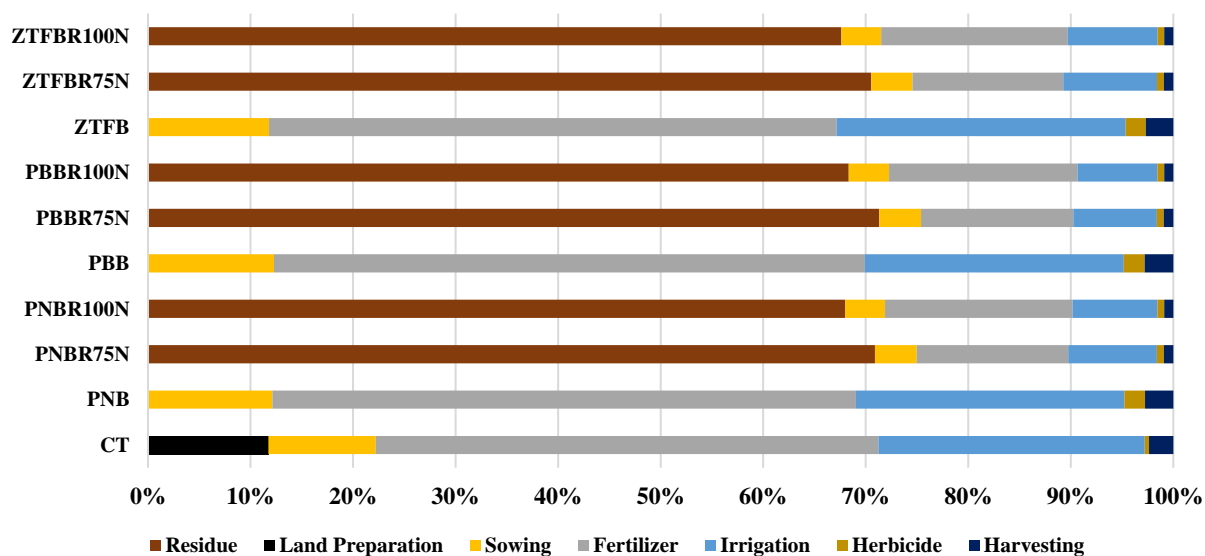


Fig: 4.5. Energy contribution of different production operations across treatments

#### 4.4.3. Nutrient uptake and use efficiency

The nutrient use efficiency (NUE) in terms of partial factor productivity (PFP) of nutrients (N, P, and K) varied significantly between the treatments in wheat due to varied tillage, residue, land configuration, and nitrogen management practices (Table 4.17). Among the treatments, the CT had lowest PFP of N, P, and K. The ZT permanent beds with and without residue led to significantly higher PFP of these nutrients than CT, and residue retention was found superior to residue removal. Among CA-based practices with residue retention, the practices with 75% N registered significantly higher PFP of N and NPK than with 100%N. The treatment ZTFBR75N registered significantly higher PFP of N (46.9 kg grain/kg N) and NPK (30.9 kg grain/kg N). These treatments with 75% N saved 25% N and ultimately increased nitrogen use efficiency than the practices with 100% N application. However, the significantly higher PFP of P (204.9 kg grain/kg P) and K (161.6 kg grain/kg K) were recorded under ZTFBR100N and was found comparable with all the zero-till with and without residue retention irrespective of N application.

Table 4.17. Partial factor productivity of nutrients across treatments

Treatments	Partial factor productivity of nutrients (kg grain/kg nutrient)			
	PFP <sub>N</sub>	PFP <sub>P</sub>	PFP <sub>K</sub>	PFP <sub>NPK</sub>
CT	31.1	178.3	140.7	22.3
PNB	33.6	192.7	152	24.1
PNBR75N	46.3	198.9	156.9	24.9
PNBR100N	35.3	202.4	159.6	25.3
PBB	33.9	194.2	153.2	24.3
PBBR75N	46.7	200.7	158.3	25.1
PBBR100N	35.5	203.6	160.6	25.5
ZTFB	34.1	195.3	154.0	24.4
ZTFBR75N	46.9	201.5	158.9	25.2
ZTFBR100N	35.8	204.9	161.6	25.6
SEm±	0.8	4.3	3.4	0.5
LSD (P=0.05)	2.4	13.0	10.2	1.6

It was also observed that the CA-based practices significantly improved nutrients (N, P, and K) uptake by wheat grain and straw (Table 4.18). The treatments with residue retention had significantly higher nutrient uptake than residue removal and CT. Also, the plots under residue

retention and 100% N application showed greater nutrient uptake compared to treatments with 75% N application. Significantly higher N uptakes by wheat grain and straw (104.2 and 28.1 kg/ha N, resp.) were observed under ZTFBR100N. This ZTFBR100N registered 19.2% and 27.7% higher N uptake by wheat grain and straw than CT, respectively. However, it remained at par with all the CA-based practices with residue retention and ZTFB.

The PBBR100N led to highest P uptake (17.1 kg/ha) by wheat grain (Table 4.18). Similarly, the highest P uptake (5.7 kg/ha) by wheat straw was recorded under this PBBR100N, and similar values were obtained in ZTFBR100N and PNBR100N and found comparable with all the ZT treatments except PNB. This treatment resulted in 41.3% and 20.8% higher P uptake by grain and straw, respectively than CT. Again, significantly higher K uptake (27.2kg/ha) by wheat grain was recorded under PBBR100N and found comparable with ZTFBR100N, PNBR100N, and ZTFBR75N (Table 4.18). The same treatment showed highest K uptake by straw (139.7 kg/ha) and was comparable with ZTFBR100N, ZTFBR75N, and PBBR75N in this regard. This treatment showed 32.7% and 24.1% higher uptake of K by wheat grain and straw, respectively than CT.

Table 4.18. Plant nutrient uptake (N, P, and K) across treatments

Treatments	N uptake (kg/ha)		P uptake (kg/ha)		K uptake (kg/ha)	
	Grain	Straw	Grain	Straw	Grain	Straw
CT	87.4	22.0	12.1	4.8	20.5	112.5
PNB	95.7	23.3	13.6	5.2	22.7	118.7
PNBR75N	100.2	24.8	16.1	5.5	23.8	124.6
PNBR100N	102.4	26.1	16.7	5.7	25.3	128.0
PBB	96.9	24.3	14.1	5.4	22.8	120.1
PBBR75N	100.3	25.9	16.3	5.6	24.5	133.8
PBBR100N	103.3	27.6	17.1	5.8	27.2	139.7
ZTFB	97.3	23.6	14.1	5.3	22.8	120.8
ZTFBR75N	101.5	25.9	16.3	5.6	24.8	134.4
ZTFBR100N	104.2	28.1	16.8	5.7	27.1	137.1
SEm±	2.4	1.0	0.8	0.2	0.8	3.1
LSD (P=0.05)	7.2	2.9	2.4	0.5	2.3	9.2

## 4.5. Soil properties

### 4.5.1. Soil physical properties

#### 4.5.1.1. Bulk density

Tillage, residue, land configuration, and N management practices had significant impacts on soil bulk density (BD) at 0-5 cm, 5-15 cm and 15-30 soil depths (Fig 4.6). The soil BD increased substantially with subsequent increase in soil depths (0-5, 5-15 and 15-30 cm) in all the treatments. The CA-based practices had lower BD values compared to CT in all soil depths except 0-5 cm depth where ZTFBR75N and ZTFBR100N led to slightly higher BD than CT. The plots that received residues had significantly lower BDs compared to plots without residue retention. The treatment PNBR100N significantly registered lower BD ( $1.34 \text{ Mg/m}^3$ ) in 0-5 cm soil layer and registered 9% lower BD than that in CT in 0-5 cm soil layer. However, it was found comparable with PNBR75N, PBBR75N, and PBBR100N in this regard. Again, at 5-15 cm soil layer, the PNBR100N showed significantly lower BD ( $1.58 \text{ Mg/m}^3$ ) and registered 3.1% lower value than in CT, however, PNBR75N, PBBR75N, PBBR100N, and PNB treatments were at par with it. Again at 15-30 cm soil layer, significantly lower BD ( $1.67 \text{ Mg/m}^3$ ) was registered by PNBR100N and recorded 2.3% lower BD compared to CT and found at par with all ZT treatments with or without residue except ZTFB. The ZTFB practice had significantly higher BD at 0-5, 5-15 and 15-30 cm soil layers.

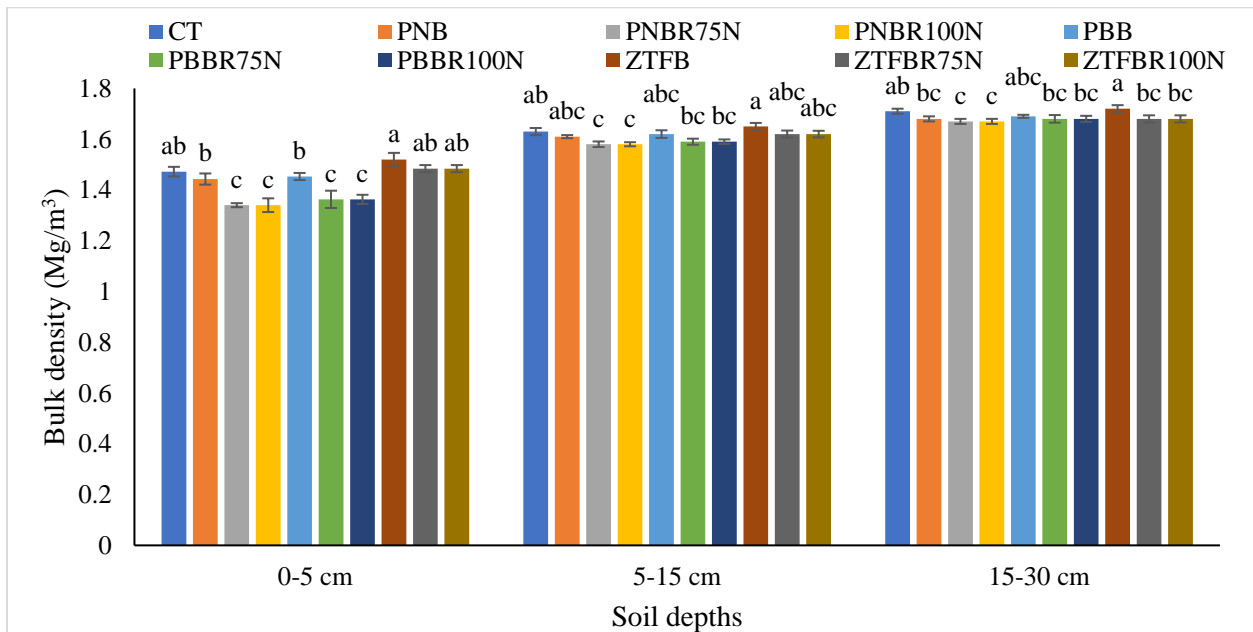


Fig. 4.6. Soil bulk density ( $\text{Mg/m}^3$ ) after wheat harvest across treatments

#### 4.5.1.2. Soil aggregate analysis

Tillage, residue, land configuration, and N management practices significantly influenced soil aggregate distribution and mean weight diameter (MWD) at 0-5, 5-15 and 15-30 cm soil depths (Table 4.19; Fig. 4.7, 4.8 and 4.9). All the CA-based ZT permanent beds with or without residue and 75% N or 100% N resulted in significantly higher values of MWD compared to CT at 0-5, 5-15 and 15-30 cm depths of soil. But, the treatments with residue retention irrespective of permanent beds and N levels (i.e., PBBR100N, PBBR75N, ZTFBR100N, ZTFBR75N, PNBR100N and PNBR75N) led to greater values of MWD than their respective residue removal practices at all the soil layers. But, at 5-15 cm and 15-30 cm soil layers, although all the CA-based ZT permanent beds with or without residue and 75% N or 100% N resulted in comparable MWDs, the PBBR100N had slightly higher values.

The CA-based ZT permanent beds with or without residue and 75% N or 100% N treatments also significantly influenced aggregate distribution in soil (Fig. 4.7, 4.8 and 4.9). All these practices resulted in comparable proportions of large macroaggregates (>2 mm) and small macroaggregates (0.253-2 mm) between them, but the proportions were significantly higher in these treatments than in CT at all depths (0-5, 5-15, 15-30 cm). The CT resulted in significantly higher microaggregates (0.050-0.253 mm) at all depths. The CA-based ZT and residue retention treatments had 58.3-62.0%, 64.4-67.3%, and 71.2-74.5%, whereas CT had 46.4%, 52.4% and 62.4% small macroaggregates at 0-5, 5-15, 15-30 cm soil depths, respectively.

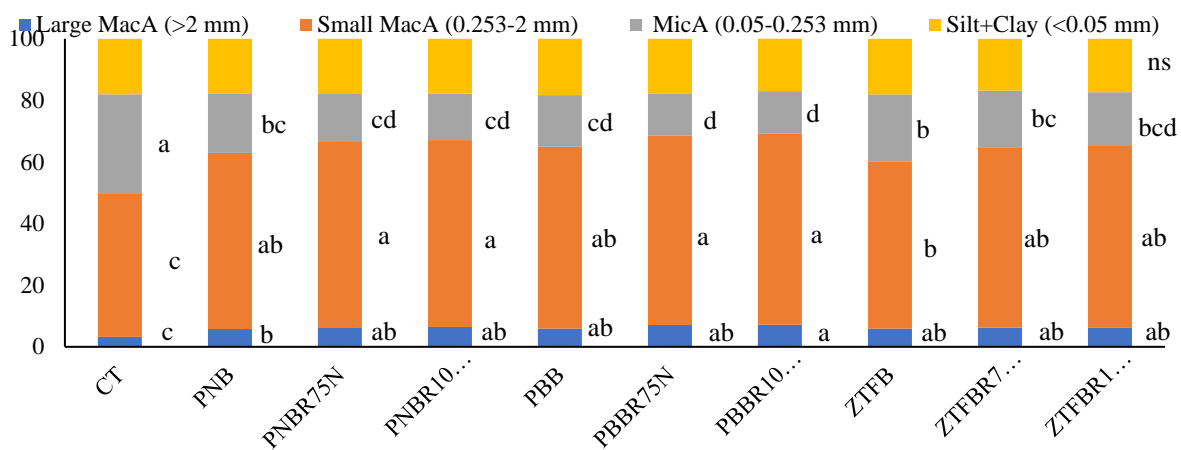


Fig:4.7. Soil aggregate distribution at 0-5 cm depth after wheat harvest across treatments  
MacA= Macroaggregate; MicA=Microaggregate

Table 4.19. Mean weight diameter of soil aggregates after wheat harvest across treatments

Treatments	Mean weight diameter (mm)		
	0-5 cm	5-15 cm	15-30 cm
CT	0.74	0.76	0.83
PNB	0.97	0.93	0.93
PNBR75N	1.02	1.00	0.97
PNBR100N	1.03	1.01	0.97
PBB	0.99	0.95	0.95
PBBR75N	1.07	1.02	1.00
PBBR100N	1.08	1.03	1.00
ZTFB	0.94	0.92	0.94
ZTFBR75N	1.00	1.00	0.97
ZTFBR100N	1.01	1.00	0.97
SEm±	0.02	0.02	0.01
LSD (P=0.05)	0.05	0.05	0.04

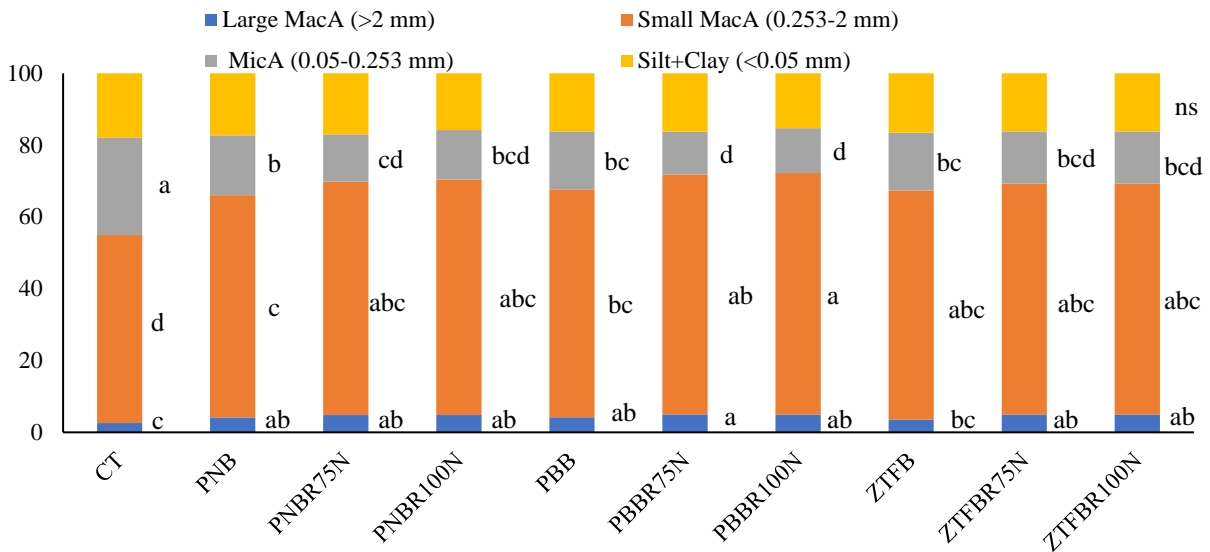


Fig:4.8. Soil aggregate distribution at 5-15 cm depth after wheat harvest across treatments

MacA= Macroaggregate; MicA=Microaggregate

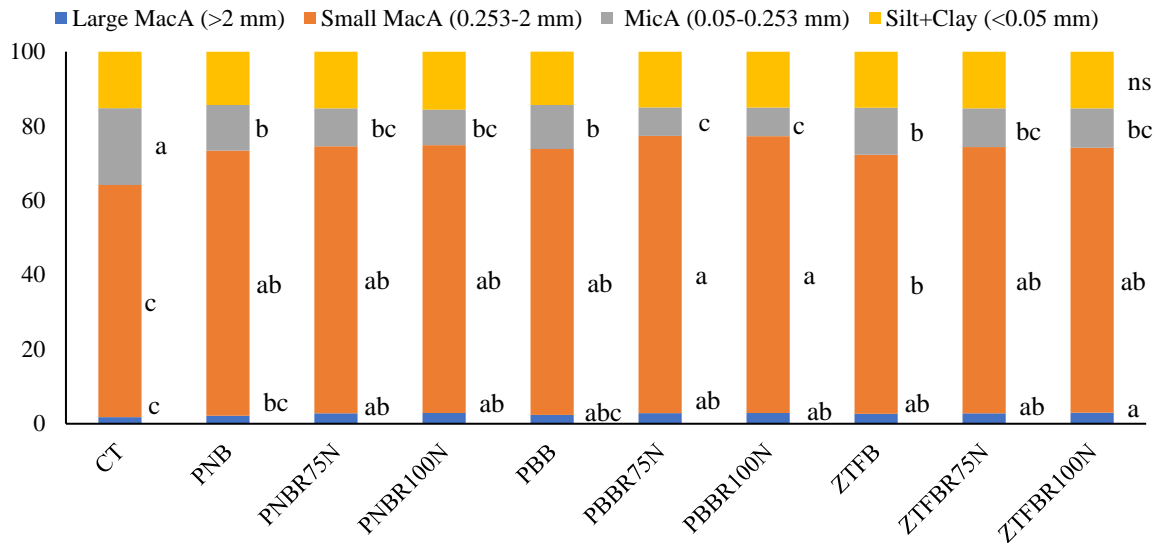


Fig:4.9. Soil aggregate distribution at 15-30 cm depth after wheat harvest across treatments

MacA= Macroaggregate; MicA=Microaggregate

#### 4.5.1.3. Soil temperature (morning and afternoon)

Tillage, residue, and land configuration adopted in this study could influence soil temperature distribution throughout wheat growing season (Fig. 4.10, 4.11, 4.12, 4.13). The morning soil temperature was relatively higher at 5-15 cm than at 0-5 cm depth of soil, and was lowest in CT plots throughout wheat growing season at both 0-5 and 5-15 cm soil layers. The CA-based permanent beds treatments with residue retention (PNBR75N, PNBR100N, PBBR75N, PBBR100N, ZTFBR75N, ZTFBR100N) had comparatively higher soil temperatures than their respective residue removal treatments and CT at both 0-5 and 5-15 cm depths.

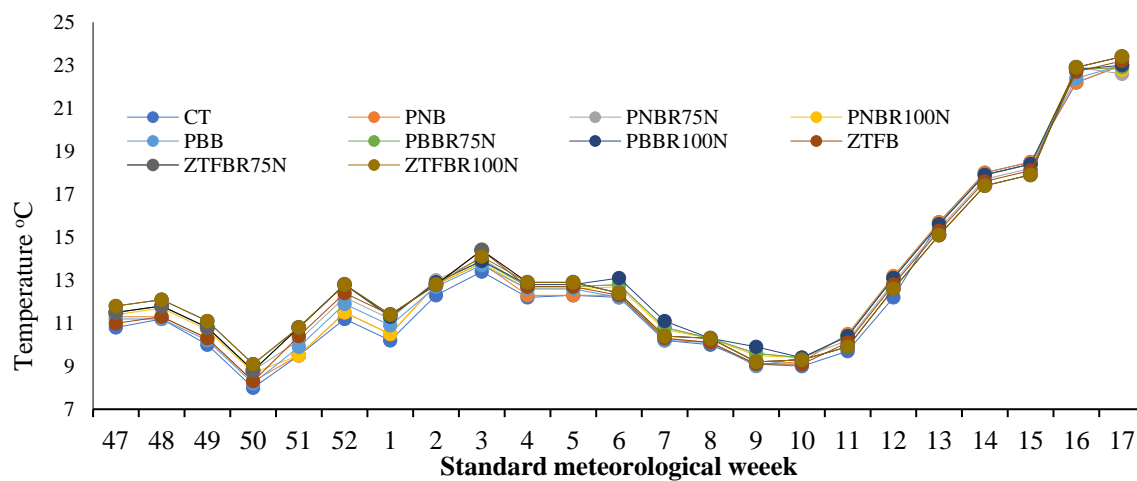


Fig:4.10. Morning soil temperature (weekly interval) at 0-5 cm depth during wheat growing period

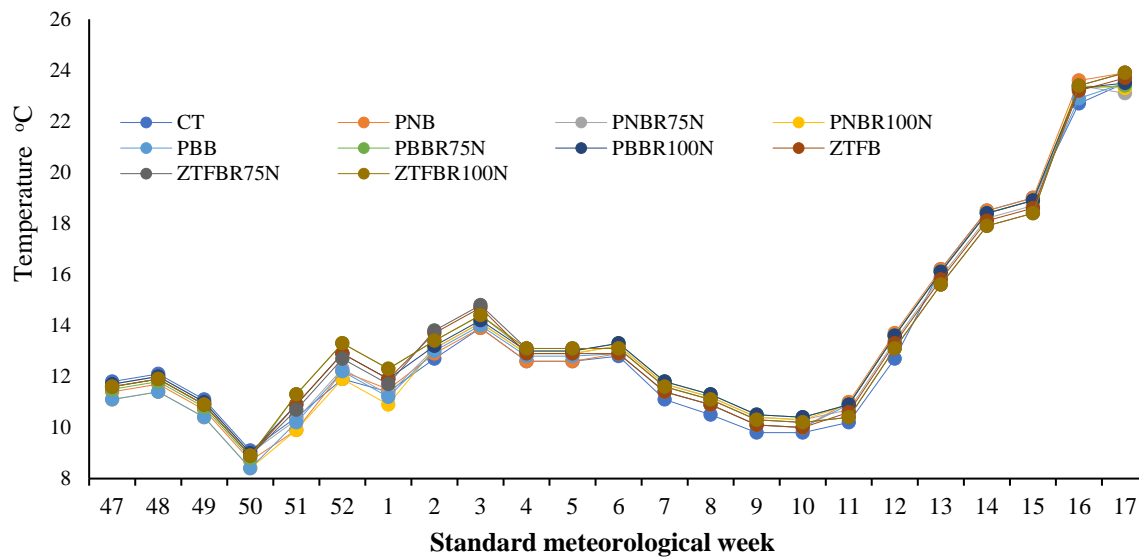


Fig.4.11. Morning soil temperature (weekly interval) at 5-15 cm depth during wheat growing period

Conversely, the afternoon soil temperature was found higher in CT up to the 12<sup>th</sup> week (Fig. 4.12 and 4.13). Later, PNB, PBB, ZTFB (without residue) also resulted in comparable but higher soil temperature with CT. Surface soil (0-5 cm) had higher afternoon temperature than sub-surface (5-15 cm) soil. The CA-based permanent beds treatments with residue retention (PNBR75N, PNBR100N, PBBR75N, PBBR100N, ZTFBR75N, ZTFBR100N) experienced relatively lower soil temperatures than their respective residue removal treatments and CT at both 0-5 and 5-15 cm depths throughout wheat growing season.

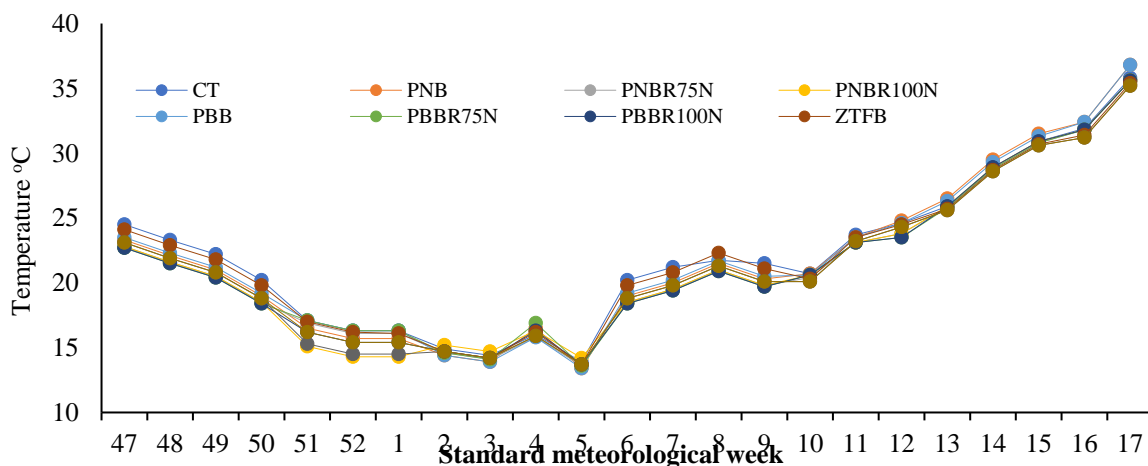


Fig. 4.12. Afternoon soil temperature (weekly interval) at 0-5 cm depth during wheat growing period

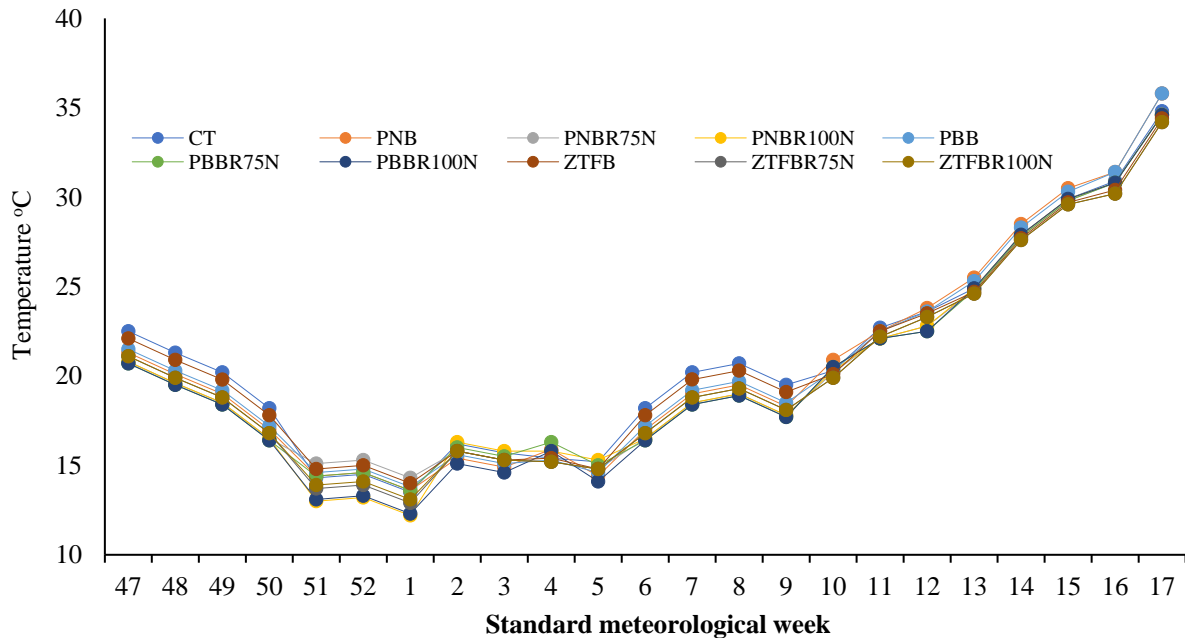


Fig. 4.13. Afternoon soil temperature (weekly interval) at 5-15 cm depth during wheat growing period

#### 4.5.2. Soil chemical properties

##### 4.5.2.1. Soil carbon status

Long-term effect (after 12 years) of CA employing tillage, residue, and land configuration significantly influenced soil carbon fractions under pigeon pea - wheat system. Lowest values of active C pool, passive C pool, and TOC were observed in CT at 0-5 cm depth (Table 4.20). The CT also showed lower values of TOC at 0-5, 5-15, and 15-30 cm depths of soil. The CA-based treatments with residue retention led to a significant improvement in soil carbon fractions across depths of soil. Among them, the PBBR100N resulted in significantly higher total soil organic carbon (TOC) at 0-5, 5-15, and 15-30 cm depths of soil than others except the PBBR75N, which had comparable TOC with it. The TOC values at 5-15 cm and 15-30 cm depths of soil were comparable between PBBR100N, ZTFBR100N, PNB100N, PBBR75N, ZTFBR75N, and PNB75N treatments. The TOC concentration was highest at 0-5 cm depth and decreased gradually with increase in depth of soil. The active C pool (Pool 1+Pool 2) under the ZT permanent beds treatments, irrespective of residue retention and N application (i.e., PBBR100N, ZTFBR100N, PNB100N, PBBR75N, ZTFBR75N, and PNB75N) ranged from 50.6 to 57.4%, 52.2 to 62.1%, and 55.3 to 62.6% of the TOC at 0-5, 5-15, and 15-30 cm soil depths, respectively. Similarly, the passive C pool (Pool 3+ Pool 4) varied between 42.6-49.5%, 37.9-47.8%, and 37.4-44.7% of the TOC at these depths of soil, respectively. Both CA and CT systems had active C pool

higher than passive C pool. Under CT, the active C pool (ranging from 61.9-74.9% of the TOC) was higher than passive C pool (ranging from 25.1-38% of the TOC) across soil depths. Residue retention treatments led to 32-44.5%, 35.1-42.2%, and 33.7-43.1% higher TOC than CT and improved soil carbon concentration at all three depths compared to residue removal and CT treatments.

Table 4.20. Soil carbon fractions (g/kg) at different depths after wheat harvest across the treatments

Treatments	0-5 cm				5-15 cm				15-30 cm			
	AP	PP	WBC	TOC	AP	PP	WBC	TOC	AP	PP	WBC	TOC
CT	5.76	3.53	6.93	9.30	4.00	1.76	4.69	5.76	3.20	1.07	3.63	4.27
PNB	6.72	5.52	7.64	12.23	3.59	2.19	3.82	5.78	2.70	1.61	3.66	4.31
PNBR75N	7.75	5.93	9.92	13.68	4.33	3.45	5.76	7.78	3.23	2.49	4.39	5.73
PNBR100N	8.16	6.05	10.28	14.21	4.56	3.52	5.97	8.08	3.30	2.54	4.48	5.84
PBB	6.72	5.89	7.88	12.61	3.12	2.86	4.29	5.98	2.70	1.95	3.88	4.65
PBBR75N	8.21	7.97	11.29	16.18	4.79	3.08	6.22	7.87	3.63	2.37	4.97	5.99
PBBR100N	8.64	8.14	11.7	16.77	5.04	3.14	6.45	8.19	3.70	2.41	5.07	6.11
ZTFB	7.2	5.38	7.88	12.59	3.12	2.84	4.06	5.96	2.40	1.94	3.58	4.34
ZTFBR75N	7.53	7.37	10.37	14.89	4.79	3.01	5.99	7.80	3.40	2.47	4.68	5.71
ZTFBR100N	7.92	7.52	10.75	15.44	5.04	3.07	6.21	8.11	3.30	2.52	4.78	5.83
SEm±	0.23	0.21	0.15	0.28	0.16	0.15	0.15	0.26	0.16	0.12	0.12	0.18
LSD (P=0.05)	0.67	0.62	0.46	0.84	0.48	0.44	0.46	0.78	0.47	0.35	0.36	0.54

AP: Active pool (Pool 1+Pool 2); PP: Passive pool (Pool 3+Pool 4); WBC: Walkley and Black carbon; TOC: Total organic carbon

#### 4.5.2.2. Soil mineral nitrogen dynamics

Soil mineral N ( $\text{NH}_4^+\text{-N}$  and  $\text{NO}_3^-\text{-N}$ ) at 0-5 and 5-15 cm soil layers estimated at 60 DAS, 90 DAS, and harvest of wheat differed significantly due to different tillage, residue, and N management practices (Table 4.21). The  $\text{NH}_4^+\text{-N}$  and  $\text{NO}_3^-\text{-N}$  were significantly higher in CA-based practices with residue retention, irrespective of N levels than in CT and ZT without residue treatments. Among N management practices, the plots with residue and 100% N resulted in significantly higher soil mineral N than residue and 75% N application. The PBBR100N led to significantly

higher soil  $\text{NH}_4^+$ -N and  $\text{NO}_3^-$ -N at all three stages at both soil depths (0-5 and 5-15 cm). But,  $\text{NH}_4^+$ -N at 0-5 cm depth, ZTFBR100N, PNBR100N, and PBBR75N were comparable with it at 60 DAS; PBBR75N at 90 DAS; and ZTFBR100N, PBBR100N, and PNBR100N at harvest in this regard. However, at 5-15 cm soil layer, ZTFBR100N, PNBR100N, and ZTFBR75N at 60 DAS; ZTFBR100N, PNBR100N, and PBBR75N at 90 DAS; and ZTFBR100N and ZTFBR75N at harvest had comparable  $\text{NH}_4^+$ -N with it. Almost similar trend was observed with respect to  $\text{NO}_3^-$ -N accumulation in soil among the treatments across depths. Again, the PBBR100N treatment resulted in significantly higher  $\text{NO}_3^-$ -N at 60 DAS, 90 DAS and harvest at 0-5 and 5-15 cm soil depths (Table. 4.21).

Treatment	60 DAS				90 DAS				Harvest			
	0-5 cm		5-15 cm		0-5 cm		5-15 cm		0-5 cm		5-15 cm	
	$\text{NH}_4^+$	$\text{NO}_3^-$	$\text{NH}_4^+$	$\text{NO}_3^-$	$\text{NH}_4^+$	$\text{NO}_3^-$	$\text{NH}_4^+$	$\text{NO}_3^-$	$\text{NH}_4^+$	$\text{NO}_3^-$	$\text{NH}_4^+$	$\text{NO}_3^-$
CT	5.6	16.5	4.6	13.5	5.4	29.4	4.0	27.4	2.6	14.3	2.3	9.6
PNB	6.0	17.0	4.7	15.3	5.9	31.1	5.1	28.6	2.6	15.2	2.9	11.8
PNBR75N	8.6	22.4	7.0	22.6	6.8	33.2	5.8	31.5	4.0	16.8	3.0	18.0
PNBR100N	8.9	26.7	8.1	24.4	7.0	34.9	6.3	33.3	4.7	20.0	3.4	20.3
PBB	5.9	16.4	4.5	16.4	5.6	31.0	5.2	27.2	2.9	12.9	2.9	11.6
PBBR75N	8.8	24.5	7.7	22.5	8.2	32.0	6.2	30.0	4.8	18.8	3.6	19.9
PBBR100N	9.8	28.9	9.7	23.8	8.7	34.8	7.0	36.6	5.4	20.3	4.6	20.5
ZTFB	7.3	16.2	5.8	17.2	5.2	31.1	5.0	25.2	2.7	11.5	3.1	10.7
ZTFBR75N	8.7	25.8	8.5	22.1	5.7	31.8	5.8	29.4	4.3	18.5	4.1	18.5
ZTFBR100N	9.6	28.1	8.8	23.0	6.9	34.1	6.5	33.5	5.2	19.2	4.2	18.6
SEm±	0.3	1.2	0.6	1.2	0.3	2.1	0.3	1.4	0.3	1.2	0.2	0.9
LSD(P=0.05)	1.0	3.6	1.7	3.7	0.9	6.2	0.9	4.3	0.8	3.6	0.5	2.6

#### 4.5.2.3. Soil N, P, and K status

The TRN practices significantly influenced soil N, P, and K status before sowing and after harvest of wheat crop (Table 4.22). Before sowing soil N content was higher in PBBR100N (291.7), but all residue retention treatments and PNB were comparable with it in this regard. After harvest of wheat, again, this PBBR100N showed significantly higher soil N (313.8), and all residue retention treatments were comparable with it. Similar trend was observed on the soil P and K contents across the treatments. The same PBBR100N resulted in significantly higher soil P and K contents before

sowing and after harvest of wheat. The PBBR75N resulted in comparable content of P and K in soil with it. The ZT permanent beds with residue treatments resulted in positive balance of N, P, and K in soil after harvest, whereas the CT showed negative balance.

Table 4.22. Soil N, P, and K before sowing and after harvest of wheat crop across the treatments

Treatments	N (kg/ha)			P (kg/ha)			K (kg/ha)		
	Initial	Final	Increase/ decrease	Initial	Final	Increase/ decrease	Initial	Final	Increase/ decrease
CT	253.7	237.6	-16.1	73.0	68.6	-4.4	436.2	427.3	-8.9
PNB	273.7	285.8	12.1	79.0	82.2	3.2	460.1	469.9	9.8
PNBR75N	289.0	302.3	13.3	85.0	88.7	3.7	506.5	523.9	17.4
PNBR100N	289.0	309.7	20.7	85.0	90.7	5.7	506.5	531.2	24.7
PBB	261.0	273.6	12.7	79.5	83.1	3.6	479.1	489.3	10.2
PBBR75N	291.7	309.8	18.1	95.0	100.4	5.4	599.8	614.7	14.9
PBBR100N	291.7	313.8	22.2	95.0	101.7	6.6	599.8	621.5	21.7
ZTFB	268.0	282.4	14.4	75.0	78.8	3.8	458.0	469.3	11.3
ZTFBR75N	286.8	306.6	19.8	83.5	88.8	5.3	483.8	501.9	18.1
ZTFBR100N	286.8	309.1	22.3	83.5	89.5	6.0	483.8	507.0	23.2
SEm±	7.1	7.7	-	2.0	3.3		9.7	8.1	
LSD (P=0.05)	21.4	23.1	-	6.1	9.9		29.2	24.1	

### 4.5.3. Soil biological properties

#### 4.5.3.1. Microbial biomass carbon (MBC)

The TRN management practices significantly influenced soil microbial biomass carbon (MBC) at 0-5 and 5-15 cm soil depths (Table 4.23). CA-based residue retention treatments showed higher MBC than those without residue and CT treatment. Among them, PBBR100N showed significantly higher values of MBC, but all the residue retention treatments were found comparable with it at 0-5 cm depth, and ZTFBR100N was comparable at 5-15 cm depth in this regard. This PBBR100N again resulted in 75.3 and 37.5% higher MBC than that in CT at 0-5 and 5-15 cm soil depths, respectively. The CA-based treatments with 100%N also showed higher MBC than 75%N application.

#### 4.5.3.2. Dehydrogenase activity (DHA)

The soil dehydrogenase activity (DHA) at 0-5 and 5-15 cm soil depths was significantly influenced by TRN practices over the years (Table 4.23). CA-based residue retention treatments showed higher DHA than without residue and CT treatment. Among them, PBBR100N showed significantly higher values of DHA, but, in this regard, all the residue retention treatments were comparable with it at both 0-5 and 5-15 cm soil depths, and ZTFB was comparable with it at 0-5 cm depth. This PBBR100N treatment resulted in 56.3% and 35.9% higher DHA over CT at 0-5 and 5-15 cm depths, respectively. The CA-based treatments with 100N showed higher DHA than 75N application. Hence, CA-based treatments could significantly improve soil biological properties than CT.

Table 4.23. Soil microbial biomass carbon and dehydrogenase activity in soil at 0-5 and 5-15 cm depths at wheat flowering across the treatments

Treatments	MBC ( $\mu\text{g/g}$ soil)		DHA ( $\mu\text{g TPF/g/24h}$ )	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm
CT	637.4	461.0	175.2	159.5
PNB	669.0	481.5	221.8	167.9
PNBR75N	1056.6	538.3	246.8	206.8
PNBR100N	1086.5	570.6	272.4	214.7
PBB	814.5	478.2	224.5	169.4
PBBR75N	1051.5	548.8	260.3	200.3
PBBR100N	1117.6	634.1	273.9	216.7
ZTFB	729.1	494.6	243.6	167.1
ZTFBR75N	1026.8	546.2	254.9	200.8
ZTFBR100N	1090.2	581.9	267.7	217.3
SE $m\pm$	58.6	19.9	12.1	9.2
LSD (P=0.05)	175.6	59.5	36.3	27.6

#### 4.6 Carbon footprint, carbon efficiency, carbon sequestration index and carbon efficiency ratio

The TRN practices significantly influenced carbon footprint in wheat production system (Fig.4.14 and Fig.4.15). The CT had significantly higher yield scale carbon footprint than rest of the

treatments. The ZT permanent beds and residue retention treatments with 75%N application registered lower carbon footprint than their respective 100%N treatments as well as residue removal treatments. The PBBR75N led to 29.3% and 14.1% lower yield scale and spatial carbon footprint than CT, respectively. This treatment showed lower yield scale carbon footprint but significantly higher carbon efficiency, carbon sequestration index and carbon efficiency ratio than others (Table 4.24). However, the PNBR75N and ZTFBR75N were comparable with it in these regards.

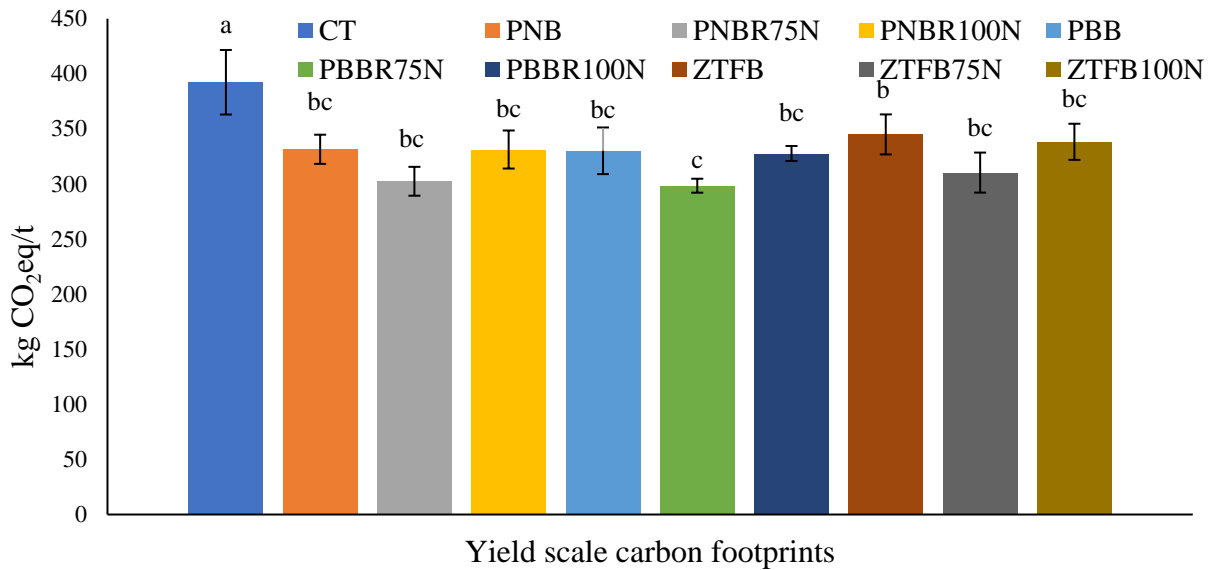


Fig.4.14. Yield scale carbon footprint of wheat production across treatments

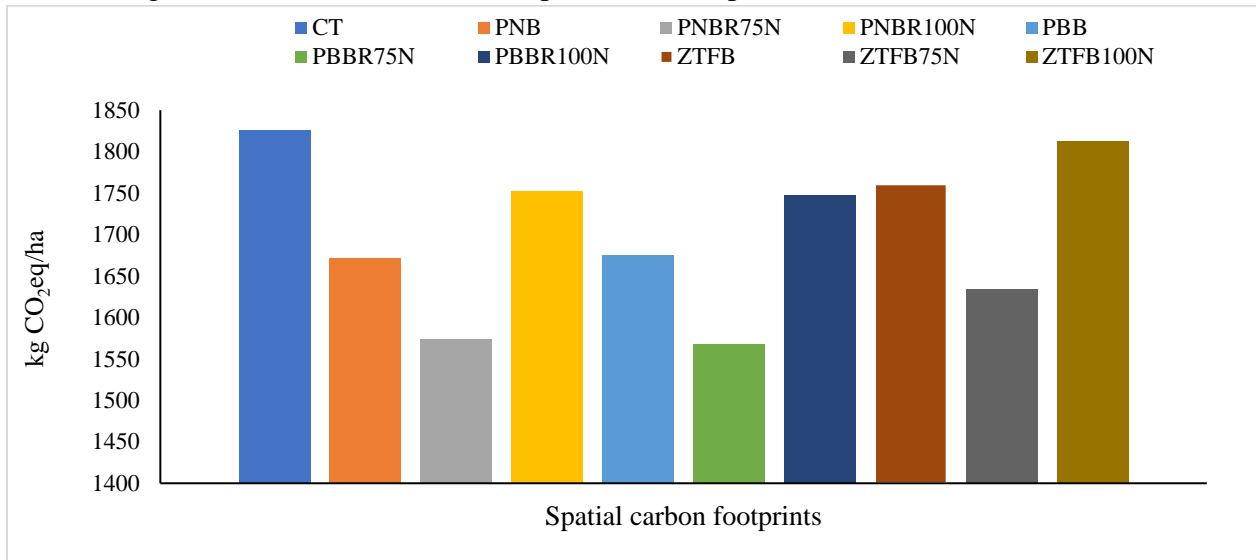


Fig. 4.15. Spatial carbon footprint of wheat production across treatments

Table: 4.24. Carbon efficiency, carbon sequestration index and carbon efficiency ratio across treatments

Treatments	Carbon efficiency	Carbon sequestration index	Carbon efficiency ratio
CT	10.77	9.77	3.75
PNB	12.34	11.34	4.43
PNBR75N	13.51	12.51	4.86
PNBR100N	12.30	11.3	4.44
PBB	12.44	11.44	4.45
PBBR75N	13.65	12.65	4.92
PBBR100N	12.40	11.4	4.48
ZTFB	11.88	10.88	4.26
ZTFBR75N	13.15	12.15	4.74
ZTFBR100N	12.01	11.01	4.34
SE <sub>m</sub> ±	0.22	0.22	0.11
LSD (P=0.05)	0.66	0.66	0.33

## DISCUSSION

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In this chapter, the cause and effect relationship of the outcomes of the current study entitled “Tillage, residue, and nitrogen effects on weeds, wheat productivity, and soil properties under Conservation-Agriculture-based pigeon pea-wheat system” on weed interference, crop productivity, profitability, resource-use efficiency, and soil properties are explained along with corroboration with previous studies.

### 5.1. Effect on weed dynamics and interference

The CA-based practices resulted in significantly lower total weed density and biomass compared to CT practice. CA-based treatments with surface residue retention were found superior in reducing grassy, broad-leaved, sedge, and total weed density compared to residue removal treatments. The dominance of *Cyperus esculentus* in wheat was significantly higher under CT practice, whereas the CA-based practices such as permanent flat-bed, permanent broad-bed, and permanent narrow-bed treatments with residue retention effectively reduced the emergence of this weed. Our close observation reveals that although *C. esculentus* is a perennial sedge like *Cyperus rotundus*, it differs profusely from *C. rotundus*. It has growing tendency like annuals, germinates in thousands/lakhs, and grows under very dense, over-crowded conditions. Its propagating structures are small seed-like tubers having less or no dormancy, which germinate instantaneously under slight stirring of soil. Its tuber also varies in shape, size from that of *C. rotundus*. In CT practice, regular tilling operations might have favoured its frequent germination and profuse fast tuberization. Otherwise, as usual, CT gets dominated with annual weeds and CA will have more problems of perennial weeds over times. Reverse could happen here, probably, because of behavioural difference in this perennial weed *C. esculentus*. Besides, rainy to winter season transition period temperature, which remained warmer also played a role. On the contrary, the retention of crop residue in CA-based treatments might have suppressed *C. esculentus* resulting in its lower infestation (Baghel *et al.*, 2020). CT wheat treatment had higher broad-leaved, sedge, and total weed densities, whereas, grassy weed infestation in CT and ZT without residue treatments were comparable at 30 DAS (Table 4.2). Similarly, at 60 DAS, PBB resulted in higher grassy weed density, followed by PNB and CT and lowest in ZTFBR75N and ZTFBR100N. Broad-leaved weeds were higher in PNB followed by CT, and sedges and total weed densities were significantly

higher in CT (Table 4.3). The ZT permanent beds with residue retention treatments had better suppression ability due to surface residue cover on weed density and growth, and could significantly reduce weed infestation (population, dry weight) than their respective without residue treatments. Probable reasons have already been discussed. Our results corroborated with those of Chhokar *et al.* (2007), Nath *et al.* (2016), and Singh *et al.* (2017). Anchored crop residue on the soil surface restricts light and acts as a physical barrier to germination of many weed species and may arrest some physicochemical changes in soil environment for weed seed emergence (Teasdale and Mohler, 1993; Nandan *et al.*, 2018). Also, the ZT systems with crop residue retention on soil surface had periodic sparse emergence of weeds, which could prolong the period of weed emergence. This facilitated crop to acquire a competitive edge over weeds, reducing the need for weed management (Christoffoleti *et al.*, 2007; Anderson, 2010; Younesabadi *et al.*, 2013; Susha *et al.*, 2014). As a result, category-wise and total weed densities were considerably reduced in these treatments when compared to residue removal treatments (Baghel *et al.*, 2020), and CT. In contrast, tillage created more favorable conditions for weed seed germination in CT (Mirsky *et al.*, 2010). The ZTFBR75N and ZTFBR100N were superior in reducing overall weed density and dry weight of weeds, because of more uniform residue cover compared to broad-bed and narrow-bed treatments. However, ZT without residue treatments such as PNB and PBB showed higher weed dry weight due to more grassy and broad-leaved weeds infestation. The application of tank-mix of herbicides (clodinafop-propargyl + metsulfuron-methyl) could considerably reduce density and dry weight of complex weed flora (Table 4.5). The grassy and broad-leaved weeds were effectively managed by this mixture (Tiwari *et al.*, 2015; Singh *et al.*, 2017).

## **5.2. Effect on crop productivity and profitability**

CA-based permanent flat-bed with residue retention irrespective of N application resulted in better plant height, LAI at 30 DAS and dry matter accumulation at 30, 60, and 90 DAS (Table 4.6, 4.7). Permanent broad bed and narrow bed treatments with residue retention irrespective of N application also showed comparable growth parameters with it. LAI was found superior in permanent broad and narrow-bed treatments with residue retention at 60 and 90 DAS, respectively (Table 4.8). The higher values of plant height, dry matter accumulation and leaf area index in residue retained treatments confirmed better growth and advantage of residue retention compared to ZT residue removal treatments and CT. The ZT permanent bed system also led to higher root

growth (length, mass, and volume density in 0-30 cm layer) (Table 4.10). Similar results were reported by Martinez *et al.* (2008), who observed that ZT increased root growth, and root length density in top soil layers. The better wheat shoot and root growth, and productivity under CA system can be attributed to better soil physical, chemical, and biological properties, improved water regime by reducing evaporation, and better weeds suppression due to long-term residue retention (Das *et al.*, 2016; Bhattacharyya *et al.*, 2015; Gupta *et al.*, 2007a). In this study, pigeon pea residue (leaf litter, stem/stover and root) varied from lowest 2.58 t/ha in CT to highest 7.31 t/ha in PBBR100N and PBBR75N in single season (Table 5.1), indicating variation in residue addition to plots depending on total biomass obtained across the treatments. This study was a continued long-term (12-year old) CA-based pigeon-wheat system, in which around 110-120 t/ha residue (i.e., biomass carbon inputs) in previous years cumulative of 11 years had been already retained across these treatments. This contributed towards better soil health in terms of better soil physical, chemical, and biological properties.

The loss of moisture from soil surface through evaporation is faster in tilled situations, resulting in poor germination, irregular crop plant stands and reduced crop development and yield (Das *et al.*, 2020). The six rows of narrow bed planted wheat and five rows of broad bed planted wheat in 140 cm bed width could produce comparable yield with 7 rows of flat bed planted wheat (Table 4.12). The comparable yield under bed planting with that of the flat-bed treatments even with less number of wheat rows could be attributed to better tillering, higher grains/spike in bed planted treatments (Shivakumar and Mishra, 2001; Bhardwaj *et al.*, 2004; Dhillon *et al.*, 2004; Sikka *et al.*, 2004; Yadav *et al.*, 2005; Ram *et al.*, 2010) and reduced lodging (Tripathi *et al.*, 1999). In this study too, wheat crop at maturity experienced lodging, and these CA-based residue retention treatments showed lower lodging score and lodging index than ZT permanent beds without residue and CT treatments (Fig. 4.4).

Similarly, wheat yield under 75%N and 100%N treatments was comparable, irrespective of land configuration (narrow, broad or flat beds). The surface residue retention over the years (around 110-120 t/ha residue in 11 years) led into higher organic matter accumulation and buildup of nutrients in top soil layers compared to CT (Bhattacharyya *et al.*, 2018; Schoenau and Campbell, 1996). The inclusion of pigeon pea as a legume component in this CA-based crop diversification could augment N reserve in soil and reduce N requirement (Powlson *et al.*, 2016).

This as well indicated savings in N under CA practices without compromising yield. Earlier several studies (Oyeogbe *et al.*, 2018; Jat *et al.*, 2019; Shekhawat *et al.*, 2021) corroborated our results. CA-based ZT permanent beds with residue retention practices might have favoured for increased photosynthesis and efficient translocation of photosynthates as well as larger sink, and a longer reproductive phase (Nath *et al.*, 2015). This was evidenced by greater number of effective tillers/m<sup>2</sup>, grains/ear, and 1000-grain weight in this study (Table 4.11). The CA-based practices with and without residue retention registered 3.1-15.7% lower cost of cultivation, but resulted in 19.4-23.8% higher net returns and 24.6-46.7% higher net B:C than CT (4.14). Higher cost in CT was mainly due to expenses for land preparation. Residue retention treatments incurred higher cost due to cost of residue. Higher cost of cultivation coupled with lower wheat yield resulted in lower net B:C in CT plots (Aryal *et al.*, 2014)

Table 5.1. Pigeon pea residue inputs added to wheat crop across the treatments

Treatment code	Pigeon pea residue input (t/ha) applied to wheat			
	Leaf litter	Stover	Root	Total residue
CT	1.20	-	1.38	2.58
PNB	1.45	-	1.75	3.2
PNBR75N	1.50	2.8	1.95	6.25
PNBR100N	1.50	2.8	1.95	6.25
PBB	1.80	-	2.23	4.03
PBBR75N	1.85	3.0	2.46	7.31
PBBR100N	1.85	3.0	2.46	7.31
ZTFB	1.70	-	1.75	3.45
ZTFBR75N	1.75	3.2	1.95	6.9
ZTFBR100N	1.75	3.2	1.95	6.9

### 5.3.Effect on resource-use efficiency

CA-based practices with residue retention especially PBBR100N registered 20.6% lower irrigation water use (238 mm) than CT, but PBBR75N was comparable. As a result, PBBR100N led to 35.8% higher irrigation water productivity and 43.8% higher total water productivity than CT (Table

4.15). Similarly, Das *et al.* (2014) reported that the CA system had 14% lower water consumption in wheat and 30% higher water-use efficiency than CT plots. Bhushan *et al.* (2007) observed 30-40% saving in irrigation water and 20% higher wheat yield under CA leading to higher irrigation water use efficiency. Lower evaporation from soil and improved availability of nutrients (Choudhury and Singh, 2013; Hazra *et al.*, 2014) might play roles for improved water productivity under PBBR systems. ZT can improve soil structure, which is associated with greater water retention, improved infiltration and lower total water usage (Erenstein, 2003). Increased root length, mass and volume density under the PBBR100N and PBBR75N treatments resulted in more water extraction from soil and a reduction in reliance on irrigation water use. In addition, permanent beds favored movement of water at a faster rate and increased its uptake that resulted in irrigation water savings (Aquino, 1998; Das *et al.*, 2014, Mohammad *et al.*, 2018). Residue retention plots had higher water productivity than no residue plots, mainly because of lower irrigation water use and higher productivity (Das *et al.*, 2018).

Input energy consumption was highest under ZTFBR100N. Residue has implication on energy, and, therefore, the ZT permanent beds with residue practices incurred higher input energy than their respective no residue plots and CT. Lowest input energy was recorded under PBB. This treatment registered 14.9% lower input energy than even CT. No residue plots had lower energy than even CT due to no energy required for land preparation. Crop residue constituted 67.6-70.9% of total energy input in CA-based residue retention treatments (Ghosh *et al.*, 2022). Having higher N dose and slightly higher residue retention, the 100% N application had little higher input energy than 75% N. However, the CA-based practices with residue retention outperformed CT as well as CA-based residue removal treatments in terms of output energy, which was higher due to higher crop productivity. But, the energy productivity and energy ratio (~energy-use efficiency) were lower in CA-based residue retention treatments due to large quantity of energy invested through addition of crop residues, which increased input energy (Table 4.16). Several researchers (Saad *et al.*, 2016; Parihar *et al.*, 2018b; Ghosh *et al.*, 2022) have reported similar results. In this study too, ZT reduced diesel energy use by 70.6% and saved diesel by ~36 litres/ha. Erenstein and Laxmi (2008) estimated a seasonal savings of diesel for land preparation under ZT ranging from 15–60 litres/ha, or an 81% savings over CT. CA-based practices with residue and 75% N registered significantly higher PFP of N and NPK than their respective 100%N treatments and CT. The N use reduced by 25% under 75% N, and similar yields under 100 and 75% N treatments were

responsible for higher N use efficiency in the 75% N treatment (Table 4.17). The N fertilizer requirement under CA may be anticipated to decrease over time as a result of buildup of organic matter (Riley *et al.*, 2017) and reduced erosion losses (Schoenau and Campbell, 1996). Singh *et al.* (2009) observed similar higher agronomic efficiency of N in wheat under residue retention was associated with either a lower rate of fertilizer N or increase in grain yield. The increased plant nutrient content in maize, wheat and mungbean grain and stover/straw under CA might be attributed to improved root growth, resulting in higher nutrient concentration and uptake in these crops owing to growing forage area for nutrient removal under permanent beds with residue (Parihar *et al.*, 2018c).

#### **5.4. Effect on soil properties and carbon footprint**

CA-based residue retention treatments resulted in lower soil BD than CT. Our results are in conformity with that of Bhattacharyya *et al.* (2015, 2018), reporting lower BD under CA plots. Residue retained plots had significantly lower BD than residue removal plots, might be attributed to enhanced SOC content, improved aggregation and increased root development under ZT with residue retention (Das *et al.*, 2014). Residues upon decomposition are converted to organic matter, which has lower specific density and higher porosity compared to soil, thereby reduces soil BD (Bhattacharyya *et al.*, 2013a). In this study, PNBR100N led to reduction in BD by 9%, 3.1%, and 2.3% than CT at 0-5, 5-15, and 15-30 cm soil layers, respectively (Table 4.19). The lower BD in this plot might be due to the addition of large quantities of crop residue *vis-à-vis* reduced traffic in bed planted ZT treatments. Parihar *et al.* (2018a) also observed decreased soil BD in ZT and residue retention plots at 0-5 cm and 5-15 cm soil depths compared to CT after 6 years. Several studies have reported higher BD under ZT without residue retention in the soil surface in comparison to tilled soils, which might be due to absence of loosening of soils through tillage (Bhattacharyya *et al.*, 2008). CA-based practices resulted in higher values of means weight diameter (MWD) compared to CT. The plots under PBBR100N had significantly greater MWD (1.08 mm, 1.03 mm, and 1.0 mm) and registered 45.9%, 35.5%, and 20% higher MWD than CT at 0-5 5-15 cm and 15-30 cm soil layer, respectively (Table 4.20). The lowest soil MWD under CT (0.74-0.83) in this study might be due to the negative effects of long-term ploughing over the crop seasons. Frequent tillage operations destroy soil structure, increase the risk of soil erosion, and decline soil quality (Nath and Lal, 2016). Repeated mechanical fragmentation of macro-

aggregates under CT decreases the size of large macro-aggregates with larger proportion of smaller-sized aggregates, silt and clay fractions (Bhattacharyya *et al.*, 2013b). ZT increases the organic carbon concentration of the surface layers, resulting in greater soil aggregate stability (Chauhan *et al.*, 2002). Higher proportion of labile organic carbon in ZT systems with inclusion of pulse also creates hotspots of microbial activity and fungal hyphae, which, in turn, promote macro-aggregation (Puget *et al.*, 1995; Jastrow, 1996; De Gryze *et al.*, 2005). The ZT with residue retention had higher soil temperature in the morning but lower soil temperature in the afternoon than that of respective residue removal treatments and CT at 0-5 and 5-15 cm soil depth. The residue retained on the soil surface played roles. Residue generally reduces radiant energy inputs leading to cooling of soil. It also reduces heat loss from the soil surface and diurnal soil temperature fluctuations, that leads to moderation of temperature under ZT with residue retention (Azooz *et al.*, 1995). Soil pH (8.10-8.24) was lower under CA-based residue retention treatments, might be the release of organic acids through decomposition of crop residues responsible (Husson *et al.*, 2018). The chelation effect and binding of solutes by soil organic matter might have reduced salt concentration in topsoil, thereby reducing soil EC (0.22-0.26 dS/m) in CA-based residue retention treatments compared to CT (0.35 dS/m). Husson *et al.* (2018) observed that CA-based residue retention systems decreased soil EC when it was originally high, and raised it when it was low.

Higher available N, P, and K in soil was observed in CA-based residue treatments because of crop residue decomposition and higher nutrients release in the soil surface (Singh and Sidhu, 2014). In our study, CA- based treatments with residue retention showed 27.2-32.1%, 29.3-48.2%, and 17.5-45.83% higher N, P, and K, respectively over CT in 0-15 cm soil (Table 4.23). Cereal straw mulching has been reported to increase soil K availability since majority of total K uptake by plants remains in straw (Chatterjee and Mondal, 1996; Hazra *et al.*, 2014). Under ZT with residue systems with inclusion of pulses in rice-wheat cropping system, possibly, added higher K in soil through pulse residues along with that of cereals (Hazra *et al.*, 2014). The partial/ apparent nutrient balance was also found positive in case of ZT with or without residue retention treatments, whereas in CT it was negative. Hence, it may be concluded that CA promotes sustainability of a cropping system (Kumar *et al.*, 2011). CA-based ZT with residue retention treatments resulted in 67.2-97.3%, 23.2-24.9%, and 35-41.4% higher TOC over CT at 0-5, 5-15 and 15-30 cm soil depths, respectively (Table 4.21). Probable reasons have been explained earlier. Addition of higher crop residues coupled with minimal soil disturbance played roles (Ghosh *et al.*, 2012; Das *et al.*, 2013). In

contrast, lower SOC in the CT treatment was mainly due to frequent tillage, crop residue removal and a negative effect on soil microbial biomass (Wang *et al.*, 2011). Across the treatments, active carbon pool (Pool1+Pool2) ranged from 51.3-67.8%, 52.2-73.21%, and 55.3-83.3%, whereas, passive carbon pool from 32.2-48.7, 26.8-48.8, and 16.7-44.7% of TOC in 0-5, 5-15, and 15-30 cm soil depth, respectively. The findings of Das *et al.* (2013) and Parihar *et al.* (2018a) corroborated our results. Inclusion of legume crop in sequence contributed to the TOC content through higher root biomass, leaf fall, and rhizodeposition of C (Ganeshamurthy, 2009; Ghosh *et al.*, 2019). Furthermore, a major proportion of legume roots are less decomposable, which ultimately adds to SOC build-up (Cadisch *et al.*, 1998; Bhattacharyya *et al.*, 2015). Higher SOC content in surface layers can be attributed to higher organic matter input due to crop residue addition (Bhattacharyya *et al.*, 2015). Crop residue retained on the soil in ZT and permanent beds get slowly decayed and play a significant role in the buildup of organic matter in surface soil (Alam *et al.*, 2014). Soil mineral N ( $\text{NH}_4^+\text{-N}$  and  $\text{NO}_3^-\text{-N}$ ) increased significantly in CA-based ZT practices with residue compared to CT and their respective residue removal treatments (Table 4.22). The plots with residue and 100% N resulted in significantly higher soil mineral N than 75% N application. This could be attributed to the increased oxidative and reductive capacity of soil and faster mineralization of immobilized N, resulting in higher availability of N in CA-based systems. Bhattacharya *et al.* (2018) reported similar higher  $\text{NH}_4^+\text{-N}$  and  $\text{NO}_3^-\text{-N}$  under CA based systems in 0-5, and 5-15 cm depths of soil. Higher MBC and DHA in upper soil layers of the CA-based residue retention systems could be due to higher organic matter, root biomass, and availability of soil moisture and aeration, favouring microbial activity (Parihar *et al.*, 2020). Further, continuous addition of diverse crop residue could serve as perfect substrate for proliferation of beneficial microorganisms and higher microbial activity in permanent raised beds (Mangalassery *et al.*, 2015; Parihar *et al.*, 2016b). Roldan *et al.* (2005) reported that soil enzyme activities had high positive correlation with ZT and negative correlation with CT. Soil enzyme activity also depends on the quantity and quality of crop residues (organic matter) applied (Chandra, 2011). Hence, higher MBC and enzymatic activity in CA-based residue retention system led to improve soil quality index and maintained agricultural sustainability (Das *et al.*, 2021).

In this study, carbon footprint varied significantly across the CA and CT systems (Fig. 4.13 and Fig. 4.14). The yield-scale carbon footprint was significantly higher under CT than in CA practices. The 75% N application, irrespective of ZT raised and flat beds with residue led to

significantly lower yield-scale carbon footprint than their respective 100%N treatments and CT. The reduction in N use by 25% under 75% N and similar yield level with 100% N treatment played roles. Similar justification holds true for the CA-based PBBR75N, which led to 29.3% and 14.1% lower yield-scale and spatial carbon footprint than CT. The PBBR75N also gave significantly higher carbon efficiency, carbon sequestration index and carbon efficiency ratio than others (Table 4.25), and PNB75N and ZTFBR75N were comparable with it. ZT with residue can lead to more carbon accumulation in soil (Lal *et al.*, 2007; Bhattacharyya *et al.* 2013b; Das *et al.*, 2013, 2018), which may reduce C-flux/emission, and, therefore, is believed to have lower carbon footprint. Ghosh *et al.* (2022) observed that a CA-based rice-wheat-mungbean system with residue retention led to 64% lower yield-scale C footprint compared to conventional (CT) rice-wheat system, and had highest C efficiency, C sustainability index and C efficiency ratio.

## SUMMARY AND CONCLUSION

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The present experiment entitled “Tillage, residue and nitrogen effects on weeds, wheat productivity, and soil properties under Conservation Agriculture-based pigeon pea-wheat system” was conducted during *rabi* (winter) 2021-2022 at ICAR- Indian Agricultural Research Institute, New Delhi with the following objective: to evaluate effects of tillage, crop residue and N on weed interference in wheat; to assess crop productivity, profitability and resource-use efficiency under conservation agriculture and N management; to estimate the effects of tillage, crop residue and N management on soil properties across CA practices. The experiment was carried out in randomized complete block design with 10 treatments having 3 replications. Wheat sowing was done on 23 November, 2021. All the crop husbandry practices were performed as per recommendations. Weed and crop biometric observations were recorded at different stages, and soil sampling was done from specific depths for different parameters described in Chapter 3. Harvesting was done on 20 April, 2022 and grain yield was reported at 12% moisture. The results obtained in the experiment are summarized and concluded as below:

### 9.1. Weed dynamics and interference in wheat

- Weed flora in the experimental wheat field comprised of *Phalaris minor* Retz. (grassy weeds); *Chenopodium album* L., *Coronopus didymus* L., *Malva parviflora* L., *Melilotus indica* L., *Parthenium hysterophorus* L., *Sonchus oleraceus* L., *Spergula arvensis* L., *Polygonum aviculare* L. (broad-leaved weeds); and *Cyperus esculentus* L. (sedge).
- Non-destructive sampling from the fixed plots at 30 DAS revealed that grassy weed density was significantly higher in PNB followed by PBB, whereas broad-leaved and sedge weed densities were found significantly higher in CT. As a result, total weed density was found significantly higher in CT and lowest in permanent flat bed with residue and 75 and 100% N application (~ZTFBR75N and ZTFBR100N). *Cyperus esculentus* density was significantly higher in CT and found comparable with PNB.
- Under non-destructive sampling at 60 DAS, the ZTFB, ZTFBR75N, and ZTFBR100N treatments led to significant reductions in grassy weeds population than other TRN practices, namely, PBB. PNB had significantly higher broad-leaved weeds density, comparable with that in CT.

- At harvest, PBB had significantly higher grassy and broad-leaved weeds, but PBBR75N, PNB, and PBBR100N for grassy weed density, and PNB and PBBR100N for broad-leaved weed density were comparable with it. But, sedge and total weed densities were significantly higher in CT. However, ZTFBR75N and ZTFBR100N could effectively reduce total weed density at harvest. Compared to CT, ZTFBR75N and ZTFBR100N led into 89.7%, 87.3% and 78.6%, 81.6% reduction in total weed population and dry weight, respectively.
- Destructive sampling at 60 DAS after a common herbicide (clodinafop-propargyl + metsulfuron-methyl tank-mix) application to all plots could reveal that the densities of grassy and broad-leaved weeds were drastically reduced, and the difference in their densities across the treatments was non-significant. But, the densities of sedges and total weed were found significantly higher in CT treatment.

## **9.2. Wheat crop productivity and profitability**

- CA-based ZT permanent beds with residue retention resulted in taller plants and higher dry matter accumulation, tillering, and LAI of wheat compared to their respective residue removal treatments and CT.
- CA-based practices with residue achieved 15.13-26.58% higher root length density, 20.9-29.16% higher root surface area density, 38.4-57.3% higher root volume density, and 31.74-50% higher root mass density than CT.
- CA-based residue retention showed lower lodging score (LS) and lodging index (LI) than their respective without residue and CT treatments. CT had significantly higher LS (35.38) and LI (35.75). Bed planting (PNB, PBB) proved to be superior to flatbed planting (ZTFB, CT) towards reducing lodging of wheat plants. Furthermore, 75%N application under residue retention provided higher tolerance to wheat plants to lodging than 100% N with residue retention.

- CA-based practices led to significant improvement in yield attributes of wheat (Table 4.11), and residue retention was found superior to without residue. The PBBR100N registered significantly higher number of ear-bearing tillers, and number of grains per spike, but PNBR75N, PNBR100N, and PBBR75N treatments were comparable on ear-bearing tillers, and PBBR75N was comparable on grains/spike. Test weight of wheat seed did not differ significantly, but was slightly higher (~1%) under the PBBR100N and ZTFBR100N than CT.
- CA-based ZT permanent beds with residue increased wheat grain yield up to 11.6-14.9%, straw yield up to 5.9-8.1%, and biological yield up to 8.1-10.8% over CT (Table 4.12). Among them, ZTFBR100N gave significantly higher grain yield (5.37 t/ha), straw yield (7.71 t/ha), and biological yield (13.08 t/ha) of wheat than CT. Otherwise, all the ZT practices with and without residue retention (PNBR75N, PBBR75N, PBBR100N, ZTFBR75N, ZTFBR75N, PNB, PBB and ZTFB) were found more or less comparable with it in these regards.
- CT wheat incurred higher cost of cultivation than other practices due to higher costs of land preparation. The ZT practices with and without residue retention registered 3.1-15.7% lower cost of cultivation, but 19.4-23.8% higher net returns and 24.6-46.7% higher net benefit:cost (B:C) than CT practice. Residue removal registered significantly higher net B:C than residue application treatments. The CA-based practices with residue retention resulted in higher costs but were found to be superior in gaining higher net returns due to enhanced yield.

### 9.3. Resource-use efficiency

- CT practice consumed highest irrigation water (300 mm). CA-based residue retention registered 9%-20.6% lower irrigation water use than CT, which increased irrigation and total water productivity. PBBR100N required 20.6% lower irrigation water (238 mm) than CT, and PBBR75N was comparable. As a result, this treatment resulted in significantly higher irrigation water productivity and total water productivity by 43.8% and 35.8% than CT, respectively.
- CA-based ZT permanent beds with residue (~PNBR, PBBR and ZTFBR) required higher input energy *vis-à-vis* generated higher output energy than their respective residue removal (~PNB, PBB, ZTFB), and CT treatments. Therefore, PBB (without residue) registered significantly higher energy productivity (0.29 kg/MJ) and energy ratio (9.86) than CA-based residue retentions, but PNB and ZTFB were comparable.

- CT treatment showed lowest partial factor productivity (PFP) of N, P, and K. ZT treatments without residue had substantially higher PFP than CT, but lower than the treatments with residue retention. ZTFBR75N led to highest PFP of N, and NPK whereas significantly higher PFP of P and K were recorded under ZTFBR100N and was found comparable with all the ZT with and without residue retention irrespective of N applications.
- Among CA-based practices with residue retention, the practices with 75% N registered significantly higher PFP of N and NPK than with 100%N. ZTFBR75N registered significantly higher PFP of N (46.9 kg grain/kg N) and NPK (30.9 kg grain/kg N). However, significantly higher PFP of P (204.9 kg grain/kg P) and K (161.6 kg grain/kg K) were recorded under ZTFBR100N but was found comparable with all the ZT with and without residue retention irrespective of N application.
- Residue retention treatments had significantly higher nutrients uptake than residue removal and CT. Also, the plots under residue retention and 100% N application showed greater nutrient uptake. Significantly higher N uptakes by wheat grain and straw (104.2 and 28.1 kg/ha N, resp.) were observed under ZTFBR100N, which registered 19.2% and 27.7% higher N uptake by wheat grain and straw than CT, respectively.
- The PBBR100N led to highest P uptake (17.1 kg/ha) by wheat grain. Similarly, the highest P uptake (5.7 kg/ha) by wheat straw was recorded under this PBBR100N. This treatment resulted in 41.3% and 20.8% higher P uptake by grain and straw, respectively than CT.
- Again, significantly higher K uptake (27.2 kg/ha) by wheat grain was recorded under PBBR100N, which showed 32.7% and 24.1% higher uptake of K by wheat grain and straw, respectively than CT.

#### **9.4. Soil properties and carbon footprint**

- The PNBR100N had significantly lower BD at 0-5 cm (1.34 Mg/m<sup>3</sup>), 5-15 cm (1.58 Mg/m<sup>3</sup>) and 15-30 cm (1.67 Mg/m<sup>3</sup>) soil layers than CT. It registered 9%, 3.1% and 2.3% lower BD than that CT in these layers of soil. However, PNBR75N, PBBR75N, and PBBR100N at 0-5 cm; PNBR75N, PBBR75N, PBBR100N, and PNB at 5-15 cm; and all ZT treatments with or without residue except ZTFB at 15-30 cm depth of soil were comparable with it in this regard.
- All the CA-based ZT permanent beds with or without residue and 75% N or 100% N resulted in significantly higher values of MWD compared to CT at 0-5, 5-15 and 15-30 cm depths of

soil. But, the treatments with residue retention irrespective of permanent beds and N levels (i.e., PBBR100N, PBBR75N, ZTFBR100N, ZTFBR75N, PNBR100N and PNBR75N) led to greater values of MWD than their respective residue removal practices at all soil layers.

- CA-based ZT and residue retention treatments had 60.3-61.1%, 64.3-66.4%, and 72.3-74.2%, whereas CT had 47.7%, 58.7% and 66.2% small macroaggregates at 0-5, 5-15, 15-30 cm soil depths, respectively.
- Morning soil temperature was relatively higher in sub-surface (5-15 cm) than in surface soil (0-5 cm). It was lowest in CT plots throughout wheat growing season at both 0-5 and 5-15 cm soil layers. The CA-based permanent beds treatments with residue retention (PNBR75N, PNBR100N, PBBR75N, PBBR100N, ZTFBR75N, ZTFBR100N) had comparatively higher soil temperatures than their respective residue removal treatments and CT at both 0-5 and 5-15 cm depths.
- Afternoon soil temperature was higher in surface soil (0-5 cm) than in sub-surface (5-15 cm) soil. The CA-based permanent beds treatments with residue retention (PNBR75N, PNBR100N, PBBR75N, PBBR100N, ZTFBR75N, ZTFBR100N) experienced relatively lower soil temperatures than their respective residue removal treatments and CT at both 0-5 and 5-15 cm depths throughout wheat growing season.
- The TOC concentration was highest at 0-5 cm depth and decreased gradually with increase in depth of soil. The active C pool (Pool 1+Pool 2) under the ZT permanent beds treatments, irrespective of residue retention and N application (i.e., PBBR100N, ZTFBR100N, PNBR100N, PBBR75N, ZTFBR75N, and PNBR75N) ranged from 50.6 to 57.4%, 52.2 to 62.1%, and 55.3 to 62.6% of the TOC at 0-5, 5-15, and 15-30 cm soil depths, respectively.
- Similarly, the passive C pool (Pool 3+ Pool 4) varied between 42.6-49.5%, 37.9-47.8%, and 37.4- 44.7% of the TOC at these depths of soil, respectively. Residue retention treatments led to 32-44.5%, 35.1-42.2%, and 33.7-43.1% higher TOC than CT and improved soil carbon concentration at all three depths compared to residue removal and CT treatments.
- The  $\text{NH}_4^+$ -N and  $\text{NO}_3^-$ -N were significantly higher in CA-based practices with residue retention, irrespective of N levels than in CT and ZT without residue treatments. Among N management practices, the plots with residue and 100% N resulted in significantly higher soil mineral N than residue and 75% N application.

- CA-based ZT permanent beds with residue retention treatments resulted in positive apparent balances of N, P, and K in soil after wheat harvest, whereas the CT showed a negative balance. The PBBR100N resulted in significantly higher soil N (313.8 kg/ha), and all the permanent beds with residue retention treatments were comparable with it. Similar trend was observed with respect to P and K contents in soil at harvest across the treatments. Again, PBBR100N led to significantly higher soil P and K contents before sowing and after harvest of wheat than all other treatments except PBBR75N.
- CA-based ZT with residue retention treatments resulted in higher MBC and DHA than their respective residue removal treatments and CT. Among them, PBBR100N led to significantly higher values of MBC and DHA than in most other treatments. It showed 75.3% and 37.5% higher MBC, and 56.3% and 35.9% higher DHA than those in CT practice at 0-5 and 5-15 cm depths of soil, respectively.
- CT had significantly higher yield scale carbon footprint than rest of the treatments. The PBBR75N had lower yield-scale and spatial carbon footprint than CT by 29.3% and 14.1%, respectively. It as well led to significantly higher carbon efficiency, carbon sequestration index and carbon efficiency ratio than rest of the treatments except PNBR75N and ZTFBR75N.

## **Conclusion**

This study revealed that CA-based treatments, especially ZTFBR100 and ZTFR75N were effective in reducing overall weed interference. The ZT permanent flat (ZTFBR100N & ZTFR75N), broad (PBBR100N & PBBR75N), and narrow (PNBR100N & PNBR75N) beds with residue treatments provided comparably higher growth parameters, yield attributes, yield and net returns in wheat than CT, but ZTFBR100N was slightly superior. These treatments when supplemented with 75% and 100% N gave comparable yield, which indicates a saving of 25% N in wheat. CA-based another practice PBBR100N gave almost similar yield, energy output, partial factor productivity of nutrients (N, P, and K) with ZTFBR100N but was superior to ZTFBR100N with respect to water productivity and soil properties, namely, aggregation, carbon and mineral N buildup, soil NPK, MBC and DHA, and soil temperature moderation. The PBBR with 100%N and 75% N were comparable in these regards. Therefore, either of these PBBR100N and PBBR75N may be recommended for wheat crop under pigeon pea-wheat system. However, considering lower GHGs emission from the lower rate of N application, the PBBR75N would be more sustainable

environmentally as well as in the long run because gradual retention of residues over the years will build up sufficient organic matter and nutrients in soil, which may substantially meet up N/nutrients demands of crops in the coming years.

## GLIMPSES OF RESEARCH ACTIVITIES



Digital water flow meter operation



Soil sampling



Soil bulk density sampling



Soil temperature measurement



Soil aggregates analysis



Yoder's apparatus



Roots sampling using root auger



Roots sample processing



Root measurement using WinRHIZO



Plant samples digestion



Soil  $\text{NH}_4^+$  and  $\text{NO}_3^-$  estimation



Distillation in kjeldahl apparatus



Soil carbon estimation



Soil available P estimation



Chloroform fumigation for MBC



Soil MBC estimation



Soil dehydrogenase activity



Operating Spectrophotometer

## **Tillage, residue and nitrogen effects on weeds, wheat productivity, and soil properties under Conservation Agriculture-based pigeon pea-wheat system**

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### **ABSTRACT**

Conservation agriculture (CA) with minimal mechanical soil disturbance, permanent organic mulch cover/cover crops and diversified crop rotation by inclusion of a legume crop holds a great promise for enhancing crop productivity, profitability, resource-use efficiency, improving soil health besides environmental sustainability. A field experiment on wheat grown under long-term (~12 years) conservation agriculture-based pigeon pea-wheat system was conducted in winter (*rabi*) 2021-22 at ICAR-Indian Agricultural Research Institute, New Delhi. The objectives were: to evaluate effects of tillage, crop residue and N on weed interference in wheat; to assess crop productivity, profitability and resource-use efficiency under conservation agriculture and N management; to estimate the effects of tillage, crop residue and N management on soil properties across CA practices. Ten treatments with three replications were laid out in a randomized complete block design. In this system, different zero-tillage practices with or without residue were compared with conventional tillage (CT) practice. Different methods of crop establishment [permanent narrow bed (PNB), broad bed (PBB) and ZT flat bed (ZTFB) with and without pigeon pea residue (R)] along with 75% and 100% recommended doses of nitrogen (75N and 100N) were integrated to designate different CA-based practices. Results revealed that, compared to CT, the CA-based practices resulted in reduction in weed density at 30 days after sowing. The ZT flat bed with residue and 75% and 100% N (~ZTFBR75N, ZTFBR100N) led into 89.7%, 87.3% and 78.6%, 81.6% reduction in weed population and dry weight, respectively. CT had significantly higher sedge weed density all through the wheat growing period. Residue retention was superior to residue removal and CT treatment on the reduction of total weed density and dry weight. The CA-based permanent flat bed, broad bed and narrow bed with residue provided higher growth, yield attributes, yield and net returns in wheat. These practices increased wheat grain yield by 11.6-14.9%, straw yield by 5.9-8.1%, and biological yield by 8.1-10.8% than CT, but ZTFBR100N was most superior. These CA practices when supplemented with 75% or 100% N gave comparable yield implying a saving of 25% N in wheat and higher partial factor productivity of N and NPK in the 75%N treatments. They also reduced irrigation water use by 9.3-20.6%. The permanent broad bed with residue and 75% and 100%N (~PBBR100N, PBBR75N) treatment shad comparable yield with ZTFBR100N and higher water-use efficiency. PNBR100N and PNBR75N registered significantly lower soil

bulk density. But, PBBR100N and PBBR75N had greater mean weight diameter and significantly improved total soil organic carbon and soil carbon and nitrogen fractions across soil depths. They led to 75.3% and 37.5% higher microbial biomass carbon and 56.3% and 35.9% higher dehydrogenase activity in 0-5 and 5-15 cm soil, respectively over CT. These two treatments (PBBR100N & PBBR75N) could save resources better, improved soil properties and gave higher yield. Therefore, either of them may be recommended for wheat crop production under pigeon pea-wheat system in the Indian IGP and in similar agro-ecologies of the tropics and sub-tropics.

## संरक्षण कृषि—आधारित अरहर—गेहूँ फसल प्रणाली में खरपतवारों, गेहूँ की उत्पादकता एवं मृदा के गुणों पर जुताई, फसल अवशेष एवं नाइट्रोजन के प्रभाव

### सारांश

संरक्षण खेती खेती की वह पद्धति है जिसमें खेत की कम से कम छेड़छाड़ करते हुए और स्थाई फसल अवशेषों को खेत की सतह पर छोड़ते हुए, दलहनी फसलों को विविध फसल चक्र में शामिल करके फसल उगाई जाती है। संरक्षण कृषि (सीए) फसल उत्पादकता, लाभप्रदता, संसाधन—उपयोग दक्षता को बढ़ाने, पर्यावरणीय स्थिरता के अतिरिक्त मृदा स्वास्थ्य में सुधार करती है। दीर्घावधि (12वर्ष) संरक्षण कृषि आधारित अरहर—गेहूँ प्रणाली के अंतर्गत भाकृ अनुप—भारतीय कृषि अनुसंधान संस्थान, नई दिल्ली के प्रक्षेत्र पर वर्ष 2021—2022 के दौरान सर्दियों (रबी) के मौसम में उगाए गए गेहूँ का प्रयोगात्मक परीक्षण किया गया था। इसका उद्देश्य गेहूँ में खरपतवार के हस्तक्षेप पर जुताई, फसल अवशेष और नाइट्रोजन के प्रभावों का मूल्यांकन करना, संरक्षण कृषि और नाइट्रोजन प्रबंधन के अंतर्गत फसल उत्पादकता, लाभप्रदता और संसाधन—उपयोग दक्षता का मूल्यांकन करना संरक्षण कृषि (सीए) विधियों में मिट्टी के गुणों पर जुताई, फसल अवशेष और नाइट्रोजन प्रबंधन के प्रभावों का अनुमान लगाना था। तीन पुनरावृत्तियों के साथ दस उपचारों को एक यादृच्छिक पूर्ण ब्लॉक अभिकल्पना में रखा गया था। इस प्रणाली में, अवशेषों के साथ या बिना विभिन्न शून्य—जुताई विधियों की तुलना पारंपरिक जुताई (सीटी) प्रक्रिया के साथ की गई थी। फसल बुवाई के विभिन्न तरीकों जैसे स्थायी संकीर्ण उठी क्यारी (पीएनबी), व्यापक क्यारी (पीबीबी) और शून्य जुताई समतल क्यारी (जेडटीएफबी) अरहर अवशेष (आर), के साथ—साथ नाइट्रोजन (75 एन और 100 एन) की 75% और 100% अनुशंसित दर के साथ विभिन्न सीए को नामित करने के लिए एकीकृत किया गया था। पारंपरिक जुताई की तुलना में परिणामों से पता चला है कि, संरक्षण कृषि आधारित विधियों के परिणाम स्वरूप बुवाई के 30 दिन बाद पर खरपतवार घनत्व में कमी आई है। जेडटी समतल क्यारी, अवशेषों और 75% और 100% नत्रजन (जेडटीएफबीआर 75 एन, जेडटीएफबीआर 100 एन) ने 89.7%, 87.3% और 78.6%, 81.6% खरपतवार संख्या और शुष्क भार, क्रमश में की कमी प्रदर्शित हुई, पारंपरिक जुताई में गेहूँ की बढ़ती अवधि के दौरान काफी अधिक सेज ने खरपतवार घनत्व

था। अवशेष प्रतिधारण कुल खरपतवार घनत्व और शुष्क भार में कमी पर अवशेष हटाने और पारंपरिक जुताई उपचार से बेहतर था। संरक्षण कृषि आधारित स्थायी समतल क्यारी, व्यापक क्यारी और अवशेषों के साथ संकीर्ण क्यारी गेहूँ में उच्च वृद्धि, उपज विशेषताओं और अधिक शुद्ध लाभ प्राप्त हुआ। इन पद्धतियों ने गेहूँ के अनाज की उपज में 11.6–14.9%, पुआल की उपज में 5.9–8.1% और जैविक उपज में पारंपरिक जुताई की तुलना में 8.1–10.8% की वृद्धि प्राप्त हुई, लेकिन जेडटीएफबीआर 100 नत्रजन सबसे बेहतर था। इन संरक्षण कृषि पद्धतियों को जब 75% या 100% एन के साथ पूरक किया जाता है, तो गेहूँ में 25% नत्रजन की बचत और 75% एन उपचार में नत्रजन और एनपीके की उच्च आंशिक कारक उत्पादकता का अर्थ तुलनीय उपज दी। उन्होंने सिंचाई जल के उपयोग को 9.3–20.6% तक कम कर दिया। अवशेषों और 75% और 100% नत्रजन (पीबीबीआर 100 एन, पीबीबीआर 75 एन) उपचार के साथ स्थायी व्यापक क्यारी में जेडटीएफबीआर 100 नत्रजन और उच्च जल-उपयोग दक्षता के साथ तुलनीय उपज थी। पीएनबीआर 100 नत्रजन और पीएनबीआर 75 एन ने काफी कम मृदा थोक घनत्व दर्ज किया। लेकिन, पीबीबीआर 100 नत्रजन और पीबीबीआर 75 एन में अधिक मृदा औसत भार प्राप्त हुआ और मिट्टी की गहराई में कुल मिट्टी कार्बनिक कार्बन और मिट्टी कार्बन और नाइट्रोजन अंशों में काफी सुधार हुआ था। उन्होंने 75.3% और 37.5% उच्च सूक्ष्मजीवाणु जनित जैव पदार्थ कार्बन और 0–5 और 5–15 सें.मी. मिट्टी में 56.3% और 35.9% उच्च डिहाइड्रोजनेज गतिविधि की भूमिका निभाई, जो पारंपरिक जुताई पर स्पष्ट रूप से है। ये दो उपचार (पीबीबीआर100 एन और पीबीबीआर 75 एन) संसाधनों को बेहतर, बेहतर मिट्टी के गुणों को बचा सकते हैं और उच्च उपज दे सकते हैं। इसलिए, उनमें से किसी एक को भारतीय-गंगा मैदानों के क्षेत्र में अरहर-गेहूँ प्रणाली के अंतर्गत गेहूँ की फसल उत्पादन के लिए और उष्णकटिबंधीय और उप-उष्णकटिबंधीय के समान कृषि-पारिस्थितिकी में अनुशासित किया जा सकता है।

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## APPENDIX

Appendix I. Meteorological data (weekly average) during wheat growing period

SMW	Tmax (°C)	Tmin (°C)	RH <sub>mr</sub> (%)	RH <sub>ev</sub> (%)	ET (mm)	Rainfall (mm)	AWS (kmph)
45	28.09	12.00	93.43	50.29	2.4	0.00	1.73
46	26.34	9.26	90.86	50.57	2.3	0.00	1.16
47	26.49	9.60	88.14	57.00	2.6	0.00	1.90
48	25.37	10.00	92.57	54.14	2.0	0.00	1.30
49	23.74	10.34	90.14	64.50	2.1	0.29	1.93
50	22.23	6.23	88.00	60.71	1.7	0.00	1.34
51	19.61	4.44	91.14	56.75	1.6	0.00	3.20
52	20.83	6.93	93.86	74.86	1.5	1.09	1.51
1	19.71	5.70	92.14	72.29	1.6	1.69	1.66
2	17.57	9.80	93.43	79.71	1.5	13.83	4.39
3	15.43	7.20	91.29	72.43	1.5	0.00	2.49
4	15.51	7.51	93.29	82.00	1.3	4.76	3.36
5	20.39	6.87	90.86	70.14	2.0	0.00	4.52
6	20.13	7.64	92.43	70.57	2.0	1.80	3.30
7	23.90	7.07	88.00	39.86	3.4	0.00	3.19
8	25.31	10.07	91.29	37.29	3.4	0.00	4.80
9	25.04	10.54	84.14	42.14	3.1	2.49	4.49
10	28.07	13.07	86.71	39.43	3.4	0.00	4.03
11	31.46	15.46	85.14	41.43	4.6	0.00	4.00
12	35.94	18.77	77.29	44.29	5.5	0.00	3.71
13	36.83	16.47	68.57	28.14	5.3	0.00	4.31
14	38.97	17.20	70.00	10.86	6.0	0.00	3.69
15	40.34	19.19	63.71	12.86	6.3	0.00	3.84
16	40.50	21.03	71.33	14.83	6.7	0.00	3.67

SMW = Standard meteorological week; Tmin = Minimum temperature; Tmax = Maximum temperature; RH<sub>mr</sub> = Morning relative humidity; RH<sub>ev</sub> = Evening relative humidity; ET= Evapotranspiration; AWS= Average wind speed

Appendix II. Inputs price used for calculating the cost of cultivation

S N	Particulars (excluding labourer's cost associated in a practice)	Unit	Unit cost (INR)
1.	Disc plough for primary tillage	per ha/pass	3500
2.	Disc harrow	per ha/pass	2000
3.	Pigeon pea residue/tonne	per tonne	2000
4.	Wheat seed /kg	per kg	40
5.	Seed drill /ha/pass	per ha/ pass	2000
6.	Glyphosate/ha	per ha	1000
7.	Clodinafop-propargyl + metsulfuron-methyl /ha	per kg	1616
8.	Neem-coated urea /kg	per kg	6
9.	DAP/kg	per kg	25
10.	MoP/kg	per kg	17
11.	Irrigation cost per irrigation	per irrigation	1000
12.	Combine Harvesting /ha	per ha	6000
13.	Labour /manday	per manday	500
14.	Price of wheat grain/tonne	per tonne	20150
15.	Price of wheat straw/tonne	per tonne	4000
*INR: Indian Rupee			

Appendix III. Energy and carbon emission equivalences of inputs for calculating energy consumption and carbon footprints across treatments

Sr. No.	Particulars	Unit	Energy equivalent (MJ/unit)	Emission factor (kg C-eq/unit)
1.	Tractor 50HP/electric motor	kg	68.4	
2.	Disc plough/disc harrow/seed drill	kg	62.7	
5.	Pigeon pea residue	kg	12.5	
5.	Diesel	litre	56.31	0.94
6.	Wheat seed	kg	15.7	
7.	Herbicide	kg	120	0.61
8.	N	kg	60.6	1.3
9.	P <sub>2</sub> O <sub>5</sub>	kg	11.1	0.2
10.	K <sub>2</sub> O	kg	6.7	0.15
11.	Water	m <sup>3</sup>	1.03	
13.	Combine Harvesting	kg	83.5	
14.	Electricity	kWh	11.93	0.0725
15.	Labour (men)	hr	1.96	
16.	Wheat grain	kg	15.7	
17.	Wheat straw	kg	12.5	