AGRI MAGAZINE
(International E-Magazine for Agricultural Articles)
Volume: 03, Issue: 09 (September, 2026)
Available online at http://www.agrimagazine.in

Nutrient Management in Conservation Agriculture: Balancing Soil Health and Crop Productivity

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Conservation agriculture (CA) is based on three major principles: minimum mechanical soil disturbance, permanent organic soil cover through crop residues or cover crops, and diversification of crop species through rotations or intercropping. Promoted globally as a climate-resilient alternative to intensive tillage-based farming, CA is credited with improving soil structure, water infiltration, and long-term soil organic carbon accumulation. However, adopting CA does not automatically improve nutrient availability to the crop; in several respects, it complicates it. Without periodic tillage to mix fertilizers and residues into the soil profile, nutrients – particularly phosphorus, potassium and immobile micronutrients – tend to accumulate near the surface rather than distributing through the root zone, a phenomenon known as nutrient stratification. Likewise, cereal residues left on the surface, with their wide carbon-to-nitrogen (C:N) ratio, can temporarily tie up available soil nitrogen as decomposer microbes outcompete the crop for it. These shifts mean that nutrient strategies developed for conventional, tillage-based systems often need to be re-thought under CA.

Nutrient Dynamics Under Conservation Agriculture

Because CA avoids periodic inversion tillage, nutrients applied at or near the surface – as well as those released from decomposing residues – tend to remain concentrated in the top few centimetres of soil rather than mixing through the profile. Recent reviews confirm that this stratification is now widely documented across no-till systems worldwide, along with accompanying shifts in soil pH near the surface that further influence nutrient availability (Chirchir et al., 2026). Nitrogen cycling is also altered: residues with a high C:N ratio can immobilize soil nitrogen during early decomposition, occasionally lowering nitrogen use efficiency in CA relative to conventional tillage in the short term (Verhulst et al., 2013). Over the longer term, however, the build-up of soil organic carbon under CA improves cation exchange capacity and moisture retention, gradually strengthening the soil's capacity to supply and retain nutrients (Mukherjee et al., 2025).

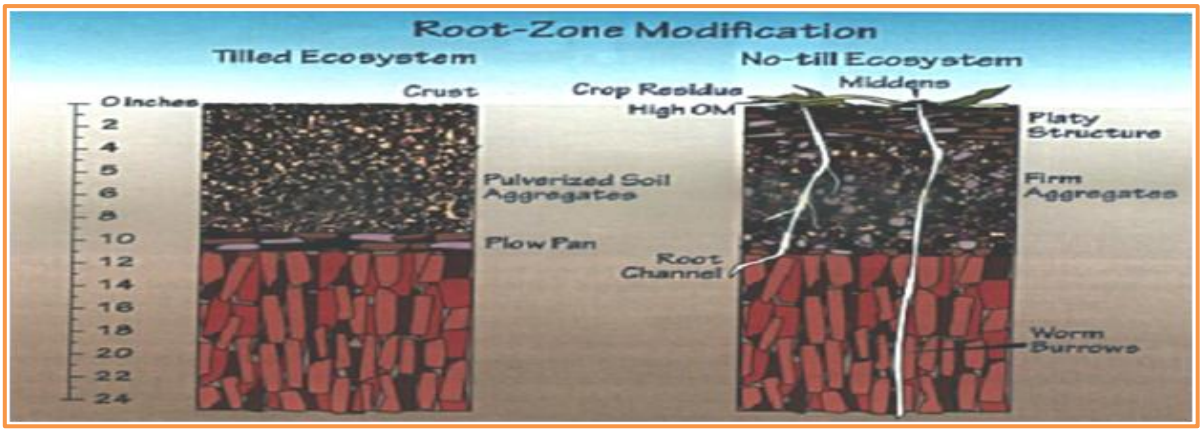

Fig. Root-Zone Modification of Tilled & No-till ecosystem (Source: S. W. Duiker and J.C. Myers. 2005 Penn State University)

Nutrient Management Strategies in Conservation Agriculture

Adapting nutrient management to CA's altered soil dynamics involves a combination of the following field-tested practices:

- **Residue Management for Balanced C:N Ratios:** Blending cereal residues with a small starter dose of nitrogen, or rotating with legumes that add lower C:N residues, offsets the temporary immobilization risk while still building soil organic matter.
- **Site- and Depth-Specific Placement:** Since broadcast phosphorus and potassium tend to stay near the surface under CA, banding or subsurface placement close to the root zone helps counter stratification and improves nutrient access for the crop.
- **Integrated Nutrient Management (INM):** Combining organic sources (farmyard manure, compost, residues) with optimized inorganic fertilizer doses supports both the immediate nutrient needs of the crop and the slower buildup of soil fertility that CA is meant to achieve.
- **Legume-Based Rotations and Cover Crops:** Including legumes in the rotation adds biologically fixed nitrogen and residues with a narrower C:N ratio, easing pressure on the nitrogen budget of the following cereal crop.
- **Precision and Soil-Test-Based Application:** Regular soil testing, along with tools such as leaf colour charts or chlorophyll meters, helps match fertilizer rates and timing to actual crop demand rather than blanket recommendations calibrated for tilled systems.

Efficacy Across Cropping Systems

Field evidence across major cropping systems supports the value of adapted nutrient management under CA. In the lower Indo-Gangetic Plains of India, long-term conservation agriculture combined with tailored rice residue and nutrient management practices improved soil nitrogen availability across a rice-based cropping system, though the benefit depended strongly on how residues and fertilizers were managed together (Mukherjee et al., 2025). Broader syntheses similarly report that nutrient strategies aligned with site-specific soil and climatic conditions consistently outperform blanket fertilizer recommendations carried over from conventional tillage systems (Yimer and Tarnawa, 2025).

Integration With Other Conservation Practices

Nutrient management under CA works best when combined with complementary practices. Cover cropping adds organic matter and can scavenge residual nutrients between main-crop seasons, reducing losses. Precision irrigation limits nutrient leaching by matching water application to crop demand, while agroforestry and mixed-cropping systems diversify nutrient cycling pathways across the field. Together, these integrations help CA deliver on both its soil health and productivity goals rather than one at the expense of the other.

Impact on Soil Health and Crop Productivity

When nutrient management is aligned with CA's principles, the benefits compound over time: soil organic carbon accumulates, nutrient- and water-holding capacity improves, and fertilizer requirements can gradually decline as native soil fertility strengthens. Farmers also benefit economically, as reduced tillage operations and better-targeted fertilizer use lower both fuel and input costs, while more resilient soils buffer yields against erratic rainfall.

Challenges and Future Prospects

Despite its promise, nutrient management under CA is not without difficulty. Nutrient stratification can create localized deficiencies that conventional soil testing protocols, designed for tilled profiles, may fail to detect accurately. Nitrogen immobilization in high-residue systems can depress yields in the initial transition years, discouraging adoption before the longer-term soil health benefits materialize. Region-specific fertilizer and placement recommendations for CA also remain limited compared with the extensive database available for conventional tillage. Looking ahead, wider use of precision soil testing, decision-support tools, and site-specific nutrient management frameworks can help farmers navigate these transition-year challenges more confidently. Continued long-term, multi-season research

across diverse cropping systems will also be essential to refine nutrient recommendations that are truly adapted to conservation agriculture rather than carried over from conventional systems.

Conclusion

Nutrient management is not incidental to the success of conservation agriculture – it is one of its central agronomic challenges. As minimum tillage, permanent soil cover and crop diversification reshape how nutrients move, stratify and become available in the soil, fertilizer strategies must be reconsidered rather than simply carried over from conventional systems. Residue-aware nitrogen management, targeted nutrient placement, integrated nutrient sources and site-specific, soil-test-based application together offer a path to closing this gap. As conservation agriculture continues to expand across diverse agro-ecologies, nutrient management calibrated to its unique soil dynamics will determine whether its promised gains in soil health and long-term productivity are fully realized.

References

1. Chirchir, J., Dyck, M., & Gorim, L. Y. (2026). Soil pH and nutrient stratification and spatial variability: a review of drivers and agronomic implications. Canadian Journal of Plant Science.
2. Mukherjee, S., Sarkar, D., Mandal, B., Kanthal, S., Ghosh, S., Sahu, B., Singh, P., Dey, A., Jaison, M., Dutta, J., Dash, B., & Saha, N. (2025). Conservation agriculture influences soil nitrogen availability in the lower Indo-Gangetic Plains. Plant and Soil, 508, 731–747.
3. Verhulst, N., Francois, I., Grahmann, K., Cox, R., & Govaerts, B. (2013). Nitrogen use efficiency and optimization of nitrogen fertilization in conservation agriculture. CAB Reviews, 8, 1–19.
4. Yimer, A. H., & Tarnawa, A. (2025). Advancing nutrient management strategies for sustainable crop productivity in a changing climate: a systematic review. The Scientific World Journal.