Chapter

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 (N_2O) 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 N_2O emissions, and N fertilizer use is a major contributor to N_2O emissions [44]. N_2O 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, N_2O emissions are influenced by increased organic residues mineralization. Moreover, optimized N fertilizer in CA would contribute to larger N_2O 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 N_2O 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 N_2O 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 N_2O 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 N_2O 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 N_2O 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 N_2O emissions in the first two years of implementation [4, 13]. Furthermore, Oyeogbe et al. [13] demonstrated that N_2O emissions based on the global warming potential (conversion to CO_2-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 N_2O 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

References

[1] FAO, 2017. Conservation agriculture – Revised version. http://www.fao.org/3/a-i7480e.pdf

[2] Palm, C., Blanco-Canqui, H., DeClerck, F., Gatere, L. and Grace, P. 2014. Conservation agriculture and ecosystem services: An overview. Agriculture, Ecosystems and Environment 187: 87-105.

[3] Montpellier Panel, 2013. Sustainable Intensification: A New Paradigm for African Agriculture, London

[4] Oyeogbe, A.I., Das, T.K, Bhatia A. and Singh S.B., 2017. Adaptive nitrogen and integrated weed management in conservation agriculture: impacts on agronomic productivity, greenhouse gas emissions and herbicide residues. Environment Monitoring and Assessment. 189(4):198. doi.org/10.1007/s10661-017-5917-3

[5] Andersson, J. A. and D'Souza. S. 2014. From adoption claims to understanding farmers and contexts: A literature review of Conservation Agriculture adoption among smallholder farmers in southern Africa. Agriculture, Ecosystems and Environment 187: 116-132

[6] Vanlauwe, B., Wendt, J., Giller, K.E., Corbeels, M., Gerard, B. and Nolte, C. 2014. A fourth principle is required to define conservation agriculture in sub-Saharan Africa: The appropriate use of fertiliser to enhance crop productivity. Field Crops Research 155: 10-13.

[7] Godfray, C., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M. and Toulmin, C. 2010. Food security: the challenge of feeding 9 billion people, Science 327: 812-818.

[8] Vermeulen, S.J., Campbell, B.M. and Ingram, J.S.I. 2012. Climate change and food systems. Annual Review of Environmental Resources 37: 195-222.

[9] Kassam, A. and Friedrich, T. 2012. An ecologically sustainable approach to agricultural production intensification: Global perspectives and developments. Field Actions Science Reports, 6: 1-7.

[10] Kassam, A., Friedrich, T. and Shaxson, F. 2014. The spread of conservation agriculture: policy and institutional support for adoption and uptake. Field Actions Science Reports 7: 1-12.

[11] Pittelkow, C.M., Liang, X., Linquist, B.A., Van Groenigen, K.J., Lee, J., Lundy, M.E., VanGestel, N., Six, J., Venterea, R.T. and van Kessel, C. 2015a. Productivity limits and potentials of the principles of conservation agriculture. Nature 517: 365-368.

[12] Das, T.K., Bhattacharyya, R., Sudhishri, S., Sharma, A.R. Saharawat, Y.S., Bandyopadhyay, K.K. Sepat, S. Bana, R.S., Aggarwal, P., Sharma, R.K., Bhatia A., Singh, G., Datta, S.P., Kar, A., Singh, B., Singh, P., Pathak, H., Vyas, A.K. and Jat, M.L. 2014. Conservation agriculture in an irrigated cotton–wheat system of the western Indo-Gangetic Plains: Crop and water productivity and economic profitability. Field Crops Research 158: 24-33.

[13] Oyeogbe, A.I., Das, T. K. and Bandyopadhyay, K.K. 2018. Agronomic productivity, nitrogen fertilizer savings and soil organic carbon in conservation agriculture: Efficient nitrogen and weed management in maize-wheat system. Archives of Agronomy and Soil Science 1635-1645. doi.org/10.1080/03650340.2018.1446524

[14] Das, T.K., Bhattacharyya, R., Sharma, A.R., Das, S., Saad, A.A. and Pathak, H. 2013. Impacts of conservation agriculture on total soil

organic carbon retention potential under an irrigated agro-ecosystem of the western Indo-Gangetic Plains. European Journal of Agronomy 51: 34-42.

[15] Srinivasarao, Ch., Venkateswarlu, B., Lal, R., Singh, A.K., Kundu, S., Vittal, K.P.R., Balaguravaiah, G., Babu, M.V.S, Charya, G.R., Prasadbabu, M.B.B. and Reddy, Y.T. 2012. Soil carbon sequestration and agronomic productivity of an Alfisol for a groundnut-based system in a semiarid environment in southern India. European Journal of Agronomy 43: 40-48.

[16] Govaerts, B., Mezzalama, M., Unno, Y., Sayre, K.D., Luna-Guido, M., Vanherck, K., Dendooven, L. and Deckers, J. 2007. Influence of tillage, residue management, and crop rotation on soil microbial biomass, and catabolic diversity. Applied Soil Ecology 37: 18-30.

[17] Lienhard, P., Tivet, F., Chabanne, A., Dequiedt, S., Lelièvre, M., Sayphoummie, S., Leudphanane, B., Prévost-Bouré, N.C., Séguy, L., Maron, P. and Ranjard, L. 2013. No-till and cover crops shift soil microbial abundance and diversity in Laos tropical grasslands. Agronomy for Sustainable Development, 33: 375-384.

[18] Rockstrom, J., Kaumbutho, P., Mwalley, J., Nzabi, A.W., Temesgen, M., Mawenya, L., Barron, J., Mutua,J. and Damgaard-Larsen, S. 2009. Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. Soil and Tillage Research 103: 23-32

[19] Thierfelder, C. and Wall, P.C. 2012. Effects of conservation agriculture on soil quality and productivity in contrasting agro-ecological environments of Zimbabwe. Soil Use Management 28: 209-220.

[20] Dendooven, L., Patino-Zúniga, L., Verhulst, N., Luna-Guido, M., Marsch R. and Govaerts, B. 2012. Global warming potential of agricultural systems with contrasting tillage and residue management in the central highlands of Mexico Agriculture, Ecosystems and Environment 152: 50-58.

[21] Sapkota, T. B., Majumdar, K., Jat, M.L., Kumara, A., Bishnoi, D.K., McDonald, A.J. and Pampolino, M. 2014. Precision nutrient management in conservation agriculture based wheat production of Northwest India: Profitability, nutrient use efficiency and environmental footprint. Field Crops Research 155: 233-244.

[22] Erenstein, O. and Laxmi, V. 2008. Zero tillage impacts in India's rice–wheat systems: A review. Soil and Tillage Research 100: 1-14.

[23] Küstermann, B., Munch, J.C. and Hülsbergen, K.J. 2013 Effects of soil tillage and fertilisation on resource efficiency and greenhouse gas emissions in a longterm field experiment in Southern Germany. European Journal Agronomy 49:61-73.

[24] Giller, K.E., Witter, E., Corbeels, M. and Tittonell, P. 2009. Conservation agriculture and smallholder farming in Africa: the heretic's view. Field Crops Research. 114: 23-34.

[25] Lundy, M.E., Pittelkow, C.M., Linquist, B.A., Liang, X., van Groenigen, K.J., Lee, J., Six, J., Venterea, R.T. and van Kessel, C. 2015. Nitrogen fertilisation reduces yield declines following no-till adoption. Field Crop Research 83: 204-210.

[26] Pittelkow, C.M., Linquist, B.A., Lundy, M.E., Liang, X., Van Groenigen, K.J., Lee, J., VanGestel, N., Six, J., Venterea, R.T. and Van Kessel, C. 2015b. When does no-till yield more? A global meta-analysis. Field Crops Research 183: 156-168.

[27] Tittonell, P., Scopel, E., Andrieu, A., Posthumus, H., Mapfumoi, P., Corbeels, M., van Halsema, G.E., Lahmar, R., Lugandu, S., Rakotoarisoa, J., Mtambanengwe, F., Pound, B., Chikowo, R., Naudin, K., Triomphe. and B, Mkomwa, S. 2012. Agroecology-based aggradation-conservation agriculture (ABACO): Targeting innovations to combat soil degradation and food insecurity in semiarid Africa. Field Crops Research 132: 168-174.

[28] Sommer, R., Thierfelder, C., Tittonell, P., Hove, L., Mureithi, J. and Mkomwa, S. 2014. Fertiliser use should not be the fourth principle to define conservation agriculture. Field Crops Research 169: 145-148.

[29] Kong, A.Y.Y., Fonte, S.J., van Kessel, C., Six, J., 2009. Transitioning from standard to minimum tillage: Trade-offs between soil organic matter stabilization, nitrous oxide emissions, and N availability in irrigated cropping systems. Soil and Tillage Research 104: 256-262.

[30] Mulvaney, R.L., Khan, S.A. and Ellsworth, T.R. 2006. Need for a soil-based approach in managing nitrogen fertilisers for profitable corn production. Soil Science Society of American Journal 70: 172-182.

[31] Rusinamhodzi, L., Corbeels, M., van Wijk, M., Rufinio, M.C., Nyamangara, J. and Giller, K.E. 2011. A meta-analysis of long-term effects of conservation agriculture practices on maize yields under rain-fed conditions. Agronomy for Sustainable Development 31: 657-673.

[32] Shibu, M.E., Van K, H., Leffelaar, P.A. and Aggarwal, P.K. 2010. Soil carbon balance of rice-based cropping systems of the Indo-Gangetic Plains. Geoderma 160: 143-154.

[33] Chivenge, P., Vanlauwe, B., Gentile, R. and Six, J. 2011. Organic resource quality influences short-term aggregate dynamics and soil organic carbon and nitrogen accumulation. Soil Biochemistry, 43: 657-666.

[34] Gentile, R., Vanlauwe, B., Chivenge, P. and Six, J. 2011. Trade-offs between the short and long-term effects of residue quality on soil C and N dynamics. Plant Soil 338: 159-169.

[35] Yadvinder-Singh, Singh, M., Sidhu, H.S., Humphrey, E., Thind, H.S., Jat, M.L., Blackwell, J. and Singh, V. 2015. Nitrogen management for zero till wheat with surface retention of rice residues in north-west India. Field Crops Research 184:183-191.

[36] Russell, A.E., Cambardella, C.A., Laird, D.A., Jaynes, D.B. and Meet, D.W. 2009. Nitrogen fertiliser effects on soil carbon balances in Midwestern U.S. agricultural systems. Ecological Application 19: 1102-1113.

[37] Chivenge, P., Vanlauwe, B., Gentile, R., Wangechi, H., Mugendi, D., van Kessel, C. and Six, J. 2009. Organic and mineral input management to enhance crop productivity in Central Kenya. Agronomy Journal 101: 1266-1275.

[38] Gentile, R., Vanlauwe, B., Kavoo, A., Chivenge, P. and Six, J. 2010. Residue quality and N fertiliser do not influence aggregate stabilization of C and N in two tropical soils with contrasting texture. Nutrient Cycling in Agroecosystems 88: 121-131.

[39] Butterbach-Bahl, K., Kesik, M., Miehle, P., Papen, H. and Li, C. 2004. Quantifying the regional source strength of N-trace gases across agricultural and forest ecosystems with process based models. Plant Soil 260: 311-329.

[40] Bijay-Singh, Sharma, R.K., Kaur, J., Jat, M.L., Yadvinder-Singh, Varinderpal-Singh, Chandna, P., Choudhary, O.P., Gupta, R.K., Thind, H.S., Singh, J.,

Uppal, H.S., Khurana, H.S., Kumar, A., Uppal, R.K., Vashistha, M. and Gupta, R., 2011. In-season estimation of yield and nitrogen management in irrigated wheat using a hand-held optical sensor in the Indo-Gangetic plains of South Asia. Agronomy for Sustainable Development 31: 589-603.

[41] Raun, W.R., Solie, J.B., Johnson, G.V., Stone, M.L., Mullen, R.W., Freeman, K.W., Thomason, W.E. and Lukina, E.V. 2002. Improving Nitrogen Use Efficiency in Cereal Grain Production with Optical Sensing and Variable Rate Application. Agronomy Journal 94: 815-820.

[42] Flower, K.C., Cordingley, N., Ward, P.R. and Weeks, C. 2013. Nitrogen, weed management and economics with cover crops in conservation agriculture in a Mediterranean climate. Field Crops Research 132: 63-75.

[43] Sainju, U., Senwo, Z.N., Nyakatawa, E.Z., Tazisong, I.A. and Reddy, K.C. 2008. Soil carbon and nitrogen sequestration as affected by long-term tillage, cropping systems, and nitrogen fertiliser sources. Agriculture, Ecosystems and Environment 127: 234-240.

[44] Syakila, A. and Kroeze, C. 2011. The global nitrous oxide budget revisited, Greenhouse Gas Measurement and Management 1(1): 17-26.

[45] Oenema, O., Wrage, N., Velthof, G.L., van Groenigen, J.W., Dolfing, J., Kuikman, P.J., 2005. Trends in global nitrous oxide emissions from animal production systems. Nutrient Cycling in Agroecosystem 72: 51-65.

[46] Hobbs, P.R. 2007. Conservation agriculture: what is it and why is it important for future sustainable food production? The Journal of Agricultural Science. 145: 127-137.

[47] West, T. O. and Marland, G. 2002. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. Agriculture, Ecosystem Environment 91: 217-223.

[48] Baggs, E.M., Stevenson, M., Pihlatie, M., Regar, A., Cook, H. and Cadisch, G. 2003. Nitrous oxide emissions following application of residues and fertiliser under zero and conventional tillage. Biology and Fertility of Soils 254: 361-370.

[49] Ussiri, D.A.N., Lal, R. and Jarecki, M.K. 2009. Nitrous oxide and methane emissions from long-term tillage under a continuous corn cropping system in Ohio. Soil and Tillage Research 104: 247-255.

[50] Almaraz, J.J., Zhou, X.M., Mabood, F., Madramootoo, C., Rochette, P., Ma, B.L. and Smith, D.L. 2009. Greenhouse gas fluxes associated with soybean production under two tillage systems in South western Quebec. Soil and Tillage Research 104: 134-139.

[51] Verachtert, E., Govaerts, B., Lichter, K., Sayre, K.D., Ceballos-Ramirez, J.M., Luna-Guido, M.L., Deckers, J. and Dendooven, L. 2009 dynamics of C and N in soil when crops are cultivated on permanent raised beds. Plant Soil 320: 281-293.

[52] Ito, T., Araki, M., Komatsuzaki, M., Kaneko, N. and Ohta, H. 2015. Soil nematode community structure affected by tillage systems and cover crop managements in organic soybean production. Applied Soil Ecology, 86: 137-147.

[53] Del Grosso, S., Ojima, D., Parton, W., Mosier, A., Peterson, G. and Schimeld, D. 2002 Simulated effects of dryland cropping intensification on soil organic matter and greenhouse gas exchanges using the DAYCENT ecosystem model. Environmental Pollution 116: S75–S83.

[54] Dai, J., Wang, Z., Li, F., He, G., Wanga, S., Li, Q., Cao, H., Luo, L., Zan, Y., Meng, X., Zhang, W., Wang, R. and Malhi, S.S. 2015. Optimising nitrogen input by balancing winter wheat yield and residual nitrate-N in soil in a long-term dryland field experiment in the Loess Plateau of China. Field Crops Research 181: 32-41.

[55] Zhou, M. and Butterbach-Bahl, K. 2014. Assessment of nitrate leaching loss on a yield-scaled basis from maize and wheat cropping systems. Plant and Soil 374: 977-991.