

**नत्रजन, भूपरिष्करण व फसल अवशेष प्रबंधन का मक्का-गेहूँ फसल चक्र में
नत्रजन गतिकी पर प्रभाव**

**Nitrogen dynamics under maize-wheat cropping system as
influenced by nitrogen, tillage and residue management options**

दीपमोहन महला

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**Division of Soil Science and Agricultural Chemistry
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New Delhi-110 012, India**

2015

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By

Deep Mohan Mahala

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CERTIFICATE

This is to certify that the thesis entitled “**Nitrogen dynamics under maize-wheat cropping system as influenced by nitrogen, tillage and residue management options**” submitted to the Faculty of the Post-Graduate School, ICAR-Indian Agricultural Research Institute, New Delhi, in partial fulfillment of the requirements for the degree of **Master of Science in Soil Science and Agricultural Chemistry**, embodies the results of *bonafide* research work carried out by **Mr. Deep Mohan Mahala**, under my guidance and supervision, and that no part of this thesis has been submitted for any other degree or diploma.

It is further certified that any assistance and help availed during the course of investigation as well as source of information have been duly acknowledged by him.

Place: New Delhi

Date:

(Dr. M.C. Meena)

Chairperson

Advisory Committee

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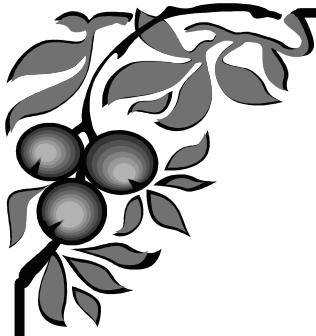
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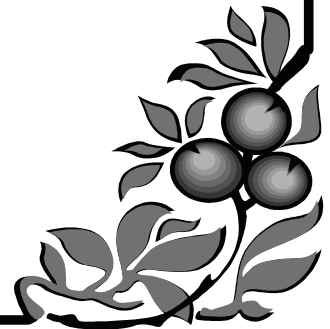
Place : New Delhi

Dated:

(Deep Mohan Mahala)



*Dedicated to
My Beloved
parents*



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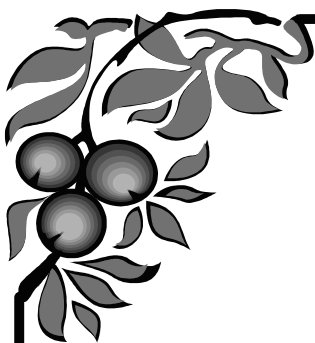
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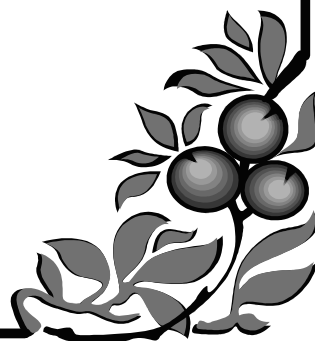
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Chapter 1

Introduction



1. INTRODUCTION

Fertilizer nitrogen (N) is a key input in food production. Nitrogen is typically required in larger quantities than any other nutrients by the crop for its normal growth and development. Therefore, proper management of N is essential to reap normal yield and profit. It is one of the most important nutrients limiting maize yield and quality in various parts of the world (Miao *et al.* 2007), including India where per cent yield decline due to N deficiency is estimated up to 50%. Cereals including rice, wheat and maize account for more than half of the total fertilizer N consumption in the world. As per estimates 50–70% more cereal grain will be required by 2050 to feed over 9 billion world population. Moreover, in the last five decades in India, nutrient use has increased by 1573%, total food grain production by 145% and average yield by 125%, despite an area increase by only 3.5% (Jat *et al.* 2011), despite this will further increase fertilizer N demand at greater magnitude unless the fertilizer N recovery efficiency in cereals is improved. Presently, the recovery of applied fertilizer N is only 30–50% by the first crop and not more than 7% by the six consecutive crops (Ladha *et al.* 2005), and remaining N is lost from the soil–plant system. Generally, use of excessive fertilizer N to avoid the risk of N deficiency further reduces its efficiency. Excessive N causes nutrient imbalances and excessive vegetative growth. Low recovery of N is not only responsible for higher cost of crop production, but also for environmental pollution (Fageria and Baligar 2005).

Low N fertility is the second most important constraint for maize production and productivity after drought in tropical regions, including Asia (Singh *et al.* 2005). The doubling of agricultural food production worldwide over past few decades has been associated with a seven fold increase in the use of N fertilizers (Hirel *et al.* 2007). Since N is the major structural constituent of cells, as N level increases the rate of vegetative and reproductive growth also increases in plants due to increase in assimilatory surface of plant as well as photosynthesis (Shrikanth *et al.* 2009). Thus, N uptake, biomass production and grain yields are strongly correlated with N requirement of a crop and hence an optimum dose under a particular management practice is vital.

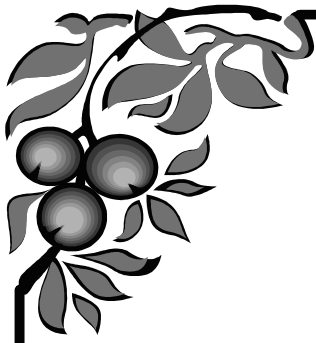
Traditionally, wheat is grown in the winter season following rice/maize in the Indo-Gangetic Plains (IGP). Farmers typically perform multiple tillage operations after the harvest of maize for wheat planting under a maize-wheat cropping system. The

intensive tillage contributes to an increased cost of cultivation leading to decreased profitability (Chhonkar *et al.* 2007; Ladha *et al.* 2009). Increased use of machinery and fuel for repeated tillage operations also emits large amount of greenhouse gases (GHGs) into the atmosphere (Rádics *et al.* 2014). The use of blanket (or age-old) nutrient recommendations in India has led to low nutrient use efficiency (NUE), lowered profits and increased environmental problems (Pampolino *et al.* 2012). Nutrient recommendations in India are based upon crop response data averaged over large geographic areas and do not take into account the spatial variability in indigenous nutrient supplying capacity of soils (Majumdar *et al.* 2013). Blanket fertilizer application, therefore, results into under-fertilization in some cases and over-fertilization in others. Surveys in the IGP revealed that farmers often apply greater than recommended rates of fertilizer N and P, but ignore sufficient application of K and other secondary and micronutrients (Singh *et al.* 2005). Such unbalanced and inadequate use of nutrients decreases the NUE and profitability, and may increase environmental risks associated with the loss of unutilized nutrient through emission or leaching. This further increases agriculture's share to total GHGs emissions.

No-till and residue retention based N management practices proved to produce more at less costs, reduce environmental pollution, promote conjunctive use of organics (avoid residue burning), improve soil health, and promote timely planting of crops to address the issues of terminal heat stresses in the region. No-till or reduced tillage has the potential to conserve SOC by reducing mineralization (Abdalla *et al.* 2013) and enhancing soil aggregation (Six *et al.* 2000). Thus, for addressing the issues of resource fatigue and bridging 'management yield gaps', no-till based N management solutions are cornerstone. Soil organic matter (SOM) turn-over can be considerably improved by addition of various sources of organic materials *i.e.* plant residues. Recycling of organic wastes for increasing soil fertility has gained importance in recent years due to high cost of mineral fertilizers and reduced availability of organic manures. According to an estimation, around 600-700 million tonnes (Mt) of agricultural wastes are available in India including 272 Mt of crop residues every year (Suthar 2008). Straw/Stover is the major component of agricultural waste, although a substantial portion of these material, is disposed-off from the field by burning. As a result, considerable amounts of organic C as well as nutrients are lost. This potent source of organic matter and nutrients could be recycled back to agricultural fields after converting these into value-added composts

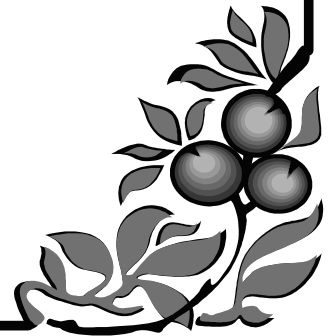
or retention of residues as such in the field for crop production as well as maintaining soil fertility. However, a shift from conventional plough-based farming practices to crop management practices based on key elements of conservation agriculture (minimal soil disturbance, surface retention of crop residues and efficient crop rotations) would exhibit variable nutrient dynamics. Furthermore, current fertilizer N recommendations on the amounts and timing of N applications are typically generalized recommendations for very large areas of maize and wheat growing tracts. Such broad-based 'blanket' recommendations of fertilizer N restrict efficient use of N fertilizer. In order to ensure high crop yields, many a times, farmers apply fertilizer N in doses much higher than the blanket recommendations. Hence, it was felt necessary to understand the impact of different N doses and application methods in a short-term maize-wheat cropping system grown under conservation agriculture in the IGP. Information is limited on the above aspects, especially under different tillage practices and residue loads. Considering these facts, the present investigation entitled **“Nitrogen dynamics under maize-wheat cropping system as influenced by nitrogen, tillage and residue management options”** has been undertaken with the following objectives:

- To study the changes in oxidizable carbon and mineralizable nitrogen in soil at different growth stages of maize and wheat under different nitrogen, tillage and residue management practices
- To study nitrogen dynamics, its use efficiency and productivity of maize-wheat cropping system under different nitrogen, tillage and residue management options



Chapter 2

Background



2. REVIEW OF LITERATURE

In view of the ever-increasing demand for improvement in productivity against the background of shrinking soil and water resources and depletion of soil fertility, expansion of multi-nutrient deficiencies, it is pertinent to develop situation specific nutrient management options for different crops and ensure their large scale adoption. When it comes to conservation agriculture (CA), nutrient management strategies of conventional agriculture are followed, because CA specific practices have not been developed. It is not understood whether the conventional agriculture based nutrient application rates, schedules and methods will perform equally well under a modified soil environment. This is in fact a major technology gap that needs to be bridged-up through well-planned experiments. Therefore, a comprehensive review of literature pertaining to the present investigation is presented hereunder.

2.1. Effect of tillage, crop residue, and source of N and its application methods on crops yield

In South Asia, rice, wheat and maize are the major cereal crops grown in rotation with non-cereal crops such as potato, mustard and legumes (Balasubramanian *et al.* 2012). Among cereals, rice and wheat give the staple sustenance to countless individuals. In South Asia, the maize–wheat cropping system is followed in countries like India, Pakistan and Nepal in area of 1.80, 1.00, and 0.04 Mha, respectively (Timsina *et al.* 2010). Inadequate and indiscriminate use of fertilizers have resulted in overmining of nutrients from the soil which ultimately triggered declining productivity growth rates in maize-wheat system. Maize is mainly a feed crop, but it is also a food crop in many poverty-stricken areas, especially in the hilly areas. This crop greatly influences the livelihoods and health of the urban and rural poor.

Maize is rising as a great expansion choice for farmers in South Asia as a non-traditional component crop in rice-wheat cropping system (Majumdar *et al.* 2012), predominantly on account of higher productivity and profitability, lesser water requirement and better flexible to biotic and abiotic stresses than rice and wheat. High yielding maize is considered as an exhaustive crop and extracts higher measures of mineral nutrients from the soil than rice or wheat. Right now, it is being favored by the farmers of Indo-Gangetic Plain (IGP) having yield potential up to 10 t ha⁻¹.

It is well perceived that for achieving high grain yield, an adequate and balanced supply of essential nutrients is required. Fertilizer requirements, particularly N fertilizer, depends on many factors, including yield target, variety, inorganic soil N, potential N mineralization, soil type and numerous environmental factors (Schlegel and Havlin 1995) and the crops having high yield potential obviously require higher application of nutrients..

Nitrogen is commonly needed in larger amounts than other nutrients for their development and improvement. Therefore, its proper management is fundamental to harvest high yield and eventually maximize economic returns. It is amongst the most critical nutrients constraining maize yield and quality in different parts of the world (Miao *et al.* 2007) and under Indian condition where per cent yield loss because of low N supply is estimated up to 50%. The doubling of farming nourishment creation worldwide over recent decades has been connected with a seven fold increment in the use of N fertilizers (Hirel *et al.* 2007). Since N is the major basic constitute of cells, as the N level builds, the rate of vegetative and conceptual development in plants take place (Shrikanth *et al.* 2009).

The measure of nutrients discharged amid the decay of a crop residue is vital in both organic and conventional farming systems (Pang and Letey 2000; Kwabiah *et al.* 2003). In view of different reports, the incorporation of crop residues increases the grain yield more than treatments in which residues were removed. Retention of crop residues resulted into more grains spike⁻¹ and 1000-grain weight, which may have brought about the higher yield (Surekha *et al.* 2003; Rachid 2011). Various researchers reported a substantial increment in cereal grain and Stover yield when crop residues were incorporated, compared with treatments where residues were evacuated (Kouyate *et al.* 2000; Shafi *et al.* 2007). On the other hand, notwithstanding numerous imperative advantages of crop residues, some of their effects can fluctuate. For instance, growth and yield of corn were reported to be lessened when winter wheat residues were utilized (Schreiber 1992; Lund *et al.* 1993), particularly when substantial wheat residues were used (Wicks *et al.* 1994; Cochran *et al.* 1982). A diminishment or increment in yield incited by distinctive crop residues and their management practices rely upon a complex interaction between soil, plant and ecological elements, as conceptualized by Kamkar *et al.* (2010).

Burning residues are usually honed particularly in the tropics to advance nutrient mineralization yet it at last causes loss of nutrients and diminishes soil fertility (Hemwong *et al.* 2008). Burning can likewise bring about a critical measure of air pollution and be harmful to advantageous spineless creatures and microorganisms (Jain *et al.* 2014; Wuest *et al.* 2005). In Europe, field burning of residues has been a more regular practice in the past. However combustion for energy or partial combustion to biochar may be future treatments of straw (Funke *et al.* 2013). Deep tillage enhances soil aeration and water infiltration by breaking-up hard pans, improves root development, and builds nutrient accessibility by quickening mineralization processes furthermore it enhances soil physical properties that prompt better crop development, thus increasing crop yield (Memon *et al.* 2013).

Legumes commonly oblige practically no N application for optimum yield as they derive a lot of plant-accessible N from biological N₂ fixation (Walley *et al.* 2007; Peoples *et al.* 2009). Furthermore, legumes can enhance soil N supply for ensuing crops through the return and mineralization of N-rich above-and below-ground crop residues (Arcand *et al.* 2014). However, the contribution of N by a legume to subsequent crops is hard to anticipate, and is subject to the particular legume, since legume species fluctuate in their ability to biologically fix atmospheric N₂ (Miller *et al.* 2003a; Walley *et al.* 2007; Peoples *et al.* 2009), furthermore on whether the legume seed was harvested or if the crop biomass was returned back to the soil as a green manure crop (St. Luce *et al.* 2013). Besides, the contribution of N by legumes may differ over the years and destinations because of variations in environmental conditions and soil properties, which influence the level of N₂-fixation, legume grain yields, and the amount and nature of crop residues (Miller *et al.* 2003a, b; Przednowek *et al.* 2004).

Legumes likewise give non-N advantages, for example, expanded water accessibility to subsequent crops (Miller *et al.* 2003a,b). Studies demonstrated that the wealth and accessibility of readily decomposable energy- and N-rich substrates by the previous legume crops gives a great environment to improving microbial growth and activity (Biederbeck *et al.* 2005). Greater microbial populations, activity and diversity can fundamentally enhance crop performance through mycorrhizal associations that enhance nutrient and water use-efficiency, and concealment of pests and diseases (Lupwayi and Kennedy 2007; Lupwayi *et al.* 2015). Incorporation of legumes can

drastically decrease weed populaces (Blackshaw *et al.* 2001; O'Donovan *et al.* 2007). In Saskatchewan, Canada, Miller *et al.* (2003a) reported that post-harvest soil water status to 122 cm-depth was up to 31 and 49 mm more prominent for all legumes (field pea, lentil and chickpea (*Cicer arietinum* L.) than for wheat under loam and clay soils, respectively. This was credited to increased water use efficiency, since the legumes obliged less water than wheat for optimal grain yield. Other non-nutrient benefits provided by legumes incorporate diminishment in pest and disease incidence (Stevenson and van Kessel 1996), upgraded soil tilth (Grant and Lafond 1993) and the development of helpful soil microorganisms that can upgrade plant uptake of nutrients and water (Lupwayi and Kennedy 2007). Decreases in pest and diseases are normally most prominent when succeeding crops are assorted, for instance with monocot and dicot crop sequences. Stevenson and van Kessel (1996) also reported a 43% expansion in wheat grain yield when preceded by field pea contrasted with spring wheat, which was credited basically to non-N advantages. A sidekick investigation of the present study by O'Donovan *et al.* (2014) demonstrated that on average, canola seed yield increased by 10% when field pea or lentil was the former crop compared with spring wheat.

2.2. Nitrogen use efficiency under different tillage, and residue management, and N supply options

2.2.1. Impact of different sources of N on NUE

Both ammonium and nitrate sources contrast in their susceptibility to losses by volatilization, denitrification and leaching. Ammonium-N and urea are more inclined to volatilization losses than are nitrate-N sources. Under alkaline soil condition, ammonium promptly changes over to ammonia gas, which can be lost to the surroundings. Therefore, these sources ought to be applied where volatilization potential is low, or placed in a manner that diminishes volatilization losses. Nitrate sources are more inclined to leaching and denitrification losses than are ammonium sources. Consequently, under conditions where leaching or denitrification is likely, ammonium or urea sources are preferred to nitrate sources. In any case, microorganisms in the soil change over ammonium to nitrate through nitrification, with the rate of transformation increasing with optimal moisture conditions and increasing soil temperature. Thus, after some time, ammonium and urea will get to be

susceptible to losses as these convert to nitrate. Placing these fertilizers in a manner to slow the transformation to nitrate will lead to decreased losses and enhanced nitrogen use efficiency (NUE).

Management strategies to minimize soil N losses and increase NUE have been widely inquired about and checked on (Dinnes *et al.* 2002; Motavalli *et al.* 2008). These techniques incorporate enhanced N fertilizer application timings, utilization and development of soil and plant testing procedures to focus in-season N availability, enhanced N fertilizer recommendations, more noteworthy utilization of variable rate N fertilizer applications and other more productive application methods, increased adoption of nutrient management planning, use of nitrification or urease inhibitors, and utilization of N fertilizer sources that are more suited for local ecological conditions (Dinnes *et al.* 2002; Motavalli *et al.* 2008). Shoji *et al.* (2001) observed increased N use efficiency and diminished soil N₂O emissions with use of a slow-release N fertilizer source contrasted with urea in corn, barley (*Hordeum vulgare* L.), and potato (*Solanum tuberosum* L.). Different scientists have likewise demonstrated diminished N₂O emanations (Vallejo *et al.* 2001; McTaggart and Tsuruta 2003) and decreases in NO₃⁻ leaching losses (Pack *et al.* 2006) with utilization of slow- or controlled-release N fertilizers contrasted with traditional N fertilizers like urea.

Improved nutrient uptake by plants from fertilizers can be achieved through modification of fertilizer products - either chemically to reduce their solvency or physically, for instance, by coating encapsulation. Slow-release or controlled release fertilizers are astounding distinct options for dissolvable fertilizers. Controlled-release compounds can possibly enhance NUE in light of the fact that N is discharged at a slower rate all through the season, and plants have the capacity to take up a large portion of the N without waste because of better synchronization between release of N and plant need (Shoji *et al.* 2001). A slow-release fertilizer is more helpful, since less frequent applications are needed.

Fashola *et al.* (2002) found that controlled-release fertilizer particularly increased yields and NUE of rice contrasted with urea. Polymer-coated products, which can be intended to release N in a controlled way are promising slow release N sources. Slow release N fertilizer developed by coating urea granules with S or by developing super granules of urea (USG) has been tried in large number of trials on rice in the Indo-

Gangatic Plains plains (Bijay-Singh and Yadvinder-Singh 2003). While S coated urea with its slow release properties out-performed prilled urea at all the areas, USGs were not a superior source of N in exceedingly porous coarse textured soils. In fact, urea super granules do not possess slow N release properties. The placement of USGs results in controlling losses through ammonium volatilization. Urea super granules, subsequently performed better than prilled urea wherever conventional urea-N was more inclined to losses by means of ammonium volatilization. Farmers' utilization of controlled-release fertilizer tends to increase in recent one decade, yet it represents just 0.15% of the aggregate fertilizer N utilized (Trenkel 1997). The primary explanation behind its constrained utilization is its high cost, which could be 3 to 10 times the expense of traditional fertilizer (Shaviv 2000).

Another way to deal with synchronize release of N from fertilizers with crop need is the utilization of N stabilizers. Nitrogen stabilizers (e.g. nitrapyrin, DCD [dicyandiamide], NBPT [n-butyl-thiophosphoric triamide] repress nitrification or urease action, in this manner slowing the transformation of the fertilizer to nitrate (Prasad and Power 1995; Havlin *et al.* 2005). Slow-release nitrogen fertilizer has been recommended as potential N source for sandy soil that control N leaching and expand N use efficiency. Various researchers have exhibited the predominance of slow release fertilizer in experiment with grain (Zeidan and El-Karamany, 2001; Bahr *et al.* 2006; Ahmed *et al.* 2007). They reported that utilization of slow release N fertilizer gave most extreme yield creation. As of late, treating wheat with 38 kg/ha slow release N fertilizer surpassed 50 kg/ha in plant tallness (cm), grain yield (g)/m², grain yield (t/ha) and harvest index, while 50 kg/ha slow-release N fertilizer gave the most elevated estimations of grain index (g), straw yield (t/ha) and biological yield in t/ha (Hassanein *et al.* 2013).

At the point when soil and environmental conditions are conducive for nitrate losses, treatment with a stabilizer will frequently increase fertilizer N efficiency. Since ammonium-N is relatively less prone to leaching or denitrification losses, N kept up as ammonium in the soil ought to be accessible for late-season uptake (Fageria *et al.* 2010). Increasing N uptake amid grain-filling demonstrates a potential favorable position of ammonium nourishment for grain production (Fageria *et al.* 2010). Nitrification inhibitors can build the fertilizer N recuperation by postponing the nitrification of ammonical fertilizers and hence minimizing the losses of N through

leaching and denitrification (Paul. 1984). Nitrification inhibition can confine the measure of inorganic N in the NO_3 form and minimize denitrification and/or leaching.

2.2.2. Effect of different method of N application on NUE

Fertilizer N-recovery efficiency up to 50-70% of total N was accomplished when it was applied at correct rate and at the correct time (Wang *et al.* 2001). To focus N application rate, it is expected to gauge the amount N the product requirements for optimum monetary yield and the amount N available from the soil for utilization by the crop (Bufole *et al.* 1997). Nitrogen supply ought to record for both the N in the soil at seeding and N to be released amid the growing season. With legume crops, it ought to additionally represent N fixation. Fertilizer N level ought to be sufficient to compensate for any shortfall between the harvest necessity and the soil supply, furthermore remembering that N losses will happen from both the soil-N and applied fertilizer-N.

The crop most efficiently uses fertilizer N when it is available amid the time of active growth. Fertilizer N applied amid the phases of crop when N uptake rate is slow, N more prone to be lost through leaching, runoff and/or volatilization. The relationship between fertilizer N uptake and aggregate N uptake over the developing season relies upon timing of the fertilizer N application (Guindo *et al.* 1994). Synchrony between plant-available N in the rooting zone and the crop uptake of N, in timing, will minimize N losses preceding plant uptake (Ladha *et al.* 2005). In coordinated field trials, utilizing N^{15} marked fertilizer, it was found that part the measure of N into three equivalent doses to be applied at planting, early tillering and booting stages of development were more compelling than N fertilizer applied in two equivalent dosages at planting and tillering or in one single dose at planting (Matzel and Lippold 1990). Application strategy has dependably been discriminating in guaranteeing efficient utilization of applied N. Deciding the right placement is as critical as deciding the right application rate and time. Various placements are available, yet most by and large include surface or sub-surface applications before or at the time of planting. Before planting, N can be broadcast (*i.e.* applied consistently on the soil surface and may or may not be incorporated), applied as a band on the surface, or applied as a sub-surface band. Applied at planting, N can be banded with the seed, underneath the seed, or beneath and to the side of the seed. Subsequent to planting,

application is normally limited to N and position can be as a top dress or a sub-surface side dress. All in all, N recovery efficiency has a tendency to be higher with banded applications in light of the fact that less contact with the soil diminishes the loss due to leaching or fixation reactions. Placement choices rely on upon the yield and soil conditions, which communicate to impact nutrient uptake and availability.

With surface application, N could be lost through volatilization until it is fused or moves into the soil with precipitation (Panda *et al.* 1994) reported that the recovery efficiency was 37% for broadcasting, 46% for banding, and 49% for deep placement of USG in direct-seeded rice in Australia. Band placement of urea solution into the anaerobic soil layer has been as powerful as deep placement of USG in diminishing volatilization and denitrification losses and enhancing grain yield (Schnier *et al.* 1988). Devasenapathy and Palaniappan (1995) assessed the efficiency of a urea solution applicator and found that band placement of urea solution at 50 kg N ha⁻¹ brought about higher yield and enhanced agronomic efficiency (AE_N) and recovery efficiency (RE_N) than with traditional three-split applications of prilled urea. Deep point placement of urea super granule, urea tablet or urea briquette (UB) is exceedingly efficient contrasted with surface broadcasting of prilled urea in flooded rice (Chauhan and Mishra 1989). The RE_N of UB deep point placement technique was 24 to 41% in dry/winter seasons and 10 to 19% in wet season, contrasted with 19-22% in dry/winter season and 7-15% in wet season for split application of N. By embracing the deep placement method, farmers in Bangladesh achieved 1 t ha⁻¹ more yield and reduced urea input by 20 to 30% (Mathot 2009).

Prilled urea is a quick releasing N fertilizer which is typically broadcast in splits that cause impressive loss as ammonia volatilization, immobilization, denitrification and surface runoff and so on. Then again, deep placement of slow releasing nitrogenous fertilizer, for example, USG decreases loss and in addition builds its utilization efficiencies. More profound placements of USGs (5.0-7.5 cm) brought about more prominent fertilizer-N recovery in the crop (70.5-78%) contrasted with the utilization of prills (Nahar 2013).

2.2.3. Impact of N management through optical sensors on NUE

To enhance fertilizer N use efficiency, it is essential to lessen losses of N from the soil-plant system by synchronizing N applications with crop demands. Since rice-

wheat systems have differentiating edaphic prerequisites, soil test based N fertilizer suggestions for the most part have not been effective. Along these lines, dynamic N management calls for plant need-based utilization of N for accomplishing high return and N use efficiency. Dynamic N management obliges fast assessment of leaf N content, which is closely related with photosynthetic rate and biomass production and is sensitive indicator of changes in crop N demand during the growing season. The chlorophyll or SPAD meter, and its reasonable and straightforward option, the leaf colour chart (LCC) can rapidly and dependably monitor relative greenness of leaf as a pointer of leaf N status. These apparatus have given a phenomenal open door regarding growing real-time N management methodologies for rice yet these instruments don't consider photosynthetic rates or the biomass production and expected yields for working out fertilizer N necessities. While chlorophyll or SPAD meter and LCC have been utilized effectively as a part of rice, their utility is regularly compelled in wheat and other upland crops. Because of ceaseless wet soil moisture regimes in rice crop, fertilizer N can be applied any time which is not valid for some upland crops. In upland crops, fertilizer applications, to be successful, must be synchronized with irrigation.

Huge field-to-field variability of soil N supply confines productive utilization of N fertilizer when broad-based area general "blanket" suggestions are utilized as a part of maize and wheat. Innovative fertilizer management needs to coordinate both preventive and field particular corrective N management strategies to expand the profitability of irrigated rice and wheat. Hand-held GreenSeeker and Holland optical sensors offer unmistakable point of interest over need based N management apparatuses like SPAD meter and leaf colour chart in that it can work out fertilizer N requirement of rice and wheat in the light of expected yields and in addition achievable greenness of the leaves. GreenSeeker handheld sensor (Trimble Navigation Limited, Sunnyvale, CA, USA) is aactive optical crop canopy sensor with a red (650 ± 10 nm) and a NIR (770 ± 15 nm) waveband.

As of late, methods based on measurements of reflectance in the red (characterized by chlorophyll content) and near infrared (characterized by living vegetation) region of the electro-magnetic spectrum for evaluating N prerequisite of crops utilizing early season assessments of N uptake and potential yield have been developed. Normalized difference vegetation index (NDVI) in light of in- season sensor reading can foresee

biomass, plant N concentrations and plant N uptake. The methodology in light of optical sensors hold promise in creating N management choices on the grounds that it offers distinct advantage of working out the fertilizer N requirement of maize and wheat crop in view of expected yields and in addition achievable greenness of the leaves.

Crop canopy sensors can be utilized to estimate crop growth in a population or group instead of individual plant or leaf, and are more proficient and suitable for huge scale applications than leaf sensors (Xue and Yang 2008). Numerous studies have been directed to estimate rice growth and N status utilizing crop canopy sensors (Nguyen *et al.* 2006; Stroppiana *et al.* 2009; Bajwa *et al.* 2010). For season and site-specific management, the crop sensor ought to be dynamic, having its own particular light source to be weather independent. It should preferably be multispectral to diminish the cost compared with hyperspectral sensors. An algorithm should also be developed to relate sensor readings to rice N status, as well as to particular N recommendations rates too.

A nitrogen fertilizer optimization algorithm (NFOA) has been produced to make in-season N recommendation for winter wheat (*Triticum aestivum* L.) by Ruan *et al.* (2002, 2005). In this methodology, potential yield with no additional N (YP0) can be evaluated before N topdressing by in-season estimate of yield (INSEY), which is ascertained by dividing NDVI, gathered by the GreenSeeker sensor, by the quantity of days from planting to the date of sensing with growing degree days more prominent than 0 °C (Raun *et al.* 2002). This in-season N management methodology has been effectively assessed for wheat in USA (Raun *et al.* 2002), Mexico (Ortiz-Monasterio and Raun 2007), China (Li *et al.* 2009; Cao *et al.* 2012), and India (Bijay-Singh *et al.* 2011).

Bijay-Singh *et al.* (2011) observed that high N use efficiency in irrigated wheat grown in northwest India can be accomplished by supplementing general fertilizer recommendation by an optical sensor based N management strategy. Observing of plant N status is essential in enhancing the harmony between crop N demand and N supply from soil and applied fertilizer (Cassman *et al.* 1996). Since leaf N content is firmly identified with photosynthetic rate (Peng *et al.* 1995) and biomass generation (Kropff *et al.* 1993), it is a sensitive indicator of the dynamic changes in crop N

demand inside of a growing season. More prominent synchrony between crop demand and nutrient supply is important to enhance NUE. In view of colour of leaf chlorophyll meter and LCC have been effectively used to know when the crop needs N application (Balasubramanian *et al.* 2004; Singh *et al.* 2002). These methods have been assessed in an extensive variety of farmer's fields in Asia and are currently positioned for more extensive scale validation and farmer adaptation. This innovation gives prompt results and has been shown as a compelling tool to schedule N treatment to crops on an as-required premise (Turner and Jund 1994).

Late advances in optical sensing have permitted the gathering of timer information on crop growth and physiological parameters temporally and spatially as influenced by natural hassles. Such data can be utilized for as a part of season crop nutrient evaluation and management (Daughtry *et al.* 2000; Zarco-Tejada *et al.* 2000). New advancements have exhibited that optical sensor based variable rate application systems intended to sense N needs late in the season could exploit early history (insect, disease, and weather) of the growing season. Yield potential could be assessed based upon the number and health of plants. A second point of preference of a late application of N is that the likelihood of N loss either to the atmosphere or through leaching or runoff is diminished and the time in between the application and plant needs is lessened.

Osborne (2007) utilized this sensor to estimate spring wheat growth and N status in South Dakota, USA and found that NDVI was essentially associated with biomass ($R = 0.83$), N focus ($R = 0.74$), and plant N uptake ($R = 0.84$) at Feekes 6 growth stage. The correlation coefficients were 0.62, 0.67, and 0.71, individually, at Feekes 10 growth stage. Li *et al.* (2010) additionally utilized the GreenSeeker sensor to estimate winter wheat growth and N status, and found that NDVI was likewise altogether connected with biomass ($R = 0.82$, and 0.71 for Feekes 4–5, Feekes 6–7, and Feekes 9–10 growth stages, individually), and plant N uptake ($R = 0.76$, and 0.72 for Feekes 4–5, Feekes 6–7, and Feekes 9–10 growth stages, respectively).

Nitrogen use efficiency, which is computed as the rate of the N content of the grain to the N-fertilizer applied, represents how well a crop has recuperated applied nitrogen fertilizer and can highlight the pathways where nitrogen can be utilized all the more efficiently (Woolfolk *et al.* 2002). The ideal utilization of N fertilizer will originate

from coordinating N supply with crop demand for N (Bhardwaj *et al.* 2010), and losses of N could be vast when the N application is not synchronized with crop growth and development.

A study at Bangladesh has indicated impressive chance to expand farmers' yields through enhanced N management with no other change in fertilizer information or crop management practices (Alam *et al.* 2006). Fertilizer management techniques need to incorporate strategies to both minimize soil losses and to ensure N fertilizer is applied when needed and also not utilizing exorbitant rates. Optical sensors, (for example, GreenSeeker) offer a chance to apply real time needs-based N fertilizer inputs to match N supply with crop N demand. Such sensors have encouraged the diminished utilization of N fertilizer in rice, with reports of N rates lessened by 25–49 kg N ha⁻¹ (Alam *et al.* 2006).

Coventry *et al.* (2011) reasoned that utilization of the GreenSeeker instrument brought about N fertilizer savings of 21–25 kg N ha⁻¹ with comparable grain yield, protein and grain hardness obtained by utilizing the suggested 150 kg N ha⁻¹. Further, where the GreenSeeker was used, the apparent recovery was 70–75% contrasted and the 60% recovery with the suggested rate. This demonstrates that farmers are liable to be over-fertilizing their crop and a more suitable N fertilizer recommendation both for yield and chapatti quality would be for use of a sum of 130 kg N ha⁻¹, with an equivalent use of 50 kg N ha⁻¹ at seeding and early tillering and a lesser rate at first node stage.

Normalized difference vegetation index (NDVI) and different lists got from estimations of canopy reflectance have been broadly utilized for in-season estimation of grain yield in different crops. Raun *et al.* (2001) set up a non-destructive system for exact estimation of YP utilizing spectral estimations. Raun *et al.* (2002) consolidated midseason yield potential forecast and N response utilizing in-season estimated yield (INSEY) and RI to build-up an algorithm for mid-season topdress N fertilization.

2.3. Soil nitrogen dynamics under different tillage, residue management, N sources and N application methods

2.3.1. Mineral Nitrogen

An insight view about the N dynamics in soil and its impacting factors will provide knowledge to improving N supply capacity of soil amid crop growth period and enhancing N use efficiency. The sources of N in soil, distinctive

agricultural practices and soil ecological processes are the key influential factors which assume significant part in determining the N dynamics in soil. Then again, there are two difficulties: (1) enhance the grain yield to fulfill expanding human necessities, and (2) build N use efficiency for sustainable agriculture (Ladha *et al.* 2005; Tilman *et al.* 2002 and Zhang *et al.* 2011). Ammonium-N ($\text{NH}_4^+\text{-N}$) and nitrate N ($\text{NO}_3^-\text{-N}$) are the principal inorganic types of N in soils; both forms can be taken up by plants. The transformation of native N, and N uptake by plants are subject to the applied N and soil conditions. For some species, including maize, the blend of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ supports preferable plant growth over either form supplied independently (Marschner 2012). The fundamental sources of soil N utilized by crops are: (i) mineralization of soil organic N; (ii) decay of plant deposits or organic amendments; and (iii) use of mineral N (Mikha *et al.* 2006). Nitrogen mineralization in soil is a key procedure that should have been completely comprehended and considered when taking care of the N demand of crops. Nitrogen mineralization brings about release of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ which are taken up by plants, and regulate the supply of form and extent of mineral-N from soil to plants (Ghosh and Kashyap 2003). Soil mineral-N is firmly correlated with soil fertility (Roy and Singh 2003) and variations in mineral N substance can likewise reflect changes in the soil quality. In agricultural ecosystems, inorganic N is frequently looked upon as the most constraining element affecting plant growth and crop yields (Tonitto *et al.* 2006). In this manner, precise estimation of N mineralization is essential for determining the rate of fertilizer application, advancing N use efficiency and minimizing adverse impacts of excessive N (Mikha *et al.* 2006; Sharifi *et al.* 2007).

Despite of the fact that the in-situ net N mineralization in soil was intensively studied, but other different pools of N in soil and their role in N mineralization and dynamics at different crop growth stages had received less consideration. Very little relevant information, especially in soil microbial biomass N and potential mineralizable N, is available under maize-wheat cropping system in short-term fertilizer experiments. Although short-term investigations can't give understanding into the N supplying capacity and soil fertility status, yet the same may provide a quick picture of the forms of N in soil which are all around identified with N mineralization in distinctive phases of crop growth.

Inorganic N compounds in soil include numerous species like NH_4^+ -N, NO_3^- -N, NO_2 , dinitrogen gas (N_2) and nitrous oxide (N_2O) and numerous other chemical or organic intermediates. Available forms of soil NH_4^+ -N and NO_3^- -N are considered as the most imperative types of N in respect to crop production than other inorganic forms. Plants generally like to take up N as NH_4^+ and NO_3^- , with the later being favored when it is available in high concentration. Singh *et al.* (1969) had discovered higher ammonium-N under legumes than under cereals. Higher rate of fertilizer N application brings about higher concentration of ammonium in soils (Rajput *et al.* 1984; Sagwal and Rahul 1984). Essentially higher nitrate-N content in plots treated with FYM was accounted for in an Ustochrept of Haryana (Sagwal and Rahul 1984). Nitrate-N substance was found to increase in Aquic Hapludoll with increase in the levels of N fertilizer applied to soil (Rajput *et al.* 1984). Gupta *et al.* (2009) discovered the most astounding NO_3^- -N content all through the soil profile under 100% NPK treatment applied to major crops grown in Punjab, demonstrating better use of N by crops under balanced fertilizer application.

Constant utilization of FYM more than seven years in an intensive cropping system on an Alfisol increased its NH_4^+ -N and NO_3^- -N content, while addition of green leaf manures did not have any significant impact. Nonetheless, a reduction in NO_3^- -N content of the soil by the utilization of FYM was seen by Rokima and Prasad (1991). The NH_4^+ -N, NO_3^- -N and NO_2 -N content of the soil expanded continuously with time taking after the 16 years of NPK fertilizer application to a soybean-wheat-maize fodder rotation on a Typic Chromustert in Madhya Pradesh. Then again, the most noteworthy N substance was seen with the use of NPK together with FYM. In another long-term fertilizer experiment with finger millet-maize-cowpea revealed that incremental addition of N and FYM had a beneficial effect on the build-up of mineral-N in soil (Lee and Wani 1989).

Jing *et al.* (2012) reported that rhizosphere acidification and high concentration of ammonium at the local site could help keep up N mostly in the ammonium form for quite a while. Consequently, confined supply of P and NH_4^+ -N may be a successful approach to enhance crop growth and nutrient uptake through

encouraging root proliferation and nutrient accessibility in farming systems (Shen *et al.* 2013).

The ability of the soil to supply N rely upon numerous elements including the amount of mineralizable organic N, the mineralization rate and intensity factors, for example, moisture and temperature (Campbell *et al.* 1981). Mineralizable N is considered as a dynamic N portion in soil N (Campbell *et al.* 1981). Mineralization of organic matter generally adds to the accessibility of N as 30-70% of total N is reinforced on the organic fractions in most farming situations (Stevenson 1994). Stanford and Smith (1972) opined that the N mineralization potential *i.e.* the amount of soil natural N that experiences mineralization gives a sign to N supplying capacity of soil. The mineralizable N contribution varies from 5 to 40% of total soil N.

2.3.2. Microbial Biomass Nitrogen

Microbial biomass constitutes a little amount of the SOM, however because of its significant biochemical role, microbial biomass assumes a noteworthy part in energy and nutrient cycling in the ecosystems. The microbial biomass nitrogen (MBN) substance in arable soils may be a sensitive indiactor of the ecological balance in soils. Its values most soils ranged between 1-6% of the total N, and the higher the share, the "healthier" the soil (Sparling 1997). It comes about because of a quicker cycle of microorganism biomass circulation than the other organic matter in soil (Sparling 1997; Kara and Bolat 2008). Microbial biomass N includes 3 to 5% of soil N (Jenkinson and Ladd 1981). Despite the fact that the soil microbial biomass is more influenced by the confinement of C instead of N. The accessibility of N is an imperative component controlling crop residue disintegration.

Determination of microbial N is imperative for the measurement of N dynamics in agricultural ecosystems on the grounds that it controls soil organic N accessibility and loss, particularly in high input systems (Moore *et al.* 2000). The content of microbial biomass N in soils relies upon the physico-chemical and chemical properties of soils (Dilly *et al.* 2003; Balik *et al.* 2004; Gajda *et al.* 2005; Zhang *et al.* 2005). It is generally higher in the forest soils, lower in prairie soils and the least in soils of arable lands (Blagodatskii *et al.* 2008). The effect of fertilization and cultivation systems on the change of the level of the microbial biomass N content is frequently analyzed

(Balik *et al.* 2004; Gajda *et al.* 2005). The substance of C and microbial biomass N in the soils is additionally utilized for the complete portrayal of the soil environment of the same areas (Zhang *et al.* 2005; Scharenbroch and Lloyd. 2004). Soil organisms go about as an important N pool in soil–plant N dynamics in terrestrial ecosystems (Bardgett *et al.* 2002, 2007; Wardle *et al.* 2004), and late studies have accentuated their significance for crop N uptake in dry tropical croplands grew on nutrient poor soil (Cookson *et al.* 2006; Singh *et al.* 2007b). To enhance the efficiency of N use in nutrient-poor agro ecosystems, it is important to explain the time-course of N partitioning between the soil N pool (MBN and inorganic N) in soil and plant N uptake amid the crop growth period, and assess the impact of area management on the soil–plant N dynamics (Kushwaha *et al.* 2000; Herai *et al.* 2006).

Numerous studies that have assessed seasonal microbial dynamics in dry tropical ecosystems have reported that MBN is lower during the rainy season, however stays high during the dry season (Sugihara *et al.* 2010). Land management (*e.g.* application of organic manure, fertilizer, soil tillage) influences soil microbial dynamics (Spedding *et al.* 2004; Joergensen and Emmerling 2006). Numerous studies have reported that organic matter application builds the MBC or MBN in tropical croplands, proposing that increased MBC or MBN adds to plant growth by advancing their nutrient source and sink capacity (Powlson *et al.* 2001; Singh *et al.* 2007a,b).

Singh *et al.* (2007b) exported a negative correlation between crop (*i.e.* rice and grain) root biomass and MBN in India in control, fertilizer and organic manure application plots; crop root biomass increased from the seedling stage to achieve a greatest level at the grain-forming stage and declined strongly from that point, while MBN diminished from the seedling stage to the grain-forming stage and increased again at the harvest stage. Studies have shown that decreasing NO_3^- leaching is the best test to enhancing the efficiency of N use in dry tropical croplands (Hartemink *et al.* 2000; Chikowo *et al.* 2006). MBN could as a temporal N sink during the rainy season by applying organic matter as reported by Herai *et al.* (2006), there is need to decrease the extreme N leaching and enhance the efficiency of N use in the soil (Mtambanengwe and Mapfumo. 2006). Several specialists noticed that long-term use of inorganic fertilizer increased organic C and aggregate N content (Blair *et al.* 2006; Manna *et al.* 2006; Šimon 2008), and also soil microbial biomass C and N (Masto *et al.* 2006; Baaru *et al.* 2007; Šimon 2008). These findings may be ascribed to

increased inputs to the soil from above- and below-ground residues and additionally rhizodeposition. These materials are the fundamental C sources for soil microorganisms.

2.3.3. Particulate Organic Matter associated Nitrogen

Particulate organic matter is viewed as an intermediately available fraction of organic C and N, and more sensitive to the land management changes contrasted with total soil organic matter (Parton *et al.* 1987; Cambardella and Elliott 1992). Same recommended by Ghani *et al.* (2003) and Handayani (2004) that particulate organic matter associated C (POM-C) and N (POM-N) are labile part of SOM and as indicators of changes occurred due to management practices (e.g., tillage, crop rotation, vegetation. Fertilization). The dynamic portions got from microorganisms [(e.g. MBC and potentially mineralizable C (PMC) and particulate organic C (POC)], and from plants are labile and have turnover time of days to years (Pampolino *et al.* 2008). POC is a transitional fraction, is very touchy to tillage systems (Franzluebbers 2000), and constitutes around 31 to 35% of total organic carbon (TOC). Developed out of partially-decomposed plant and animal residues, POM is thought to be an energy source for microbes (Christensen 2001), and has been associated with different indices of N supply and nutrient cycling. Both POM-C and -N, when associated with information about as of late incorporation of crop residues, were found to be good indicators of N mineralization potential in systems under, legume-based organic, and fertilizer based fertility management (Willson *et al.* 2001).

Soil N supply was fundamentally identified with the combined impacts of POM-N, mineral-N and sand content, which explained 68 and 71% of the variation in grain yield and N uptake. Griffin and Porter (2004) reported that the incorporation of red clover as spread crop in 2-yr potato rotations increased the extent of total soil N as POM-N by 1320% contrasted with rotations that did not contain a legume cover crop. The extent of total soil N ascribed to the labile organic N portions was inside of the reported reach for MBN (Willson *et al.* 2001; Biederbeck *et al.* 2005), POM-N and light fraction organic matter N (LFOM-N) (Gregorich *et al.* 2006; Sharifi *et al.* 2007; Sequeira and Alley 2011). Studies demonstrate that POM-N may shift month to month or occasionally, consequent upon site qualities, timing, amount and nature of organic residue inputs and the season of soil used for POM extraction

(Yakovchenko *et al.* 1998). Henceforth, POM-N is a dynamic pool that changes over the long time. The POM-N is an intermediate pool between fresh plant residues and balanced out organic N that is for the most part associated with sand-sized particles in soils (Gregorich *et al.* 2006). The way that POM-N was the biggest labile organic N fractions measured shows that there was potentially a collection of POM-N because of slow decomposition of crop residues coming about because of the no-till practices and the sub-humid to semi-arid-dry conditions at the destinations (Yu-Hua *et al.* 2007).

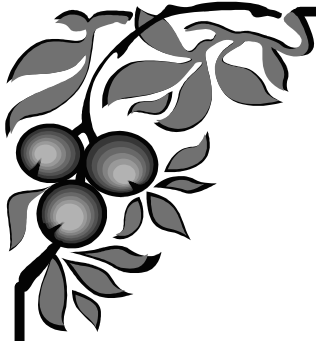
During the growing season, the gathered POM-N could have mineralized, accordingly increasing soil mineral-N accessibility especially in the faba bean green manure plots. Studies reported that POM is a promptly available substrate for organisms and a significant source of N to crops (Gregorich *et al.* 2006). The relationship between POM-N and soil N supply was superior as reported in a few studies (Sharifi *et al.* 2007), yet weaker than others (Spargo *et al.* 2011).

2.4 Soil Carbon dynamics under different tillage, residue management, N sources and N application methods

Better agronomic practices, for example, conservation tillage, organic amendments, crop rotation, and residue management, could enhance SOM amount and quality (Lal 2004). Labile organic matter pools, including microbial biomass, soluble organic matter, and potentially mineralizable or extractable C and N can reflect soil organic matter quality (Haynes 2005). Among these organic matter pools, soil microflora is in charge of changing organic matter into inorganic nutrients (Chu *et al.* 2007; Ryan *et al.* 2009). Soluble organic matter represents to a versatile source of energy and C for the soil microbial groups (Kalbitz *et al.* 2000) and an essential source of mineralizable N, P, and S (Haynes 2005).

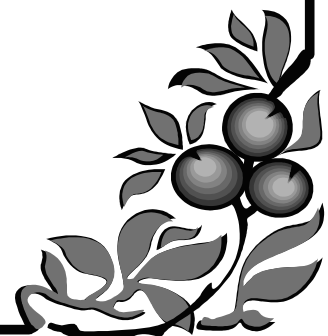
Optimum plant production can be accomplished by legitimate determination of tillage practices, fertilizers and natural deposits. In these situations, consolidation of organic residue by tillage can likewise enhance efficiency and build-up the soil organic matter (SOM), content of the soil (Khan *et al.* 2009). A perpetual soil spread, through the utilization of cover crops and crop residue mulch maintenance, consolidated with reduced tillage could be the best management practice for SOM restoration and control of erosion (Derpsch 2005; Hobbs 2007). Organic amendments assume an essential part in the change of SOM levels and in the soil physical properties (Hati *et*

al. 2007). Residue maintenance in fields can increase soil aggregation and accumulation of SOC, however the outcomes rely on the quality and amount of the residue application (Chivenge *et al.* 2007). Straw removal has frequently been seen to decrease SOC content compared with straw maintenance (Mann *et al.* 2002). Nonetheless, as of late, farmers in Asia have increased the use of inorganic fertilizers to the detriment of organic materials because of increased labour costs and the approach of automated reaping. Crop residues are sometime burned in the field, keeping in mind the end goal to avoid blocking tillage and seeding operations for the following crop. In any case, disposal of crop residues in this fashion decreases the amount of organic C, which is coming back to the soil; in addition, the practice causes air pollution and has been rebuked for declining levels of soil nutrients (Nguyen *et al.* 1994). The recycling of organic sources is turning into a continuously important part of sustainable agriculture for its role in minimizing environmental problems (Pathak *et al.* 2006). Yadav *et al.* (2000) and Surekha *et al.* (2006) found that use of organic manures had distinct advantageous effect on rice and wheat yields in the IGP region, albeit conflicting results were reported by Dawe *et al.* (2003) in their studies on serious rice cropping frameworks. This obvious inconsistency may be because of contrasts in soil type and the nature of the organic materials applied in the diverse studies (Dawe *et al.* 2003; Chivenge *et al.* 2011). Crop productivity enhancement due to adequate input of plant nutrients is important for the stability of agricultural production systems. In zones where mechanical harvesting is practiced, a large amount of crop residues is left in the field, which can be recycled for nutrient supply. Around 25% of N and P, 50% of S, and 75% of K uptake by cereal crops are retained in crop residues, making them significant nutrient sources.



Chapter 3

Materials and Methods



3. MATERIALS AND METHODS

The investigation entitled "*Nitrogen dynamics under maize-wheat cropping system as influenced by nitrogen, tillage and residue management options*" involved determination of important nitrogen fraction including mineral N and soil organic matter (SOM), and studying their relationships with crops yields under different nitrogen sources, rates, methods of application, and tillage and residue management options in a conservation agriculture (CA)-based ongoing field experiment under maize-wheat cropping system at Indian Agricultural Research Institute (IARI), New Delhi was chosen. Soil and plant samples were collected at different growth stages of maize (2014) and wheat (2014-15) from this experiment. Subsequently, yield data were recorded at the time of maturity of crops. Detailed description of materials used and methods followed for different studies are furnished hereunder:

The experimental site

An on-going field experiment on conservation agriculture initiated during kharif 2013 in the Mid-Block 8C of IARI Research Farm was chosen further study. The institute (IARI) is located at 28° 37' - 28° 39' N latitude, 77° 9' - 77°11' E longitude and 228m above mean sea level. The climate is semi-arid, subtropical with hot and dry summers (May-June) and severe cold winters (December-January), intervened by short monsoon period of 2-3 months mainly spread during July to September. On the basis of 30 years of climatic data, the mean maximum temperature, minimum temperature and rainfall were 32.1 °C, 17.3 °C and 788 mm, respectively. On an average, 84% of mean annual rainfall is received through north-west monsoon (July to September) and 12% of the rainfall during the winter months, *i.e.* November to March.

The experimental soil represents Indo-Gangetic plain and belongs to Mehrauli series of order Inceptisol. Taxonomically it classified as Typic Haplustept. The soil is alluvial, sandy loam in texture with low CEC, alkaline in reaction, free from salinity and has nearly level to gently sloping topography. Prior to establishment of the experiment, the site was kept for long-time. The physico-chemical characteristics of the initial surface soil (0-15 cm) table 3.1.

Table 3.1. Some important physicochemical properties of the experimental soil

Parameter	Values	Reference
Mechanical composition		Bouyoucos (1962)
Sand (%)	58.2	
Silt (%)	23.8	
Clay (%)	18.0	
Texture	Sandy loam	
pH	8.55	Jackson (1973)
EC (dSm ⁻¹)	0.55	Jackson (1973)
Bulk density (Mg m ⁻³)	1.54	Veihmeyer and Hendrickson (1948)
Organic carbon (%)	0.35	Walkley and Black (1934)
CEC [cmol(p ⁺) kg ⁻¹ soil]	10.5	Jackson (1973)
NH ₄ ⁺ -N (mg kg ⁻¹)	10.1	Keeney and Nelson (1982)
NO ₃ ⁻ -N (mg kg ⁻¹)	8.10	Keeney and Nelson (1982)
0.5 M NaHCO ₃ -extractable P (kg ha ⁻¹)	16.4	Olsen <i>et al.</i> (1954)
Neutral 1 N NH ₄ OAc-extractable K (kg ha ⁻¹)	165	Hanway and Heidel (1952)

Treatments and crop management practices

Field experiment comprises 30 treatment combinations involving N fertilizer rates, sources, application methods, and tillage practices and crops residue management options. The treatments are being evaluated on a permanent (undisturbed) layout of split-plot design, with plot size 25 m x 4.0 m. Details of treatments are given in table 3.2 and wheats crop performance is shown in plate 3.1.

The recommended NPK rates were 150 kg N, 80 kg P and 60 kg K ha⁻¹ for both maize and wheat crops. Fertilizer P and K were applied through diammonium phosphate (DAP) and muriate of potash (MOP), respectively, wherein different N fertilizers were used as source of N as given in table 3.2. All other deficient nutrients were applied before start of the experiment. Different levels of N (*i.e.* 80, 50 and 33% of recommended rate of N, as per treatments) and entire P and K were applied as basal dose at the time of sowing and further N was applied based on the requirement as assessed weekly with the help of GreenSeeker. At the end, total applied N was calculated under different N treatments (Table 3.3). Forty percent of the ground crop residue (CR) was retained in CA-treatment. Beside summer greengram (cv.Pusa Vishal)



Plate 3.1. Wheat crop performance under CA



Plate 3.2. NDVI observations through GreenSeeker of wheat crop

was sown in CA treatments after wheat harvest, to utilize the residual soil fertility. After pod-picking the greengram residues (above ground biomass) were retained on the soil surface, by spraying of glyphosate. All crops were sown on the permanent raised beds, which were re-shaped annually before sowing of wheat.

Table 3.2. Treatment details of the experiment

S. No.	Treatment Code	Treatment details
(A)	Main-plot	: Tillage operations
1	CA	: M ₁ : Conservation agriculture (No-tillage + Residue retention)
2	CT	: M ₂ : Conventional tillage (Tillage + No-residue)
(B)	Sub-plot	: Sensor based N application
1	80%	: T ₁ : 80% N basal + split (GreenSeeker-based)
2	50%	: T ₂ : 50% N basal + split (GreenSeeker-based)
3	33%	: T ₃ : 33% N basal +split (GreenSeeker-based)
(C)	Sub-sub plot	: Source of N and application methods
1	USG	: S ₁ : Urea super granules-band placement
2	IFDC	: S ₂ : Slow release N fertilizer (Urea stabilized with DCD and N-(n-butyl) thiophosphorictriamide)-band placement
3	Urea-band	: S ₃ : Prilled urea-band placement
4	Urea-broad	: S ₄ : Prilled urea-broadcast
5	Urea-spray	: S ₅ : Prilled urea foliar spray- (2% urea solution w/v)

Maize (cv. PMH1) and wheat (cv. HDCSW18) were grown as test crops. Maize was sown in the month of July 2014 and harvested in October 2014, while wheat was sown in November 2014 and harvested in April 2015. Necessary agronomic package of practices for CA and CT were followed for controlling weeds, insects and diseases. Need-based irrigations were given during crops growth period. The performance of different N sources *vis-à-vis* urea broadcast, urea band placement, urea super granules, slow release N fertilizer and foliar spray (2%) under maize-wheat cropping sequence was evaluated by measuring the yield and N uptake of nutrients by crops.

Collection and preparation of soil and plant samples

The plot-wise soil (rhizosphere) and plant samples were collected at four different physiological growth stages of maize namely, V₄ (collar of 4th leaf visible), V₈ (collar of 8th leaf visible), grain- filling and maturity stages. In case of wheat, rhizosphere soil and plant samples were collected at crown root initiation (CRI), panicle initiation and physiological maturity stages. Immediately after collection, about 100 g of moist soil samples from each plot were kept in a deep freezer at 4 °C and subsequently used for determination of mineral N and microbial parameters. After harvest of crops, soil samples were also collected for determination of different fractions of nitrogen. Remaining portion of soil samples were air-dried in shade, ground to pass through 2-mm sieve, used for other chemical analyses.

After the harvest of maize and wheat crop, the grain and stover/straw yields of each plot were recorded separately. The representative grain and stover/straw samples of maize and wheat from each plot were collected and processed. Air-dried grain and stover/straw samples were dried in an electrical oven at 60±2 °C for 48 h or till constant weight. Samples were finely ground by a stainless steel Wiley mill using 0.5 mm sieve. Ground samples were properly stored in plastic containers for estimation of total N contents.

Soil analyses

The initial soil samples were analyzed for soil texture, reaction (pH), electrical conductivity (EC), cation exchange capacity (CEC), organic carbon, available P and available K as per methods described by Page *et al* (1982). The following standard methods were used for analysis of soil samples:

Mineral nitrogen (NH₄⁺-N + NO₃-N)

Mineral N (NH₄⁺-N and NO₃-N) was determined by first extracting the soil samples with 2M KCl (soil : solution ratio of 1:10) followed by determination of NH₄⁺-N by steam distillation with magnesium oxide (MgO) in a micro-Kjeldahl distillation unit (Keeney and Nelson, 1982). The ammonia (NH₃) evolved was trapped in 2% H₃BO₃ containing mixed indicator (0.099 g bromocresol green and 0.066 g methyl red dissolved in 100 mL of 95% ethanol), and then determined by titration against standard H₂SO₄. The same procedure was used for NO₃-N after reduction with Devarda's alloy.

Walkley-Black Carbon

Walkley-Black organic carbon (WBC) content in soil was determined by wet oxidation method as outlined by Walkley and Black (1934).

Microbial Biomass Carbon

Microbial biomass carbon (MBC) in soil was determined by fumigation-extraction method (Jenkinson and Powlson, 1976). For this purpose, 10 g of moist soil was fumigated with chloroform (CHCl_3) in vacuum desiccator and extracted with 0.5 M K_2SO_4 (soil: solution of 1:2.5). A duplicate soil sample as such (non-fumigated) was also extracted with 0.5 M K_2SO_4 in a similar fashion. Both the extracts of non-fumigated and fumigated soil were subjected to wet oxidation. About 10 mL of the extract was treated with 2 mL of 0.2 N $\text{K}_2\text{Cr}_2\text{O}_7$, 10 mL of conc. H_2SO_4 and 5 mL of H_3PO_4 and the mixture was digested at 100 °C for 30 min under refluxing condition. Samples were cooled and titrated with a solution of 0.005 N ferrous ammonium sulphate using diphenylamine as an indicator. The MBC was computed by subtracting the amount of organic carbon in fumigated soil from that of non-fumigated one and it was expressed on oven dry weight basis. The amount of the MBC in soil was calculated as follows:

$$\text{Microbial biomass carbon} = (\text{OC}_F - \text{OC}_{UF}) / K_{EC}$$

where, OC_F and OC_{UF} are the organic carbon extracted from fumigated and unfumigated soil, respectively (expressed on oven dry basis), and K_{EC} is the efficiency of extraction. A value of 0.25 is considered as a general K_{EC} value for microbial extraction efficiency and used for calculation

Microbial Biomass Nitrogen

Microbial biomass nitrogen (MBN) in soil was estimated by fumigation extraction method (Jenkinson and Powlson, 1976). Soil sample (20 g) was taken in duplicate in 100 mL glass breaker and moistened with distilled water. One set was kept inside a vacuum desiccator and fumigated as described in case of determination of MBC. The fumigated and non-fumigated soils were extracted with 0.5 M K_2SO_4 (1:4 soil: solution ratio) and nitrogen content in the extract was determined by following the modification procedure of Brookes *et al.* (1985) in which 40 mL of the extract was taken and total N was measured after digestion. Then, 1 mL of 0.19 M CuSO_4 solution and 10 mL of conc. H_2SO_4 were added to the extract in 250 mL capacity of nitrogen digestion and

distillation tube and mixture was refluxed for 3 h. After cooling, distilled water (20 mL) was added to the digestion tube. The content of the tube was then steam-distilled with 40% NaOH and the liberated NH_3 was absorbed in 4% H_3BO_3 containing mixed indicator (0.099 g bromocresol green and 0.066 g methyl red dissolved in 100 mL of 95% ethanol) and then determined by titration against standard H_2SO_4 . The amount of the MBN in soil was calculated as follows:

$$\text{Microbial biomass nitrogen} = (\text{ON}_F - \text{ON}_{UF}) / K_{EC}$$

where, ON_F and ON_{UF} are the organic nitrogen extracted from fumigated and unfumigated soil, respectively (expressed on oven dry basis), and K_{EC} is the efficiency of extraction (0.45) as per Bremner and Kessel (1990).

Particulate Organic Carbon and Particulate Organic Nitrogen

The particulate organic carbon (POC) and *particulate organic nitrogen* were determined following the procedure as outlined by Camberdella and Elliot (1992). Air-dried soil sample (10 g, 2-mm sieved) was shaken with 0.5% sodium hexametaphosphate in a shaker for 15 h. The soil suspension was passed through 0.053 mm sieve by spraying water on the top of the sieve. The solid portion which was retained on the sieve, termed as particulate organic matter (POM). This solid portion was transferred to small pre-weighed aluminum box by washing with spray of water. It contains both particulate organic matter and sand particles. The aluminum box was kept inside an oven at 50 ± 1 °C temperature for 72 h for drying and finally recorded the weight of the aluminum box. The solid materials in aluminum box were then ground in a pestle and mortar so as to make fine powder. Total organic carbon and total nitrogen contents in use dried material (POM) was determined by CHNS analyzer.

Plant Analyses

Total nitrogen in plant samples was determined by micro-Kjeldahl method. Processed grain and straw/stover samples (0.5 g) were digested with 8 mL of concentrated H_2SO_4 and 2 g digestion mixture (K_2SO_4 : CuSO_4 :Se in the ratio of 200:20:1) in micro-Kjeldahl tubes in a block digester at 370-390 °C till the content turned light green. After digestion the material was diluted by adding 20 ml of distilled water, made alkaline with 40% NaOH and steam distilled in a micro-Kjeldahl system. The NH_4 -N was steam-distilled for 4 minutes and was adsorbed in 4% boric acid containing mixed indicator (methyl red + bromocresol green), followed by titration against 0.1 N H_2SO_4 .

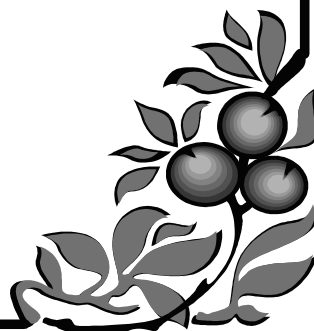
Statistical Analyses

Data generated from the field experiments were subjected to the statistical analyses using ANOVA of relevant experimental design. Data were assessed by Duncan's multiple range tests (Duncan, 1955) with a probability $P < 0.05$. Least significant difference (LSD) between means was calculated using the SAS program. Pearson's correlation matrix for yield, N uptake and different fractions of carbon and nitrogen in soils was computed by the SAS.



Chapter 4

Results



4. RESULTS

The results obtained in the present investigation entitled “*Nitrogen dynamics under maize-wheat cropping system as influenced by nitrogen, tillage and residue management options*” are presented in this chapter under the following heads:

4.1 Effect of tillage, crop residue, and N sources and application methods on maize and wheat yields

4.2 Fertilizer N economy in maize and wheat under different tillage, and residue management, and N supply options

4.3 Nitrogen uptake and its use efficiency under different tillage, and residue management, and N supply options

4.4 Soil C dynamics under different tillage, residue management, N sources and N application methods

4.5 Soil N dynamics under different tillage, residue management, N sources and N application methods

4.1 Effect of tillage, crop residue, and N sources and application methods on maize and wheat yields

Maize yields

Grain yield of maize varied from 6.55 to 8.25 t ha⁻¹ with a mean of 7.47 t ha⁻¹ under conservation agriculture (CA), and from 6.10 to 8.90 t ha⁻¹ with a mean of 7.48 t ha⁻¹ under conventional tillage (CT) across the levels, sources and methods of N application (Table 4.1). Yield differences between CA and CT were not statistically significant, fertilizer N scheduling resulted in significant variation in grain yield. Under both CA and CT application of 50% N as basal dressing proved superior to 33% or 80% basal dressing. Sources or methods of N application did not bring the significant change in the grain yield of maize under CA, whereas band placement of IFDC-product produced significantly higher maize grain yield under CT (8.05 t ha⁻¹) as compared to other N management options which were at par. Stover yield ranged between 10.2 to 16.2 t ha⁻¹ with a mean of 12.3 t ha⁻¹ under CA and between 9.30 to 16.2 t ha⁻¹ with a mean of 13.0 t ha⁻¹ under CT (Table 4.2). Alike grain yield, stover yield under CA and CT at par, although the same were significantly higher with 80% basal N treatment under both CA and CT. Basal N application gave stover yield in the order: 80% N > 50% N > 33% under CA as well as CT. The effect of N

sources/methods was significant. Band placement of urea produced significantly higher maize stover yield under CA (14.5 t ha⁻¹) as well as under CT (14.2 t ha⁻¹) as compared to other N management options.

Wheat yields

Averaged across N scheduling levels, sources and methods of application, the grain yield of wheat was significantly ($p < 0.05$) higher under CA (5.00 t ha⁻¹) compared with CT (4.71 t ha⁻¹) (Table 4.3). Among N scheduling levels 50% basal N application produced highest grain yield under both CA and CT, followed by 33% and 80% basal N application. Among sources and methods of N application, band placement of USG or IFDC-product was invariably superior to other options, whereas urea-broadcasting resulted in lowest grain yield under both CA and CT. Interaction of different factors were significant, indicating that 50% basal dressing of USG or IFDC-product under CA was superior to other tillage and N management options. Wheat straw yield varied from 7.10 to 12.4 t ha⁻¹ (mean 10.1 t ha⁻¹) under CA and from 6.80 to 11.5 t ha⁻¹ (mean 10.3 t ha⁻¹) under CT (Table 4.4). Treatment effect related to N management options on straw yield was not significant.

4.2. Fertilizer N economy in maize and wheat under different tillage, and residue management, and N supply options

Data illustrated in fig 4.1 revealed that CA required only 99 kg N ha⁻¹ in maize as against 109 kg ha⁻¹ under CT. Among N scheduling levels fertilizer N input was highest (128 kg ha⁻¹ under CA and 139 kg ha⁻¹ under CT) with 80% basal dressing. Similarly urea-broadcasting treatment required highest N application under both the cultivation practices *i.e.* CA and CT. In wheat, fertilizer N economy under CA was relatively greater, as the average fertilizer N requirement under CA was 136 kg ha⁻¹ whereas the same under CT was 188 kg ha⁻¹ (Fig. 4.2). Basal dressing of 50% or 33% of total N required less fertilizer N as compared to 80% basal application. Among sources and methods, fertilizer N application was highest under urea-broadcasting, and the lowest under band placement of USG and IFDC-product. Thus, the results clearly indicated the possibility of curtailing 62 kg N ha⁻¹ (*i.e.* 10 kg in maize and 52 kg in wheat) with the adaptation of CA, without any yield penalty in maize-wheat cropping system.

Table 4.1. Grain yield (t ha⁻¹) of maize under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-band	7.60	7.40	7.30	7.43a	7.31	8.10	7.10	7.50a
IFDC-band	6.55	8.25	8.25	7.68a	7.90	8.90	7.35	8.05a
Urea-band	6.80	7.35	7.52	7.22a	6.80	8.12	7.90	7.61a
Urea-broadcast	7.60	7.80	6.80	7.40a	6.80	6.90	7.20	6.97b
Urea-foliar spray	7.15	8.10	7.65	7.63a	6.10	7.62	8.15	7.29ab
Mean	7.14a	7.78a	7.50a	7.47a	6.98a	7.93a	7.54a	7.48a

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

Table 4.2. Stover yield (t ha⁻¹) of maize under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-band	13.6	12.8	10.2	12.2b	11.1	15.3	9.35	11.9b
IFDC-band	11.9	13.6	10.4	12.0b	11.9	13.6	12.8	12.8b
Urea-band	15.3	16.2	11.9	14.5a	15.3	12.8	14.5	14.2a
Urea-broadcast	15.3	10.4	10.2	12.0b	17.0	10.2	9.50	12.2b
Urea-foliar spray	11.9	10.2	11.1	11.1bc	13.6	12.8	16.2	14.2a
Mean	13.6a	12.6a	10.7b	12.3a	13.8a	12.9a	12.4b	13.0a

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

Table 4.3. Grain yield (t ha⁻¹) of wheat under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-band	5.00	5.50	5.80	5.43a	4.88	4.99	4.99	4.95a
IFDC-band	5.10	5.60	5.50	5.40a	5.00	5.10	4.98	5.03a
Urea-band	4.70	5.20	4.66	4.85b	4.30	5.10	4.84	4.75ab
Urea-broadcast	4.40	4.50	4.20	4.37c	4.20	4.40	4.17	4.26c
Urea-foliar spray	4.90	5.20	4.70	4.93b	4.50	4.50	4.71	4.57bc
Mean	4.82b	5.20a	4.97b	5.00a	4.58b	4.82a	4.74a	4.71b

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

Table 4.4. Straw yield (t ha⁻¹) of wheat under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-band	11.5	10.5	6.70	9.57a	11.3	9.40	10.2	10.3a
IFDC-band	12.4	9.50	11.0	11.0a	11.5	10.1	10.0	10.5a
Urea-band	7.10	10.2	10.0	9.10b	11.2	11.1	11.3	11.2a
Urea-broadcast	12.0	8.70	11.3	10.7a	10.0	6.80	10.1	8.97b
Urea-foliar spray	10.1	10.3	9.80	10.1a	10.0	11.4	10.0	10.5a
Mean	10.6a	9.84a	9.76a	10.1a	10.8a	9.76a	10.3a	10.3a

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

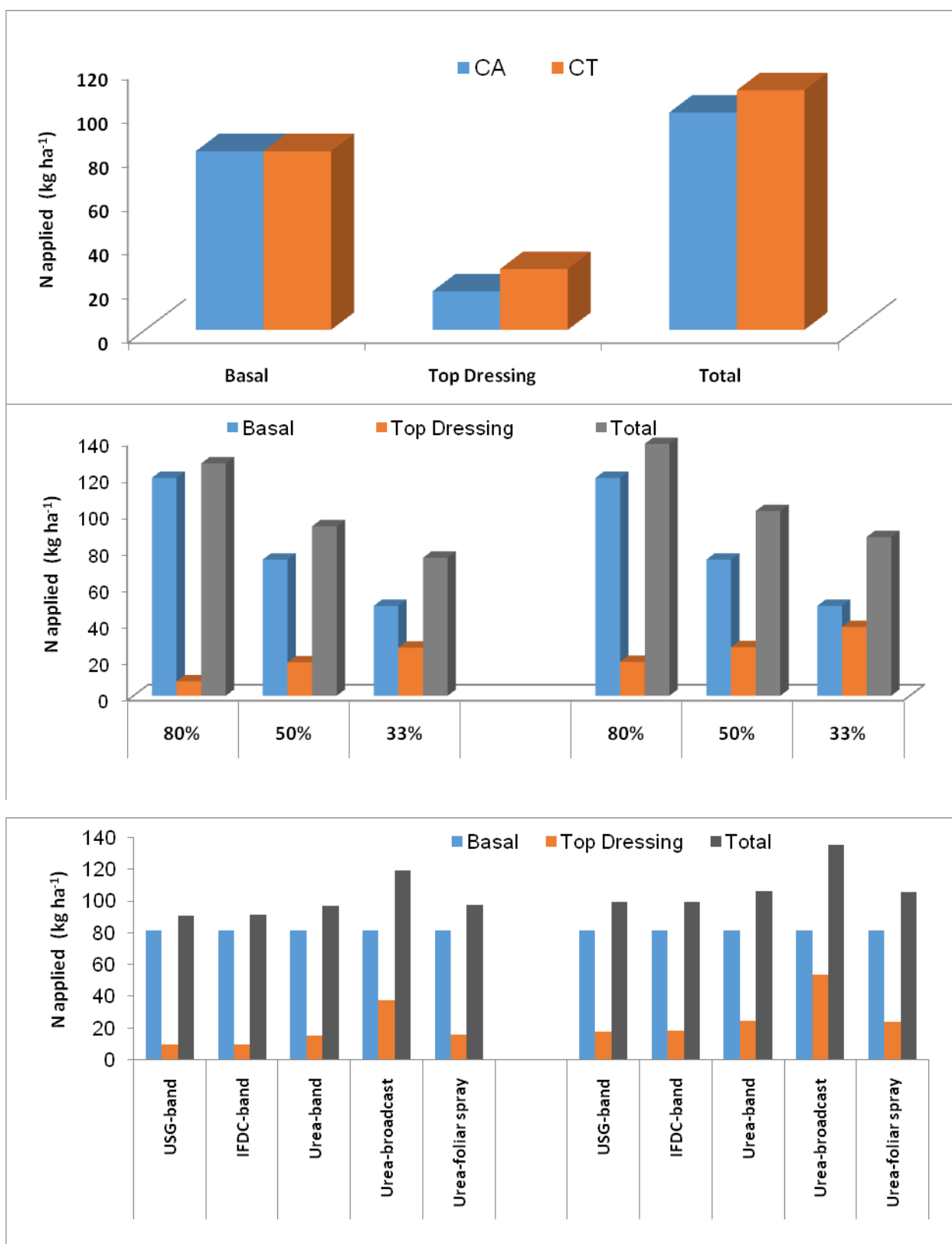


Fig 4.1. Total fertilizer N applied in maize

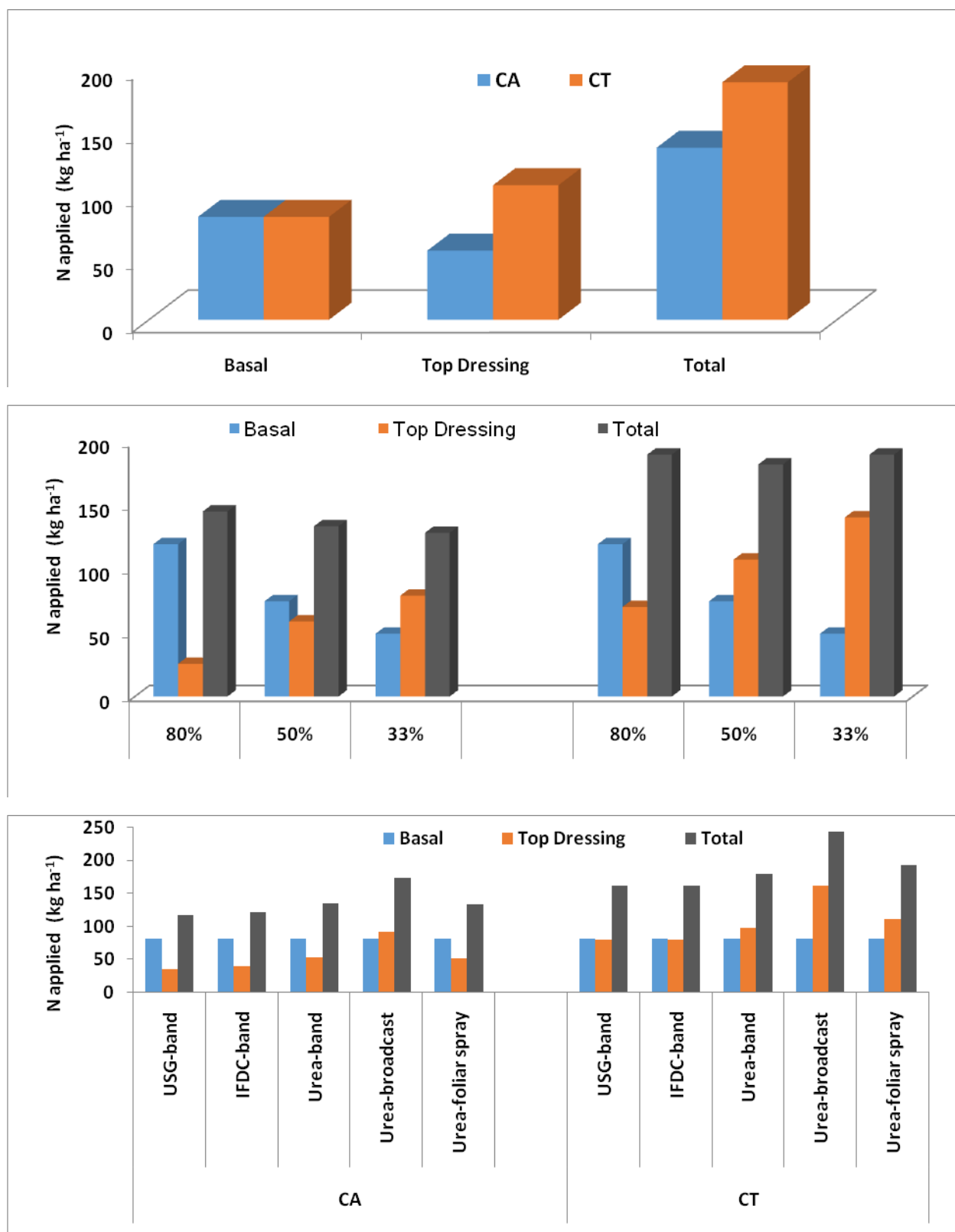


Fig. 4.2. Total fertilizer N applied in wheat

4.3. Nitrogen uptake and its use efficiency under different tillage, and residue management, and N supply options

Total N uptake

Total uptake (grain + stover) of N by maize averaged at 103 kg ha⁻¹ under CA and 107 kg ha⁻¹ under CT (Fig 4.3). Within each cultivation practice N uptake increased with increasing basal N application. The uptake values did not differ much due to sources and methods of application.

In wheat, total N uptake was 106 and 104 kg ha⁻¹ under CA and CT, respectively. As averaged across N management options (Fig 4.4). In general, application of 50% N as basal dressing resulted in higher N uptake under CA and CT. Under CA, N uptake with band placement of USG, IFDC-product or prilled urea was higher than urea-broadcasting or foliar application.

N use efficiencies

N use efficiencies in maize and wheat were computed as agronomic efficiency (AE_N), partial factor productivity (PFP_N) and recovery efficiency (RE_N).

(i) Agronomic efficiency of N

The agronomic efficiency of N (AE_N) in maize varied from 16.0 to 49.7 kg grain kg⁻¹ N in different treatments. Although, the differences between CA and CT was not significant. Basal application of 33% or 50% of fertilizer N gave higher AE_N compared to 80% basal N application. Among the sources and methods lowest AE_N values were recorded under urea-broadcast treatment (Fig. 4.5).

Average across N management options, AE_N was higher under CA (23.1 kg grain kg⁻¹ N) compared with CT (15.1 kg grain kg⁻¹ N) (Fig 4.6). Alike maize 80% basal dressing resulted in relatively lower AE_N compared with 50% or 33% basal dressing under both CA and CT practices. Among sources and methods USG and IFDC-product gave higher AE_N values over other options under CA. The AE_N under urea broadcasting was invariably lowest under both cultivation practices.

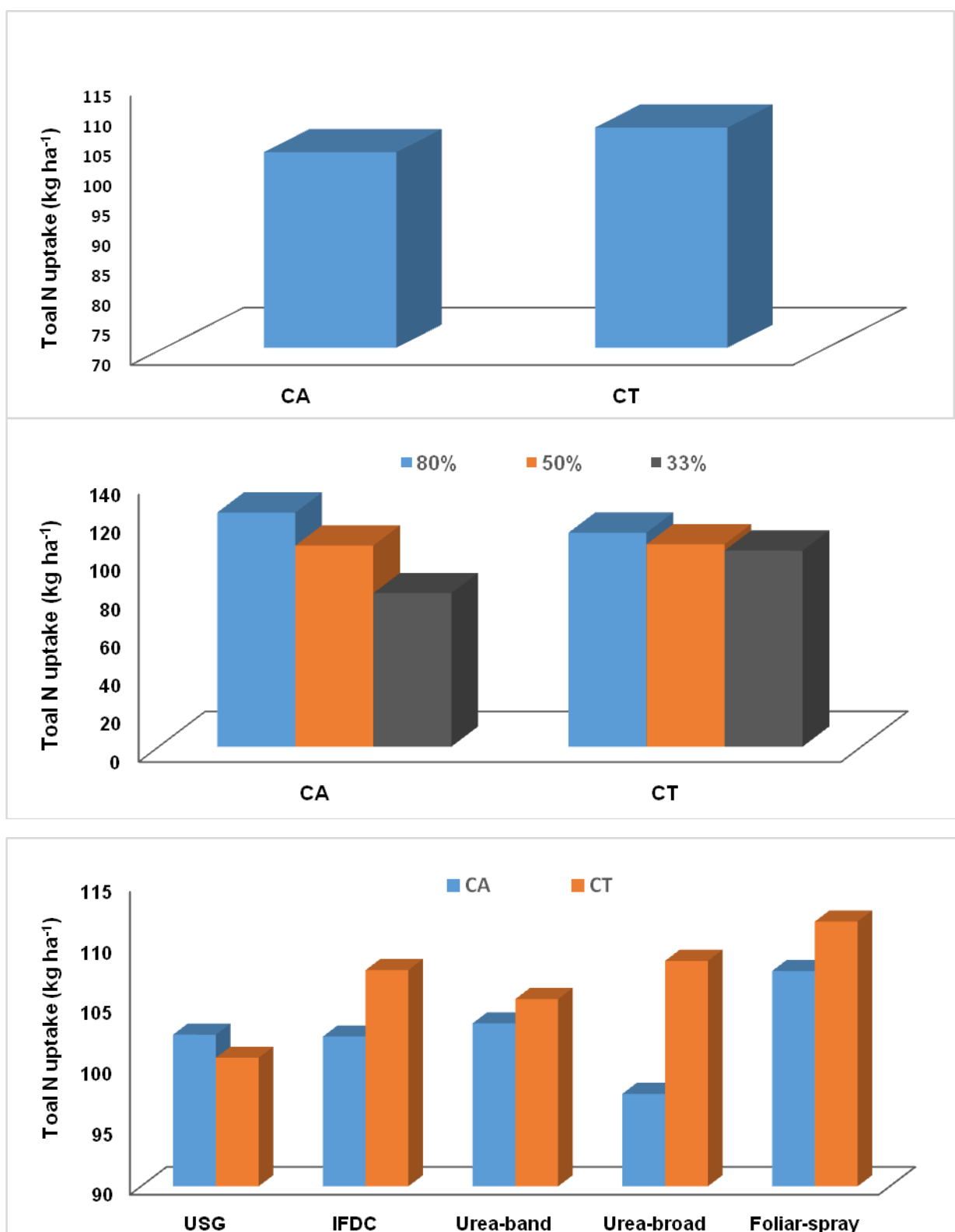


Fig. 4.3. Effect of different N management options on total N uptake by wheat

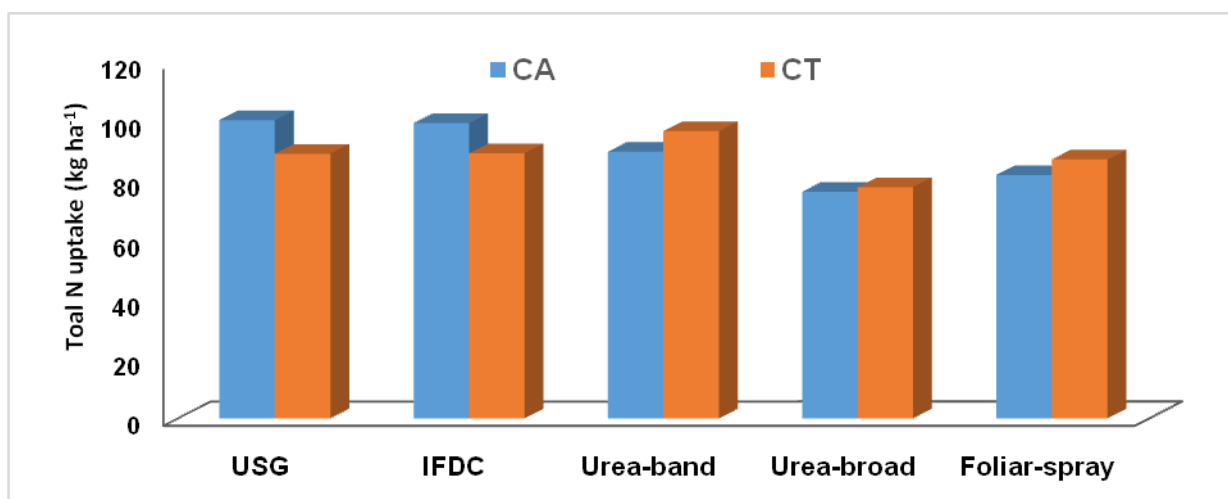
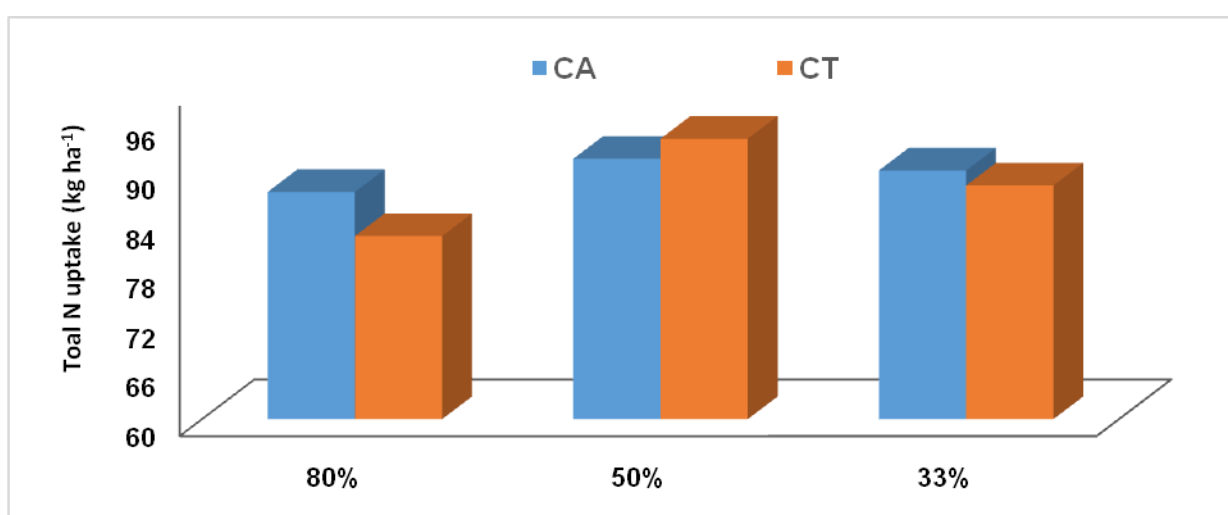
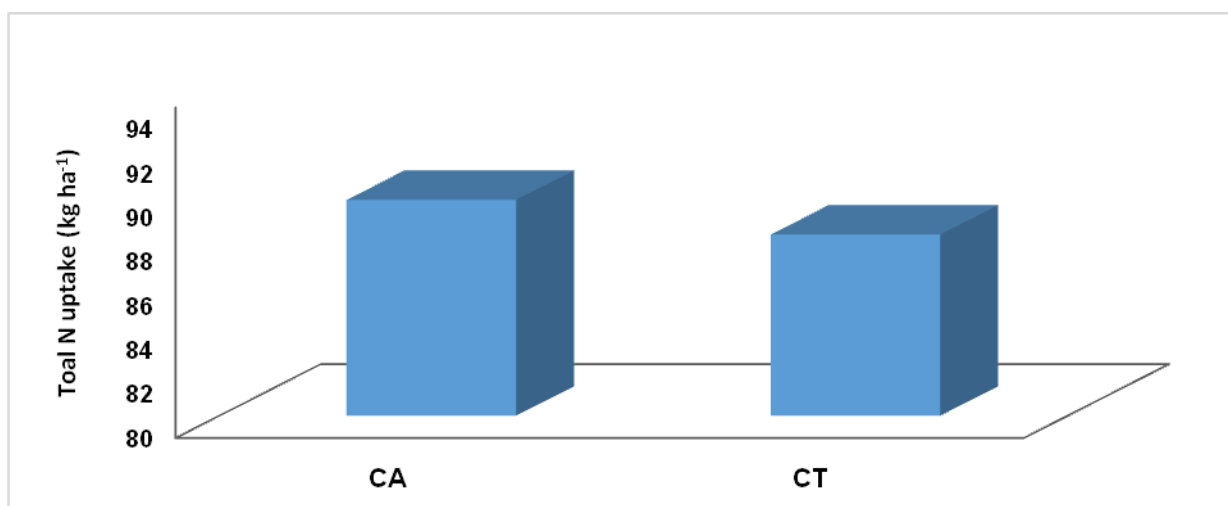


Table 4.4. Effect of different N management options on total N uptake by maize crop

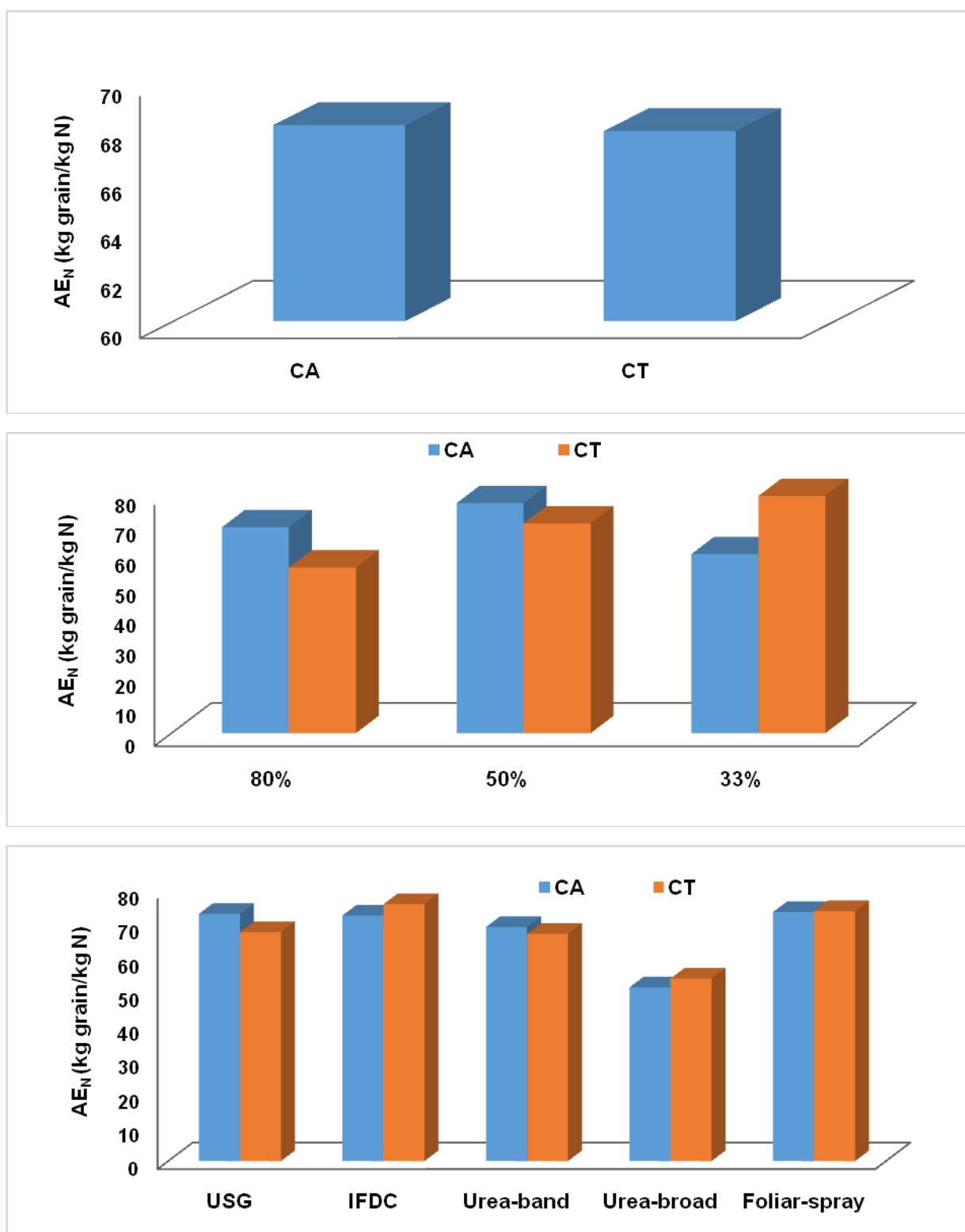


Fig. 4.5. Agronomic efficiency of N (AE_N) in maize under different N management options

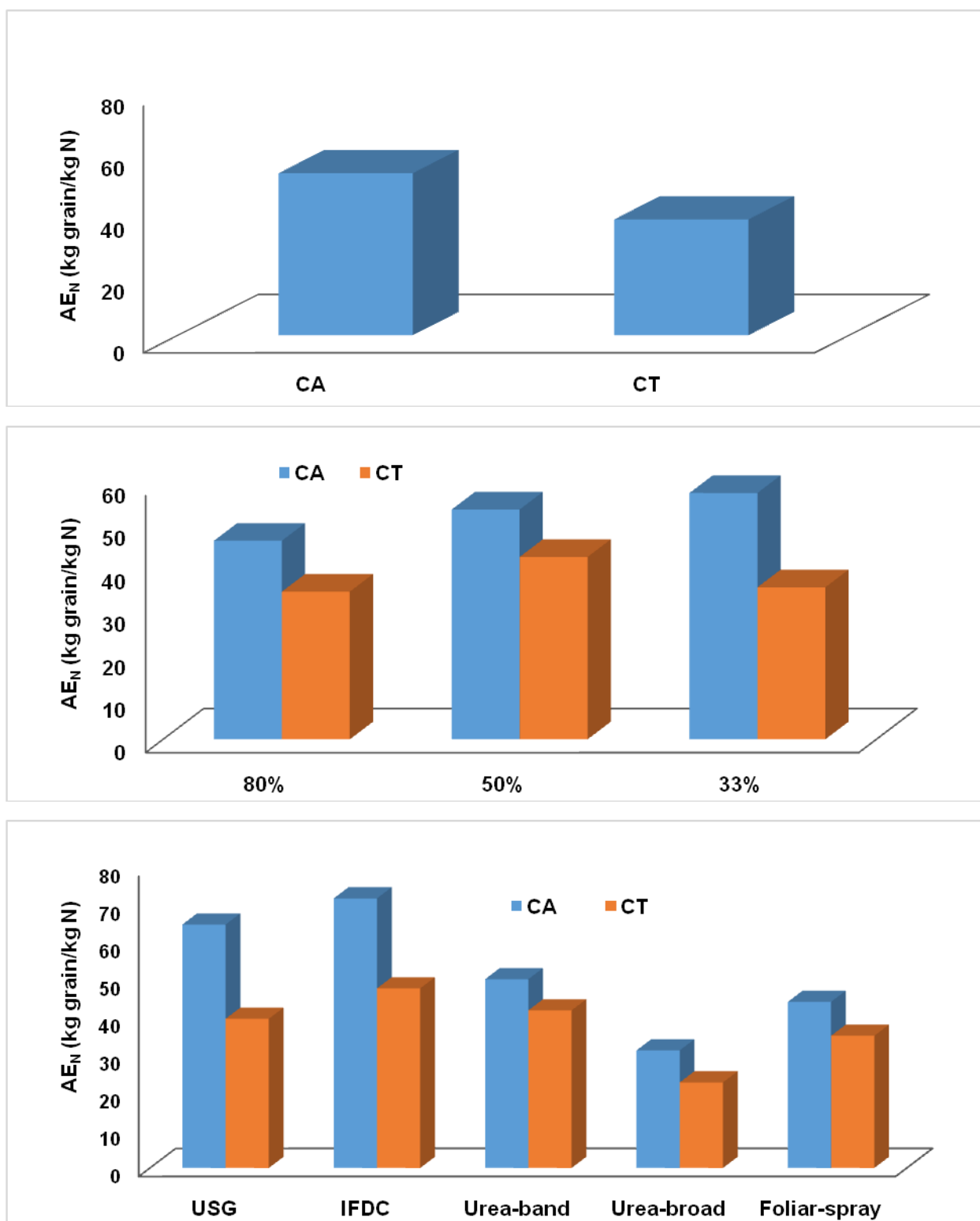


Fig. 4.6. Agronomic efficiency of N (AE_N) in wheat under different N management options

(ii) Partial factor productivity of N

The partial factor productivity of N (PFP_N) in maize was 76.2 and 73.3 kg grain kg^{-1} N under CA and CT, respectively (Fig 4.7). Among N scheduling options, PFP_N was consistently higher under 33%. Basal dressing followed by 50% and 80% basal dressing under both CA and CT practices. Sources and methods of N application did not differ markedly with respect to PFP_N , except that the values were lowest under urea broadcasting.

The PFP_N values for wheat were relatively lower compared to maize, as the PFP_N values for CA and CT were averaged at 38.4 and 26.1 kg grain kg^{-1} N, respectively (Fig 4.8). The effect of N management options on PFP_N was almost similar to maize as the PFP_N was smaller with 80% basal N and with urea broadcasting under both CA and CT.

(iii) Recovery efficiency of N

Recovery efficiency of N (RE_N), computed as per cent recovery of fertilizer N applied did not differ between CA and CT in maize (Fig 4.9). CA was apparently advantages in terms of RE_N , as the averaged values (56.1%) was greater than that under CT (54.7%). Also the effect of N scheduling was generally inconsistent. However, band placement or foliar application resulted in significantly higher RE_N compared to urea broadcasting under both cultivation practices.

In wheat, CA was apparently advantages in terms of RE_N , as the averaged values (52.5%) was significantly greater than that recorded under CT (37.5%) (Fig 4.10). The RE_N was also higher with 50% or 33% basal N application (53.7% and 57.5%, respectively) under CA, and with 50% basal N application (42.6%) under CT. Among sources and methods of N under CA or CT band placement of prilled or modified urea gave higher RE_N compared to foliar application or broadcasting of urea. On the whole RE_N in wheat was highest under CA treatments receiving band placement of IFDC-product (71.8%) followed by band placement of USG (64.9 %).

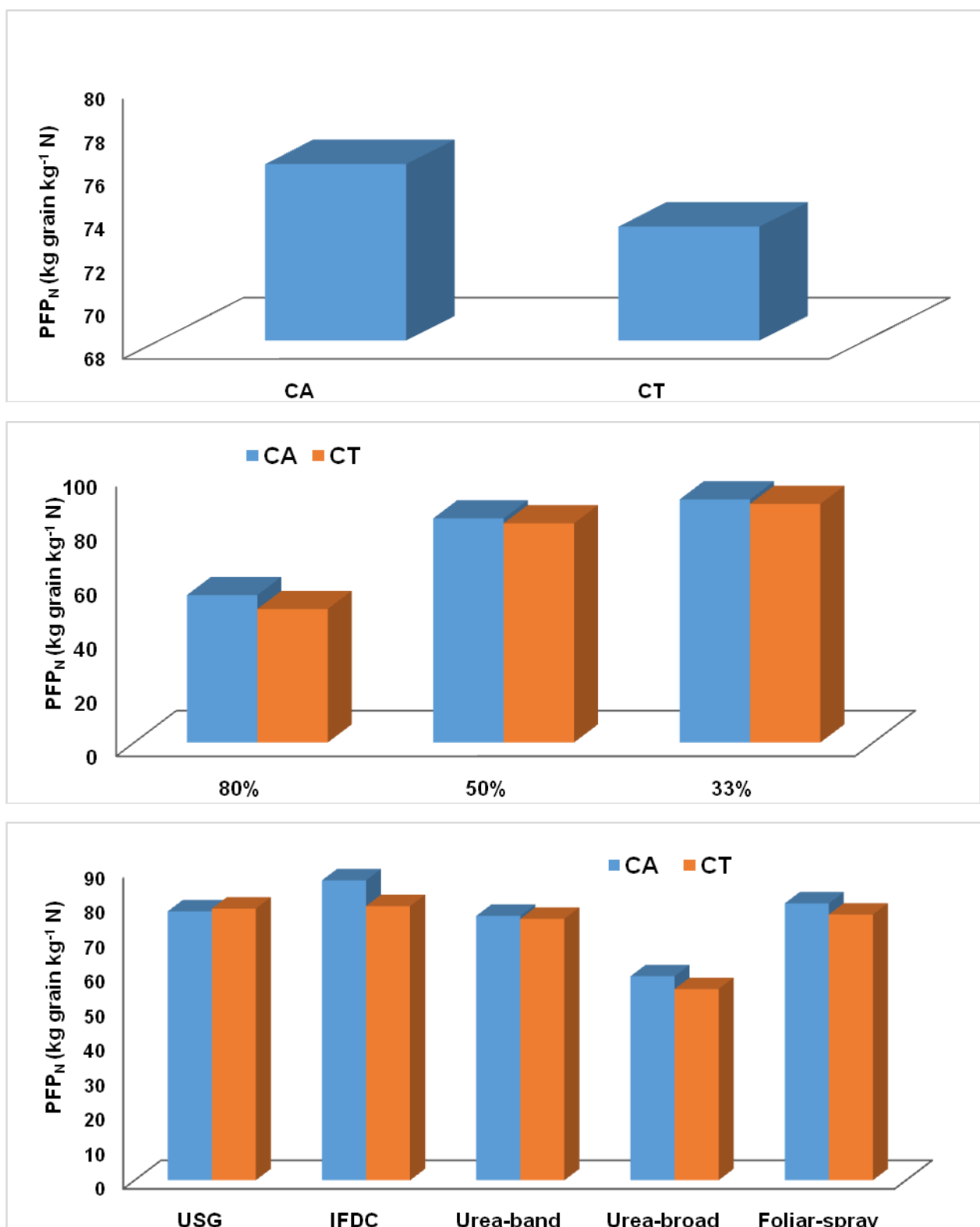


Fig. 4.7. Partial factor productivity of N (PFP_N) in maize under different N management options

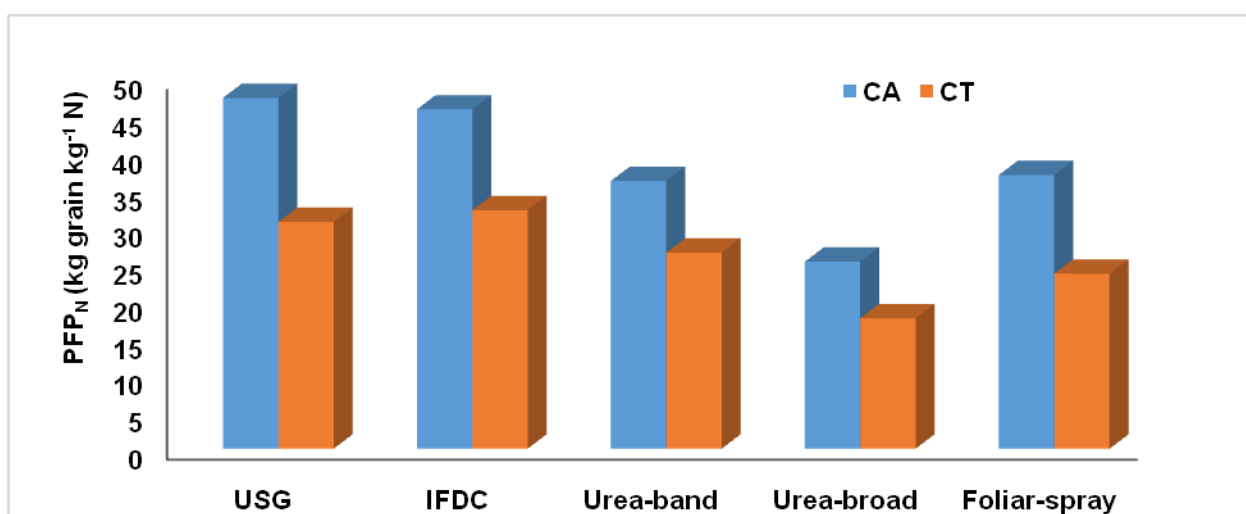
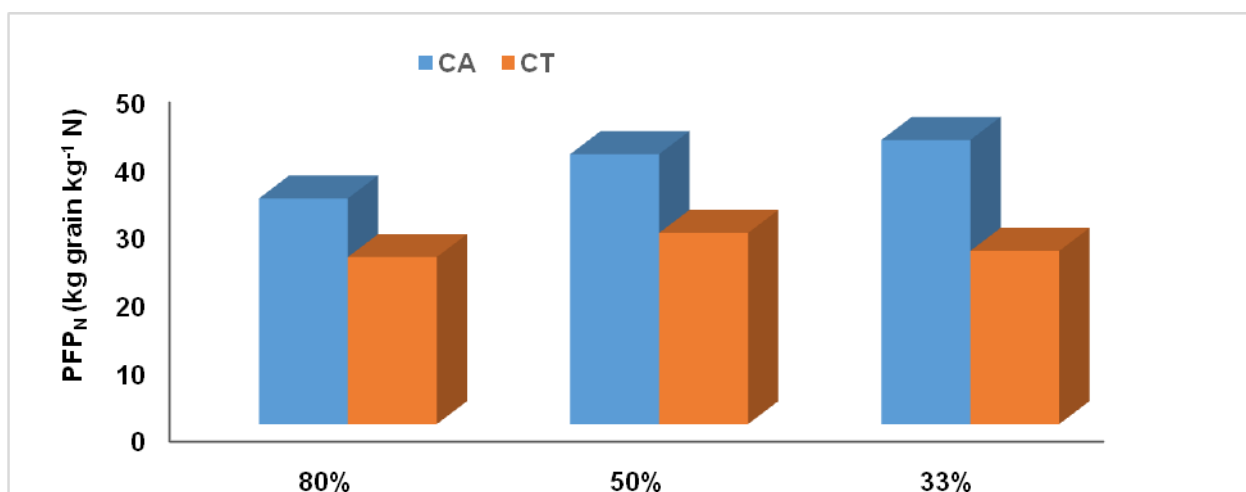
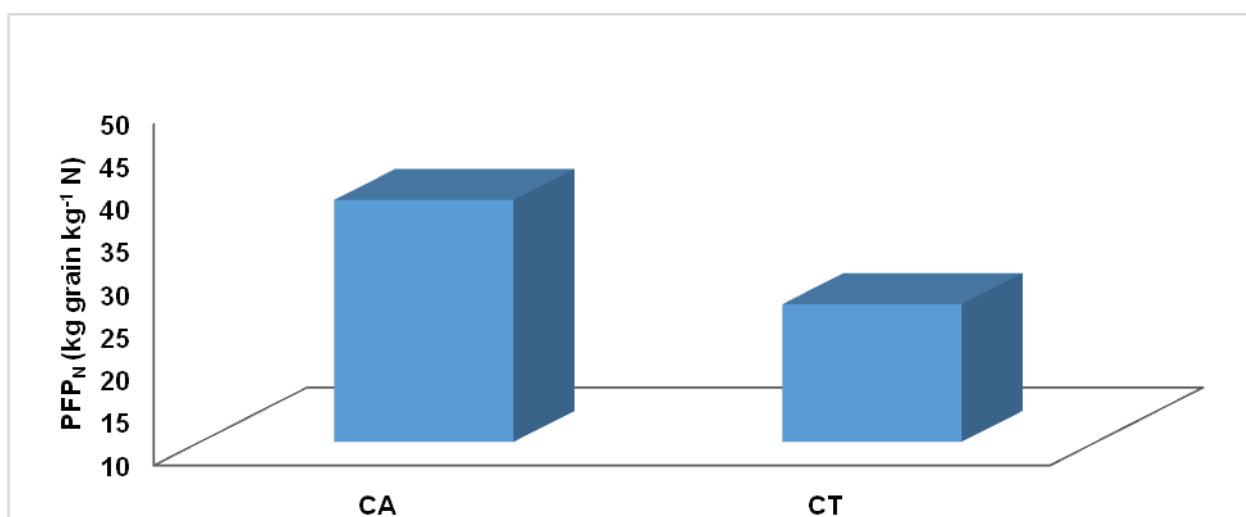


Fig. 4.8. Partial factor productivity of N (PFP_N) in wheat under different N management options

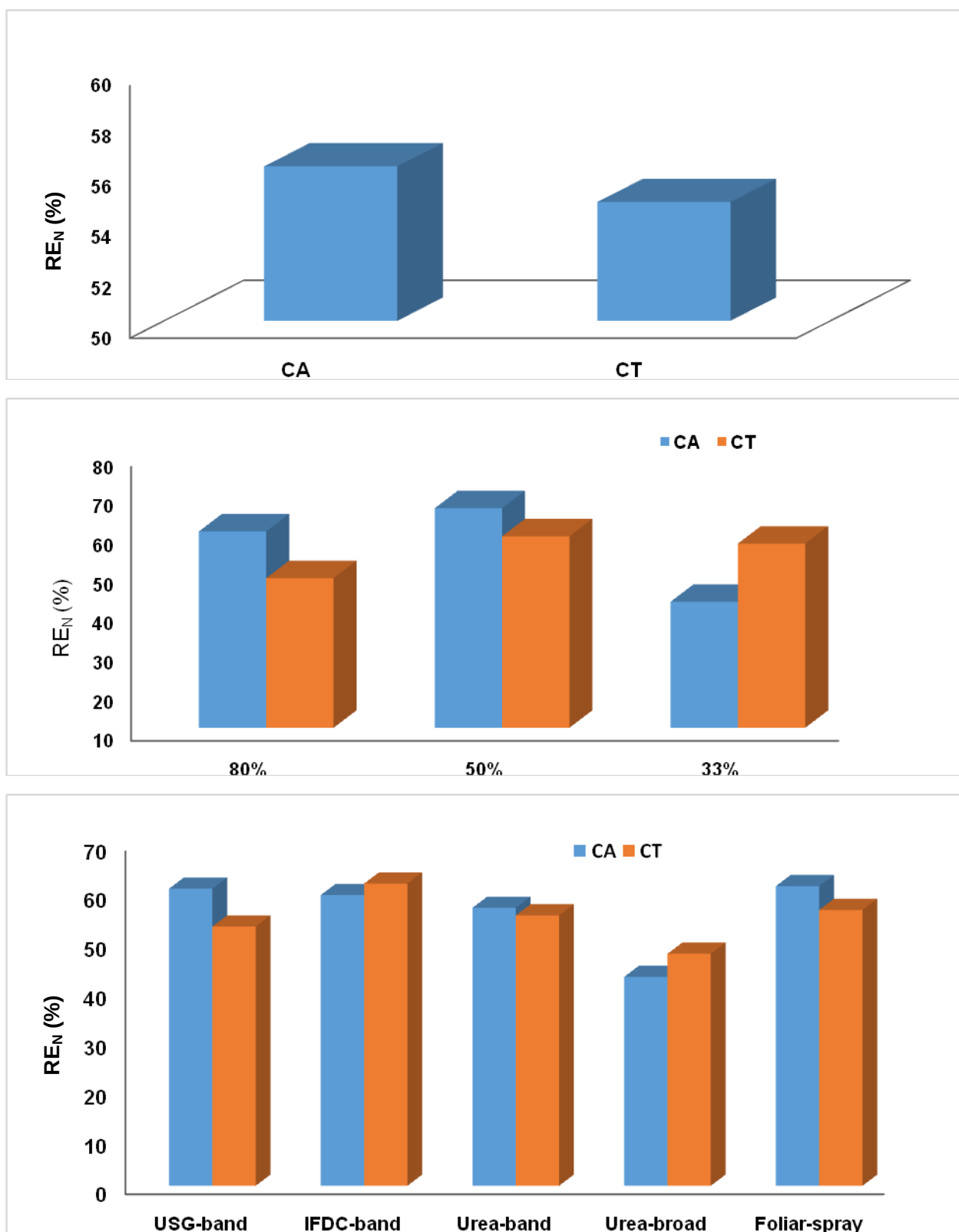


Fig. 4.9. Recovery efficiency of N (RE_N) in maize under different N management options

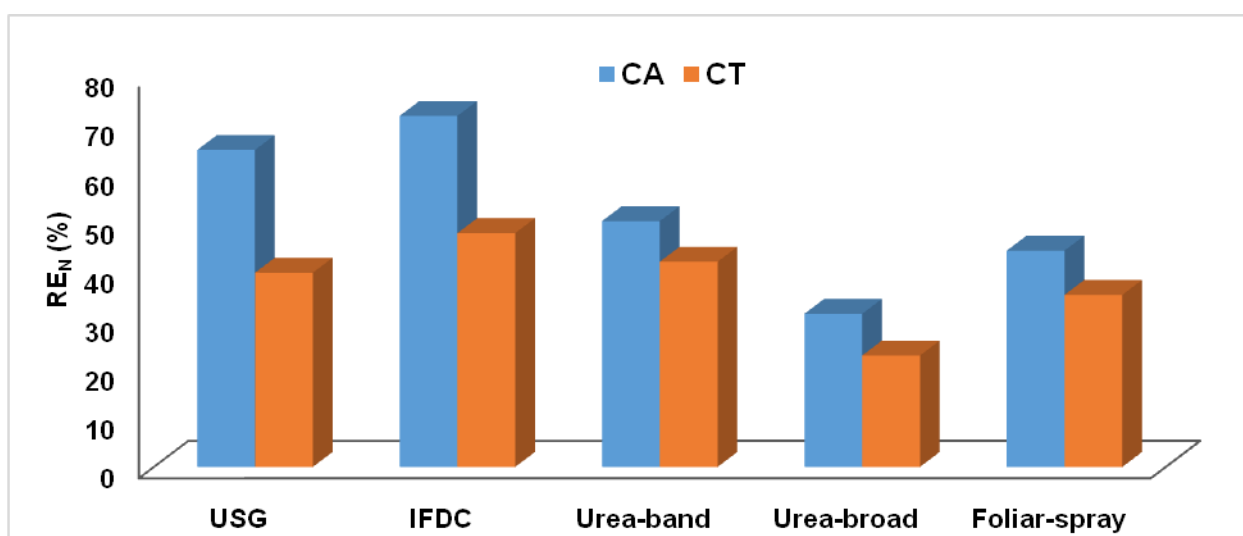
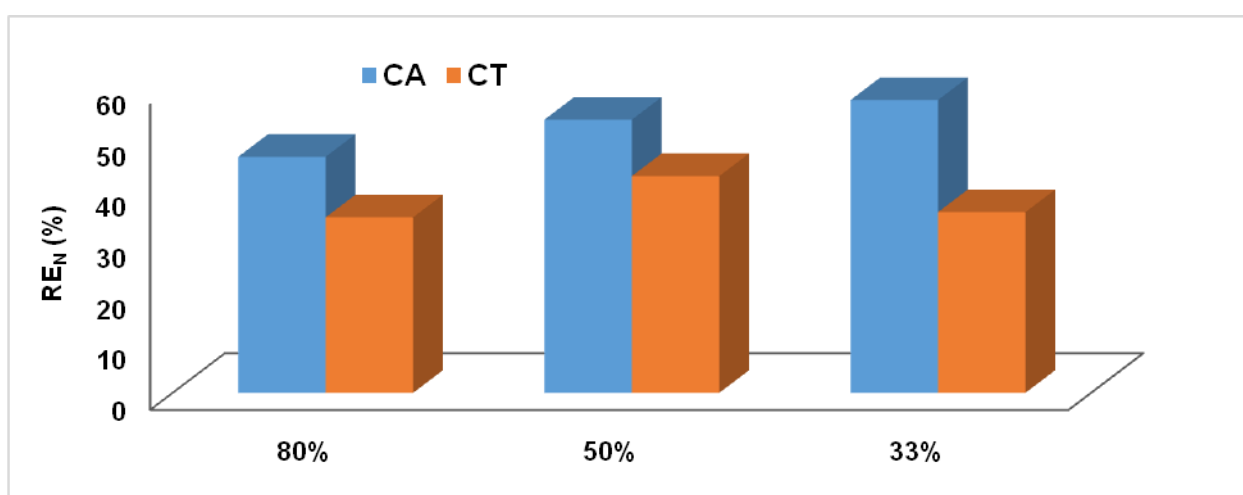
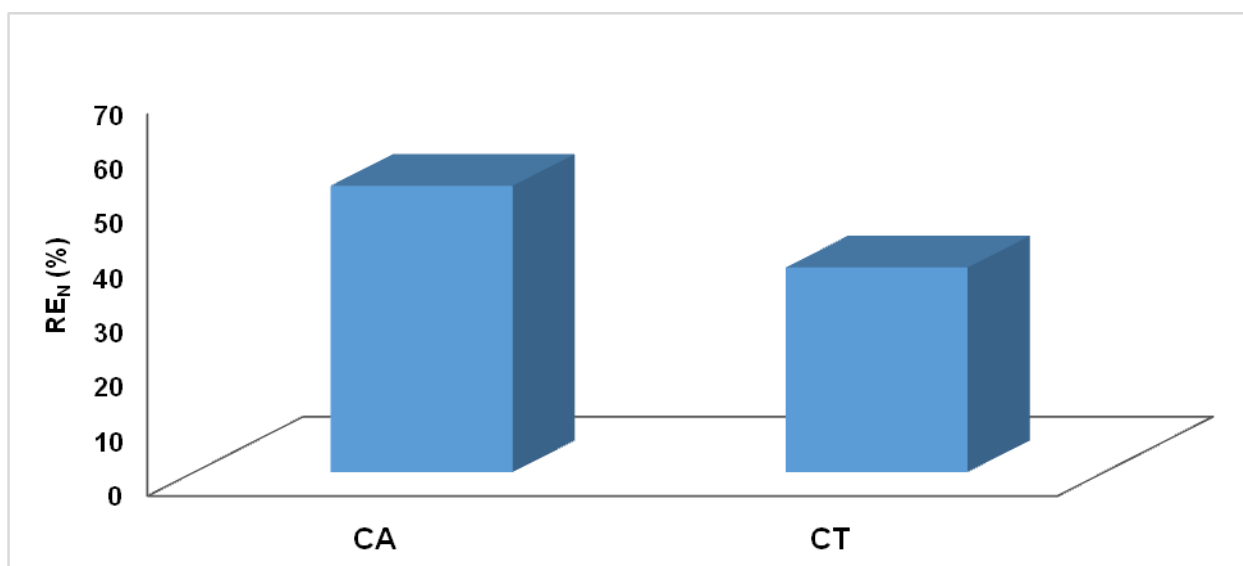


Fig. 4.10. Recovery efficiency of N (RE_N) in wheat under different N management options

4.4 Soil carbon dynamics under different tillage, residue management, N sources and N application methods

Walkley-Black C

In maize, Walkley-Black C (WBC) content in upper layer (0-15 cm) of soil under CA and CT practices got decreased from V4 (0.64 and 0.54%, respectively) to physiological maturity (0.53 and 0.49%, respectively) (Fig. 4.11). The WBC content under CA was significantly higher over CT by 18%, 9%, 17% and 6% at V4, V8, grain filling and physiological maturity, respectively. Among N scheduling options WBC content was in surface soil of CA practices invariably lowest in the treatments receiving 33% N as basal dressing under both CA and CT practices. The effect of sources and methods of N on WBC content was inconsistent, though the values under all options decreased with the advancement in crop growth stages.

WBC content in sub-surface layer (15-30 cm) was lower than surface layer (0-15 cm), although the values under CT had an edge over CA at most of the growth stages in maize (Fig. 4.12). Increase in WBC content with advancing crop growth was inconsistent in CA plots only. In this layer too, WBC content was higher in the treatments receiving larger proportions of fertilizer N input as basal dressing. Other treatments did not exhibit consistent trends with respect to WBC in sub-surface layer. In wheat, WBC content in surface layer was higher in CA compared with CT, whereas reverse was true for sub-surface (15-30 cm) layer (Figs. 4.13 and 4.14). Under both CA and CT fertilizer N scheduling with higher proportion as basal application exhibit higher WBC content at all crop growth stages, although the values decreased from CRI stage to physiological maturity. Alike maize, no definite trends was recorded as far as N sources and methods are concerned.

Microbial biomass C

Microbial biomass C (MBC) content of soil at physiological maturity of maize was higher under CA compared with that under CT, as also in surface layer compared with sub-surface (Tables 4.5 and 4.6). The MBC content in surface layer, averaged across N management options, was 675 mg ka⁻¹ under CA and 540 mg kg⁻¹ CT. The corresponding values of MBC in sub-surface layer of CA and CT were 401 and 280 mg kg⁻¹, respectively. In both the layers MBC content was relatively higher when 50% of fertilizer N was applied at the time of sowing. Sources and methods of N did

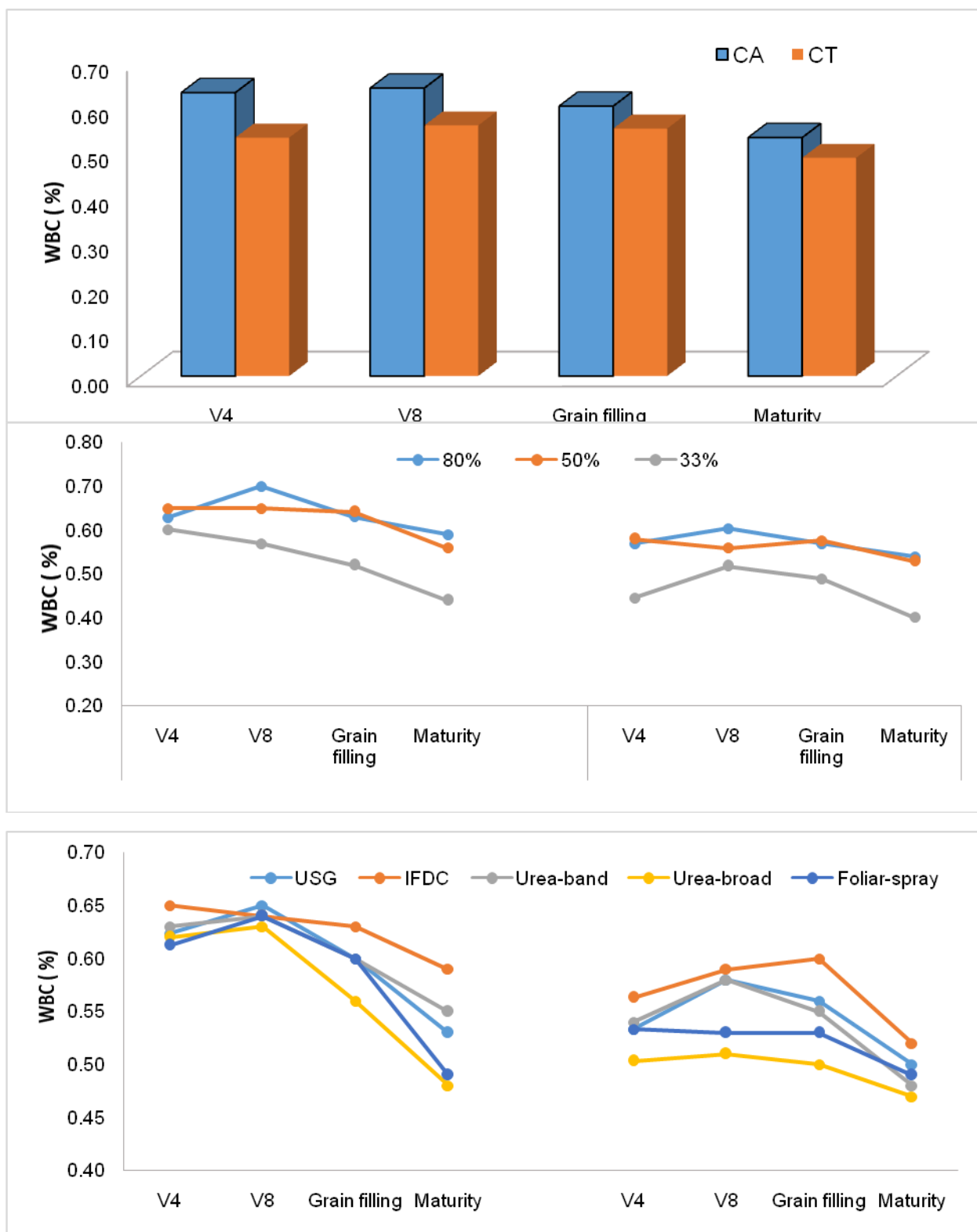


Fig 4.11. Walkley-Black C (WBC) content of surface (0-15 cm) soil at different growth stages of maize under different treatment options

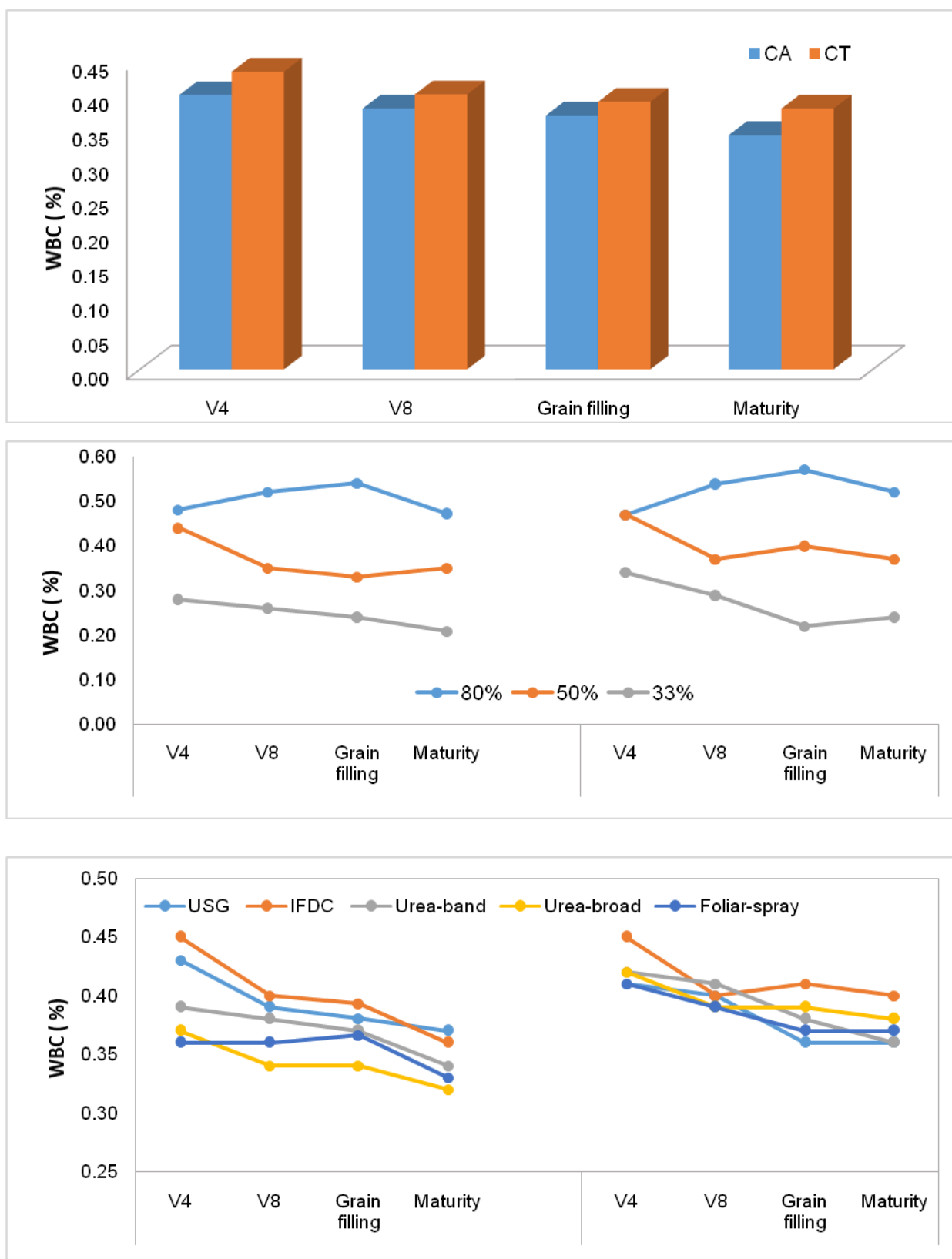


Fig 4.12. Walkley-Black C (WBC) content of sub-surface (15-30 cm) soil at different growth stages of maize under different treatment options

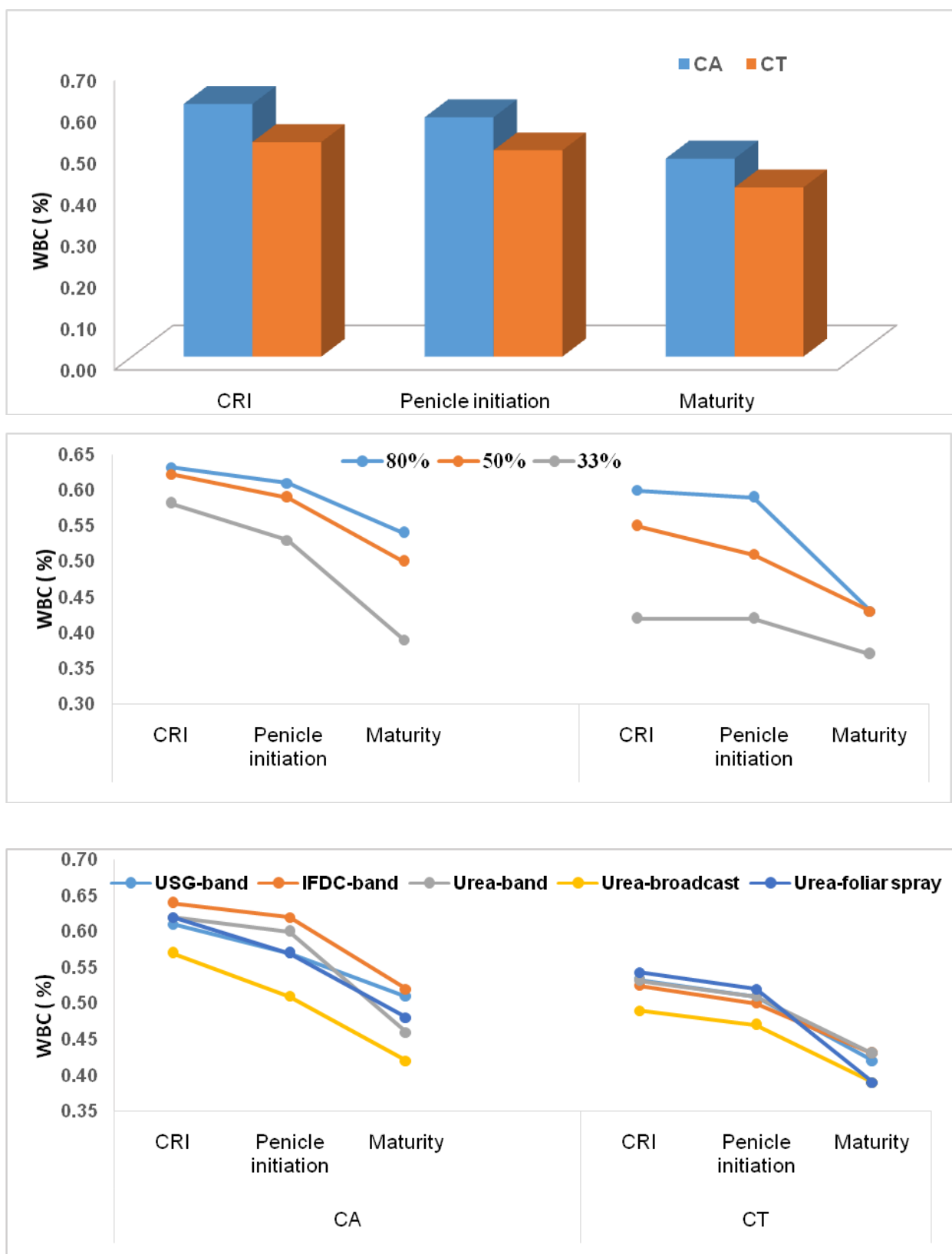


Fig 4.13. Walkley-Black C (WBC) content of surface (0-15 cm) soil at different growth stages of wheat under different treatment options

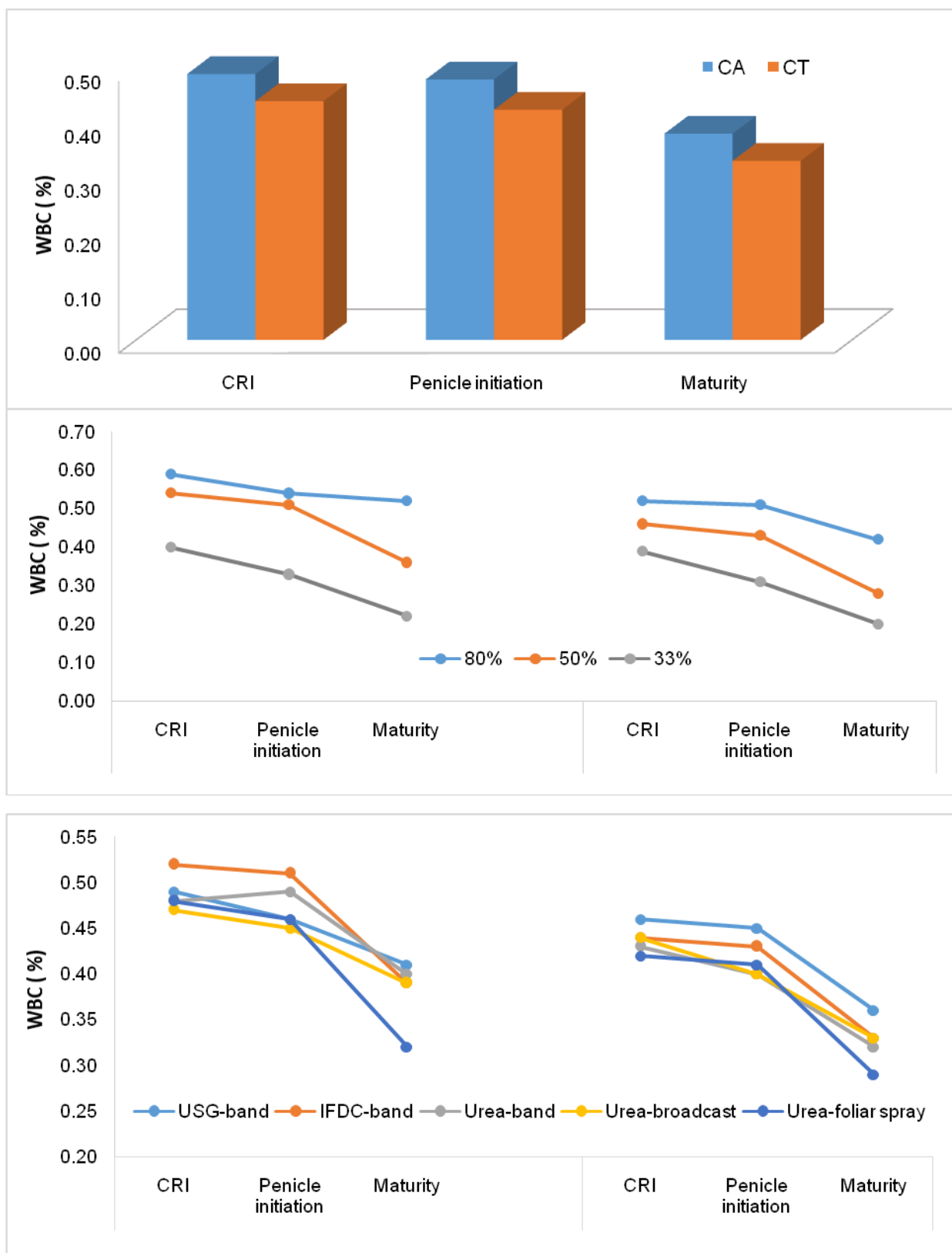


Fig. 4.14. Walkley-Black C (WBC) content of sub-surface (15-30 cm) soil at different stages of wheat under different treatment options

Table 4.5. Microbial biomass C (mg kg⁻¹) content in surface (0-15 cm) soil at physiological maturity of maize under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	663	756	647	689a	558	550	552	553a
IFDC-Band	669	716	643	676a	542	532	563	546a
Urea-Band	669	717	675	687a	532	587	528	549a
Urea-Broadcast	677	673	658	669a	514	543	534	530a
Urea-foliar spray	667	640	651	652a	514	536	516	522a
Mean	669a	700a	655a	675a	532a	549a	539a	540b

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

Table 4.6. Microbial biomass C (mg kg⁻¹) content in sub-surface (15-30 cm) soil at physiological maturity of maize under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	542	490	295	442a	360	285	237	294ab
IFDC-Band	496	573	194	421a	292	246	254	264b
Urea-Band	534	497	284	438a	431	276	227	311a
Urea-Broadcast	447	476	140	354b	423	264	214	300a
Urea-foliar spray	245	540	260	348b	244	247	197	229c
Mean	453b	515a	235c	401a	350a	264b	226b	280b

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

not bring significant change in MBC content in surface layer, whereas in sub-surface layer the change was significant.

In subsequent wheat MBC content of soil followed the trend similar to maize as the values were significantly greater under CA as also in the surface layer (Tables 4.7 and 4.8). As far as the effect of N scheduling is concerned higher N basal application supported higher MBC content in both soil layers and under both cultivation practices. In wheat also, soil MBC content did not differ significantly with respect to N sources and application methods.

Particulate organic matter associated C

Particulate organic matter associated C (POM-C) content of surface and sub-surface soil was measured at physiological maturity in maize (Tables 4.9 and 4.10) and wheat (Tables 4.11 and 4.12). In the surface layer POM-C content was almost statistically similar under CA (2.40%) and CT (2.33%) whereas in sub-surface soil the values under CT (1.53%) were apparently greater than CA (1.38%). Basal application of 50% or 80% of total fertilizer N resulted in higher POM-C compared to 33% basal N application. The POM-C content of both soil layer differ significantly due to N sources and methods of application. In CA as well as CT it was found significantly highest under band application of USG except surface layer of CA where it was recorded higher under foliar spray of urea.

Averaged across N scheduling levels, sources and application methods, POM-C in 0-15 cm soil layer was higher by 2.71% under CA and 2.62% under CT (Table 4.11) at physiological maturity in wheat. In 15-30 cm layer, POM-C content was relatively lower (Table 4.12) though the values were greater under CT (1.85%) compared with CA (1.57%). Application of 50 or 80% of the fertilizer N at the time of sowing resulted in higher POM-C content compared to 33% basal N application under both CA and CT practices. Alike POM-C content in preceding maize crop, the values of POM-C in wheat differ significantly due to N sources and method of application.

Table 4.7. Microbial biomass C (mg kg⁻¹) content in surface (0-15 cm) soil at physiological maturity of wheat under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	720	632	333	562a	523	433	323	426a
IFDC-Band	684	614	295	531a	476	393	390	420a
Urea-Band	685	590	478	584a	540	409	296	415a
Urea-Broadcast	732	584	476	597a	417	556	445	473a
Urea-foliar spray	663	560	359	528a	442	378	270	364b
Mean	697a	596b	388c	560a	480a	434b	345c	419b

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

Table 4.8. Microbial biomass C (mg kg⁻¹) content in sub-surface (15-30 cm) soil at physiological maturity of wheat under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	457	458	217	377c	387	234	196	272b
IFDC-Band	494	535	259	429ab	343	310	223	292ab
Urea-Band	526	517	322	455a	376	328	287	330a
Urea-Broadcast	563	480	362	468a	393	304	246	314a
Urea-foliar spray	434	532	303	423b	395	302	155	284b
Mean	495a	504a	292b	431a	379a	296b	221c	299b

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

Table 4.9. Particulate organic matter associated C (%) content in surface layer of soil at physiological maturity of maize under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	2.37	3.26	1.90	2.51b	2.26	2.21	1.57	2.01c
IFDC-Band	2.52	2.33	1.27	2.04c	3.38	2.17	1.78	2.44a
Urea-Band	2.24	2.55	1.96	2.25c	2.68	3.20	2.16	2.68a
Urea-Broadcast	2.83	2.29	2.19	2.44bc	2.25	2.96	1.77	2.33b
Urea-foliar spray	3.45	3.53	1.37	2.78a	2.04	2.01	2.52	2.19c
Mean	2.68a	2.79a	1.74b	2.40a	2.52a	2.51a	1.96b	2.33a

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

Table 4.10. Particulate organic matter associated C (%) content in sub-surface layer of soil at physiological maturity of maize under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	2.84	1.39	1.28	1.84a	2.82	1.24	0.76	1.60a
IFDC-Band	1.38	0.98	0.82	1.06d	2.29	1.76	0.77	1.61a
Urea-Band	1.62	1.57	0.65	1.28c	2.72	1.07	0.80	1.53ab
Urea-Broadcast	1.58	1.55	0.71	1.28c	2.17	1.38	0.74	1.43b
Urea-foliar spray	1.58	1.37	1.37	1.44b	2.18	1.47	0.79	1.48b
Mean	1.80a	1.37b	0.97c	1.38a	2.43a	1.38b	0.77c	1.53a

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

Table 4.11. Particulate organic matter associated C (%) content in surface layer of soil at physiological maturity of wheat under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	2.81	3.49	2.46	2.92a	2.49	2.35	2.85	2.56b
IFDC-Band	2.94	2.63	1.53	2.37b	3.55	2.54	1.99	2.69ab
Urea-Band	2.62	2.82	2.25	2.57b	2.87	3.30	2.46	2.87a
Urea-Broadcast	3.14	2.52	2.44	2.70b	2.54	3.26	1.97	2.59b
Urea-foliar spray	3.52	3.73	1.75	3.00a	2.37	2.35	2.37	2.36c
Mean	3.01a	3.04a	2.09b	2.71a	2.76a	2.76a	2.32b	2.62a

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

Table 4.12. Particulate organic matter associated C (%) content in sub-surface layer of soil at physiological maturity of wheat under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	2.65	1.41	1.43	1.83a	2.63	1.37	2.16	2.05a
IFDC-Band	1.84	1.36	1.19	1.47c	2.35	1.90	1.16	1.80c
Urea-Band	1.75	1.84	1.05	1.55bc	3.05	1.47	1.24	1.92b
Urea-Broadcast	1.85	1.84	1.03	1.57b	2.36	1.78	1.03	1.72c
Urea-foliar spray	1.65	1.52	1.18	1.45c	2.39	1.75	1.09	1.74c
Mean	1.95a	1.59b	1.18c	1.57b	2.56a	1.65b	1.33c	1.85a

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

4.5 Soil nitrogen dynamics under different tillage, residue management, N sources and N application methods

Soil mineral-N in maize

Compared with CT, adoption of CA maintained significantly ($p < 0.05$) higher NH_4^+ -N content in the surface soil layer (0-15 cm), although the values showed a decline trend with the advancement in crop growth (Fig 4.15). Highest NH_4^+ -N content (31.5 mg kg^{-1} under CA and 26.4 mg kg^{-1} under CT) was recorded at V4 stage which come down to 13.8 mg kg^{-1} under CA and 9.8 mg kg^{-1} at physiological maturity in maize. The effect of N scheduling was inconsistent under CA. Under CT, however, higher basal application rate helped maintaining higher NH_4^+ -N content during vegetative stages *i.e.* V4 and V8 stage and thereafter the effect of N scheduling on NH_4^+ -N content was not spectacular. Modified urea materials (*i.e.* USG and IFDC-product) tended to maintained higher NH_4^+ -N content in CA as well as CT, though the same could not attained statically significant at all growth stages. In sub-surface layer, the differences in NH_4^+ -N content between CA and CT was recorded at V4 stage only and thereafter the values were statistically similar under CA and CT (Fig 4.16). Among N management treatments, 33% basal N application and urea broadcasting generally maintained low NH_4^+ -N content at different growth stages.

The NO_3^- -N content of surface soil layer was higher under CA than under CT at V4 and V8 stage, whereas in sub-surface soil the values were constantly greater under CT at all growth stages (Figs. 4.17 and 4.18) of maize. Among N scheduling options, higher basal application rates resulted in relatively higher NO_3^- -N content at different growth stages, although such trend were more apparent under CT in both soil layers. Interestingly modified urea materials (USG and IFDC-product) helped maintaining higher NO_3^- -N content in the surface layer across the growth stages, whereas NO_3^- -N contain under these treatments was comparatively lower in the sub-surface layer.

Soil mineral-N content in wheat

The NH_4^+ -N content of the surface soil under CA was 18.1, 13.9 and 10.5 mg kg^{-1} at CRI, panicle initiation and physiological maturity, respectively. The corresponding values for CT were 14.4, 13.0 and 11.4 mg kg^{-1} (Fig 4.19). The NH_4^+ -N content in sub-surface layer at different growth stages of wheat was 15.3, 12.7 and 8.5 mg kg^{-1} under CA and 13.9, 12.1 and 10.0 mg kg^{-1} under CT, respectively (Fig. 4.20).

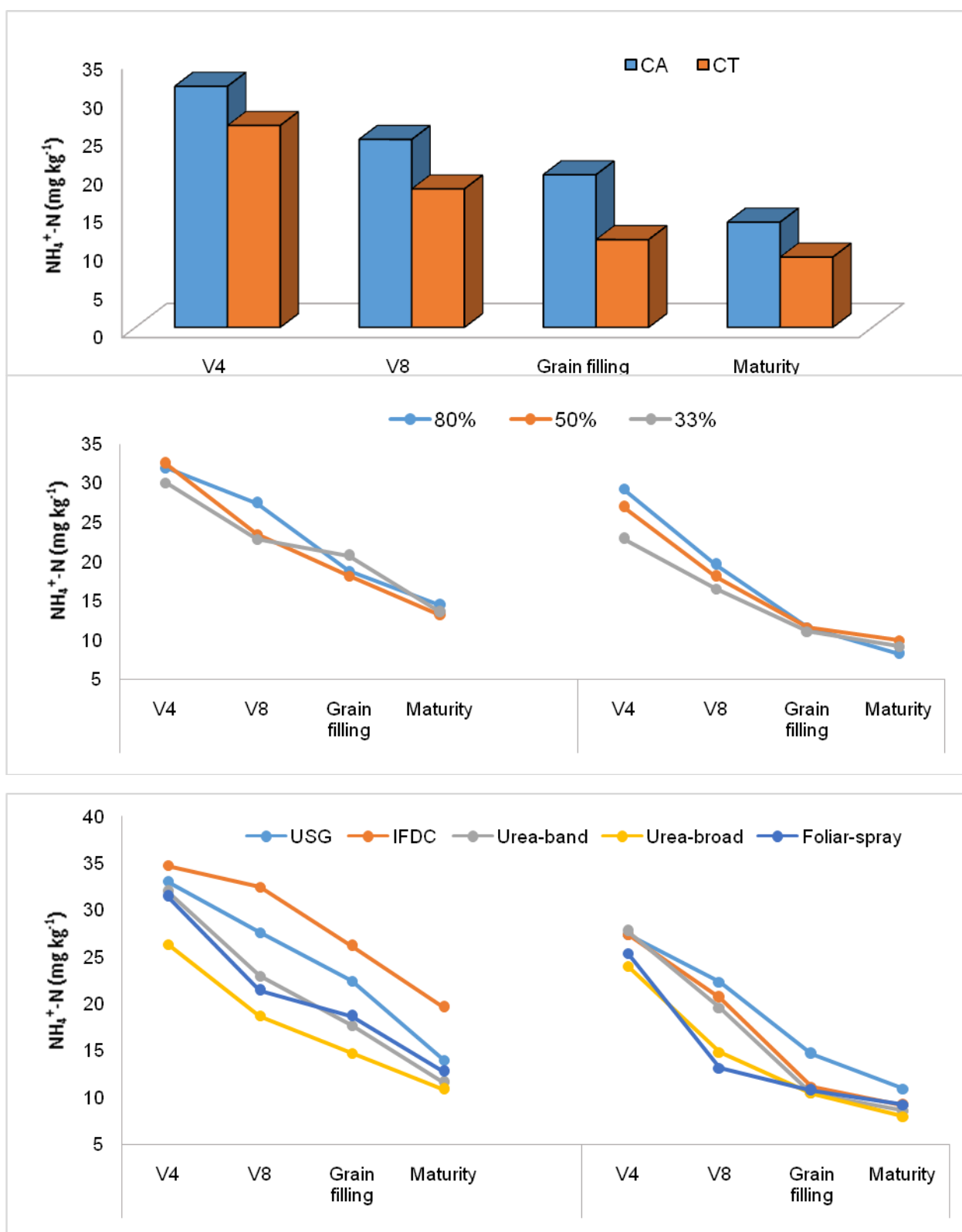


Fig 4.15. NH_4^+ -N content of surface (0-15 cm) soil at different growth stages of maize under different treatment options

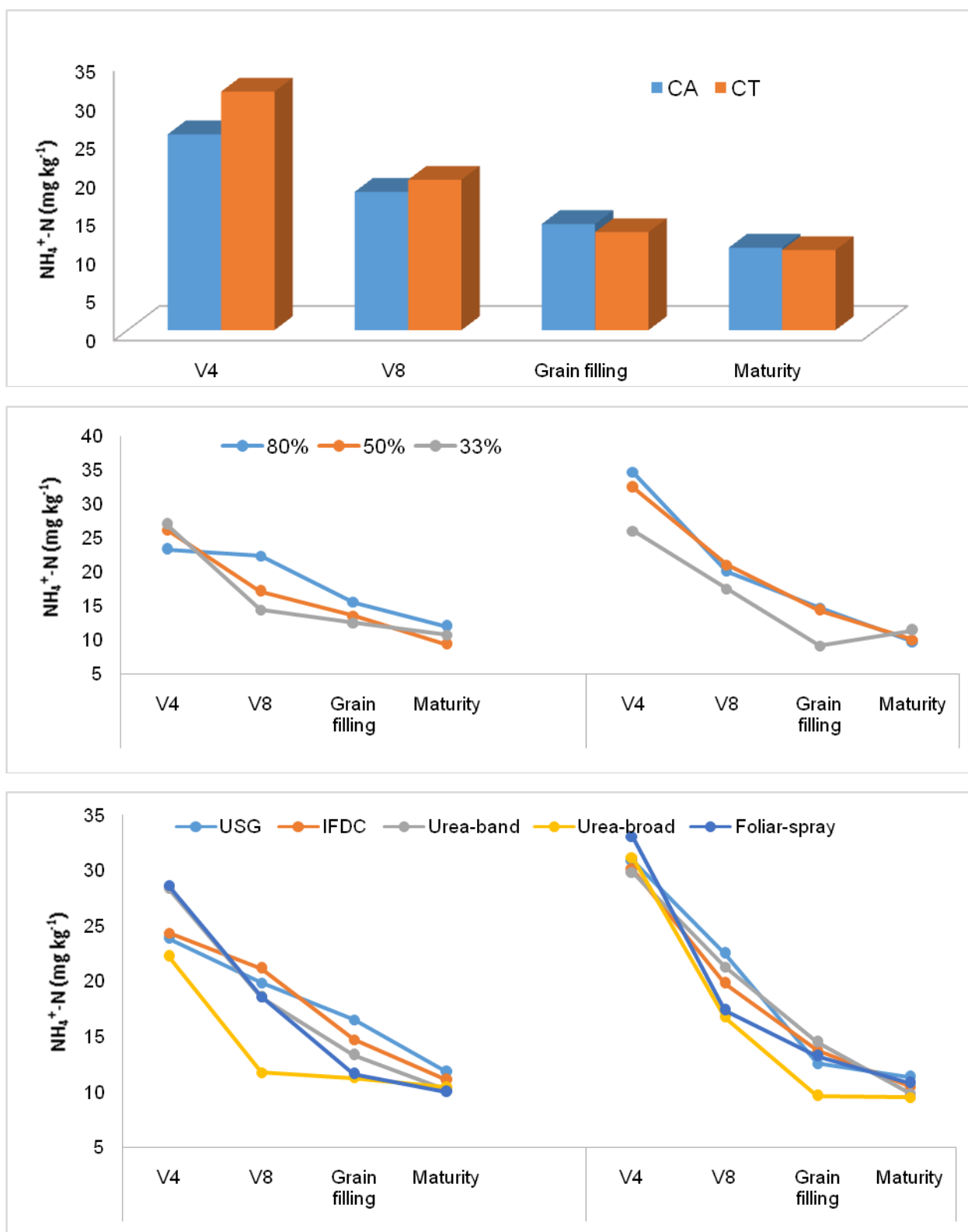


Fig. 4.16. $\text{NH}_4^+\text{-N}$ content of sub-surface (15-30 cm) soil at different growth stages of maize under different treatment options

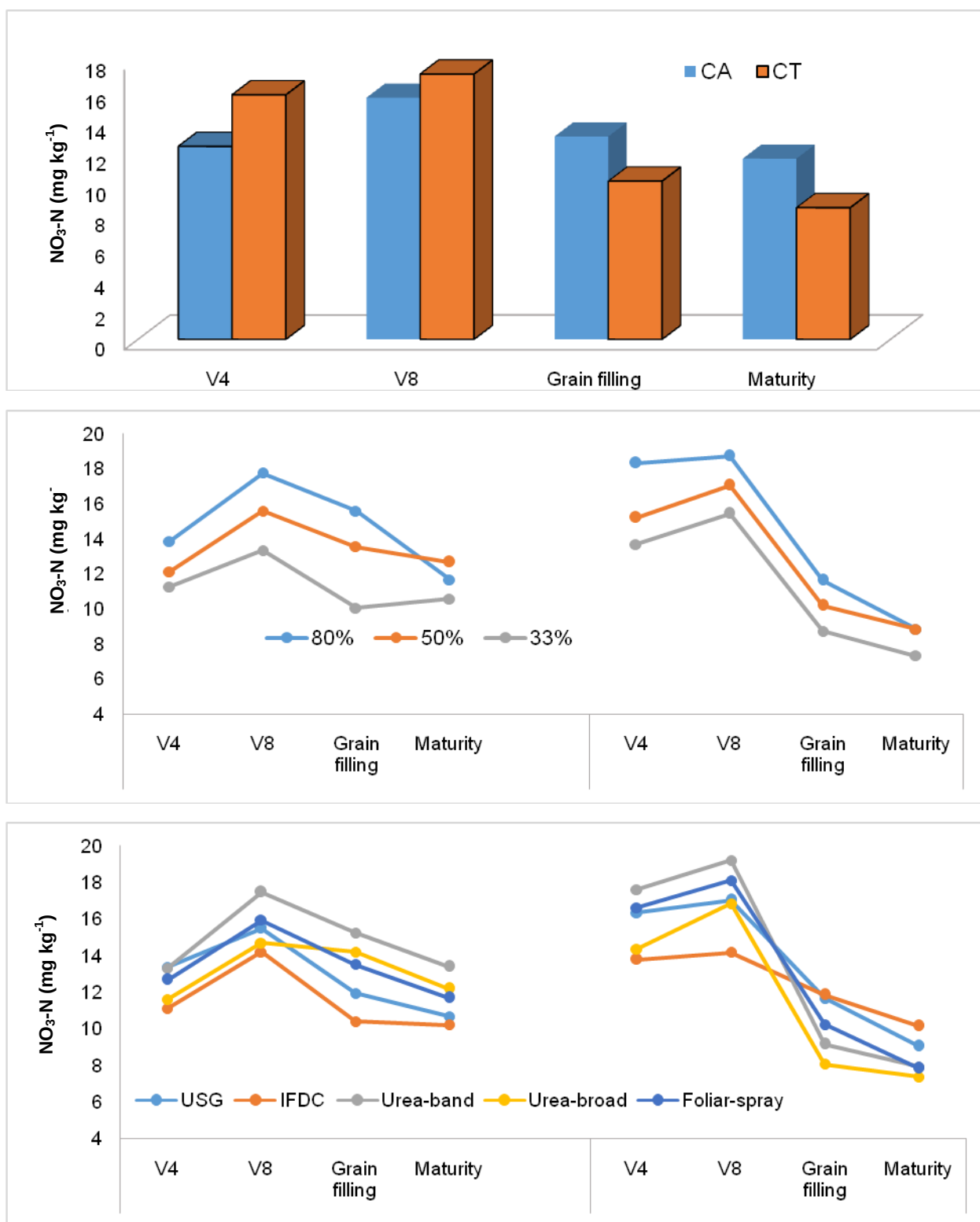


Fig 4.17. NO₃⁻-N content of surface (0-15 cm) soil at different growth stages of maize under different treatment options

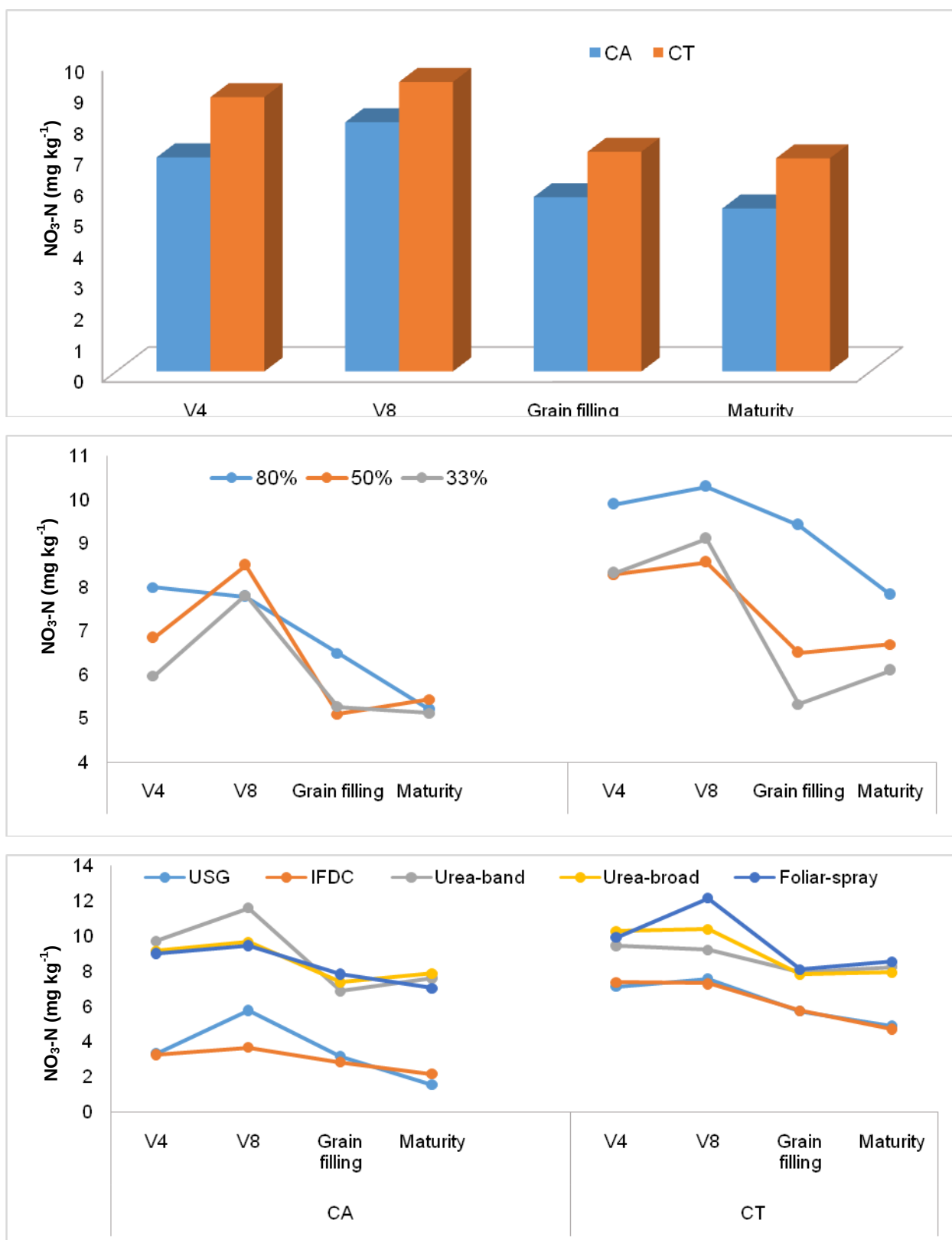


Fig. 4.18. NO₃⁻-N content of sub-surface (15-30 cm) soil at different growth stages of maize under different treatment options

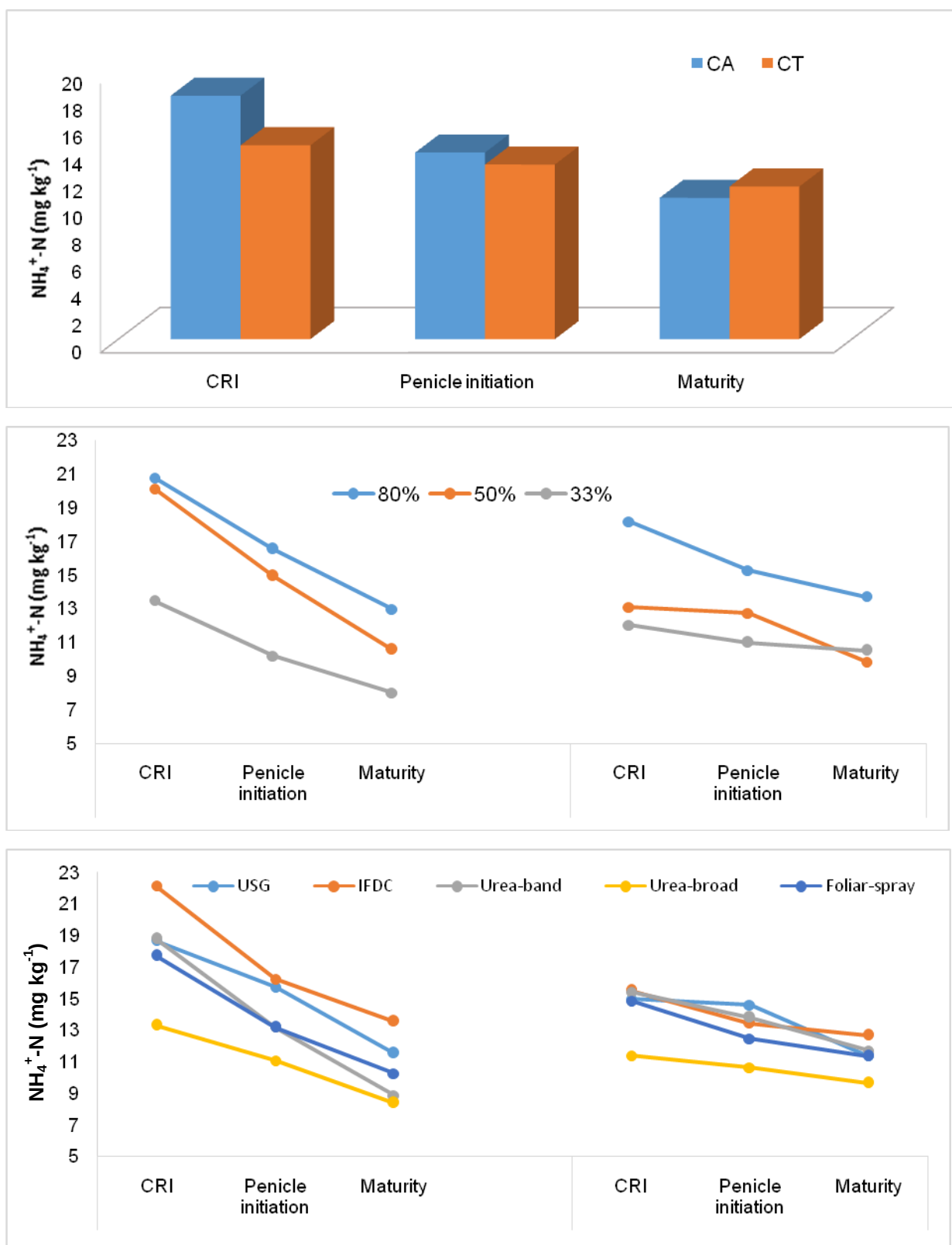


Fig. 4.19. NH_4^+ -N content of surface (0-15 cm) soil at different growth stages of wheat under different treatment options

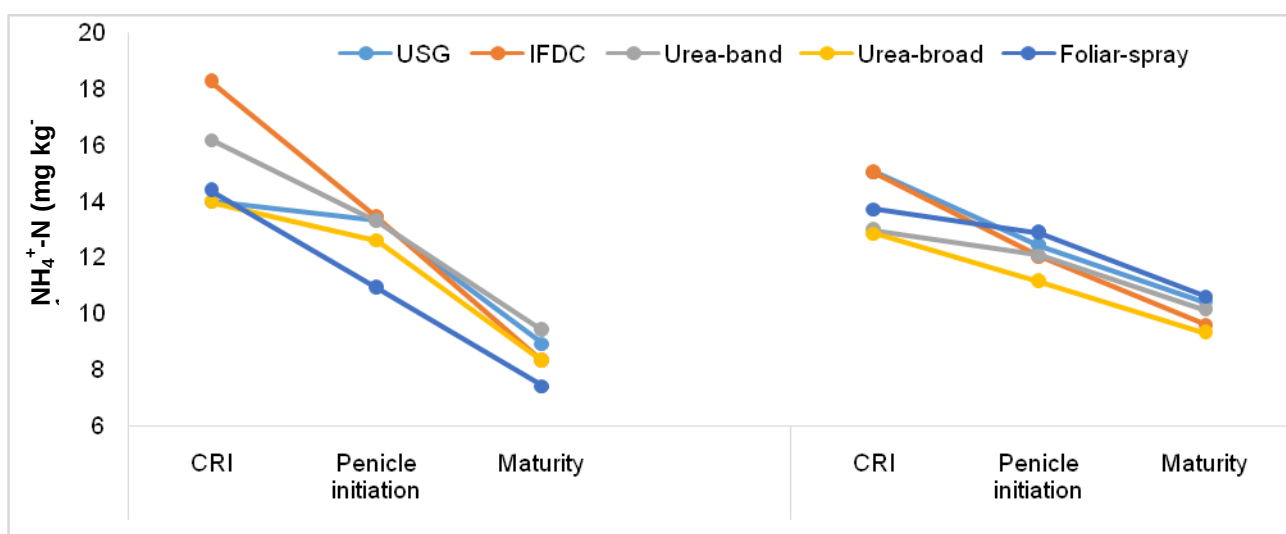
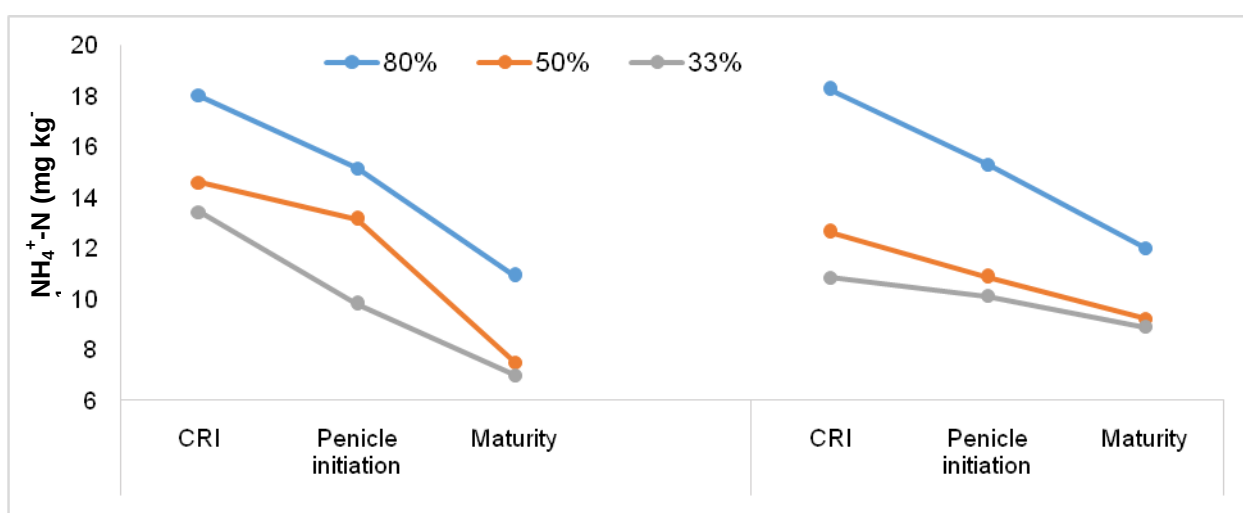
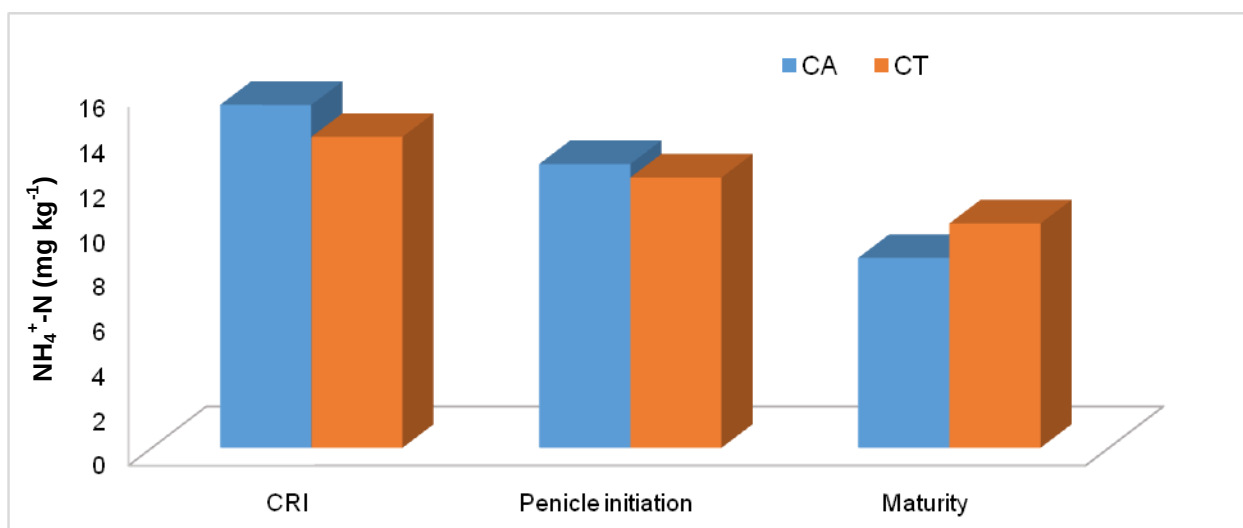


Fig. 4.20. $\text{NH}_4^+\text{-N}$ content of sub-surface (15-30 cm) soil at different growth stages of wheat under different treatment options

Adoption of CA exhibited higher NH_4^+ -N content at CRI stage and panicle initiation only. The NH_4^+ -N content in both soil layers under CA as well as CT was higher in the treatments that received relatively higher basal N application. Among the N sources and methods, urea broadcasting recorded lowest NH_4^+ -N content in the surface layer at all growth stages.

The NO_3^- -N content in surface as well as sub-surface soil layers was greater under CT, though the difference was more spectacular in sub-surface layer (Figs. 4.21 and 4.22). Higher basal dressing rates maintained relatively higher NO_3^- -N content at all growth stages in both soil layers and under both cultivation practices. Sources of N and application methods exhibited inconsistent effect on NO_3^- -N content at different growth stages of wheat.

Microbial biomass N

In maize, microbial biomass N (MBN) content of soil differed significantly between CA and CT: the averaged values of 64.8 mg kg^{-1} under CA and 57.9 mg kg^{-1} under CT in surface layer, and 47.6 mg kg^{-1} under CA and 42.4 mg kg^{-1} under CT in sub-surface layer (Tables 4.13 and 4.14). Soil MBN content was consistently higher in the plots that received higher basal N application and *vice-versa* in both soil layers and cultivation practices. Band placement of USG and IFDC-product resulted in higher MBN content compared with other options, and the trend was similar under both cultivation practices.

Alike maize, soil MBN content in wheat was higher under CA, as the values under CA averaged at 69.2 mg kg^{-1} and 62.0 mg kg^{-1} in surface layer and 51.2 and 47.0 mg kg^{-1} in sub-surface layer (Tables 4.15 and 4.16). An increase in basal N application led to increased MBN content irrespective of cultivation practices. Sources of N and application methods show significant results but could not exhibit consistent effect on MBN content, although USG band placement had an edge over other options.

Particulate organic matter associated N

In maize, particulate organic matter associated N (POM-N) content of surface or sub-surface soil did not differ significantly due to cultivation methods (Tables 4.17 and 4.18). Application of $1/3^{\text{rd}}$ of fertilizer N as basal dressing resulted in lowest POM-N content under CA and CT, although such an effect of N scheduling was more apparent

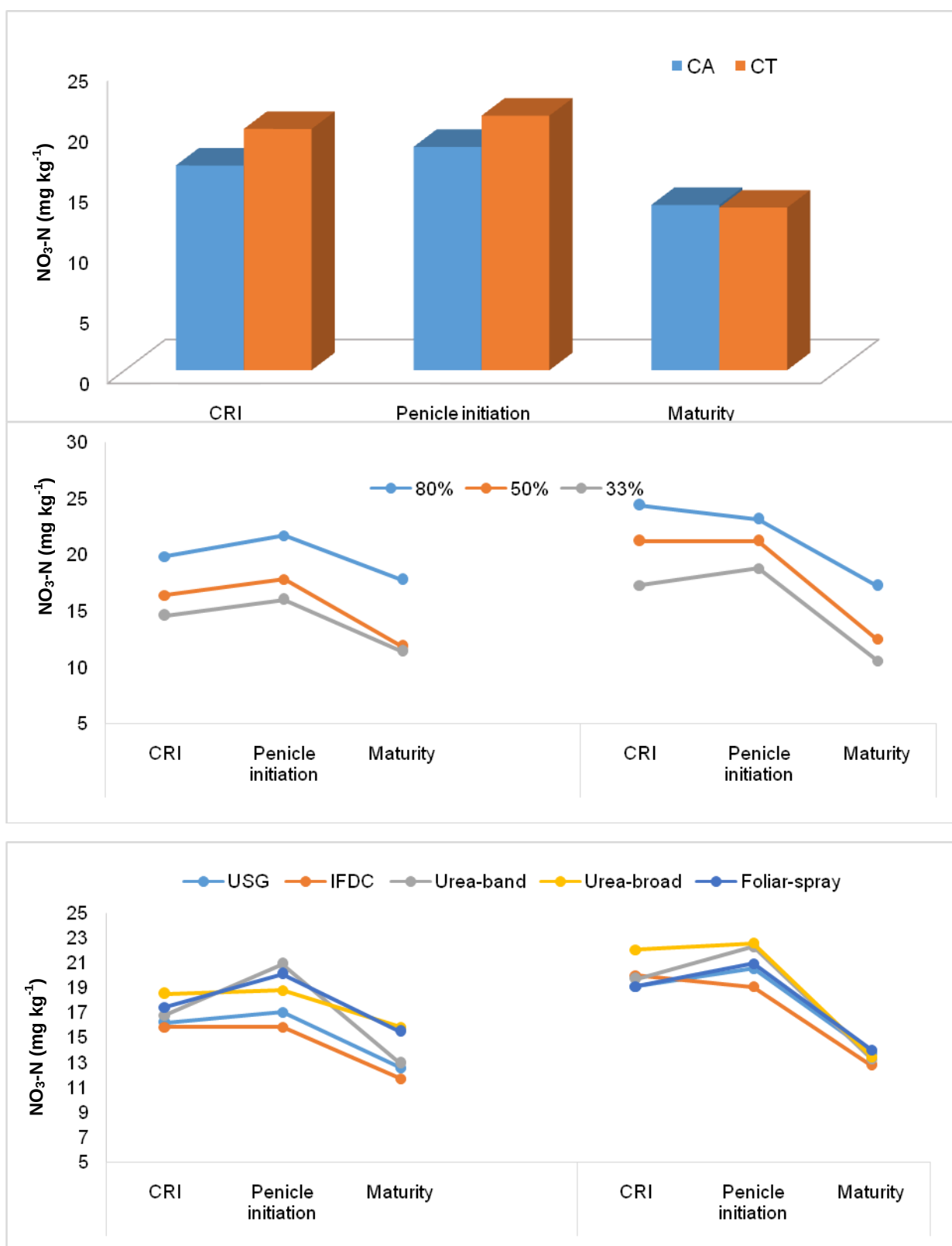


Fig. 4.21. NO_3^- - N content of surface (0-15 cm) soil at different growth stages of wheat under different treatment options

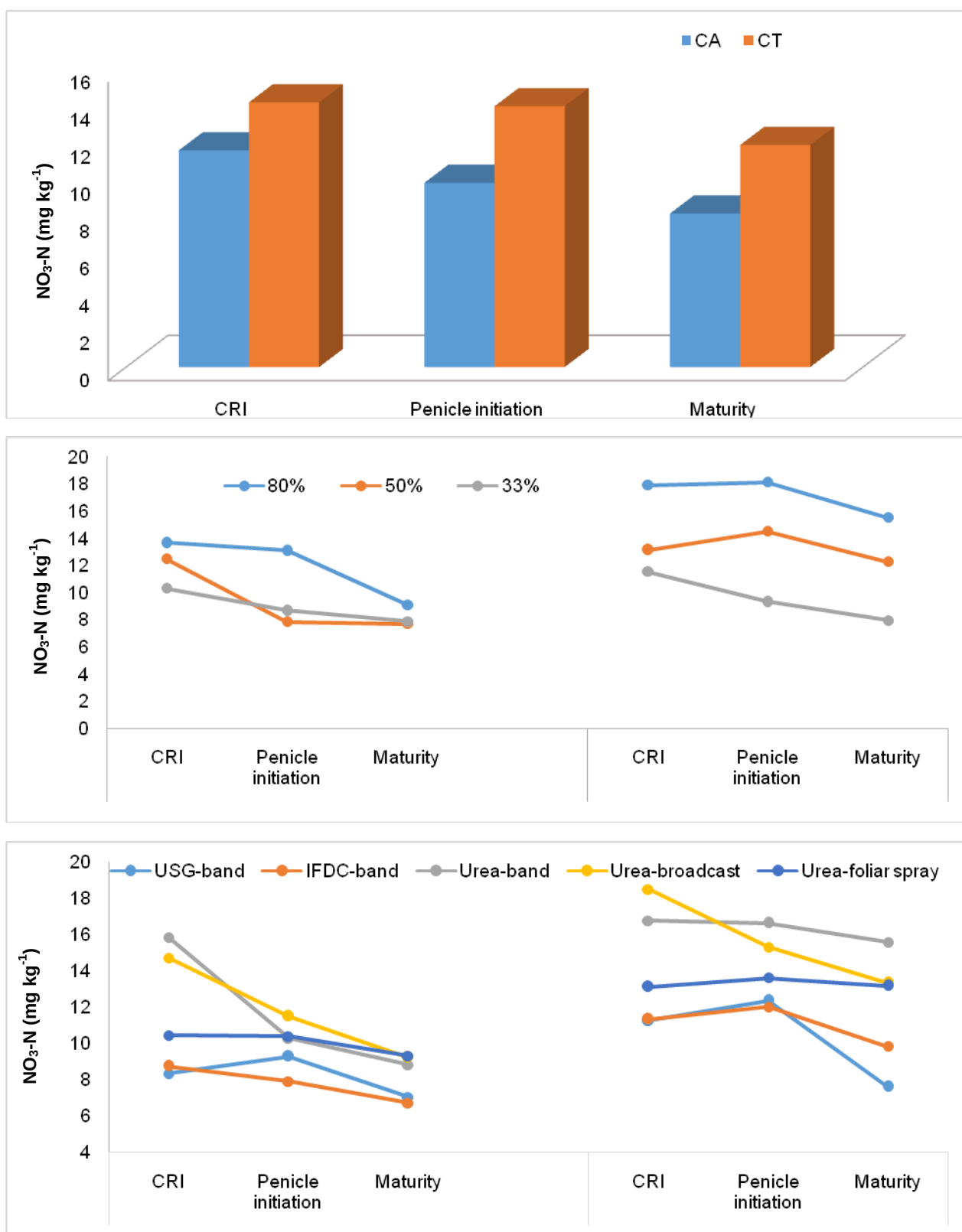


Fig. 4.22. NO₃⁻ N content of sub-surface (15-30 cm) soil at different growth stages of wheat under different treatment options

Table 4.13. Microbial biomass N (mg kg⁻¹) content in surface soil at physiological maturity of maize under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	92.3	62.1	63.2	72.5a	83.4	72.7	45.0	67.0a
IFDC-Band	85.2	59.8	56.0	67.0b	96.5	63.6	51.0	70.3a
Urea-Band	81.1	46.7	54.1	60.6c	60.5	40.0	46.2	48.9b
Urea-Broadcast	82.0	56.3	46.0	61.4c	64.6	39.7	48.2	50.8b
Urea-foliar spray	53.8	86.2	45.5	61.8c	65.0	45.8	46.0	52.3b
Mean	79.7a	63.2b	53.9c	64.8a	74.0a	52.4b	47.3c	57.9b

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

Table 4.14. Microbial biomass N (mg kg⁻¹) content in sub-surface soil at physiological maturity of maize under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	68.5	50.1	41.0	53.2a	61.4	62.5	31.0	51.6a
IFDC-Band	65.2	45.2	51.2	53.9a	68.4	39.0b	34.0	47.1b
Urea-Band	46.1	25.8	50.6	40.8d	40.2	37.8	35.0	37.7d
Urea-Broadcast	55.7	46.2	37.2	46.4b	54.7	34.8	32.0	40.5c
Urea-foliar spray	36.5	56.8	37.2	43.5c	36.6	34.0	34.0	34.9e
Mean	54.4a	44.8b	43.4b	47.6a	52.3a	41.6b	33.2c	42.4b

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

Table 4.15. Microbial biomass N (mg kg⁻¹) content in surface soil at physiological maturity of wheat under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	92.1	65.4	67.4	75.0a	85.3	75.2	51.7	69.7a
IFDC-Band	90.2	65.8	54.7	70.2b	75.2	66.4	53.3	65.0b
Urea-Band	86.4	61.2	57.6	68.4b	64.8	57.9	54.8	59.2c
Urea-Broadcast	88.2	66.2	55.2	69.9b	65.9	55.7	53.8	58.5c
Urea-foliar spray	69.2	67.6	51.2	62.7c	68.2	49.8	55.2	57.7c
Mean	85.2a	65.2b	57.2c	69.2a	71.9a	61.0b	53.2c	62.0b

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

Table 4.16. Microbial biomass N (mg kg⁻¹) content in sub-surface soil at physiological maturity of wheat under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	73.1	50.4	44.0	55.8a	63.7	54.6	39.1	52.5a
IFDC-Band	67.5	46.	42.7	52.3b	70.1	43.7	38.5	50.8a
Urea-Band	55.2	42.1	42.7	46.7c	45.2	42.8	39.7	42.6c
Urea-Broadcast	67.2	47.6	44.8	53.2b	56.2	40.9	40.3	45.8b
Urea-foliar spray	47.9	51.7	44.0	47.9c	50.7	39.7	41.5	44.0b
Mean	62.2a	47.7b	43.6b	51.2a	57.2a	44.3b	39.3c	47.0b

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

Table 4.17. Particulate organic matter associated N (%) content in surface soil at physiological maturity of maize under different treatment options

N sources and	CA	CT
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methods	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	0.30	0.33	0.24	0.29a	0.27	0.31	0.25	0.27a
IFDC-Band	0.28	0.28	0.21	0.26a	0.37	0.25	0.25	0.29a
Urea-Band	0.24	0.31	0.24	0.26a	0.31	0.34	0.28	0.31a
Urea-Broadcast	0.31	0.26	0.28	0.28a	0.27	0.29	0.25	0.27a
Urea-foliar spray	0.31	0.33	0.21	0.28a	0.26	0.26	0.30	0.27a
Mean	0.29a	0.30a	0.24b	0.27a	0.29a	0.29a	0.27b	0.28a

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

Table 4.18. Particulate organic matter associated N (%) content in sub-surface soil at physiological maturity of maize under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	0.28	0.22	0.18	0.23a	0.30	0.21	0.18	0.23a
IFDC-Band	0.22	0.19	0.17	0.19bc	0.24	0.22	0.17	0.21b
Urea-Band	0.22	0.19	0.16	0.19c	0.24	0.21	0.19	0.21b
Urea-Broadcast	0.22	0.20	0.18	0.20b	0.28	0.23	0.17	0.23a
Urea-foliar spray	0.20	0.20	0.19	0.20b	0.26	0.22	0.19	0.22ab
Mean	0.23a	0.20b	0.18c	0.20b	0.26a	0.22b	0.18c	0.22a

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

Table 4.19. Particulate organic matter associated N (%) content in surface soil at physiological maturity of wheat under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	0.33	0.36	0.28	0.32a	0.29	0.24	0.27	0.27c
IFDC-Band	0.33	0.30	0.25	0.29b	0.38	0.28	0.28	0.31a
Urea-Band	0.25	0.35	0.29	0.29b	0.32	0.38	0.29	0.33a
Urea-Broadcast	0.36	0.31	0.31	0.33a	0.29	0.29	0.28	0.29b
Urea-foliar spray	0.34	0.37	0.24	0.32a	0.31	0.29	0.32	0.30b
Mean	0.32b	0.34a	0.27c	0.31a	0.32a	0.30b	0.28c	0.30a

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

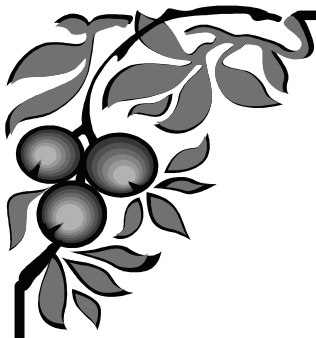
Table 4.20. Particulate organic matter associated N (%) content in sub-surface soil at physiological maturity of wheat under different treatment options

N sources and methods	CA				CT			
	Basal-N			Mean	Basal-N			Mean
	80%	50%	33%		80%	50%	33%	
USG-Band	0.20	0.24	0.22	0.22a	0.31	0.21	0.19	0.24a
IFDC-Band	0.18	0.22	0.16	0.19bc	0.25	0.20	0.18	0.21b
Urea-Band	0.16	0.20	0.17	0.18c	0.22	0.26	0.18	0.22a
Urea-Broadcast	0.22	0.21	0.24	0.22a	0.28	0.22	0.20	0.23a
Urea-foliar spray	0.23	0.23	0.14	0.20b	0.20	0.21	0.23	0.21b
Mean	0.20a	0.22a	0.19b	0.20b	0.25a	0.22b	0.19c	0.22a

Note: Means having similar alphabet(s) are statistically similar and those having dissimilar alphabet(s) differ significantly at 0.05 level of probability.

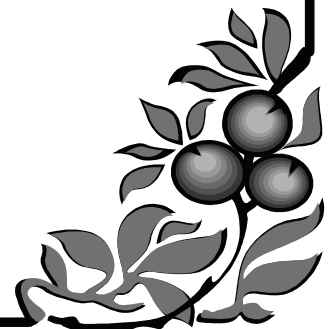
in sub-surface soil. Sources and methods of N did not bring significant change in POM-N in surface soil layer.

The POM-N content of soil at physiological maturity of wheat followed trends similar to those recorded in maize (Tables 4.19 and 4.20). Whereas CA and CT did not differ significantly. Application of 80% or 50% of N as basal dose maintained relatively higher POM-N content in both soil layers compared with 33% basal N application. Differences in POM-N content due to N sources and methods were found significant too except surface layer POM-N content in maize crop but could not exhibit consistent effect, although USG band placement had an edge over other options in CA in sub-surface level of maize and in both layers of wheat.



Chapter 5

Discussion



5. DISCUSSION

Conventional farming practices characterized by excessive tillage, crop residue removal and monoculture are often associated with the degradation of soil mainly in terms of depletion of SOC, sub-soil compaction and loss of biodiversity (Lal *et al.* 2004). Conservation agriculture (CA), on the other hand, is an alternative practice that involves minimum soil disturbance, crop residue retention and crop rotation (Govaerts *et al.* 2007; Giller *et al.* 2009). The CA is postulate to conserve soil organic matter (SOM), energy, irrigation water and biodiversity (Lal *et al.* 2004; Pretty *et al.* 2006). Previous studies on evaluation of CA mostly remain confined to rice-wheat cropping system and that too up to comparison of yield and some soil physico-chemical parameters under CA *vis-à-vis* conventional practices followed by the farmers (Dwivedi2014). Nutrient management protocols under CA even for N, are not available, which restrict efficient N management in CA based cropping systems. Nitrogen application schedules, rates and methods developed and validated for conventional system are, therefore adapted under CA, leaving a great scope for developing CA specific N management protocols.

Results of the present investigation, aimed at evaluating different N management options under CA *vis-a-vis* conventional tillage (CT) practices in maize-wheat cropping system, underline the necessity for modification of N management strategies for enhancing N use efficiency under CA. It is interesting to record that the maize grain yield under CA was similar to CT and wheat grain yield under CA was significantly higher to that CT with relatively less fertilizer N use under CA. In fact, the N top dressing requirement as assessed by using GreenSeeker was relatively less under CA in both the crops, which ultimately led to curtailment in fertilizer N uses. On the whole, curtailment in fertilizer N application was to the extent of 62 kg ha⁻¹ in maize-wheat cropping system (10 kg ha⁻¹ in maize + 52 kg ha⁻¹ in wheat). Such advantages of CA was apparently due to higher N use efficiency and better mineralization of N during the cropping period. Research evidences support enhancement of N use efficiency due to adoption of CA practices in different cropping systems (Dawson *et al.* 2008). Although integration on lowering of fertilizer N requirement under CA is scare, the available reports suggesting higher use

efficiency under CA (Huang *et al.* 2008) imply that fertilizer N application could be reduced under CA. The present investigation, thus supports the intention that fertilizer N use could substantially curtail in CA *vis-à-vis* CT in maize-wheat system without compromising on crop productivity, as the annual, grain productivity (maize+wheat) averaged at 12.5 t ha⁻¹ under CA and this 12.2 t ha⁻¹ under CT. Among N scheduling treatments 50% basal N application proved superior to other scheduling options with respect to grain yield of both maize and wheat. On the other hand, straw/stover yields were significantly higher with 80% basal N application. These results are explainable as there is likelihood of excessive N supply to the crop during vegetative early growth stages under 80% basal N application which resulted in higher vegetative growth with concomitant reduction in grain yield under this treatment. Earlier studies frequently indicated the superiority of split N application compared with larger basal dressing (McEwen 1970; Ohnishi *et al.* 1999). The hypothesis of excessive N supply under 80% basal N application is substantiated by constantly higher mineral N content under this treatment at different growth stages. Mineral N content of only two soil layers (0-15 and 15-30 cm) was measured. In the present study any leaching of unutilized nitrates beyond root zone could not be ascertained, nonetheless such possibility cannot be ruled out under 80% basal N treatment, as nitrate leaching beyond root zone consent upon unbalanced fertilizer use has been documented elsewhere (Dinnes *et al.* 2002; MacDonald *et al.* 2002).

Among N sources and methods of application, band placement of slow release modified urea material (*i.e.* USG and IFDC product) resulted in higher yield and NUE compared with urea broadcasting. These results corroborated earlier findings suggesting the superiority of slow release N fertilizers over prilled urea (Lunt 1971; Prasad *et al.* 1971; Christianson 1988; Ni *et al.* 2009) and also that of band placement over broadcasting (Cao *et al.* 1984; Schnier *et al.* 1988; Schnier *et al.* 1993).

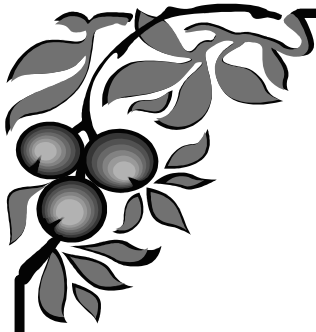
Low N use efficiencies in the cropping systems have remained a great concern (Cassman *et al.* 2002), as these not only increase the cost of production but also pollute surface and ground water resources and environment (Zhu and Chen 2002). Diagnostic surveys in Indo-Gangetic plains revealed that some farmers of high productivity areas have started using higher fertilizer N than the recommended rate in order to attain the yield levels those were obtained earlier with relatively less fertilizers (Dwivedi *et al.* 2003). Such undesirable changes in fertilizer use pattern are

indicator of decline in N use efficiency. Whereas generally reported NUE (recovery efficiency) values hardly exceeds 50%, use of USG or IFDC product in the present investigation recorded RE_N values as high as 61.7%. Since in the present study, apparent N recovery was assessed, the results need further verification using radiotracer techniques (^{15}N). Which underline the worth of these materials in enhancing NUE under CA practices.

Soils of IGP are inherently low in SOC content and N supply (Yadav *et al.* 2000). Augmentation of these parameters through judicious soil and nutrient management is a prerequisite for sustaining high productivity levels on these soils (Chikowo *et al.* 2004). In the present investigation, different C fractions viz. WBC, MBC and POM-C were higher under CA compared with CT. Which further establish the significance of CA in restoration of soil health. Improvement in SOC as a result of no-till farming has been frequently documented in India (Das *et al.* 2013) and elsewhere (Lal and Kimble 1997). As all CA treatments in the present study included crop residue retention the role of crop residue in modifying the SOC levels could not be ascertain. However, studies undertaken elsewhere suggested that the necessity of crop residue retention to achieve full advantages of CA (Chivenge *et al.* 2007; Hobbs *et al.* 2008). There is need to include residual removal treatment in such experiments to quantify the effect of crop residues. Some reports indicate an increase in soil bulk density under no-till farming, which could be offset easily with residue retention. The residue retention on soil surface under CA not only the supplement plant nutrients but proved advantageous in several ways such as mulching effect, smothering weed infestation, addition of SOC *etc.* (Barnes and Putnam 1983; Reddy 2001). A decrease in the rhizospheric WBC content with advancement in crop growth stages in maize and wheat recorded in the present case could be ascribed to change in microbial activity in the rhizosphere which obviously decline as the crop advanced towards maturity (Mahmood *et al.* 1997; Clapp *et al.* 2000).

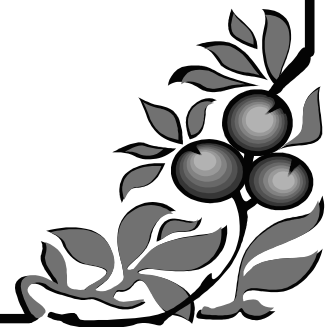
Although present study underline superiority of CA with respect to fertilizer N economy NUE, mineral-N and SOC content, yet a few missing links were also noted. Measurement of mineral-N in the soil profile (root zone and beyond root zone) and that of MBC and MBN at different crop growth stages in subsequent studies would help a lot in explaining some of the results. The findings of the present study will

serve as valuable information at the very inception of the on-going experiment. Yet more stable and explainable results would come with the passage of time.



Chapter 6

Summary and Conclusion



6. SUMMARY AND CONCLUSIONS

In India, cereals including rice, wheat and maize account for more than half of the total fertilizer N consumption. However, recovery of applied fertilizer N is only 30–50% by the first crop. In conventional farming (CT) practices, crop residue removal and burning are often associated with the degradation of soil mainly in terms of depletion of soil organic C (SOC), sub-soil compaction and loss of biodiversity. Such practices have been considered as detrimental to soil and environmental health. Traditionally, the intensive tillage contributes to an increased cost of cultivation leading to decreased profitability. On the other hand under CA, no-till and residue retention based N management practices proved to produce more at less costs, reduce environmental pollution, promote conjunctive use of organics (avoid residue burning), improve soil health, and promote timely planting of crops to address the issues of terminal heat stresses in the region. Considering these facts, the present investigation entitled **“Nitrogen dynamics under maize-wheat cropping system as influenced by nitrogen, tillage and residue management options”** has been undertaken (i) to study the changes in oxidizable carbon and mineralizable nitrogen in soil at different growth stages of maize and wheat under different nitrogen, tillage and residue management practices, and (ii) to study nitrogen dynamics, its use efficiency and productivity of maize-wheat cropping system under different nitrogen, tillage and residue management options. The salient findings of the present investigation are summarised as follows:

Rhizospheric organic C content under conservation agriculture (CA *i.e.*, no-tillage and crop residue retention) was higher than conventional practice in both maize and wheat irrespective of treatments and crop growth stages. While soil MBC, POM and POM-C contents were generally higher under CA as compared to that under CT. Also, these SOC fractions were invariably greater in surface (0-15 cm) soil compared with sub-surface (15-30 cm) soil layer across the treatments.

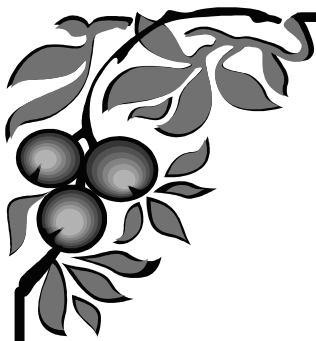
Conservation agriculture helped retaining higher contents of $\text{NH}_4\text{-N}$ in upper soil layer during both maize and wheat crops. $\text{NH}_4\text{-N}$ content of soil decreased with the progress of crop growth stages, and was lowest at maturity in both the crops. In case of nitrate-N ($\text{NO}_3\text{-N}$), CT showed higher values as compared to CA in 0-15 and 15-30 cm soil layers. Among N sources, USG and IFDC-product maintained higher $\text{NO}_3\text{-N}$ content in the surface layer, indicating reduced downward movement of $\text{NO}_3\text{-N}$ in

soil. Mineral-N ($\text{NH}_4\text{-N} + \text{NO}_3\text{-N}$) content of soil was highest in the treatments receiving 80% of N as basal dressing. A decrease in basal N application decreased mineral-N content in soil under both crops. Different forms of N viz. mineral N, MBN, and POM-N were higher under CA and in the upper soil layer in case of both crops.

Grain yield of maize and wheat was higher under CA, which was not significantly affected by sources and methods of N application. Among nitrogen use efficiency (NUE) indices, recovery efficiency and partial factor productivity were higher under CA, whereas agronomic efficiency did not exhibit such advantage of CA. Treatment options viz., 50% N as basal and remaining N on sensor-based application, and use of USG or IFDC-product resulted in higher NUE.

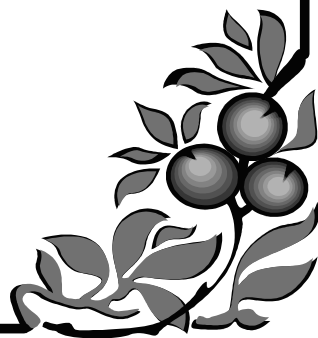
Based on the findings of the present investigation, the following conclusions can be drawn:

- Study revealed the possibility enhancing NUE with the adoption of CA.
- It was possible to curtail fertilizer N, especially in wheat, with the adoption of CA without any adverse effect on yield.
- Application of 50% N as basal and sensor-based topdressing of N was effective in reducing the applied rate of N. Further, sources like USG and IFDC-product also helped significantly in curtailing fertilizer N.



Chapter 7

Abstracts *(English and Hindi)*



Nitrogen dynamics under maize-wheat cropping system as influenced by nitrogen, tillage and residue management options

Abstract

Conservation agriculture (CA), an alternative practice that involves minimum soil disturbance, crop residue retention and crop rotation, is postulated to conserve soil organic matter (SOM), energy, irrigation water and biodiversity. On the other hand, conventional tillage practices (CT) characterized by excessive tillage, crop residue removal and monoculture are often associated with the degradation of soil mainly in terms of depletion of SOC, sub-soil compaction and loss of biodiversity. As fertilizer nitrogen (N) is the one of key input in food production, it is typically required in larger quantities than any other nutrients by the crop for its growth and development. Therefore, proper management of N is essential to reap high yield and ultimately the profit. In view of scarcity of information on N management protocols under CA, a field experiment was initiated in kharif 2013 at IARI farm, to evaluate different N management options i.e. basal application of 80, 50 and 33% of total fertilizer requirement followed by need-based top dressing as suggested by GreenSeeker, and N sources and methods of application on crop yield, N uptake, N use efficiencies (NUE), and temporal changes in soil organic C and mineral-N in maize (*Zea mays* L.)-wheat (*Triticum aestivum* L.) cropping system under CA and CT practices. In both maize and wheat, CA comprised of no tillage with 40% of maize and wheat residue retention on the soil surface, CT comprised of conventional tillage with crop residue removal. Results revealed that maize grain yield was statistically similar under both cultivation practices i.e. CA (7.47 t ha⁻¹) and CT (7.48 t ha⁻¹), whereas grain yield of wheat was significantly higher under CA (5.0 t ha⁻¹) than that under CT (4.71 t ha⁻¹). The N top dressing requirement as assessed by using GreenSeeker was relatively less under CA in both the crops, which ultimately curtailed fertilizer N application in this cultivation practice. Averaged across N management options, it was possible to curtail 62 kg fertilizer N ha⁻¹ in maize-wheat cropping system under CA without any detrimental effect on the annual productivity. Such advantages of CA were apparently due to higher N use efficiency and better mineralization of N during the cropping period. The N use efficiencies in maize crop i.e. AE_N, PFP_N and RE_N were averaged at 30.7 kg grain kg⁻¹ N, 76.2 kg grain kg⁻¹ N and 56.1%, respectively under CA,

compared with 32.5 kg grain kg⁻¹ N, 38.4 kg grain kg⁻¹ N and 46.8%, respectively under CT and in wheat crop efficiencies were averaged at 23.1 kg grain kg⁻¹ N, 26.1 kg grain kg⁻¹ N and 52.5%, respectively under CA, compared with 15.1 kg grain kg⁻¹ N, 73.3 kg grain kg⁻¹ N and 37.5%, respectively under CT. Among N sources and methods of application band placement of slow release modified urea materials (i.e. USG and IFDC-product) resulted in higher yields and NUE compared with urea broadcasting. In CA, Walkley-Black C (WBC) and mineral-N (NH₄⁺-N + NO₃⁻-N) contents were significantly higher compared with CT in the surface layer (0–15 cm depth). Similarly different fractions of SOC (MBC and POM-C) and N (MBN and POM-N) were significantly (p<0.05) lower under CT. Results thus indicated superiority of CA over CT particularly with respect to increase in SOC and mineral-N content and enhancement in the NUE. The benefits associated with CA present a greater potential for its adoption to sustain soil health and crop productivity of maize–wheat cropping system.

नत्रजन, भूपरिष्करण व फसल अवशेष प्रबंधन का मक्का-गेंहू फसल चक्र में नत्रजन गतिकी पर प्रभाव

सारांश

संरक्षित कृषि (सी.ए.), एक वैकल्पिक क्रिया है जो न्यूनतम मृदा हलचल, फसल अवशेष रखाव व फसल चक्र पर आधारित है जिसकी अवधारणा मृदा कार्बनिक पदार्थ (एस.ओ.एम.), ऊर्जा, सिंचाई जल व जैव विविधता को संरक्षित करना है। इसके विपरीत, पारम्परिक जुताई क्रियाएँ (सी.टी.) जो की आधिकारिक भूपरीक्षण, फसल अवशेष निकालने व एकाकी फसल चक्र पर आधारित हैं जिनके कारण मृदा में कार्बनिक पदार्थ की कमी, निचली मृदा में कठोरपन व जैव विविधता का हास हो रहा है। चूँकि उर्वरक नत्रजन (N) खाद्यान्न उत्पादन में मुख्य आगत है इसलिए यह फसल की वृद्धि व विकास हेतु अन्य पोषक तत्वों की तुलना में ज्यादा मात्रा में चाहिए। अतः, ज्यादा उत्पादन व लाभ के लिए उचित नत्रजन प्रबंध अतिआवश्यक है। संरक्षित खेती में नत्रजन प्रबंधन के दिशानिर्देशों की कमी को ध्यान में रखते हुए भारतीय कृषि अनुसंधान संस्थान के प्रक्षेत्र पर खरीफ २०१३ मौसम के दौरान विभिन्न नत्रजन प्रबंध के विकल्पों जैसे ८०, ५०, व ३३ % नत्रजन को आधार खुराक के रूप में व उसके बाद ग्रीनसीकर द्वारा संस्तुत मांग आधारित नत्रजन व नत्रजन के श्रोत तथा उनके लगाने के तरीकों का मक्का-गेंहू फसल चक्र में संरक्षित व पारम्परिक जुताई क्रियाओं में फसल उपज, नत्रजन ग्रहण, नत्रजन उपयोग दक्षताओं तथा समय के साथ मृदा कार्बन व लवणीय-नत्रजन पर प्रभाव का अध्ययन किया गया। मक्का व गेंहू में संरक्षित कृषि के अंतरगत शुन्य-जुताई व दोनों फसलों के ४०% प्रतिशत फसल अवशेषों का मृदा सतह पर रखाव जबकि पारम्परिक जुताई के अंतरगत जुताई के साथ-साथ फसल अवशेषों को भी खेत से बाहर निकाला गया। परिणामों के आधार पर यह पाया गया की उपज दोनों उगाने की क्रियाओं में सांख्यिकीय दृष्टि से समान जो कि सी.ए. (७.४७ स/है.) तथा सी.टी. (७.४८ स/है.) थी जबकि गेंहू की उपज सी.ए. (५.० स/है.) से सार्थक रूप से सी.टी. (४.७१ टन/है.) की तुलना में ज्यादा थी। ग्रीनसीकर के अध्ययन से सुझाई गयी नत्रजन टॉप ड्रेसिंग की मात्रा दोनों फसलों में सी.ए. के अंतरगत कम थी जो की उर्वरक नत्रजन की मात्रा इस क्रिया में कम करने हेतु सार्थक हुई। मक्का-गेंहू फसल चक्र में विभिन्न नत्रजन प्रबंधन विकल्पों में औसतन ६२ कि.ग्रा./ उर्वरक N की कमी संभव हुई व इसके द्वारा वार्षिक उत्पादकता पर भी कोई विपरीत/प्रतिकूल प्रभाव नहीं पड़ा। उच्च नत्रजन उपयोग दक्षता तथा फसल अवधि में ज्यादा नाइट्रोजन खनिजीकरण के कारण सी.ए. के अंतरगत ये लाभ देखे गये। नत्रजन उपयोग दक्षताएँ जैसे शष्य दक्षता, अंशकारिक उत्पादकता व पुनःग्रहण दक्षता मक्का में क्रमशः सी.ए. में औसतन 30.7 कि.ग्रा. दाना बढ़ाव/ कि.ग्रा. N, 76.2 कि.ग्रा. दाना बढ़ाव/ कि.ग्रा. N व 56.1 प्रतिशत थी जबकि सी.टी. में ये दक्षताये क्रमशः 32.5 कि.ग्रा. दाना बढ़ाव/ कि.ग्रा. N, 38.4 कि.ग्रा. दाना बढ़ाव/ कि.ग्रा. N व 46.8 प्रतिशत थी। तथा गेंहू में सी.ए. में औसतन 23.1 कि.ग्रा. दाना बढ़ाव/ कि.ग्रा. N, 26.1 कि.ग्रा. दाना बढ़ाव/ कि.ग्रा. N व 52.5 प्रतिशत थी जबकि सी.टी. में ये दक्षताये क्रमशः 15.1 कि.ग्रा. दाना बढ़ाव/ कि.ग्रा. N, 73.3 कि.ग्रा. दाना बढ़ाव/ कि.ग्रा. N व 37.5 प्रतिशत थी विभिन्न श्रोत व उपयोग की विधियों में यूरिया छिड़काव की बजाय रूपांतरित यूरिया उत्पादों (जैसे युएसजी व

आईएफडीसी- उत्पाद) को पट्टियों में डालने से अधिक उपज प्राप्त हुई | सी.ए. के अन्तरगत वाक्ले-ब्लेक कार्बन तथा लवणीय-N (अमोनिकल व नाइट्रेट- नाइट्रोजन) की मात्रा ऊपरी परत (०-१५ से.मी. गहराई) में सी.टी. की बजाय ज्यादा थी | इसी प्रकार से SOC के विभिन्न खंड (MBC व POM -C) व नाइट्रोजन के प्रारूप (MBN व POM - N) भी सी.टी. में कम पाये गये (पी - ०.०५). इस प्रकार निष्कर्ष यह बताते हैं कि सरंक्षित कृषि परम्परागत जुताई की तुलना में मृदा में कार्बनिक कार्बन व लवणीय नाइट्रोजन तथा नत्रजन उपयोग दक्षताओं को बढ़ाने में बेहतर हैं | सरंक्षित कृषि से होने वाले लाभ यह दर्शाते हैं कि इसको अपनाने से मक्का-गेंहूँ फसल चक्र में टिकाऊ मृदा स्वास्थ्य व फसल उत्पादकता को बनाया जा सकता है।

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