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Properties of a cultivated soil of irrigated rice under conservation agriculture principles

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ABSTRACT

The practice of miles of hectares in different parts of the world has determined that the concepts and principles of Conservation Agriculture (CA) are of international validity. However, in irrigated rice cultivation, there are still few studies carried out and there is significant variability in the information on its effect on the soil and the agricultural yield of the crop, depending on the type of soil. The objective of this work was to evaluate the effect of CA on the physical and chemical properties of a Gleysol Plinthic soil dedicated to the cultivation of irrigated rice in Los Palacios municipality. The research was conducted in an area of 2.63 ha in which the three basic principles of the CA (no-tillage, soil mulch cover and diversified cropping) were implemented. The results show that after four cycles of planting under the CA there was an increase in organic matter from 2.41 to 3.66 % with respect to the baseline. The total porosity was increased to 9.51 %, the apparent density decreased to 0.04 g cm^{-3} and the penetration resistance was reduced from 4.29 to 3.41 MPa, showing enhanced soil health.

Keywords: Zero tillage, organic matter, soil bulk density, soil mulch and diversified cropping.

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INTRODUCTION

Rice is one of the most widely grown crops in the world and is the staple food for more than half of the global population (Gharsallah et al., 2023). In Cuba, rice is one of the most common cereal foods, with a national demand of 700,000 t with an average consumption rate of more than 70 kg per person per year. However, national production only guarantees 40 % of consumption demand, so the government is obliged to import more than 400,000 t of rice annually to supplement local productivity (ONEI, 2022).

To reduce this import volume, since 2012, the country has embarked on a comprehensive development program for rice crops, incorporating new planting areas, and introducing modern technologies, with the intention of increasing production and yields. This program has allowed that in the year 2018, more than 300,000 t of husk rice have been produced, which constitutes the largest historical record of production in the country (ONEI, 2022).

Rice is mainly traditionally cultivated in Cuba, based on the disc harrow and permanent flooding, which contributes to soil degradation (Díaz et al., 2009; Ruiz et al., 2016). However, the current conditions of climate change increase the demand for the sustainability of agricultural systems. Therefore, rice production in Cuba must adapt to provide food to the population in a sustainable way and at the same time need to conserve and improve the soils.

The Los Palacios municipality, in Pinar del Río Province, is one of the main rice producers in the country. In that region, rice is affected by the low physical and chemical fertility of the soils (Pérez et al., 2018; Pozo et al., 2017).

A viable alternative may be the adoption of an agricultural system that allows the conservation of soil fertility such as CA. The FAO cited by Kassam et al. (2022) defines CA as an agricultural system that is characterized by three fundamental principles: keep the soil permanently covered with crop residues or vegetation covers for at least 30 %, a minimum disturbance of soil and diversification of species grown in rotation.

Globally, CA is used with good results in approximately 205.4 M hectares worldwide, mainly in countries such as the United States, Brazil, Argentina, Canada and Australia, in soils that vary from 90 % sand in Africa and Australia to 80 % clay in Brazil and can be applied to all crops (Kassam et al., 2022). Even in South American countries (Argentina, Brazil, Paraguay and Uruguay), they are using it in more than 70 % of their total cultivation area, with experiences of restoring degraded areas to productive agricultural land (Kassam et al., 2022).

In the cultivation of irrigated rice, there are still few studies and the adoption rates in countries that apply CA are also low. On the other hand, there is good acceptance among rice researchers and producers in Brazil, China and India (Huang et al., 2018; Kaur and Singh, 2017). However, there is a significant variability in information about the effect of CA on different types of soil in Cuba.

The determination of properties sensitive to soil use and management practices, such as organic matter, bulk density, porosity and resistance to penetration (Issaka et al., 2019; Soracco et al., 2018; Yadav et al., 2017), can be an effective tool to evaluate the effect of CA on the soil. The objective of this work is to evaluate the effect of CA on the physical and chemical properties of a Gleysol Plinthic Soil dedicated to irrigated rice cultivation in Los Palacios municipality.

MATERIALS AND METHODS

The research was carried out between 2017 and 2019, in an area of 2.63 ha, in the Scientific and Technological Unit Los Palacios (UCTB-LP), belonging to The National Institute of Agricultural Sciences (INCA). The area is located in the southern plain of Pinar del Río Province (Figure 1), at 22°33’59’’ north latitude and 83°14’15’’ west latitude, at 32 meters above sea level.

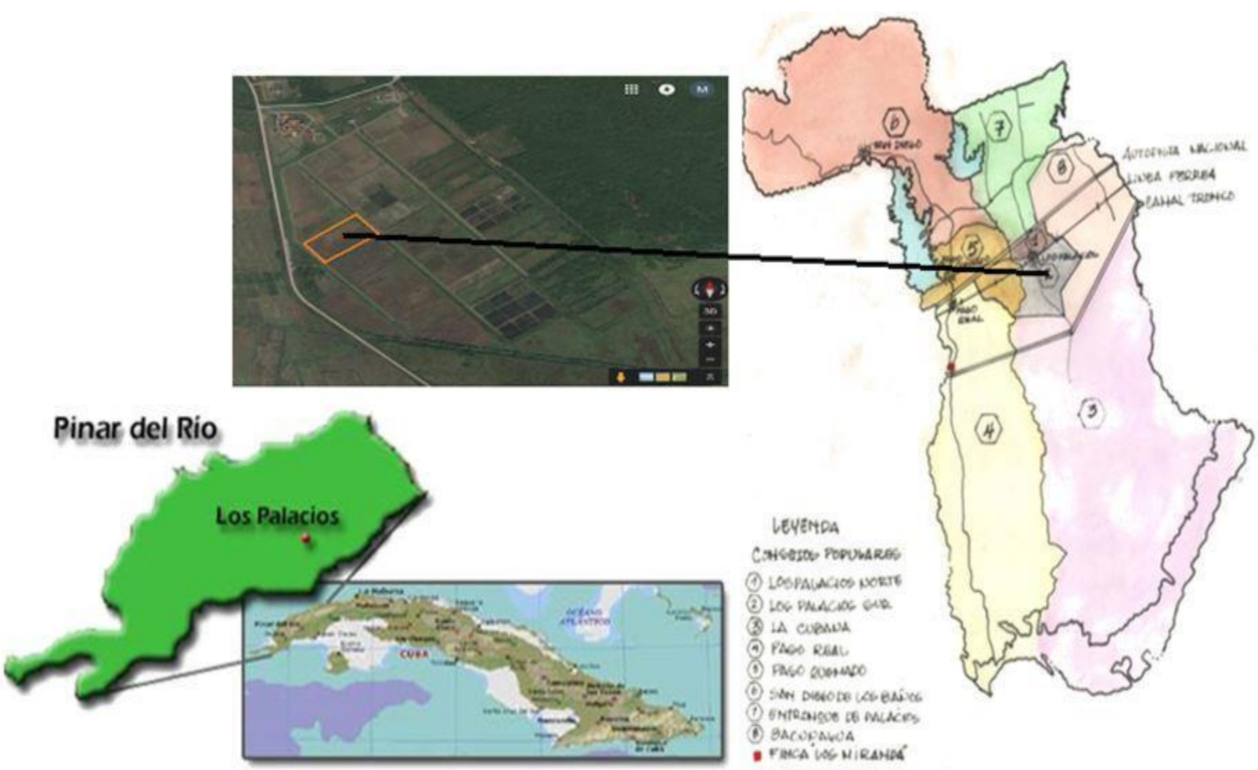

Figure 1. Locations of the experimental area, indicated en satellite image of the UCTB-LP (Google Earth, 2020).

The experimental soil was Concretionary Gley Ferralitic soil, according to the Second Genetic Classification of Soils of Cuba, which is correlated to the Gleysol Plinthic soil (FAO, 2014) with more than 20 years under intensive rice cultivation. This soil has a sandy loam texture (Table 1). The effective depth of the soil is 17 cm, where a ferruginous hard pan appears. It is a soil with very low natural fertility and poor internal drainage, suitable for growing rice.

To implement the basic principles of conservation agriculture, soil preparation was carried out in January 2018 (Table 2). After scarifying the soil, it was left fallow for 170 days and then herbicide (glyphosate at a rate of 3 L ha^{-1}) was applied. Subsequently, the existing plant material was packed, after 7 days, and corn was sown at a rate of 30 kg ha^{-1}, with a distance of 70 cm. To obtain adequate soil coverage, after 60 days (August 20, 2018), the corn was settled and the weeds were dried.

Then, after 10 days, the cultivation of the INCA LP-5 rice cultivar was seeded. It was planted for two consecutive seasons (spring and cold). Finally, after the soil was left fallow for 112 days, weed control and corn planting were carried out on October 15, 2019, which was harvested dry. The till technology conducted in this period is shown in Table 3.

Table 1. Main characteristics of the study soil, according to Cid et al. (2012).

Depth (cm)	Texture (%)			Infiltration	Exchangeable cations ($cmol^{+}kg^{-1}$)			
	Sand	Clay	Silt	($m\cdot dia^{-1}$)	Ca^{++}	Mg^{++}	Na^{+}	K^{+}
20	39.9	27.4	32.7	1.2	15.28	0.54	0.11	0.09

Table 2. Soil preparation technology used to create the necessary conditions to implement the CA principles.

No.	Work	Aggregation		Working depth (cm)
		Tractor	Implement	
1	Plowing	MTZ- 80	Disks harrow 965 kg	10.0
2	Crossing	MTZ- 80	Disks harrow 965 kg	15.0
3	Fluffing	MTZ- 80	Disks harrow 965 kg	15.0
4	Topographic survey	Belarus 952.3	Topographic and design kit AGForm-3D (GPS)	15.0
5	Fluffing	Belarus 952.3	9 organs tiller	15.0
6	Land leveling	ITO 1804	laser land levelling MARA-3m	15.0
7	Fluffing	Belarus 952.3	9 organs tiller	15.0

Table 3. Till technology used for rice seeding.

No.	Crops	Work	Aggregation		Working depth (cm)
			Tractor	Implement	
1	Rice-Corn	Herbicide application	MTZ- 80	Spraying	-
2	Rice-Corn	Overthrow	Belarus 572	Rollo GENOVESE	-
3 A	Rice	Sowing	YTO 1204	Baldan seed drill SPD-5000	2.0
3 B	Corn	Sowing	Belarus 572	VENCE TUDO seed drill	2.0

The irrigation regime used for rice cultivation was non-permanent watering. The germination was achieved without the seeds remaining under a permanent sheet of water. From the 3rd to 5th leaf a sheet of water was established in the plot, which was suspended for nitrogen fertilization, herbicide application, controlled water stress and when the crop reached 50 % panicles.

The bulk density (Bd), specific weight or real density (Dr) and total porosity (Pt) were evaluated for three consecutive years: 2017, 2018 and 2019, at depth ranges of 0 to 5, 5 to 10 and 10 to 15 cm, for each depth range four replicates were taken. The values obtained for each depth range and year were averaged and expressed as a single value. The Bd of the soil was determined by the ring method, following the Cuban norm (NC ISO 10272, 2003). The Dr was determined from a composite sample from each depth range. For its determination, 50 ml pycnometers were used, following the procedure described in Cuban norm (NC ISO 11508, 2000). The total porosity was estimated using the Da and the Dr according to the Cuban norm (NC 20, 2010), following the mathematical model described below:

$$P_t = (1 - \frac{B_d}{D_r}) * 100$$

Where: P_t- Total porosity (%), B_d- Bulk density (g cm^{-3}), D_r- Real density (g cm^{-3}).

The natural humidity of the soil was determined by the gravimetric method, according to the Cuban norm (NC 110, 2010). The organic matter was determined by the colorimetric method, described in the Cuban norm (NC 51, 1999).

The penetration resistance (Rp) was determined by the Eijkelkamp manual penetrometer Model: P.O. Box 4, 6987 ZG Giesbeek, Dutch-made, equipped with an 11.28 mm diameter conical tip and 1cm^2 base area. The instrument is capable of registering values of 100-1000 N, from 1 to 50 cm in depth, with an appreciation of ± 8 %. The soil moisture content during the resistance penetration procedures was around 80 % of the field capacity.

All the evaluated properties were determined in three moments: Before establishing the CA technology (November 2017), at the end of the first rice harvesting (2018) and after the second green manure (corn) incorporation (2019).

Statistical analysis was performed using the free InfoStat statistical package for Windows. The arithmetic mean and standard error statistics were determined; in addition, the predicted and studentized residuals were determined to verify the assumptions of normal distribution and homogeneity of variance. Data were statistically analyzed using analysis of variance (ANOVA) and comparisons of means were made using Duncan's multiple range test with probability $p<0.05$.

RESULTS AND DISCUSSION

Organic matter (OM)

There is a significant difference in the OM content in the soil (Figure 2). An increase in organic matter from 2.41 to 3.66 % was observed, with respect to 2017, reflecting a favorable effect of CA on the soil. Although, the values corresponding to 2017 and 2018 are similar to those found by Pozo et al. (2017) at the depth of 0 -14 cm (from 2.5 to 2.7 %), which they considered adequate for this type of soil, according to clay content. According to the Technical Instructions for the Cultivation of Rice (MINAG, 2014) is considered normal for the development of the cultivation to have values above 3 %, so the result obtained in 2019 can be considered very good.

Other authors have also found significant increases in OM in CA practices. Simon et al. (2009) in a clay loam soil from the Czech Republic found that no-tillage increased the OM content in the soil in a relatively short time. Also, Shahid et al. (2020) in wheat-rice systems, in clayey soils in Pakistan, found that the OM of the soil

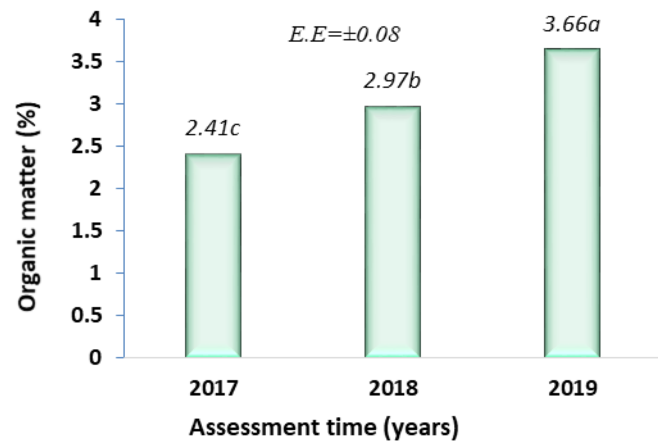

Figure 2. Soil organic matter content from 2017 – 2019 in soil under CA at a depth of 0-15 cm. Values with different letters indicate significant differences for $p<0.05$. Standard error of the mean (E.E.).

improved significantly from the first year of the study, with zero tillage, which was associated with less soil reduction and crop production waste naturally. This behavior is in correspondence with the results obtained and confirms that the tillage system is one of the management practices that can significantly influence this soil property.

Bulk density (Bd)

There is no significant difference in the effect of CA on Bd (Figure 3). The results show for all periods and range a decrease in the Bd, as well as an increase in the Bd with a depth during the planting cycles using the principles of CA.

The bulk density values obtained are higher than those obtained by Díaz et al. (2009) in the same soil (1.18 g cm^{-3}) but with more than 15 years of undisturbing. However, the values are lower than 1.6 g cm^{-3}, a value reported by Pozo et al. (2017) when they studied the same type of soil, under intensive rice cultivation for more than 50 years.

The increase in the values of bulk density with depth is a normal behavior in cultivated soils and coincides with results published by other authors in different types of soil (Herrera et al., 2017; Sartori et al., 2022). Similarly, Harika et al. (2022) suggest that the density of the soil increases with the crop cycle, which justifies the existence of such high values in 2017, even after two and a half years of the soil being fallow, and also corroborates the state of degradation of this rice soil.

On the other hand, the bulk density in no-tillage systems, as well as during the transition process from a traditional system to a no-tillage system, has produced contradictory results. Generally, in long-term experiments with more than 5 years, an increase in bulk density is

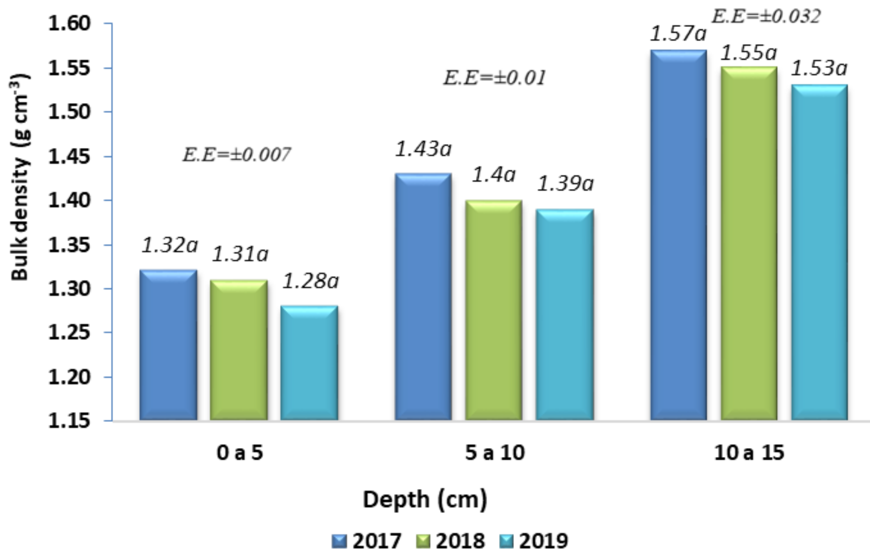

Figure 3. Bulk density of the soil at different evaluation times. Values with different letters at the same depth indicate significant differences for p<0.05. Standard error of the mean (E.E.).

reported in rice soils planted with zero tillage. However, the opposite can occur when the soil has a clayey texture or a high content of organic matter (Jat et al., 2018; Sartori et al., 2022). Yadav et al. (2017) in a similar three-year study, in Northeast India on loamy soil, reported significantly lower soil bulk density and concluded that the adoption of CA can improve the productivity of the system, and the sequestration of C and N in the rice fields. A similar observation obtained by Issaka et al. (2019) in Ghana, evaluating the effect of zero tillage on Gleysol soil, for two years, reported a decrease in bulk density from 1.56 to 1.32 g cm^{-3}.

Real density (Dr)

The values obtained for Dr for each range of depth did not show differences between them, being equal to 2.35 g cm^{-3}. These values are lower than those reported by González et al. (2014), who obtained Dr values of 2.62 g cm^{-3}. However, it corresponds to what was observed by Díaz et al. (2009) in a soil analogous to Los Palacios and Harika et al. (2022) in India, who point out that soil Dr is a property that varies within very narrow limits and is not influenced by rice cultivation technologies.

Total porosity (Pt).

There is no significant difference in the effect of CA on Pt (Figure 4). A noticeable trend reveals an upward shift in the ranking of this property at various depths compared to the 2017 baseline. This suggests a positive impact of CA on the total porosity (Pt). Furthermore, it can be seen that Pt decreases abruptly with increasing soil depth up to 15 cm. This behavior may be associated with the intensive cultivation of irrigated rice for more than 20 years, where efforts are made to reduce the infiltration of water into the soil to maintain a permanent layer of water.

The result observed in Pt coincides with a decrease in the bulk density for the different moments and depths of evaluation, which constitutes normal behavior in agricultural soils. Although the results differ from the optimal Pt conditions suggested by Díaz et al. (2009) for rice cultivation (between 54 and 57 %), the positive effect over time of the implementation of the CA also coincides with results obtained by Selau (2017) in similar studies of medium and long duration, in irrigated rice production systems in Rio Grande, Brazil.

These results are lower than those found by Pozo et al. (2017) of 0-14 cm depth (54.3 %), as well as those obtained by Nelson et al. (2012) in a similar soil of Brazil (48 % at the depth of 0-50 cm) when evaluating the effect of zero tillage on irrigated rice. Instead, they are similar to those found by Muñoz (2016) in Casanare, Colombia in soils under monoculture intensive rice cultivation, for more than 20 years, with average porosity values between 44.09 and 46.72 %, compared to those described by Díaz et al. (2004) in similar soils (41.13 %).

Penetration resistance (Rp)

Figure 5 represents the Rp at soil depth. The results

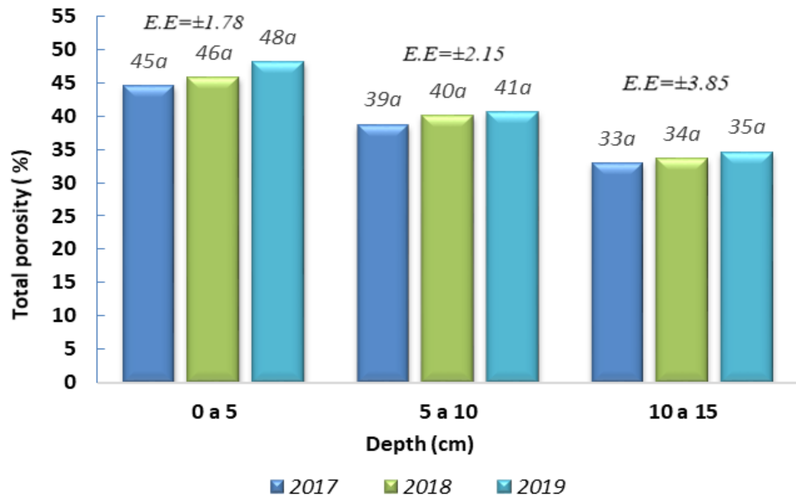

Figure 4. Total porosity of the soil at different evaluation times. Values with different letters at the same depth indicate significant differences for p<0.05. Standard error of the mean (E.E.).

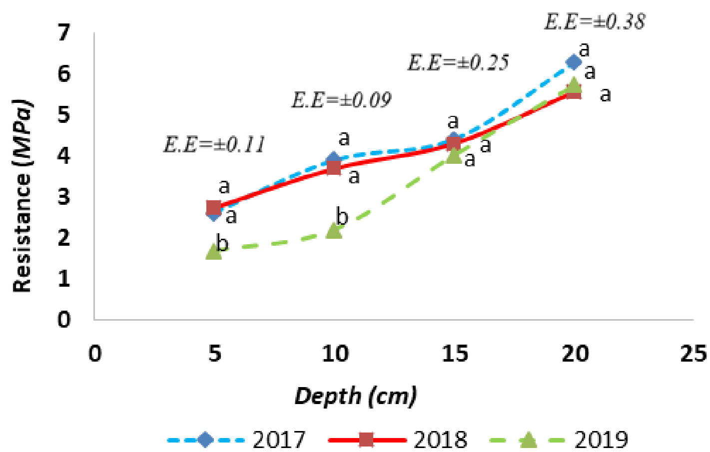

Figure 5. Behavior of penetration resistance in the soil. Values with different letters at the same depth indicate significant differences for p<0.05. Standard error of the mean (E.E.).

show a tendency towards a decrease in Rp values with respect to 2017. The Rp decreases from 4.29 MPa to 3.01 MPa, evidencing the favorable effect of CA on the soil.

The obtained results, in the years 2017 and 2018, show compaction problems in the study areas, which is related to the tillage systems and the forms of rice cultivation previously used, showing values higher than 3 MPa. However, the year 2019 shows a clear decrease in the value of Rp compared to previous years, for depths of 5, 10 and 15 cm, which may be associated with CA actions carried out in the areas. Similar results were obtained by Sartori et al. (2022) in Italy and Botta et al. (2015) in Argentina.

Values of Rp greater than 2.5 MPa could produce difficulties for the root development of the crop, and may remain impeded at depths greater than 8 to 10 cm and values greater than 3.5 MPa, according to Micucci and Taboada (2006). However, the values observed in 2019 until a depth of 12 cm are considered good for rice planting.

Penetration resistance depends on texture, bulk density, total porosity, organic matter content, and soil moisture content, and is specifically correlated with tillage systems Afzalinia and Zabihi (2014). The abrupt change shown in 2019 for the depth from 0 to 10 cm, may be associated with higher moisture content in the soil, an increase in organic matter and the keeping of the soil untilled condition, covering the surface in 90 % with the rest of the harvest, which favors the retention of water in the soil.

CONCLUSIONS

- The application of CA principles in irrigated rice cultivation has a significant effect on increasing the organic matter content of Gleysol Plinthic soil.
- After four sowing cycles, the penetration resistance was reduced from 4.29 to 3.41 MPa and as a trend, the total porosity increased by 9.51 % and the bulk density decreased by 4 g cm^{-3}, concerning the baseline, which shows that CA can contribute to the improvement and conservation of rice soils.
- Considering that the best physical and chemical conditions for crops are preferably found in soils with high OM content, the implementation of CA can help rice farmers sustainably intensify their cropping systems.

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Conflict of interest

The authors declare no conflict of interest.

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