Effect of conservation tillage and precision nitrogen management on wheat: A review

ABSTRACT

Wheat is the world's most important protein source and provides on average about 21 % of the daily dietary protein intake **(Shiferaw *et al.,* 2013)**. Sustainability and profitability of the wheat crop system in Indian agriculture is the lifeline and future of the Indian economy with more than 60% of people living in rural areas.Intensive ploughing results in a decrease in soil organic matter by accelerating the oxidation and breakdown of organic matter which leads to the degradation of soil properties. Conservation Agriculture (CA), comprising minimum soil disturbances, and retention of the rational amount of crop residues is widely promoted for resource conservation, reducing soil degradation, adapting cropping systems to climatic extremes, and improving long-term agricultural sustainability. The immobilization of N is one of the major constraints of CA which is mainly associated with permanent residue cover on the soil surface **(Kong *et al.,* 2009).** The use of some tools in season for precision N management like SPAD meter, NDVI sensor, site-specific nutrient management through soil test crop response, nutrient expert LCC, etc., helps in fulfilling the crop nutrient requirement with less environmental footprints **(Kumar *et al.,* 2014)**. This paper attempts to review the research experiments in which precision nitrogen management tools were used in conservation agriculture and discuss the impacts of these precision nitrogen management tools and techniques on growth, productivity and nutrient use efficiency (NUE) in wheat.

Keywords- Conservation tillage, precision nitrogen management, nutrient use efficiency, SPAD meter, LCC

1. Introduction

Wheat (*Triticum aestivum* L.) also known as the king of cereals, is the important and strategic cereal crop for the majority of habitants on the earth and is the most important staple food of about 36% of the world population. In developing countries, wheat provides about 18 % of daily caloric needs. Wheat is also the world's most important protein source and provides on average about 21 % of the daily dietary protein intake **(Shiferaw *et al.*, 2013)**. Sustainability and profitability of the wheat crop system in Indian agriculture is the lifeline and future of the Indian economy with more than 60% of people living in rural areas.

The crop contributes towards the livelihood of a large number of people in India. It is sown mainly through intensive tillage agricultural practices. There are various constraints under traditional/ conventional agricultural practices like soil degradation & compaction, depletion of water resources and loss of biodiversity, etc. In the western Indo-Gangetic Plains (IGP), water is increasingly becoming scarce because agriculture is facing rising competition from the urban and industrial sectors **(Toung and Bhuiyan, 1994)**. In many parts of the region, over-exploitation and poor groundwater management have led to a decreased water table and negative environmental impacts **(Saharawat *et al.*, 2010)**. Deterioration of land quality due to different forms of soil degradation and excess residue burning are other pervasive problems in the region **(Das *et al.*, 2013)**. These factors lead to the consideration of conservation agriculture (CA) for sustained productivity, profitability, and soil quality **(Kassam *et al.*, 2011)**. CA has three principles: (i) minimizing mechanical soil disturbance; (ii) cover crops and/ or crop residues (mainly residue retention); (iii) diversification of crops in associations, sequences, and rotations to enhance system resilience. CA is reported to enhance soil organic carbon (SOC) content, and input use efficiency and has the potential to reduce greenhouse gas emissions **(Bhattacharyya *et al.*, 2013)**.

In 2021, the last year for which we have official production statistics, the world produced an estimated 776.5 Mt of pulses with China, India, and Russia accounting for 38% of global production.The production and productivity of the Wheat crop were quite low when India became independent in 1947. The production of Wheat was only 6.46 million tonnes and productivity was merely 663 kg per hectare during 1950-51, which was not sufficient to feed the Indian population. The Country used to import Wheat in large quantities for fulfilling the needs of our people from many countries like the USA under PL-480. The reasons for the low production and productivity of Wheat at that time were (a) the tall-growing plant habit resulting in lodging when grown under fertile soils, (b) the poor tillering and low sink capacity of the varieties used, (c) higher susceptibility to diseases, (d) the higher sensitivity to thermo & photo variations, etc., resulting in poor adaptability, and (e) longer crop duration resulting in a long exposure of plants to the climatic variations and insect pest/disease attacks.The Government of India appointed a commission in 1961 to assess the feasibility of increasing crop productivity under prevailing Indian ecological conditions. As a result of various steps taken by Govt. of India, the Wheat scenario in our country has completely changed. In the post-Independence era, the country used to import Wheat for our needs but due to a bumper increase in the production and productivity of Wheat in the 'Green Revolution' period in the late sixties, our country became self-dependent on Wheat production. At present, the country is producing excess Wheat than the requirement and Godowns are over-flooded with Wheat.

Today National wheat production is 109.52 Mt with an acreage of 31.6 Mha and productivity of 3.46 t ha-1. The top 3 producing states are U.P.>M.P.>Punjab. U.P. is a top producing state in India with 35.5 Mt of production and contributing 32% of total national production.

2. Conservation Agriculture

Conservation agriculture (CA) mainly comprises three crop management principles, viz. minimum or no-tillage (minimum soil disturbance), surface residue retention, and crop rotation. The effect of CA on crop yield components and its application in various farming perspectives is under debate across the world. The existing crop production systems involving repeated tillage and straw removal practices result in surface crusting and soil compaction, which reduce water infiltration and enhance soil erosion, ultimately causing an overall deterioration in soil physical health. However, it is inevitable to maintain soil physical health at its optimum level for sustainable crop production, efficient use of natural resources, and improved response to added inputs.

Conservation agriculture was originally designed as a response to the US Dust Bowl **(Baveye *et al.*, 2011)**. Since then, the adoption of CA has been rapid, particularly in North America, South America, and Australia **(Derpsch, 2001)**. It is primarily practiced on large-scale, mechanized farms, and requires large applications of herbicides to control weeds that are normally controlled by tillage. There are now concerted efforts that are promoting CA in smallholder systems in South Asia **(Hobbs *et al.*, 2008)** and Sub-Saharan Africa **(Valbuena *et al.*, 2012)**. Whether CA, which was designed in high-input systems in more temperate regions, can work and deliver ES in smallholder systems of the tropics and subtropics is unclear and warrants further consideration based on the evidence to date.

3. Constraints for the adoption of conservation agriculture

A mental change of farmers, technicians, extensionists, and researchers away from soil degrading tillage operations towards sustainable production systems like no-tillage is necessary to obtain changes in the attitudes of farmers **(Derpsch, 2001)**. **Hobbs and Govaerts (2010)** however, noted that probably the most important factor in the adoption of CA is overcoming the bias or mindset about tillage. It is argued that convincing the farmers that successful cultivation is possible even with reduced-tillage or without tillage is a major hurdle in promoting CA on a large scale. In many cases, it may be difficult to convince the farmers of the potential benefits of CA beyond its potential to reduce production costs, mainly by tillage reductions. CA is now, considered a route to sustainable agriculture. The spread of conservation agriculture, therefore, will call for scientific research linked with development efforts.

The following are a few important constraints that impede the broad-scale adoption of CA.

- Lack of appropriate seeders especially for small and medium-scale farmers: Although significant efforts have been made in developing and promoting machinery for seeding wheat in no till systems, successful adoption will call for accelerated effort in developing, standardizing, and promoting quality machinery aimed at a range of crop and cropping sequences. These would include the development of permanent bed and furrow planting systems and harvest operations to manage crop residues.
- The widespread use of crop residues for livestock feed and fuel: Especially under rainfed situations, farmers face a scarcity of crop residues due to less biomass production of different crops. There is competition between CA practice and livestock feeding for crop residue. This is a major constraint for the promotion of CA in rainfed situations.
- Burning of crop residues: For timely sowing of the next crop and without machinery for sowing under CA systems, farmers prefer to sow the crop in time by burning the residue. This has become a common feature in the rice-wheat system in north India. This creates environmental problems for the region.
- Lack of knowledge about the potential of CA to agriculture leaders, extension agents, and farmers: This implies that the whole range of practices in conservation agriculture, including planting and

harvesting, water and nutrient management, diseases and pest control, etc. need to be evolved, evaluated and matched in the context of new systems.

- Skilled and scientific manpower: Managing conservation agriculture systems, will call for enhanced capacity of scientists to address problems from a systems perspective and to be able to work in close partnerships with farmers and other stakeholders. Strengthened knowledge and information-sharing mechanisms are needed.

4. Precision Nutrient Management

Precise nutrient management is a science-based approach by which crops receive nutrients as and when needed, according to specific field conditions in a given cropping season. Precision nutrient management is the science of using advanced, innovative, cutting-edge, site-specific technologies to manage spatial and temporal variability in inherent nutrient supply from soil to enhance productivity, efficiency, and profitability of agricultural production systems. It requires an understanding of the spatial variability in soils **(Jin and Jiang, 2002).**

The 4 R's of precise nutrient management are

- **Right Source**
- **Right Rate**
- **Right Time**
- **Right Place**

The most widely and indiscriminately used nutrient in crop production is nitrogen. The dynamics of nitrogen supply to plants govern the content of chlorophyll in plants and thus spectral properties of plant leaves can be used as an index to coin precision nitrogen management strategies. As the plant demand for nutrients other than nitrogen cannot be easily accessed from the spectral properties of the leaves, other techniques are being employed for making precision nutrient management decisions while considering spatial and temporal variability in nutrient supply from the inherent sources.

5. Precision Nitrogen Management

Tools and Techniques

5.1 Optical Sensors:

A wide range of optical sensors are available and classified as multispectral and hyperspectral sensors. A multispectral sensor such as Crop Circle (450-880 nm) and CropScan (440-1750 nm) has a wide spectral resolution (10 to 20 nm) with a limited number of wavebands (3 to 16) used to describe nitrogen **(Roberts *et al.*, 2009)**, biomass variation, and leaf area index **(Darvishzadeh *et al.*, 2006)** while hyperspectral sensors such as ASD FieldSpec (350-2500 nm) have a fine spectral resolution (1-2 nm) with continuous wavebands (2150) across the electromagnetic spectrum which provides detailed biophysical and biochemical information. Interpretation of the spectral reflectance data can be done by using univariate and multivariate regression approaches calculated as spectral indices.

5.2 Chlorophyll Meters:

Chlorophyll meters are reliable alternatives to traditional tissue analysis as plant N nutritional diagnostic tools. The most widely used chlorophyll meter is the hand-held Minolta SPAD-502. The SPAD 502 chlorophyll meter (Soil-Plant Analysis Development) is a quick, non-destructive hand-held device developed by Minolta, Osaka, Japan. It instantly provides an estimate of leaf N status as chlorophyll content **(Boggs et al., 2003)** by clamping the un-plucked leafy tissue in the meter using two LEDs (light-emitting diodes) emitting red (ë = 650 nm) and infrared (ë = 940 nm) light. The red and infrared radiations are made to pass through the leaf. A portion of the light is absorbed and the rest is transmitted through the leaf, and a silicon photodiode detector converts it into an electrical signal. The amount of light reaching the detector is inversely proportional to the amount of chlorophyll in the path of the light. The leaf chlorophyll content is displayed in arbitrary units (0–99.9) and the meter readings are unitless which need to be calibrated with chlorophyll or N content and leaf greenness.

5.3 Leaf Colour Chart (LCC):

A leaf color chart is a high-quality plastic strip with different shades of green colour ranging from light yellowish green to dark green. **Furuya (1987)** reported the use of LCC technology in Japan. An improved version of the six-panel LCC (IRRI-LCC, six-panel) was developed through the collaboration of the International Rice Research Institute (IRRI) with agricultural research systems of several countries in Asia.

5.4 Nutrient Management Models:

Nutrient Expert (NE) and QUEFTS models are generally used as computer-based decision support systems for precision nutrient management in crop production. The models are designed to consider spatial and temporal variability in nutrient supply and ensure need-based nutrient applications. The nutrient expert (NE) develops farmers’ specific fertilizer recommendations based on 3-5 years' previous yield, organic and inorganic fertilizers applied, attainable yield, soil fertility indicators, residue content, and growing environment information. It takes care of the availability of resources to estimate their yield target. The algorithm for calculating fertilizer requirements in Nutrient Expert is developed from a set of on-farm trial data using site-specific nutrient management (SSNM) guidelines. It is a highly interactive computer-based tool that rapidly tells about the fertilizer requirement of a particular field.

5.5 Omission Plot Technique (OPT):

The omission plot technique is used to estimate fertilizer requirements for attaining a yield target. In this technique, all the major nutrients are applied except the nutrient of interest i.e., omitted nutrient. The technique provides an estimate of the indigenous nutrient supply of the soil. For example, if all the nutrients except for P are applied in the P-omission plot, then the yield will be limited by the indigenous supply of P. The yield gap between the maximum achievable yield and the yield in the omission plot technique is then used to calculate the fertilizer requirement.

6. Effect on growth

When it comes to precision N-management techniques and tillage crop establishment procedures, furrow irrigated raise bed (FIRB) and N 80-LCC measured wheat plant height at harvest significantly higher than conventional tillage and farmer fertilisation approaches. Similar to how conventional tillage and farmer fertilisation approaches recorded the lowest dry-matter accumulation at 90 DAS of wheat crop, FIRB and N-80 LCC recorded significantly the highest. When wheat was fertilised with N-80 LCC and elevated beds that were irrigated by furrows, the number of tillers increased dramatically at 90 DAS. Wheat plants gradually grew taller till they were fully mature (Gawdiya , 2020). Similar results were also reported by Biradar, 2012, where, precision nutrient management treatments recorded maximum plant height of wheat than farmers fertilizer practice as balanced application of nutrients as per crop need under N 80- LCC enhances the nutrient use efficiency.

Table I: Effect of tillage crop establishment methods and precision nitrogen management on plant height, dry-matter accumulation and tillers m^{-2} of wheat crop

Treatments	**Plant height at harvest (cm.)**	**Dry matter accumulation at 90 DAS (g m^{-2})**	**Tiller m^{-2} at 90 DAS**
Tillage crop establishment methods (TCEM)			
T_1 – ZTW	**97.1**	**846.9**	**352.7**

T_2 – RT	**93.3**	**840.9**	**333.3**
T_3 – FIRB	**104.7**	**871.5**	**368.3**
T_4 – CTW	**89.1**	**822.9**	**339.9**
C.D. (P=0.05)	**1.7**	**14.5**	**9.8**
Precision nitrogen management			
F_1 - N 80:20	**95.6**	**821.1**	**339.2**
F_2 – NE 33:33:33	**98.1**	**864.5**	**360.1**
F_3 - N 80-LCC	**100.1**	**916.9**	**373.0**
F_4 - SR 50:50	**93.9**	**819.9**	**343.1**
F_5 - FFP	**92.5**	**805.5**	**327.5**
C.D. (P=0.05)	***1.2***	***8.5***	***6.9***

Source: Gawdiya, 2020

Budhar (2005) stated that a consistent supply of N supplied at the seedling stage served to generate a favourable influence on growth features, which may be the cause of the higher plant height and greater number of tillers at LCC 4 and 5. With higher LCC values of N application ranging from 3 to 5, there has been a progressive and noticeable rise in tiller output at 80 DAS. When it came to producing tillers per hill among the LCC values used for N application, LCC 5 stood out as being superior, especially at the last stages of growth at 60 and 80 DAS when the tiller count at LCC 5 was the greatest and much greater than LCC 3 and 4. According to Mohanty et al. (2015), the maximum NAR was produced by STCR and absolute control at 0-30 and 60-90 DAS, respectively, for precision N-management strategies in wheat. However, at 30–60 DAS, various precision N–management techniques had little to no impact on NAR. It was abundantly obvious that the direct and indirect effects of enhanced nutrition gave the crop an initial boost, increasing RGR and NAR under conservation agriculture.

7. Effect on yield.

The amount of crop dry matter accumulated, the number of tillers, the number of grains spike-1, and the grain weight, among other factors, all affect grain output. The most crucial factor for assessing the results of applied treatments is grain yield. Crop productivity is the pace at which a crop accumulates biomass and is primarily dependent on photosynthesis, which is the process by which green plants transform light energy into chemical energy.

Mahajan (2018) reported that (FIRB) significantly outperformed all other treatments in terms of maximum grain output as seen in Table II (52.6 q ha^{-1}). Nevertheless, treatment T1 (wheat sown with no tillage) outperformed the other treatments. During the experiment, T5 outperformed reduced (T2) and roto tillage (T3). When compared to T4 (wheat sown on FIRB) and T5 (wheat sown by conventional tillage), the decline in grain production caused by reduced tillage and roto tillage procedures was 24.6 and 9.1 percent, respectively. However, compared to the other tillage practise plots, the yield of wheat planted in raised beds with furrow irrigation increased by 18.4%.

Table II: Effect of tillage crop establishment methods and nitrogen management on yield and test weight of wheat

Treatments	**Grain yield (q ha^{-1})**	**Straw yield (q ha^{-1})**	**Test weight (g)**	**Harvest Index (%)**
Tillage Crop establishment methods (TCEM)				
T_1 ZT	**48.7**	**57.5**	**41.2**	**45.8**
T_2 RT	**41.9**	**50.9**	**39.6**	**45.2**
T_3 RTW	**37.4**	**44.8**	**37.4**	**45.0**
T_4 FIRB	**52.6**	**63.8**	**42.3**	**45.2**
T_5 CTW	**43.6**	**56.6**	**40.3**	**43.5**
SEm±	**0.51**	**0.53**	**0.4**	**0.45**
C D (P=0.05)	***1.68***	***1.75***	***1.31***	***1.45***
Precision N management				
F_1 Control	**33.8**	**45**	**36.5**	**42.9**
F_2 RDF (150:60:40)	**45.4**	**55.3**	**40.3**	**45.1**
F_3 SPAD	**47.1**	**58.2**	**41.4**	**44.7**
F_4 Targeted yield	**51.7**	**59.4**	**41.6**	**46.5**
F_5 LCC	**46.2**	**55.7**	**40.9**	**45.4**
SEm±	**0.78**	**1.01**	**0.65**	**0.74**
C D (P=0.05)	***2.22***	***2.93***	***1.87***	***2.13***

Source: Mahajan (2018)

According to Biradar *et al.* (2006), fertiliser application based on SSNM principles produced noticeably higher grain yields than farmer practise (FP) and the required amount of fertiliser (RDF). Averaging 3.7 t ha-1, or 23 percent greater than the RDF and 39 percent more than the FP, was the average wheat yield in the SSNM practise. According to Khurana *et al.* (2008), a N management schedule that took real-time variation in crop N requirement at critical wheat growth stages into consideration. Average grain production increased from 4.2 to 4.8 tha-1 as compared to current farmers' fertiliser practises (FFP), while plant N, P, and K accumulations increased by 12 to 20% when using SSNM.

Singh *et al.* (2014) reported from Meerut that the mean grain yield of wheat was 5.30 t ha1 , 4.47 t ha-1 and 3.8 t ha-1 under OPT, SR and FFP, respectively. On an average, the OPT out-yielded the SR and FFP by 0.82 t ha-1 and1.5 t ha-1 or by 18% and 39%, respectively.

8. Effect on NUE

Ghosh *et al.*, 2017, reported that, wheat's Agronomic N use efficiency (AEN), N recovery efficiency (REN), internal N use efficiency (IEN) and partial factor productivity of applied N (PFPN) were significantly impacted by N management practises (Table III). The maximum AEN and REN were obtained with medium rate N application at medium SPAD level (N25S40), which was higher than those obtained with high (N35) and low (N15) rate N topdressing at high (S42) and low SPAD (S38) levels, as well as FTNM and FFP. In comparison to low rate of N topdressing at low SPAD level (N15S38), high rate of N topdressing at high SPAD level (N35S42), and FTNM, N25S40 increased AEN and REN by 29.2 and 50.9 percent, 50 and 8.8 percent, and 58.5 and 15.1 percent, respectively. Regardless of SPAD levels, increasing the rate of N topdressing in wheat caused the IEN and PFPN to gradually drop. As a result, moderate (N25) and low (N15) rates of N topdressing at medium (S40) and low (S38) SPAD levels respectively resulted in significantly higher IEN and PFPN than high rate of N topdressing at high SPAD level (N35S42). FTNM also considerably reduced IEN and PFPN as compared to low to moderate (N15-25) rates of N topdressing at low to medium SPAD levels (S38-40). Moderate rate of N topdressing at medium SPAD level (N25S40) caused higher IEN (+19.1%) and PFPN (+41.5%) than FTNM.

Table III: Effect of nitrogen management practices on nutrient use efficiency

Treatment	**N rate**	**REN**	**AEN**	**PFPN**	**IEN**
	(kg ha–^{1})	**(kg kg^{-1})**	**(kg kg–^{1})**	**(kg kg–^{1})**	**(kgkg–^{1})**
S38N15	**70**	**0.53**	**19.5**	**46.5**	**49.1**
S38N25	**68.3**	**0.70**	**20.5**	**46.5**	**42.4**
S38N35	**95**	**0.69**	**17.6**	**38.5**	**38.6**
S40N15	**90**	**0.59**	**21.4**	**45.1**	**46.7**

S40N25	**101.7**	**0.80**	**25.2**	**46.6**	**40.9**
S40N35	**118.3**	**0.70**	**18.3**	**36.1**	**36.9**
S42N15	**105**	**0.60**	**21.1**	**42.2**	**45.7**
S42N25	**110**	**0.71**	**19.4**	**38.3**	**38.4**
S42N35	**118.3**	**0.74**	**16.8**	**34.9**	**34.7**
FTNM	**120**	**0.70**	**15.9**	**32.9**	**34.3**
FFP	**80**	**0.69**	**20.2**	**45.8**	**42.3**
Control	**0**	**–**	**–**	**–**	**66.7**
SEm (±)		**0.06**	**1.8**	**2.1**	**2.1**
LSD (0.05)		**0.17**	**5.2**	**6.2**	**6.3**

Source: Ghosh *et al* (2017)

The harvest index for potassium, phosphorus, and nitrogen was considerably higher in SSNM and significantly lower in absolute control. Absolute control yielded significantly higher harvest indices of nitrogen and phosphorus among the various N precision management techniques, however the harvest index of potassium was not significantly impacted. Regardless of the wheat treatments used, the nutrient harvest index was in the order of P>N>K, indicating that more P was ingested in the grain than K was in the straw (Mohanty *et al.*, 2016).

Mahajan, 2018, reported that, Nitrogen, phosphorus and potassium harvest index was higher in ZTW (T1) and lowest in FIRB (T4) treatments. Among different precision N management practices, significantly higher nitrogen, phosphorus harvest index was obtained with absolute control (F1), however, harvest index of potassium was not significantly affected by different precision N management. The nutrient harvest index was in the order of P, N and K from highest to lowest. The recovery of any nutrient applied shows the soil supplying capacity and the inherent capacity of the plant to utilize nutrient. It is also dependent on the growing environment and method of application. Apparent nutrient recovery in wheat was significantly influenced by different tillage practices and precision N management practices The potassium recovery of the crop was more than 100% of the applied nutrient which was due to high level of K in the soil in addition to lower K fertilizer doses. Due to different tillage practices FIRB resulted significantly higher nitrogen and phosphorus apparent recovery; whereas different tillage practices fertility had significant effect on potassium apparent recovery, though highest potassium apparent recovery was recorded with FIRB followed by zero tillage plots. Because of different tillage practices more availability of nutrients by FIRB, significantly higher apparent recovery (% nutrient applied) was obtained as all of these nutrients are synergistic in nature. Among precision N management practices targeted yield based nitrogen management resulted significantly higher apparent recovery (N, P & K). However, nitrogen apparent recovery was found at par with SPAD.

Conclusion

Farm management must employ more environmentally friendly agricultural practises if it is to increase crop output efficiency and lower environmental dangers associated with agriculture. These requirements can be met through precision agriculture. As is commonly agreed, it can assist farmers in applying the proper input in the proper quantity, at the proper location, at the proper time, and in the proper manner. When making decisions on the production of wheat crops, the within-field variability is the main source of uncertainty. At both the geographical and temporal scales, variability must be understood and controlled. In order to produce variable wheat N fertilisation, novel experimental methods, distant and proximal sensing, and crop simulation models will increasingly be used to analyse field variability at a cheap cost.

Farmers and researchers can learn a tonne of information. In any case, it has been challenging to evaluate the quality of the gathered data in order to turn it into N management decisions that are both economically and environmentally sustainable. To advance our understanding of the factors that affect wheat production, more studies must be undertaken across a variety of sites using consistent approaches. The major shortcoming in conservation agriculture is immobilization of N in crop residues which decreases available N for wheat, precision N management techniques can help us provide N in a sustainable manner.

Looking at the research findings we can conclude that when it comes to growth, productivity and NUE wheat grown in FIRB performs better while economically speaking zero tillage fared better than other tillage methods.Precise nitrogen management involving LCC, SPAD, NE, GS, and targeted yield not only increase growth, yield and NUE but also turned out more profitable than a blanket application of N.

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