RESEARCH PAPER

CROP RESIDUES STIMULATE YIELD-SCALED GREENHOUSE GAS EMISSIONS IN MAIZE-WHEAT CROPPING ROTATION IN A SEMI-ARID CLIMATE

Morad Mirzaei*[1,2], Manouchehr Gorji Anari[1], Maurício Roberto Cherubin[3,4], Nermina Saronjic[5], Seyed Mohammad Nasir Mousavi[6,7], Azin Rooien[8], Mohammad Zaman[9], Andrés Caballero-Calvo*[10]

[1]Department of Soil Science and Engineering, Faculty of Agricultural Engineering and Technology, University of Tehran, Karaj, Iran

[2]School of Natural Sciences, Botany Discipline, Trinity College Dublin, Dublin 2, Ireland

[3]Department of Soil Science, "Luiz de Queiroz" College of Agriculture, University of São Paulo, 11 Pádua Dias Avenue, Piracicaba, São Paulo 13418-900, Brazil

[4]Center for Carbon Research in Tropical Agriculture (CCARBON) - University of São Paulo, 11 Alameda das Palmeiras, Piracicaba, São Paulo 13418-900, Brazil

[5]Institute of Soil Research, Department of Forest and Soil Sciences, University of Natural Resources and Life Sciences (BOKU), Vienna, Austria

[6]Department of Plant, Food, and Environmental Sciences, Faculty of Agriculture, Dalhousie University, Halifax, NS B2N 5E3, Canada

[7]Institute of Land Use, Engineering and Precision Farming Technology, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, 138 Böszörményi St., 4032 Debrecen, Hungary

[8]Department of Landscape Protection and Environmental Geography, Institute of Earth Science, Faculty of science and technology, University of Debrecen, 4032 Debrecen, Hungary

[9]Soil and Water Management & Crop Nutrition Section, Joint FAO/IAEA Division of Nuclear Techniques in Food & Agriculture, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Vienna, Austria

[10]Departamento de Análisis Geográfico Regional y Geografía Física, Facultad de Filosofía y Letras, Campus Universitario de Cartuja, University of Granada, 18071 Granada, Spain.

***Corresponding author:** andrescaballero@ugr.es, mirzaei.morad95@ut.ac.ir

Received: October 13st, 2022 / Accepted: November 14th, 2023 / Published: December 31st, 2023

https://DOI-10.24057/2071-9388-2023-2629

ABSTRACT. Mitigating yield-scaled greenhouse gas emissions (YSE) is beneficial for enhancing crop yield, reducing greenhouse gas (GHG) emissions, and advancing climate-smart agronomic management practices. This study aims to evaluate the impact of different crop residue rates– 100% (R_{100}), 50% (R_{50}), and residue removal (R_0) – on the YSE indicator within a maize-wheat cropping rotation under both conventional tillage (CT) and no-tillage (NT) systems in a semi-arid region. In the NT system, crop residues had a notable effect on the YSE indicator for wheat. Specifically, R_0 exhibited a 39% and 20% decrease in YSE for wheat compared to R_{100} and R_{50}, respectively. Interestingly, crop residue did not significantly influence YSE for maize under the NT system. On the other hand, in the CT system, YSE for maize in R_0 was 33% and 25% lower than that in R_{100} and R_{50}, respectively. Additionally, compared to R_0, there were observed increases of 28% and 20% in YSE for wheat in R_{100} and R_{50} under the CT system, respectively. Our findings show that crop residue removal decreases YSE under both CT and NT systems. However, given that this practice degrades soil quality and results in lower yields, it is not considered a sustainable management practice compared to residue retention options. This research highlights the importance of evaluating GHG mitigation strategies by concurrently considering both emissions and crop production. Nevertheless, it is essential to conduct off-site assessments of GHG emissions from crop residue application and also engage in long-term studies to comprehend the full potential of crop residue management on YSE.

KEYWORDS: oil health, cropping system, food security, conservation agriculture, soil management, climate change, greenhouse gas emissions

CITATION: Mirzaei M., Anari M. G., Cherubin M. R., Saronjic N., Mousavi S. M. N., Rooien A., Zaman M., Caballero-Calvo A. (2023). Crop Residues Stimulate Yield-Scaled Greenhouse Gas Emissions In Maize-Wheat Cropping Rotation In A Semi-Arid Climate. Geography, Environment, Sustainability, 4(16), 125-132
https://DOI-10.24057/2071-9388-2023-2629

Conflict of interests: The authors reported no potential conflict of interest.

INTRODUCTION

Due to anthropogenic activities, global concentrations of greenhouse gases (GHG), such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), have increased (O'Neill et al. 2021;IPCC, 2021). Enhancing agricultural productivity through strategic management techniques, such as reduced use of conventional agronomic practices, may mitigate GHG emissions (Ceschia et al. 2010; Radicetti et al. 2020; Mohammed et al. 2022; Mirzaei et al. 2022a, 2022b). Land management practices often determine whether cropland soils act as net sinks or sources of GHG emissions (Ceschia et al. 2010; Radicetti et al. 2019; Bossio et al. 2020).

Mitigating GHG emissions and increasing soil organic carbon sequestration are achievable through improved management practices (Paustian et al. 2016; Minasny et al. 2017; Ogle et al. 2019; Lal et al. 2021). Agricultural practices, including crop residue management, significantly influence soil C and GHG emissions, and crop productivity by impacting dynamic changes in carbon and nitrogen in soil, nutrient availability, and factors influencing GHG emissions such as soil moisture, temperature, and microbial activity (Yao et al. 2013; Jin et al. 2014; Cherubin et al. 2018; Vasconcelos et al. 2018; Battaglia et al. 2021; Drury et al. 2021; Mirzaei et al. 2021; Tenelli et al. 2021; Liu et al. 2022; Mancinelli et al. 2023). Therefore, evaluating the effect of agricultural practices is crucial for developing more sustainable approaches with high crop yields, lower potential for GHG emissions, and reduced global warming impact (Pratibha et al. 2016; Mancinelli et al. 2020; Mirzaei et al. 2023).

Metrics such as greenhouse gas intensity (GHGI) or yield-scaled metrics assess GHG emissions per unit of crop yield, considering both food production and climate change concerns (Mosier et al. 2006; Van Groenigen et al. 2010; Pratibha et al. 2016; Li et al. 2022). The yield-scaled emissions (YSE) approach is an effective integrated assessment method for evaluating changes in crop management operations destined to optimize cropping practices, achieve food security, and simultaneously reduce the impacts of climate change (Van Groenigen et al. 2010, Abalos et al. 2016).

While previous studies have assessed the effect and mitigation potential of agronomic practices on GHG emissions (Six et al. 2004; Zhao et al. 2016; Xia et al. 2017), few studies have been linked to crop yield (Van Groenigen et al. 2010; Linquist et al. 2012; Feng et al. 2013; Van Kessel et al. 2013; Zhang et al. 2015). Comprehensive assessments of cropping practices per unit yield (yield-scaled) are suggested to benefit food security and GHG mitigation goals (Van Groenigen et al. 2010; Linquist et al. 2012; IPCC, 2014). Therefore, the integrated evaluation of both crop yield and GHG emissions is crucial for optimizing cropping system practices.

The maize-wheat rotation is one of the most common grain production cropping systems (Pooniya et al. 2022), producing a substantial amount of crop residues annually (Bao et al. 2022). However, a significant portion of these residues is removed for fodder, energy production, or other purposes, or burned (Mirzaei et al. 2021). To date, there is no information about the effects of crop residue management practices on GHG emissions, especially yield-scaled GHG emissions from agricultural soil in Iran. We hypothesized that total residue removal treatment would lead to large yield-scaled GHG emissions. The objective of this study is to assess the effects of different crop residue rates (100 %, 50 %, and total residue removal) on wheat and maize yield-scaled GHG emissions under conventional tillage (CT) and no-tillage (NT) systems in a semi-arid region in Iran.

Materials and methods

Site description and experimental layout

The study took place at the Agriculture Research Station of the College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran (35˚48' 32″ N, 50˚ 58′ 06″ E, 1308 m a.s.l.) in 2018 (Fig.1). This region has semi-arid climate conditions, with an annual precipitation of 245 mm and an annual mean temperature of 13.7 °C (Tabari and Talaee, 2011). For the experiment, two fields with a wheat (*Triticum aestivum L.*) - maize (*Zea mays L.*) cropping rotation background were chosen, managed under CT and NT practices. The soil in the CT field was classified as sandy loam with 57% sand, 24.4% silt, and 18.6% clay. In the NT field, soil was classified as clay loam with 52.5% sand, 28.1% silt, and 19.4% clay. Both fields had a soil pH of 7.7 and no salinity issues. Organic carbon content was 8.9 g kg^{-1} under CT and 11.3 g kg^{-1} under NT. Total nitrogen (TN), available phosphorus (AP), and available potassium (AK) under CT were 0.8 mg kg^{-1}, 13.5 mg kg^{-1}, and 150.6 mg kg^{-1} respectively. Under the NT system, these values were 1.0 mg kg^{-1}, 15.2 mg kg^{-1}, and 258.2 mg kg^{-1} for TN, AP, and AK respectively. The experiment was set up as a randomized complete block with three replicates. In total, 18 plots (3×4 m) were designated for both fields. In this research, in order to facilitate the application of crop residue treatments and planting operations, the residue treatments were first applied to the designated plots, followed by the planting of crops. Finally, the plots were separated based on the specific dimensions.

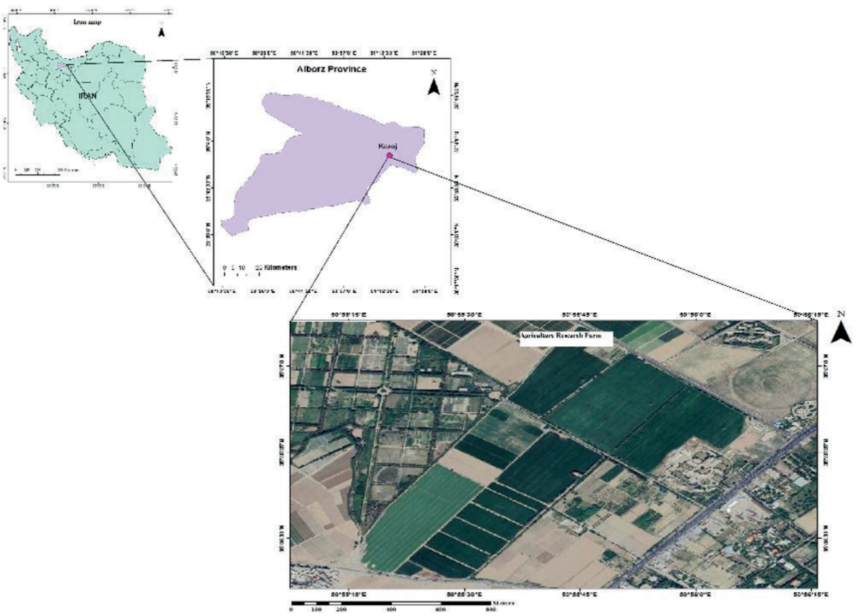


Fig. 1. Geographical location of the study area

Treatment implementation and cultivation practices

Wheat residue rates and maize planting

After harvesting wheat on July 6, 2018, three wheat residue rates – 100 % (R_{100}), 50 % (R_{50}), and no residue (R_0) – were applied to both CT and NT fields on July 11, 2018. The residue rates were achieved by weighing post-harvest crop residue samples collected across the farm at several locations using a wooden quadrat (1m×1m). The average weight per square meter was then scaled up to a hectare. For the R_{100} and R_{50} treatments, the residue was distributed over the soil surface, while for the R_0 treatment the residue was completely removed from the plots. Next, maize seeds were planted. In the NT field, sowing was carried out using a planter with a single colter. In the CT, before seed placement with a row crop planter, the soil was cultivated with a moldboard plow to a depth of 35 cm, followed by disking and leveling. Basal NPK fertilizers were applied: 23, 36, and 68 kg ha^{-1} of N, K_2O, and P_2O_5 respectively, with additional top-dressing of 37 and 125 kg ha^{-1} N at eight and ten leaves stages, post-cultivation. Plots were irrigated at 7-10 days intervals.

Maize residue rates and wheat planting

In October 2018, Maize was harvested, and three maize residue rates (R_{100}, R_{50}, and R_0) were applied to the same plots. The residue application process mirrored that of wheat residues. Winter wheat was planted in November 2018 using a drilling machine, with basal fertilization of 23, 80, and 90 kg ha^{-1} N, K_2O, and P_2O_5. Additional fertilizers of 50, 50, and 23 kg ha $^{-1}$ N were applied during late tillering, stem elongation, and spiking, respectively.

Greenhouse gas sampling and analysis

Flux measurements were performed every 7–10 days in summer, and every 14 days in winter using the static closed chamber method (De Klein and Harvey, 2013). This method is one of the most popular tools for flux measurements from agricultural soil (De Klein and Harvey., 2013). A polyvinyl chloride (PVC) chamber measured carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) efflux. Gas sampling was conducted at 9-10 am at 0, 30, and 60 min time points. At each time point, a 20 ml gas sample was taken by inserting a needle attached to a 20 ml syringe in the sampling port and transferred into 12-ml pre-vacuumed vials sealed with butyl rubber septa (Glass vials (e.g. Exetainer®, Labco Limited, High Wycombe, UK)).

Gas chromatography (Teif Gostar Faraz, TG 2552, Iran; Brucker, Germany) was used for the analysis, with concentrations of N_2O, CH_4, and CO_2 measured using an electron capture detector (ECD), a flame ionization detector (FID), and a thermal conductivity detector (TCD), respectively (Al-Shammary et al. 2022). The fluxes were calculated based on changes in linear concentration gradient over time and on the ratio between chamber volume and soil surface area (Liebig et al. 2010; De Klein and Harvey., 2013; Bayer et al. 2014). Linear interpolation of data points and the integration of the underlying area were used to calculate the cumulative rate of GHG fluxes (Sainju et al. 2012; Wegner et al. 2018).

Yield-scaled CO_2 equivalent GHG fluxes were determined by dividing the global warming potential (GWP) of GHG fluxes in CO_2 equivalents by dry yield, with CH_4 concentration assumed to be zero, as it constantly was below the detection level (Johnson et al. 2012; Bayer et al. 2014; Hurisso et al. 2016). Equations (1) and (2) were used for calculations.

$$Yield-scaled\ emission\ \left(MgCO_{2\_}eq.Mg\ dry\ yield^{-1}\right)=\frac{GWP\left(MgCO_{2\_}eq\right)}{Dry\ yield\,(Mg)} \quad (1)$$

$$GWP=\left(CO_2\times 1\right)+\left(N_2O\times 298\right)+\left(CH_4\times 25\right) \quad (2)$$

Yield Measurement

Maize and wheat yields within each plot were determined using a 1m×1m quadrat. The entire harvested plants were dry-weighted for each plot, and the mean was calculated as yield.

Statistical analysis

The general linear models (GLM) procedure in SAS 9.4 software (SAS Institute Inc., Cary, NC, USA) was used for data analysis. A mean comparison was performed by using the Duncan method at the 0.05 statistical significance level.

Results and discussion

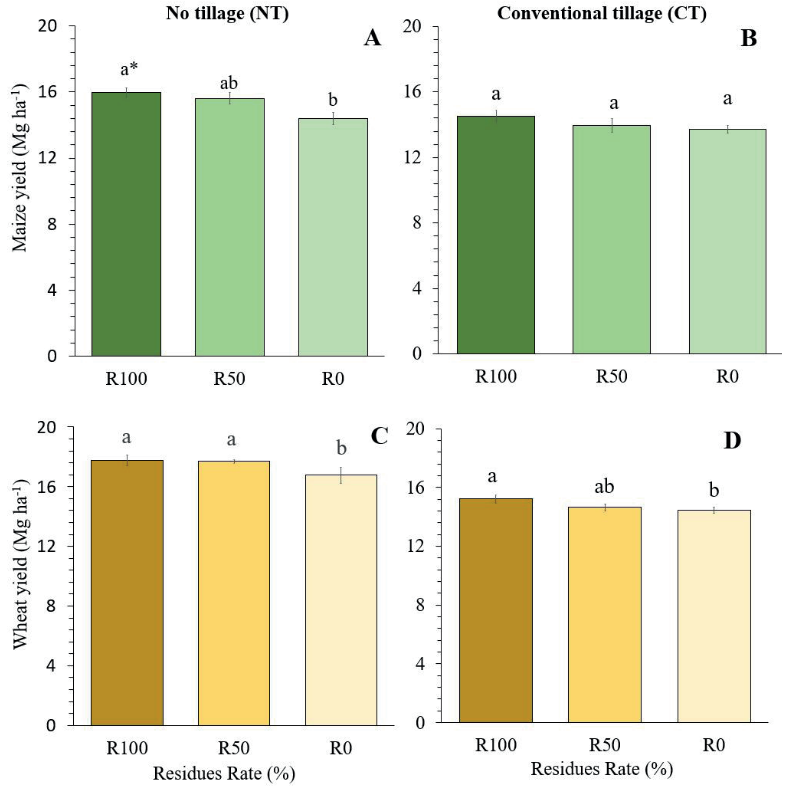
Crop yield and GWP of GHG emissions in maize-wheat cropping rotation under NT and CT systems

In the NT system, the addition of crop residue positively impacted maize yield, with significant increases observed in full residue retention (R_{100}) compared to residue removal (R_0). However, no significant differences were observed between R_{50} and R_0 (Fig. 2A). Conversely, In the CT system, residue had no significant impact on maize yield (Fig. 2B). Wheat yield in the NT system increased with rising residue amounts in R_{100} and R_{50} compared to R_0 (Fig. 2C). In the CT system, wheat yield significantly increased in R_{100} compared to R_0, but no significant differences were noted between R_{50} and R_0 treatments (Fig. 2D). The enhanced crop yield attributed to crop residue can be influenced by improved soil quality, regulated soil temperature, increased soil organic matter, and higher nutrient availability (Choudhury et al. 2014; Mu et al. 2016; Pant et al. 2017; Maw et al. 2019). Conversely, the decreased crop yield in residue removal can be linked to reduced water availability, high daily soil temperature fluctuations, increased soil compaction, augmented surface runoff, and lower nutrient intake (Blanco-Canqui and Lal, 2009; Cherubin et al. 2018; Carvalho et al. 2019; Cherubin et al. 2021). For a more in-depth discussion on the crop yield response to crop residue management in this experiment, refer to Mirzaei et al. (2021).

Full retention of crop residue resulted in higher GHG emissions during the maize season under the NT system, with R_{100} showing a significant increase compared to R_0. However, no significant differences were observed between R_{100} and R_{50} treatments (Fig. 3A). In the CT system, the GWP of GHG in maize showed a significant increase in R_{100} and R_{50} compared to R_0 (Fig. 3B). The GWP index for the wheat crop, under both systems, also increased with rising residue amounts, and R_{100} and R_{50} both showed a significant increase compared to R_0 (Figs. 3C and 3D). In line with our findings, Dendooven et al. (2012) reported that, under semi-arid conditions in Mexico, removing crop residue reduced the GWP of GHG 1.3 times in a wheat-maize rotation. Similarly, Zhang et al. (2014) found that residue treatments significantly increased GWP by 9-30% relative to no residue treatment during a rice-growing season in China. Enhanced GWP in crop residue treatment is attributed to both crop residue and GHG emissions from the soil. Crop residue plays a crucial role in GHG emissions by altering carbon (C) and nitrogen (N) dynamics (Guzman et al. 2015; Nawaz et al. 2017; Seiz et al. 2019; Essich et al. 2020; Al-Shammary et al. 2023), and indirectly influencing the soil environment (Baggs et al. 2006; Taghizadeh-Toosi et al. 2021). The lower GWP of GHG in plant residue removal treatment may be due to reduced C and N uptake into the soil, along with microclimatic variations related to changes in soil cover (Jin et al. 2014). In Brazil, Gonzaga et al. (2019) also found a reduction in N2O emissions under total sugarcane straw removal. However, indiscriminate sugarcane straw removal led to reduced crop yields (Carvalho et al. 2019), soil C stocks (Tenelli et al. 2021), and soil health (Cherubin et al. 2021).

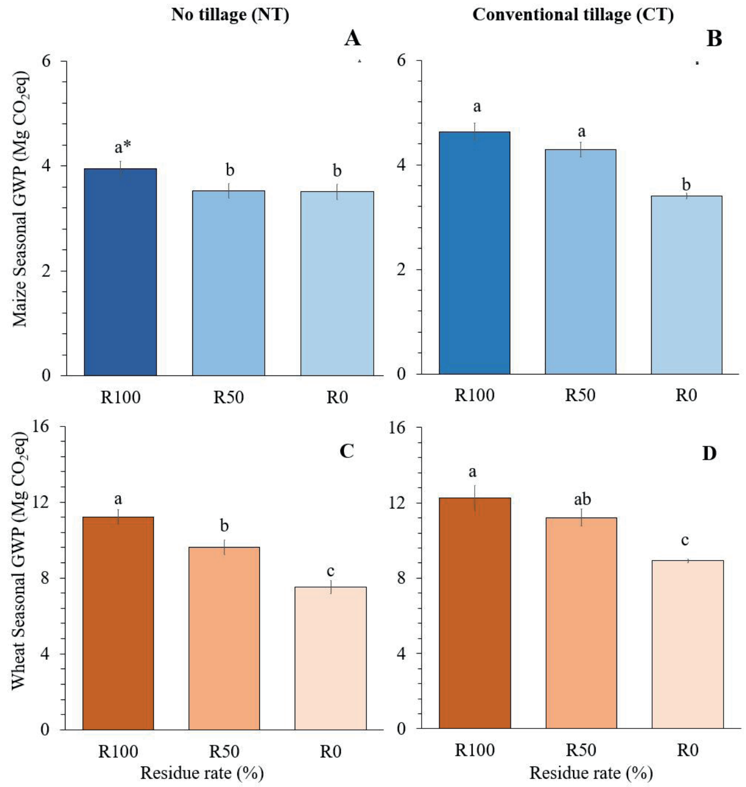
The effect of crop residue on YSE in maize-wheat cropping rotation under NT and CT systems

In the NT system, maize YSE was not significantly affected by crop residues (Fig. 4A), potentially due to the short-term duration of the corn season, insufficient for crop residue to show their true effect. However, crop residue



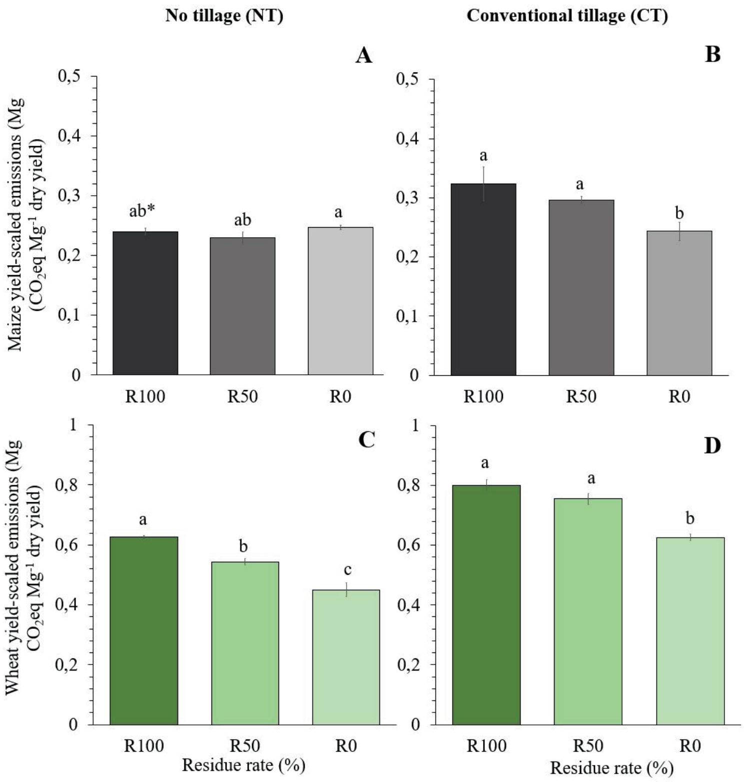
*. Similar letters indicate no significant difference. Whiskers represent standard error (n=3).

Fig. 2. Impact of residue rate on seasonal maize (A and B) and wheat (C and D) yield under NT (left) and CT (right) systems



* Similar letters indicate no significant difference. Whiskers represent standard error (n=3).

Fig. 3. Impact of residue rate on maize (A and B) and wheat (C and D) seasonal GWP of GHG fluxes under NT (left) and CT (right) systems



* Similar letters indicate no significant difference. Whiskers represent standard error (n=3).

Fig. 4. Impact of residue rate on maize (A and B) and wheat (C and D) YSE under NT (left) and CT (right) systems

rates significantly impacted ($p < 0.05$) YSE for wheat (Fig. 4B). The highest amount of YSE for wheat (0.62 Mg CO_2eq Mg^{-1} dry yield) was obtained from the R_{100} treatment, 39 % higher compared to the R_0 treatment (0.45 Mg CO_2eq Mg^{-1} dry yield). Additionally, R_{50} (0.54 Mg CO_2eq Mg^{-1} dry yield) resulted in a 20 % increase over R_0.

In the CT system, YSE for both maize and wheat crops increased with rising residue rates (Figs. 4C and 4D), although no significant differences were observed between R_{100} and R_{50}. For maize, R_{100} (0.32 Mg CO_2eq Mg^{-1} dry yield) and R_{50} (0.30 Mg CO_2eq Mg^{-1} dry yield) led to 33% and 25% increases in YSE compared to R_0 (0.24 Mg CO_2eq Mg^{-1} dry yield). Similarly, for wheat, 28% and 20% increases in YSE were noted in R_{100} (0.8 Mg CO_2eq Mg^{-1} dry yield) and R_{50} (0.75 Mg CO_2eq Mg^{-1} dry yield) compared to R_0 (0.62 Mg CO_2eq Mg^{-1} dry yield).

Higher YSE for wheat and maize in residue treatments compared to residue removal could be attributed to the strong influence of residue on the GWP of GHG relative to crop yield. Compared to R_0, R_{100}, and R_{50} led to 6% and ~2% increases in maize yield under the CT system, respectively (Fig. 2B), while the GWP of GHG for this crop showed 36% and 26% increases for R_{100} and R_{50} under the CT, respectively (Fig. 3B). Furthermore, under the NT system, wheat yields were 6% and 5.5% higher for R_{100} and R_{50} than R_0, respectively, whereas, in the CT system, R_{100} and R_{50} resulted in 5% and 1% higher yields than R_0 (Figs. 2C and 2D). In addition, the GWP of GHG for wheat was 50% and 28% higher in R_{100} and R_{50} than in R_0 under the NT system. These quantities were equivalent to 37% and 25% under the CT system (Figs. 3C and 3D).

In the CT system, there were no significant differences in YSE for both maize and wheat crops between R_{100} and R_{50} treatments (Figs. 4B and 4D) due to the lack of significant differences between GWP and crop yield in these two treatments (Figs. 2B and 2D; 3B and 3D). In both tillage systems, YSE was higher in wheat than in maize cultivation (Fig. 4). This difference is primarily driven by the higher GWP of GHG emissions in wheat than in maize (Fig. 3). Additionally, the longer crop season of wheat (November 2018 – July 2019) compared to maize (July 2018 – October 2018) contributes to higher emissions of GHG.

Our results, indicating higher YSE in areas with substantial crop residue maintenance, align with data reported in rice and rice-wheat cropping systems in China (e.g., Feng et al. 2013; Yao et al. 2013; Zhang et al. 2015). However, Pratibha et al. (2016) reported lower YSE with an increase in crop residue and a decrease in tillage intensity for both pigeon pea and castor crops in semi-arid regions of Southern India. Zhang et al. (2014) reported that residue mulching decreased YSE for rice by 35-72% relative to no residue treatment in China. These discrepancies with other studies highlight the importance of considering different residue management practices and their duration.

Conclusions

The assessment of cropping systems' effects on crop YSE is valuable for selecting innovative and promising management practices to balance higher yields and lower GHG emissions. Our findings demonstrate that crop residue removal mitigates wheat and maize YSE under both CT and NT systems. In addition, YSE was higher for both crops under CT compared to the NT system. Furthermore, wheat had higher YSE than maize under both tillage systems. Despite the lower YSE in crop residue removal, this practice negatively impacts crop productivity, C sequestration, soil health, and biodiversity. Additionally, residue removal accelerates soil quality degradation. Thus, considering all these aspects, retaining 50% of post-harvest crop residue in the field may be considered as a more sustainable crop residue management in the study area. Finally, considering the perspectives of farmers, particularly in terms of economic viability, is essential for the successful implementation of new management strategies.

Ethical approval statement

The authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

This research does not involve human or animal participants.

All authors consent to the submission of this manuscript to this journal.

Availability of data

The data that support the findings of this study are available from the corresponding author [ACC] upon reasonable request.

REFERENCES

Abalos D., Jeffery S., Drury C.F. & Wagner-Riddle, C. (2016). Improving fertilizer management in the US and Canada for N2O mitigation: understanding potential positive and negative side-effects on corn yields. Agric. Ecosyst. Environ. 221 214–21.

Al-Shammary, A.A.G., Caballero-Calvo, A., Abbas Jebur, H., Khalbas, M.I. & Fernández-Gálvez, J. (2022). A novel heat-pulse probe for measuring soil thermal conductivity: Field test under different tillage practices. Computers and Electronics in Agriculture, 202, 107414, 1-13. https://doi.org/10.1016/j.compag.2022.107414

Al-Shammary, A. A. G., Al-Shihmani, L. S. S., Caballero-Calvo, A., & Fernández-Gálvez, J. (2023). Impact of agronomic practices on physical surface crusts and some soil technical attributes of two winter wheat fields in southern Iraq. Journal of Soils and Sediments, 1-20. https://doi.org/10.1007/s11368-023-03585-w

Baggs, E. M., Chebii, J., and J. K. Ndufa (2006). A short-term investigation of trace gas emissions following tillage and no-tillage of agroforestry residues in western Kenya. Soil and Tillage Research. 90(1-2): 69-76.

Bao, X., Wen, X., Sun, X., & Bao, G. (2022). The effects of crop residues and air temperature on variations in interannual ecosystem respiration in a wheat-maize crop rotation in China. Agriculture, Ecosystems & Environment, 325, 107728.

Battaglia, M., Thomason, W., Fike, J. H., Evanylo, G. K., von Cossel, M., Babur, E., ... & Diatta, A. A. (2021). The broad impacts of corn stover and wheat straw removal for biofuel production on crop productivity, soil health and greenhouse gas emissions: A review. Gcb Bioenergy, 13(1), 45-57.

Bayer, C., de Souza Costa, F., Pedroso, G. M., Zschornack, T., Camargo, E. S., de Lima, M. A., ... & Macedo, V. R. M. (2014). Yield-scaled greenhouse gas emissions from flood irrigated rice under long-term conventional tillage and no-till systems in a Humid Subtropical climate. Field Crops Research, 162, 60-69.

Blanco-Canqui, H., & Lal, R. (2009). Corn stover removal for expanded uses reduces soil fertility and structural stability. Soil Science Society of America Journal, 73(2), 418-426.

Bossio, D. A., Cook-Patton, S. C., Ellis, P. W., Fargione, J., Sanderman, J., Smith, P., ... & Griscom, B. W. (2020). The role of soil carbon in natural climate solutions. Nature Sustainability, 3(5), 391-398.

Carvalho, J. L. N., Menandro, L. M. S., de Castro, S. G. Q., Cherubin, M. R., Bordonal, R. D. O., Barbosa, L. C., ... & Castioni, G. A. F. (2019). Multilocation straw removal effects on sugarcane yield in south-central Brazil. BioEnergy Research, 12(4), 813-829.

Ceschia, E., Béziat, P., Dejoux, J. F., Aubinet, M., Bernhofer, C., Bodson, B., et al. (2010). Management effects on net ecosystem carbon and GHG budgets at European crop sites. Agric. Ecosyst. Environ, 139 (3), 363–383. doi:10.1016/ j.agee.2010.09.020.

Cherubin, M. R., Bordonal, R. O., Castioni, G. A., Guimaraes, E. M., Lisboa, I. P., Moraes, L. A., ... & Carvalho, J. L. (2021). Soil health response to sugarcane straw removal in Brazil. Industrial Crops and Products, 163, 113315.

Cherubin, M. R., Oliveira, D. M. D. S., Feigl, B. J., Pimentel, L. G., Lisboa, I. P., Gmach, M. R., ... & Cerri, C. C. (2018). Crop residue harvest for bioenergy production and its implications on soil functioning and plant growth: A review. Scientia Agricola, 75, 255-272.

Choudhury, S.G.; Srivastava, S.; Singh, R.; Chaudhari, S.; Sharma, D.; Singh, S.; Sarkar, D. (2014). Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice–wheat cropping system under reclaimed sodic soil. J. Soil Tillage Res. 136, 76–83.

Collins, H.P., P.A. Fay, E. Kimura, S. Fransen, and A. Himes (2017). Intercropping with switchgrass improves net greenhouse gas balance in hybrid poplar plantations on a sand soil. Soil Sci. Soc. Am. J. 81:781–795. doi:10.2136/ sssaj2016.09.0294.

Dendooven, L., Patiño-Zúñiga, L., Verhulst, N., Luna-Guido, M., Marsch, R., & Govaerts, B. (2012). Global warming potential of agricultural systems with contrasting tillage and residue management in the central highlands of Mexico. Agriculture, Ecosystems & Environment, 152, 50-58.

De Klein, C., & Harvey, M. (2013). Nitrous Oxide Chamber Methodology Guidelines, Global Research Alliance on Agricultural Greenhouse Gases. Publisher: Ministry of Primary Industries, Wellington, New Zealand.

Drury, C. F., Woodley, A. L., Reynolds, W. D., Yang, X. M., Phillips, L. A., Rehmann, L., & Calder, W. (2021). Impacts of corn stover removal on carbon dioxide and nitrous oxide emissions. Soil Science Society of America Journal, 85(5), 1334-1348.

Essich, L., Nkebiwe, P. M., Schneider, M., & Ruser, R. (2020). Is Crop Residue Removal to Reduce N2O Emissions Driven by Quality or Quantity? A Field Study and Meta-Analysis. Agriculture, 10(11), 1-20.

Essich, L., Nkebiwe, P. M., Schneider, M., & Ruser, R. (2020). Is Crop Residue Removal to Reduce N2O Emissions Driven by Quality or Quantity? A Field Study and Meta-Analysis. Agriculture, 10(11), 1-20.

Feng, J., Chen, C., Zhang, Y., Song, Z., Deng, A., Zheng, C., & Zhang, W. (2013). Impacts of cropping practices on yield-scaled greenhouse gas emissions from rice fields in China: a meta-analysis. Agriculture, Ecosystems & Environment, 164, 220-228.

Gan, Y., Liang, C., Huang, G., Malhi, S. S., Brandt, S. A., and Katepa-Mupondwa, F. (2012). Carbon footprint of canola and mustard is a function of the rate of N fertilizer. Int. J. Life Cycle Assess. 17 (1), 58–68. doi:10.1007/s11367-011-0337-z

Gonzaga, L. C., Zotelli, L. D. C., de Castro, S. G. Q., de Oliveira, B. G., Bordonal, R. D. O., Cantarella, H., & Carvalho, J. L. N. (2019). Implications of sugarcane straw removal for soil greenhouse gas emissions in São Paulo State, Brazil. BioEnergy Research, 12(4), 843-857.

Guzman, J., Al-Kaisi, M., & Parkin, T. (2015). Greenhouse gas emissions dynamics as influenced by corn residue removal in continuous corn system. Soil Science Society of America Journal, 79(2), 612-625.

Hurisso, T. T., Norton, U., Norton, J. B., Odhiambo, J., Del Grosso, S. J., Hergert, G. W., & Lyon, D. J. (2016). Dryland Soil Greenhouse Gases and Yield-Scaled Emissions in No-Till and Organic Winter Wheat–Fallow Systems. Soil Science Society of America Journal, 80(1), 178-192.

Intergovernmental Panel on Climate Change. Agriculture, Forestry and Other Land Use (AFOLU) (2015). In Climate Change 2014, Mitigation of Climate Change; Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014; Chapter 11.

IPCC, 2021. In: Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., P´ean, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Yelekçi, W.T.O., Yu, R., Zhou, B. (Eds.), Climate Change 2021: the Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge.

Jin, V. L., Baker, J. M., Johnson, J. M. F., Karlen, D. L., Lehman, R. M., Osborne, S. L., ... & Wienhold, B. J. (2014). Soil greenhouse gas emissions in response to corn stover removal and tillage management across the US Corn Belt. BioEnergy Research, 7(2), 517-527.

Johnson, J. M., Weyers, S. L., Archer, D. W., & Barbour, N. W. (2012). Nitrous oxide, methane emission, and yield-scaled emission from organically and conventionally managed systems. Soil Science Society of America Journal, 76(4), 1347-1357.

Li, Y., Feng, H., Wu, W., Jiang, Y., Sun, J., Zhang, Y., Cheng, H., Li, C., Siddique, K.H. and Chen, J., 2022. Decreased greenhouse gas intensity of winter wheat production under plastic film mulching in semi-arid areas. Agricultural Water Management, 274, p.107941.

Linquist, B., Groenigen, K. J., Adviento-Borbe, M. A., Pittelkow, C., and Kessel, C. (2012). An agronomic assessment of greenhouse gas emissions from major cereal crops. Glob. Change Biol. 18 (1), 194–209. doi:10.1111/j.1365- 2486.2011.02502.x.

Lal, R., Mello, F. F. D. C., Damian, J. M., Cherubin, M. R., & Cerri, C. E. P. (2021). Soil carbon sequestration through adopting sustainable management practices: potential and opportunity for the American countries. Ed. Instituto Interamericano de Cooperación para la Agricultura.

Liu, W., Liu, Y., Liu, G., Xie, R., Ming, B., Yang, Y., ... & Hou, P. (2022). Estimation of maize straw production and appropriate straw return rate in China. Agriculture, Ecosystems & Environment, 328, 107865.

Mancinelli, R., Marinari, S., Allam, M. and Radicetti, E., 2020. Potential role of fertilizer sources and soil tillage practices to mitigate soil CO2 emissions in mediterranean potato production systems. Sustainability, 12(20), p.8543.

Mancinelli, R., Marinari, S., Atait, M., Petroselli, V., Chilosi, G., Jasarevic, M., Catalani, A., Abideen, Z., Mirzaei, M., Allam, M. and Radicetti, E., 2023. Durum Wheat–Potato Crop Rotation, Soil Tillage, and Fertilization Source Affect Soil CO2 Emission and C Storage in the Mediterranean Environment. Land, 12(2), 326.Maw, M.J.; Goyne, K.W.; Fritschi, F.B. (2019). Soil carbon changes following conversion to annual biofuel feedstocks on marginal lands. Agron. J., 111, 4–13.

Minasny, B., Malone, B. P., McBratney, A. B., Angers, D. A., Arrouays, D., Chambers, A., et al. (2017). Soil carbon 4 per mille. Geoderma, 292, 59–86. doi:10.1016/j.geoderma.2017.01.002.

Mirzaei, M., Gorji Anari, M., Razavy-Toosi, E., Asadi, H., Moghiseh, E., Saronjic, N., & Rodrigo-Comino, J. (2021). Preliminary Effects of Crop Residue Management on Soil Quality and Crop Production under Different Soil Management Regimes in Corn-Wheat Rotation Systems. Agronomy, 11(2), 302.

Mirzaei, M., Anari, M. G., Razavy-Toosi, E., Zaman, M., Saronjic, N., Zamir, S. M., ... & Caballero-Calvo, A. (2022). Crop residues in corn-wheat rotation in a semi-arid region increase CO2 efflux under conventional tillage but not in a no-tillage system. Pedobiologia, 93, 150819. https://doi.org/10.1016/j.pedobi.2022.150819

Mirzaei, M., Gorji Anari, M., Saronjic, N., Sarkar, S., Kral, I., Gronauer, A., Mohammed, S. and Caballero-Calvo, A., 2023. Environmental impacts of corn silage production: influence of wheat residues under contrasting tillage management types. Environmental Monitoring and Assessment, 195(1), 171. https://doi.org/10.1007/s10661-022-10675-8

Mirzaei, M., Gorji Anari, M., Taghizadeh-Toosi, A., Zaman, M., Saronjic, N., Mohammed, S., Szabo, S., Caballero-Calvo, A. (2022). Soil nitrous oxide emissions following crop residues management in corn-wheat rotation under conventional and no-tillage systems. Air, Soil and Water Research, 15, 1-12. https://doi.org/10.1177/11786221221128789

Mohammed, S., Mirzaei, M., Pappné Törő, Á., Anari, M. G., Moghiseh, E., Asadi, H., ... & Harsányi, E. (2022). Soil carbon dioxide emissions from maize (Zea mays L.) fields as influenced by tillage management and climate. Irrigation and Drainage, 71(1), 228-240.

Mosier, A.R., Halvorson, A.D., Reule, C.A., Liu, X.J.J. (2006). Net global warming potential and greenhouse gas intensity in irrigated cropping systems in northeastern Colorado. Journal of Environmental Quality 35, 1584–1598.

Mu, X.; Zhao, Y.; Liu, K.; Ji, B.; Guo, H.; Xue, Z.; Li, C. (2016). Responses of soil properties, root growth and crop yield to tillage and crop residue management in a wheat–maize cropping system on the North China Plain. Eur. J. Agron, 78, 32–43.

Nawaz, A., Lal, R., Shrestha, R. K., & Farooq, M. (2017). Mulching Affects Soil Properties and Greenhouse Gas Emissions Under Long-Term No-Till and Plough-Till Systems in Alfisol of Central Ohio. Land Degradation & Development, 28(2), 673-681.

O'Neill, M., Lanigan, G. J., Forristal, P. D., & Osborne, B. A. (2021). Greenhouse Gas Emissions and Crop Yields From Winter Oilseed Rape Cropping Systems are Unaffected by Management Practices. Frontiers in Environmental Science, 377.

Ogle, S. M., Alsaker, C., BaldockBernoux, J. M., Bernoux, M., Breidt, F. J., McConkey, B., et al. (2019). Climate and Soil Characteristics Determine where No-Till Management Can Store Carbon in Soils and Mitigate Greenhouse Gas Emissions. Sci. Rep. 9, 11665. doi:10.1038/s41598-019-47861-7.

Pant, P.K.; Ram, S.; Singh, V. (2017). Yield and soil organic matter dynamics as affected by the long-term use of organic and inorganic fertilizers under rice–wheat cropping system in subtropical mollisols. J. Agric. Res, 6, 399–409.

Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G. P., & Smith, P. (2016). Climate-smart soils. Nature, 532(7597), 49-57.

Pooniya, V., Zhiipao, R. R., Biswakarma, N., Kumar, D., Shivay, Y. S., Babu, S., ... & Lama, A. (2022). Conservation agriculture based integrated crop management sustains productivity and economic profitability along with soil properties of the maize-wheat rotation. Scientific reports, 12(1), 1-13.

Pratibha, G., Srinivas, I., Rao, K. V., Shanker, A. K., Raju, B. M. K., Choudhary, D. K., ... & Maheswari, M. (2016). Net global warming potential and greenhouse gas intensity of conventional and conservation agriculture system in rainfed semi arid tropics of India. Atmospheric Environment, 145, 239-250.

Radicetti, E., Campiglia, E., Langeroodi, A.S., Zsembeli, J., Mendler-Drienyovszki, N. and Mancinelli, R., 2020. Soil carbon dioxide emissions in eggplants based on cover crop residue management. Nutrient Cycling in Agroecosystems, 118, 39-55.

Radicetti, E., Osipitan, O.A., Langeroodi, A.R.S., Marinari, S. and Mancinelli, R., 2019. CO2 flux and C balance due to the replacement of bare soil with agro-ecological service crops in Mediterranean environment. Agriculture, 9(4), 71.

Seiz, P., Guzman-Bustamante, I., Schulz, R., Müller, T., & Ruser, R. (2019). Effect of crop residue removal and straw addition on nitrous oxide emissions from a horticulturally used soil in South Germany. Soil Science Society of America Journal, 83(5), 1399-1409.

Six, J.; Ogle, S.M.; Conant, R.T.; Mosier, A.R.; Paustian, K. (2004). The potential to mitigate global warming with no-tillage management is only realized when practised in the long term. Glob. Chang. Biol, 10, 155–160.

Tabari, H., & Talaee, P. H. (2011). Analysis of trends in temperature data in arid and semi-arid regions of Iran. Global and Planetary Change, 79(1-2), 1-10.

Taghizadeh-Toosi, A., Janz, B., Labouriau, R., Olesen, J. E., Butterbach-Bahl, K., & Petersen, S. O. (2021). Nitrous oxide emissions from red clover and winter wheat residues depend on interacting effects of distribution, soil N availability and moisture level. Plant and Soil, 1-18.

Tenelli, S., Bordonal, R. O., Cherubin, M. R., Cerri, C. E. P., & Carvalho, J. L. N. (2021). Multilocation changes in soil carbon stocks from sugarcane straw removal for bioenergy production in Brazil. GCB Bioenergy, 13(7), 1099-1111.

Trumbore, S. (2000). Age of soil organic matter and soil respiration: radiocarbon constraints on belowground C dynamics. Ecol. Appl. 10 (2), 399–411.

Van Groenigen, J. W., Velthof, G. L., Oenema, O., Van Groenigen, K. J., Van Kessel, C., (2010). Towards an agronomic assessment of N2O emissions: a case study for arable crops, European Journal of Soil Science, 61, 903–913.

Van Kessel, C.; Venterea, R.; Six, J.; Adviento-Borbe, M.A.; Linquist, B.; Van Groenigen, K.J. (2013). Climate, duration, and N placement determine N2O emissions in reduced tillage systems: A meta-analysis. Glob. Chang. Biol., 19, 33–44.

Vasconcelos, A. L. S., Cherubin, M. R., Feigl, B. J., Cerri, C. E., Gmach, M. R., & Siqueira-Neto, M. (2018). Greenhouse gas emission responses to sugarcane straw removal. Biomass and Bioenergy, 113, 15-21.

Xia, L.; Lam, S.K.; Chen, D.; Wang, J.; Tang, Q.; Yan, X. (2017). Can knowledge-based N management produce more staple grain with lower greenhouse gas emission and reactive nitrogen pollution? A meta-analysis. Glob. Chang. Biol., 23, 1917–1925.

Yao, Z., Zheng, X., Wang, R., Xie, B., Butterbach-Bahl, K., & Zhu, J. (2013). Nitrous oxide and methane fluxes from a rice–wheat crop rotation under wheat residue incorporation and no-tillage practices. Atmospheric Environment, 79, 641-649.

Zhang, L., Zheng, J., Chen, L., Shen, M., Zhang, X., Zhang, M., ... & Zhang, W. (2015). Integrative effects of soil tillage and straw management on crop yields and greenhouse gas emissions in a rice–wheat cropping system. European Journal of Agronomy, 63, 47-54.

Zhang, Z. S., Cao, C. G., Guo, L. J., & Li, C. F. (2014). The effects of rape residue mulching on net global warming potential and greenhouse gas intensity from No-Tillage paddy fields. The Scientific World Journal, 2014.

Zhao, X.; Liu, S.; Pu, C.; Zhang, X.; Xue, J.; Zhang, R.; Wang, Y.; Lal, R.; Zhang, H.; Chen, F. (2016). Methane and nitrous oxide emissions under no-till farming in China: A meta-analysis. Glob. Chang. Biol., 22, 1372–1384.