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The birth of a new cropping system: towards sustainability in the sub-tropical lowland agriculture

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ABSTRACT

Developing cropping systems that meet multiple demands of high production, resource-use efficiency and low ecological footprint is a major global challenge. In Southern Brazilian lowlands, irrigated rice (*Oryza sativa* L.) in combination with fallow for beef production is the dominant cropping system. This system is key to Brazilian food security but faces problems of resource use efficiency, soil preservation and greenhouse gas emissions typically associated to rice irrigation. In this research, a multi-criteria analysis of the usual rice-fallow system, and a number of alternative production Schemes – i.e., the more recent rice-soybean (*Glycine max* (L.) Merr.) rotations and the newly developed systems based on large ridges, was made. The latter is based on the construction of large ridges (8 m width) on which rainfed maize (*Zea mays* L.) and soybean, conducted in no-tillage, are integrated with either beef-livestock production or cover crops in winter. This study was done in an experiment that lasted for nine years. The five cropping systems were managed as independent fields and a range of indicators related to crop management, productivity and sustainability was measured. The Rice-Fallow system required the lowest amount of energy, but it had the lowest energy use efficiency and highest carbon-based environmental footprints, when expressed as greenhouse gasses emitted per kg of food produced. The rice-soybean rotation system presented an improved performance for the carbon-based footprints in comparison to the rice-fallow system. Within rice-soybean rotation, using minimum-tillage instead conventional tillage increased the overall carbon balance and the carbon sequestered into the soil as organic matter. Most strikingly, the new ridge-based systems exhibited the most favourable values for many of the indicators. The more diverse rotation system, and particularly the extension of the growing season to winter, resulted in improvements in soil quality, biomass production and carbon sequestration into the soil. Water- and light- use efficiency were increased, whereas greenhouse gas emissions reduced. The ridge-based crop-livestock integration offered the best balance between food production and environmental preservation. This cropping system is potentially one of best alternatives to increase agricultural diversification and sustainability in the sub-tropical lowlands such as in southern Brazil. This shows that modifications of cropping systems can result in major simultaneous improvements in yield, resource-use efficiency and ecological sustainability.

1. Introduction

Current cropping systems are under an increased pressure of producing more food with less inputs and to combine this high efficiency with the smallest possible negative impact on the environment (Brentrup et al., 2004; Schipanski et al., 2014). Engineering systems that meet these multiple demands is complex, particularly for agriculture in sensitive environments, like the lowlands (Durno et al., 1992). The lowlands in sub-tropical South America comprise important agricultural production systems, a large repository of freshwater and wild life. In the south of Brazil the lowlands cover a total area of 6 million hectares. Next to the environmental services provided by the natural landscapes, food production, an important additional ecosystem service, is provided through agriculture. Approximately eighty percent of rice, the main food of the Brazilian population, is produced under surface irrigation in the temperate lowlands in the south of Brazil.

Irrigated rice has been the main crop in the lowlands of south Brazil for more than a century. Rice is cultivated in 1.2 million hectares yearly, but a large part of the anthropic lowlands commonly remains fallow, or are destined for extensive beef-cattle production. The most

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common soils in this environment, gleysols and planosols, are characterized by poor drainage and a high bulk density (Lima et al., 2009). These conditions make the fields well suited for irrigated rice production, but form serious restrictions for species which do not tolerate waterlogging. As a result, rice is the main crop, and usually even the sole crop, in the agricultural systems of the lowlands.

There is however no doubt that alternation of irrigated rice with other crops bears positive implications for sustainability of the lowland agro-ecosystems (Komatsuzaki and Ohta, 2007; Hokazono and Hayashi, 2015). Crop rotation helps reduce weed problems (Erasmo et al., 2004; Andres et al., 2012) and increases soil quality (Everaarts et al., 2015). In addition, emissions of methane and other greenhouse gasses, typical for irrigated rice, can be reduced with crop rotation in lowlands (Nishimura et al., 2011; Weller et al., 2016). Despite the advantages of more diversified cropping systems and the high demand for grains other than rice in local and international markets, the use of crop rotation is not widely practiced in the wetlands. Currently, less than one-third of irrigated rice in south Brazil is rotated with other grain crops, mostly with soybean (IBGE, 2015). Also winter cover crops, like black oat, forage radishes and vetches (*Avena strigosa*, *Raphanus* sp. and *Vicia* sp., respectively), species which provide relevant environmental services for agricultural systems in the uplands (Schipanski et al., 2014; Teixeira et al., 2016), hardly adapt to the typical soil conditions in lowlands and are therefore almost absent. Obviously, the only way to create conditions that would support more diversified systems is by removing the inherent restrictions of hydromorphic soils for growing other crops. One alternative in this sense is the establishment of large ridge based systems (Fig. 1), where the alternation of ridges and small channels create a drier environment, well suited for the production of crops that do not tolerate waterlogging, as well as the introduction of cover crops during winter time. Due to the large area under fallow in the south Brazilian lowlands, introduction of such novel systems does not necessarily compete for land with the current rice production systems.

Identification of the most adequate cropping system for the lowlands, which would simultaneously achieve economic, environmental and technical demands, is an intricate task. Some production oriented, short-term studies indicated technical advantages of crop rotation and integrated crop-livestock systems over mono-crop models (Balbinot Junior et al., 2009; Vernetti Junior et al., 2009; Ferreira et al., 2014). However, long-term studies, in which sustainability is assessed from an integrated perspective and addressing a wide range of criteria, are missing. Such studies are required to capture differences that only become apparent in the long run, and also would prevent that erratic short-time events, like a drought in a specific cropping season, would distort the analysis. Considering that lowlands are one of the most attractive new frontiers for rainfed crops in southern Brazil (Feix and Leusin, 2015) and elsewhere (Durno et al., 1992), a critical analysis of current and alternative cropping systems is an important step for identifying how to best equilibrate increased food production with environmental preservation.

In this research, we analysed three rice-based cropping systems and two novel ridge-based production models implemented in the Brazilian temperate lowlands. For the rice-based models, the systems were distributed in a coherent range of configurations: one simple model (rice-fallow) plus two more elaborated systems (rice-soybean in conventional and minimum till). In addition, the ridge-based models represent two feasible alternatives: both contained summer rainfed grain crops, with one model prioritizing winter cover crops and the second focusing on crop-livestock integration. During nine consecutive years, data were collected in these cropping systems, which were composed by farm-size plots located side-by-side within an experimental station. For each of the cropping systems, indicators reflecting a range of aspects related to field and crop management, productivity and sustainability were assessed and analysed.

2. Material and methods

2.1. Site description

This study was conducted in the Lowlands Experimental Station (LES), which belongs to Embrapa (Brazilian Agricultural Research Corporation), near Pelotas, in Rio Grande do Sul (RS state), southern Brazil (31.8134 S; 52.4736 W). The experiment started in May 2006, when five cropping systems were established in a uniform 33-ha area inside LES. This field had been maintained in fallow with spontaneous vegetation since 2000, and cultivated with irrigated rice in the 2004/05 and 2005/06 cropping seasons. The terrain is flat, at 13 m above sea level and the soil is classified as Solodic haplic eutrophic Planosol, belonging to the Pelotas mapping unit (Streck et al., 2008). A soil analysis just prior to the start of the experiment indicated an average soil bulk density of 1.49 kg dm^{-3} and a composition of 283 g dm^{-3} clay, 551 g dm^{-3} silt and 608 g dm^{-3} sand. The climate is humid temperate (Cfa, according to Köppen's classification (Alvares et al., 2013)), with an average temperature of 17.8 °C and yearly precipitation of 1367 mm.

The five production systems, for which a description is included below, varied in size between 3.1 and 11.0 ha. The size varied due the permanent structure (roads, channels, fences) in the experimental station. The names of cropping systems and the essential characteristics are, noting that systems d and e are novel:

a) Rice and fallow ("Rice-Fallow"): dry-seeded irrigated rice with

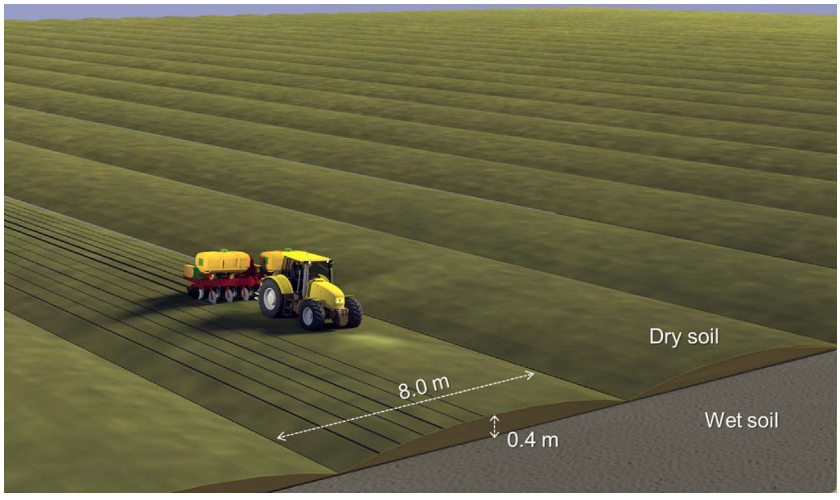

Fig. 1. Simplified drawing of a lowland field conducted with large ridges.