संरक्षित खेती के अंतर्गत मक्का-गेहूं फसल तंत्र में नाइट्रोजन एवं खरपतवार प्रबंधन

NITROGEN AND WEED MANAGEMENT IN MAIZE (*Zea mays* L.) – WHEAT [*Triticum aestivum* (L.) emend Fiori & Paol] CROPPING SYSTEM UNDER CONSERVATION AGRICULTURE

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By

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This is to certify that the thesis entitled **"Nitrogen and weed management in maize (*Zea mays* L.) – wheat [*Triticum aestivum* (L.) emend Fiori & Paol] cropping system under conservation agriculture"** submitted to the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Agronomy**, embodies the results of bonafide research work carried out by **Mr. Anthony Imoudu Oyeogbe (Roll no. 10206)** under my guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.

The supports received during the course of the investigation have been duly acknowledged.

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Chairperson
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Date:

Dedicated to the memory of my late parents, who passed away
whilst my academic expedition in India. I am short of words to say
I missed you both. Eavesdropping to listen to your conversation
about me. Tears in my eyes. Adieu!!!!

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ABBREEVIATIONS USED

CA	Conservation agriculture
NT	No-till
ZT	Zero-till
CT	Conservation tillage
BAU	business-as-usual
GS	GreenSeeker
GHGs	Greenhouse gases
FAO	Food and Agriculture Organisation
N_2O	Nitrous oxide
CO_2	Carbondioxide
SOC	Soil organic carbon
TN	total nitrogen
C	Carbon
N-P-K	Nitrogen-phosphorus-potassium
DAS	Days after sowing
STV	Soil test value
NDVI	Normalised difference vegetation index
IGP	Indo-Gangetic Plains
₹	Rupees
USD/$	United States dollar
g kg	Gram per kilogram
µg g	Microgram
$dS\ m^{-1}$	Deci Siemens per metre
t ha	Tonne hectare
kg ha	kilogram per hectare
kg ha mm	Kilogram per hectare per millimeter
$Mg\ m^{-3}$	Mega gram per meter cube
WEY	Wheat equivalent yield

INTRODUCTION Chapter 1

The future of crop production is threatened by accelerating soil degradation, increasing greenhouse gas emissions and the negative impact of climate change and variability. This is accentuated by the unsustainable ‘business-as-usual’ (BAU) conventional crop production systems. Conventional agronomic and soil management practices, and the input-intensive agricultural intensification are the major reasons for the declining soil and crop productive capacity. The degradation of these ecosystem functions are exacerbated by the increase in human population and activities (Godfray *et al*., 2014; 2010). Therefore, to ensure food security for the 9+ billion people come 2050, cropland resources must be managed in a sustainable way to continue to provide sufficient food for the increasing demand. Farmers will have to produce more food from the dwindling resources while sustaining environmental quality. Agricultural land and soils are critical elements to sustainable management of agro-ecosystems (Lal, 2013; Mark *et al*., 2009), worth over 1 trillion USD in economic valuation (Costanza *et al*., 1997). Hence, the search for locally adapted farming systems that can enhance productivity, whilst conserving the natural resource base and the ecosystem functions they provide is envisaged (Hobbs, 2007).

Current farming practices disrupt sustainable ecosystem and are a major source (19–29%) of anthropogenic greenhouse gas emissions causing global warming (IPCC, 2014; Vermeulen *et al*., 2012). Thus the quest for sustainable crop production systems capable of feeding the world now and in the future, while maintaining and enhancing ecosystem services, has increased the worldwide adoption of conservation agriculture (Kassam *et al*., 2014; Palm *et al*., 2014). Since the 21st century, conservation agriculture (CA) has dominated scientific and policy thinking space about agricultural research for sustainable development (Andersson and D’Souza, 2014; Kassam and Friedrich *et al*., 2012). Conservation agriculture practices affect the underlying biodiversity; promote soil health and productive capacity compared to conventional BAU system. These modifications influence the delivery of enhanced ecosystem services including climate regulation through soil disturbance mitigation; carbon sequestration and reduction in greenhouse gas emissions; regulation and retention of moisture through soil physical, chemical and biological properties; and the payment for these ecosystem services (Palm *et al*., 2014; FAO, 2013). Conservation agriculture is currently practiced on 155 million hectares of land (Kassam *et al.*, 2014), equivalent to 9% of global arable land, nearly the size of India's agricultural land area.

The multifaceted problems of stagnating or low yields, resource scarcity vis-à-vis receding groundwater, soil organic carbon depletion, and negative environmental externalities e.g. nutrient leaching, increasing soil-water salinity, and the adverse effects of climate change generated by the conventional BAU production system particularly the dominant rice–wheat system in the Indo-Gangetic Plains (IGP), has resulted to the increasing adoption of conservation agriculture (CA) technologies being developed for the cereal production systems of South Asia to address these imbroglio (Alam *et al.*, 2015 Laik *et al.*, 2014; Gathala *et al.*, 2014; Das *et al.*, 2014).

Conservation agriculture (CA) is a resource-conserving concept that strives to achieve increased profits, sustained productivity and food security while preserving the resource base and the environment (*http://www.fao.org/ag/ca/1a.html*). CA is focused on enhancing the natural biological processes above- and below- ground. The use of external agrochemicals and mineral nutrients (organic and inorganic) are applied at an optimum level that do not interfere with the natural biological processes. Conservation agriculture– a more encompassing concept is distinct from conservation tillage (CT) and no-tillage (NT) (Hobbs *et al.*, 2008; Derpsch *et al.*, 2010; 2014). Conservation tillage is often linked with some degree of tillage reduction, which permit some crop residues on the surface soil, whereas no-tillage (NT) is sowing crops in untilled soil by opening a narrow slot or trench of appropriate depth to afford suitable seed coverage. The terms NT or zero-till (ZT) have been used interchangeably, although in India ZT is preferably used.

Conservation agriculture is characterized and quantified by three linked principles practiced mutually, namely:

- Continuous no or minimal mechanical soil disturbance – direct seeding or planting into undisturbed or untilled soil, in order to maintain or improve soil organic matter content, soil structure and overall soil health. The disturbance area must be less than 15 cm or 25% of the cropped area, in addition to no interrupted tillage.
- Permanent organic matter soil cover with cover crops or crop residues– this shields the soil surface, conserves nutrients and water, promotes soil biological activity and

contributes to integrated weed management. Soil cover should be preferably 100%; however surface ground cover of 30% has been promoted as adequate.

• Diversified crop rotation–both annuals and perennials as intercrops or sequences contributing to enhanced crop and soil productivity; human and livestock nutrition; and enhanced system resilience. Mono-cropping is allowed provided no productivity limitation in the cropping area.

From this definition, one can infer that CA refers to an array of specific or individual practices that ensure these three principles are applied simultaneously. Conservation agriculture or no-till farming system is seen as a frontier to a new paradigm of ecologically-sustainable intensification of crop production system (Pretty and Bharucha, 2014; Montpellier Panel, 2013, Kassam and Friedrich, 2012) and a climate-smart agriculture (FAO, 2010; 2011). It addresses soil degradation, erosion and greenhouse gas emissions (GHG) emissions element of unsustainable BAU approach of crop production intensification and has been touted as one of the ‘‘greener’’ solutions that can mitigate the negative effects of soil degradation and climate change under a range of farming systems.

The touchstone of CA is the promotion of below and above the ground productive capacity of the soil, plant, microbe and root to function in an optimum environment (Kassam and Friedrich, 2012; FAO, 2010). CA has both agricultural and environment benefits: enhancing resource use efficiency *viz*; builds soil structure and fertility through soil aggregate stability (Bhattacharyya *et al*., 2013; Hobbs, 2008), improve water infiltration and retention (Thierfelder and Wall, 2012; Rockstrom *et al*., 2009), accumulate soil organic matter and carbon sequestration (Das *et al*., 2013; Srinivasarao *et al*., 2012); promote microbial diversity (Leinhard *et al*., 2013; Govaerts *et al*., 2007), reduce GHG emissions (Dendooven *et al*., 2012; Ussiri and Lal, 2009); saves time, labour and fuel or energy consumption (Sapkota *et al*., 2014; Küstermann *et al*., 2013; Erenstein and Laxmi, 2008); ensure early planting for initial nitrogen flush utilization thereby improving yield (Thierfelder *et al*., 2014; Erenstein and Laxmi, 2008); promote diverse food for human and livestock nutrition (FAO, 2010), enhance ecosystem services and the payment for these environmental services (Palm *et al*., 2014; FAO, 2013). In contrast, however, CA has not provided the robust significant benefits associated with its practice across scale. This has risen doubts over the productive capacity of CA to ensure food security, with calls for CA to be location-specific and tailored to reflect the particular conditions of individual farmers and agro-climatic conditions particularly in water stress or limited areas (Lundy *et al*., 2015; Pittelkow *et al*., 2015a, b; Tittonell *et al*., 2012; Giller *et al*., 2009).

Notwithstanding the numerous environment and agricultural benefits, several on-farm research have reported crop residue scoping, weed proliferation and nitrogen immobilization as major trade-offs associated with CA production system (Yadvinder-Singh *et al*., 2015; Kumar *et al*., 2013; Chauhan *et al*., 2012; Mashingaidze *et al*., 2012; Kong *et al*., 2009). Integrating nitrogen fertilization and weed management under conservation agriculture systems are agronomic management practices that can enhance the success of CA farming system. These agronomic management practices have receive recent attention to be included as principles of CA or an aggradation phase CA (Vanlauwe *et al*., 2014; Tittonell *et al*., 2012; Farooq *et al*., 2011).

Since the introduction of CA in India, significant advancement has been made with reducing tillage for wheat in the rice–wheat systems in the IGP (Erenstein and Laxmi, 2008). The intensive tillage, puddling and transplanting required for rice have limited its adoption. The use of ZT in wheat opens up the opportunity for the application of ZT to other crops (e.g., pulses, vegetables). Also, the scope of increasing cropping diversity in the IGP (e.g., double cropping in rice–fallow systems; and triple cropping in rice–wheat systems). At the same time, the practice of ZT merely for wheat confines the magnitude of some of the potential environmental and economic gains. These gains accumulated (e.g., increased organic matter, residual moisture) in the ZT wheat are lost during the rice growing season (Erenstein and Laxmi, 2008; Tripathi *et al*, 2005). However, a diversification to maize offers a full CA based maize–wheat system in the IGP. In recent times, farmers in the IGP have begun adopting CA practices through the use of mechanized–Turbo Happy Seeder cum fertiliser drill that can sow seeds and fertiliser directly into unploughed soil simultaneously (Yadvinder-Singh *et al*., 2015).

The drivers of CA adoption in the IGP has been the substantial benefits CA generates at farm level. Erenstein and Laxmi (2008) stated that ZT wheat after rice produces considerable benefits at the farm level (₹4350 ha^{-1} or US$97 ha^{-1}) through the combination of a ‘yield effect’ (+5–7% yield increase, particularly due to more timely wheat sowing) and a ‘cost savings effect’ (₹2320 ha^{-1} or US$52 ha^{-1}, particularly tillage savings). These benefits explain the spread across the Indian IGP, further advanced with mechanical innovation. Zero-till wheat in the rice–wheat systems alleviate the difficulty of rice residue management by ensuring timely wheat planting, control the resistant wheat weed– i.e., *Phalaris minor* Retz., reducing production costs and saving water. However, these significant immediate and ongoing benefits of CA is yet to transform into wide spread adoption of the CA technologies.

The argument among farmers is that of limited on-farm/local evidences of the benefits of CA over BAU practices: competing use of crop residues for livestock feed and for energy; knowledge ‘know-how’; limited farm machinery that can effectively seed into sufficient crop residue biomass; and the stiff mind-sets (bias) of sowing in cleaner plot than untilled plot. In addition, the indivisible ‘package’ CA promotes. Amongst researchers and farmers, nitrogen (N) immobilisation resulting from the retention and slow decomposition of surface crop residues associated with limited soil N; and weed infestation due to tillage aversion are major trade-offs that has limited its potential so far.

Therefore, for the expansion of CA-based practices in Asia, both as a productivity-enhancing and resource-saving paradigm (Andersson and D’souza, 2014; Vanlauwe *et al*., 2014; Sommer *et al*., 2014), there is a need to tackle the major trade-offs associated with this technology. Henceforth, a sensitive CA that aims at an integrated management of these trade-offs is envisaged, to minimize the over dependence on herbicide and fertilizer applications which is however beyond the reach of smallholder farmers. There is still a paucity of research on CA across crops and agro-ecologies in the IGP; few studies have focus on weed and nitrogen management individually under CA system, but none have consider the interactive effects of N and weed management simultaneously under CA systems.

Hence, we propose an integrated best management ‘sensitive’ CA system that encompasses complimentary systems: soil-based N management, which uses soil tests (Mulvaney *et al*., 2006) to assess the inherent soil N; and the plant-based management, uses GreenSeeker-sensor (Bijay-Singh *et al*., 2011; Verhulst *et al*., 2011; 2009) to read the N status of plants. These allow for the precise assessments of N requirements and supplementations after the crops have started to grow. In addition, the synergistic effects of herbicide combinations, and the inclusion of brown manuring (*Sesbania aculeata* killed by herbicide, and left to decompose) to supress weeds and fix biological N for soil fertility enhancement. Weed and nitrogen management practices to improve crop and soil productivity under CA, to a larger degree, depend on inherent soil properties, land history, environmental factors and management. Therefore, the interactive effects of weed and nitrogen management in maize–wheat system under a sensitive CA is essential in understanding and developing best management practices and prediction.

Our overall aim is to present the synergies of integrating best agronomic management practices (nitrogen and weed management) under CA in maize–wheat system for enhancing crop and soil productivity with greater emphasis on environmental sustainability and ecosystem functioning in the IGP. We emphasise the possibility of the inclusion or scaling-up of N and weed management strategies as rational ‘sensible' agronomic practices in CA based systems. The overriding objective of our study is the short-time enhancement of soil fertility (C and N build-up) to help reduce the yield declines associated with the trade-offs (nitrogen immobilisation and weed pressure) expected in CA systems during the transitioning period (first three years) from conventional practices. We do this by means of the following specific objectives:

- To evaluate weed and N management effects on weeds suppression.
- To evaluate the effects of N and weed management on crops and cropping system productivity and profitability.
- To assess the soil health (soil physical, chemical and biological properties) as influenced by N and weed management.
- To quantify the derived residue C and N inputs, carbon and nitrogen retention efficiency, water productivity, and the effectiveness of GreenSeeker-guided N management.
- To appraise the greenhouse gases (N_2O and CO_2) emissions, and herbicide residues in soil as affected by N and weed management.

REVIEW OF LITERATURE Chapter 2

2.1 Historical perspective and modern adoption of conservation agriculture

2.1.1 Worldwide scenario

Interest in sustainable crop production systems has grown ever since the sustainability of industrial agricultural systems has been questioned in the 1940’s. No-tillage crop production originated from the USA in the 1940s to alleviate the major wind erosion famously known as the ‘‘Dust Bowl’’ in the 1930s (Faulkner, 1943; 1987; Baveye *et al*., 2011). Edward Faulkner’s book *Plowman’s Folly*, first published in 1943–is a revolutionary in the history of agricultural practices. He probed the perception of ploughing. Some of his reports are:

“No one has ever advanced a scientific reason for ploughing. There is simply no need for ploughing in the first instance. Most of the operations that customarily follow ploughing are entirely unnecessary, if the land has not been ploughed there is nothing wrong with our soil, except our interference; and it can be said with considerable truth that the use of the plough has actually destroyed the productiveness of our soils”.

The statements were scrutinised by both farmers and researchers, because alternatives to tillage at that time did not allow effective control of weeds or sowing into residues-laden soil surface. Today, CA technology which has driven sustainable agriculture in the global north is becoming more widely accessible. No-till became a prominent farming practice in the USA in the 1960s, which nowadays is called CA. Today, CA is practiced globally on an estimated 155 million hectares in all continents and agricultural ecologies (Kassam *et al*., 2014). North and South America have the largest area under CA (about 100 M ha), while Africa and Europe have the least (about 3 M ha). In India, there are divergent views on the area of land under CA (Derpsch *et al*., 2010), Erenstein, (2011) estimated that CA is practiced on about 1.5 M ha in the Indo-Gangetic Plains (IGP), and is otherwise known through resource conservation technologies (RCTs). The aggregate of no-till and reduced till wheat area in the IGP is about 2 million hectares in 2004–2005. Recent assessments of CA in the IGP across India, Pakistan Bangladesh, and Nepal and in the rice–wheat cropping system with large adoption of no-till wheat is about 5 million ha, but only marginal adoption of permanent no-till systems and full CA (Friedrich *et al*., 2012).

In India, the adoption of no-till practices by farmers is mainly in the wheat season of the rice–wheat double cropping system. CA based cropping system practiced in the IGP is rarely a full conservation agriculture but rather a stepwise adoption or periodic CA which involve reduce or minimum tillage including crop residue and rotation in one season i.e., in wheat crop and not in rice crop, grown in the succeeding season (Derpsch *et al*., 2010; Erenstein and laxmi, 2008; Tripathi *et al*., 2005).

2.2 Conservation agriculture in the Indo-Gangetic Plains

2.2.1 Drivers and regional diversity

The spread of CA is concentrated in the rice–wheat system in the Indian IGP. Indian IGP comprises of Trans (GP), upper (GP), middle (GP) and the lower (GP). The TGP is the food hub of South Asia's 'Green Revolution'. No doubt, it heralded the introduction, opportunities and challenges of conservation agriculture (Erenstein and laxmi, 2008). The IGP of South Asia includes India, Nepal, Bangladesh and Pakistan.

Resource conservation technologies (RCTs) are one of the major drivers of sustainable agricultural intensification in the IGP vis-à-vis the increasing soil carbon depletion, declining groundwater table, increasing air pollution and the stagnating or low yields of the rice–wheat system (Erenstein 2011; Humphreys *et al*., 2010). ZT wheat after rice is the most widely adopted resource conserving technology in South Asia and in the Indian IGP. Thus it has become the predominant CA based cropping system. Zero-till wheat is aided by significant costs savings and potential yield increases (Erenstein and Laxmi, 2008). In these systems, zero tillage is only applied to the wheat crop–and does not essentially involve the retention of crop residue as mulch or the use of crop rotations. Also, the subsequent rice crop continuously puddled and transplanted. This anomaly in CA practices (in one season and not in the other) present a serious inadequacy from the ecologically-sustainable intensification outlook, as the benefits accumulated in the wheat season is lost in the subsequent puddled and transplanted rice. Even in zero tillage wheat, farmers usually do not intentionally retain mulch and often burn the preceding rice straw–although the anchoring straw remained in the soil after burning may be enough to satisfy the requirements of residue mulch in CA. This suggests that farmers decides what components of CA practices that satisfies their aspiration and are available or easy to use *vis-à-vis* the prospects, limitations and trade-offs they face. Moving towards a full conservation agriculture calls for an improved management of crop residue and its retention and the shift towards direct-seed aerobic rice and crop diversification.

Regional inequality in terms of agricultural productivity seems to favour the less intensified E– IGP areas than the highly intensified NW IGP, in terms of yield gains and cost savings from ZT practice (Erenstein and Laxmi, 2008). Although, CA has a much wider spread in the NW–IGP, benefiting the already productive areas (Corbishley and Pearce, 2006). Socioeconomic and system benefits of ZT in India is not a function of farm size – smallholders have taken the advantage of ZT-drill contract services. However, the reduced labour savings may boomerang against employment generation for farm labours who depend on land preparation for their livelihoods (Laxmi *et al*., 2007). The use of ZT in wheat unwraps the opportunity for the adoption of a full CA cropping system, and to other crops (pulses and vegetables) in the IGP. It also opens the scope for triple cropping in rice–wheat systems thereby increasing cropping intensity and diversity. For the expansion and scaling up of CA, it will have to deal with the impeding trade-offs or short falls associated with this anomaly.

Highlights of the reviews is presented in the following broad headings**:**

2.3 Conservation agriculture impacts on:

- Weed dynamics
- Yield/productivity
- Water use, retention and efficiency
- Soil carbon accumulation
- Income and profitability
- Labour use, employment and livelihoods
- Greenhouse gas emissions
- Microbial diversity and activity
- Ecosystem and environmental sustainability

2.3.1 Conservation agriculture impact on weed dynamics

Weed pressure and crop yield are inversely related—weed management is therefore essential to achieving the likely yield gains obtainable in CA systems. Tillage aversion in CA reduce the scope of suppressing weeds at the initial stage of transition. Thus the dynamics of weed ecology and growth under CA will change compared to conventional tillage systems. No-till systems tend to amass weed seeds near the soil surface where they are expected to germinate yet exposed to greater decay through weather variability and predation (Mashingaidze *et al.,* 2012; Gallandt *et al*., 2004). Weed emergence under reduced tillage systems can be higher over tilled field, due to the absence of soil inversion. Weed seeds remained or buried in the soil surface layer where they enforce dormancy until suitable conditions stimulated their germination (Mashingaidze *et al.,* 2012). CA systems with minimum disturbance are well disposed to instigate more weed seeds on the surface, whereas systems with frequent disruption bury weeds (Chauhan *et al*., 2006). Thus the management of weeds in CA needs to be proactive.

One of the major drivers of CA in the IGP was the reduction of the herbicide resistant weed–*Phalaris minor* Retz. (littleseed canary grass) in wheat due to the continuous application of isoproturon herbicide. Thus the ability to control this major weed became the initial reason for the adoption of ZT (Erenstein and laxmi 2008). With the adoption of ZT wheat in the IGP, the early sowing and emergence of wheat suppressed weed proliferation. Controlled soil traffic in ZT reduce herbicide-resistant *Phalaris minor* (Mehta and Singh, 2005; Malik *et al.,* 2002; Mehla *et al*., 2000). Laxmi *et al*. (2003) reported that 51% of farmers in Haryana and 85% in Bihar observe that weed infestation particularly *P. minor* has decreased with the adoption of ZT in wheat. The intensity of *P. minor* decreased by 30–40% in ZT when compared to CT, while the amount of broad-leaved weeds increased (Singh *et al*., 2005). While some weeds reduce after a few years of CA compared with CT (Chauhan *et al*., 2006), others can proliferate (Chhokar *et al*., 2007). Observed increase in soil quality, possibly due to increase in broad-leaved weeds have been reported in IGP (Laxmi *et al*., 2007). Weed dry biomass left on the NT surface are more vulnerable to decay (Chauhan *et al*., 2006; Gallandt, 2004).

The adoption of ZT in rice–wheat systems in the IGP has comparatively reduced weeds in the wheat crop (Franke *et al*., 2007; Chauhan *et al*., 2012). Malik *et al*. (1998) suggested that the uncropped period (avoidance of land preparation) in ZT provides an opportunity for effective control of problematic weeds by stimulating its emergence followed by the use non-selective herbicide. Tillage effect on the magnitude of the weed seedbank depends on many interacting factors e.g. weather, duration of experiment, and the field history (Mohler, 1993). Several studies showed tillage has no effect, increases or reduces weed seedbank densities (Murphy *et al*., 2006; Sosnoskie *et al*., 2006; Bàrberi *et al*., 2001). The weed seedbank response to tillage depends on the weed species (Farooq *et al*., 2011). The dynamics of pests and diseases is adjusted in CA system (Jaipal *et al*., 2002; Laxmi *et al*., 2007; Chauhan *et al.,* 2002). Nematodes population in wheat crop were reduced due to the adoption of ZT (Dabur *et al*., 2002). Increasingly, more rodent damage has been reported (Laxmi *et al*., 2007), which is associated with residue retention. This calls for closer monitoring.

Increasing concerns about the environmental impacts of herbicide use in crop production require the investigation of innovative cropping systems that would reduce their reliance on herbicides. CA emphasises the reduction of herbicide use for weed control in cropping systems, integrating multiple non-chemical weed management strategies in CA-based cropping system promotes sustainability (Nichols *et al*., 2015; Kumar *et al*., 2013; Farooq *et al*., 2011). Active residual effect of herbicide in soil and crop produce is a major contended issue for human health. Likewise in crop rotating system, herbicide use in preceding crop may have negative effect on the succeeding crops. Muoni *et al*. (2013) reported that the residual atrazine effect to control weeds in maize did not influence the emergence, seedling growth and yield of the succeeding soybean. Likewise, typical weeds managed by atrazine emerged in the succeeding season suggesting the biodegradation of atrazine under CA

2.3.2 Conservation agriculture impact on yield

To sustainably meet global food demand whilst conserving the environment, conservation agriculture (CA) has been touted as the new paradigm of sustainable crop production intensification (Montpellier Panel, 2013; FAO; 2010). In recent years, there has been polarisation of views about the positive impacts of CA farming practices in all agroecosystems on yield and carbon sequestration and greenhouse gas emissions. The challenges for CA intensification is how to further increase yields but significantly reduce the negative environmental impacts. Thus, the calls for CA to be site- and soil- specific and the advancement of conservation agriculture based on the three principles practiced simultaneously. Resource-poor and vulnerable smallholder farming systems faces the challenge of practicing CA as an indivisible package, thereby increasing the likelihood of yield declines rather than gains. Although the cost-effective benefit of CA may be driven by variable cost abatement rather than improved yields, farmers who focus on short-term gains see the negative yield as a principal factor to discourage the adoption of conservation agriculture.

The short-term crop productivity declines typifies a key barrier for farmers/producers considering conservation agriculture. Pittelkow *et al.* (2015b) stated the irrespective of whether the other two conservation agriculture principles are implemented, no-till reduces yields in the first few years following adoption. However, the yield drop in initial years is diminished when all three principles are applied as against a single principle (23.0% versus 211.4%, respectively). In a global meta-analysis examining 5,463 paired yield observations from 610 peer reviewed studies across 48 crops and 63 countries, Pittelkow *et al.* (2015a) found that NT often leads to yield declines (5.7%) compared to CT systems. They emphasised that this yield response is variable, particularly when NT is practiced jointly with the other two CA principles (residue retention and crop rotation reduce the negative impacts of no-till by 4.8 and 3.8%, respectively), produces similar or greater yields than conventional tillage. Furthermore, no-till in combination with the other two principles (i.e., crop residue and crop rotation influence crop yields in rainfed regions, decreasing yield losses by 10.1 and 11.0%, respectively), and considerably improved crop productivity by 7.3% in dry climates, suggesting CA as a climate change adaptation approach for the water-stressed regions.

They further categorised yield impacts by crop, region, and other influencing variables. Across all observations (all crop categories and locations), no-till yields reduced by 5.1%. Yields were not reduced for oilseeds, cotton and legume crops, but significantly declined by 20.4 and 21.4% for miscellaneous (e.g., barley, millet, oat, rye, sorghum, tef, triticale), and root crops, respectively. Yields for cereals were moderately negatively impacted by no-till practices (5%). The negative yield impacts of no-till were smaller for wheat (2.6%) and miscellaneous cereals (3%) and highest in rice (7.5%) and maize (7.6%). With latitude effect, no-till reduced yields the most in the tropics (15.1%) and the least in temperate (3.4%). Overall, no-till yields were reduced by 12% without N fertilizer addition and 4% with inorganic N addition.

Zero-tillage wheat in the rice–wheat systems is the major driver of CA in the IGP— reducing system constraints by ensuring earlier wheat planting, suppressing resistant weed, and reducing production costs and saving water. The increased yield effects of ZT wheat are mostly due to timely sowing, and enhanced water and nutrients use efficiency and weed control. A yield gain of 15.4% was reported by Mehla *et al.* (2000) in on-farm trials in Haryana i.e., 9.4% due to timeliness and 6.0% due to enhanced efficiency arising from enhanced fertilizer and water-use efficiency and marked reduction in weed population. Erenstein and Laxmi, (2008) on-station trials across the Indian IGP showed that wheat yields with ZT increases in the range of 1–12%, with an average gain of 240 kg ha^{-1} or 6.4%. Few exceptions showed a decline in ZT yield particularly in the NW-IGP, suggesting already timely wheat planting (Hobbs, 2001). Late sowing of wheat after rice result in decrease yield in wheat (Erenstein and Laxmi, 2008). Marginal decline of 20 kg ha^{-1} in the NW, whereas in the E-IGP, an average increase of 460 kg ha^{-1} was reported. Yield increases were consistent over locations with the longer year trial possibly indicating enhanced ZT skills 'learning curve effect' (Erenstein and Laxmi, 2008; Pittelkow *et al.*, 2015b).

Jat *et al.* (2014) evaluated a 7-year impact of CA and CT in rice–wheat system in Eastern IGP. Wheat yield and the system productivity were higher in the CA systems over CT and mixture of CT and CA systems after the second year. While rice yield was higher in CT than in CA in the first three years. Yields were higher in CA system after the sixth year. Wheat had lower yield when preceding rice grown with intensive tillage operations. Farmer's survey obtained in NW–IGP reviewed an 8% yield gain for ZT wheat over the conventional grown (Veettil and Krishna, 2013). The early sowing resulted in substantial efficiency gain (16%) compared to the conventional late wheat. Nkala *et al.*, (2011) observed similar increase in productivity due to the early crop planting in Mozambique. Das *et al.*, (2014) evaluated a 4 year CA based cotton–wheat system in the IGP, mean seed cotton yield increased by 24 and 51% in the ZT-permanent broad-bed with residue retention (PBB + R) compared to ZT-narrow-bed without residue retention (PNB) and CT, respectively. Also, PBB + R had significantly higher mean wheat grain yield than flat-bed zero tilled (ZT) and CT. The equivalent yield (system productivity) in terms of wheat increased by 15 and 13% under PBB + R than PBB and PNB + R plots.

2.3.3 Conservation agriculture impact on water use and retention

Water limitation is becoming an impediment to agricultural intensification in the IGP, as competition for domestic and industrial uses increases. In the NW-IGP, the severe depletion of the water tables is due to the exploitation of groundwater resources for rice production (Kumar and Ladha, 2011; Chauhan *et al*., 2014). This overexploitation of groundwater is excerbated by poor water management (Hobbs and Gupta, 2003), thus the acute agricultural water shortage been faced in this region calls for a proactive approach to efficient crop water use and productivity. There is an increasing agreement that CA technologies can be successful in efficient utilisation and saving of water both in rainfed and irrigated agroecosystems. Several researchers have suggested the need to tailor CA in drought-prone area (e.g., Pittelkow *et al.*, 2015b; Tittonell *et al*., 2012; Giller *et al*., 2009). No-till performed best under rainfed conditions in dry climates, with yields often similar or higher than conventional tillage in the favour of CA claims to enhanced water use efficiency (Pittelkow *et al.*, 2015a; Serraj and Siddique, 2012; Rusinamhodzi *et al*., 2011; Rockstrom *et al.*, 2009; Hobbs *et al*., 2008).

Conservation agriculture is an important strategy to deal with soil moisture stress due to climate change. Its principles promote the characteristics of soil moisture conservation and water use efficiency. CA has been recognised with potentials for yield gains in dryland and performed significantly better than conventional tillage, likely due to the higher infiltration, retention and conservation of soil moisture (Thierfelder *et al*., 2010). CA in combination with integrated best agronomic management practices can improve benefits in water-stressed regions. Increasing crop productivity in these areas, attuned to the local conditions sensitive to farmers' production objectives and needs can reduce the present and impending food insecurity. In the IGP, ZT save irrigation water in the range of 20–35% in the wheat crop compared to CT with reduced water use by about 10 cm ha^{-1} (Erenstein *et al*., 2012; Chandra *et al*., 2007; Hobbs and Gupta, 2003). Water productivity increased in residue retention CA plots over non-residue and CT plots in a cotton-based system (Das *et al*., 2014). This water savings is largely due to utilisation of the residual moisture in CA system which is productively utilised by the succeeding crop instead of being lost to evaporation.

Pittelkow *et al.* (2015b) analyses of datasets across 48 crops and 63 countries showed that CA adoption in dry climates in combination with the other two principles performed significantly better than conventional tillage due to the higher retention of soil moisture. The improved water infiltration, retention and greater soil moisture conservation in CA translates into yields benefit (7.3%), particularly under rainfed conditions. In addition, CA make sure crops are planted and harvested earlier, practically reducing the need extra lifesaving irrigations, which become immediate cost savings. The reduced water use, better infiltration, and water retention have been related to decreased soil erosion, reduce evaporation losses, soil structure improvement, and enhance biodiversity below- and above- soil (Kassam *et al.*, 2009; Erenstein *et al.*, 2012).

2.3.4 Conservation agriculture impact on soil carbon accumulation and aggregation

Soil carbon (C) depletion is exacerbated by land misuse and soil mismanagement. The adoption of a recuperative land use and best/recommended management practices such as CA on agricultural soils can reduce the rate of C loss into the atmosphere. Soil organic carbon (SOC) enrichment of atmospheric CO_2 have positive impacts on food security and the environmental quality. A sizeable part of the dwindling SOC pool can be returned by implementation of the three CA principles practiced mutually, with other systems of sustainable soil and water management (Lal, 2015; Pretty *et al.*, 2011).

On-farm research suggests that CA have great potential to sequester C, thereby improving organic matter and soil productive capacity to intensify crop production. Several studies on CA in improving SOC accumulation are in support and against the capacity of CA to sequester carbon (Govaerts *et al.*, 2009). The extent of soil organic C sequestration seems inconsistent, even within related soils, sites, and environmental conditions (Franzluebbers 2010). SOC dynamic is relatively complex and can be greatly influenced by agricultural practices and affected by complex interactions (climate, soil texture, rotation) in both spatial and temporal variation (Cong *et al.*, 2014). Research has shown that a greater change in the SOC sequestered in soil occurs in the surface 15 cm with a conversion from conventional to conservation agriculture system.

Based on a global data analyses (67 long-term agricultural experiments) on SOC sequestration rates by tillage and crop rotation of long-term agricultural experiments. West and Post, (2002) observed that C sequestered from CT to NT showed a greater increased in the 0–15 cm soil depths, with little or no increase in the 15–35 cm soil depths in the NT plots. A significant increase occurred in the 15–35 cm depths when CT transform into NT. A change from CT to NT will increase soil C accumulation which is expected to have a delayed response (3–5 years), reach peak sequestration in 5–10 years and then decline to a new equilibrium in 15–20 years, and may continue for a longer period of time (40–60 years). The short-term increase in SOC will be due to reduced tillage, while the long-term increase by diversified rotation both arising from decreased SOC decomposition rate and increase residue return. These findings are in conformity with the results reported by Kern and Johnson, (1993), Franzluebbers and Arshad, (1996), Paustian *et al.* (1997), Smith *et al*. (1998).

Baker e*t al*. (2007) emphasised that studies that supports no-till as a system to sequester SOC measured carbon stock only to about 30 cm without measuring the root growth beyond 30 cm of the soil depth which have a greater capacity to sequester C. Similar observations were reviewed by Blanco-Canqui and Lal (2008), when croplands profile are measured below 30 cm, soil carbon sequestration showed no differences between no-till and CT fields. Similarly, Poirier, *et al*. (2009) reported that the amount of sequestered C show no difference between NT and CT when influenced by the interactive effects of tillage and fertilization. The lower C accumulation observed in CT fields were compensated for with higher C at the lower soil layer. In contrast, SOC content in the 0–60 cm layer was greater in ZT (117.7 Mg C ha^{-1}) compared to CT (76.8 Mg C ha^{-1}) when residue was retained, but similar when it was removed (Dendooven *et al*., 2012).

Similar observation in relation to root C sequestration below 30 cm depth was reiterated by Gal *et al*. (2007). Results from a 28-year experiment comparing CT *vs* NT established that NT had considerable SOC and total N gains at the 0–15 cm soil depth, a similar OC and total N status at the middle depth of 15–30 cm, but a gain in OC in CT system in the 30–50 cm depth interval. This SOC increase at this depth in CT might be due to the inversion effects of tillage by incorporating crop residues and the root distribution differences in the deeper soil profile for soil C cycling into more stable C pools. They emphasised sampling of soil OC and total N stocks expressed on mass basis (t ha^{-1}) to a depth of 1m vis-à-vis the bulk density value. However, the IPCC, (2007) regulates that SOC stocks at 30 cm is sufficient to make judgements on carbon sequestration.

The effect of a 5-year seasonal/cyclic tillage operations of CT and NT on SOC, soil aggregation and particulate organic matter-carbon in the Indian Himalayas indicated that the NT–NT, NT–CT and CT–NT had 16, 12, and 10% higher total SOC content compared with CT-CT in the 0–5cm soil layer. No impact on SOC in the 5–15 cm soil layer was observed. The active-labile pools of SOC were positively affected by conservation tillage practices whereas the less labile pools were influenced by the continuous NT and NT–CT in the 0–5 cm depth. NT–NT and NT–CT had greater proportion of microaggregates within macroaggregates than CT–CT plots in the surface layer (Bhattacharyya *et al.*, 2009). Combining residue with ZT resulted in better soil surface aggregation, aggregate size and stability, and total organic carbon than CT (Madari *et al.*, 2005; Roldan *et al.*, 2003).

In summary, there is an agreement among scientists or a thumb rule that CA tends to show increased carbon at the upper soil depths (0–20 cm) where crop residues are found, but at greater depths CT soils typically sequester more carbon due to homogenous soil layer resulting from soil inversion by tillage rather than by SOC stratification in zero-till layers in CA. Short-time (>10years) CA management to SOC dynamics is often complex and often variable.

2.3.5 Conservation agriculture impact on income and profitability

The rapid spread of NT wheat in the IGP has been attributed to the significant, immediate and ongoing savings in production cost ‘cost saving effect’ and yield increase ‘yield effect’ (Erenstein and Laxmi, 2008). This economic benefits of CA is often due to cost reductions rather than increased yields. Farmers by and large have contending usage of crop residues– either as fodder or as extra revenue source that explain the low implementation of CA in the IGP. Adoption of CA in mixed crop–livestock systems is often burdensome, here the farmer sometimes have to purchase residue off-farm, which in most cases they do not prefer. Thus avoiding CA for assured livestock feed is their utmost priority or in the other instance retaining less than for 30% soil cover.

Erenstein and Laxmi (2008) reported 15-16% saving on operational costs, which corresponds to ₹2320 ha^{-1} (US$52 ha^{-1}) particularly tillage savings for land preparation for wheat establishment and the value of the yield increase which amounts to 5–7% yield due to enhanced timeliness of wheat planting after rice. The net benefit of ZT over CT averages ₹4350 ha^{-1} (US$97) across IGP studies—the cost saving effect amounts to 53% whereas yield effect was 47%. The net profit gain represents a substantial 11–17% of CT gross income (Erenstein and Laxmi, 2008; Nagarajan *et al*., 2002). In a CA precision nutrient management practices in wheat, Sapkota *et al.* (2014) reported that the total cost of production in CT was significantly higher (US$1029 ha^{-1}) over NT wheat system (US$965 ha^{-1}). Whereas, gross return was higher in NT (US$1434 ha^{-1}) than in CT (US$ 1383 ha^{-1}) system resulting to higher net return under NT than CT system. Net returns in a cotton-based CA was higher when residues were retained than with no residue and in CT (Das *et al*., 2013).

Leinhard *et al.* (2014) evaluated different N levels in a rice–maize–soybean CA *vs*. CT systems in Laos. CA had higher system productivity, net income (200 to 1300 US$ ha^{-1}), and labour productivity (1.5–3 fold) regardless of fertilization levels, and the opportunity of income diversification towards livestock production. In the E–IGP, Jat *et al.* (2014) reported that higher net returns in CA systems than in CT based system even in the first year in rice–wheat system. Economic advantage was realized after two years for wheat and the combine system while it was three years for rice.

Beuchelt *et al*. (2014) analysed the social and income trade-offs of competing uses of crop residues on gross margins of maize and barley at regional, community and household levels associated with the introduction of CA in Mexico. Results showed that retaining residues *in-situ* enhanced gross margins, with 45% residues retention maximizing gross margins in status quo where expenditures are forgone for the existing use of crop residues.

2.3.6 Conservation agriculture impact on labour use, employment and livelihoods

Seasonality of labour demands and the opportunity costs in terms of potential for off-farm wage earning are important factors to consider in the overall benefits of agricultural labour saving. The time and resources saved through ZT are utilised by farm household for social, leisure and other productive purposes. Thus adoption of ZT can enhances farmers' livelihoods through labour saved for engagements in other activities.

Investigating the changes in livelihood outcomes following the adoption of CA and its ability to improve smallholder farmers' livelihoods in rural Mozambique, Nkala *et al.* (2011) reported evidences in support of the productivity-enhancing benefits of CA (improved yields) which correlates perfectly in the short-term but this did not translate to significant direct effect on household incomes and food. Women folks greatly cherish ZT arising from less hectic schedule of field operation in conventional systems (Halbrendt *et al.* 2014). However, the labour savings have affected farm workers who depends on land preparation for their livelihoods in the IGP (Laxmi *et al.*, 2007).

Conservation agriculture's labour reductions benefits may help some (gender-wise) more than others, Halbrendt *et al.* (2014) assessed the gender impacts and feasibility of CA practices in a smallholder farms in Nepal. They stressed that CA practices have unfair reallocation of labour between men and women, women bear an unequal burden (53–55%) of farm labour, yet are not taken into consideration over adoption of new practices. Active participation by women in the design and implementation of CA projects can improve its expansion, boosting the livelihoods of rural women thereby ensuring gender justice, and equal involvement in decision-making.

Erenstein and Laxmi, (2008) emphasised that ZT in the Indian IGP does not generate substantial savings in labour use in land preparation and crop establishment due of the widespread mechanization already in place. However, several ZT studies in the IGP have reported savings in tractor operational time, savings in labour use in land preparation and crop establishment and savings in diesel for land preparation (Nagarajan *et al.*, 2002). Laxmi *et al.* (2007) reported an average of 8.9 h ha^{-1} (81%) savings in tractor operational time, across IGP, the reduced turn-around time ensured wheat are sown 10 and 25 days in advance in Haryana and Bihar, respectively. This translated to savings of 5 mandays ha^{-1} in Haryana and 4 mandays ha^{-1} in Bihar and marginal labour savings of 4.3% in Haryana (Sharma *et al.*, 2002). Labour demand per manday was double as a result of increased weed pressure in CA over CT. As a result of weed pressure, labour demand persisted under CA even after several years.

However, the net return was 42.7% higher under CA compared with CT (Nyamangara *et al*., 2013). Seasonal saving in diesel for land preparation to the tune of 75–81% across IGP studies has been reported. (Laxmi *et al*., 2007; Hobbs and Gupta, 2003). The cost savings in land preparation and crop establishment averages Rs 1690 ha^{-1} across IGP and represents 75% of the costs savings effect (Erenstein and Laxmi *et al*., 2008). Combining herbicides and hand weeding reduced the weeding time which compensated for the higher input costs, farmers set aside US$388 value of time, which can be employed for other off- or on-farm and social activities (Muoni *et al.,* 2013).

A positive relationship has been established between markets and practices of CA in Nepal. Halbrendt *et al.* (2014) posited by that proximity of the market is a deciding factor in the practice of CA, as markets create non-farm opportunities that compete with time allocated for agricultural activities. Further away the household is to the market, the less livelihood to be involved with other contending market driven activities. Thus the households have limited options with an increased chance of practicing conservation agriculture. Results did not present a significant direct effect of CA on household incomes and food security indicating the possibility of an indirect link between CA, household income, and food security. However, a direct relationship between CA and productivity was observed suggesting that changes in productivity are immediate benefits of CA whereas household incomes and food security modifications might take place in the long term. In contrast, the wide adoption and scale of ZT cultivation and remoteness of the community in the IGP were the determining factors of the efficiency gain (Veettil and Krishna, 2013).

2.3.7 Conservation agriculture impact on greenhouse gas emissions

The evolution of CA was the resultant of the famous 'dust bowl' in US in 1930s. Concerns about human health and the sustainability of our common planet have received global attention. Agricultural soil management is the largest source of N_2O emissions. This emissions are largely driven by increasing N fertiliser input, including manure, and crop residues additions for increasing crop production. The concentration of atmospheric greenhouse gas (GHG) from cropland is increasing due largely to fossil-fuel and biomass combustion, wetland cultivation, N fertilization, manure and crop residue management. Enriching atmospheric C into cropland soils can partly offset fossil-fuel emissions (Wang *et al*., 2010; Lal *et al*., 2007; West and

Marland, 2002). However, the GHG benefits of increasing soil C are only moderately offset because cropland tends to increase the net GHG fluxes to the atmosphere (Del Grosso *et al.*, 2002).

Conservation agriculture system is an environment friendly and a “greener” solution that can mitigate the negative effects of environmentally damaging GHG emissions from the BAU conventional production system. It emphasises on the efficient use of fertilizer, pesticides and farm machinery (West and Marland, 2002). CA offers a wide range ecosystem services including: avoidance of biomass burning, soil disturbance mitigation, reduced runoff, soil and water pollution and soil degradation (Kassam and Friedrich, 2012; Palm *et al.*, 2014; Mark *et al.*, 2009). Recent reviews have highlighted the CA ecosystem services and the constraints in achieving them (Palm *et al.*, 2014; FAO 2013; Lal, 2013).

Current agricultural intensification damage the environment and are a major source (19–29%) of anthropogenic greenhouse gas emissions causing global warming (IPCC, 2014). An important strategy to mitigate the GHG effect while intensifying agricultural production is to switch to CA from conventional farming systems (Küstermann *et al.*, 2013; West and Marland, 2002). However, there has been polarisation of views about the impacts of CA farming practices on GHG emissions. The challenges for CA intensification are how to further increase yields but greatly reduce the negative environmental impacts.

Conservation agriculture emits less CO_2 than conventional tillage (Sainju *et al.*, 2008; Almaraz *et al.*, 2009; West and Marland, 2002). An upsurge in CA over CT has also been reported (Oorts *et al.*, 2007). Emission of N_2O increases in CT (Ussiri *et al.,* 2009; Baggs *et al.*, 2003), decreases in CT (Steinbach and Alvarez, 2006; Robertson *et al.*, 2000), or has no effect (Jantalia *et al.*, 2008). CT had no significant effect on CO_2 emissions devoid of crop residue retention (Dendooven *et al.*, 2012). The amount of C flux to the atmosphere under CA is less in CA due to the reduction in the use of agricultural machinery and of fossil-fuel consumption (West and Marland, 2002). Better soil structure with less compact soils in CA will reduce emissions of N_2O as compared to CT, whereas increased organic matter and mineralisation, mineral N with enhanced moisture contents and will enhance emissions of N_2O in CA compared to CT (Dendooven *et al.*, 2012).

Several factors can influence the emission of GHGs: high temperature, more decomposition of organic material and emission of CO_2 (Almaraz *et al.*, 2009), irrigation or high soil water content increases microbial activity and emission of CO_2, N fertilization increase mineralization of organic material (Ussiri and Lal, 2009) with more emission of N_2O, presence and type of residues with application of fertilizer will excite its decomposition and mineralization and more available organic C for emission (Vanhala *et al.*, 2007). Management practices, soil characteristics particularly soil structure and clay content, pH and sodicity also influence decomposition of organic matter.

The practice of retaining crop residue under CA based system exposes more organic matter for C decomposition and thus the propensity for greater microbial activity for CO_2 and N_2O emissions. While removal of residues in CT presents less organic matter for emissions. Likewise the availability of soil organic matter for emission increases with tillage due to soil disturbance and subsequent disruption of soil aggregate, thus enhancing C and N mineralization and decomposition (Verachtert *et al*., 2009). It can be argued that crop residue decomposition is lower in CA due to less contact between organic material and soil microorganisms compared to when it is incorporated in CT, which results in greater mineralization (Ussiri *et al*., 2009). Dendooven *et al.* (2012) reported that residue retention in CA or incorporation in CT, offsets the cumulative tillage effects of CO_2 emission. The removal of crop residue significantly reduced CO_2 fluxes due to little or no residue-C substrate for soil microorganism's activity for decomposition and subsequent. Baker *et al.* (2007) reported that CA is susceptible to C emission after the experimentation period due to incessant mineralisation of organic residue that is left retained on the soil surface.

The emission of N_2O in soil is due to nitrification–aerobic and denitrification–anaerobic conditions. Environmental factors such as cropping systems, inorganic or organic fertilization, soil management practices, and soil moisture regimes influenced emissions (Ellert and Janzen, 2008; Zou *et al*., 2007; Baggs *et al*., 2003). Under high soil-water content or anaerobic condition**,** denitrification sways N_2O emissions (Azam *et al*., 2002). Emission of N_2O perfectly correlates to the concentration of NH_4^+ in soil (Harrison and Webb, 2001). Fertilization is the major contributor to N_2O emissions from soil (IPCC, 2014).

Rochette *et al.*, (2008) estimated that 35% of N_2O emission for Canada arises from fertilizer applications, and 24% from crop residues. Crop residues retention will significantly increase the emission of N_2O compared to residue removal. Many interacting processes influence N_2O emission. Lower temperatures, less compact soils and enhanced soil structure in CA compared to CT will reduce N_2O emissions, whereas increased moisture, soil organic matter and mineral N contents will favour emissions of N_2O in CA over CT. Del Grosso et al. (2002) simulated N_2O emission rates from conventional tilled and no-till crop soil, highest emissions rate were found in CT and lower emissions for the CA cropped soil. The C emissions from crop production using CT, RT, and NT were 52.8, 41.0, and 29.0 kg C ha^{-1} per year, respectively (Kern and Johnson 1993). West and Marland, (2002) estimated the total C emissions values based on tillage and crop type in the US, combined CO_2 emissions from agricultural inputs and machinery were less in NT (137 kg C ha^{-1}) over CT practices (168 kg C ha^{-1}) per year. Maize produced the largest amount of emissions, while soybeans had the least. The difference between the two crops was due to fertilizer N application.

Conservation agriculture can lower the net global warming potential (GWP) (Sapkota et al., 2014; Pathak and Wassman, 2007). The contribution to global warming potential (GWP) is higher with N_2O emission than CH_4 (Dendoveen *et al.*, 2012; Ussiri and Lal, 2009; Robertson *et al.*, 2000). Also, GWP increases with crop residue management than tillage; crop residues removal reduced the GWP by 1.3 times. CA Removal of crop residues in CA; and CT with residue retention or removal are net sources of CO_2. However, CA had a negative net GWP with residue retention (Dendoveen *et al.*, 2012). Machinery use was the major factor which influenced the difference observed in GHG emission between CA and CT (West and Marland, 2002). Fuel savings significantly reduce GHG emissions to the tune of 93 kg CO_2 ha^{-1} across India (Laxmi *et al.*, 2007). Reduced tillage utilised lower consumption of diesel fuel (–35%) and fossil energy (–10%) than CT in Germany (Küstermann *et al.*, 2013). Sapkota *et al.* (2014) reported that wheat production under CA with precision nutrient managements had lower GWP compared to CT with farmers' fertilization practice.

2.3.8 Conservation agriculture impact on microbial diversity

Since the advent of industrial farming, soil's productive capacity—a diversity of cohabiting faunas as a living, dynamic and biological system (Doran, 2002) has seen a rapid decline over time. This degradation of soil health associated with microbial biomass diminution affects the soil ecosystems to uphold biological productivity (Kassam *et al.*, 2014). With this decline, significant soil biological activity and functional diversity has been lost. The touchstone of CA is the promotion of below- and above- ground productive capacity of the soil, plant, microbe and root to function in an optimum environment (Kassam *et al.*, 2009). Conservation agriculture practices promotes microbial activity through soil surface residue accumulation and decomposition by micro- and macro-organisms predation. CA system favours healthier equilibrium of soil organisms (Hobbs *et al.*, 2008). Interactions between microorganism and rhizodeposition influence crop and soil productive capacity. Crop-weed interaction in CA ecosystems balances the detrimental effect of weeds with the beneficial aspects of biodiversity (Turner *et al.,* 2007; Zimdahl, 1980), by recycling weed biomass into soil C and N pool (Palaniappan and Annadurai, 2012).

Conservation agrobiodiversity delivers numerous ecosystem functions and services (Kassam *et al.*, 2014; Swift *et al.* 2008). Principal ecosystem functions are achieved by the soil biota *viz:* organic matter decomposition through enzymatic activity of macro- and micro faunas; nutrient uptake and cycling from atmospheric nitrogen fixation and below soil layers, organic matter decomposition, dynamics, and transformations through microorganisms; bioturbation and rhizodeposition through the activities of plant roots and macrofauna that create vertical and horizontal pathways transiting matters between soil layers; and disease, weed and pest control through regulations of pathogens activities predators. These soil biological processes and ecosystem functions can be performed adequately in CA soils that regulate soil disturbance with better soil structure and encourage diversified crop systems.

Microorganisms influences soil productivity through carbon, nitrogen and biomass recycling. Therefore, numerical abundance, fast reproductive rates and metabolic activity, and tolerance to a wide-ranging environmental conditions are key features of soil microbial populations (Doran, 2002). Microorganisms occupy about 5% of the soil, they constitute an enormous microbial biomass and diversity, and mutually with plants, make up the major biological portion of soils and rhizospheres

(Brady and Weil, 2002). Microbial activity provides a quality measure of biological stock and dynamic as about 90% of the energy in the soil environment flows through microbial decomposers (Green *et al*., 2006). Within natural and sustainable agriculture systems, weed management is the aims rather than complete weed eradication. The intent is to regulate appropriate weed levels, taking into cognisance of both the ecological and economic effects (Turner, 2007). Farming practices that sustains soil microorganisms' activity can also lead to weed suppression by the biological agents (Farooq *et al*., 2011; Kennedy, 1999).

Productive cropland soil is a living system where biological processes by soil microorganisms are vital elements in the formation, conservation, and improvement of soil health and its productive capacity. Soil physical and chemical properties are strongly influenced by soil biological characteristics such as organic matter recycling in soil and the soil biodiversity dynamics. However, the decline of soil biological health and the resultant loss in soil productive capacity is not accorded significant importance in farming system management research. Therefore, an effective and self-sustainable system must prioritize the role of living organisms in the preservation of soil health.

Permanent soil cover with live or dead mulch – a fundamental principle of CA enriches microbial and nutrient recycling with food, nutrients and energy for their functioning (FAO, 2011; Hobbs *et al*., 2008). Surface mulch improved soil quality due to increase in soil C, enzymes and biotic activity (Karlen *et al*., 1994), aid biological soil tillage through their rooting e.g., legumes and macro- and micro-faunas can reduce compaction under CA systems through horizontal and vertical inversions (Hobbs *et al.,* 2008). Higher biological activity associated with abundant residue biomass on the soil surface can result in N immobilisation in organic form. Residue retention under CA resulted in significantly higher soil microbial population, activity and functional diversity than in CT (Lupwayi *et al*, 1999). Doran (2002) reported that organic C and N surplus and biological activity were intense in the surface soil (0–8 cm) under NT, subjected to greater potential for immobilization of plant available N in organic forms. Inclusion of high-biomass oat cover crop in CA system was reported to be effective in controlling weeds with improved soil N mineralization (Flower *et al*., 2013). Microbial biomass carbon was significantly higher under CA compared with CT (Govaerts *et al.,* 2007).

Soil microbial biomass carbon is a sensitive indicator of changes in soil processes due to its faster rate of turnover than total organic matter (Jenkinson *et al*., 2004). Microbial biomass and activity are soil quality index used to assess soil microbial activity and monitor soil recovery (Benitez *et al*., 2004) and the effects of cropping, rotation and agronomic practices on soil health (Limon-Ortega *et al*., 2006) and as is a sink and source for plant nutrients (Hobbs *et al*., 2008). Soil enzyme activity can function as an indicator of soil health, they act as mediators of many processes in cells that include organic matter transformation, organic nutrients release for plant growth, N fixation, nitrification, denitrification and detoxification. Measuring soil enzymes is a possible indicator of the biological status of soil to effect the enzyme-catalyst processes. Soil enzymes have been used to assess soil health, examine soil microbial activity (Anderson *et al*, 2004), evaluate soil resilience to wastes (Benitez *et al*., 2004), and evaluate soil after fumigation (Klose and Ajwa, 2004).

Robust link between soil microbial biomass, fertility and health have been established (Kassam *et al*., 2014; Ladd, *et al*., 2004). Increased soil microbial biomass occurs rapidly in a few years following transition from CT to CA (Alvarez and Alvarez 2000). Repeated tillage resulted in a decrease in microbial biomass carbon; microbial biomass carbon in CA was greater by 7–36% than in CT (Soon and Arshad, 2005). Residue retention in CA increased total C and microbial biomass by 45 and 83%, respectively, at 0–50 cm soil depth over CT (Balota *et al*., 2004). Increased microbial biomass influenced greater soil aggregate stability and nutrient cycling and also control pathogen (Carpenter-Boggs *et al*. 2003). Residue soil cover stimulates proliferation of biological diversity below- and above- ground; likewise beneficial insects was greater with residue mulch (Jaipal *et al*., 2002; Kendall *et al*., 1995)

2.3.9 Conservation agriculture impact on environment sustainability

Over the last decade, conservation agriculture system has been envisaged as one of the greener solutions to help secure environmental sustainability and sustain food security in the IGP (Hobbs, 2007). Conservation agriculture technologies combined with best agronomic management practices are being developed for the cereal production systems of South Asia to address the multifaceted problems of stagnating yield, resource depletion (water, labour and energy), negative environmental trade-offs (residue burning), and adverse climate change impacts caused by the conventional production system.

With greater adoption of CA systems, there is huge scope to sequester SOC and reduce N leaching, which would increase soil productivity, moderate nitrous oxide emissions from excess N fertilisation and avoid biomass burning, thus contributing to positive balance between C and N inputs and outputs. Good agricultural practices (GAP) and best agronomic management practices (BMPs) can address the increasing concern regarding *in situ* recycling of biomass on croplands to safeguard the world's common property–soil, water, air and biodiversity and deal with the increasing pressure on food security.

2.4 Integrated best (agronomic) management practices influences conservation agriculture system

Transitioning to conservation agriculture (CA) from the conventional 'business-as-usual' crop production system in the short-time (1–3 years of CA adoption) increases nitrogen (N) immobilisation and weed infestation. Weed pressure due to tillage and herbicide aversion; and the improper management of surface residues associated with N immobilisation are major trade-offs in CA based system (Nichols *et al.,* 2015; Farooq *et al*., 2011; Giller *et al*., 2009), particularly in the early stages (1–3 years). This has limited CA expansion in the Indo-Gangetic Plains (IGP). Thus, the inclusion of weed (Farooq *et al*., 2011) and N (Vanlauwe *et al*., 2014) management as a fourth principle in CA is gaining momentum. Henceforth, a sensitive CA that aims at an integrated management of these trade-offs is envisaged. Other limitations of CA, but not exclusive includes yield reductions (short-term), soil compaction, incompatible machinery, mind-sets *vis-a-vis* clean field, and the know-how (indivisible package and 'learning curve effect')

The yield declines were reduced when residue retention and crop rotation were also practiced, emphasising the significance of executing the complete principles of conservation agriculture as part of an integrated management system rather than no-till alone. Sufficient inorganic N fertilizer is an important factor in minimizing yield penalties associated with no-till practices in the short-time (Yadvinder-Singh *et al*., 2015; Pittelkow *et al*., 2015a,b; Lundy *et al*., 2015; Vanlauwe *et al*., 2014; Corbeels *et al*., 2014; Sapkota *et al*., 2014; Rusinamhodzi e*t al*., 2011).

Additional inorganic N fertilisation following the transition from conventional to CA enhanced N mineralisation (Yadvinder-Singh *et al*., 2015), offsets temporary N immobilisation and oxidation of C (Gentile *et al*., 2011; Russell *et al*., 2009), and minimise yield penalties (Pittelkow *et al*., 2015b; Lundy *et al*., 2015). In contrast, N fertilization with residue input resulted in little or loss of SOC and N content and stabilization (Chivenge *et al*., 2011a; Gentile *et al*., 2010; Khan *et al*., 2007; Nardi *et al*., 2004). Additionally, quantity of residue return (Das *et al*., 2013; Srinivasarao, *et al*., 2012) and quality (Chivenge *et al*., 2011b; Gentile *et al*., 2010) influences the SOC pool. Therefore, an integrated best management practices that includes rational agronomic management (e.g., nitrogen, weed and residue management) with the core CA based practices (minimum soil disturbance, permanent soil cover and crop diversification) is envisaged. In recent years, researchers in the IGP have develop various strategies of integrated best agronomic management practices under CA systems (e.g. Alam *et al*., 2015; Yadvinder-Singh *et al*., 2015; Gathala *et al.,* 2014; Laik *et al*., 2014; Sakpota *et al*., 2014; Kumar *et al*., 2013; Bijay-Singh *et al*., 2011). Synergies between best management practices in CA-based systems integrates crop and resource management that allows the interaction of various resource-conserving agronomic technologies with greater emphasis on environmental sustainability (Lal, 2015; Ladha *et al*., 2009).

2.4.1 Minimum tillage, permanent soil cover and crop rotation effect: Core pillars of conservation agriculture system

Soil disturbance regulation, surface residue management and crop rotation are fundamentals (core pillars) of CA. Controlled traffic or minimum physical soil disturbance on cropland– zero or reduced tillage enhances soil natural processes and recycling. This ensures that soil life, aggregates and structural quality is preserved, which promotes ecosystems sustainability. Permanent soil cover regulates erosion and temperature effect on surface soil, provides substrate for microorganism existence (Kassam and Friedrich, 2012). Soils under diverse cropping systems by and large have a higher SOC pool than monocultures. Exclusion of summer fallow and growing a winter cover crop augments soil quality through SOC sequestration (Wang *et al*., 2010; West and Post, 2002). Crop diversification through rotations, cover- and inter-crops contributes to recycling nutrients, disrupt weed, pest and disease cycles, enhance biological nitrogen fixation (BNF) when legumes are included and ensure diversify food diets. Agroecosystems sustainability can be enhance by changing from monoculture to rotation cropping (Lal, 2009).

Addressing the challenges faced by the increasingly unsustainability of the rice–wheat system in the IGP. Different cropping system scenarios in the 1GP of India and Bangladesh (farmers–'business-as-usual' conventional practices, integrated crop resource management, conservation agriculture and crop diversification), designed to meet the present and future changes in agricultural intensification have been evaluated (Alam *et al*., 2015; Gathala *et al.,* 2014; Laik *et al*., 2014). CA integrated with best management practices had higher yield with 30–50% lower irrigation use with 40–140% increase in irrigation water productivity; and 11–17% reduction in energy use than CT. Net returns increased by 79% with reduction in production cost to the tune of US$ 55 ha^{-1} in CA + best management based systems than CT. Crop diversification and legume inclusion enhanced yield, system productivity and economic returns.

Das *et al.* (2013) evaluated the impacts of CA in a cotton–wheat system; diversified with maize, wheat and greengram on total SOC addition in IGP. Results showed CA-based practices had 28 and 26% higher total SOC stock than CT in the 15 cm soil depth increments, but similar SOC stocks at 30 cm layer. Gross SOC input under CA was 10.2% and 7.6% higher than in CT. Residue had no impact on SOC stocks in all layers (0–30 cm), yet the addition of cotton, maize, and wheat residues increased total SOC by 13% in the surface 0–5cm layer. Wheat and greengram yields were not affected by tillage. Residue input contributed 9.3% of the gross C stocks. In a CA-based wheat, Kumar *et al*., (2013) reported that the energy use efficiency, specific energy, and operational field capacity in CA improved by 13, 17 and 81%, respectively compared to CT. Also, net income increased by 33 and 22% compared to CT.

Tillage and cropping systems influenced short-term (≤10-year) SOC and total N dynamics in different soil associations in a corn–soybean rotation in US (Al Kaisi *et al*., 2005). At the end of 7 years of tillage practices averaged across the soil associations, the increase in SOC and TN contents occurred mostly in the 0 –15 cm soil depth, greater in no-till than in conventional tillage. The SOC and TN increase in no-till were attributed to the decreased mineralization rate of soil organic matter rather than stratification of SOC and TN in the soil profile or the C and N inputs from crop residue. Similar observation were made by Gal *et al.* (2007) on the long-term (28 years), NT obviously resulted in more OC and N stocks in the surface 15 cm than CT, but declined severely with depth. Conventional tillage resulted in substantially more OC and N in the 30–50 cm depth interval. This suggest that long term OC or N gains under no-till are greatly dependent on sampling depth, thus tillage comparisons should go beyond the 30cm.

Increasing rotation complexity i.e., moving from monoculture or fallow to NT rotation system resulted in sequestering greater SOC, whereas already practicing NT, increasing rotation complexity did not effect a significant increase in SOC. It is plausible that SOC under NT is closer to a maximum steady-state (finite level) than that of CT, and thus stands to gain less organic C under a rotation enhancement (West and Post, 2002). The inclusion of perennial grasses resulted in greater SOC and TN contents in the 0–30 cm soil depth than continuous maize–soybean–alfalfa rotation after 10 years of management (Al Kaisi *et al.*, 2005), whereas maize–soybean rotation did not have an impact on SOC and total N content (Gal *et al.*, 2007).

The effect of tillage practices and nitrogen management (3-yr) in sorghum in semi-arid India showed that water use efficiency (WUE) increased by 6% in convention tillage (CT) compared to reduced tillage (RT). While, it was 11% and 18% higher with integrated nitrogen management (INM) and inorganic applied alone, respectively, compared to organic material alone (Patil, 2013). Similar effect on wheat after rice was reported by Gangwar *et al.* (2006), RT resulted in higher wheat grain yield (5.10 Mg ha^{-1}) compared to CT and ZT with 150 kg N ha^{-1}. ZT had the highest SOC, soil bulk density and weed dry weight. Incorporating residue resulted in the highest grain yield, infiltration rate and SOC after the third year of cropping. Increasing the N input from 65 to 105 kg N ha^{-1} in maize produced significant increases in yield (+11%) for CT, and an increase in yield of (+16%) for RT (Kustermann *et al.*, 2013). Alvarez, (2005) reported that the effect of N fertilizer rate and tillage was greater under rotations containing more crops per year or with maize as the main component of the cropping sequence.

2.4.2 Nitrogen and residue management influence conservation agriculture system

The global amounts of soil N in the tropics is estimated to be 20–22 Pg of N for the upper 30cm depth (Batjes, 1996). Terrestrial ecosystems long-term C pool take place through the formation and stabilization of soil organic matter (Franzluebbers, 2010). Therefore increasing N stocks through conservation agriculture (CA) cropland will benefit soil-crop productive capacity and ecosystem functioning. N contents in soil directly enhances soil-crop productivity. The fertilizer effects on SOC and total N accumulation are related to the amount of biomass C produced and returned to the soil and its decomposition (Lal *et al.*, 2007). A major concern is that not all soils are able to accumulate the same amount of SOC given equivalent crop residue inputs (Six *et al.*, 2002).

The dynamics of SOC and N is the net balance of inorganic and organic inputs in soil and losses through decomposition, mineralisation and immobilisation (Shibu *et al.*, 2010). Accumulation of C also leads to N accumulation (Sainju *et al.*, 2008). Soil carbon sequestration is likely to increase as long as the C input from crop residue increases, and is not oxidised as CO_2 to the atmosphere (Reicosky, 1997). Optimising N fertilisation is a short-time strategy of increasing C accumulation (Batjes, 1996). Additional inorganic N fertilisation following the transition from conventional to CA enhance N mineralisation and minimises yield penalties. Additionally, quantity and quality of residue retain influences the SOC pool. Therefore, appropriate nitrogen (N) fertilization enhances productivity and biomass accumulation (Vanlauwe *et al.*, 2011; Chivenge *et al.*, 2009), improves nutrient-use efficiency and reduces N leaching (Dai *et al.*, 2015; Zhou and Butterbach-Bahl, 2014; Gentile *et al.*, 2010). However, increases in SOC and N might hasten N dynamics with emissions of potent greenhouse gas–nitrous oxide (Butterbach-Bahl *et al.*, 2004).

Increasing nitrogen application in NT resulted in higher SOC in fertilised plot over control by nearly 2 t soil C ha^{-1} to each 1 t N fertiliser ha^{-1} (Alvarez, 2005). Similar findings were reported by Liebig *et al.* (2002) on SOC sequestration rates, which increased by 1.0–1.4 Mg C ha^{-1} yr^{-1} with high N application. Li *et al.* (2003) reported that 1.6% of SOC is lost due the less (25%) aboveground residues returning in soil. Zero-till with crop residues removal decreased the total C in the 0–60 cm soil depth by 1.5 times compared to when residues were returned (Dendooven *et al.,* 2012).

Based on a global data set and across a broad range of crops, Pittelkow *et al*. (2015a, b) and Lundy *et al*. (2015) emphasised the importance of implementing the 3 principles of CA simultaneously with sufficient N fertilization would offsets yield declines in CA systems, particularly in tropical regions. The impacts of implementing no-till with and without N fertilizer, residue management, and rotation in various crops and climates using datasets pooled across agroclimatic zones showed yields under no-till reduced by 12% without N fertilizer and 4% with inorganic N fertilizer addition; higher in maize than in wheat. Inorganic N rates between 80 and 120 kg N ha^{-1} reduced yield by 4% under no-till. Growing legumes under no-till led to similar yield obtained in conventional tillage without N addition. When crop rotation and residue retention were practiced simultaneously with no-till, the negative impacts of no-till decreased. Residue removal led to significantly higher yield reductions for maize but not in wheat. In tropical regions, yield reductions without N and with residue retention and crop rotation were much smaller compared to humid climates.

Similar observation of N fertilization in minimizing yield reduction in NT were made from the same datasets of Pittelkow *et al*. (2015b) by Lundy *et al*. (2015). Comparisons of NT and CT systems from 325 peer-reviewed literature between 1980 and 2013, N fertilization rate was the most critical factor for NT yield declines in tropical regions, but this was not the case with temperate regions. Yields decreased 10.7% and 3.7% in NT compare to CT in tropical and temperate regions, respectively. Also, decreases in NT yield were particularly observed at low N fertilisation in the first 2 years of adoption. With the addition of N fertilizer (75–100 kg N $ha^{-1}yr^{-1}$), improved yield drastically. In addition, without crop rotation and residues, NT yield declines were higher with low N fertilization rate in tropics.

Management response of N fertilisation to SOC and N dynamics within a short period is often complex and has yielded variable results on SOC accumulation. The impact of tillage and N fertilizer improved SOC, when crop residues were returned to the soil. The increased carbon sequestration was greater with higher N application, SOC sequestration between fertilised and control increased by nearly 2 t C ha^{-1} to each 1 t N fertilizer ha^{-1} (Alvarez, 2005). Küstermann *et al*. (2013) reported that reduced tillage with high N produced higher yield, C sequestration and N accumulation in crop rotations in Germany. Yet, higher pesticide use and soil compaction than conventional. SOC and N stocks in the tilled treatments decreased by about 300 kg C $ha^{-1}yr^{-1}$, whereas they increased by 150–500 kg C $ha^{-1}yr^{-1}$ and 4000–5000 kg N ha^{-1} in reduced tillage.

Precision N management under CA wheat systems in northwest India, increased grain and biomass yield over state recommendation by 5 and 3%; and by 14 and 9% than farmer's fertilisation practice (Sapkota *et al*., 2014). To reduce soil N immobilization caused by cereal residues, Flower *et al.* (2013) estimated the inclusion of high biomass oat cover effect on mineralisation, oat crop require similar N rate to that after harvested cereals for enhanced mineralisation. Organic amendments application (e.g. manures) can influence N availability in CA based system. Combining organic and inorganic N sources provide a more effective strategy to enhancing soil N fertility in CA in the long-term (Vanlauwe *et al*., 2011; Sainju *et al*., 2008; Palm *et al*., 2001). Yields response with inorganic N additions were similar to conventional tillage; organic N fertilizers tend to remain unavailable for a long time and are more vulnerable to losses (Pittelkow *et al*., 2015b; Lundy *et al*., 2015).

2.4.3 Weed management influence conservation agriculture system

Increasing concern about weed interference in CA systems have necessitated the call for the inclusion of weed management as one of the basic principles of CA (Farooq *et al*., 2011; Giller *et al*., 2009). Globally, weeds proliferation within CA based systems is a challenging management problems (Lafond *et al*., 2009; Giller *et al*., 2009), particularly with the increase development of herbicides resistance weeds. Importantly, soil cover with residue retention and crop rotation, which are fundamental principles of CA are in themselves methods of weed control, yet CA systems rely on herbicides for weed management. Minimum soil disturbance over a long term practice also reduces the weed populations from the absence of creating favourable germinating conditions and encouraging dormant weed seeds at the surface through tillage (Baral, 2012). Crop rotation is an effective practice for weed control rotating crops with different life cycles is a very effective cultural practice of controlling problematic weed like *Phalaris minor* in wheat. The retention of crop residue in suppressing weeds is well documented. Thus CA can go a long way in reducing weeds and its seedbanks over time. CA systems advocate that at least 30% of the soil covered– this amount of residue may enhance soil quality, but insufficient to significantly reduce weed population (Liebman and Mohler, 2001).

One of major drivers of CA in the IGP was the reduction of the herbicide resistant weed–*Phalaris minor* in wheat (Erenstein and Laxmi, 2008). However, following conversion from conventional practice to CA would require the need to destroy existing weed seedbanks with the use of herbicides to ensure immediate benefits. Weeds suppression from herbicides application before or at the commencement of sowing is an important strategy that enhance greater advantage over weeds. Perennial and problematic weeds are difficult to manage at the initial stage of CA. As such, a greater amount of herbicide might be necessary in the initial years of transitioning to significantly reduce the weed seedbank. This initially weeds pressure following transition to CA should not be discouraging, as it can be a temporary phenomenon (Farooq *et al*., 2011; Nichols *et al*., 2015).

The retention of crop residues provide physical barriers that suppresses weeds by physically inhibiting weed seedlings from light penetration necessary for germination (Chhokar *et al*., 2007). This reduction in light has damaging effects on seedling growth. Crop rotations are undeniably the most effective way to control weeds in cropping systems; break the life cycles of weeds, pest and disease. Rotating crops will alternate selection pressures, preventing one weed from being dominating, thus preventing its establishment. Crops diversification allows control of weeds with different emergence seasons, preventing a particular type of weed from constantly completing its life cycle. CA works mutually to reduce weed pressure compared to conventional systems (Anderson, 2015; Murphy *et al*., 2006). Crop diversification interact with tillage practice to create dissimilar communities of weeds. A 14-year in the US reported that as tillage intensity reduced, perennial weeds increased, this increase was greater in a continuous maize compared to a two-year rotation of maize and soybean indicating that crop rotation reduced proliferation of perennial weeds (Buhler *et al.* 1994).

Implementing no-till without residue retention and crop rotation can result in severe weed problems (Nichols *et al*., 2015). The consequence of ample crop residues retention may result in low effective herbicide rates thereby lowering herbicide efficacy on weeds and quicken resistance to the herbicides (Busi and

Powles, 2009; Neve and Powles, 2005). Thus the impacts of the crop residue types, amounts and placement on herbicide efficacy warrants urgent concern (Flower *et al.*, 2012). This interaction between greater weed suppression with accumulating residue cover and the reduced herbicide absorption has been highlighted by Johnson *et al.* (1989). This is of greater concern for the sustainability of conservation agriculture. Although crop residue can intercept herbicide, but does not reduced weed control (Ngwira *et al.*, 2014; Chauhan, 2013), crop residues can intercept about 70% of the applied herbicide (Sadeghi *et al.*, 1998). Weed suppression effected by surface residue compensates for the reduced herbicide contact with weeds (Teasdale *et al.*, 2003). Chauhan *et al.* (2006) reported that residue cover under CA can affect the herbicides bioavailability (e.g. trifluralin), and these herbicides can react chemically with residues.

Integrating multiple non-chemical weed management strategies in CA-based cropping system promotes sustainability as herbicide use faces criticism due to their adverse residual effect on soil and crop product over a long period. Synergistic effects of utilizing multiple control tactics are vital and their importance is significant. Kumar *et al.* (2013) reviewed several promising non-chemical approaches in suppressing weeds under CA e.g. weed-competitive cultivars and certified seeds, cover cropping (live/dead), stale seedbed, brown manuring, and water and nutrient management practices. Additional cultural practices for CA include: selecting highly competitive varieties; altering planting dates; preventing weed seed recruitment; adjusting planting arrangement, densities and fertilizer placement; and microbial bio-controls (Nichols *et al.*, 2015; Farooq *et al.*, 2011).

The potential of weed suppression presented by early crop planting have been demonstrated by the case of *Phalaris minor* in the rice-wheat systems in the IGP. Adoption of NT ensured wheat are planted 10–20 days earlier, allowing the crop to establish before *Phalaris minor* emergence (Chauhan *et al.*, 2012; Erenstein and Laxmi 2008). Weeds uptake nutrients more competitively than crops– altering timing, placement, and source offers advantage to the crop. Deep placement of fertilizers can reduce weed biomass compared to broadcasting (Liebman and Mohler, 2001). Stale seedbed technique of applying irrigation to sprout weeds prior to sowing, followed by a non-selective herbicide to kill them (Mulvaney *et al.*, 2014; Chauhan *et al.*, 2012; Renu *et al.*, 2010) have been proved effective. The use of microorganisms have potential for biological weed control (Stubbs and Kennedy, 2012; Farooq *et al.,* 2011; Kennedy, 1999)

Kumar *et al.* (2013) reviewed various non-chemical methods and proposed alternative strategies in reducing weed pressure in CA rice–wheat system in the IGP. Soil surface mulching with crop residue significantly suppress the emergence of weeds and seed predation. In rice, retention of wheat residue mulch up to 5 t ha^{-1} reduced weed density by 22 to 76% and stimulated predation of weeds seeds. Rice residue mulch (6 to 10 t ha^{-1}) in combination with early sowing reduced weed emergence by over 80% in wheat. Stale seedbed in ZT accompanied by non-sensitive herbicide before rice sowing reduced weed density by 44–68% and 77–85% in ZT direct seeded rice (Renu *et al*., 2010). The inclusion of high biomass oat and pasture cover crop are effective weed control strategy in a continuous cereal rotations; the phase at which the cover crops (preferably at late flowering or soft dough stage) are killed by herbicide is essential, as this can influence the soil moisture retention when delayed (Flower *et al*., 2012). Kumar *et al.* (2012) reported that *P. minor* was greatly reduced when rice-wheat was rotated with clover or oat for fodder in 3 years in place of wheat after rice. In zero-till direct seeding of rice, weed pressure can be reduced by the presence of short duration legume crops (e.g. mungbean, *Sesbania*) during the uncultivated period between harvest of wheat and planting of rice.

Combination of various IWM techniques for control weeds to reduce reliance on herbicides showed no significant increase in weed density in the IWM systems over the standard reference (herbicide + tillage) after 6 years period (Chikowo *et al*., 2009). Usman *et al*. (2012) reported that herbicide combination and tillage effectively and economically control weeds and enhance wheat yield in rice-wheat cropping system of Pakistan. Weeds density reduced by 93 and 95% with herbicide combination over control. Muoni *et al*., (2013) reported that herbicide combination reduced the weed density but increased the production cost. However the reduce weeding time compensated for the higher cost of cultivation, which resulted to about US$388 worth of time saved for the farmer for off-farm activities. Combining herbicides had no effect on maize grain yields than manual weeding due that appropriate and timely weeding.

MATERIALS AND METHODS Chapter 3

The field experimentation entitled ‘nitrogen and weed management in maize – wheat cropping system under conservation agriculture’ was conducted during rainy (*kharif*) – winter (*rabi*) seasons of 2013–14 and 2014–15 to evaluate the effects of weed and nitrogen management on weed suppression, productivity and profitability, soil health, greenhouse gases emissions, herbicide residues and resource-use efficiency.

3.1 Experimental site and cropping history

The field trial was conducted at the Research Farm of the Indian Agricultural Research Institute (28° 40’ N, 77° 11’ E; 228 m above sea level) in New Delhi, Northwest IGP. The plot was under soybean–wheat system with recommended mineral fertilisation for both crops for two years before commencement of this experiment. A yield response index of maize–wheat to GreenSeeker (GS) with the designated treatments were evaluated before the actual experimentation.

3.2 Climate and weather

The climate of the research farm is semi-arid with dry hot summer from May to June with mean maximum temperature of 40° to 45°C, and cold winters from December to January with mean minimum temperature of ~2°C. The average annual rainfall is about 650 mm with 80% rainfall expected during rainy season from July to September. The annual pan evaporation is about 850 mm. The mean wind velocity varies from 3.5 km hr^{-1} during October to 7.6 km hr^{-1} during April. Mean relative humidity attains the maximum (> 90%) during rainy and the minimum (< 45%) during the summer months. During the experimentation periods, the weekly average meteorological data was recorded at Indian Agricultural Research Institute Meteorological Observatory, New Delhi. Details of the weather conditions during the cropping seasons are presented graphically in Figures 3.1a & b.

3.3 Experimental field

The field soil is well drained, non-calcareous and slightly alkaline classified under the major group of IGP alluvium as Typic Haplustept according to the U.S. Taxonomy. The surface soil (0–15 cm) is low in organic carbon and available N; medium in P and K. and free from salinity at the start of the experiment. The soil has a land surface slope of less than 2%. Details of physico-chemical properties of the field plot of soil are given in Table 3.1

Table 3.1. Soil Physico-chemical properties of the experimental plot

Soil properties	Value	Method adopted
Sand (g kg^{-1})	630	International Pipette method (Piper, 1950)
Silt (g kg^{-1})	251	
Clay (g kg^{-1})	119	
Textural class	Sandy loam	
Bulk density (Mg m^{-3})	1.58	
Soil pH (1:2.5 soil : water)	7.7	Beckman's glass electrode (Jackson, 1973)
Electric conductivity (dS m^{-1})	0.47	Solubridge method (Jackson, 1973)
Organic carbon (g kg^{-1})	5.01	Potassium dichromate (Walkley and Black, 1934)
Available N (kg ha^{-1})	163.2	Modified Kjeldahl (Subbiah and Asija, 1956)
Available P (kg ha^{-1})	11.7	Olsen's method (Olsen *et al.*, 1954)
Available K (kg ha^{-1})	235	Flame photometer (Jackson, 1973)

3.4 Experimental details

The experimental design was a split plot with weed management (three levels) as the main plot and N fertilisation (four levels) as the sub plot treatments with three replications. The main and sub-plots were 32 m by 4.2 m and 7 m by 4.2 m plot area (Figure 3.1). The details of treatment philosophies are described below (Table 3.2).

Table 3.2 Treatments adopted in the maize-wheat cropping system for two consecutive years (under fixed lay-out)

Treatment philosophy	**Treatment description**		**Treatment notations**
	Maize	**Wheat**	
Weed management (Main plot): Herbicide combinations to provide synergistic weed control effect, while brown manuring (*Sesbania aculeata* killed with herbicide which turned brown-coloured residues left for decomposition) as a cover crop to suppress weed during early stages of maize growth and to enhance soil fertility.	Weedy check (control)	Weedy check (control)	W_1
	Atrazine (0.75 kg ha^{-1}) + pendimethalin (0.75 kg ha^{-1}) (pre-emergent tank-mix)	Pendimethalin (1.0 kg ha^{-1}) + carfentrazone-ethyl (0.02 kg ha^{-1}) (pre-emergent tank-mix)	W_2
	Brown manuring (*Sesbania aculeata* L.) was knocked down with 2,4-D (0.25 kg ha^{-1}) at 25 days after sowing	Clodinafop-propargyl (0.06 kg ha^{-1}) + carfentrazone-ethyl (0.02 kg ha^{-1}) (post-emergent tank-mix)	W_3
Nitrogen management (Subplot): Based on (i) soil test values (Table 2) to determine an optimised N rate as a transition phase strategy from conventional to conservation agriculture system. This was followed by (ii) plant sensor [GreenSeeker (GS)] based N application to regulate supplemental N requirements that corresponds with crops' demand	100% N applied as whole at sowing (basal application); based on soil test value (STV)	Same as in maize	N_1
	50% N at sowing (STV) + 25% N as broadcast at 25 days after sowing (STV) + rest N guided by GS that corresponded with crops' demand	Same as in maize	N_2
	50% N at sowing (STV) + rest N guided by GS that corresponded with crops' demand	Same as in maize	N_3
	80% N at sowing (STV) + rest N guided by GS that corresponded with crops' demand	Same as in maize	N_4

3.5 Conservation agriculture practices

3.5.1 Field management

The initial surface wheat residue (i.e. 40% of residue biomass produced plot-wise) was retained from previous wheat cropping before commencement of this experiment, while the harvested maize and wheat residues were retained *in situ* on surface soil in respective plots for the present experimentation (i.e. 50 and 40% of maize and wheat aboveground residues, respectively). A no-till 'Turbo Happy Seeder' cum fertiliser drill was used for sowing to ensure controlled traffic and minimum soil disturbance in a CA mode.

3.5.2 Weed management

To facilitate zero-till sowing, glyphosate at 1.0 kg ha^{-1} was applied to the existing weeds before each cropping season. For brown manuring, *Sesbania aculeata* was broadcasted on the day of maize sowing as a leguminous cover crop to suppress weeds during the early stages of maize growth. The *Sesbania* was sprayed down using 2,4-D (0.25 kg ha^{-1}) and the brown-coloured residues were left as brown manure. Weedy check plots were without any weed control measures.

Herbicide combinations (Table 3.2) were tank-mixed (*in-situ*) at the study site and sprayed as pre-emergent at 2 DAS or post-emergent at 30 DAS as applicable. For maize: weed treatments were weedy check (control) (W_1), herbicide combinations (W_2) – atrazine + pendimethalin (0.75 + 0.75 kg ha^{-1}, respectively) as tank-mix pre-emergent and (W_3) – brown manuring + 2, 4-D at 0.25 kg ha^{-1}. Whereas for wheat: weedy check (W_1); herbicide combinations *viz.* (W_2) – pendimethalin + carfentrazone-ethyl (1.0 + 0.02 kg ha^{-1}, respectively) as tank-mix pre-emergent and (W3) – clodinafop-propargyl + carfentrazone-ethyl (0.06 + 0.02 kg ha^{-1}, respectively) as tank-mix post-emergent at 30 DAS.

3.5.3 Nitrogen management

Soil samples before sowing were analysed to appraise the native soil N content for the determination of an optimised N rate as a transiting phase strategy (from conventional to CA) for soil fertility improvement. The native soil available N (0–15 cm) was considerable low (163 kg N ha^{-1}), based on the N-limit rating for the IGP. Thus, an additional 50 and 25% N (i.e. 60 and 30 kg N ha^{-1}, respectively) for maize and wheat were suggested. Therefore, N rates at 180 and 150 kg N ha^{-1} for maize and wheat, respectively, were designated as the optimised recommended N rate (as a standard, 120 kg N ha^{-1} are recommended for both crops) for sustained productivity. Subsequent N fertilisation were applied as demanded by crop(s) based on the GreenSeeker (GS) readings.

Recommended N dosage was calculated from the soil test value and from information provided by the plant sensor GS for midseason N supplementations. Thus N rates for both crops were assigned at 4 levels (Table 3.1) viz. N_1– whole 100% N basal application (all at sowing); N_2– 50% basal + 25% N broadcast at 25 DAS + rest N by GS; N_3– 50% basal + rest N by GS; N_4– 80% + rest N by GS. Maize fertilization rate were: N 180: P 90: K 45 kg ha^{-1}; whereas wheat fertilization rate were: N 150: P 75: K 37.5 kg ha^{-1} for the. To ensure nutrient balance, P and K were attuned to match the optimised N rate in the ratio 4:2:1. All P (DAP) and K (MOP) were applied as band placement beneath the seeds at the time of sowing.

3.5.3.1 GreenSeeker N guidance

The GS^{TM} sensor is a patented technique used to measure crop reflectance, which calculate the normalized difference vegetation index (NDVI). The sensor was designed for N and crop management in precision agriculture, and has been calibrated for the IGP in South Asian conditions (Bijay-Singh, et al. 2011; Cao *et al.*, 2012). The NDVI measures the fraction of the emitted visible red (VIS; 650±10nm) and near infrared (NIR; 770±15nm) radiation in the sensed area that is returned to the sensor (reflectance) as it moves over the crop surface at a distance of 0.6–1.0m. These fractions are used within the sensor to compute NDVI according to the following formula: NDVI= NIR–VIS/ NIR+VIS. The full description of the GS device is described in Govaerts and Verhulst (2010). N fertilisations were made when there is a requirement for N supplementation as regulated by GS-sensor.

Beginning at 30 days after sowing and continue till grain filling stage, NDVI measurements were taken once a week in the middle rows of the crop, and subsequently, a day after fertilisation every time in the same two rows in the central part of each plot. To compute and calibrate the response index of both crops to NDVI, we followed Raun et al. (2002); where the average NDVI of N-rich (non-limiting) plots with 180 and 150 kg N ha^{-1} applied in split doses for maize and wheat, respectively, (i.e., N_2) divided by the average NDVI of the plots that is characteristic of the farmers' fixed N fertilisation at sowing (i.e., N_1) in a CA mode in the previous year (2012–2013). The quantitative response index is then multiplied with the yield with no added fertilisation (YP_0; N_1) to determine the potential yield with added N fertilisation (YP_n; N_2). The supplemental (in-season) fertiliser N dose to be applied using the GS was determined based on the difference between the YP_n and YP_0 N-uptake. The mean N contents of maize and wheat grain at harvest were multiplied with the YP_n and YP_0 values, respectively, and then divided by 0.5 (efficiency factor for South Asian conditions) to estimate the fertiliser N requirement (Bijay-Singh *et al.*, 2011).

$$\text{Fertiliser N requirement} = \frac{\text{N content of grains (\%) x } (YP_n - YP_0)}{100 \text{ x } 0.5}$$

For maize: supplemental GS– guided N fertilisations were applied in N_2–at 58 DAS; N_3–at 38 and 63 DAS; N_4– at 50 DAS. For wheat: N_2–at 62 DAS; N_3–at 43 and 77 DAS; N_4– at 61 DAS in the first year. Whereas in the second year for maize, N_2–at 60 DAS; N_3–at 43 and 65 DAS; N_4– at 55 DAS. For wheat: N_2–at 60 DAS; N_3–at 47 and 65 DAS; N_4– at 60 DAS. A part of the recommended N-dose was not applied in the different N levels, as the sensor did not detect the need for midseason N requirement. Thus considerable fertiliser N were saved (Table 4.40)

3.6 Herbicides

3.6.1 Pendimethalin

Pendimethalin [N-(1-ethylpropyl)-2, 6-dinitro-3, 4-xylidine; Stomp, Prowl, Pendilin, Herbadox®] is a derivative of the 2, 6-dinitroanilines and is formulated mainly as emulsifiable concentrate. Pendimethalin is wholly a pre-emergence herbicide. Maize, wheat and rice tolerates pendimenthalin by depth protection, hence pre-emergence is recommended. It is selective to a wide range of cereals, pulses, oilseeds and vegetables and highly effective against broad-spectrum of weeds like *Trianthema portulacastrum, Amaranthus viridis, Chenopodium album, Digitaria sanguinalis, Echinochloa colona, Phalaris minor, Avena fatua/ sterilis ssp ludoviciana.*

3.6.2 Atrazine

Atrazine [2-chloro-4-ethylamino-6-isopropylamino-1,3,5-s-triazine; Atrataf, Solaro, Aatrex, Gesaprim®] is a derivative of the chloro-s-triazines and is formulated mainly as wettable powder (WP). It has a broad-spectrum effect and can be applied either as pre- or post-emergence against broad-leaved and grassy weeds. It is effective against

Trianthema portulacastrum, *Digera arvensis*, *Echinochloa colona/crusgalli*, *Eleusine indica*, *Dactyloctenium aegypticum*, *Digitaria sanguinalis.*

3.6.3 Carfentrazone-ethyl

Carfentrazone-ethyl (Ethyl 2-chloro-3-[2-chloro-4-fluoro-5-[4- (difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1- yl]phenyl]-propanoate; Aim, Affinity, F-6285) is mainly a broad-leaved weed killer herbicide employed in wheat. It is, however, effective against *Phalaris minor* and other grasses. It is slightly phytotoxic to wheat immediately after application, but wheat recovers soon.

3.6.4 Clodinafop-propargyl

Clodinafop-propargyl, marketed as Topik 15 WP® (prop-2-ynyl(R)-2-[4-(5-chloro-3-fluoro-2-pyridyloxy) phenoxy] propionate) controls most of the prominent grass weeds like *Phalaris minor, Avena fatua/ sterilis ssp ludoviciana, Alopecurus myosuroides, Echinochloa crusgalli* etc. It is recommended for wheat, triticale and rye. It should be applied as post-emergent i.e. after the appearance of 3–6 leaf stage under warm, moist condition. It is taken up by the grass weeds, which causes cessation of its active growth within 48 hours after application. Drying of the affected weed species occurs within 2 weeks, depending on environmental condition and species involved. It degrades rapidly in soil with little or no activity/efficacy on subsequent weeds growth. Suitable for combination with other herbicides e.g. bromoxynil, ioxynil, triasulfuron, 2,4-D, isoproturon to control grass and broad-leaved weeds.

3.7 Crop management and field operations

The agronomic management practices schedule (e.g., herbicide application, fertilization irrigation etc.) for the maize and wheat cropping seasons are shown in Appendix I & II.

3.7.1 Crop varieties and sowing

3.7.1.1 Maize *cv.* DHM 117

Maize *cv.* DHM 117 is a single cross hybrid with pedigree from BML 6 × BML 7. It has characteristics of the orange-yellow flint type grain with high response to fertilization and tolerant to lodging. The average yield is 7.5 t ha^{-1}. The leaves remains green till maturity with high fodder value. Maize was sown at 60 cm row spacing and 30 cm plant to plant, while *Sesbania aculeata* was broadcasted as intercrop at 20 kg ha^{-1} seed rate on the same day of maize sowing. The *Sesbania* intercrop was sprayed down using 2,4-D (0.25kg ha^{-1}) and the brown-coloured residues were left as brown manure. Weedy check plots were without any weed control measures.

3.7.1.2 Wheat cv. HD 2967

Wheat cv. HD 2967 is a widely adapted variety that carries diversified genes. It has high resistance against most leaf rust and blight disease and virulent races of yellow rust disease. It matures in 130-135 days with an average yield 5.04 t ha^{-1}. This variety is mainly recommended for irrigated conditions in NW–IGP. It was drilled at 22.5 cm row spacing with 100 kg ha^{-1} seed rate. Sowing was done in July (7, 2013 and 11, 2014, respectively) for maize, while wheat was sown in November (15, 2013 and 4, 2014, respectively). Basal N applications were made at sowing for the respective N levels and the rest N were applied as guided by GreenSeeker.

3.7.2 Gap filling and thinning

To maintain the desired plant to plant spacing in both crops, filling of crop-free space and thinning of packed space were done between 7–10 days after sowing.

3.7.3 Irrigation

Pre-sowing irrigation was given at the onset of sowing when soil moisture was insufficient. Subsequent irrigations were applied as and when required. Depth of irrigation water was maintained at 6 cm in all the plots. Details of the number of irrigations for both crops are given in Appendix I & II.

3.7.4 Crop protection measure

To reduce the damage of sprawling bird on germinating seedlings and grain-filled maize cobs or wheat earhead, a person was employed for caring the birds. A tank-mixture of chlorpyriphos (0.5%) and endosulfan (0.3%) solution was sprayed over the standing crops in each cropping season to control termite and some insects.

3.7.5 Harvesting and threshing

Harvesting was done manually for determining net plot yields. For maize: the cobs from the middle rows (3.5 m x 3.5 m) of each plot were harvested. In wheat: the entire plants from the base were cut off from the middle rows (3.5 m × 3.15 m) for threshing. The harvested plot areas were designated as the net plot area for each crop.

3.8 Biometric observations and measurement

3.8.1 Weeds

3.8.1.1 Weed density and dry weight

Weed populations (species-wise) in each plot were assessed randomly at 20, 40, 70 DAS and harvest for maize, whereas 20, 40, 70, and 110 DAS for wheat using a quadrat of size 50 cm × 50 cm (0.25 m^2). The sampled weeds were sun-dried for 2 days and later oven-dried at 65–70°C till constant weight. The population and dry weight of weeds were expressed in no. m^{-2} and g m^{-2}, respectively.

3.8.1.2 Weed control efficiency

For the comparison of the treatment performance based on the weed density in treated and control plots, the weed control efficiency (WCE) of different treatments were determined as described by Das (2008) using the following equation.

$$\text{WCE (\%)} = \frac{(\text{WD}_\text{C} - \text{WDt})}{\text{WDc}} \times 100$$

where, WDc and WDt are weed density in control and treated plots, respectively.

3.8.1.3 Weed control index (WCI)

Weed control index was derived from the weed dry matter weight in control and treated plots. The WCI of the different treatments were determined following the formula described by Das (2008).

$$\text{WCI (\%)} = \frac{(\text{WD}_\text{C} - \text{WDt})}{\text{WDc}} \times 100$$

Where, WDc and WDt are weed dry matter weight in control and treated plots, respectively.

3.8.1.4 Weed index (WI)

Weed index was determined based on the crop yields in weed-free and treated plots. It expresses the yield losses due to weeds across the treatments (Das, 2008).

$$\text{WI (\%)} = \frac{(\text{Ywf} - \text{Yt})}{\text{Ywf}} \times 100$$

where Ywf is the crop yield obtained from the highest-yielder plots, Yt is the crop yield in the treated plots. In this study, N_2 (50% basal + 25% N broadcast at 25 DAS + rest N by GS) that gave higher yields was considered as representative of the weed-free plot.

3.8.2 Crop

3.8.2.1 Plant Height

The plant heights of both crops were measured at periodic intervals of 40, 70 DAS and harvest for maize, while 40, 70, 110 DAS and harvest for wheat. Five plants were tagged randomly in the middle rows of each plot during the growing season. Height were taken from the base/ground level to the apex leaf.

3.8.2.2 Dry matter accumulation

Destructive sampling of dry matter yield was done for both crops at 20, 40, 70 DAS and harvest for maize and 40, 70 and 110 DAS and harvest for wheat. Five plants were selected randomly for the dry matter accumulation in maize, whereas in wheat, a row length of 100 cm was designated for the dry matter accumulation. The plant samples were oven-dried at 65–70°C for 48 hrs and their dry weights were expressed in g m^{-2}.

3.9 Growth parameters

3.9.1 Maize

Plant heights were measured at 40, 70 and 100 DAS from five randomly selected plants in five rows. At 40, 70 and 100 DAS, five maize plants were sampled for leaf area estimation using a leaf area meter (LI-COR 3100, LI-COR, Lincoln, NE, USA) and leaf area index (LAI) was determined.

3.9.2 Wheat

Plant heights were measured at 40, 70 and 110 DAS from five randomly selected plants in five rows. At 40, 70 and 110 DAS, wheat plants from 10 cm row-length were sampled for leaf area estimation using a leaf area meter (LI-COR 3100, LI-COR, Lincoln, NE, USA) and leaf area index (LAI) was determined.

3.10 Yield attributes and yield

3.10.1 Maize

Cobs harvested from the net plot area in each plot were expressed as cob m^{-2}. Five cobs were threshed and the number of grains per cob was obtained. From the threshed cob, 100 grains were weighed, and expressed as 100-grain weight in grams. The cobs harvested from each net plot area were threshed and the grains obtained were expressed as the maize grain yield in t ha^{-1}; stover yield from similar net plot area in each plot were weighed and expressed in t ha^{-1}.

3.10.2 Wheat

Ear-bearing tillers from one meter row-length in each plot were counted and expressed as spike m^{-2}. Ten spikes were randomly selected and their lengths were measured and the spikes were threshed to obtain the grains per spike. Wheat 1000 grains were weighed from the threshed grains and expressed as 1000-grain weight in grams. The harvested ear-bearing tillers from each net plot area were threshed and the grains obtained were expressed as the wheat grain yield in t ha^{-1}; straw yield from similar net plot area in each plot were weighed and expressed in t ha^{-1}. Grain yields of maize and wheat were recorded at 15 and 12% moisture content, respectively

3.11 Quantification of the above- and below-ground biomass returned

The aboveground maize and wheat biomass (residues) at 50 and 40%, respectively, of the total aboveground residue produced in each cropping season were retained/ returned in the respective plots (i.e. maize residue to wheat and wheat residue to maize) on the surface soil. Wheat residue is a highly demanding livestock feed in the IGP, hence removed from the field. The belowground root biomass C inputs were estimated from the quotients of the aboveground biomass produced to the respective shoot: root of maize (6.25) and wheat (7.4), multiply by 40% of C present in biomass.

3.12 Biological yield

The sum of the dried-weighed harvested produce (grain and straw) from each net plot, expressed t ha^{-1} designates the total biological yield.

3.13 Harvest index

The quotient of the economic yield (grains) to the total biological yield (grains + straw) was expressed as the harvest index in percentage.

$$\text{HI (\%)} = \frac{\text{Economic yield}}{\text{Total biological yield}} \times 100$$

3.14. System productivity

The system productivity (t ha^{-1}) calculated based on the equivalent yield of crops was expressed in terms of wheat equivalent yield (WEY).

$$\text{System productivity} = \frac{\text{Maize grain yield} \times \text{price of grain}}{\text{Price of wheat}} + \text{wheat grain yield}$$

3.15 Soil physical analyses

3.15.1 Bulk density

Undisturbed core samplers of copper cylinder of 5 cm in height and 5 cm in diameter were collected from each plot (clean soil surface without residues) at depth increments of 0–5, 5–15 and 15–30 cm after crop harvest for bulk density determination (Blake and Hartge, 1986).

3.15.2 Saturated hydraulic conductivity

The undisturbed soil core samplers collected were used for hydraulic conductivity determination by constant head permeameter determination. One end of the core sampler is closed with filter paper/muslin cloth and saturate overnight by placing the permeameter in a tray filled with water. The permeameter is placed on the stand and the siphons maintain a constant head of 3 cm of water on the top of the soil by siphon tubes. The amount of water flow through the soil were measured with a graduated cylinder in a given time interval until a constant is reached.

$$\text{Saturated hydraulic conductivity (Ks)} = Q \times L / A \times t \times (h + L)$$

Where Q = volume of water collected, (cm^3); L= Length of soil column, cm; A = Cross sectional area of the permeameter, cm^2; t = Time interval of collection, min h = Depth of the water above the soil, cm.

3.15.3 Soil aggregation stability

Soil aggregate clods were collected from 0–15 cm soil depth and air-dried at room temperature for one month for the determination of size distribution and stability of soil aggregates (Kemper and Rosenau, 1986). The air-dried clods were broken with hammer to pass through a 4–8 mm sieve size. A 100 g of the aggregate sizes (4–8 mm size) were placed on the top of 6 sieves size (4, 2, 1, 0.5, 0.25 and 0.1 mm) on a wet sieve shaker with the top sieve at 3 cm above the water for 10 minutes for slaking. The nested sets of sieves moved up and down through a vertical distance of about 3 cm submerged in water drum for another 10 minutes. Aggregates from the each sieves were collected, oven-dried at 105°C for 24 h and weighed to determine the mean weight diameter (MWD). For aggregate stability analysis, 5% solution of calgon sodium hexametaphosphate were added in the oven-dried aggregate from each sieve size for dispersion of organic matter. The primary particles in each beaker were oven-dried and weighed. The percent distribution of aggregates in different sizes was obtained by subtracting the primary particles retained in respective sieves greater than 250 mm diameter.

$$\text{MWD} = \Sigma\, x_i w_i \,/\, W$$

$$\text{WSA}\ (\%) = \left[\frac{(\text{aggregate} - \text{sand}) > 0.25\text{mm}}{W}\right] 100$$

Where, x is the mean diameter of a particular size range of aggregates separated by sieving, w is the oven dry weight of aggregates in that size range as a fraction of the total weight and W is the total dry weight of the sample analysed. While > 0.25mm denotes the primary (sand) particle after dispersion of respective size range.

3.16 Soil chemical analyses

3.16.1 Soil organic carbon and total nitrogen contents

Soil organic carbon (SOC) content was determined by wet oxidisable potassium dichromate method (Walkley and Black, 1934). Total nitrogen in soil was determined by modified Kjeldahl method (Keeney and Nelson, 1982).

3.16.2 Soil available nitrogen, phosphorus and potassium contents

The soil samples were taken from 0–15 cm soil layers at the onset and completion of experimentation period. Samples were air-dried at room temperature, and sieved through a 2 mm mesh openings for the determination of available N, P and K analyses. The soil available N, P and K contents expressed in kg ha^{-1} were analysed by alkaline permanganate method (Subbiah and Asija, 1956), Olsen's method (Olsen *et al.*, 1954), and ammonium acetate extraction method (Jackson, 1973), respectively.

3.16.3 Plant total nitrogen content

Harvested residue (straw) samples were milled and analysed for total N contents using modified Kjeldahl method (Keeney and Nelson, 1982).

3.17 Soil biological analyses

3.17.1 Determination of soil microbial biomass carbon

Soil microbial biomass and enzyme activities *viz*: microbial biomass carbon (MBC), fluorescein diacetate, urease activity and alkaline phosphatase were measured at the vegetative and reproductive stages of crop growth. Moist soil samples from 0–15 cm depth were taken in sampling bags from each plot. Moist samples were protected from drying and immediately analysed (within 4 days) for microbial activities.

Microbial biomass carbon in soil samples was estimated using chloroform fumigation method (Nunan *et al.*, 1998). A 17.5 g soil was taken from each sample in an in closed-capped bottle in two replicates with 1.0 ml of chloroform added in each bottle. A non-fumigated set was also prepared in a 250 ml conical flask. Both samples were incubated in dark for 24 hours and then evaporation of closed-capped bottles containing chloroform were opened and placed in water bath at 50°C. A 70 ml 0.5 M K_2SO_4 was added to all samples and placed on shaker for 30 minutes. The corresponding supernatant were filtered with Whatman no. 42 filter paper and read with spectrophotometer at 280 nm absorbance.

$$\text{MBC } (\mu\text{g C g}^{-1} \text{ of soil}) = \frac{(\text{Absorbance of fumigated soil} - \text{Absorbance of non-fumigated soil}) \times 15487}{\text{Oven-dried weight of soil}}$$

3.17.2 Determination of fluorescein diacetate

Fluorescein diacetate (FDA) hydrolysis in soil was analysed with 1 g soil sample in test tubes with 5 ml of 60 mM potassium phosphate buffer (7.6 pH) and 10 µl FDA stock solution added; and then incubated at 37ºC for two hours. A control for each sample without FDA solution was prepared. 0.2 ml (5% v/v) acetone reagent was added in each test tube to stop the reaction and filtered through Whatman no. 42 filter paper. The corresponding supernatant were filtered with Whatman no. 42 filter paper and read with spectrophotometer at 490 nm absorbance. FDA enzymes hydrolysed was expressed in µg of fluorescein released ml^{-1} (µg fluorescein g^{-1} soil h^{-1}) (Schnurer and Rosswall, 1982).

3.17.3 Determination of alkaline phosphatase

Alkaline phosphatase activities in soil were analysed with the use of *p*-nitro phenyl phosphate (pNPP) (Tabatabai and Bremner, 1969). 100 mg of soil samples were taken in a 2 ml micro-centrifuge tube and 0.5 ml of 100 mM phosphate buffer (pH 7.6) and 10 mM of pNPP (as substrate) in 100 µl solution were added. The reaction mixture was adjusted to 1.0 ml with distilled water. The tubes were placed in a vortex for two minutes at room temperature and later incubated at 37ºC for 1 h in shaking condition at 100 revolutions per minute (rpm). The incubated samples were then placed in centrifuge at 10000 rpm for 5 min. The corresponding supernatant was obtained in a test tube and 2 ml of 1.0 M NaOH was added. The phosphatase present in the yellow colored filtrate was determined spectrophotometrically at 430 nm. Phosphatase activities were expressed in µmol phosphatase released g^{-1} soil h^{-1}.

3.17.4 Determination of urease activity

Urease activity in soil was analysed as per Nannipieri et al. (1980). A 0.08 M urea solution with double reagent of phenol 50 g/litre + sodium nitroprusside 50 mg/200 ml water and sodium hydroxide 25 g/litre + sodium hypochlorite 10.5 ml/200 ml water. A 500 µl of 0.08 M urea solution (substrate) was added in a 1 g of soil sample in a capped glass bottle. The bottles were incubated at 37ºC for two hours. 10 ml of 1 N HCl were added and kept in a shaker for 30 min and the suspension filtered. 1 ml aliquot was taken with 5 ml each of reagent added. The volume of the reaction mixture was adjusted to 1.0 ml with distilled water. The tubes were left for 30 min for color development. The blue colored filtrate was analyzed with spectrophotometer at 625 nm absorbance. Urease activity was expressed μg of urease released g^{-1} soil h^{-1}.

3.18 Measurement of derived above- and below- ground residue C and N inputs

Annual C and N inputs from the retained crop residues into soil were measured up to the 30 cm soil depth. Derived C inputs refer to the amount of C present in the retained residue i.e. 40% C is assumed to be present in the total biomass of all crops (Bolinder *et al*., 2007; Das *et al*., 2013). The belowground root biomass C inputs were estimated from the quotients of the aboveground biomass produced to the respective shoot: root of maize (6.25) and wheat (7.4), multiply by 40% of C present in biomass. From the total aboveground biomass produced, 70% of the biomass C from roots (and rhizodeposition) remained within 0–30 cm soil layer for maize and wheat (Kundu *et al*., 2001; Das *et al*. 2013). N inputs were calculated as the product of the quantity of retained residues and the total N concentration in crop residues after harvest (Al- Kaisi *et al*., 2005; Gal *et al*., 2007).

3.18.1 Soil organic C and TN pools analyses

The bulk density values were used to convert SOC and TN concentration (g kg^{-1}) to mass per soil area (Mg ha^{-1}) within a certain soil depth using the equation from Ellert and Bettany (1995).

SOC and N stocks (Mg ha^{-1}) = conc. × bulk density × depth × 10000 m^{-2} ha^{-1} × 0.1

Where conc. = element concentration (g kg^{-1}); bulk density (Mg m^{-3}); soil depth (m)

3.19 Greenhouse gases emission analyses

Greenhouse gas emissions were measured *in-situ* with a closed chamber technique as described by Bhatia *et al*. (2013). Gas fluxes from the soil within the closed-chambers were collected periodically. A change in concentration of gases with time during the period was measured to describe the linear concentration change. The closed-chambers (50 cm height, 20 cm length and 20 cm width) had a silicon septum fitted at the top of chamber to collect gas samples. They were firmly inserted into soil and the channels filled with water for an air-tight condition. Gas flux samples using surgical syringes were taken from the headspace immediately after sealing into soil at equal time interval (0, 30 and 60 minutes) every week and subsequently after fertilization. Temperature inside the chamber and the ambient were recorded. The gas samples were then analysed immediately with gas chromatograph (GC) to determine the amount of flux at a given time. Concentration of N_2O in the gas samples was analysed by gas chromatograph fitted with an electron capture detector (ECD), while CO_2 concentration in the gas samples was analyzed by gas chromatograph (GC) fitted with a flame ionization detector (FID).

3.19.1 Nitrous oxide (N_2O) flux

Nitrous oxide (N_2O) flux was calculated from the following equations: N_2O emission was expressed as N_2O–N in g ha^{-1}

$$N_2O \text{ flux} = [(Ct - Co)/t] \times H \times 44/22.4 \times 10000 \times 24 \text{ mg ha}^{-1} \text{ d}^{-1}$$

Where (C_t –C_o) is the change in concentration at time t, Cross-sectional area of the chamber (m^2) = A; Volume of headspace (L) = 1000 X AH; N_2O concentration at 0 time = C_o; N_2O concentration after time t = C_t; When t is in hours, then flux (mL $m^{-2}h^{-1}$) = [(Ct-Co) × AH)/ (A × t); Molecular weight of N_2O is 44,

3.19.2 Carbondioxide (CO_2) flux

CO_2 flux was calculated from the following equations.

Flux of gases (F as g CO_2-C m^{-2} day^{-1}) can be computed as:

$F = (Dg/Dt)\ (V/A)\ k$

Where Dg/Dt is the linear change in CO_2 concentration inside the chamber (g CO_2–C m^{-3} min^{-1}); V is the chamber volume (m^3); A is the surface area of the chamber (m^2) and k is the time conversion factor (1440 min day^{-1}). Chamber gas concentration can be converted from molar mixing ratio (ppm) determined by GC analysis to mass per volume by assuming ideal gas relations. Hourly CO_2 fluxes were calculated from the time vs. concentration data using the following formula. CO_2 emission was expressed as CO_2–C in kg ha^{-1}.

$$CO_2\text{-C flux} = (DX \times EBV\ (STP) \times 12 \times 103 \times 60) / (106 \times 22400 \times T \times A)$$

Where, DX = Difference in flux value between 30 min and 0 min (converted to ppm based on the standard CO_2 values), EBV= effective box volume, T= Flux time in min, A= cross sectional area of the chamber.

3.20 Herbicide Residues Analyses

Soil samples from 0–15 cm depth were collected after harvest of each crop for herbicide residues analyses. Pure analytical grade (95–98%) of pendimethalin, atrazine, carfentrazone-ethyl and clodinafop-propargyl were used as standard solutions. Pendimethalin and atrazine were analysed by gas liquid chromatography (GC), while carfentrazone-ethyl and clodinafop-propargyl were analysed by high performance liquid chromatography (HPLC).

3.20.1 Standard solution preparation

10 mg of each herbicide was taken in 10 ml volumetric flask and made up the volume with appropriate solvent to obtain 1000 ppm (1000 µg/ml) stock solution. From this solution different dilutions were prepared (100, 50, 25, 10, 5, 1, 0.5 ppm) by respective solvent.

3.20.2 Herbicide residue extraction from soil

Analysis was carried out using standardized HPLC and GC condition as described above. The retention time (RT) and the peak area of herbicides in the sample and standard solution were recorded.

3.20.2.1 Pendimethalin and Atrazine

A 50 g representative soil sample was extracted with acetone three times (70 + 50 + 30 ml) by shaking on a horizontal shaker for 30 min for each time. The contents were filtered under suction; the solvent of filtrate was evaporated with rotary vacuum evaporator to minimum, transferred to a separating funnel and diluted with 50 ml 10% aqueous NaCl and partitioned with dichloromethane (DCM) three times (50+50+40 ml). The organic phase (lower portion in separator funnel) was collected and dried over anhydrous Na_2SO_4 (5 g). Solvent was evaporated to dryness on a rotary vacuum evaporator. Residues, thus obtained, were re-dissolved in 2 ml hexane: acetone (9:1) and analyzed using gas chromatography (GC).

3.20.2.2 Carfentrazone-ethyl and clodinafop-propargyl

The soil sample (10 gm) were place in a 50 ml conical flask and 10 ml distilled water was added to it. The contents were horizontal shaker for 30 min. The soil along with water was transferred into a centrifuge tube and centrifuged on a Remi-24 Model at 5000 rpm for 10 min at room temperature. The supernatant water was filtered with

Whatman No. 1 filter paper and kept for further clean up by solid phase extraction cartridge. The clean-up were done with RP-18 Bond Elute (Merck) SPE cartridge (3 g). Cartridge was conditioned with acetonitrile (2 ml) followed by equilibration with distilled water (2 ml). A 5 ml of sample extract (in water) was loaded onto the cartridge followed by washing with distilled water (2 ml). Finally the cartridge was eluted with 2 ml acetonitrile (HPLC grade) which was used for injection to HPLC.

The quantity of herbicide present in the extract was calculated using the following equation:

$$Y = \frac{D}{B} \times \frac{C}{W} \times V$$

Where, Y= concentration of herbicide residue in sample (µg/g); D= peak area of sample; B= peak area of standard; C= concentration of standard solution (µg/g); W= weight of the soil taken (g); V= final volume of made for analysis.

3.21 Resource-use efficiency

3.21.1 Nitrogen economy and efficiency

Nitrogen economy was based on the effectiveness of the GreenSeeker sensor. The designated amount of N recommended and that applied; the N not applied designates the N economy expressed in kg ha^{-1} or %.

Nitrogen efficiency (kg grain yield kg^{-1} N) was calculated on the basis of grain yield to the N applied. It denotes the partial factor productivity of applied N.

3.21.2 Carbon retention efficiency

Carbon retention efficiency (CRE) were calculated using the equation from Bhattacharyya *et al.* (2009).

$$\text{CRE (\%)} = \left[\frac{\text{SOC}_{\text{final}} - \text{SOC}_{\text{initial}}}{\text{MCI}}\right] 100$$

Where SOC final and SOC initial represent SOC (Mg ha^{-1}) in the final and initial soils, respectively, and ECI is the cumulative estimated C input (Mg ha^{-1}) between the initial and the final year of experimentation.

3.21.3 Nitrogen retention efficiency

Nitrogen retention efficiency (NRE) was adapted from CRE.

$$\text{NRE (\%)} = \left[\frac{\text{TN}_{\text{final}} - \text{TN}_{\text{initial}}}{\text{MNI}}\right] 100$$

Where TN final and TN initial represent TN (Mg ha^{-1}) in the final and initial soils, respectively, and MNI is the cumulative measured N input (Mg N ha^{-1}) between the initial and the final year of experimentation.

3.21. System water productivity

System water productivity (kg ha^{-1} mm^{-1}) was calculated based on the quotient of wheat equivalent yield to the total water applied (summation of irrigation and effective rainfall).

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

Where yield is wheat equivalent yield; total water use is the summation of irrigation applied and the effective rainfall. Irrigation applied was estimated from the number of irrigation to the depth of water (6 mm). Effective rainfall was calculated from the USDA derived method ($Pe= Pt (125 - 0.2 Pt)/ 125$ when $Pt < 250$ mm; or $Pe= 125 + 0.1Pt$ when $Pt \geq 250$mm), where Pe= monthly effective rainfall (mm) and Pt= total monthly rainfall (mm).

3.22 Economic/profitability analysis

The economic analysis in terms of gross and net returns and net benefit: cost ratio (returns per rupee invested) were estimated from the existing price rate of inputs and output (Appendix IV–VII). The total variable inputs cost were included in the total cost of production e.g. costs of ploughing, seeds, sowing, fertilizers, irrigation, crop protection, harvesting, threshing etc. The fixed input–land rental value was included in the cultivation cost. Returns per input were calculated from:

Gross returns = price of the grains and stover/straw produced

Net returns = gross returns – total costs of cultivation

Net benefit: cost ratio = Net returns / total cost of cultivation.

3.22.1 System economics

The sum of cost of cultivation, gross and net returns and benefit cost were maize–wheat cropping were calculated to express the system economics.

3.23 Statistical analysis

The data sets (year-wise and the pooled of two years) were subject to analysis of variance (ANOVA) using the SAS software package (Version 9.0) to test whether significant differences existed between the treatments (Gomez and Gomez, 1984). Considering non-normality distribution of data on weed density and dry weight across the treatments/plots, the data were transformed by square-root method ($\sqrt{x}+0.5$) to satisfy conditions for the analysis of variance comparison.The treatment means were compared with the least significant difference (LSD) test at $p \leq 0.05$.

EXPERIMENTAL RESULTS Chapter 4

The results on the experimentation entitled ‘nitrogen and weed management in maize–wheat cropping system under conservation agriculture’ during the rainy and winter seasons of 2013–2015 have been depicted in tabular and graphical formats. The treatment effects have been presented individually and interactively along with their respective standard error of means and error bars where necessary, according to least significant difference at $P \leq 0.05$.

4.1 Weed growth

4.1.1 Maize

4.1.1.1 Weed flora and category-wise weed distribution

Weed flora present during the growing period include three broad-leaved, two grassy and one sedge weeds. Prominent broad-leaved weeds were *Commelina benghalensis* (L.)*, Digera arvensi*s (L.) Forsk. and *Trianthema portulacastrum* (L.). Whereas *Dactyloctenium aegyptium* (L.), *Digitaria sanguinalis* (L.) were the grassy weeds, and sedge *Cyperus rotundus* (L.).

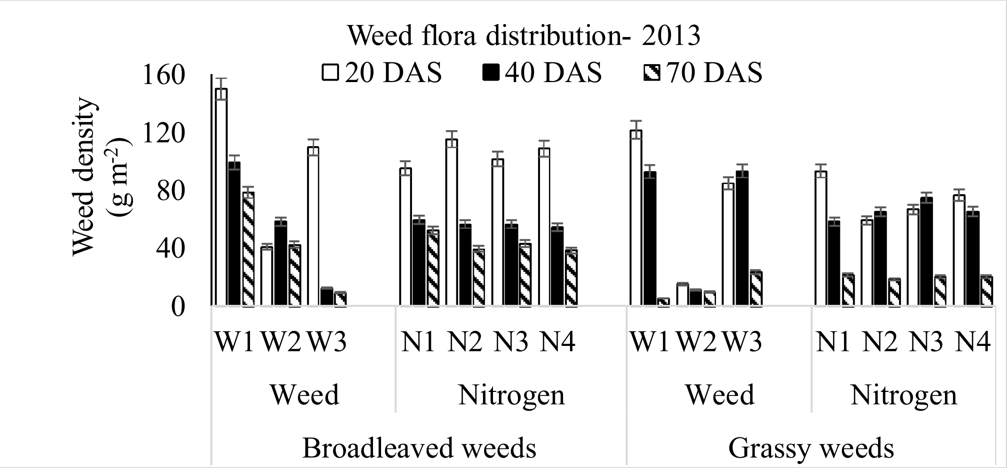


Figure 4.1 Weed flora distribution and density in maize at 20, 40 and 70 days after sowing (DAS) as influenced by weed and N management in 2013. Error bars in a columns denotes LSD ($p \leq 0.05$).

The distribution of grassy and broad-leaved weeds differed significantly between the weed management treatments (Figures 4.1 and 4.2). There were more broad-leaved weeds in the weedy check (W_1), whereas grassy weeds proliferated in the brown manured plots (brown manuring killed with 2,4-D at 25 days after sowing;

manured plots (brown manuring killed with 2,4-D at 25 days after sowing; W_3). In weedy check, *Commelina benghalensis* (about 95%) were more dominant. The brown manuring treatment (W_3) resulted in fewer broad-leaved, yet higher grassy weeds than in atrazine + pendimethalin (W_2).

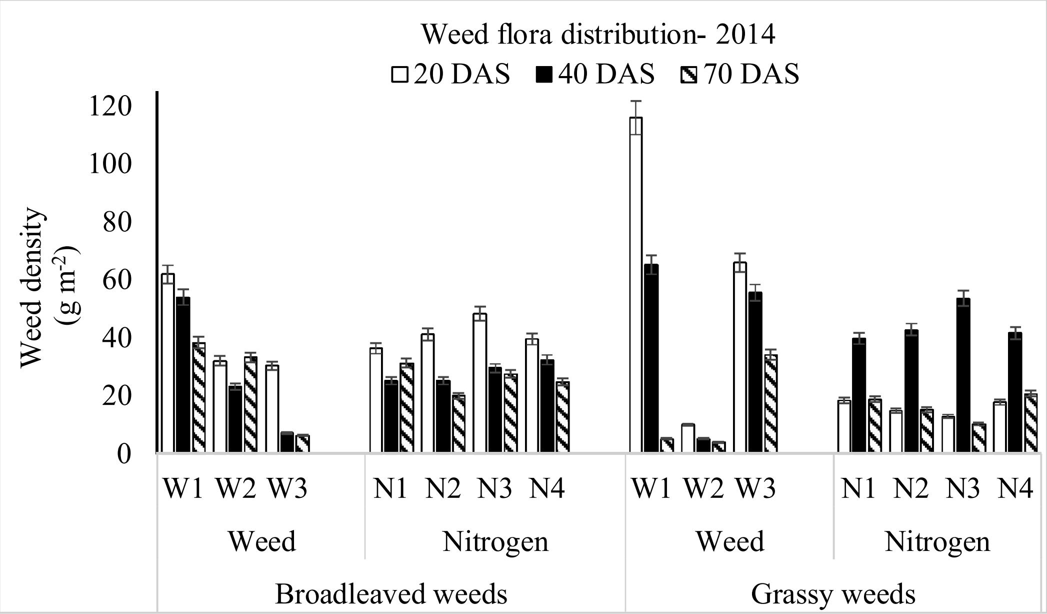


Figure 4.2 Weed flora distribution and density in maize as influenced by weed and N management in 2014. Error bars in columns denotes LSD ($p \leq 0.05$).

4.1.2 Total weed density

The weed management treatments on total weed density differed significantly at 20 and 40 DAS in both years (2013 and 2014) (Figure 4.3). Among the weed management treatments, the pre-emergent herbicide combination (W_2; atrazine + pendimethalin) had lower total weed density than the brown manuring (W_3; brown manuring + 2,4-D) and weedy check (W_1) at 20, 40 and 70 DAS. Nitrogen management did not show consistent significant differences on the total weed density. However, higher N fertilisation at sowing (N_1– 100% whole basal application and N_4– 80% + rest N by GS) influenced weed density than with the lower fertilisation at 20 DAS. Also, supplemental N fertilisation in the GreenSeeker treatments resulted in higher weed density at 40 DAS. Furthermore, weed density were suppressed drastically at 70 DAS in both years. The total weed density in the second year were 31, 39 and 44% lower in the weedy check, atrazine + pendimethalin, and brown manuring + 2,4-D plots, respectively, over the first year.

The interaction effects between the treatments were significant in the second year at 20 and 40 DAS (2014).

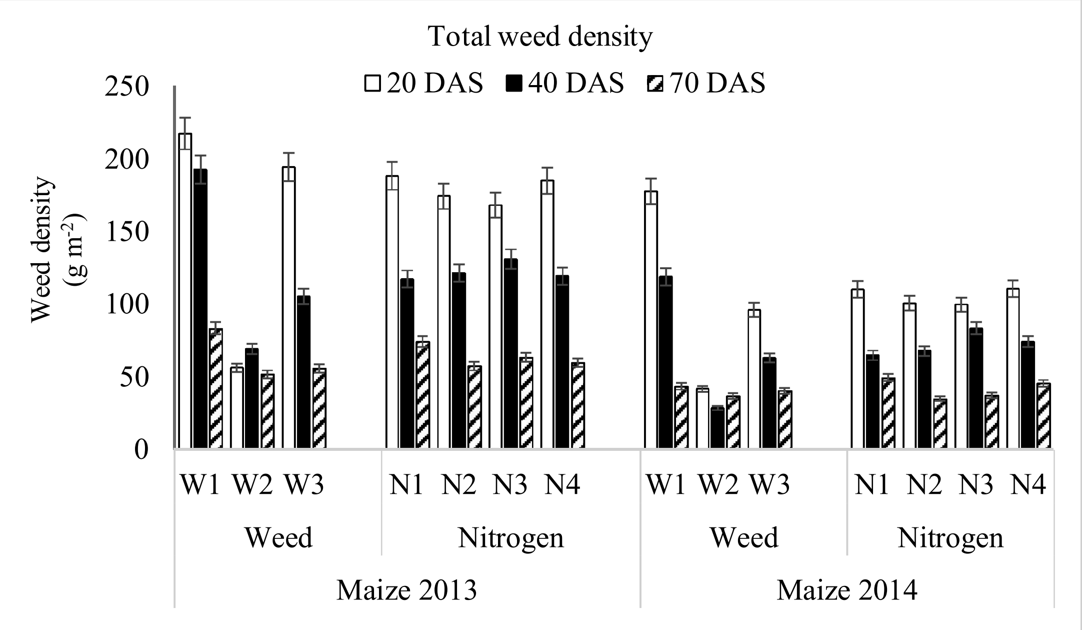


Figure 4.3 Total weed density in maize at 20, 40 and 70 DAS as influenced by weed and N management in 2013 and 2014. Error bars in columns denotes LSD ($p \leq 0.05$).

4.1.3 Weed dry weight

Weed management treatments differed significantly on weed dry weight at 20, 40, 70 DAS in both years (Table 4.1). Atrazine + pendimethalin (W_2) resulted in significantly lower total weed dry weight than that in brown manuring (W_3) and weedy check (W_1) at all these dates. N fertilisation could not bring about significant variations in weed dry weight, but higher N fertilisation at sowing (N_1– 100% whole basal application; and N_4– 80% + rest N by GreenSeeker) resulted in slightly higher weed dry weight than that with lower N fertilisation (i.e. N_2– 50% + 25% broadcast + rest N by GreenSeeker; and N_3– 50% + rest N by GreenSeeker). Also, additional N fertilisation in the GreenSeeker treatments (N_2 and N_3) resulted in higher weed dry weight at 40 DAS. There were no significant interaction between weed and nitrogen management effects in the first year (2013), yet the treatment effects consistently interacted in the second year (2014).

Table 4.1 Total weed dry weight in maize at 20, 40 and 70 DAS as influenced by weed and N management in 2013 and 2014

Treatment	2013 (g m^{-2})			2014 (g m^{-2})		
	20 DAS	40 DAS	70 DAS	20 DAS	40 DAS	70 DAS
Weed (W) management						
W_1	62.4 (8.1)	167.2 (13.0)	98.0 (9.8)	27.0 (5.6)	145.9 (12.2)	73.2 (8.2)
W_2	5.5 (2.4)	24.2 (4.8)	13.1 (4.0)	8.0 (3.2)	11.7 (3.8)	9.6 (3.2)
W_3	49.4 (7.2)	108.4 (10.4)	53.8 (7.2)	12.5 (4.0)	69.7 (8.2)	39.2 (6.4)
SEm±	4.2 (0.4)	12.4 (0.4)	17.5 (0.9)	3.7 (0.5)	7.2 (0.4)	12.5 (1.0)
LSD ($P \leq 0.05$)	16.4 (1.5)	48.8 (1.4)	68.8 (3.4)	14.6 (1.9)	28.5 (1.6)	49.0 (4.1)
Nitrogen (N) management						
N_1	40.6 (6.2)	81.6 (8.6)	63.9 (7.6)	17.6 (3.8)	67.3 (7.8)	45.6 (6.4)
N_2	35.6 (5.9)	115.6 (10.2)	46.3 (6.8)	17.0 (4.4)	76.4 (8.2)	31.3 (5.6)
N_3	35.7 (5.9)	103.2 (9.4)	53.6 (7.0)	17.6 (4.6)	78.3 (8.2)	39.6 (6.0)
N_4	45.2 (6.6)	97.2 (9.2)	52.8 (7.0)	15.4 (4.2)	78.4 (8.2)	39.5 (6.0)
SEm±	3.2 (0.2)	12.0 (0.7)	5.0 (0.3)	1.8 (0.2)	7.8 (0.4)	3.0 (0.2)
LSD ($P \leq 0.05$)	9.4 (0.7)	35.5 (2.1)	14.9 (0.9)	5.4 (0.6)	21.4 (1.2)	2.3 (0.7)
W*N ($P \leq 0.05$)	NS	NS	NS	9.3 (1.1)	12.7 (1.2)	15.7 (1.3)

Values in parentheses denotes square-root ($\sqrt{X} + 0.5$) transformed values

4.1.4 Weed control efficiency

Weed control efficiency (WCE) differed significantly between the weed management treatments at 20 DAS in both years (Table 4.2), but their effects were non-significant at 40 and 70 DAS. WCE was higher in atrazine + pendimethalin (W_2) than brown manuring (W_3) at 20 DAS, but comparable at 40 and 70 DAS. The WCE declined over time with the pre-emergent herbicide combination (atrazine + pendimethalin), whereas increased at 40 DAS for brown manuring. N fertilisations effects did not show any difference in respect of the WCE. Also with the N fertilisations effect, WCE declined at 70 DAS. There were no significant interaction effects between weed and N management treatments on the WCE.

Table 4.2 Weed control efficiency (WCE) in maize at 20, 40 and 70 DAS as influenced by weed and N management in 2013 and 2014

Treatment	WCE (%) – 2013			WCE (%) – 2014		
	20 DAS	40 DAS	70 DAS	20 DAS	40 DAS	70 DAS
Weed (W) management						
W_1	0.0	0.0	0.0	0.0	0.0	0.0
W_2	52.8	49.8	43.2	60.0	55.0	45.7
W_3	35.6	46.5	40.8	37.5	49.1	45.3
SEm±	3.4	1.7	1.2	4.8	1.8	1.4
LSD ($P \leq 0.05$)	13.2	NS	NS	18.8	NS	NS
Nitrogen (N) management						
N_1	31.5	33.5	32.2	32.3	32.6	32.4
N_2	32.4	39.6	32.8	33.9	34.7	32.6
N_3	35.2	30.3	32.8	36.1	38.4	34.3
N_4	32.0	36.1	31.8	33.0	39.8	34.7
SEm±	2.7	2.0	2.0	2.9	2.2	2.0
LSD ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS
W*N ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS

4.1.5 Weed control Index

Weed control index (WCI) differed significantly with the weed management treatments at 20 DAS in both years (Table 4.3), whereas N fertilisations were not significantly different. The WCI for the herbicide combination of atrazine + pendimethalin (W_2) decreased over days of sowing, and were between 63–75% and 68–80% in the first and second year, respectively, whereas for brown manuring effects (W_3), WCI were between 40–60%, which increased over days of sowing. Consistent interactions between the treatments were observed at 20 DAS in both years.

Table 4.3 Weed control index (WCI) in maize at 20, 40 and 70 DAS as influenced by weed and N management in 2013 and 2014

Treatment	WCI (%) – 2013			WCI (%) – 2014		
	20 DAS	40 DAS	70 DAS	20 DAS	40 DAS	70 DAS
Weed (W) management						
W_1	0.0	0.0	0.0	0.0	0.0	0.0
W_2	75.3	69.6	62.9	80.0	73.6	68.0
W_3	40.1	55.7	51.1	40.3	59.9	53.9
SEm±	3.9	4.4	4.0	6.9	4.0	3.7
LSD ($P \leq 0.05$)	15.5	NS	NS	27.0	NS	NS
Nitrogen (N) management						
N_1	45.9	39.0	41.5	45.0	39.9	44.6
N_2	40.2	35.0	46.0	38.3	41.0	38.8
N_3	39.1	42.0	41.7	38.6	44.1	48.3
N_4	49.3	44.3	40.7	42.5	42.5	46.2
SEm±	2.4	4.2	2.5	2.4	1.8	2.6
LSD ($P \leq 0.05$)	7.0	12.4	7.3	7.2	5.3	7.8
W*N($P \leq 0.05$)	10.5	NS	NS	12.5	9.1	NS

4.1.6 Weed Index

The weed index (WI) as a measure of the yield loss, based on the yield obtained in the highest N treatment (N_2) differed significantly with the weed and N management treatments in both years. Weed treatment effect with the pre-emergent herbicide combination (W_2; atrazine + pendimethalin) had the least weed index (about 5–7% yield loss) in both years. While weedy check (W_1) had the highest (about 9–14%). Among the N fertilisation effects, whole N fertilisation applied as basal (N_1) resulted in the highest weed index (about 13–20% yield loss), whereas the GreenSeeker N_3–50% + rest N by GreenSeeker had the least weed index (about 7–9%) in both years. Significant interactions between the treatments effects were recorded in 2014.

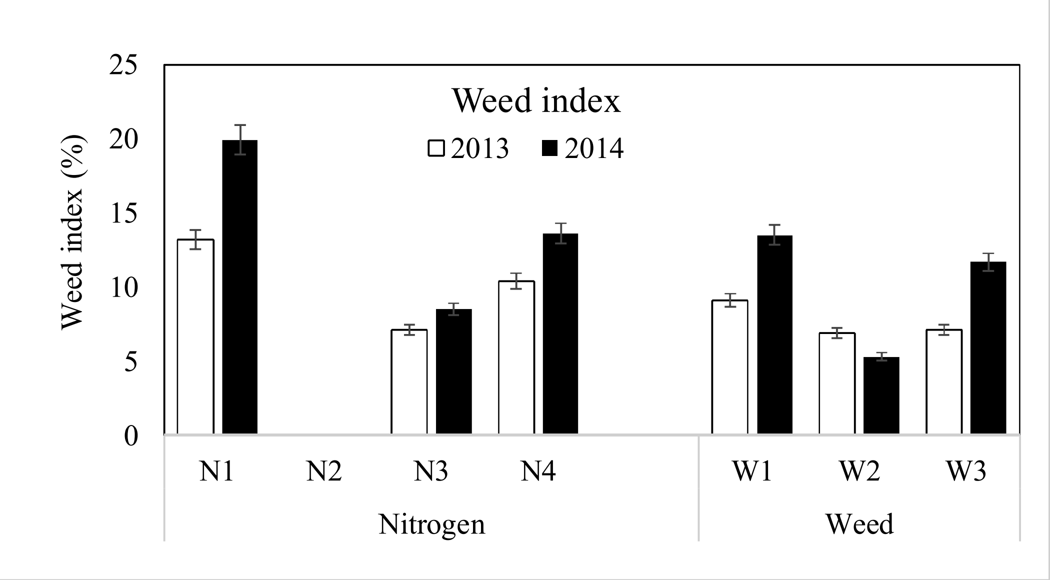


Figure 4.4 Weed index in maize as influenced by weed and N management in 2013 and 2014. Error bars in columns denotes LSD ($p \leq 0.05$).

4.1.2 Wheat

4.1.2.1 Weed flora and category-wise weed distribution

Six broad-leaved and two grassy weed flora were present in both cropping years. The broad-leaved weeds were swine cress (*Coronopus didymus* L.), sweet clover (*Melilotus indica* Lamk), Indian sorrel or toothed dock (*Rumex dentatus* L.), pimpernel (*Anagallis arvensis* L.), corn spurrey (*Spergula arvensis* L.), and common lambsquarters (*Chenopodium album* L.); whereas the grassy weeds were wild oat (*Avena sterilis* ssp *ludoviciana Durieu*) and littleseed canarygrass (*Phalaris minor* Retz.). There were more grassy weeds than broad-leaved (Figure 4.5 and 4.6). About 80–90% of the grassy weeds present were *Avena sterilis* ssp *ludoviciana.* However, the distribution of weed flora between the weed management treatments was not significantly different (Figures 4.5 and 4.6) in both years.

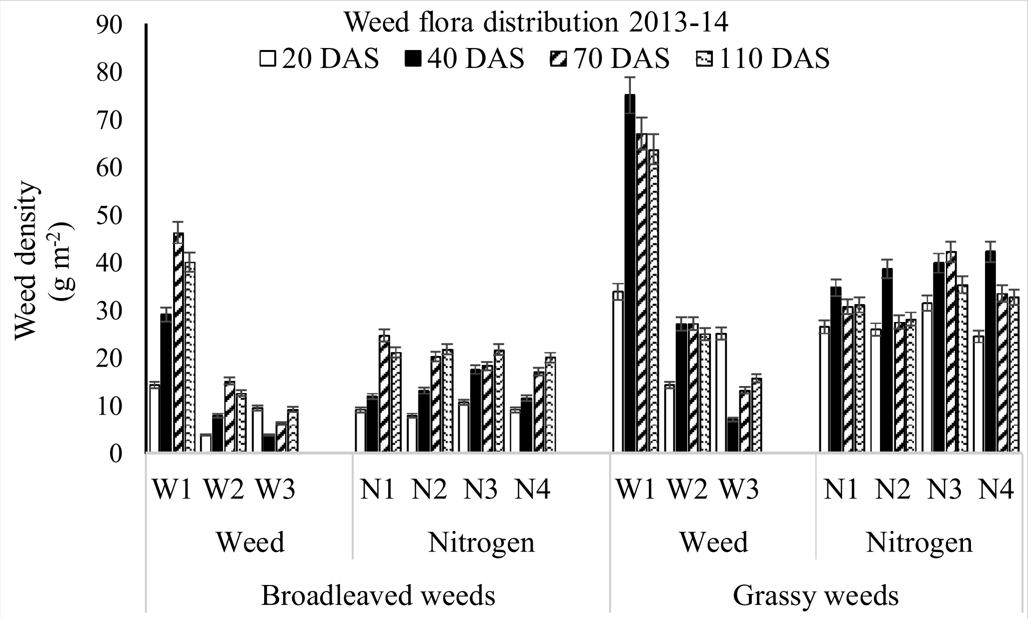


Figure 4.5 Weed flora distribution and density in wheat at 20, 40, 70 and 110 DAS as influenced by weed and N management in 2013–14 and 2014–15. Error bars in columns denotes LSD ($p \leq 0.05$).

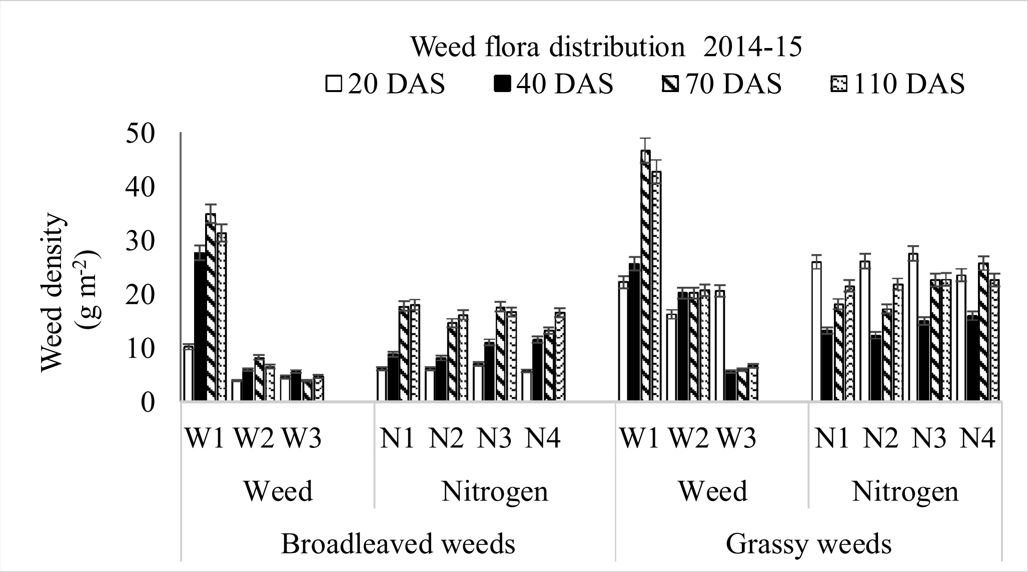


Figure 4.6. Weed flora distribution and density in wheat at 20, 40, 70 and 110 DAS as influenced by weed and N management in 2013–14 and 2014–15. Error bars in columns denotes LSD ($p \leq 0.05$)

4.1.2.2 Weed density

Total weed density differed significantly between the weed management treatments at 20, 40, 70 and 110 DAS in both cropping years (2013–14 and 2014–15) (Figure 4.7). Weed density increased over time (days of sowing) with the weedy check (W_1). Whereas the post-emergent (W_3; clodinafop + carfentrazone) applied 30 DAS suppressed weed growth over time (i.e. at 40, 70 and 110 DAS) than the pre-emergent (W_2; pendimethalin + carfentrazone) applied at sowing, which had the least weed growth at 20 DAS. The N fertilisations effect did not show significant differences between the N levels. There were significant interaction effects between the treatments at 70 and 110 DAS in both years. Weed density were suppressed in the second year over the first year by 35, 23 and 36% in the weedy check, pre-emergent (pendimethalin + carfentrazone) and post-emergent (clodinafop + carfentrazone), respectively.

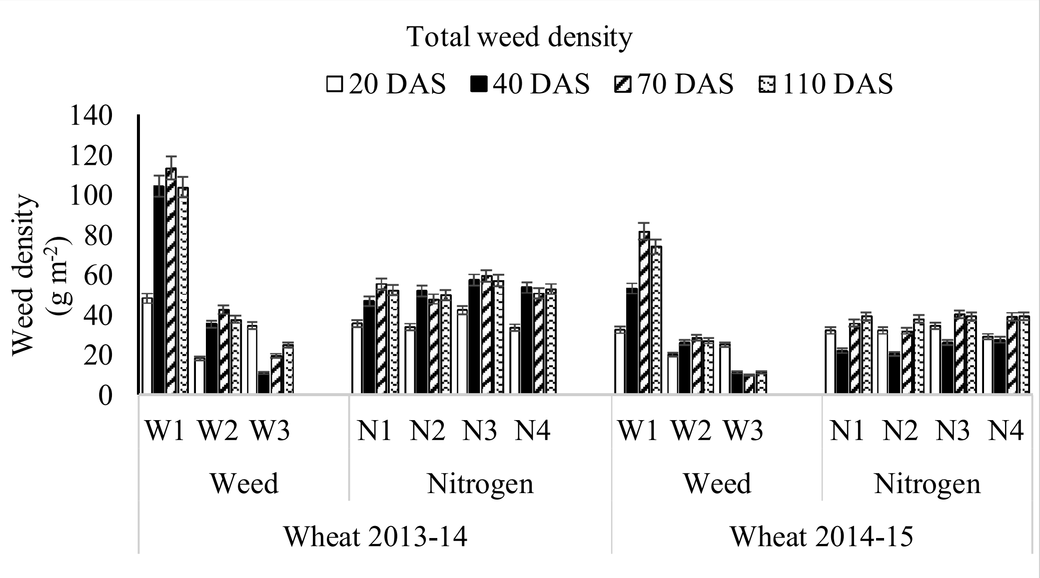


Figure 4.7 Total weed density in wheat at 20, 40, 70 and 110 DAS as influenced by weed and N management in 2013–14 and 2014–15. Error bars in columns denotes LSD ($p \leq 0.05$).

4.1.2.3 Weed dry weight

The total weed dry weights were significantly different at 40 and 70 DAS in both years under weed management treatments (Table 4.4). Weed dry matter weights were highest in weedy check (W_1) and least in the post emergent (W_3; clodinafop + carfentrazone) herbicide combination. It increased in weedy check and the pre-emergent (W_2; pendimethalin + carfentrazone) herbicide combination, whereas decreased in the post-emergent (clodinafop + carfentrazone) herbicide combination with the advancement of days/stages of crop. N fertilisations did not show significant differences between the N levels except at 70 DAS in the second year (2014–15). The highest weed dry weight was observed in the (N_3– 50% + rest N by GS and N_4– 80% + rest N by GS) with higher supplemental N fertilisations and least with N_2– 50% + 25% broadcast + rest N by GS. There were significant interactions between the weed and N treatments at 70 DAS in both years.

Table 4.4 Total weed dry weight in wheat at 20, 40, 70 and 110 DAS as influenced by weed and N management in 2013–14 and 2014–15

Treatment	2013–14 (g m^{-2})				2014–15 (g m^{-2})			
	20 DAS	40 DAS	70 DAS	110 DAS	20 DAS	40 DAS	70 DAS	110 DAS
Weed (W) management								
W_1	7.2	67.5	195.1	212.4	5.7	19.8	155.2	172.0
	(2.8)	(8.2)	(14.4)	(16.4)	(2.6)	(4.8)	(12.6)	(13.6)
W_2	6.0	11.7	46.7	60.2	5.0	6.0	39.2	44.4
	(2.6)	(3.6)	(6.7)	(8.2)	(2.4)	(2.6)	(6.1)	(8.2)
W_3	6.0	5.0	16.1	22.3	5.2	5.0	9.2	22.3
	(2.6)	(2.4)	(4.2)	(4.6)	(2.4)	(2.4)	(3.2)	(4.6)
SEm±	0.3	11.3	16.1	15.5	0.3	2.6	10.1	9.4
	(0.1)	(0.8)	(0.7)	(0.6)	(0.1)	(0.4)	(0.8)	(0.6)
LSD ($P \leq 0.05$)	1.2	44.5	63.0	60.9	1.0	10.4	39.7	36.9
	(0.3)	(3.2)	(2.7)	(2.5)	(0.3)	(1.4)	(3.0)	(2.4)
Nitrogen (N) management								
N_1	5.7	28.2	159.2	166.2	5.3	12.4	67.9	74.2
	(2.6)	(5.2)	(12.7)	(12.8)	(2.4)	(3.6)	(8.1)	(8.4)
N_2	6.0	32.4	143.3	163.3	4.6	10.5	53.2	78.3
	(2.6)	(5.4)	(11.9)	(12.8)	(2.4)	(3.4)	(7.4)	(8.4)
N_3	6.0	31.2	168.7	169.3	4.9	12.6	75.2	79.3
	(2.6)	(5.3)	(12.9)	(12.9)	(2.4)	(3.6)	(8.3)	(8.8)
N_4	5.8	31.6	176.9	171.5	5.3	10.7	72.6	77.5
	(2.6)	(5.3)	(13.2)	(13.0)	(2.4)	(3.1)	(8.2)	(8.8)
SEm±	0.2	4.4	10.0	8.0	0.3	1.6	4.0	6.3
	(0.1)	(0.5)	(0.3)	(0.3)	(0.1)	(0.4)	(0.4)	(0.3)
LSD ($P \leq 0.05$)	0.8	13.0	28.4	23.8	0.8 (	4.5	15.6	18.6
	(0.2)	(1.4)	(0.7)	(0.6)	0.2)	(1.0)	(1.1)	(0.6)
W*N ($P \leq 0.05$)	NS	NS	28.3	22.5	NS	NS	15.8	14.6
			(5.3)	(4.8)			(4.0)	(3.8)

Values in parentheses denotes square-root ($\sqrt{X + 0.5}$) transformed values

4.1.2.4 Weed control efficiency

Weed control efficiency (WCE) differed significantly with the weed management treatments at 40, 70 and 110 DAS in both years (Table 4.5). However, the weed treatment effects did not differ at 20 DAS. WCE were highest in the post emergent (clodinafop + carfentrazone) herbicide combination at 40, 70 and 110 DAS. The WCE by clodinafop + carfentrazone were between 36–70%, whereas it was 35–48% for the herbicide combination (pendimethalin + carfentrazone) in the first and second year, respectively. N treatment effects did not differ significantly with WCE. There were no interactions between weed and N management effects.

Table 4.5 Weed control efficiency (WCE) in wheat at 20, 40, 70 and 110 DAS as influenced by weed and N management in 2013–14 and 2014–15

Treatment	WCE (%) – 2013				WCE (%) – 2014			
	20 DAS	40 DAS	70 DAS	110 DAS	20 DAS	40 DAS	70 DAS	110 DAS
Weed (W) management								
W_1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W_2	46.6	41.2	36.1	34.6	47.9	44.8	42.9	36.6
W_3	35.9	65.2	58.7	57.5	39.3	69.9	66.0	58.1
SEm±	4.9	6.0	4.0	3.8	3.4	3.4	4.6	4.0
LSD ($P \leq 0.05$)	NS	23.7	15.7	14.9	NS	13.3	18.1	15.6
Nitrogen (N) management								
N_1	31.4	35.6	31.0	28.3	35.1	39.8	38.4	33.2
N_2	30.7	36.5	36.9	30.2	34.5	37.3	40.4	36.7
N_3	35.3	37.6	34.0	29.8	36.4	37.4	39.4	35.7
N_4	31.9	39.2	31.2	28.9	38.9	38.5	40.3	33.9
SEm±	3.7	2.5	2.4	3.4	3.2	5.6	1.6	1.7
LSD ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS
W*N ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS

4.1.2.5 Weed control Index

Weed control index (WCI) differed significantly with the weed management treatments at 40, 70 and 110 DAS in both years (Table 4.6). WCI increases over time (days of sowing) with the post-emergent (W_3; clodinafop + carfentrazone) herbicide combination (ranged between 42–83%) than with pre-emergent (W_2; pendimethalin + carfentrazone) herbicide, which showed a decline (ranged between 48–62%). The WCI did not differ significantly between the N fertilisation levels.

Table 4.6 Weed control index (WCI) in wheat at 20, 40, 70 and 110 DAS as influenced by weed and N management in 2013–14 and 2014–15

Treatment	2013–14				2014–15			
	20 DAS	40 DAS	70 DAS	110 DAS	20 DAS	40 DAS	70 DAS	110 DAS
Weed (W) management								
W_1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W_2	48.2	56.2	54.8	55.1	48.8	62.2	62.0	59.6
W_3	42.3	67.4	78.8	77.9	42.8	77.4	82.5	79.8
SEm±	2.6	5.2	5.4	4.4	2.7	3.9	4.9	4.1
LSD ($P \leq 0.05$)	NS	20.4	21.2	17.2	NS	15.0	19.1	15.9
Nitrogen (N) management								
N_1	34.3	45.6	49.6	35.2	36.7	45.3	44.8	35.8
N_2	34.5	48.6	47.5	36.7	38.3	50.5	48.9	37.3
N_3	36.8	44.2	43.6	36.3	36.8	47.2	42.9	36.9
N_4	34.5	44.6	48.2	35.8	37.1	47.3	45.6	36.0
SEm±	3.9	2.6	4.7	3.1	4.4	5.1	2.4	2.3
LSD ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS
W*N ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS	12.4	NS

4.1.2.6 Weed Index

The weed index (% yield loss) as a function of the highest yield in N_2 – 50% + 25% broadcast + rest N by GS were significantly different with the N fertilisation effects (Figure 4.8). Among the N fertilisation effects, WI increased by 12% in both years in N_1– 100% whole basal application, whereas it was 5.2 and 7.7% higher in N_3– 50% + rest N by GS; and 5.7–9% higher in N_4– 80% + rest N by GS. WI did not differ significantly between the weed management treatments. The WI declined over the years (lower in the second year than the first) between the weed treatments, but increased (higher in the second than first year) with N fertilisation effects. The post-emergent (W_3; clodinafop + carfentrazone) had lower WI (5.3 and 6.9% in the first and second year, respectively) than the pre-emergent (W_2; pendimethalin + carfentrazone) herbicide combinations (5.4 and 7.9% in the first and second year, respectively). Weedy check (W_1) resulted in the highest WI (8.9 and 9.4%, respectively). There were no significant interactions between the Weed and N treatments.

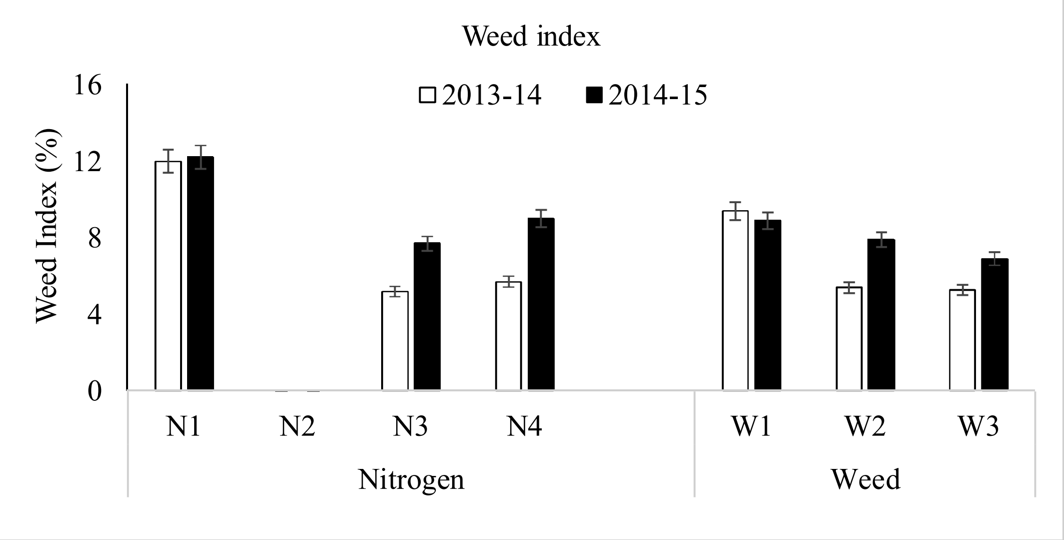


Figure 4.8 Weed index in wheat as influenced by weed and N management in 2013–14 and 2014–15. Error bars in columns denotes LSD ($p \leq 0.05$).

4.2 Crop growth and productivity

4.2.1 Maize

4.2.1.1 Growth parameters

Weed and N management effects differed significantly on plant heights, dry matter accumulation and leaf area index at 70 DAS and 100 DAS in both years of cropping (2013 and 2014) (Table 4.7 and 4.8). However, at 40 DAS, there were no significant differences between treatment effects. Among the weed management effects, brown manuring + 2 4-D and the pre-emergent (W_2; atrazine + pendimethalin) resulted in greater plant height, dry matter accumulation and leaf area index than weedy check (W_1).

Table 4.7 Growth parameters in maize as influenced by weed and N management in 2013

Treatment	Plant height (cm)			Dry matter accumulation (g plant^{-1})			Leaf area index		
	40 DAS	70 DAS	100 DAS	40 DAS	70 DAS	100 DAS	40 DAS	70 DAS	100 DAS
Weed (W) management									
W_1	128.7	185.9	185.3	47.5	133.4	187.9	2.23	4.17	3.70
W_2	135.9	200.4	201.5	50.7	136.3	198.6	2.27	4.26	3.82
W_3	130.2	202.7	202.8	48.8	142.0	211.7	2.33	4.22	3.84
SEm±	3.2	3.6	3.8	1.3	1.8	1.7	0.03	0.04	0.03
LSD ($P \leq 0.05$)	NS	14.1	14.9	NS	7.1	6.7	NS	NS	0.12
Nitrogen (N) management									
N_1	131.1	184.4	184.9	49.3	123.0	179.4	2.17	4.11	3.63
N_2	133.6	213.5	214.5	52.1	145.6	212.6	2.30	4.30	3.88
N_3	127.5	197.3	201.6	45.6	142.0	197.7	2.28	4.26	3.81
N_4	134.3	190.1	191.1	49.1	134.3	188.7	2.21	4.20	3.74
SEm±	3.8	3.4	3.3	1.4	3.2	2.7	0.02	0.04	0.04
LSD ($P \leq 0.05$)	NS	10.2	9.8	4.2	9.4	8.0	0.07	0.12	0.12
W*N ($P \leq 0.05$)	NS	NS	8.2	NS	NS	7.9	NS	NS	0.10

Between the N management effects, the optimised GreenSeeker-guided N fertilisations (i.e. N_2– 50% + 25% broadcast + rest N guided by GS; followed by N_3– 50% + rest N guided by GS and N_4– 80% + rest N guided by GS, respectively) resulted in greater plant height, dry matter accumulation and leaf area index than whole N basal application (N_1– 100% whole). There were consistent significant interactions between the treatment effects on plant height, dry matter accumulation and leaf area index at 100 DAS in both years.

Table 4.8 Growth parameters in maize as influenced by weed and N management in 2014

Treatment	Plant height (cm)			Dry matter accumulation (g plant^{-1})			Leaf area index		
	40 DAS	70 DAS	100 DAS	40 DAS	70 DAS	100 DAS	40 DAS	70 DAS	100 DAS
Weed (W) management									
W_1	137.2	201.1	195.3	49.6	153.4	191.2	2.26	4.39	3.76
W_2	149.3	210.5	211.5	53.8	163.2	199.3	2.34	4.41	3.89
W_3	145.0	213.4	212.8	51.2	164.6	201.8	2.37	4.42	3.93
SEm±	3.1	2.6	3.5	1.7	1.8	1.8	0.03	0.07	0.04
LSD ($P \leq 0.05$)	NS	10.2	13.7	NS	7.1	7.1	NS	NS	0.17
Nitrogen (N) management									
N_1	131.1	201.7	193.9	50.9	143.2	188.9	2.21	4.25	3.77
N_2	133.6	215.1	224.5	54.1	165.6	200.7	2.38	4.57	3.97
N_3	127.5	209.6	210.6	49.2	160.3	198.9	2.34	4.43	3.91
N_4	134.3	206.9	203.1	50.1	154.7	192.6	2.29	4.39	3.85
SEm±	3.4	2.7	3.3	1.7	1.8	3.2	0.02	0.07	0.03
LSD ($P \leq 0.05$)	NS	8.0	10.7	NS	5.4	9.4	0.09	0.22	0.09
W*N ($P \leq 0.05$)	NS	NS	8.0	NS	NS	7.9	NS	NS	0.11

4.2.1.2 Yield attributes

There were significant differences between the treatment effects on maize yield attributes (Table 4.9). Number of cobs (cobs/m^2) and grains (grains/cob) differed significantly with weed and N management effects in both years of cropping. However, there were no significant differences with grain (seed) weight (100– seed weight). Brown manuring (W_3) had greater number of cobs, grains/cob and seed weight than weedy check (W_1). Atrazine + pendimethalin (W_2) resulted in comparable number of cobs, grains/cob and seed weight as brown manuring. Nitrogen management with the optimised GreenSeeker-guided N fertilisations (i.e. N_2– 50% + 25% broadcast + rest N by GreenSeeker; followed by N_3– 50% + rest N by GS and N_4– 80% + rest N by GS, respectively) resulted in greater number of cobs, grains/cob and seed weight than whole N basal application (N_1). There were no significant interactions between the treatment effects in both years.

Table 4.9 Yield attributes in maize as influenced by weed and N management in 2013 and 2014

Treatment	2013			2014		
	Cobs m^{-1}	Grain cob^{-1}	100-grain weight	Cobs m^{-1}	Grain cob^{-1}	100-grain weight
Weed (W) management						
W_1	5.8	354	24.0	5.9	359	24.2
W_2	6.0	382	24.7	6.1	391	24.8
W_3	6.1	388	24.9	6.3	398	24.7
SEm±	0.05	4.0	0.3	0.10	3.4	0.2
LSD ($P \leq 0.05$)	0.19	15.7	NS	0.38	13.3	NS
Nitrogen (N) management						
N_1	5.7	350.8	24.2	5.8	356	24.3
N_2	6.2	381.3	24.7	6.3	393	24.8
N_3	5.9	374.8	24.4	6.2	380	24.8
N_4	5.8	365.7	24.3	5.9	369	24.5
SEm±	0.09	3.2	0.2	0.09	2.29	0.3
LSD ($P \leq 0.05$)	0.27	9.6	NS	0.27	6.8	NS
W*N ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS

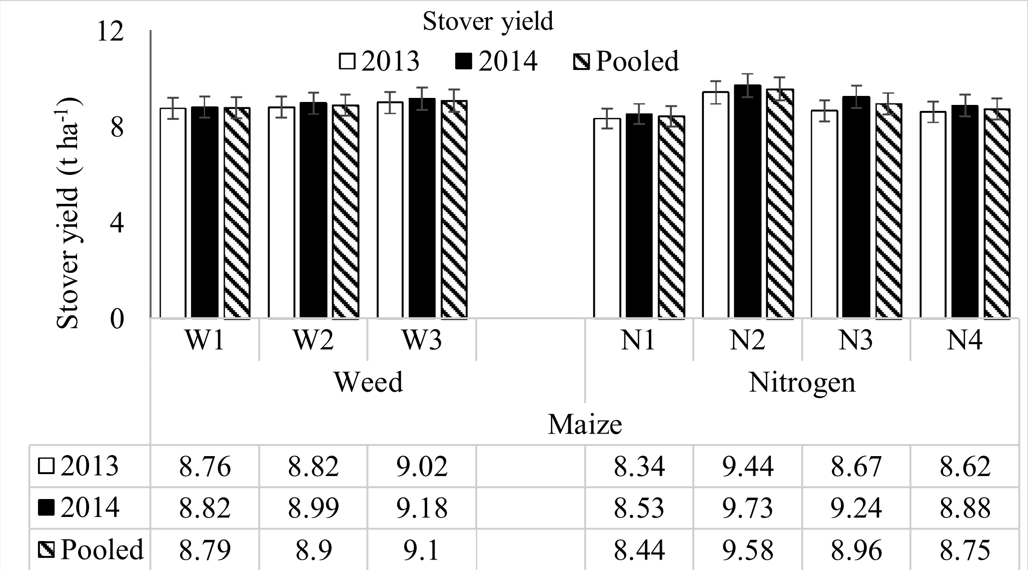
4.2.1.3 Grain and stover yields

Maize grain yield differed significantly with weed and nitrogen management effects (Table 4.10). However, stover yield did not vary significantly with the weed treatment effects in both years of cropping (Figure 4.9). Between the weed management treatments, grain yield increased by 8 and 12% in the brown manuring (W_3) over weedy check (W_1) in 2013 and 2014, respectively. Likewise, stover yields in both years were 3 and 4% higher in brown manuring + 2,4-D than weedy check. The herbicide combination (W_2; atrazine + pendimethalin) resulted in comparable grain and stover yields with brown manuring.

Table 4.10 Grain yield in maize as influenced by weed and N management in 2013 and 2014

Treatment	Grain (t ha^{-1})		
	2013	2014	Pooled
Year 2013	–	–	4.73
Year 2014	–	–	4.95
SEm±	–	–	0.15
LSD ($P \leq 0.05$)	–	–	NS
Weed (W) management			
W_1	4.49	4.60	4.54
W_2	4.85	5.10	4.97
W_3	4.86	5.16	5.01
SEm±	0.08	0.12	0.10
LSD ($P \leq 0.05$)	0.31	0.47	0.40
Nitrogen (N) management			
N_1	4.44	4.43	4.43
N_2	5.12	5.53	5.33
N_3	4.77	5.08	4.92
N_4	4.59	4.76	4.68
SEm±	0.08	0.09	0.07
LSD ($P \leq 0.05$)	0.22	0.28	0.20
W*N ($P \leq 0.05$)	0.65	0.50	0.34

The optimised GreenSeeker (N_2– 50% + 25% broadcast + rest N by GS) resulted in 13–25% higher grain and stover yields than entire N application as basal in both years of cropping. Moreover, N_2 had 9–16% higher grain and stover yields than the other GreenSeeker N_3 –50% + rest N by GS, and N_4–80% + rest N by GS treatments. The pooled grain yields over the years did not differ significantly. Interaction effects were pronounced in the grain and pooled yields but not with the stover.



	W1	W2	W3		N1	N2	N3	N4
□2013	8.76	8.82	9.02		8.34	9.44	8.67	8.62
■2014	8.82	8.99	9.18		8.53	9.73	9.24	8.88
▧Pooled	8.79	8.9	9.1		8.44	9.58	8.96	8.75

Figure 4.9 Stover yield in maize as influenced by weed and N management in 2013 and 2014. Error bars in columns denotes LSD ($p \leq 0.05$).

4.2.1.4 Total biomass yield and harvest index

The yearly and two-year pooled total biomass yield of maize differed significantly between the weed and N management treatments in both years. Among N management effects, the brown manuring (W_3) had 7 and 5% higher total biomass yield than weedy check (W_1) in 2013 and 2014, respectively, whereas it was 2% higher than in atrazine + pendimethalin (W_2). For the N fertilisations effects, the optimised GreenSeeker (N_2– 50% + 25% broadcast + rest N by GS) had 14 and 18% higher total biomass than whole N as basal application (N_1) in first and second year, respectively. In contrast, it had 7–12% higher total biomass yield than the other GreenSeeker treatments (N_3–50% + rest N by GS), and (N4–80% + rest N by GS). The harvest index showed no significant differences across the treatments. There were no significant interactions on total biomass yield and harvest index.

Table 4.11 Total biomass yield and harvest index in maize as influenced by weed and N management in 2013 and 2014

Treatment	Total biomass (t ha^{-1})			Harvest index (%)		
	2013	2014	Pooled	2013	2014	Pooled
Year 2013	-	-	13.50	-	-	35.11
Year 2014	-	-	14.05	-	-	35.19
SEm±	-	-	0.17	-	-	0.75
LSD ($P \leq 0.05$)	-	-	0.49	-	-	NS
Weed (W) management						
W_1	12.95	13.71	13.33	34.7	33.4	34.0
W_2	13.66	14.09	13.88	35.6	36.2	35.9
W_3	13.88	14.34	14.11	35.1	35.9	35.5
SEm±	0.19	0.11	0.18	1.56	0.76	1.08
LSD ($P \leq 0.05$)	0.75	0.44	0.70	NS	NS	NS
Nitrogen (N) management						
N_1	12.78	12.96	12.87	34.8	34.0	34.4
N_2	14.56	15.26	14.91	35.2	36.3	35.7
N_3	13.44	14.32	13.88	35.6	35.5	35.5
N_4	13.22	13.64	13.43	34.8	35.0	34.9
SEm±	0.20	0.22	0.15	0.60	0.78	0.51
LSD ($P \leq 0.05$)	0.60	0.65	0.44	NS	NS	NS
W*N ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS

4.2.2 Wheat growth and productivity

4.2.2.1 Growth parameters

There were significant differences between weed and nitrogen effects on plant height, dry matter accumulation and leaf area index at 70 DAS and 110 DAS in 2013–14 and 2014–15 (Tables 4.12 and 4.13). However at 40 DAS, the growth parameter did not differ significantly. Among the weed management effect, the pre-emergent (W_2; pendimethalin + carfentrazone) and post-emergent (W_3; clodinafop + carfentrazone) herbicide combinations resulted in greater plant height, dry matter accumulation and leaf area index than that of weedy check (W_1). N fertilisations with the optimised GreenSeeker-guided N fertilisations (i.e. N_2– 50% + 25% broadcast + rest N by GS resulted in greater plant height, dry matter accumulation and leaf area index followed by N_3– 50% + rest N by GS and N_4– 80% + rest N by GS, respectively) than entire N as basal application (N_1). There were only significant interactions on the growth parameters at 110 DAS in both years.

Table 4.12 Growth parameters in wheat as influenced by weed and N management in 2013–14

Treatment	Plant height (cm)			Dry matter accumulation (g m^{-1})			Leaf area index		
	40 DAS	70 DAS	110 DAS	40 DAS	70 DAS	110 DAS	40 DAS	70 DAS	110 DAS
Weed (W) management									
W_1	38.7	55.1	98.1	42.7	159.0	607.6	0.84	4.74	5.19
W_2	39.5	57.5	99.5	43.1	171.7	659.6	0.91	5.04	5.47
W_3	39.3	57.2	99.9	45.3	174.5	661.4	0.92	5.29	5.69
SEm±	0.4	0.4	0.3	2.5	2.7	3.9	0.03	0.11	0.07
LSD ($P \leq 0.05$)	NS	1.4	1.3	NS	10.6	15.3	NS	0.44	0.27
Nitrogen (N) management									
N_1	38.9	56.2	96.4	43.5	158.8	606.6	0.86	4.77	5.04
N_2	39.3	56.9	99.9	45.9	175.3	673.3	0.93	5.19	5.65
N_3	39.2	56.9	99.7	43.3	173.8	644.1	0.88	5.20	5.54
N_4	39.1	56.5	97.8	43.7	165.6	627.6	0.89	4.93	5.44
SEm±	0.4	0.5	0.8	2.2	2.3	2.8	0.04	0.12	0.10
LSD ($P \leq 0.05$)	NS	NS	2.4	NS	6.8	8.3	NS	0.36	0.29
W*N ($P \leq 0.05$)	NS	NS	1.9	NS	NS	9.7	NS	NS	0.3

Table 4.13 Growth parameters in wheat as influenced by weed and N management in 2014–15

Treatment	Plant height (cm)			Dry matter accumulation (g m^{-1})			Leaf area index		
	40 DAS	70 DAS	110 DAS	40 DAS	70 DAS	100 DAS	40 DAS	70 DAS	110 DAS
Weed (W) management									
W_1	38.9	55.2	97.9	43.2	167.0	618.8	0.88	5.10	5.22
W_2	40.3	57.3	99.8	45.6	181.8	670.1	0.97	5.27	5.55
W_3	40.0	58.0	99.9	44.2	181.2	674.6	0.95	5.43	5.78
SEm±	0.30	0.8	0.4	2.4	4.1	4.7	0.03	0.04	0.08
LSD ($P \leq 0.05$)	NS	3.3	1.8	NS	8.2	18.4	NS	0.15	0.31
Nitrogen (N) management									
N_1	39.4	56.7	96.9	43.4	168.1	628.7	0.86	5.02	5.04
N_2	39.8	57.6	99.9	45.8	183.2	686.4	0.93	5.44	5.65
N_3	39.5	56.6	99.7	43.9	181.3	667.3	0.88	5.35	5.54
N_4	39.6	56.5	98.3	43.6	174.1	645.6	0.89	5.25	5.34
SEm±	0.4	0.6	0.4	2.2	1.8	2.9	0.04	0.11	0.15
LSD ($P \leq 0.05$)	NS	NS	1.2	NS	5.5	8.6	NS	0.32	0.44
W*N ($P \leq 0.05$)	NS	NS	1.4	NS	6.0	11.7	NS	0.23	0.34

4.2.2.2 Yield attributes

Weed management resulted in significant difference only on spike m^{-2}, whereas N fertilisations had significant differences on both spike m^{-2} and grain spike^{-1} (Table 4.14). There were no differences with spike length and grain weight (1000–seed weight). The pre- (W_2; pendimethalin + carfentrazone) and post-emergent (W_3; clodinafop + carfentrazone) herbicides resulted in higher spike length, number of spikes and grain and grain weight than weedy check (W_1). Nitrogen management with the optimised GS-guided N fertilisations (i.e. N_2– 50% + 25% broadcast + rest N by GS; followed by N_3– 50% + rest N by GS and N_4– 80% + rest N by GS, respectively) resulted in higher spike length, number of spikes and grains, and grains weight than weedy check. Significant interaction effects between the treatments were observed with spike m^{-2} in both years.

Table 4.14 Yield attributes in wheat as influenced by weed and N management in 2013–14

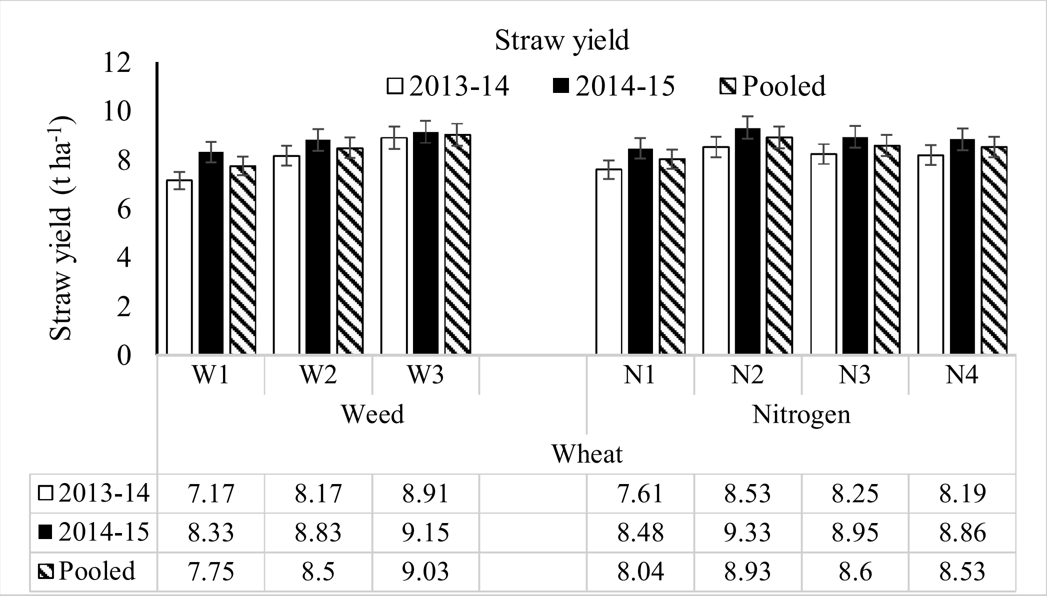
Treatment	2013–14				2014–15			
	Spike length (cm)	Spike m^{-2}	Grain Spike^{-1}	1000-seed weight	Spike length (cm)	Spike m^{-2}	Grain Spike^{-1}	1000-seed weight
Weed (W) management								
W$_1$	11.5	317.6	61.5	38.6	11.72	328.8	62.2	39.1
W$_2$	11.6	325.1	61.7	38.6	11.73	337.4	62.9	39.2
W3	11.6	327.5	61.9	38.7	11.78	338.4	63.7	39.2
SEm±	0.1	2.2	0.5	0.2	0.04	1.6	0.3	0.2
LSD ($P \leq 0.05$)	NS	8.6	NS	NS	NS	6.3	1.2	NS
Nitrogen (N) management								
N$_1$	11.6	314.1	60.2	38.7	11.72	323.3	61.8	39.1
N$_2$	11.6	342.4	62.9	38.8	11.79	350.2	64.2	39.4
N$_3$	11.6	330.5	62.6	38.7	11.77	337.6	63.8	39.1
N$_4$	11.6	323.3	61.8	38.7	11.74	328.3	62.0	39.1
SEm±	0.1	4.4	0.6	0.2	0.04	3.8	0.5	0.2
LSD ($P \leq 0.05$)	NS	13.2	2.4	NS	NS	11.3	1.6	NS
W*N ($P \leq 0.05$)	NS	9.9	NS	NS	NS	8.2	1.3	NS

4.2.2.3 Grain and straw yields

Wheat grain and straw yields differed significantly between the weed and N management treatments (Table 4.15 and Figure 4.10). Grain yield was increased by 24 and 17% in the clodinafop + carfentrazone (post-emergent) over weedy check in 2013–14 and 2014–15, respectively. Also, it was 10% higher, respectively, over pendimethalin + carfentrazone (W$_2$; pre-emergent) in both years. Likewise, straw yields in both years were 24 and 17% higher in clodinafop + carfentrazone (W$_3$; post emergent) than weedy check (W$_1$), respectively; and 9 and 4% higher than pendimethalin + carfentrazone, respectively. The optimised GS-guided N (N$_2$– 50% + 25% broadcast + rest N by GS) resulted in 10–14% higher grain and straw yields than entire N as basal in both years. Also, N$_2$ had 4–9% higher grain and straw yields than the other GS (N$_3$ and N$_4$) treatments. The pooled straw yield of two years differed significantly.

Table 4.15 Grain yield in wheat as affected by weed and N management in 2013–14 and 2014–15

Treatment	Grain (t ha^{-1})		
	2013–14	2014–15	Pooled
Year 2013-14	-	-	4.84
Year 2014-15	-	-	5.01
SEm±	-	-	0.11
LSD ($P \leq 0.05$)	-	-	NS
Weed (W) management			
W_1	4.31	4.64	4.47
W_2	4.85	4.96	4.91
W_3	5.35	5.46	5.40
SEm±	0.19	0.12	0.08
LSD ($P \leq 0.05$)	0.75	0.48	0.32
Nitrogen (N) management			
N_1	4.49	4.75	4.62
N_2	5.12	5.41	5.26
N_3	4.89	4.99	4.94
N_4	4.85	4.92	4.89
SEm±	0.08	0.07	0.05
LSD ($P \leq 0.05$)	0.22	0.20	0.16
W*N ($P \leq 0.05$)	NS	NS	NS



	W1	W2	W3	N1	N2	N3	N4
□2013-14	7.17	8.17	8.91	7.61	8.53	8.25	8.19
■2014-15	8.33	8.83	9.15	8.48	9.33	8.95	8.86
▧Pooled	7.75	8.5	9.03	8.04	8.93	8.6	8.53

Figure 4.10 Straw yield in wheat as affected by weed and nitrogen management in 2013–14 and 2014–15. Error bars in columns denotes LSD ($p \leq 0.05$).

4.2.2.4 Total biomass yield and harvest index

The total biomass yield and harvest index differed significantly with weed and N treatment effects (Table 4.16). Among weed management, clodinafop + carfentrazone (W_3; post-emergent) had 24 and 13% higher total biomass yield than weedy check (W_1) in 2013–14 and 2014–15, respectively, whereas it was 10 and 6% higher, respectively, than in pendimethalin + carfentrazone (W_2). Between the N fertilisations, the optimised GS (N_2–50% + 25% broadcast + rest N by GS) had 13 and 11% higher total biomass than whole N as basal application (N_1) in both years, respectively. Moreover, it had 4–7% higher than the GS N_3–50% + rest N by GS, and N_4 –80% + rest N by GS, respectively. The pooled yield over years differed significantly. The harvest index showed no significant differences in first year, but a significant difference existed in second year and on the pooled data between the treatments.

Table 4.16 Total biomass yield and harvest index in wheat as influenced by weed and N management in 2013–14 and 2014–15

Treatment	Total biomass (t ha^{-1})			Harvest (%)		
	2013–14	2014–15	Pooled	2013–14	2014–15	Pooled
Year 2013	-	-	12.95	-	-	37.3
Year 2014	-	-	13.87	-	-	36.7
SEm±	-	-	0.19	-	-	0.08
LSD ($P \leq 0.05$)	-	-	0.55	-	-	NS
Weed (W) management						
W_1	11.47	12.97	12.22	37.5	35.7	36.6
W_2	13.02	13.80	13.41	37.3	35.9	36.6
W_3	14.26	14.61	14.43	37.5	37.4	37.4
SEm±	0.47	0.23	0.19	0.3	0.3	0.2
LSD ($P \leq 0.05$)	1.83	0.89	0.76	NS	1.3	0.7
Nitrogen (N) management						
N_1	12.10	13.23	12.66	37.2	35.9	36.5
N_2	13.64	14.75	14.20	37.5	36.7	37.1
N_3	13.14	13.95	13.54	37.2	35.8	36.5
N_4	13.04	13.78	13.41	37.2	35.7	36.5
SEm±	0.21	0.19	0.15	0.2	0.2	0.1
LSD ($P \leq 0.05$)	0.62	0.55	0.45	NS	0.5	0.3
W*N ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS

4.2.3 System productivity

The system productivity (expressed as wheat equivalent yield) differed significantly between the weed and N management treatments (Table 4.17). It was increased by 16 and 15% in the brown manuring + herbicide combination (W_3) over weedy check (W_1) in 2013 and 2014, respectively, whereas it was 5 and 6% higher than herbicide combinations alone (W_2) in 2013 and 2014, respectively. Among the N fertilisation treatments, optimised GreenSeeker N_2– 50% + 25% broadcast + rest N by GS resulted in 15 and 19% higher system productivity than whole basal application at sowing (N_1– 100% whole) in 2013 and 2014, respectively. Furthermore, it increased by 8–13% in N_2 over the other GreenSeeker N_3 – 50% + rest N by GS and N_4 – 80%

+ rest N by GS. The pooled system productivity over years did not differ significantly.

Table 4.17 System productivity as influenced by weed and N management in 2013–14 and 2014–15

Treatment	System productivity (wheat equivalent yield) (t ha^{-1})		
	2013–2014	2014–2015	Pooled
Year 2013	–	–	9.23
Year 2014	–	–	9.62
SEm±	–	–	0.17
LSD ($P \leq 0.05$)	–	–	NS
Weed (W) management			
W_1	8.47	8.90	8.69
W_2	9.35	9.70	9.52
W_3	9.86	10.25	10.05
SEm±	0.24	0.23	0.16
LSD ($P \leq 0.05$)	0.93	0.91	0.61
Nitrogen (N) management			
N_1	8.61	8.86	8.74
N_2	9.87	10.55	10.21
N_3	9.32	9.71	9.51
N_4	9.12	9.35	9.23
SEm±	0.12	0.14	0.11
LSD ($P \leq 0.05$)	0.36	0.40	0.31
W*N ($P \leq 0.05$)	NS	NS	NS

4.3 Economics

4.3.1 Maize

4.3.1.1 Cost of cultivation

The cost of raising maize was 3% higher in the second year over that in first year under both weed and N management treatments (Table 4.18). The cost of raising maize was highest in the herbicide combinations followed by brown manuring + 2,4-D treatment (W_3), and least in weedy check (W_1).

Table 4.18 Cost of cultivation, gross and net returns and net benefit:cost (Net B: C) in maize as influenced by weed and N management in 2013 and 2014

Treatment	Cost of cultivation		Gross returns		Net returns		Net B:C	
	(× 10^3 ₹ ha^{-1})							
	2013	2014	2013	2014	2013	2014	2013	2014
Weed (W) management								
W_1	31.80	32.82	75.2	77.9	43.4	45.2	1.37	1.38
W_2	33.87	34.89	80.7	84.3	46.8	49.4	1.38	1.42
W_3	32.93	33.95	81.2	85.4	48.2	51.5	1.46	1.52
SEm±	–	–	1.2	1.6	1.2	1.5	0.04	0.05
LSD ($P \leq 0.05$)	–	–	4.8	6.1	4.8	6.1	NS	NS
Nitrogen (N) management								
N_1	32.79	33.81	74.4	74.6	41.6	40.8	1.27	1.20
N_2	33.01	34.03	85.4	91.4	52.4	57.4	1.59	1.69
N_3	32.81	33.84	79.3	84.5	46.5	50.7	1.42	1.50
N_4	32.85	33.87	76.9	79.7	44.1	45.8	1.34	1.35
SEm±	–	–	1.1	1.2	1.1	1.2	0.03	0.04
LSD ($P \leq 0.05$)	–	–	3.3	3.6	3.3	3.6	0.10	0.11
W*N ($P \leq 0.05$)	–	–	NS	6.2	NS	6.2	NS	0.18

The higher variable costs incurred in these treatments was due to the additional costs for herbicides, brown manuring and labour. For the N fertilisation management, the costs of cultivation were comparable between N applied entirely at sowing and N applied as supplement during the growing seasons. The total cost of cultivation increased by 6 and 3% in the herbicide combination (W_2; atrazine + pendimethalin) than brown manuring + 2,4-D and weedy check, respectively. The cost of cultivation for the N management was highest in N_2– 50% + 25% broadcast + rest N by GS, but comparable with the other GreenSeeker treatments (N_3– 50% + rest N by GS; and N_4– 80% + rest N by GS). The GreenSeeker supplemental treatments had 0.5–0.7% higher total cultivation cost than whole basal N fertilisation (N_1– 100% whole).

4.3.1.2 Gross returns

There were significant differences between weed and N management effects on the gross returns obtained in 2013 and 2014 (Table 4.18). The brown manuring (W_3) had 8 and 10% higher gross returns than weedy check (W_1) in the 2013 and 2014, respectively. However, atrazine + pendimethalin (W_2) had comparable gross returns with brown manuring. Also, optimised GS N_2 resulted in 15 and 22% higher gross returns than whole basal application at sowing (N_1– 100% whole) in 2013 and 2014, respectively. Furthermore, gross returns increased by 11 and 15% in N_2 – 50% + 25% broadcast + rest N by GS over the other optimised GS N_4– 80% + rest N by GS, respectively, and 8% over N_3– 50% + rest N by GS, respectively, in the first (2013) and second year (2014). The interaction between Weed and N treatments were significant only in second year.

4.3.1.3 Net returns

The net returns achieved due to weed and N treatments in 2013 and 2014 were significantly different (Table 4.18). Net returns increased by 11 and 14% higher in the brown manuring (W_3) than weedy check (W_1) in the 2013 and 2014, respectively; while it was 3 and 4% greater than the atrazine + pendimethalin (W_2). Also, optimised GS–N_2 resulted in 26 and 40% higher net returns than whole basal application at sowing (N_1– 100% whole) in 2013 and 2014, respectively. Besides, net returns increased by 19 and 25% in N_2 – 50% + 25% broadcast + rest N by GS over the other optimised GS N_4– 80% + rest N by GS, respectively, and 13% over N_3– 50% + rest N by GS, respectively, in the 2013 and 2014. The interaction effects between the treatments were significant in the second year of maize cropping.

4.3.1.4 Net benefit:cost

The weed management treatments did not differ significantly for the net benefit: cost (B: C) in 2013 and 2014 (Table 4.18). However, brown manuring (W_3) resulted in 7–10% higher net B:C than weedy check (W_1) and atrazine + pendimethalin (W_2). In contrast, net B:C showed significant difference between the N treatments. Optimised

GS-based N application (N_2) resulted in 25 and 40% greater net B:C than whole basal application at sowing (N_1– 100% whole) in 2013 and 2014, respectively. In addition, net B:C in N_2 – 50% + 25% broadcast + rest N by GS was 12% higher over N_3– 50% + rest N by GS and 19 and 25% higher over N_4– 80% + rest N by GS in 2013 and 2014, respectively.

4.3.2 Wheat

4.3.2.1 Cost of cultivation

The total cultivation cost for wheat was 3% higher in 2013–14 than in 2014–15 (Table 4.19). Raising wheat under weed and N management incurred 3 and 5% higher costs with the pre-emergent herbicide combination (W_2; pendimethalin + carfentrazone) than the post-emergent (W_3; clodinafop + carfentrazone) and weedy check (W_1), respectively in both years. But, the costs of wheat cultivation with the N fertilisation were comparable in both years of cropping.

4.3.2.2 Gross returns

The treatment effects on the gross returns achieved in 2013–14 and 2014–15 were significantly different (Table 4.19). Gross returns was increased by 25 and 17% in the post-emergent (clodinafop + carfentrazone) than weedy check in the 2013–14 and 2014–15, respectively; whereas it was 10% greater than the pre-emergent (pendimethalin + carfentrazone) herbicide combinations. The optimised GS-guided N_2 – 50% + 25% broadcast + rest N by GS resulted in 13% higher gross returns than whole basal application at sowing (N_1) in 2013–14 and 2014–15, respectively. Besides, the gross returns increased by 5–9% in N_2 over the other optimised GS N_3 – 50% + rest N by GS and N_4– 80% + rest N by GS in the 2013 and 2014.

4.3.2.3 Net returns

The weed and N management effects had significant influence on the net returns obtained in 2013–14 and 2014–15 wheat cropping (Table 4.19). Net returns obtained in the post-emergent (W_3; clodinafop + carfentrazone) were 19 and 17% higher than that in pre-emergent (W_2; pendimethalin + carfentrazone) and 42 and 27% greater over that obtained in weedy check (W_1) in 2013–14 and 2014–2015, respectively. Furthermore, the optimised GreenSeeker N_2– 50% + 25% broadcast + rest N by GS resulted in 22% higher net returns than whole basal application at sowing (N_1) in

2013–14 and 2014–15, respectively. Whereas, the net returns increased by 7–14% in N_2 over the other optimised GS N_3– 50% + rest N by GS and N_4– 80% + rest N by GS in the first and second year. The interactions between the treatment effects were significant only in first year.

Table 4.19 Cost of cultivation, gross and net returns and net benefit:cost (net B: C) in wheat as influenced by weed and nitrogen management in 2013 and 2014

Treatment	Cost of cultivation		Gross returns		Net returns		Net B:C	
	(× 10^3 ₹ ha^{-1})							
	2013–14	2014–15	2013–14	2014–15	2013–14	2014–15	2013–14	2014–15
Weed (W) management								
W_1	33.22	32.19	74.6	81.6	41.4	49.4	1.25	1.53
W_2	34.97	33.94	84.2	87.2	49.3	53.2	1.41	1.57
W_3	34.10	33.07	93.0	95.5	58.9	62.5	1.73	1.89
SEm±	–	–	3.2	1.9	3.2	1.9	0.09	0.06
LSD ($P \leq 0.05$)	–	–	12.7	7.5	12.7	7.5	0.37	0.22
Nitrogen (N) management								
N_1	33.96	32.93	78.1	83.4	44.1	50.5	1.30	1.53
N_2	34.28	33.25	88.7	94.4	54.4	61.2	1.59	1.84
N_3	34.08	33.05	84.9	87.8	50.8	54.8	1.49	1.66
N_4	34.08	33.05	84.2	86.6	50.2	53.6	1.47	1.62
SEm±	–	–	1.3	1.2	1.3	1.2	0.04	0.04
LSD ($P \leq 0.05$)	–	–	3.9	3.5	3.9	3.5	0.11	0.10
W*N ($P \leq 0.05$)	–	–	NS	NS	NS	NS	NS	NS

4.3.2.4 Net benefit:cost

The weed and N management effects differed significantly for the net B:C (Table 4.19). Clodinafop + carfentrazone (W_3) had 22 and 38% greater net B:C than pendimethalin + carfentrazone (W_2) and weedy check (W_1) in the 2013–14; whereas, it increased by 20 and 24% in 2014–15, respectively. Optimised GS N_2– 50% + 25% broadcast + rest N by GS resulted in 22–20% greater net B:C than whole basal application at sowing (N_1) in 2013–14 and 2014–15, respectively; while the net B:C in N_2 was 8–14% higher over N_3 – 50% + rest N by GS and N_4 – 80% + rest N by GS in 2013–14 and 2014–15, respectively.

4.3.3 System economics and profitability

The weed and N management had significant impact on the system economics and profitability obtained over the two year maize–wheat cropping system (Table 4.20).

Table 4.20 System economics of maize–wheat cropping as influenced by weed and N management (pooled mean two years)

Treatment	Cost of cultivation	Gross returns	Net returns	Net B:C
	(× 10^3 ₹ ha^{-1})			
Weed (W) management				
W_1	65.0	154.7	89.7	2.76
W_2	68.8	168.2	99.3	2.89
W_3	67.0	177.6	110.6	3.30
SEm±	–	1.9	1.9	0.06
LSD ($P \leq 0.05$)	–	7.5	7.5	0.22
Nitrogen (N) management				
N_1	66.7	155.3	88.5	2.65
N_2	67.3	180.0	112.7	3.35
N_3	66.9	168.3	101.4	3.03
N_4	66.9	163.8	96.9	2.90
SEm±	–	0.17	1.7	0.05
LSD ($P \leq 0.05$)	–	5.0	5.0	0.15
W*N	–	NS	NS	NS

Among the weed management treatments, the costs of cultivation were 5.5 and 1.6% higher in herbicide combinations alone (W_2) and brown manuring (maize) + herbicides combination (wheat) (W_3), respectively over weedy check (W_1). However, gross and net returns and net B:C were 15, 23 and 20% higher in brown manuring (maize) + herbicides combination (wheat) than weedy check. Furthermore, these variables were increased by 5, 11 and 14% in the brown manuring-herbicide combination than that in only herbicide combinations treatments. The costs of cultivation were comparable with the N management treatments. Gross and net returns and net B:C were 16, 27 and 26% higher over whole basal application at sowing (N_1). Likewise, these were increased by 7, 12 and 12% in the other optimised GS N_3– 50% + rest N by GS and N_4– 80% + rest N by GS (averaged) than weedy check.

4.4 Quantification of the above-(shoot) and below-ground (root) residues retention

4.4.1 Maize

4.4.1.1 Stover retention

Above-ground maize residue biomass retained in respective plots (i.e. 50% of the total above-ground stover produced in each cropping season) did not differ significantly with the weed management treatments, but differed with N fertilisations (Table 4.21). The optimised GS N_2– 50% + 25% broadcast + rest N by GS had 13% higher stover biomass retention than whole N as basal application (N_1– 100% whole) in both years, respectively. It also had about 5–10% higher residue than other GS N_3– 50% + rest N by GS, and N_4 – 80% + rest N by GS in both years.

4.4.1.2 Estimated root biomass yield and retention

Based on the above-ground biomass produced and the root: shoot, the estimated maize root biomass yield differed significantly with N fertilisations (Table 4.21). Weed management showed no significant effect on root biomass yield. Optimised GreenSeeker N_2 – 50% + 25% broadcast + rest N by GS resulted in 14% higher root biomass yield than whole basal application at sowing (N_1– 100% whole) in the first and second year, respectively. Also, root biomass yield increased by 9 and 6% in N_2 than the other GreenSeeker N_3– 50% + rest N by GS, and N_4 – 80% + rest N by GS, respectively.

Table 4.21 Stover and root biomass retention in maize as influenced by weed and N management in 2013 and 2014

Treatment	Stover biomass (t ha^{-1})			Root biomass (t ha^{-1})		
	2013	2014	Pooled	2013	2014	Pooled
Year 2013	-	-	4.40	-	-	1.40
Year 2014	-	-	4.53	-	-	1.45
SEm±	-	-	0.07	-	-	0.04
LSD ($P \leq 0.05$)	-	-	NS	-	-	NS
Weed (W) management						
W_1	4.38	4.41	4.39	1.38	1.43	1.41
W_2	4.41	4.49	4.45	1.41	1.44	1.43
W_3	4.51	4.59	4.55	1.44	1.47	1.46
SEm±	0.05	0.05	0.09	0.07	0.02	0.06
LSD ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS
Nitrogen (N) management						
N_1	4.17	4.27	4.22	1.33	1.37	1.35
N_2	4.72	4.86	4.79	1.51	1.56	1.54
N_3	4.33	4.62	4.48	1.39	1.48	1.44
N_4	4.31	4.44	4.37	1.38	1.42	1.40
SEm±	0.09	0.11	0.07	0.03	0.03	0.03
LSD ($P \leq 0.05$)	0.27	0.32	0.21	0.09	0.10	0.19
W*N($P \leq 0.05$)	NS	NS	NS	NS	NS	NS

4.4.2 Wheat

4.4.2.1 Straw retention

Above-ground wheat residue biomass retained in respective plots (i.e. 40% of the total above-ground wheat straw produced in each cropping season) differed significantly with the weed management and N fertilisation treatments in both years (Table 4.22). Post-emergent clodinafop + carfentrazone (W_3) had 24 and 10% higher straw biomass retention than weedy check (W_1) in 2013 and 2014, respectively, whereas it was 9 and 4% higher, respectively, than the pre-emergent pendimethalin + carfentrazone (W_2). Also, the optimised GreenSeeker N (N_2– 50% + 25% broadcast + rest N by GS) had 12 and 10% higher straw biomass retention than whole N as basal application (N_1) in both years, respectively. While it was 3–5% higher than the other

GS N_3 – 50% + rest N by GS and N_4– 80% + rest N by GS. Pooled yield over years differed significantly.

4.4.2.2 Estimated root yield and retention

Based on the above-ground biomass produced and the root: shoot (7.4), the estimated wheat root biomass retention differed significantly with weed management and N fertilisations (Table 4.22).

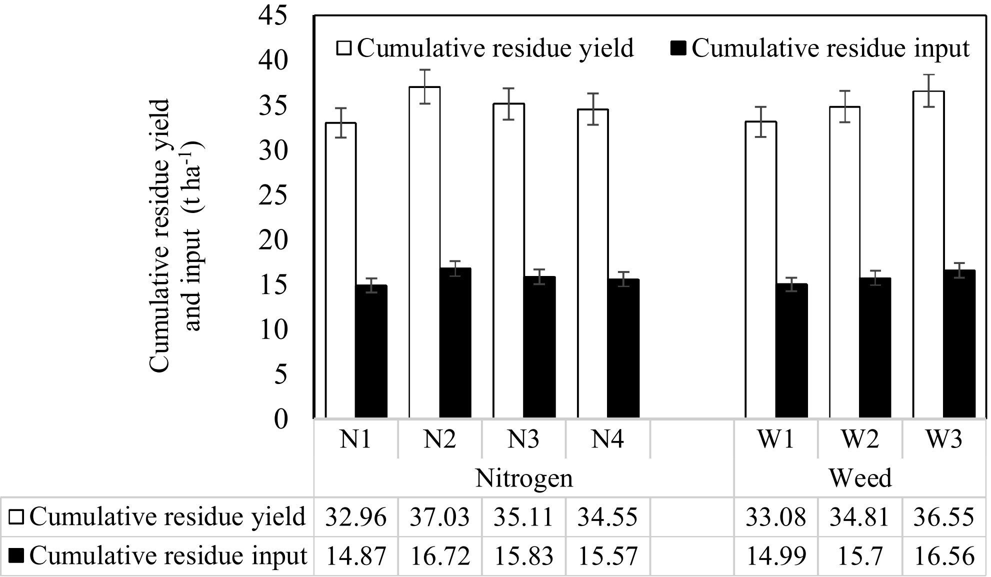
Table 4.22 Straw and root biomass retention in wheat as influenced by weed and N management in 2013–14 and 2014–15

Treatment	Straw biomass (t ha^{-1})			Root biomass (t ha^{-1})		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
Year 2013	-	-	3.25	-	-	1.14
Year 2014	-	-	3.54	-	-	1.20
SEm±	-	-	0.09	-	-	0.03
LSD ($P \leq 0.05$)	-	-	0.26	-	-	NS
Weed (W) management						
W_1	2.87	3.33	3.10	0.97	1.13	1.05
W_2	3.27	3.53	3.40	1.10	1.19	1.15
W_3	3.56	3.66	3.61	1.23	1.29	1.26
SEm±	0.11	0.04	0.05	0.04	0.02	0.03
LSD ($P \leq 0.05$)	0.44	0.17	0.18	0.15	0.06	0.08
Nitrogen (N) management						
N_1	3.04	3.39	3.22	1.03	1.15	1.09
N_2	3.41	3.73	3.57	1.15	1.26	1.21
N_3	3.30	3.58	3.44	1.11	1.21	1.16
N_4	3.28	3.54	3.41	1.11	1.20	1.16
SEm±	0.06	0.05	0.04	0.02	0.02	0.04
LSD ($P \leq 0.05$)	0.17	0.15	0.12	0.06	0.05	0.08
W*N ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS

Clodinafop + carfentrazone (W_3; post-emergent herbicide) had 27 and 14% higher root biomass yield than weedy check (W_1) in 2013–14 and 2014–15, respectively, whereas it had 12 and 8% higher than pendimethalin + carfentrazone (W_2; pre-emergent herbicide). Also, the optimised GreenSeeker N_2–50% + 25% broadcast + rest N by GS had 12 and 10% higher root biomass than whole N as basal application (N_1) in both years, respectively. While it was 4% higher than GS N_3 – 50% + rest N by GS, and N_4– 80% + rest N by GS in the first and second year, respectively.

4.4.3 Cumulative above- and below- ground biomass yield and input

Cumulative above-ground residue yield and input over two years differed significantly between the weed and N treatments (Figure 4.11). Among the weed management treatments, cumulative biomass yield increased by 1.74 and 3.47 t ha^{-1} in brown manuring + herbicide combination (W_3) over herbicide combination alone (W_2) and weedy check (W_1), respectively. The N management with optimised GreenSeeker N treatments (N_2) increased cumulative yield and input by 2.6 and 1.2 t ha^{-1}, respectively than over whole N fertilisation.



	N1	N2	N3	N4		W1	W2	W3
	Nitrogen					Weed		
□ Cumulative residue yield	32.96	37.03	35.11	34.55		33.08	34.81	36.55
■ Cumulative residue input	14.87	16.72	15.83	15.57		14.99	15.7	16.56

Figure 4.11 Cumulative above-ground residue yield and input as influenced by weed N management after two years of maize–wheat cropping. Error bars in columns denotes LSD ($p \leq 0.05$).

The estimated total root biomass yield were 10 and 21% greater in brown manuring (maize) + herbicide combination (wheat) over herbicide combination alone and weedy check, respectively. While the optimised GS–N treatments (averaged) had 8% greater cumulative root biomass yield than whole N fertilisation.

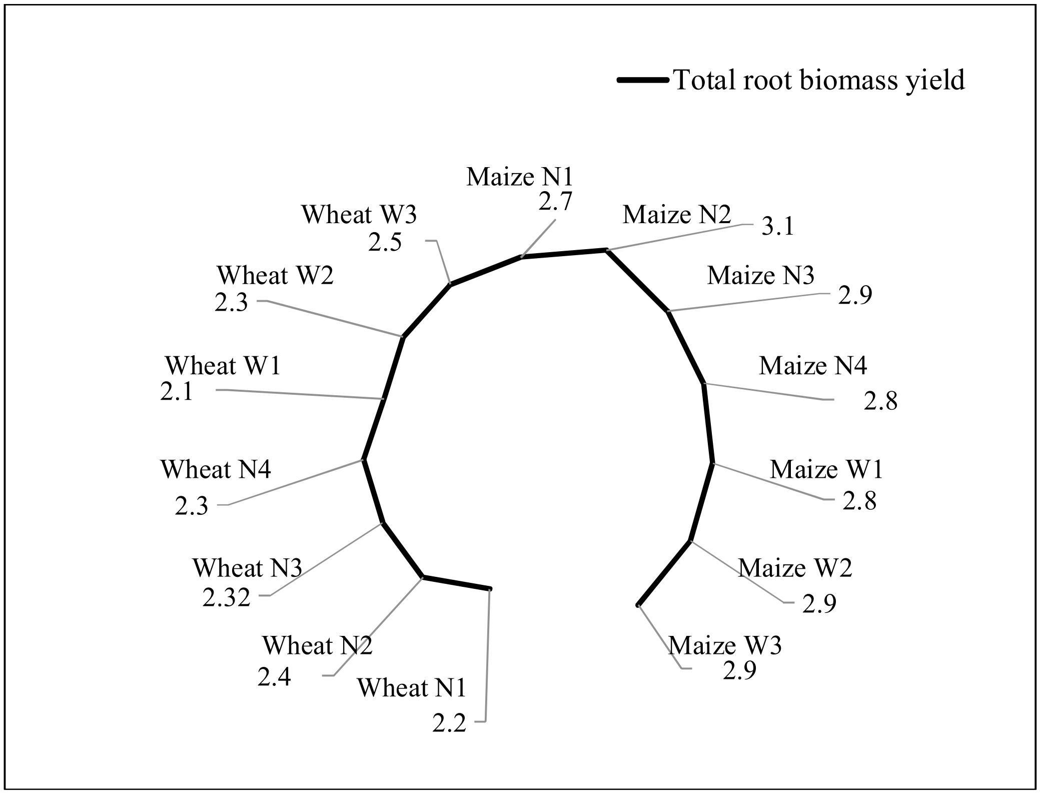


Figure 4.12. Estimated total root biomass yield (t ha^{-1}) as influenced by weed and N management after two years of maize–wheat cropping.

4.5 Soil properties

4.5.1 Physical properties

4.5.1.1 Soil bulk density

The impact of weed management and N fertilisation had a marked effect on the soil bulk density after two years of maize–wheat cropping (Table 4.23). At 0–5 cm and 5–15 cm soil depths, the brown manuring (maize) + herbicide combinations (wheat) (W_3) resulted in 1.3–2.6% less soil bulk density compared to herbicide combinations (W_2; maize–wheat) alone and weedy check (W_1), respectively. Among the GreenSeeker N fertilisation treatments, N_2–50 + 25% + rest N by GS had the least bulk density, which was 2% lower compared to N_1– 100% whole basal fertilisation. At 15–30 cm, there were no marked effects on bulk density between the treatments.

Table 4.23 Soil bulk density at depth increment as influenced by weed and N management after two years of cropping

Treatment	Bulk density Mg m^{-3}		
	0-5 cm	5-15 cm	15-30 cm
Weed (W) management			
W_1	1.50	1.54	1.61
W_2	1.52	1.55	1.60
W_3	1.48	1.52	1.58
SEm±	0.004	0.008	0.006
LSD ($P \leq 0.05$)	0.02	0.02	NS
Nitrogen (N) management			
N_1	1.51	1.55	1.60
N_2	1.49	1.52	1.59
N_3	1.50	1.53	1.60
N_4	1.50	1.54	1.59
SEm±	0.004	0.007	0.007
LSD ($P \leq 0.05$)	0.01	0.02	NS
W*N ($P \leq 0.05$)	NS	NS	NS

4.5.1.2 Mean weight diameter

There were no significant differences between the treatments on mean weight diameter at the end of first (in 2014) and second cropping (in 2015) maize–wheat) cycle at 0–15 cm soil depth (Figure 4.13). The brown manuring + herbicide combinations (W_3) and weedy check (W_1) had 4 and 8% higher mean weight diameter, respectively, than herbicide combinations alone (W_2) in the 0–5 cm depth at the end of the first and second year, respectively. But, at 5–15 cm soil depth, brown manuring + herbicide combinations resulted in 5 and 7% higher mean weight diameter than weedy check and herbicide combinations alone at the end of the first and second year, respectively. Among the N fertilisations, the optimised GreenSeeker–N treatments (averaged) resulted in 5 and 10% higher mean weight diameter compared to N_1 – 100% whole basal application at 0–5 cm and 5–15 cm soil depths, respectively.

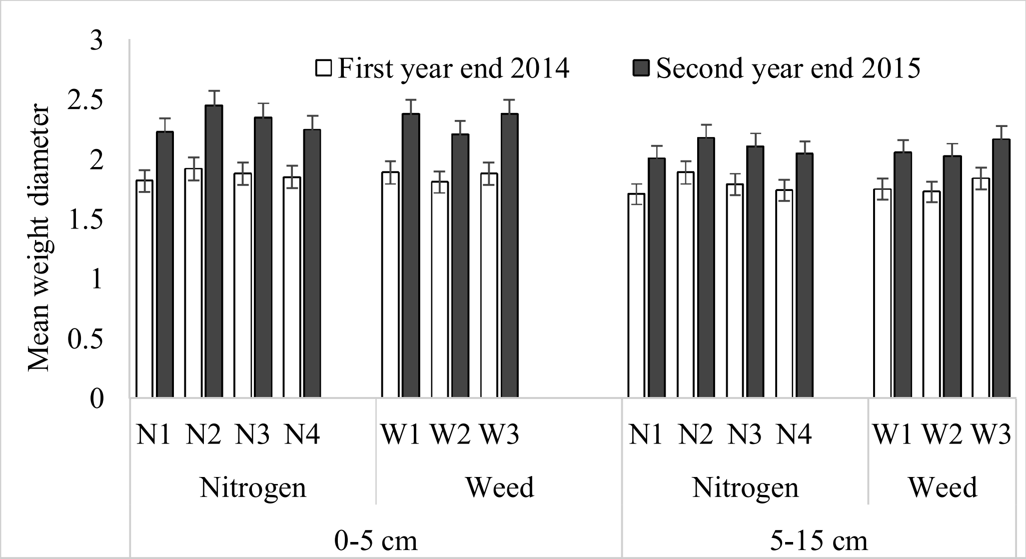


Figure 4.13. Mean weight diameter at depth increment as influenced by weed and N management at the end of first (2014) and second year (2015) maize–wheat cropping cycle. Error bars in columns denotes LSD ($p \leq 0.05$).

4.5.1.3 Saturated hydraulic conductivity

There were no significant differences between the treatments on saturated hydraulic conductivity at the end of first (2014) and the second maize–wheat cropping cycle (2015) at 0–15 cm soil depth (Figure 4.14). Saturated hydraulic conductivity was higher at the surface 0–5 cm than 5–15 cm soil depths in the second year over first year. The brown manuring + herbicide combinations (W_3) and weedy check (W_1) had higher hydraulic conductivity than herbicide combinations alone (W_2). Likewise, the optimised GreenSeeker–N treatments resulted in greater hydraulic conductivity than whole N fertilisation as basal. At the end of first year (2014), hydraulic conductivity ranged between 0.61–0.66 and 0.48–0.52 cm/h at 0–5 and 5–15 cm soil depths across the weed and N treatments. But, it ranged between 0.80–0.84 and 0.59–0.63 cm/h at 0–5 and 5–15 cm soil depths at the end of the second cropping year (2015).

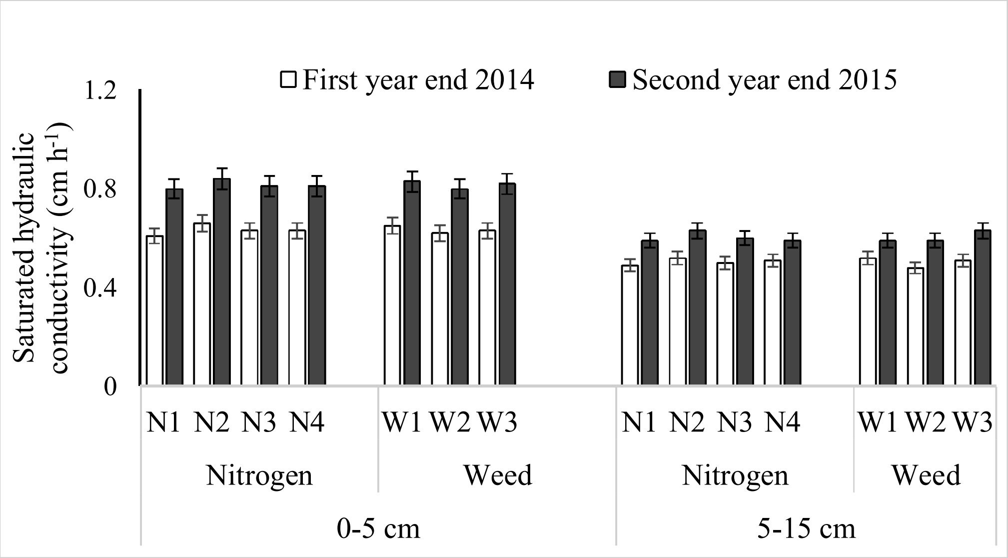


Figure 4.14. Saturated hydraulic conductivity at depth increment as influenced by weed and N management at the end first and second year. Error bars in columns denotes LSD ($p \leq 0.05$).

4.5.1.4 Water stable aggregates

Weed and N management had significant influence on water stable aggregate (%) at the end of two years of maize–wheat cropping (Figure 4.15). The brown manuring + herbicide combinations (W_3) and weedy check (W_1) had 3 and 5% higher water stable aggregates, respectively, than herbicide combinations alone (W_2) in the 0–5 cm depth. While at 5–15 cm soil depth, brown manuring + herbicide combinations and weedy check resulted in 4% higher water stable aggregates than herbicide combinations alone at the end of first and second cropping year, respectively. Among the N treatment at 0–5 cm soil depth, the optimised GS N2– 50% + 25% broadcast + rest N by GS resulted in 8 and 9% higher water stable aggregates compared to the entire N_1 basal application at the end of first and second cropping year, respectively. Likewise, at 5–15cm depth, the optimised GS–N_2 treatment resulted in 4% higher water stable aggregates, respectively, compared to the entire N_1 basal application.

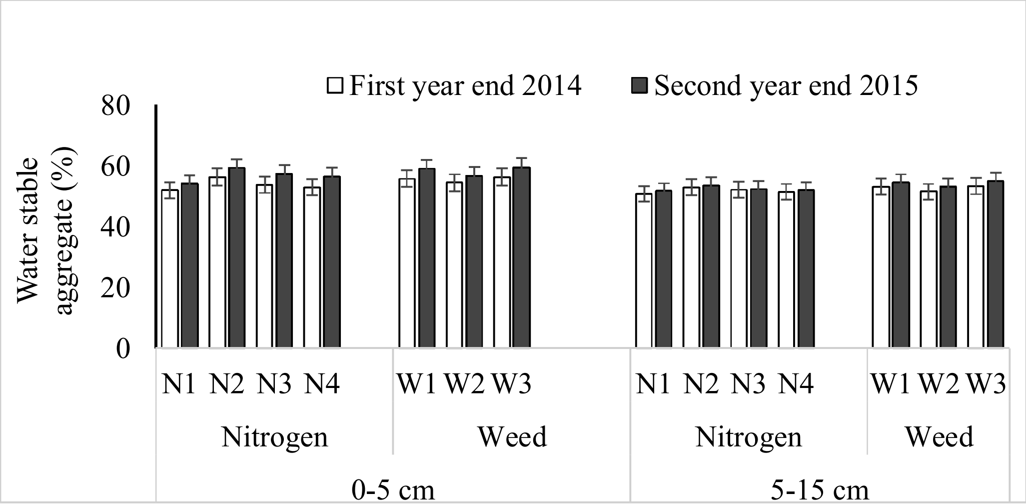


Figure 4.15. Water stable aggregates at depth increment as influenced by weed and N management at the end of first and second year. Error bars in columns denotes LSD ($p \leq 0.05$).

4.6 Soil chemical properties

4.6.1 Maize

4.6.1.1 Measured above- and below-ground residue derived C input

The above- and below-ground derived C input did not differ significantly with the weed management treatments (Table 4.24). The brown manuring (W_3) resulted in 3–5% higher derived residue C input than atrazine + pendimethalin (W_2) and weedy check (W_1) in both years of cropping. Whereas N fertilisation effects on derived C input were significantly different, N_2 –50% + 25% broadcast + rest N by GreenSeeker resulted in 13 and 14% higher derived residue C input than whole N basal application (N_1– 100% whole basal) in 2013 and 2014, respectively. Also, N_2 had 2–5% higher residue derived C than the other GreenSeeker N_3– 50% + rest N by GreenSeeker and N_4 – 80% + rest N by GreenSeeker. The estimated derived root C input did not differ significantly with weed management treatments, but were significantly different with N treatment effects. The optimised GreenSeeker fertilisation N_2 – 50% + 25% broadcast + rest N by GreenSeeker resulted in 14 and 16% higher root biomass derived C than whole N_1 basal application at sowing in 2013 and 2014, respectively. Furthermore, the GreenSeeker N_2 had 7–8% higher derived root C than the other GS N_3 and N_4 in both years.

Table 4.24 Above (stover)-and below (root)-ground biomass derived C input in maize as influenced by weed and N management

Treatment	Measured stover C input (Mg ha^{-1})			Estimated root C input (Mg ha^{-1})		
	2013	2014	Pooled	2013	2014	Pooled
Year 2013	–	–	1.76	–	–	0.39
Year 2014	–	–	1.81	–	–	0.41
SEm±	–	–	0.06	–	–	0.01
LSD ($P \leq 0.05$)	–	–	NS	–	–	NS
Weed (W) management						
W_1	1.75	1.76	1.76	0.38	0.40	0.39
W_2	1.76	1.80	1.78	0.39	0.40	0.40
W_3	1.80	1.84	1.82	0.40	0.41	0.41
SEm±	0.09	0.02	0.05	0.02	0.004	0.01
LSD ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS
Nitrogen (N) management						
N_1	1.67	1.71	1.69	0.37	0.38	0.38
N_2	1.89	1.95	1.92	0.42	0.44	0.43
N_3	1.73	1.85	1.79	0.39	0.41	0.40
N_4	1.72	1.78	1.75	0.39	0.40	0.39
SEm±	0.04	0.04	0.03	0.01	0.01	0.01
LSD ($P \leq 0.05$)	0.11	0.13	0.08	0.02	0.03	0.02
W*N ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS

4.6.1.2 Measured above-ground residue derived N input

Derived N input (based on the total N in stover and the retained stover yield) from the stover did not differ significantly between the weed management treatments, but had a marked effect due to the N management (Table 4.25). Among the N fertilisation effects, N_2 –50% + 25% broadcast + rest N by GreenSeeker had 10 kg ha^{-1}ha higher derived residue N input than whole N basal application (N_1– 100% whole basal); and 5–7 kg ha^{-1}higher than the other GreenSeeker N_3– 50% + rest N by GreenSeeker and N_4 – 80% + rest N by GreenSeeker over the two year period.

Table 4.25 Above-ground residue (stover) derived N input in maize as influenced by weed and N management

Treatment	Maize total N input (kg ha^{-1})		
	2013	2014	Cumulative
Weed (W) management			
W_1	25.23	27.11	52.34
W_2	25.86	26.38	52.24
W_3	26.83	27.36	54.18
SEm±	1.23	0.35	1.39
LSD ($P \leq 0.05$)	NS	NS	NS
Nitrogen (N) management			
N_1	24.12	24.70	48.82
N_2	28.78	29.63	58.41
N_3	25.75	27.38	53.13
N_4	25.23	26.09	51.32
SEm±	0.50	0.66	0.81
LSD ($P \leq 0.05$)	1.49	1.96	2.41
W*N ($P \leq 0.05$)	NS	NS	NS

4.6.2 Wheat

4.6.2.1 Measured above- and below-ground residue derived C input

The above-ground wheat residue (straw) and below-ground root biomass derived C input were significantly different with weed and N management treatments (Table 4.26). Among the weed management treatments, post-emergent (W_3; clodinafop + carfentrazone) herbicides resulted in 23 and 10% higher derived residue C input than weedy check (W_1); and 8 and 4% higher than the pre-emergent (W_2; pendimethalin + carfentrazone) in 2014 and 2015, respectively. While N fertilisation effects with N_2 – 50% + 25% broadcast + rest N by GS resulted in 11% higher derived residue C input than whole N basal application (N_1) in both years, respectively. Also, N_2 had 4% higher residue derived C than the other GS N_3 – 50% + rest N by GS and N_4 – 80% + rest N by GS, respectively**.** The pooled residue C input differed significantly across the years. The estimated root derived C input increased by 26 and 13% under clodinafop + carfentrazone over weedy check in 2014 and 2015, respectively; and 10% higher than pendimethalin + carfentrazone. The optimised GS fertilisation N_2 resulted in 10% higher root biomass derived C than whole N_1 basal application at sowing in 2013 and 2014, respectively. Pooled root C inputs over years were significantly different.

Table 4.26 Above (straw)-and below (root)-ground biomass derived C input in wheat as influenced by weed and N management over the years

Treatment	Measured residue C input (Mg ha^{-1})			Estimated root C input (Mg ha^{-1})		
	2013–14	2014–15	Pooled	2013–14	2014–15	Pooled
Year 2013	-	-	1.30	-	-	0.31
Year 2014	-	-	1.41	-	-	0.34
SEm±	-	-	0.03	-	-	0.004
LSD ($P \leq 0.05$)	-	-	0.09	-	-	0.02
Weed (W) management						
W_1	1.15	1.33	1.24	0.27	0.32	0.29
W_2	1.31	1.41	1.36	0.31	0.33	0.32
W_3	1.42	1.46	1.44	0.34	0.36	0.35
SEm±	0.05	0.02	0.02	0.011	0.004	0.004
LSD ($P \leq 0.05$)	0.17	0.07	0.07	0.04	0.02	0.02
Nitrogen (N) management						
N_1	1.22	1.36	1.29	0.29	0.32	0.30
N_2	1.36	1.49	1.43	0.32	0.35	0.34
N_3	1.32	1.43	1.38	0.31	0.34	0.33
N_4	1.31	1.42	1.36	0.31	0.34	0.32
SEm±	0.02	0.02	0.02	0.005	0.005	0.004
LSD ($P \leq 0.05$)	0.07	0.06	0.05	0.02	0.01	0.01
W*N ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS

4.6.2.2 Measured above-ground residue derived N input

The weed management and N fertilisation had a marked impact on the derived N input (Table 4.27). Among weed management treatments, derived N input was increased by 8 and 4.4 kg ha^{-1} in the post-emergent (W_3; clodinafop + carfentrazone) herbicides than in weedy check (W_1) and pendimethalin + carfentrazone (W_2), respectively, over the two-year period. Among the N management effects, N_2 –50% + 25% broadcast + rest N by GreenSeeker had 6 kg ha^{-1} higher derived residue N input than whole N basal application (N_1– 100% whole basal); and 3 kg ha^{-1} higher than the other GreenSeeker N_3– 50% + rest N by GreenSeeker and N_4 – 80% + rest N by GreenSeeker over the two-year period.

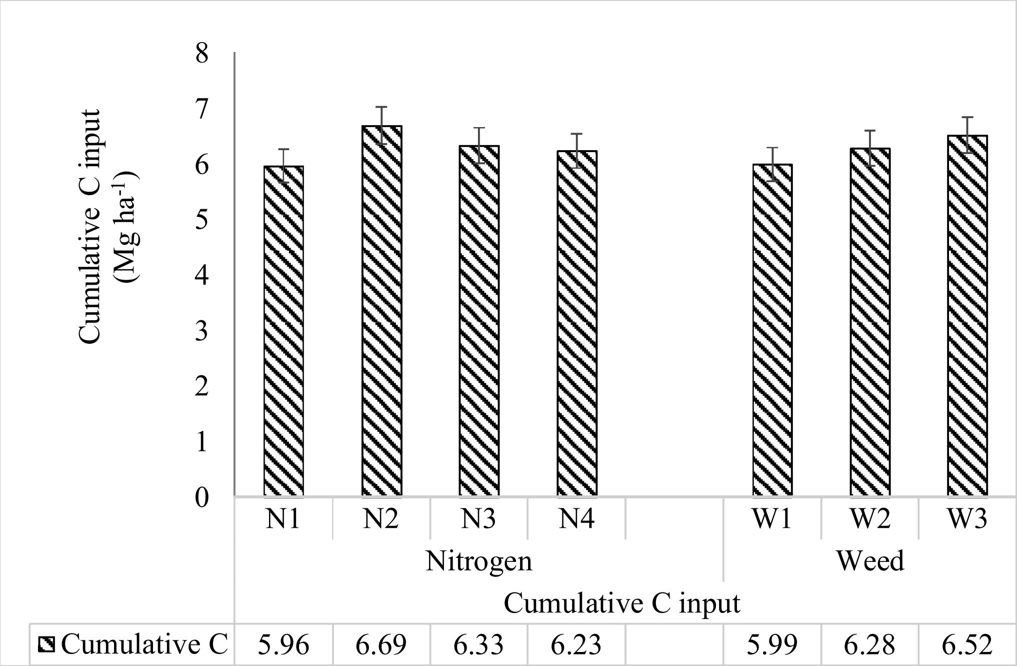
Table 4.27 Aboveground residue (straw) derived N input in wheat as influenced by weed and N management over the years

Treatment	Straw N input (kg ha^{-1})		
	2013–14	2014–15	Cumulative
Weed (W) management			
W_1	17.04	19.83	36.87
W_2	19.32	21.05	40.36
W_3	21.69	23.08	44.77
SEm±	0.71	0.30	0.61
LSD ($P \leq 0.05$)	2.78	1.18	2.38
Nitrogen (N) management			
N_1	17.61	19.90	37.51
N_2	20.87	22.88	43.75
N_3	19.59	21.40	40.99
N_4	19.32	21.09	40.41
SEm±	0.34	0.30	0.49
LSD ($P \leq 0.05$)	1.00	0.89	1.45
W*N ($P \leq 0.05$)	NS	NS	NS

4.6.3 Cumulative above- and below-ground derived C and N inputs

The impact of the weed and N management had a marked influence on the cumulative above- and below-ground residues derived C and N input over the two-year maize–wheat cropping cycle. Cumulate above-ground derived C input differed significantly (Figure 4.16), and residue C input increased by 4 and 9% due to brown manuring (maize) + herbicide combination (wheat) (W_3) over herbicide combination alone (W_2) and weedy check (W_1), respectively. Among the N management treatments, N_2 –50% + 25% broadcast + rest N by GreenSeeker resulted in 12%

higher derived residue C input than whole N basal application (N_1– 100% whole basal); and 6–7% higher than the other GreenSeeker N_3– 50% + rest N by GreenSeeker and N_4 – 80% + rest N by GreenSeeker over the two year period.



	N1	N2	N3	N4		W1	W2	W3
▨ Cumulative C	5.96	6.69	6.33	6.23		5.99	6.28	6.52

Figure 4.16 Cumulative above-ground residue derived C input as influenced by weed and N management, respectively, after two years of maize–wheat cropping.

The estimated cumulative root derived C input differed significantly (Figure 4.17), root C input increased by 6 and 11% in brown manuring (maize) + herbicide combination (wheat) (W_3) over herbicide combination alone (W_2) and weedy check (W_1), respectively. Among the N management effects, N_2 –50% + 25% broadcast + rest N by GreenSeeker has 12% derived root C input than whole N basal application (N_1– 100% whole basal); and 6% higher than the other GreenSeeker N_3– 50% + rest N by GreenSeeker and N_4 – 80% + rest N by GreenSeeker over the two year period.

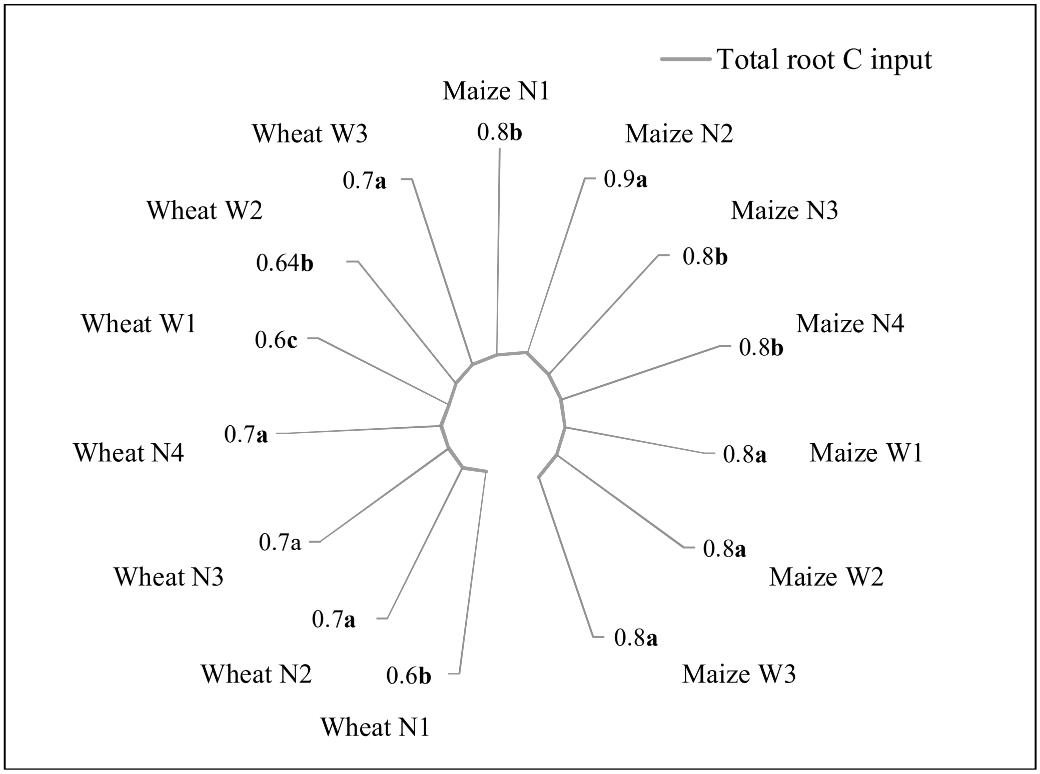
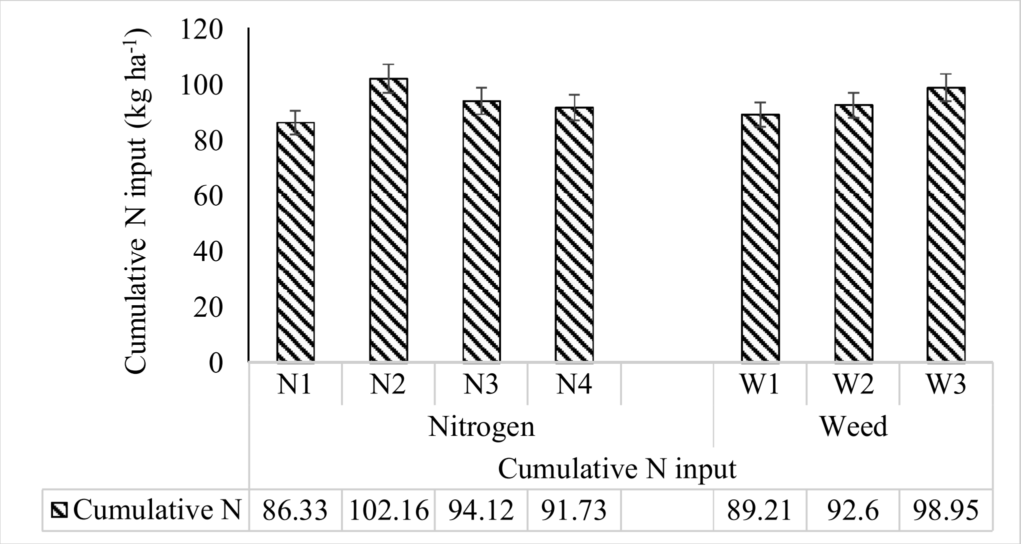


Figure 4.17 Estimated total root C input in maize and wheat (Mg ha^{-1}) as influenced by weed and N management after two years of maize–wheat cropping cycle

The impact of weed management and N fertilisation had a marked effect on the total derived N input (Figure 4.18). Among weed management effects, the total derived N input increased by 10 kg ha^{-1} and 6 kg ha^{-1} in the post-emergent (W_3; clodinafop + carfentrazone) herbicides than weedy check (W_1) and pendimethalin + carfentrazone (W_2), respectively, over the two-year period. Among the N management effects, N_2 – 50% + 25% broadcast + rest N by GreenSeeker had 16 kg ha^{-1} higher derived residue N input than whole N basal application (N_1– 100% whole basal); and 8–10 kg ha^{-1} higher than the other GreenSeeker N_3– 50% + rest N by GreenSeeker and N_4 – 80% + rest N by GreenSeeker over the two-year period.



	N1	N2	N3	N4		W1	W2	W3
▧ Cumulative N	86.33	102.16	94.12	91.73		89.21	92.6	98.95

Figure 4.18 Cumulative residue derived total N (kg ha^{-1}) as influenced by weed and N management after two years of maize–wheat cropping cycle

4.6.4 Soil organic carbon and total nitrogen contents

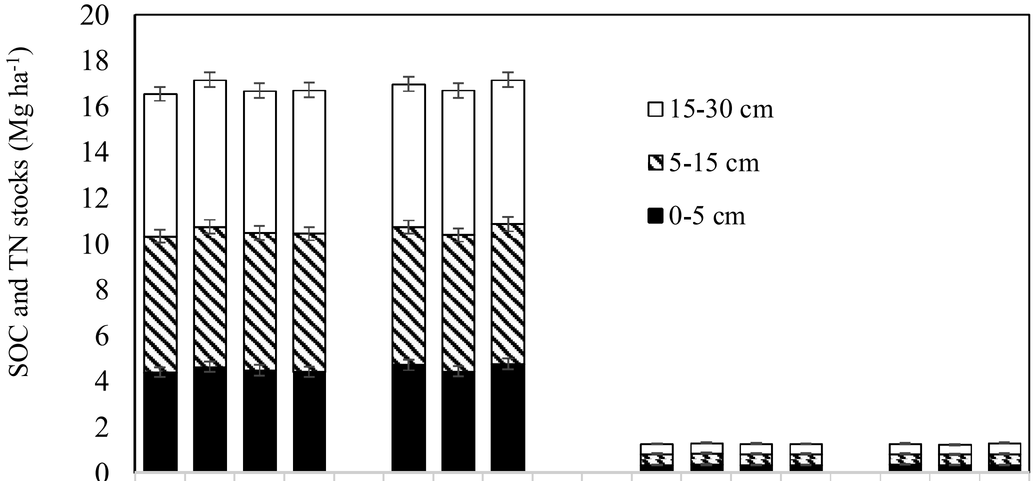
Weed and nitrogen management effect had a pronounced influence on soil organic carbon (SOC) and total N content after two years of experimentation (Table 4.28). There were significance differences between the treatment effects on SOC up to the 15 cm soil depth. At 15–30 cm, no marked effects were recorded. Also total N (TN) did not show any significant difference between the treatment effects at all depth increments Among the weed management treatment, brown manuring + herbicide combinations (W_3) and weedy check (W_1) resulted in 7% higher SOC, respectively, than the herbicide combinations alone (W_2) at 0–5 cm soil layer. Whereas, in the 5–15 cm soil depth, SOC and TN contents increase by 3 and 7%, respectively, in the brown manuring + herbicide combinations over the weedy check. Optimizing fertiliser N by the GreenSeeker resulted in greater soil organic carbon (SOC) and total nitrogen (TN) contents in all soil depth compared to whole N fertilisation at sowing. At 0–5 cm soil, optimised GS (N_2–50 + 25% + rest N by GS) resulted in 6 and 4% greater SOC and TN, respectively, compared to entire N applied as basal (N_1), whereas at 5–15 cm soil depth, N_2 had 5 and 7% greater SOC and TN, respectively, than those in whole basal N application. Interaction effects on the SOC between the treatments were significant only at 0–5cm soil depth.

Table 4.28 Soil organic carbon (SOC) and total nitrogen (TN) contents at depth increments as influenced by weed and N management after two years

Treatment	0–5 cm ($g\ kg^{-1}$)		5–15 cm ($g\ kg^{-1}$)		15–30 cm ($g\ kg^{-1}$)	
	SOC	TN	SOC	TN	SOC	TN
Weed(W) management						
W_1	6.2	0.50	3.9	0.30	2.6	0.18
W_2	5.8	0.45	3.8	0.30	2.6	0.18
W_3	6.2	0.47	4.0	0.32	2.7	0.20
SEm±	0.03	0.03	0.05	0.01	0.06	0.01
LSD ($P \leq 0.05$)	0.11	NS	0.10	NS	NS	NS
Nitrogen (N) management						
N_1	5.8	0.47	3.8	0.30	2.6	0.18
N_2	6.2	0.49	4.0	0.32	2.7	0.19
N_3	6.0	0.46	3.9	0.30	2.6	0.19
N_4	5.9	0.47	3.9	0.30	2.6	0.19
SEm±	0.04	0.02	0.03	0.01	0.04	0.01
LSD ($P \leq 0.05$)	0.12	NS	0.09	NS	NS	NS
W*N ($P \leq 0.05$)	0.14	NS	NS	NS	NS	NS

4.6.5 Soil organic carbon and total nitrogen stocks

Based on the bulk density value and soil organic carbon concentrations at respective depth, the weed and N management had a marked effect on SOC and TN stocks after two years of experimentation (Figure 4.19). In the surface 0–5 cm soil depth, brown manuring + herbicide combinations and weedy check had 7% greater SOC pools, respectively, compared to the herbicide combinations alone, whereas in the 5–15 cm soil depth, SOC and TN stocks increased by 1.5 and 4%, respectively, in brown manuring + herbicide combinations (W_3) over weedy check (W_1). Among N management effects on the 0–5 cm soil depth, the N_2 – 50 + 25% + rest N by GS resulted in 4 and 3% higher SOC and TN stocks, respectively, compared with the entire N fertilisation at sowing, but in the 5–15 cm soil depth, SOC and TN stocks were increased by 1.5 and 4%, respectively.

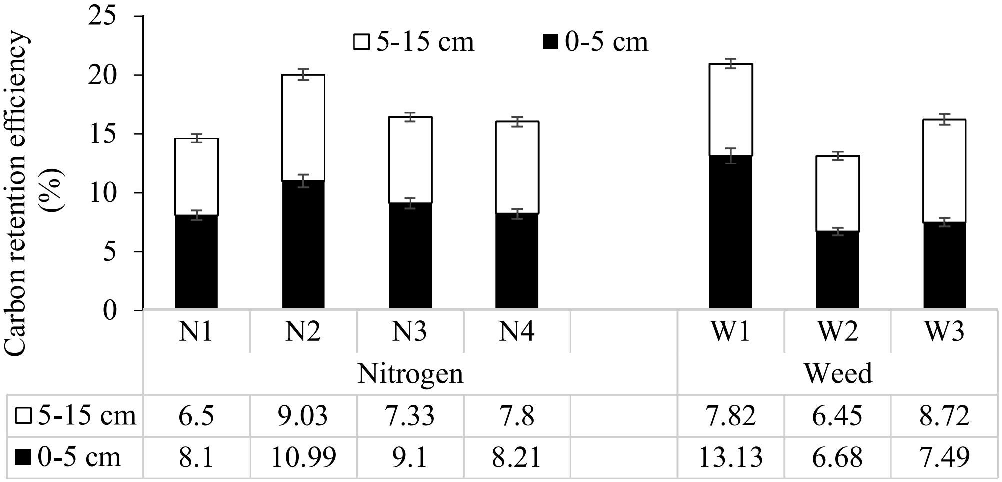


	N1	N2	N3	N4		W1	W2	W3			N1	N2	N3	N4		W1	W2	W3
	Nitrogen					Weed					Nitrogen					Weed		
	SOC stock										TN stock							
□ 15-30 cm	6.21	6.42	6.21	6.27		6.24	6.3	6.3			0.44	0.45	0.45	0.44		0.44	0.42	0.47
▨ 5-15 cm	5.93	6.12	5.99	6.02		6.01	5.96	6.1			0.47	0.49	0.47	0.47		0.46	0.47	0.48
■ 0-5 cm	4.4	4.62	4.48	4.42		4.72	4.43	4.76			0.35	0.36	0.35	0.35		0.37	0.34	0.35

Figure 4.19 Soil organic carbon (SOC) and total nitrogen (TN) stocks as influenced by weed and N management at depth increments after two years of maize–wheat cropping cycle. Error bars in columns denotes LSD ($p \leq 0.05$).

4.6.6 Soil organic carbon retention efficiency

Weed and N effects on soil organic C retention efficiency were significantly different in the 0–5 cm surface soil (Figure 4.20). However, there were no significant differences in 5–15 cm soil depth. The retention efficiency of soil organic C in the surface 0–5cm soil were about 1.2 times greater than that in 5–15 cm soil. Among the weed management, SOC efficiency were higher in the weedy check (W_1) than the herbicide combination alone (W_2) and the brown manuring + herbicide combination (W_3), respectively at the surface 0–5 cm soil depth. Whereas in the 5–15 cm, brown manuring + herbicide combination had higher SOC retention efficiency than weedy check and herbicide combination alone. The GreenSeeker treatments resulted in greater C retention efficiency than whole N_1 basal fertilisation.

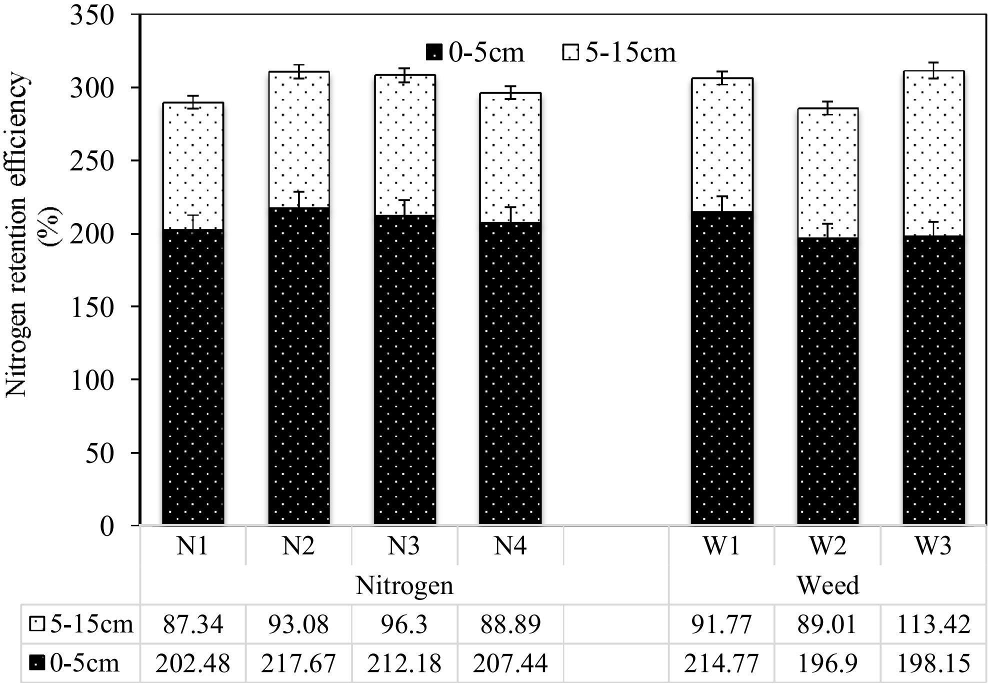


	N1	N2	N3	N4		W1	W2	W3
	Nitrogen					Weed		
□ 5-15 cm	6.5	9.03	7.33	7.8		7.82	6.45	8.72
■ 0-5 cm	8.1	10.99	9.1	8.21		13.13	6.68	7.49

Figure 4.20. Carbon retention efficiency as influenced by weed and N management at depth increment, respectively. Error bars in columns denotes LSD ($p \leq 0.05$).

4.6.7 Soil total N retention efficiency

Weed and N effects had an impact on soil total N retention efficiency (Figure 4.21). However, there were no significant differences between treatment effects at both soil depths. Soil total N retention efficiency in the surface 0–5cm soil was about 2.3 times greater than 5–15 cm soil depth. Among the weed management, TN retention efficiency were higher in the weedy check (W_1) than the herbicide combination alone (W_2) and the brown manuring + herbicide combination (W_3), at surface soil 0–5 cm. Whereas at 5–15 cm soil depth, brown manuring + herbicide combination had greater TN retention efficiency than weedy check and herbicide combination alone. The GreenSeeker treatments resulted in greater N retention efficiency than whole N_1 basal fertilisation.



	N1	N2	N3	N4		W1	W2	W3
	Nitrogen					Weed		
□5-15cm	87.34	93.08	96.3	88.89		91.77	89.01	113.42
■0-5cm	202.48	217.67	212.18	207.44		214.77	196.9	198.15

Figure 4.21 Nitrogen retention efficiency as influenced by weed and N management at depth increments, respectively. Error bars in columns denotes LSD ($p \leq 0.05$)

4.6.8 Available soil N-P-K contents

There were no significant differences between the treatments on soil available NPK contents at the end of 2014 and 2015 maize–wheat cropping seasons (Table 4.29). However, the available soil NPK contents increased by 30, 20 and 5%, respectively, in the second year over that in first year. The brown manuring (maize) + herbicide combinations (wheat) (W_3) had higher NPK contents than weedy check (W_1), and herbicide combinations alone (W_2) after two-years of cropping. Furthermore, the GreenSeeker–N fertilisations resulted in greater NPK than whole N applied as basal.

Table 4.29 Soil available nitrogen (N), phosphorus (P) and potassium (K) as influenced by weed and N management at the end of the first and second year cropping cycle

Treatment	2013–14 (kg ha^{-1})			2014–15 (kg ha^{-1})		
	N	P	K	N	P	K
Weed (W) management						
W_1	128.5	14.5	244.6	174.1	17.65	255.1
W_2	126.5	13.0	234.4	170.1	16.55	249.2
W_3	133.3	14.6	241.4	173.9	18.11	249.2
SEm±	4.1	1.7	8.0	5.3	0.4	9.5
LSD ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS
Nitrogen (N) management						
N_1	127.0	13.9	232.5	165.6	16.07	248.1
N_2	131.6	14.7	244.0	179.1	18.04	254.9
N_3	131.0	13.8	242.8	174.9	17.67	252.0
N_4	128.0	13.8	241.1	174.1	17.97	250.1
SEm±	3.4	1.1	15.1	6.6	1.1	16.7
LSD ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS

4.7 Microbial biomass and enzyme activity

4.7.1 Maize

4.7.1.1 Soil microbial biomass carbon

Weed and N management had significant effect on soil microbial biomass carbon (MBC) at the vegetative and reproductive growth stages in 2013 and 2014 (Tables 4.30 and 4.31). Among the weed treatment effects, the brown manuring (W_3) resulted in 27 and 14% higher soil MBC than the herbicide combination (W_2; atrazine + pendimethalin); and 20 and 4% higher than weedy check (W_1), respectively, at the vegetative and reproductive stages. In the second year (Table 31), brown manuring resulted in 10 and 4% higher soil MBC than atrazine + pendimethalin and weedy check, respectively, at the vegetative stage. Whereas at the reproductive stage, brown manuring resulted in 13% higher MBC than atrazine + pendimethalin, but was comparable with weedy check. N fertilisation effect with the GS N_2 – 50% + 25% broadcast + rest N by GreenSeeker had 19% greater soil MBC than entire N_1 basal application at the vegetative stage in both years, whereas it was

27 and 20% greater at the reproductive stage in the 2013 and 2014, respectively. Furthermore, N_2 had higher soil MBC than the other optimised GS (N_3– 50% + rest N by GS and N_4– 80% + rest N by GS. There were no interaction effects between the treatments in the first year, but the treatments interacted significantly at both growth stages in the second year.

Table 4.30 Microbial activity in maize as influenced by weed and N management in 2013

Treatment	2013			
	Microbial biomass carbon (µg g^{-1} soil)		Fluorescein diacetate (µg g^{-1} soil h^{-1})	
	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage
Weed (W) management				
W_1	31.09	204.44	0.02	0.10
W_2	29.41	186.44	0.02	0.10
W_3	37.32	212.10	0.02	0.11
SEm±	1.75	6.12	0.002	0.005
LSD ($P \leq 0.05$)	6.88	16.17	NS	NS
Nitrogen (N) management				
N_1	29.24	177.69	0.02	0.09
N_2	34.66	225.69	0.02	0.11
N_3	34.35	203.67	0.02	0.10
N_4	33.19	196.95	0.02	0.10
SEm±	1.77	7.00	0.003	0.012
LSD ($P \leq 0.05$)	5.26	20.79	NS	NS
W*N ($P \leq 0.05$)	NS	NS	NS	NS

4.7.1.2 Fluorescein diacetate

Weed and N management effects on fluorescein diacetate (FDA) did not differ significantly at both the vegetative and reproductive growth stages in first year (Table 4.30). However, the treatment effects significantly influenced FDA activity in second year (Table 4.31) both at the vegetative and reproductive stages. Brown manuring (W_3) resulted in 20% higher FDA activity than atrazine + pendimethalin (W_2) and weedy check (W_1), respectively, at the reproductive stage. N fertilisation with the GreenSeeker N_2– 50% + 25% broadcast + rest N by GreenSeeker had 33%

greater FDA activity than the entire N_1 basal application at both the vegetative and reproductive growth stages, respectively. There were significant interactions between the Weed and N treatments at the vegetative growth stage.

Table 4.31 Microbial activity in maize as influenced by weed and N management in 2014

Treatment	2014			
	Microbial biomass carbon ($\mu g\ g^{-1}$ soil)		Fluorescein diacetate ($\mu g\ g^{-1}$ soil h^{-1})	
	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage
Weed (W) management				
W_1	111.92	165.18	0.11	0.25
W_2	105.54	145.04	0.11	0.24
W_3	116.06	164.02	0.12	0.29
SEm±	1.96	3.54	0.008	0.01
LSD ($P \leq 0.05$)	7.69	13.90	NS	0.04
Nitrogen (N) management				
N_1	101.97	147.65	0.09	0.22
N_2	121.18	177.17	0.12	0.29
N_3	114.37	159.98	0.12	0.27
N_4	107.18	153.79	0.11	0.26
SEm±	3.75	8.58	0.009	0.02
LSD ($P \leq 0.05$)	10.99	25.48	0.03	0.06
W*N ($P \leq 0.05$)	14.44	17.45	0.05	NS

4.7.1.3 Urease

The treatment effects on urease activity were significantly different in the first and second year of maize cropping at both stages of growth (Table 4.32 and 4.33). In the first year (2013), the herbicide combination (W_2; atrazine + pendimethalin) resulted in 17 and 4% higher urease activity than brown manuring (W_3) and weedy check (W_1), respectively, at reproductive stage. While in the second year, urease activity increased by about 10% in atrazine + pendimethalin than brown manuring and weedy check at both the vegetative and reproductive growth stages, respectively. N fertilisation effect with the whole N_1 basal application resulted in 5–11% greater urease activity than the average of the GreenSeeker–N fertilisations at both the vegetative and reproductive growth stages, respectively, in the first and second year. There were interaction effects between the treatments at the reproductive growth stage in the second year of maize cropping.

Table 4.32 Enzyme activity in maize as influenced by weed and N management in 2013

Treatment	2013			
	Urease ($\mu g\ NH_3\ g^{-1}$ soil h^{-1})		Alkaline phosphatase (NPP μg moles g^{-1} soil)	
	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage
Weed (W) management				
W_1	52.43	21.41	0.05	0.09
W_2	55.57	22.25	0.05	0.08
W_3	50.26	18.94	0.06	0.10
SEm±	1.94	0.34	0.004	0.005
LSD ($P \leq 0.05$)	NS	1.34	NS	0.02
Nitrogen (N) management				
N_1	54.57	22.87	0.05	0.07
N_2	50.38	20.05	0.05	0.10
N_3	50.44	20.38	0.05	0.09
N_4	52.31	21.18	0.05	0.09
SEm±	2.36	0.89	0.003	0.007
LSD ($P \leq 0.05$)	7.02	2.66	NS	0.02
W*N ($P \leq 0.05$)	NS	NS	0.01	NS

4.7.1.4 Alkaline phosphatase

The weed and N management had a marked effect on alkaline phosphatase at reproductive growth stage in both years of cropping (Table 4.32 and 4.33). Brown manuring (W_3) resulted in 25 and 17% higher phosphatase activity than atrazine + pendimethalin (W_2) in 2013 and 2014, respectively, at the reproductive growth stage. While N_2 – 50% + 25% broadcast + rest N by GS had 30 and 21% higher phosphatase activity than whole N_1 basal application in 2013 and 2014, respectively. Weed and N interaction effects were significant at the vegetative stage in both years of maize cropping.

Table 4.33 Enzyme activity in maize as influenced by weed and N management in 2014

Treatment	2014			
	Urease (μg NH_3 g^{-1} soil h^{-1})		Alkaline phosphatase (NPP μg moles g^{-1} soil)	
	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage
Weed (W) management				
W_1	76.43	42.96	0.09	0.14
W_2	83.00	46.62	0.08	0.12
W_3	75.54	42.61	0.09	0.14
SEm±	2.69	0.86	0.004	0.002
LSD ($P \leq 0.05$)	NS	3.37	NS	0.01
Nitrogen (N) management				
N_1	82.29	46.40	0.08	0.14
N_2	75.37	42.64	0.09	0.17
N_3	79.87	42.91	0.08	0.15
N_4	80.77	44.22	0.09	0.14
SEm±	2.61	1.11	0.005	0.006
LSD ($P \leq 0.05$)	NS	3.28	NS	0.02
W*N ($P \leq 0.05$)	NS	5.68	0.03	NS

4.7.2 Wheat

4.7.2.1 Soil microbial biomass carbon

Weed and N management had significant effects on soil microbial biomass carbon (MBC) at the vegetative and reproductive stages of growth in both years of cropping (Table 4.34 and 4.35). In the first year (2013–14) of wheat cropping, weedy check (W_1) resulted in 8 and 2% higher soil MBC than the pre-emergent (W_2; pendimethalin + carfentrazone) herbicide combinations, respectively, at the vegetative and reproductive stages. Whereas in the second year (2014–15), weedy check had 6 and 7% greater soil MBC than pendimethalin + carfentrazone at the vegetative and reproductive growth stages, respectively. The post-emergent (W_3; clodinafop + carfentrazone) had comparable MBC as weedy check in both years. N fertilisations with the GreenSeeker resulted in 10 and 17% higher in N_2 – 50% + 25% broadcast + rest N by GreenSeeker than entire N_1 basal application at vegetative and reproductive stage, respectively. Furthermore, N_2 had 14 and 7% greater MBC than the whole N_1 basal application in the second year. There were consistent interactions between the treatments on MBC in both growth stages and years of wheat cropping.

Table 4.34 Microbial activity in wheat as influenced by weed and N management in 2013–14

Treatment	2013–14			
	Microbial biomass Carbon ($\mu g\ g^{-1}$ soil)		Fluorescein diacetate ($\mu g\ g^{-1}$ soil h^{-1})	
	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage
Weed (W) management				
W_1	180.90	145.16	0.14	0.11
W_2	167.66	142.58	0.12	0.10
W_3	175.06	143.47	0.13	0.11
SEm±	2.45	3.36	0.005	0.01
LSD ($P \leq 0.05$)	9.61	NS	0.03	NS
Nitrogen (N) management				
N_1	166.08	130.04	0.12	0.09
N_2	182.35	152.31	0.14	0.12
N_3	177.55	150.71	0.14	0.11
N_4	172.18	141.88	0.13	0.10
SEm±	3.30	5.73	0.005	0.008
LSD ($P \leq 0.05$)	9.80	17.01	0.01	0.02
W*N ($P \leq 0.05$)	16.47	19.47	NS	NS

4.7.2.2 Fluorescein diacetate

Weed and N management effects had a marked effect on fluorescein diacetate (FDA) at both the vegetative and reproductive growth stages (Table 4.34 and 4.35). Weedy check (W_1) had between 11–27% greater FDA activity than pendimethalin + carfentrazone (W_2); and 8–11% than clodinafop + carfentrazone (W_3) at the vegetative and reproductive growth stages, respectively, in both years. N management effects with the N_2 – 50% + 25% broadcast + rest N by GreenSeeker resulted in 17–33% higher FDA activity than the entire N_1– 100% whole basal application at vegetative and reproductive stage, respectively, in both years of cropping. Weed and N interaction effects were significant in both vegetative and reproductive growth stages in the second year.

Table 4.35 Microbial activity in wheat as influenced by weed and N management in 2014–15

Treatment	2014–15			
	Microbial biomass Carbon (μg C g^{-1} soil)		Fluorescein diacetate (μg fluorescein g^{-1} soil h^{-1})	
	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage
Weed (W) management				
W_1	154.31	153.40	0.14	0.41
W_2	145.80	143.55	0.11	0.34
W_3	151.58	152.53	0.13	0.37
SEm±	2.27	2.47	0.005	0.02
LSD ($P \leq 0.05$)	8.91	9.69	0.02	0.06
Nitrogen (N) management				
N_1	145.20	138.91	0.12	0.34
N_2	154.65	159.32	0.14	0.41
N_3	156.02	159.19	0.13	0.39
N_4	146.37	141.87	0.12	0.36
SEm±	3.91	4.91	0.007	0.01
LSD ($P \leq 0.05$)	8.65	14.57	0.02	0.04
W*N ($P \leq 0.05$)	13.43	15.45	0.05	0.07

4.7.2.3 Urease

The treatment effects on urease activity were significantly different in the first and second year at both stages of growth (Table 4.36 and 4.37). In the first year, urease activity increased by 27 and 8% in the pendimethalin + carfentrazone (W_2) than weedy check (W_1) at vegetative and reproductive stage, respectively. While it increased by 11 and 14% than weedy check, respectively, in the second year. The post-emergent herbicide combination (W_3) had comparable urease activity as the pre-emergent (W_2). The whole N_1 basal application resulted in 8 and 5% greater urease activity than the average of the optimised GreenSeeker–N treatments at both the vegetative and reproductive growth stages, respectively, in the first year. Whereas it was 13 and 11% higher in the entire N_1 basal application than weedy check at the vegetative and reproductive stages, respectively, at the end of second year (2014–15). There were significant interaction effects between the treatments at the reproductive growth stage in the both years of cropping.

Table 4.36 Enzymes activity in wheat as influenced by weed and N management in 2013–14

Treatment	2013–14			
	Urease (μg g^{-1} soil h^{-1})		Alkaline phosphatase (μg moles g^{-1} soil)	
	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage
Weed (W) management				
W_1	21.28	57.04	0.25	0.08
W_2	26.98	61.69	0.18	0.06
W_3	23.02	58.41	0.25	0.08
SEm±	1.29	1.07	0.01	0.004
LSD ($P \leq 0.05$)	5.08	4.20	0.05	0.01
Nitrogen (N) management				
N_1	24.72	61.14	0.23	0.07
N_2	22.02	54.03	0.23	0.08
N_3	23.12	57.97	0.22	0.08
N_4	23.66	63.04	0.24	0.07
SEm±	1.45	3.33	0.02	0.005
LSD ($P \leq 0.05$)	NS	NS	NS	NS
W*N ($P \leq 0.05$)	NS	6.78	NS	NS

4.7.2.4 Alkaline phosphatase

The weed and N management had a pronounced influence on phosphatase activity at both growth stages (Table 4.36 and 4.37). Soil phosphatase increased by 39 and 33% in the weedy check (W_1) and clodinafop + carfentrazone (W_3), respectively, at vegetative and reproductive stage in 2013–14. Whereas, it increased by 7 and 9% in 2014–15. N treatment effects did not differ significantly in 2013–14, but in 2014–15, soil phosphatase increased significantly by 18 and 22% than whole N_1 applied as basal at the vegetative and reproductive growth stage, respectively. Weed and N had consistent significant interaction effects in both growth stages in the second year of cropping.

Table 4.37 Enzymes activity in wheat as influenced by weed and N management in 2014–15

Treatment	2014–15			
	Urease ($\mu g\ g^{-1}$ soil h^{-1})		Alkaline phosphatase (μg moles g^{-1} soil)	
	Vegetative stage	Reproductive stage	Vegetative stage	Reproductive stage
Weed (W) management				
W_1	76.56	58.88	0.48	0.58
W_2	85.06	67.24	0.46	0.54
W_3	79.30	59.60	0.49	0.59
SEm±	1.26	1.65	0.006	0.006
LSD ($P \leq 0.05$)	4.93	6.46	0.02	0.02
Nitrogen (N) management				
N_1	87.62	66.34	0.44	0.51
N_2	75.22	57.57	0.52	0.62
N_3	75.34	58.74	0.50	0.62
N_4	81.04	62.97	0.46	0.55
SEm±	4.04	2.181	0.02	0.02
LSD ($P \leq 0.05$)	11.99	6.48	0.05	0.05
W*N ($P \leq 0.05$)	NS	11.22	0.08	0.09

4.8 Greenhouse gases emissions

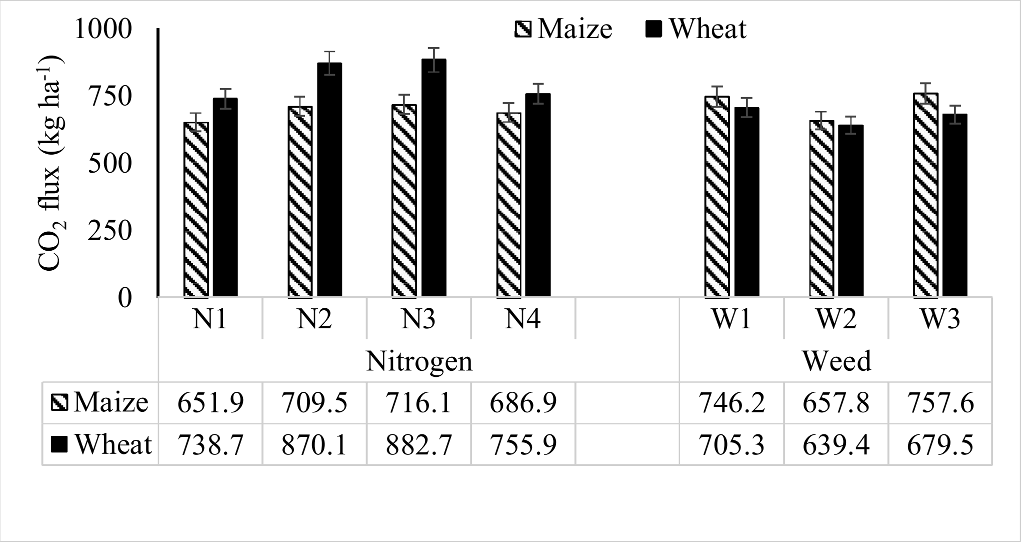
4.8.1 Maize

4.8.1.1 CO_2 emissions

The emissions of CO_2 were significantly different with the weed and N management treatments (Figure 4.22). Among the weed management treatments, brown manuring (W_3) and weedy check (W_1) emitted higher CO_2 flux than the herbicide combination (W_2). Also, the GreenSeeker N fertilisations had greater CO_2 emissions than whole N_1 fertilisation as basal. There were significant interactions between the W x N treatments.

4.8.1.2 N_2O emissions

Weed and N management effects did not differ significantly for N_2O emissions (Figure 4.23). The brown manuring (W_3) and weedy check (W_1) emitted less N_2O flux than the herbicide combination (W_2). The GreenSeeker N treatments resulted in greater N_2O emissions than whole N fertilisation as basal. There were significant interactions between the treatments.



	N1	N2	N3	N4		W1	W2	W3
▨ Maize	651.9	709.5	716.1	686.9		746.2	657.8	757.6
■ Wheat	738.7	870.1	882.7	755.9		705.3	639.4	679.5

Figure 4.22. Emission of CO_2-C in maize and wheat as influenced by weed and N management in the 2014–15. Error bars in columns denotes LSD ($p \leq 0.05$).

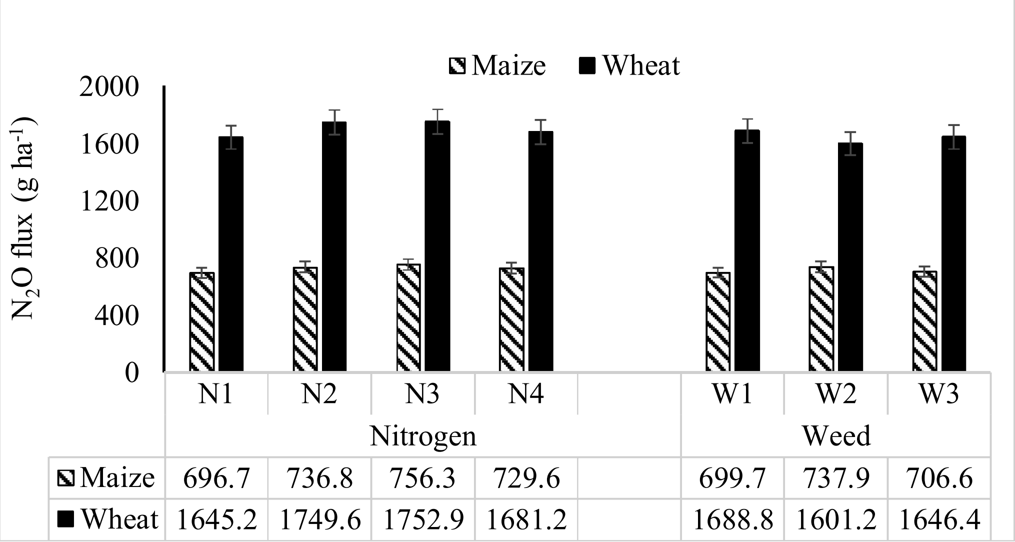
4.8.2 Wheat

4.8.2.1 CO_2 emission

Weed and N management effects significantly influenced the emissions of CO_2 (Figure 4.22). Although, there were no significant different between the weed management treatments, N fertilisation treatment effects differed significantly. The weedy check (W_1) emitted more CO_2 than the pre–emergent (W_2) and the post-emergent (W_3) herbicide combinations. While GreenSeeker N treatments resulted in greater CO_2 emissions than whole N fertilisation as basal. There were consistent interaction effects between the treatments.

4.8.2.2 N_2O emission

The treatment effects on N_2O emissions were significantly different (Figure 4.23). Higher N_2O flux was emitted in the weedy check (W_1) than the pre–emergent (W_2) and the post-emergent (W_3) herbicide combination. Also, the GS N treatments resulted in greater CO_2 emissions than whole N fertilisation as basal. There were consistent interaction effects between the treatments.



	N1	N2	N3	N4		W1	W2	W3
▧ Maize	696.7	736.8	756.3	729.6		699.7	737.9	706.6
■ Wheat	1645.2	1749.6	1752.9	1681.2		1688.8	1601.2	1646.4

Figure 4.23. Emissions of N_2O-N in maize and wheat as affected by weed and N management in the 2014–15. Error bars in columns denotes LSD ($p \leq 0.05$).

4.9 Herbicide residues in soil

4.9.1 Maize

The recovery rate of the herbicides in the soil samples ranged between 78–94% at 1 ppm. From the herbicide combination of atrazine and pendimethalin; atrazine residues were below detectable limit in the soil samples at the end of maize growing season in both years (Table 4.38). But, pendimethalin residue was detected in soil to the tune of 22.4 and 20.2 g ha^{-1} in 2013 and 2014, respectively. 2,4–D was not analysed. About 3% of the pendimethalin (0.75 kg ha^{-1}) applied remained as residue in soils after harvest.

Table 4.38 Residues of herbicides at harvest soil after maize in respective years

Weed management	Maize (g ha^{-1})		
	Atrazine	Pendimethalin	
	2013 & 2014	2013	2014
W1	—	—	—
W2	BDL	22.4	20.2
W3	—	—	—

BDL: below detectable limit

4.9.2 Wheat

Herbicide residues in soil were detected after wheat cropping in both years (Table 4.39). Pendimethalin residue in soil in the pre-emergent (W_2; pendimethalin + carfentrazone-ethyl) herbicide combinations was 44.2 and 67.2 g ha^{-1} in the first and second year, respectively. But, the carfentrazone-ethyl residues were between 3.3 and 3.4 g ha^{-1}. Also, in the post-emergent herbicide combination of clodinafop-propargyl + carfentrazone-ethyl (W_3), the carfentrazone-ethyl residues were between 2.2–2.5 g ha^{-1} in the first and second year, respectively. While clodinafop-propargyl was undetectable in both years, about 4–7% of the pendimethalin (1.0 kg ha^{-1}) and 6–12% of the carfentrazone (0.02 kg ha^{-1}) applied remained active in soil after harvest.

Table 4.39 Residues of herbicides at harvest soil after wheat in respective years

Weed management	Wheat (g ha^{-1})					
	Pendimethalin		Carfentrazone-ethyl		Clodinafop-propargyl	
	2013–14	2014–15	2013–14	2014–15	2013–14	2014–15
W1	—	—	—	—	—	—
W2	44.2	67.2	1.2	1.5	—	—
W3	—	—	2.3	2.4	BDL	BDL

BDL: below detectable limit

4.10 Nitrogen economy

The actual N applications during the growing seasons are depicted in (Table 4.40). N savings by the GreenSeeker over whole N_1 basal application (year-wise maize–wheat cropping) were 45% greater in N_3– 50% + rest N by GS; 25% in N_2 – 50% + 25% broadcast + rest N by GS; and 16% in N_4– 80% + rest N by GS. Our 'best–optimised N rate' (N_2–50 + 25% + rest N by GS; 155 kg N ha^{-1} for maize and 133 kg N $ha^{-1}$for wheat) resulted in about 1.2 times greater net productivity and profitability with enhanced soil quality than entire N fertilisation. Yield gains (10 and 7% higher for maize and wheat, respectively) were achieved with the lowest optimised GS-guided N fertilisation (N_3–50% N + rest by GS; i.e. 135 kg/N ha for maize and 120 kg N ha^{-1} for wheat) compared to entire N application

Table 4.40 Actual nitrogen (N) applications and savings

N levels	N fertilisation based on soil test value (kg N ha^{-1})		N fertilisation guided by GreenSeeker (kg N ha^{-1})		Actual N applied (kg N ha^{-1})		Total N savings (kg N ha^{-1})
	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize–wheat
N_1	180	150	–	–	180	150	–
N_2	135	113	20	20	155 (14)	133 (11)	42 (25)
N_3	90	75	25+20	25+20	135 (25)	120 (20)	75 (45)
N_4	144	120	20	20	164 (9)	140 (7)	26 (16)

Values in bracket denotes N (%) savings (i.e. N dosage not applied, as the sensor did not detect the need for N supplementation) compared to the whole N fertiliser at sowing.

4.10.1 Nitrogen efficiency

Nitrogen use efficiency was influenced by weed and N management effects (Tables 4.41 and 4.42). In maize, weed treatment effects were significantly different in the second year (2014). The brown manuring (W_3) resulted in higher N use efficiency than herbicide combination and weedy check. Optimising N fertiliser by GreenSeeker (N_3– 50% + rest N by GS) showed 43 and 53% greater N use efficiency than whole basal (N_1) application in both years, respectively. Also, N use efficiency were 5–7% higher in N_3 (50% + rest N by GS) than the GS optimised N_2 (50 + 25% + rest N by GS); and 27–29% than N_4 (80% + rest N by GS). Pooled data analysis showed no significant difference, yet there were significant interactions between treatments in second year (2014).

4.41 Nitrogen use efficiency (kg grain kg^{-1} N) in maize as influenced by weed and N management in 2013 and 2014.

Treatment	kg grain kg^{-1} N		
	2013	2014	Pooled
Year 2013	–	–	30.25
Year 2014	–	–	31.74
SEm±	–	–	0.85
LSD ($P \leq 0.05$)	–	–	NS
Weed (W) management			
W_1	28.72	29.56	29.14
W_2	30.97	32.58	31.78
W_3	31.08	33.09	32.08
SEm±	0.77	0.81	0.69
LSD ($P \leq 0.05$)	NS	3.16	2.71
Nitrogen (N) management			
N_1	24.66	24.60	24.63
N_2	33.02	35.71	34.37
N_3	35.32	37.61	36.47
N_4	28.01	29.05	28.53
SEm±	0.51	0.56	0.42
LSD ($P \leq 0.05$)	1.50	1.65	1.24
W*N ($P \leq 0.05$)	NS	2.86	2.14

In wheat, weed management treatments differed significantly on N use efficiency in both years (Table 4.42). The post-emergent herbicide combination (W_3) resulted in higher N use efficiency than pre–emergent herbicide combination (W_2) and weedy check (W_1). Optimising N fertiliser by GreenSeeker (N_3– 50% + rest N by GS) showed 36 and 31% higher N use efficiency than whole basal (N_1) application in both years, respectively. Also, N use efficiency were 5–2% higher in N_3 (50% + rest N by GS) than the GS optimised N_2 (50 + 25% + rest N by GS); and 18% than N_4 (80% + rest N by GS). Pooled year analysis showed no significant difference. There were no significant interaction effects between treatments.

Table 4.42 Nitrogen use efficiency (kg grain kg^{-1} N) in wheat as influenced by weed and N management in 2013–14 and 2014–15.

Treatment	(kg grain kg^{-1} N)		
	2013–2014	2014–2015	Pooled
Year 2013	–	–	35.94
Year 2014	–	–	37.29
SEm±	–	–	0.99
LSD ($P \leq 0.05$)	–	–	NS
Weed (W) management			
W_1	31.99	34.42	33.20
W_2	36.05	36.87	36.46
W_3	39.78	40.57	40.18
SEm±	1.46	0.90	0.65
LSD ($P \leq 0.05$)	5.73	3.53	2.55
Nitrogen (N) management			
N_1	29.92	31.66	30.79
N_2	38.47	40.70	39.58
N_3	40.73	41.61	41.17
N_4	34.64	35.17	34.90
SEm±	0.58	0.51	0.40
LSD ($P \leq 0.05$)	1.72	1.51	1.18
W*N ($P \leq 0.05$)	NS	NS	NS

4.11 System water productivity

The weed and N management had significant impact on the water productivity in the maize–wheat system in both years. The brown manuring + herbicide combination (W_3) resulted in 5 and 15% higher system water productivity than herbicide combinations alone (W_2) and weedy check (W_1), respectively. Optimising N fertiliser by GreenSeeker had 15 and 19% higher water productivity in the GS optimised N_2 (50 + 25% + rest N by GS) than whole basal (N_1) application in both years, respectively. Also, water productivity was 6–9% higher in the GS optimised N_2 (50 + 25% + rest N by GS) than N_3 (50% + rest N by GS); and 8–13% than N_4

(80% + rest N by GS). Pooled analysis showed significant difference between the years, however, there were no significant interactions between the W x N treatments.

Table 4.43 System water productivity (kg wheat grain ha^{-1} mm^{-1}) as influenced by weed and N management in 2013–14 and 2014–15

Treatment	kg wheat grain ha^{-1} mm^{-1}		
	2013–2014	2014–2015	Pooled
Year 2013	–	–	8.24
Year 2014	–	–	9.71
SEm±	–	–	0.28
LSD ($P \leq 0.05$)	–	–	0.81
Weed (W) management			
W_1	7.56	8.99	8.27
W_2	8.35	9.79	9.07
W_3	8.80	10.35	9.57
SEm±	0.21	0.23	0.15
LSD ($P \leq 0.05$)	0.83	0.92	0.58
Nitrogen (N) management			
N_1	7.68	8.94	8.31
N_2	8.81	10.65	9.73
N_3	8.31	9.80	9.06
N_4	8.14	9.44	8.79
SEm±	0.11	0.14	0.10
LSD ($P \leq 0.05$)	0.32	0.41	0.30
W*N ($P \leq 0.05$)	NS	NS	NS

Total amount of irrigation in 2013–14 (420 mm); Total effective rainfall in 2013–14 (700.5). Total amount of irrigation in 2014–15 (420 mm); Total effective rainfall in 2013–14 (570.7).

DISCUSSION Chapter 5

The weed and nitrogen management treatments on maize–wheat productivity, profitability, soil health, greenhouse gases emissions, soil herbicide residues, and resource-use efficiencies have been analysed and interpreted individually and interactively, where necessary. Relationship between the findings to previous findings in similar studies and beyond, where it deems relevant have been made. The wider implications of the management practices have also been highlighted. Theoretical implications of the results and practical applications have been discussed.

Weather conditions

The weather parameters (Figures 3.2a, b) showed a clear fluctuation in the amount of rainfall received in both years. During maize growing seasons, the amount of rainfall received were 1181 mm in 2013, and 451 mm in the 2014. The rainfall distribution in the first year influenced maize growth and development. In the wheat growing seasons (winter of 2013–14 and 2014–15), the amount of rainfall received were 153 mm in the first year, and 419 mm in the second year. The rainfall distribution in the second year had less influence on wheat growth and development stages. The occurrence of higher amount of rainfall (above the optimum) at the later stage of wheat growth resulted in about 5% crop lodging, yet, did not influence yield. The rainfall amount had a marked effect on fertiliser availability and losses, microorganisms' activities and greenhouse gases fluxes.

5.1 Effects on weed suppression

Weed growth in the maize–wheat system was effectively suppressed in the growing and developing phases of both crops. Tillage avoidance in CA reduces the scope of suppressing weeds at the early growth stages, thus the dynamics of weed ecology and growth will change under CA systems, particularly at the initial stage. Weeds pressure following conversion to CA is a temporary phenomenon (Nichols *et al*., 2015; Farooq *et al*., 2011) following transition from conventional practice to CA, therefore would require the need to destroy existing weed seed banks with the use of herbicides to ensure immediate benefits. Nichols *et al*. (2015) and Muoni *et al*. (2013) reported that weed suppression with herbicides at the onset of sowing provide a fair advantage for the crop over weeds

Weed suppression at the developmental stage in maize is largely attributed to its vigorous growth, enhance by the responsiveness of maize to synchronous N fertilisation. Also, the efficacy of the pre-emergent herbicide combination (atrazine + pendimethalin) on weed control is due to the broad-spectrum synergistic effect. Yet, the brown manuring demonstrates greater efficiency in reducing broad-leaved weeds. Kumar *et al.* (2012) reported that weed pressure can be drastically reduce by including short duration legume crops e.g. (mungbean or *Sesbania*) during the fallow or at the early growth periods. It is usually suggested to combine atrazine with other compatible herbicides to increase its efficacy on weed suppression (Williams *et al.*, 2011; Muoni *et al.*, 2013). Moreover, effective weed control in the wheat growing season is significantly attributed to the pre-and post-emergent herbicide combinations effects. Besides, higher wheat density utilise the growing space, water and nutrients to the detriment of the weeds present, particularly at the early growth stage. Increasing crop density is an effective approach to mitigating weed interference (Nichols *et al.*, 2015; Kumar *et al.*, 2013; Farooq *et al.*, 2011). The effectiveness of higher wheat density and the pre-emergent herbicides (applied one day after sowing) did not provide a long-term weeds control effect, but the post-emergent herbicides combination show a superior weed control advantage than pre-emergent over time. This reflects the effectiveness of post and/or sequential herbicide application in wheat to improve weed management (Susha *et al.*, 2014). This is so because higher wheat density can suppress weeds growth at the early growth stages, but requires an additional weed management measures at the later development stage of growth.

Effective weed management and suppression with herbicides were pronounced when herbicides were combined, Muoni *et al.* (2013) reported that combining herbicides increases its efficacy on problematical weed species. Similar observation was reported by Usman *et al.* (2012), combining herbicides with tillage effectively reduce weed growth by about 93–95% over control, with increase in wheat yield. Additionally, CA works mutually to reduce weed interference compared to conventional systems (Anderson, 2015; Murphy *et al.*, 2006). Significantly, lower weed density in the succeeding (second) year is a reflection of the cumulative surface residue effect, which provide a greater weed suppression effect. The retention of surface residue mulch in CA system is an better strategy to control weeds. Notably, soil cover with residue retention and crop rotation are fundamental principles of CA, which are in themselves methods of weed control (FAO, 2008; Chhokar *et al*., 2007). The interaction between greater weed suppression with accumulating residue cover is well documented (Johnson *et al*. 1989), sufficient surface residues return (50 and 40% of the total maize and wheat residues produced plot-wise, respectively) contributed to the integrated weed management measures adopted. Likewise, the avoidance of tillage might have contributed to the absence of a favourable germinating conditions at the surface that would otherwise create and encourage dormant weed seeds growth (Baral, 2012). Conservation agriculture advocate that at least 30% of the soil surface is covered, yet this amount of residue seems insufficient to significantly reduce weed density (Liebman and Mohler, 2001), but can enhance soil quality. Kumar *et al*. (2013) reported that the retention of residue mulch to the tune of 5–10 t ha^{-1} reduced weed density in wheat by over 80%, and also stimulate the predation of weeds seeds.

Integrating several non-chemical weed management strategies in CA-based cropping system can promote sustainability, as herbicide use have adverse residual effect on soil and crop produce over a long period. Weed suppression with the inclusion of brown manuring validates herbicide reduction as weed control measure, this is a climate-smart approach in CA for the advancement of ecological farming (Das *et al*., 2014; Kumar *et al.* 2013). Chikowo *et al*. (2009) reported that that integrated weed management techniques over a 6-year period reduce weed density and reliance on herbicides. The consequence of ample crop residues retention may also result in weeds receiving low effective herbicide rates thereby lowering herbicide efficacy and quicken resistance to the herbicides (Busi and Powles, 2009; Neve and Powles, 2005). Thus the impacts of the kinds, amounts and placements of crop residues on herbicide efficacy warrant urgent concern (Flower *et al*., 2013). Moreover, weed suppression with accumulating residue cover and interactions reduce herbicide absorption Johnson *et al*. (1989). This is of greater concern for the sustainability of conservation agriculture.

The yield gains (as a function of the yield loss denoted by weed index) is due to optimised and synchronous N fertilisation through GreenSeeker. Mehla *et al*. (2000) reported an increase in wheat yield gain under ZT to the tune of 15.4% (of these, 6.0% was due to enhanced efficiency arising from enhanced fertilizer- and water-use efficiency and marked reduction in weed population, whereas the rest 9.4% was as a result of timeliness of sowing. Combining herbicides had no effect on grain yield of maize over manual weeding due to appropriate and timely weeding (Muoni *et al.*, 2013)

5.2 Effects on crop and system productivity

Higher productivity in the brown manuring (maize), and the herbicide combinations (maize and wheat) is largely attributed to the synergistic weed control effect, thus less weed interference on available growth resources. Additionally, more space, nutrients and water were available for crop growth over weeds. Crop yield and weed pressure are inversely related, hence weed management is essential in achieving the likely yield gains obtainable in CA systems. Nichols *et al.* (2015) and Farooq *et al.* (2011) reported that crop growth and yield declines when weeds are strategically managed at the onset of conversion to CA. Additionally, sufficient N fertilization influence productivity, this is necessary in minimizing yield penalties associated with CA practices in the early period of conversion (first three years) (Yadvinder-Singh *et al.*, 2015; Pittelkow *et al.*, 2015a,b; Lundy *et al.*, 2015; Vanlauwe *et al.*, 2014; Corbeels *et al.*, 2014; Rusinamhodzi e*t al.*, 2011; Sapkota *et al.*, 2014).

Consistent higher yields by the brown manuring (maize) and the herbicide combinations (maize and wheat) treatments is due to the greater resource-use efficiency over weedy check. Improve productivity in these treatments is attributed to the availability of crop growth resources (sustain N availability) and favourable conditions (weed suppression) effected by the brown manuring and herbicides combination during the entire growing season. Combining organic and inorganic N sources provide a more effective approach to enhancing N fertility in CA systems (Vanlauwe *et al.*, 2011; Sainju *et al.*, 2008). This indicates that N availability and supply is vital for greater crop residue mineralisation, and for the crop use, the synchronous N fertilisation guided by GreenSeeker, and N supply by the brown manuring improve productivity. The brown manuring suppress weeds at the early growth stage in maize; and N supply after decomposition.

The optimisation and synchronisation of fertiliser N by the GreenSeeker improve crop productivity. This emphasises the need to match N fertilisations with crop demands, uptake and growth during the growing period by in-season sensor N management (Bijay-Singh *et al.*, 2011; Raun *et al.*, 2002). Application of N to actual crop requirement improved crop yield (Vanlauwe *et al.*, 2011; Ju *et al.*, 2009; Li *et al.*, 2007; Kramer *et al.*, 2002; Meisinger and Delgado, 2002). In contrast, Yadvinder-Singh *et al.* (2015) reported that higher N losses was observed with substantial N application at sowing than with split N fertilization to coincide with crop needs. Thus suggests that large pools of would-be soil nitrate are lost in the absence of crop demand. In-season N fertilisation ensure that sufficient N was available to improve maize and wheat productivity. Pittelkow *et al.* (2015b) and Lundy *et al.* (2015) reported that sufficient inorganic N fertilisation is the most important factor that can minimise yield penalties associated with CA practices in the short-time in tropical regions, yet growing legumes under CA system improve yield similar to conventional tillage without N addition.

Lundy *et al.* (2015) and Pittelkow *et al.* (2015b) reported that increasing N fertilizer (75–100 kg N ha) in CA based, yields improved by 12% in maize and wheat system in tropical regions. Under precision nutrient management in CA wheat after conventional rice practices, grain and biomass yield of wheat increase by 5 and 3%, respectively, over the state recommendation rate; and by 14 and 9%, respectively than the farmer's fertilisation practice in the IGP (Sapkota *et al.,* 2014). Our best GreenSeeker-N rate (50% basal + 25% broadcast + rest by GreenSeeker) is in agreement with the findings of Yadvinder-Singh *et al.* (2015) that appropriate N fertilisation under CA-based wheat in the IGP wheat (75% N at crown root initiation stage + and the rest as split) reduce N lose, enhance mineralisation and biomass yield. Increasing N fertilisation from 65 to 105 kg N ha^{-1} in maize increase yield by 11% for conventional tillage and 16% for reduced tillage (Kustermann *et al.*, 2013). 'Our best optimised GreenSeeker-N rate' (i.e. 155 and 133 kg ha^{-1} for maize and wheat, respectively; optimised N_2– 50% + 25% broadcast + rest N by GreenSeeker) influenced yields gains of 20 and 14% (mean of two years) for maize and wheat, respectively, over whole N basal application at sowing.

The increased yield effects in CA-based wheat are mostly due to timely sowing, N availability and weed control efficiency (Erenstein and Laxmi, 2008; Mehla *et al.*, 2000). Therefore, appropriate nitrogen (N) fertilization can improve productivity (Vanlaume et al., 2014; 2011; Chivenge *et al.*, 2009), enhance nutrient-use efficiency and reduce N leaching (Zhou and Butterbach-Bahl, 2014; Dai *et al.*, 2015; Gentile *et al.*, 2010). Employing the three principles of CA simultaneously with sufficient N fertilization would offset yield declines in CA systems, particularly in tropical regions. Likewise, practicing CA in tropical regions without N fertilizer and residue management increase yields loss by 12%, whereas with inorganic N fertilizer addition, yields loss increase by 4%; higher in maize (–7%) than in wheat (–5%). Growing legumes under CA system show similar yield as with conventional tillage without N addition (Pittelkow *et al.*, 2015a, b; Lundy *et al.*, 2015).

5.2.2 Effect on crop & system profitability

Rainfall had an influence on the total costs incurred for raising maize and system. Additional irrigation in the second year (2014) increase the higher cost of cultivation than in the first year (2014). Also, the cost of raising wheat was lower in the second year (2014–15) than in the first year (2013–14), due to high rainfall occurrence. In maize, the high cost of cultivation with the herbicide combinations and the brown manuring + 2,4-D treatments were due to the additional costs incurred for the herbicides, brown manure and labour. In wheat, the cost of the pre-emergent herbicides and the rate applied were much higher than the post-emergent. This resulted in slightly higher cost expended for the pre-emergent herbicide combinations treatment. For N management, the cost of cultivation was comparable between the treatment levels for both crops. The comparable cost is due to the substantial fertiliser N dose that was not applied in the GreenSeeker guided N treatments, though it incurred extra labour costs. The surplus N fertiliser not applied (due to the GreenSeeker N-use efficiency) offsets the additional labour charges for the supplemental N application in the GreenSeeker treatments. Muoni *et al.* (2013) reported that herbicide combination increase the production cost but reduce the weed density, hence the time saved from weeding compensates for the higher cost of cultivation, and this resulted to about US$388 worth of additional time for the farmer for off-farm activities. The retention of residue in a CA based cotton system increased the cost of cultivation (Das *et al.*, 2014). Erenstein and Laxmi, (2008) reported that the significant, immediate and ongoing cost saving in CA production system is the major driver of the rapid spread of NT wheat in the IGP.

Higher gross returns obtain in the brown manuring and the herbicide combination in maize is a function of improved net productivity (total biomass yield) obtained in these treatments over weedy check. In wheat, the higher gross returns obtain in the post-emergent herbicide combination is due to significantly higher yields than that in both the pre-emergent and the weedy check. Also, higher yields in the GreenSeeker–N treatments influence greater income over that in whole N basal application. Erenstein and Laxmi, (2008) reported that 5–7% (corresponds to ₹ 2320 ha^{-1}) of the 15–16% savings on operational costs in ZT wheat is due to the yield improvement. Additionally, higher net returns in the brown manuring over atrazine + pendimethalin in maize; and in the post emergent over the pre-emergent herbicides in wheat is a reflection of the lower cost of cultivation, and the higher yield produced. Although, weedy check treatment incurred the least cost of cultivation compared with the brown manuring, and the herbicide combinations, yet it recorded the lowest returns due to lesser yields (gross returns). Higher net returns in the GreenSeeker–N treatments is due to the higher gross returns (yield) over whole N application at sowing. In a CA + best management based systems in the IGP of Bangladesh, net returns improve by 79%, with reduction in production cost of about US$ 55 ha^{-1} than the conventional tillage (Alam *et al*., 2015). Erenstein (2011) and Nagarajan *et al*. (2002) reported that the net benefit of ZT over CT is about ₹ 4350 ha^{-1} across IGP– the cost saving effect amounts to about 53%, whereas yield effect was 47%. This net profit represents a substantial 11–17% of CT gross income

The comparable benefit-cost ratio between the weed management treatments in maize is a reflection of the marginal variations in terms of the cultivation costs and net returns between the treatments, while in wheat, the higher net benefit-cost in the post-emergent is largely due to the large yield gap over the other treatments. However, this was not the case with N management effects, significantly different benefit-cost ratio among the optimised GreenSeeker-guided N treatments reveals the wider variation in their net returns. In Laos, Leinhard *et al.* (2013) reported that CA system show higher net income (about 200 to 1300 US$ ha^{-1}), and labour productivity (1.5–3 fold) regardless of the fertilization levels. In the E–IGP, Jat *et al.* (2014) reported that net returns in was higher in a CA rice–wheat than in the CT system, even in the first year. This cost saving and yield increase effects have been attributed to the rapid spread of ZT wheat in the IGP, the economic benefits of CA is often driven by the cost reductions rather than increased yields (Erenstein and Laxmi, 2008).

5.3 Effects on soil health

5.3.1 Soil physico-chemical properties

The appropriateness of N fertilisation by the soil- and crop- based strategies improve soil quality. Improved soil organic C and total N stocks in the surface soil (particularly in the upper 15 cm), within a short-term is largely attributed to sufficient N availability, which influence crop residues decomposition. Also, crop residues return as substrate influence continuous organ matter mineralisation and soil C and total N accumulation, particularly in the surface soil. Optimising N fertilisation is a short-time strategy of increasing C accumulation (Alvarez, 2005; Batjes, 1996). The accumulation of C also leads to N accumulation (Sainju *et al.*, 2008). Carbon sequestration increased as more nitrogen and crop residues were applied to the system, Alvarez, (2005) reported that the application of 1 t N fertilizer ha^{-1}, SOC accumulation increases by about 2 t soil C ha^{-1}. Sufficient inorganic N fertilisation following the transition from conventional to CA enhances N mineralisation (Lundy *et al.*, 2015, Pittelkow *et al.*, 2015b; Vanluawe *et al.*, 2014). Similar observation was made by Yadvinder-Singh *et al.* (2015b) that appropriate inorganic N management in a wheat based CA system in the IGP, enhances N availability.

Improved SOC and TN accumulations were influenced by the fertilizer effects, which is related to the quantity of biomass C produced and that returned on cropland for decomposition. This suggests that N supply through organic and inorganic sources can improve SOC and total N pools. The quantity of residues return (Srinivasarao *et al.*, 2012; Das *et al.*, 2013) and quality (Gentile *et al.*, 2010; Chivenge *et al.*, 2011b) influences SOC pool. However, not all soils can accumulate the same amount of SOC given equivalent crop residue inputs (Six *et al.*, 2002). Li *et al.* (2003) reported that 1.6% of SOC is lost due the less (25%) aboveground residues returning in soil. Combining fertiliser N with organic residue improve crop residue decomposition (Yadvinder-Singh *et al.*, 2015; Kong *et al.*, 2009). Thus, appropriate N fertilization can offset temporary N immobilisation and oxidation of C (Gentile *et al.*, 2011; Russell *et al.*, 2009), enhance biomass accumulation (Chivenge *et al.*, 2009; Vanlauwe *et al.*, 2011), and influence nutrient-use efficiency and N leaching (Dai *et al.*, 2015; Zhou and Butterbach-Bahl, 2014; Gentile *et al.*, 2010). Furthermore, the improve soil organic carbon and total N accumulations at the surface (5 cm) and deeper soil (30 cm) layers is plausibly due to rhizodeposition/bioturbation produced by brown manure–*Sesbania* (Srinivasarao *et al.*, 2015; Roldan *et al.*, 2004; Sturz and Christie, 2003), and the decayed weed biomass (Laxmi *et al.*, 2007; Gallandt, 2004). About 2.4 and 1.2 t ha^{-1} (i.e. 1.2 and 0.6 t ha^{-1} yr^{-1}) of decomposed *Sesbania* and dry matter weeds biomass), respectively, were added over the two-year cropping period. This reiterates the benefits of legumes in CA systems in increasing N availability, reducing herbicide application dose, leading to enhanced productivity and soil ecosystem sustainability (Drinkwater *et al.*, 2000; Caamal Maldonado *et al.*, 2001). Rusinamhodzi *et al.* (2009) reported the leguminous crop residues (cowpea) decomposes readily than cotton residues (more lignin content) in CA system. Applying organic amendments is an important strategy of N availability, combining organic and inorganic N sources provide a more effective approach to enhancing N fertility in CA in the long-term (Vanlauwe *et al.*, 2011; Sainju *et al.*, 2008; Palm *et al.*, 2001).

The decomposition of organic matter influenced by sufficient N availability stimulated biological activities– e.g. arthropods, earthworm and termites responsible for the marked organic matter stratification (horizontal and vertical redistribution) between the soil strata (Thierfelder *et al.*, 2013; Luo *et al.*, 2010; Baker *et al.*, 2007; Gregorich *et al.*, 2001). The increase in SOC and TN contents in no-tillage were attributed to the decreased mineralization rate of organic matter rather than stratification of SOC and TN in the soil profile or the C and N inputs from crop residue (Al Kaisi *et al.*, 2005).

5.3.2 Effect on microbiological activity

Adequate N fertilisation, and brown manuring with *Sesbania* influence N availability, which provide a substrate for greater microbial and enzyme activity. Improved microbial population suggests the rapid response of soil microbial biomass C to management changes. Optimising N fertiliser, adequate crop residues and brown manuring contributed to the enriched soil environment with greater microbial and enzymes activities. Availability and supply of N is a key component influencing organic matter decomposition rate, and biological activity. The enriched rhizosphere ecosystem were significantly induce by the decomposed above and below- ground biomass. This provides additional N supply for micro-flora and fauna activities, hence recycle into soil organic matter pool, suggesting horizontal scattering of roots and higher root density of above- and below-ground biomass influence soil microbial and enzyme activities near the surface and deeper soil depth (Jaipal *et al.*, 2002; Ballcoelho *et al.*, 1998). Moreover, higher microbial population in the brown manuring is plausibly due to enhanced rhizodeposition/bioturbation induced by the brown manure (*Sesbania*) root nodulation, which created a tilled layer within the soil depths (Sturz and Christie, 2003, Roldan *et al.*, 2003).

Therefore, adequate crop residues return and decomposition ensures continuous supply of C substrates that serves as an energy source for improving microorganism's activity. This decomposed biomass transforms into greater N additions, suggesting that N supply through organic and inorganic sources can enhance mineralization with increase in microbial cycling and population (Gal et al., 2007). Residue retention in CA influence microbial biomass and total C by 83 and 45% (Balota *et al.*, 2004), increasing microbial biomass influences soil nutrient cycling (Carpenter-Boggs *et al.* 2003). Thus, the greater soil microbial cycling and activity were responsible for the inversion of organic matter within the soil layer. (Thierfelder *et al.*, 2013; Gal *et al.* 2007). Our results agree with the findings of Hobbs *et al.* (2008), that legume cover cropping aids biological soil tillage below-ground through their rooting. Greater biomass decomposition, root density, and rhizodeposition influences microbial populations that flourishes in surface soil layer with more root distribution and excretion at lower depths (Allmaras *et al.*, 2004). This positive effects of the decomposed biomass on the surface soil (decay weeds and brown manure), and in the deeper soil (brown manure roots) indicates greater N addition through rhizodeposition/bioturbation associated with abundant microbial and enzyme activities (Gal *et al.* 2007; Gallandt *et al.* 2004).

The rapid response and increase in soil microbial population is a reflection of the microbial biomass carbon as a sensitive indicator of changes in soil processes due to its faster rate of turnover than aggregate organic matter (Jenkinson *et al.*, 2004). Therefore, the agronomic management changes imposed (optimised N fertilisation and the inclusion of brown manuring) is a confirmation of N availability on microbial activities, and improved soil health (Limon-Ortega *et al.*, 2006). Our results are in agreement with the concept that CA practices promotes optimum soil environment, where roots efficiently interact and utilise nutrients from soil microorganisms and decomposed residue for better crop and soil performance

(Thierfelder and Wall, 2010; Kassam *et al*., 2009). This enhanced microbial activity and nutrient cycling instigated organic C and N leaching below the residue enriched surface (Gal *et al*., 2007). Similarly, the avoidance of tillage naturally enhances soil biological properties and the overall health of the soil (Leinhard *et al*., 2013). Improved soil enzymes activity is attributed to catalytic reaction of soil phosphatases enzymes with residue mulch, this improve soil C, enzymes and biotic activity (Karlen *et al*., 1994). Phosphatases catalyses organic phosphomonoesters, and are important in the mineralization of soil P, soil enzymes are transformers of organic matter for N fixation and plant growth. Therefore, soil phosphatase is a valid indicator of the improved biological soil status, and its capacity to respond to immediate management changes was induce by sufficient N supply from inorganic fertilisation and the decomposed biomass. Urease activity in soil decreases with increases in organic matter decomposition (soil microbial biomass), urease activity shows negative correlation with microbial biomass. Urease is affected by nitrogen availability in soils and are tightly bound to soil organic matter and minerals (McCarty and Bremner, 1991; McCarty *et al*, 1992).

The diversity of CA farming systems is improved with weeds (Turner *et al*., 2007), but can be both a blessing (Zandstra and Motooka, 1978) and a nuisance (Streibig, 1988). The presence of decomposed weed biomass substrate improved the organic matter contents, particularly in the topmost soil layer, suggesting that increased N transformation by decomposers or N immobilization can be particularly essential in systems that have stored high C:N residues on the soil surface (Drinkwater *et al*., 2000).

5.4 Effects on greenhouse gases emissions

5.4.1 CO_2 emissions in maize and wheat

Higher emission of CO_2 in brown manuring and weedy check than in the herbicide treated plots is largely due to the increasing organic matter mineralisation and C oxidation influence by the decomposing crop residues, *Sesbania* and weeds biomass. Unlike in the herbicides treated plots, the brown manuring and the weedy check plots produce additional residue biomass (i.e. 2.4 t ha^{-1} of brown manure and 1.2 t ha^{-1} of weed) over the two year cropping period. Supplemental N applications in the GreenSeeker-guided treatments influences organic residues decomposition with subsequent CO_2 emissions. This is not the case with the whole N fertilisation at sowing, where a one-time N application would have result to greater leaching losses. Also, the crop residue management had marked effect on CO_2 emissions, retaining crop residues in CA are net sources of CO_2 (Almaraz *et al*., 2009), the type of crop residues will stimulate its decomposition, and more available organic C emissions (Vanhala *et al*., 2007), removing crop residues reduces the GWP by 1.3 times (Dendoveen *et al*., 2012),

In wheat, higher fluxes of CO_2 in the weedy check than in the herbicide combinations (pre-and post-emergent) might be attributed to the rapid organic matter mineralisation stimulated by the presence of weed biomass, whereas the herbicides treated plot was without additional weed biomass. Decomposing weed biomass in the weedy check plot amounts to about 1.2 t ha^{-1} over the two year period (0.5–0.6 t ha^{-1} yr^{-1}), weed biomass left on the no-till surface are more vulnerable to decay (Gallandt, 2004). The practice of crop residues retention under CA based systems exposes more organic matter for decomposition, hence the propensity for greater microbial activity responsible for decomposition leading to higher CO_2 and N_2O emissions, yet removing residues presents less organic matter decomposition (Dendooven *et al.* 2012). Baker *et al.* (2007) reported that continuous C emissions occurs in CA system, even after the experimentation period due to the organic residues left on the soil surface.

5.4.2 N_2O emissions in maize and wheat

Conversely, lower emission of N_2O in the brown manuring and weedy check in maize is probably due to the increase uptake of fertiliser N by the brown manure (*Sesbania*) and weeds present in these plots, while surplus N would have been lost in the herbicides treated plots with less biomass. Supplemental N applications in the GreenSeeker treatments coincides with subsequent measurement of the gas fluxes, thus more N_2O emissions were recorded in these treatments, while the whole N application at sowing result to a higher and one-time emission peak, which were liable to greater N losses (leaching). Better soil structure with less compact soils in CA will reduce emissions of N_2O, whereas soil organic matter, moisture and mineral N contents will enhance emissions of N_2O in CA (Dendooven *et al*., 2012). Combining N fertilization with crop residues increases organic matter mineralisation, and therefore more emission of N_2O (Ussiri and Lal, 2009). In wheat, the greater emission of N_2O in the weedy check plot is largely influence by additional organic matter present. Equally, subsequent in-season N additions in the GreenSeeker treatments will release N_2O emissions. Wheat produce more CO_2 and N_2O emissions than maize, this can be attributed to the quantity of residues return (50% of maize residues in wheat, while 40% of wheat's in maize), and the rainfall regime in wheat season, which greatly influence decomposition with more emissions of CO_2 and N_2O. Environmental factors such as cropping systems, inorganic or organic fertilization, soil management practices, and soil moisture regimes influences emissions (Ellert and Janzen, 2008; Zou *et al*., 2007; Baggs *et al*., 2003).

5.5 Effects on herbicide residues in soil

Unlike the pendimethalin and carfentrazone residues present in soils after harvest, the non-detection of atrazine and clodinafop residues might be attributed to rapid degradation of the chemical components coupled with the low dose application as in the case of the latter. Muoni *et al*. (2013) reported that characteristic weeds controlled by atrazine emerged in the following season suggesting biodegradation of atrazine under CA. Chauhan *et al*., (2006) reported that crop residue under CA can affect the bioavailability of herbicides, which can react chemically with residues. Active herbicide residual effect in soil can pose adverse effect on the succeeding/component crops.

Additionally, the consequence of ample crop residues retention in CA may result in weeds and soils receiving low herbicide rates thereby lowering herbicide efficacy, soil herbicides residues and quicken resistance to the herbicides (Busi and Powles, 2009; Neve and Powles, 2005) or effect rapid biodegradation (Muoni *et al*., 2013). This warrant greater attention, and is of greater concern for the sustainability of conservation agriculture.

SUMMARY AND CONCLUSION Chapter 6

Our overall aim is to present the synergies of integrating best agronomic management practices (nitrogen and weed management) within the core CA in maize–wheat system for enhancing crop and soil productivity with greater emphasis on environmental sustainability and agroecosystem functioning in the IGP. We emphasise the possibility of the inclusion or scaling-up of N and weed management strategies as rational ‘sensible' agronomic practices in CA based systems.

We conducted for the first time in the Indo-Gangetic Plains, a comprehensive interactive best management practices within the core conservation system (CA) system that incorporates the principles of CA system with the inclusion of rational agronomic practices. The integration of nitrogen and weed management practices in CA based system mitigates the trade-offs of N immobilisation and weed pressure. Augmenting the native soil N and reducing weed pressure at the onset of CA ensures the benefits of improved crop productivity and soil quality are achieved in the short-time. The optimization and synchronization of fertilizer N enhanced yield and soil health. Likewise, the brown manuring and herbicide combinations effects suppressed weeds, improved crop yield soil health. Gaining a better understanding of the transitioning phase from the conventional ‘business-as-usual’ crop production practices to conservation agriculture system, the knowledge of potential interactions between the N, herbicide and residue management is a pre-requisite in the maize-wheat system. The extent to which the accrued benefits were actually accumulated in a short-time period (two years) emphasises the possibility of the inclusion or scaling-up of N and weed management strategies as sensible agronomic practices in CA based systems.

Weed suppression: The brown manuring in maize and herbicide combinations (post-emergent) in wheat provide a broad-spectrum weed control effect, which improve crop growth and productivity. The inclusion of brown manuring in maize suppresses weeds and enhanced soil fertility, while the post-emergent herbicide combination in wheat show a better weed control effect. Moreover, weed density was about 40% lower in the weedy check (without weed control measures) after the second year of maize and wheat cropping, this is attributed to the cumulative crop residues effect on weed suppression.

Crop and system productivity: Our 'best optimised' GreenSeeker N-rate (N_2–50% basal + 25% broadcast at 25 days after sowing + rest N by GreenSeeker i.e., 155 and 133 kg N ha^{-1} for maize and wheat, respectively) influence greater crops and system productivity than the whole (100% N_1) basal application, and the other GreenSeeker N_3 –50% basal + rest N by GreenSeeker, and N_4–80% basal + rest N by GreenSeeker. The brown manuring (maize) + herbicide combinations (clodinafop + carfentrazone) (wheat) provides an effective weed control effects, which resulted in higher crop and system productivity.

Soil health: The prerequisite of soil test, residues return, and the synchronization of N fertilisation with the GreenSeeker ensured an optimal N availability and supply. Our 'best optimised' GreenSeeker–N rate applications improves soil organic C and total N contents. The availability of N contributed to greater microbial and enzyme activity (microbial biomass C, fluorescein diacetate and phosphatase), enhances soil organic carbon, total N accumulations and soil aggregate stability. The combination of brown manuring (maize) + herbicides (wheat) stimulates substantial above- and below-ground derived C and N inputs and outputs, and soil available N-P-K contents.

Economics and profitability: Although, the cost of raising the maize–wheat system cropping system were marginally higher in the herbicide combinations and brown manuring treatments, the greater efficiency (weed suppression, enhance soil and crop productivity) of these treatments offsets the additional cost of herbicides and labour. The brown manuring in maize and the post-emergent (clodinafop + carfentrazone) in wheat produce higher crop and system profitability. The benefit of raising maize–wheat with the brown manuring (maize) + herbicide combination (wheat) were highly profitable than the herbicide combination alone. By ensuring an efficient N use economy and efficiency, the GreenSeeker treatments provide an efficient cost-effective approach that outweighs the additional labour cost for the subsequent N fertilisations. Optimised N_2 –50% basal + 25% rest N by GreenSeeker provided the highest crop & system profitability. i.e. higher benefit to cost for raising maize and wheat, respectively, and as a system.

Greenhouse emissions and herbicide residue in soil: The optimisation of N fertilisation by the GreenSeeker reduce surplus N fertilisation, hence emissions of potent greenhouse gases were minimised. Although, substantial amount of organic C were oxidised, the efficiency of N uptake were greater with the brown manuring (maize) + herbicide combination (wheat). Likewise, efficient N applications in the GreenSeeker-guided N treatments, otherwise would have leach beyond crop use by full N application at sowing. The brown manuring in maize and the post-emergent herbicide combination produce less active residue in soil, the minimum dose applied in these treatments were more effective in managing weeds with little or no adverse effect on soil ecosystem functioning and human health.

GreenSeeker N economy and efficiency: Complementary soil test and GreenSeeker based approaches for N management reduced excess N applications close to rates that were synchronised to maize and wheat requirements. This is a better option to reduce excessive fertilisation while maximising crop yields and environmental sustainability. The combination of brown manuring and the post-emergent combined herbicides with the GreenSeeker N applications improved weed suppression, enhanced crop productivity and profitability with considerable improvement in soil chemical, biological and physical health. This precise N fertilisation strategy by GreenSeeker minimised excess N_2O and CO_2 emissions. Hence, we recommend complementary soil test and GreenSeeker approach in managing the complexity of N availability and crop residues; and the integration of brown manuring in maize, and herbicide combination in wheat in reducing weed proliferation in CA maize-wheat system in the NW-IGP of India for farmer's adoption.

This is the first time in the IGP, the inclusion of a rational 'sensitive' weed and nitrogen management within the core CA practices was studied. The synchronisation of N fertilisation enhanced N availability, while integrated weed management influenced greater weed suppression. The strategies of optimise N fertilisation by soil test and GreenSeeker guided N management maximise C and N inputs and outputs. The optimised N_2–50% basal + 25% broadcast + rest N guided by GreenSeeker improve crop productivity and profitability, and reduce surplus N_2O emissions. The inclusion of brown manuring in maize, with the post-emergent herbicide combinations in wheat result in greater weed suppression, net productivity, SOC and total N sequestration, and microbial proliferation. Therefore, for the short-time enhancement of soil health (C and N build-up); and the long-term CA intensification and sustainability to help reduce yield declines, the synchronisation and optimisation of fertiliser (N_2–50% basal + 25% broadcast + rest N by GreenSeeker) in maize and wheat, and the integration of brown manuring (maize) + clodinafop + carfentrazone (post-emergent herbicide combination in wheat) can be recommended to farmers/producers to help reduce the trade-offs (nitrogen immobilisation and weed pressure) expected in CA systems during the transitioning period (first three years) from conventional practices.

ABSTRACT

Weed interference due to the avoidance tillage and nitrogen (N) immobilisation owing to the mismanagement of surface crop residues are major trade-offs in conservation agriculture (CA) system, particularly in the initial periods (1–3 years) of conversion from conventional system. Therefore, we propose an integrated weed and N management in a CA based maize–wheat system by integrating weed management measures to reduce weed interference; and the complementary soil test and plant sensor (GreenSeeker) based approaches to enhance N mineralisation and availability.

We investigated weed and N management effects on weed suppression, productivity, profitability, soil health, and resource-use efficiency in a maize–wheat CA system over a two year period. Three weed (main plot) and four nitrogen (N) (sub-plot) management treatments were assessed in a split plot design. Weed management treatments were herbicide combinations, brown manuring with *Sesbania* killed by 2,4-D, and weedy check (control). Nitrogen management were whole N application (N_1; 100% basal); N_2–50% basal + 25% broadcast at 25 days after sowing + rest N guided by GreenSeeker (GS); N_3– 50% + rest N by GS; and N_4– 80% + rest N by GS.

Our results showed that weeds suppression was increased by 77% in the pre-emergent (atrazine + pendimethalin) herbicide combination; and 53% in the brown manuring over weedy check in maize. The weed control index was 62–80% by the atrazine + pendimethalin; and 40–60% by brown manuring over weedy check. The post-emergent herbicide combination (clodinafop + carfentrazone) in wheat reduced weed dry matter by 89%; while it was 74% in pre-emergent (pendimethalin + carfentrazone) over weedy check. The weed control index was 48–62% in the pre-emergent; and 42–83% in post-emergent herbicide combinations over weedy check.

Our 'best optimised' GreenSeeker–N rate (N_2–50% basal + 25% broadcast at 25 days after sowing + rest N by GreenSeeker i.e., 155 and 133 kg N ha^{-1} for maize and wheat, respectively) resulted in 20 and 14% higher maize and wheat grain yields (mean of two years), respectively, than whole N_1 (100% basal) application. Among the weed management treatment in maize, brown manuring resulted in 10% higher grain yield (mean) over weedy check, while the pre-emergent herbicide combination had comparable grain yield as with the brown manuring. But, in wheat, yield

increased by 10 and 20% in the post-emergent over the pre-emergent herbicide combinations and weedy check, respectively. The system productivity (based on wheat equivalent yield) increased by 17% in the best optimised GS N_2 rate over whole N_1 basal application. Likewise, the brown manuring (maize) + post-emergent herbicide combinations (wheat) resulted in 6 and 16% greater system productivity than herbicide combinations alone and weedy check, respectively.

Net profitability (mean) in maize increased by ₹5565 and ₹1780 in the brown manuring and pre-emergent herbicide combination, respectively, over weedy check. Whereas the best optimised GS N_2, increased net profitability by ₹13674 over whole N basal (N_1); and ₹6310 and ₹9923 than GS guided N_3 and N_4 rates, respectively. In wheat, net profitability were ₹15333 and ₹9500 higher in the post-emergent herbicide combination over weedy check and the pre-emergent herbicide combinations, respectively. While the best optimised GS N_2 increased net profitability by ₹10490 over whole N_1; and ₹5000 and 5900 than GS N_3 and N_4, respectively. Furthermore, the system net profitability was increased by 27% in the best optimised GS N_2 over whole basal (N_1); and 12% over GS N3 and N_4.

Soil organic carbon (SOC) and total N sequestrations after two years cropping increased by 2 and 1.3% in the optimised GreenSeeker treatments than whole N basal, whereas, the brown manuring + herbicide combinations were 3 and 6% higher over herbicide combination alone. Also, microorganisms and enzymes activities were increased by 1.3 times in the optimised GreenSeeker treatments than whole N basal; and 1.2 times in the brown manuring + herbicide combinations over weedy check. However, the weedy check resulted in comparable SOC and total N pools; microorganisms and enzymes activities with the brown manuring + herbicide combinations. Precision N fertilisation by the GreenSeeker and brown manuring minimised excess N_2O and CO_2 emissions with greater fertiliser N savings. Herbicide residues in soil were below detectable limit with the herbicide combinations.

We conclude that the efficiency of weed management by brown manuring and its synergy with herbicide combinations suppress weeds, and contribute to crop and soil productivity. The synchronization of N fertilisation based on the appraisal of the inherent soil N, and the Greenseeker in-season N supplementation enhance net primary productivity. This ‘sensitivity’ N and weed management in CA reduce excessive N and herbicide applications close to rates that were synchronise with crop requirements and weed control.

संरक्षित खेती के अंतर्गत मक्का-गेहूं फसल तंत्र में नाइट्रोजन एवं खरपतवार प्रबंधन

सार

पारंपरिक खेती के संरक्षित खेती में बदलाव में विशेष रूप से आरंभिक अवधि (1-3 वर्ष) में सतह पर फसल अवशेषों के कुप्रबंधन से जुताई में अरूचि एवं नाइट्रोजन (एन) की गतिहीनता के कारण खरपतवारों का प्रकोप संरक्षित खेती (सीए)तंत्र की मुख्य बाधाए हैं। इसलिए हम एक सीए आधारित मक्का-गेहूं तंत्र में खरपतवार में कमी करने वाले समेकित खरपतवार प्रबंधन उपायों तथा एक पूरक मृदा परीक्षण एवं एन-खनिजीकरणऔर उसकी उपलब्धता में बढ़ोतरी के लिए प्लांट सेंसर (ग्रीन सीकर) आधारित विधियों द्वारा एक समेकित खरपतवार एवं एन-प्रबंधन का सुझाव देते हैं।

हमने एक मक्का-गेहूं सीए तंत्र में दो वर्षों से भी अधिक समय तक खरपतवार संदमन, उत्पादिता, होने वाले लाभ, मृदा स्वास्थ्य एवं संसाधन उपयोग क्षमता पर खरपतवार एवं एन-प्रबंधन के प्रभावों का अध्ययन किया। एक विभक्त भूखंड डिजाइनमें तीन खरपतवार संबंधी (मुख्य भूखण्ड)एवं चार नाइट्रोजन (एन) (उप भूखंड) प्रबंधन उपचारों में शाकनाशी संयोजनों, 2,4-डी प्रदान करना एवं खरपतवार युक्त चैक का समावेश था। नाइट्रोजन प्रबंधन में, सम्पूर्ण एन अनुप्रयोग (एन$_1$_100% आधारतभूत); एन$_2$ – 50% आधारभूत + बुवाई के 25 दिन बाद 25 प्रतिशत बिखेर कर + शेष एन ग्रीन सीकर (जीएस) के निर्देशानुसार; एन$_3$ – 50% आधारभूत + शेष एन जीएस द्वारा; एवं एन$_4$ – 80% आधारभूत + शेष एन जीएस द्वारा, इन चार उपचारों का समावेश था। मक्का की फसल में हमारे द्वारा प्राप्त परिणामों ने दर्शाया कि मक्का की फसल में पूर्व-निर्गमन (एट्राजीन + पेंडीमेथालिन) शाकनाशी संयोजन में खरतपवार युक्त चैक की तुलना में खरपतवारों के संदमन में 77 प्रतिशत बढ़ोतरी हुई तथा भूरी खाद प्रदान करने पर 53 प्रतिशत की बढ़ोतरी हुई। खरपतवार युक्त चैक की तुलना में एट्राजीन + पेंडीमेथालिन द्वाराखरपतवार नियंृण सूचकांक 62-80 प्रतिशत तथा भूरी खाद देने पर 40-60 प्रतिशत पाए गए। गेहूं में खरपतवारयुक्त चैक की तुलना में पश्च निर्गमन शाकनाशी संयोजन (क्लोडिनाफॉप + कारपेन्ट्राजोन) में यह कमी 74 प्रतिशत थी। खरपतवार युक्त चैक की तुलना में, पूर्व निर्गमन में खरतपवार नियंत्रण सूचकांक 48-62 प्रतिशतथा तथा पश्च निर्गमन शाकनाशी संयोजनों में 42-83 प्रतिशत था।

सम्पूर्ण एन$_1$ (100 प्रतिशत आधारभूत) अनुप्रयोग की तुलना में मक्का एवं गेहूं की फसल के लिए हमारी 'सर्वोत्तम इष्टतमीकृत' ग्रीन सीकर एन दर (एन$_2$ – 50 प्रतिशत आधारभूत + 25 प्रतिशत बुआई के 25 दिन बाद छिड़ककर + शेष एन ग्रीन सीकर द्वारा अर्थात् मक्का एवं गेहूं के लिए क्रमश: 133 कि.ग्रा. एन प्रति हैक्टर से अनुप्रयोग के द्वारा सम्पूर्ण एन$_1$ (100 प्रतिशत आधारतभूत) अनुप्रयोग की तुलना में मक्का एवं गेहूं की दाना उपज (दोनों वर्षों का औसत) क्रमश: 20 प्रतिशत एवं 14 प्रतिशत अधिक पाई गई। मक्का की फसल में खरपतवार प्रबंधन प्रभावों में से, खरपतवारयुक्त चैक की तुलना में भूरी खाद देने के परिणामस्वरूप 10 प्रतिशत अधिक दाना उपज हुई जबकि पूर्व निर्गमन शाकनाशी संयोजन का दाना उपज पर प्रभाव भूरी खाद देने के समकक्ष था। गेहूं की फसल में पूर्व निर्गमन शाकनाशी संयोजनों एवं खरपतवार युक्त चैक की अपेक्षा पश्च निर्गमन शाकनाशी संयोजनों द्वारा उपज में बढ़ोतरी क्रमश: 10 एवं 21 प्रतिशत अधिक थी। सम्पूर्ण एन$_1$ आधारभूत अनुप्रयोग की तुलना में, सर्वोत्तम इष्टतमीकृत जीएस एन$_2$ दर के द्वारा तंत्र उत्पादिता (गेहूं समतुल्य उपज पर आधारित) में 17 प्रतिशत की बढ़ोतरी हुई। इसी प्रकार से अकेले शाकनाशी संयोजनों एवं खरपतवार युक्त चैक की तुलना में भूरी खाद (मक्का) + पश्च निर्गमन

शाकनाशी संयोजनों (गेहूं) के अनुप्रयोग के परिणामस्वरूप तंत्र उत्पादिता में क्रमश: 6 एवं 16 प्रतिशत की बढ़ोतरी हुई।

मक्का में खरपतवारयुक्त चैक की तुलना में भूरी खाद देने एवं पश्च निर्गमन शाकनाशी संयोजन में शुद्ध लाभ (औसत) में बढ़ोतरी क्रमश: 5565 रु. एवं 1780 रु. थी। सम्पूर्ण आधारभूत एन (एन$_1$) की तुलना में सर्वोत्तम इष्टतमीकरण जीएस एन$_2$ से शुद्ध लाभ में 13674 रु. की बढोतरी तथा जीएस के निर्देशानुसार एन$_3$ एवं एन$_4$ दरों की तुलना में क्रमश: 6310 रु. एवं 9923 रु. की बढ़ोतरी हुई। गेहूं में खरपतवार युक्त चैक एवं पूर्व निर्गमन शाकनाशी संयोजन में शुद्ध लाभ क्रमश: 15333 एवं 9500 रु. अधिक प्राप्त हुए, जबकि सम्पूर्ण एन$_1$ की अपेक्षा सर्वोत्तम इष्टतमीकृत जीएस एन$_2$ से शुद्ध लाभ में 10490 रु. की बढ़ोतरी हुई तथा जीएस एन$_3$ एवं एन$_4$ की तुलना में क्रमश: 5000 रु. एवं 5900 रु. की बढ़ोतरी हुई। इसके अतिरिक्त सर्वोत्तम इष्टतमीकृत जीएस एन$_2$ द्वारा तंत्र शुद्ध लाभ में सम्पूर्ण आधारभूत एन (एन$_1$) की तुलना में 27 प्रतिशत तथा जीएस एन$_1$ एवं एन$_4$ की तुलना में 12 प्रतिशत की बढ़ोतरी हुई।

सम्पूर्ण आधारभूत एन की तुलना में, इष्टतमीकृत ग्रीन सीकर उपचारों में दो वर्षों तक फसल लेने के बाद मृदा जैविक कार्बन (एसओसी) एवं कुल एन विविक्तीभवन में क्रमश: 2 एवं 1.3 प्रतिशत की बढ़ोतरी हुई जबकि अकेले शाकनाशी संयोजनकी तुलना में भूरी खाद+ शाकनाशी संयोजनों में यह 3 एवं 6 प्रतिशत अधिक थी। साथ ही सम्पूर्ण आधारभूत एन की अपेक्षा इष्टतमीकृत ग्रीन सीकर उपचारों में सूक्ष्मजीव एवं एंजाइम प्रक्रियाओं में 1.3 गुना बढ़ोतरी हुई तथा खरपतवारयुक्त चैक की तुलना में भूरी खाद + शाकनाशी संयोजनों में 1.2 गुना बढ़ोतरी हुई। वैसे खरपतवारयुक्त चैक के एसओसी एवं कुल एन भंडार, सूक्ष्मजीव एवं एंजाइम सक्रियताएं, भूरी खाद + शाकनाशी संयोजनों से तुलनीय थे।

ग्रीन सीकर द्वारा परिशुद्ध एन उर्वरण तथा भूरी खाद के अनुप्रयोग ने अधिक N_2O एवं CO_2 उत्सर्जनों को न्यूनतम किया और साथ ही अधिक उर्वरक एन की बचत की। कम मात्रा में अनुप्रयोग से मृदा में शाकनाशी-अवशेष पहचान योग्य सीमा से कम पाए गए।

इस अध्ययन से हम यह निष्कर्ष निकाल सकते हैं कि भूरी खाद द्वारा खरपतवार प्रबंधन एवं इसकी शाकनाशी संयोजनों के साथ संगतता खरपतवारों का संदमन किया तथा अधिक फसल एवं मृदा उत्पादिता में योगदान दिया। अंतर्निहित मृदा एन की समीक्षा पर आधारित कार्बन अवशेष समृद्ध मृदा के साथ संगत एन उर्वरण तथा ग्रीन सीकर मिडसीजन एन अनुपूर्ति एवं खरपतवार प्रबंधन हेतु इस सीए आधारित विधि 'संवेदनशीलता' ने आवश्यकता से अधिक एन एवं शाकनाशी अनुप्रयोगों में कमी की जिसकी फसल आवश्यकताओं एवं खरपतवार नियंत्रण के साथ संगतता थी।

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APPENDIX I

Maize field operations schedule (2013 & 2014)

Field Operation	**2013**	**2014**
Pre-sowing irrigation	-	07.07.14
Pre-sowing glyphosate application	03.07.13	08.07.14
Residue laying	07.07.13	06.07.14
Fertiliser application and sowing	07.07.13	12.07.14
Fertiliser application -1st topdressing	02.08.13	07.08.14
Atrazine + pendimethalin application	08.07.13	13.07.14
Irrigation	-	16.07.14
Irrigation	-	04.08.14
Fertiliser application- 2nd top dressing	14.08.13	25.08.14
GreenSeeker Observation-1st	14.08.13	13.08.14
Sampling for weed at 40DAS	15.08.13	20.08.14
Fertiliser application - 3rd top dressing	28.08.13	08.09.14
Fertiliser application - 4th top dressing	08.09.13	13.09.14
GreenSeeker Observation-2nd	21.08.13	20.08.14
GreenSeeker Observation-3rd	21.08.13	27.08.14
GreenSeeker Observation-4th	28.08.13	04.09.14
GreenSeeker Observation-5th	04.09.13	11.09.14
Irrigation	07.09.13	15.09.14
GreenSeeker Observation-6th	11.09.13	18.09.14
Sampling for plant parameter at 70DAS	15.09.13	21.09.14
Sampling for weed at 70DAS	15.09.13	21.09.14
Irrigation	17.9.13	-
Fertiliser application- 5th top dressing	19.09.13	20.09.14
GreenSeeker Observation-7th	19.09.13	25.09.14
Harvesting	20.10.13	22.10.14
Shelling	18.11.13	20.11.14

APPENDIX II

Wheat field operations schedule (2013–14 & 2014–15)

Field Operation	**2013–14**	**2014-15**
Pre-sowing irrigation	10.11.13	30.10.14
Pre-sowing glyphosate application	13.11.13	01.11.14
Residue laying	08.11.13	30.10.14
Fertiliser basal application and sowing	15.11.13	04.11.14
Pendimethalin + carfentrazone application	16.11.13	05.11.14
Sampling for weed at 20DAS	05.12.13	24.11.14
Irrigation	07.12.13	19.11.14
Sampling for plant parameter at 40DAS	24.12.13	13.12.14
GreenSeeker observation-1st	26.12.13	15.12.14
Fertiliser application - 2nd top dressing	29.12.13	20.12.14
Irrigation	08.01.14	22.1.15
Fertiliser application - 3rd top dressing	17.01.14	02.01.15
GreenSeeker Observation-2nd	03.01.14	22.12.14
Irrigation	03.02.14	-
GreenSeeker Observation-3rd	10.01.14	29.12.14
GreenSeeker Observation-4th	17.01.14	04.01.15
GreenSeeker Observation-5th	23.01.14	11.01.15
Sampling for weed at 70 DAS	23.01.14	12.1.14
GreenSeeker Observation-6th	29.01.14	18.01.15
Fertiliser application - 4th top dressing	01.02.14	25.01.15
GreenSeeker Observation-7th	07.02.14	25.01.15
Irrigation	15.03.14	-
Harvesting	15.04.14	20.04.15
Threshing	25.04.14	25.04.15

APPENDIX III

Prices of inputs and produce used for economic analyses of the maize–wheat cropping system

S.No	Particulars	Item	Quantity	Rate
A	INPUT PRICES			
1	Seed	Maize	20 kg	100/kg
		Wheat	100kg	30/kg
		Sesbania	20kg	30/kg
2	Fertilizer application			
		Urea	315 kg ha^{-1}	12/kg
		DAP	195 kg ha^{-1}	50/kg
		MOP	75 kg ha^{-1}	25/kg
3	Chemicals			
	glyphosate-41EC		1.0 kg a.i.(2.5 l)	240/litre
	atrazine-50WP		0.75 kg a.i.(1.5 kg)	400/kg
	pendimethalin-30EC		1.0 kg a.i.(3.33 l)	450/litre
	carfentrazone-40WDG		0.02 kg a.i.(50g)	75/50g
	Clodinafop-propargyl-15WP		0.06 kg a.i (400g)	280/kg
	2,4 D-80SP		0.25 kg a.i (300g)	330/kg
	Chlorpyriphos 17.8 EC		0.05% kg a.i (1.25 l)	180/litre
	Endosulfan 35 EC		0.07% (1.0 litres)	300/litre
4	Operations			
	sowing	10 man days	6 hours	250/man
	irrigation		1 ha	500/irrigation
	harvesting		1 ha (20mandays)	250/man
	shelling		1 ha	250/man
5	Fixed asset			
	Land rental	4 months (maize)	1500/ha/annum	500/4months
		6 months (wheat)	1500/ha/annum	750/6months
	Output prices			
	Main product	Maize grain	100 kg	1200 (2013–14)
				1320 (2014–15)
B		Wheat grain	100 kg	1300 (2013–2014)
				1430 (2014–15)
	By-product	Maize stover	100 kg	100
		Wheat straw	100 kg	200

APPENDIX IV

Cost of cultivation (₹/ha) of maize 2013

MAIZE–1st year, 2013														
Treatment		Herbicide application		Wheat residues	Sowing			Herbicide application		Fertiliser application				
MAIN-PLOT (Weed management)	SUB-PLOT (Nitrogen Management)	Glyph-osate	Labor 2 man days		Maize seed (20kg)	Labor 10 man-days	*Sesbania* seeds (20 kg)	Atrazine + Pendi methalin (tank-mix)	Labor 2 man-days	UREA	DAP	MOP	Labor 4-man days	Top dress 2 man days
Weedy check	100+0	600	500	8000	1000	2500	0	0	0	1890	4875	1350	1000	0
	50+25+GS	600	500	8000	1000	2500	0	0	0	1607	4875	1350	1000	500
	50+GS	600	500	8000	1000	2500	0	0	0	1418	4875	1350	1000	500
	80+GS	600	500	8000	1000	2500	0	0	0	1701	4875	1350	1000	250
Atrazine + Pendi	100+0	600	500	8000	1000	2500	0	1518	500	1890	4875	1350	1000	0
	50+25+GS	600	500	8000	1000	2500	0	1518	500	1607	4875	1350	1000	500
	50+GS	600	500	8000	1000	2500	0	1518	500	1418	4875	1350	1000	500
	80+GS	600	500	8000	1000	2500	0	1518	500	1701	4875	1350	1000	250
Brown manuring	100+0	600	500	8000	1000	2500	600	0	500	1890	4875	1350	1000	0
	50+25+GS	600	500	8000	1000	2500	600	0	500	1607	4875	1350	1000	500
	50+GS	600	500	8000	1000	2500	600	0	500	1418	4875	1350	1000	500
	80+GS	600	500	8000	1000	2500	600	0	500	1701	4875	1350	1000	250

Cost of cultivation (₹/ha) of maize 2013….continued

Irrigation		Crop protection			Harvest	Packaging Shelling, cleaning		Others	Miscellaneous		TOTAL
2 nos.	Labor 4 man days	Insecti-cides	Labor 2-man days	Bird scare 15-man days	Labor 10-man days	Thresh + combine	Labor 4- man day		Interest 6%	Land rent 4 mths	
1000	1000	525	500	1500	2500	750	1000	500	732	500	31722
1000	1000	525	500	1500	2500	750	1000	500	737	500	31943
1000	1000	525	500	1500	2500	750	1000	500	732	500	31750
1000	1000	525	500	1500	2500	750	1000	500	733	500	31784
1000	1000	525	500	1500	2500	750	1000	500	780	500	33788
1000	1000	525	500	1500	2500	750	1000	500	785	500	34009
1000	1000	525	500	1500	2500	750	1000	500	781	500	33816
1000	1000	525	500	1500	2500	750	1000	500	782	500	33850
1000	1000	525	500	1500	2500	750	1000	500	758	500	32848
1000	1000	525	500	1500	2500	750	1000	500	763	500	33070
1000	1000	525	500	1500	2500	750	1000	500	759	500	32876
1000	1000	525	500	1500	2500	750	1000	500	760	500	32911

APPENDIX V

Cost of cultivation (₹/ha) of maize 2014

MAIZE—2nd year, 2014														
Treatment		Herbicide application		Wheat residue	Sowing			Herbicide application		Fertiliser application				
Mainplots (Weed management)	Subplots (Nitrogen management)	Glypo-sate	Labor 2 man-days		Maize seeds 20kg	Labor 10 man-days	*Sesbania* seeds (20kg)	Atrazine + Pendimet-halin (tankmix)	Labor 2 man-days	UREA	DAP	MOP	Labor 4-Man days	Top dress 2 man-day
Weedy check	100+0	600	500	8000	1000	2500	0	0	0	1890	4875	1350	1000	0
	50+25+GS	600	500	8000	1000	2500	0	0	0	1607	4875	1350	1000	500
	50+GS	600	500	8000	1000	2500	0	0	0	1418	4875	1350	1000	500
	80+GS	600	500	8000	1000	2500	0	0	0	1701	4875	1350	1000	250
Atrazine + Pendi	100+0	600	500	8000	1000	2500	0	1518	500	1890	4875	1350	1000	0
	50+25+GS	600	500	8000	1000	2500	0	1518	500	1607	4875	1350	1000	500
	50+GS	600	500	8000	1000	2500	0	1518	500	1418	4875	1350	1000	500
	80+GS	600	500	8000	1000	2500	0	1518	500	1701	4875	1350	1000	250
Brown manuring	100+0	600	500	8000	1000	2500	600	0	500	1890	4875	1350	1000	0
	50+25+GS	600	500	8000	1000	2500	600	0	500	1607	4875	1350	1000	500
	50+GS	600	500	8000	1000	2500	600	0	500	1418	4875	1350	1000	500
	80+GS	600	500	8000	1000	2500	600	0	500	1701	4875	1350	1000	250

Cost of cultivation (₹/ha) of maize 2014….continued

Irrigation water		Crop protection			Harvest	Packaging Shelling, cleaning			Miscellaneous		TOTAL
4 nos.	Labor 4 man days	Insecti-cides	Labor 2-man days	Bird scare 15-man days	Labor 10-man days	Thresh + combine	Labor 4- man day	Others	Interest 6%	Land rent 4 mths	
2000	1000	525	500	1500	2500	750	1000	500	756	500	32746
2000	1000	525	500	1500	2500	750	1000	500	761	500	32967
2000	1000	525	500	1500	2500	750	1000	500	756	500	32774
2000	1000	525	500	1500	2500	750	1000	500	757	500	32808
2000	1000	525	500	1500	2500	750	1000	500	804	500	34812
2000	1000	525	500	1500	2500	750	1000	500	809	500	35033
2000	1000	525	500	1500	2500	750	1000	500	805	500	34840
2000	1000	525	500	1500	2500	750	1000	500	806	500	34874
2000	1000	525	500	1500	2500	750	1000	500	782	500	33872
2000	1000	525	500	1500	2500	750	1000	500	787	500	34094
2000	1000	525	500	1500	2500	750	1000	500	783	500	33900
2000	1000	525	500	1500	2500	750	1000	500	784	500	33935

APPENDIX VI

Cost of cultivation (₹/ha) of wheat 2013–14

WHEAT—1st year, 2013-14											
treatment		Herbicide application		Maize residue	sowing			Herbicide application			
Mainplots (Weed management)	Subplots (Nitrogen management)	Glyphosate	Labor 2 man-days		Wheat seeds (20 kg)	Labor 10 man-days	Thinning/ filling 3 mandays	Pre-emergent (tank-mix)	Labor 2 man-day	Post-emergent (tank-mix)	Labor 2 man-days
Weedy check	100+0	600	500	5000	2500	2500	900	0	0	0	0
	50+25+GS	600	500	5000	2500	2500	900	0	0	0	0
	50+GS	600	500	5000	2500	2500	900	0	0	0	0
	80+GS	600	500	5000	2500	2500	900	0	0	0	0
Pendim+ Carfentrazone	100+0	600	500	5000	2500	2500	900	1200	500	0	0
	50+25+GS	600	500	5000	2500	2500	900	1200	500	0	0
	50+GS	600	500	5000	2500	2500	900	1200	500	0	0
	80+GS	600	500	5000	2500	2500	900	1200	500	0	0
Clodinafop + carfentrazone	100+0	600	500	5000	2500	2500	900	0	0	352	500
	50+25+GS	600	500	5000	2500	2500	900	0	0	352	500
	50+GS	600	500	5000	2500	2500	900	0	0	352	500
	80+GS	600	500	5000	2500	2500	900	0	0	352	500

Cost of cultivation (₹/ha) of wheat 2013–14….continued

Fertiliser application					Irrigation		Crop protection		Harvest			Miscellaneous			TOTAL
UREA	DAP	MOP	Labor 4 man-days	Top dress 2 man-days	5 nos.	Labor 4 man-days	Insec-ticides	Bird Scare 15 man-days	Labor 10 man days	Package thresh combine	Labor 3 man days	others	Interest rate 6%	Land rent 6 mths	
1890	4875	1350	1000	0	2500	1000	525	1500	2500	1000	750	500	942	750	37763
1701	4875	1350	1000	500	2500	1000	525	1500	2500	1000	750	500	951	750	37949
1512	4875	1350	1000	500	2500	1000	525	1500	2500	1000	750	500	945	750	37565
1758	4875	1350	1000	250	2500	1000	525	1500	2500	1000	750	500	945	750	38333
1890	4875	1350	1000	0	2500	1000	525	1500	2500	1000	750	500	993	750	39713
1701	4875	1350	1000	500	2500	1000	525	1500	2500	1000	750	500	1002	750	39649
1512	4875	1350	1000	500	2500	1000	525	1500	2500	1000	750	500	996	750	39265
1758	4875	1350	1000	250	2500	1000	525	1500	2500	1000	750	500	996	750	40033
1890	4875	1350	1000	0	2500	1000	525	1500	2500	1000	750	500	967	750	38700
1701	4875	1350	1000	500	2500	1000	525	1500	2500	1000	750	500	977	750	38636
1512	4875	1350	1000	500	2500	1000	525	1500	2500	1000	750	500	971	750	38252
1758	4875	1350	1000	250	2500	1000	525	1500	2500	1000	750	500	971	750	39020

APPENDIX VII

Cost of cultivation (₹/ha) of wheat 2014–15

WHEAT—2nd year, 2014-15											
Treatment		Herbicide application		Maize residue	Sowing			Herbicide application			
Mainplots (Weed management)	Subplots (Nitrogen management)	Glyphos-ate	Labor 2 man-days		Wheat seeds (20 kg)	Labor 10 man-days	Thinning/ filling	Pre-emergent (tank-mix)	Labor 2 man-day	Post-emergent (tank-mix)	Labor 2 man-days
							3 mandays				
Weedy check	100+0	600	500	5000	2500	2500	900	0	0	0	0
	50+25+GS	600	500	5000	2500	2500	900	0	0	0	0
	50+GS	600	500	5000	2500	2500	900	0	0	0	0
	80+GS	600	500	5000	2500	2500	900	0	0	0	0
Pendim+ Carfentrazone	100+0	600	500	5000	2500	2500	900	1200	500	0	0
	50+25+GS	600	500	5000	2500	2500	900	1200	500	0	0
	50+GS	600	500	5000	2500	2500	900	1200	500	0	0
	80+GS	600	500	5000	2500	2500	900	1200	500	0	0
Clodinafop + carfentrazone	100+0	600	500	5000	2500	2500	900	0	0	352	500
	50+25+GS	600	500	5000	2500	2500	900	0	0	352	500
	50+GS	600	500	5000	2500	2500	900	0	0	352	500
	80+GS	600	500	5000	2500	2500	900	0	0	352	500

Cost of cultivation (₹/ha) of wheat 2014–15…continued

Fertiliser application					Irrigation		Crop protection		Harvest			Miscellaneous			TOTAL
UREA	DAP	MOP	Labor 4 man-days	Top dress 2 man-days	3 nos.	Labor 4 man-days	Insect-icides	Bird Scare 15 man-days	Labor 10 man days	Package thresh combine	Labor 3 man days	others	Interest 6%	Land rent 6 mths	
1890	4875	1350	1000	0	1500	1000	525	1500	2500	1000	750	500	912	750	32052
1701	4875	1350	1000	500	1500	1000	525	1500	2500	1000	750	500	921	750	32372
1512	4875	1350	1000	500	1500	1000	525	1500	2500	1000	750	500	915	750	32177
1758	4875	1350	1000	250	1500	1000	525	1500	2500	1000	750	500	915	750	32173
1890	4875	1350	1000	0	1500	1000	525	1500	2500	1000	750	500	963	750	33803
1701	4875	1350	1000	500	1500	1000	525	1500	2500	1000	750	500	972	750	34123
1512	4875	1350	1000	500	1500	1000	525	1500	2500	1000	750	500	966	750	33928
1758	4875	1350	1000	250	1500	1000	525	1500	2500	1000	750	500	966	750	33924
1890	4875	1350	1000	0	1500	1000	525	1500	2500	1000	750	500	937	750	32929
1701	4875	1350	1000	500	1500	1000	525	1500	2500	1000	750	500	947	750	33250
1512	4875	1350	1000	500	1500	1000	525	1500	2500	1000	750	500	941	750	33055
1758	4875	1350	1000	250	1500	1000	525	1500	2500	1000	750	500	941	750	33050