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Nitrogen Management in Conservation Agriculture

Anthony Imoudu Oyeogbe

Abstract

Transitioning to conservation 'sustainable' agriculture (CA) from the conventional 'industrial' agriculture often increase nitrogen (N) limitation, particularly in the first few years. Inadequate N availability is associated with the permanent crop residues on the soil surface. The soil available N for crop uptake is immobilized by microbial sources of organic residues mineralization. The increase in N immobilization contributes to yield declines, and thus, researchers are advocating for the inclusion of N management as the fourth principle in CA. The challenge for CA under optimized N fertilization is how to reduce environmentally-damaging greenhouse gases (GHG) emissions from yield-related productivity. This paper focuses on efficient N management under CA system. Here, we showed the impacts of adaptive N management on crop yields increase, soil health enhancement, and greenhouse gases mitigation. We conclude that efficient N management using innovative technologies and good agronomic practice can scale-up the adoption of CA. An adaptive N management in CA can maintain environmental benefits while contributing to improved soil health and crop productivity. Moreover, the implementation of adaptive N management must be tailored to crop and soil types and location-specific.

Keywords: N immobilization, adaptive N fertilization, crop N demands, soil N test value, sensor-N guidance

1. Introduction

Conservation agriculture (CA) is a resource-efficient system that is capable of increased soil quality, crop productivity, and environmental sustainability [1]. CA system provides multiple ecosystem services and promotes agrobiodiversity ([2], Montpellier [3]). It is characterized and quantified by three principles practised simultaneously, namely; zero/minimum tillage; permanent soil cover; and diversified crop rotation:

- Continuous zero or minimum soil tillage: direct seeding or planting into undisturbed or untilled soil, to maintain or improve soil organic matter content, soil structure, and soil health. The disturbance area must be less than 15 cm or 25% of the cropped area, in addition to no interrupting tillage.
- Permanent organic matter soil cover with cover crops or crop residues: this shields the soil surface, conserves nutrients and water, promotes soil biological activity, and contributes to weed management. Soil cover should be preferably 100%, however, surface soil cover of 30% is seen as adequate.

- Diversified crop rotation: both annuals and perennials as inter- and sequential-cropping, contributing to dietary diversity, human and livestock nutrition, and enhanced cropping system resilience. Mono-cropping is allowed provided no productivity limitation is envisaged in the cropping area.

The synergy of CA principles contributes to on-farm resource use efficiency, sufficiency and sustainability [4]. However, N immobilization under CA-based cropping systems is a major trade-off between resource use efficiency and sustainability. In promoting CA as a productivity-enhancing, resource-saving and eco-friendly paradigm of sustainable intensification, there is the need to address the challenges of increased limitation of soil available N [5, 6]. The inclusion of adaptive N management in CA can contribute to increased crop yields during the early (first three) years of transition from the conventional production system to CA.

2. Conservation agriculture: sustainable agriculture and food security

Feeding the projected 9+ billion people come 2050 call for the implementation of sustainable production systems globally [7]. Conventional agriculture disrupts agroecosystem sustainability, and are a major source (19–29%) of anthropogenic greenhouse gas emissions [8]. Thus, the quest for sustainable crop production intensification has dominated both the scientific and policy thinking space in the last two decades with regards to food security [5]. CA is a paradigm of sustainable intensification with numerous agricultural and environmental benefits (Montpellier [3]). It promotes on-farm biodiversity and ensures ecosystem sustainability [2, 9].

Currently, CA is practised on 155 million hectares of land [10], equivalent to 9% of global arable land [11]. Research studies on CA have highlighted the numerous agricultural and environmental benefits, which includes increased crop yields [12, 13], soil carbon sequestration [14, 15], microbial diversity [16, 17], soil-water retention capacity [18, 19], GHG emissions mitigation [20, 21], early planting time, labour, and energy savings [22, 23], and dietary diversity for human and livestock nutrition [1].

Nevertheless, the multiple benefits of CA have not provided the impetus for robust implementation across scales. Several on-farm research under CA management has reported a reduction in crop yields, particularly in the early phase of transition [11, 24–27]. The decrease in crop yield is ascribed to the increased N immobilization by organic residues, which limits soil available N uptake for crop growth. Researchers have advocated the need for the inclusion of N management [6, 28]. Tailoring N management in CA-based cropping systems can improve the soil organic matter efficiency while contributing to crop yield increase.

3. Nitrogen immobilization: a tradeoff in conservation agriculture

N immobilization is one of the major tradeoffs in CA, which is associated with the permanent organic residues soil cover. Increased N immobilization affect crop yields, particularly in the early stages (1–3 years) of CA implementation [29]. Other trade-offs in CA includes soil compaction, incompatible machinery, and technical know-how. These trade-offs in CA have affected widespread adoption [24]. Thus, the need for a soil-based approach in managing N fertilizers [30], including locally-adapted N management can contribute to yield increase in CA [6, 28].

The significance of CA is the improvement in soil quality, crop productivity, and environmental sustainability [9]. CA practices applied together are of critical importance to soil processes and ecosystem functioning. More specifically, the synergies of minimal soil disturbance, permanent soil cover and crop diversification create an optimal soil environment that stimulates the organic matter efficiency. Increased soil organic matter influences the microbial communities, which are responsible for improving the soil and crop productive capacity. However, N availability in CA is negatively affected by the permanent crop residues on the soil surface. The diverse microbial communities in soil utilize the available soil N for residue-C decomposition, which is detrimental to the crop N uptake in a short time.

Based on a global data set and across a broad range of crops, Lundy et al. [25]; Pittelkow et al. [11, 26] and Rusinamhodzi et al. [31] reported the impact of N fertilization in CA. These authors showed that adequate N fertilization can offset yield declines in CA systems, particularly in tropical regions. Furthermore, they reported that the effects of implementing CA with and without N fertilizer, residue management, and crop rotation in various crops and climates showed yield declines under CA by 12% without inorganic N fertilizer and 4% with N fertilizer addition. For instance, the addition of inorganic N fertilizer (80–120 kg N ha⁻¹) reduced yield by 4% under CA. Also, the inclusion of legumes in CA-based cropping systems produced comparable yield to that of conventional tillage without N addition.

4. Nitrogen management and availability in conservation agriculture

Dynamics of N availability is the net amount of inorganic and organic inputs in soil undergoing decomposition, mineralization and immobilization [32]. Also, the quantity and quality of organic residues influence the N availability [33, 34]. The mineralization of organic residues increases with N fertilization [35], and this offsets the temporary immobilization of available N [34, 36]. Adequate N fertilization during the transition from conventional to CA would contribute to the rapid mineralization of organic residues, which in turn minimizes microbial N immobilization and increases N availability for crop uptake [37, 38]. Therefore, ensuring adequate N fertilization is an immediate strategy of alleviating N limitations in residue-laden soils under CA. However, increasing inorganic N fertilization might hasten organic residues N mineralization, which is associated with the potent greenhouse nitrous oxide (N₂O) emissions [39].

The appropriateness of N fertilizer application is a recommended management practice in minimizing crop yield declines in CA [11, 13, 25, 26, 35]. Increasing N fertilizer rate in CA is more important in the tropics than the temperate region [25]. For instance, decreases in crop yields were observed at low N fertilization in the first 2 years of adoption under tropical conditions compared to the temperate. However, the addition of N (75–100 kg N ha⁻¹ yr.⁻¹) fertilizer improved yields by up to 12% under tropical environment [25, 26]. In the Indo-Gangetic Plains, Oyeogbe et al. [4, 13] showed that optimizing N fertilizer dose in maize and wheat to 180 and 150 kg N ha⁻¹, respectively, increased the grain yield by 20 and 14%. Also in northwest India, wheat grain yields under precision N management increased by 14% compared to farmers fertilization practice [21]. In Germany, adjusting the N input from 65 to 105 kg N ha⁻¹ in maize produced significant yield increases up to 16% under conservation tillage system [23].

Adaptive N management using good agronomic practices and novel technologies can optimize N availability in CA. Oyeogbe et al. [13] and Sapkota et al. [21] demonstrated that N fertilizer management by soil N test assessment and optical sensor (GreenSeeker™) technology increased the grain yields of maize and wheat

compared to farmers practice under CA of the Indo-Gangetic Plains. Yadvinder-Singh et al. [35] reported that split N fertilizer applications following the optical sensor guidance improved the yields of wheat under CA. In-season N fertilization guided by the optical sensor ensures that adequate N is available for organic residues mineralization and crop uptake [35, 40, 41].

Also, organic amendments can influence N availability in a CA-based system. To reduce soil N immobilization in cereal-based CA cropping systems, Flower et al. [42] included high biomass oat cover crop to reduce soil N immobilization. Pittelkow et al. [26] and Lundy et al. [25] reported that crop yields response with inorganic N additions were similar to that of conventional tillage system. Combining organic and inorganic N fertilizers can contribute to a more efficient soil available N under long-term CA system [43]. In the Indo-Gangetic Plains, brown manuring is becoming an effective organic N strategy under CA [12]. Oyeogbe et al. [4, 13] showed that the inclusion of brown manuring had a positive effect on yields of maize and wheat by supplying additional N.

5. Nitrogen fertilizer and nitrous oxide emissions in conservation agriculture

Agricultural soils are the largest source of N₂O emissions, and N fertilizer use is a major contributor to N₂O emissions [44]. N₂O is mostly produced by microbial transformations of N in soils and is often enhanced where available N exceeds crop demand [45]. Under the CA system, N₂O emissions are influenced by increased organic residues mineralization. Moreover, optimized N fertilizer in CA would contribute to larger N₂O emissions. Thus, the challenge for CA is how to effectively manage the permanent organic residues and optimized N fertilization, and reduce environmentally-damaging GHG emissions from yield-related productivity. CA is an eco-friendly 'greener' production system, which is capable of alleviating the GHG emissions compared to conventional 'industrial' production system [46]. It emphasizes on the efficient use of fertilizer, pesticides, and farm machinery are important strategies to mitigate GHG emissions while improving crop productivity [23, 47]. However, there are negating views about the positive impacts of CA practices on GHG emissions. Several research findings reported increased N₂O emissions from the organic residues decomposition under CA [20, 48, 49]. Retaining crop residues on the soil surface is susceptible to increased microbial N transformations and associated N₂O emissions.

Several factors such as high temperature and N fertilization can influence larger emissions of GHG in CA. High temperature and N fertilizer application increase the decomposition and mineralization of organic residues [49, 50]. However, organic N mineralization and associated N₂O emissions decrease in CA due to the absence of soil tillage [51]. Ito et al. [52] indicated that tillage exerted stronger effects on nematode community structure than organic residue management. And thus, it can be argued that the mineralization of organic residues is lower in CA due to less contact between the organic residues and soil organisms compared to conventional tilled system associated with greater N mineralization [49]. Del Grosso et al. [53] simulated the N₂O emission rates from conventional tilled and no-till soil, larger emissions rate were found in the conventional system compared to CA soil. Oyeogbe et al. [4] demonstrated that tailoring N fertilizer application to crop demands can reduce N₂O emissions under CA. Adaptive N-rate (i.e. 155 and 133 kg ha⁻¹ for maize and wheat, respectively) influenced yield gains of about 20 and 14%, respectively, while reducing N₂O emissions in the first two years of implementation [4, 13]. Furthermore, Oyeogbe et al. [13] demonstrated that N₂O emissions based on

the global warming potential (conversion to CO₂-eq) was decarbonized through increased soil carbon sequestration efficiency under adaptive N fertilizer management in CA. Therefore, efficient N fertilization in CA can improve crop productivity, enhance nutrient use efficiency [35], reduce N leaching losses [54, 55], and deactivate N₂O emissions [4, 21].

6. Conclusion

Increased N limitation in CA contributes to crop yield declines, particularly in the first few years of implementation. In promoting CA both as a productivity-enhancing and resource-saving paradigm, there is a need to tailor N availability to crop demands. Adaptive N management in CA can alleviate N limitation of microbial origin and contribute to yield increase, soil quality and environmental sustainability. More importantly, adaptive N management in CA should align with the crop and soil types in diverse agroecological conditions. Therefore, integrating good agronomic practices and innovative technologies in CA such as N management could lead to wide-spread adoption.

Conflict of interest

The author declares no conflict of interest.

Author details

Anthony Imoudu Oyeogbe
University of Rostock, Rostock, Germany

*Address all correspondence to: anthony.oyeogbe@gmail.com

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