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Including cover crops during fallow periods for increasing ecosystem services: Is it possible in croplands of Southern South America?

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ABSTRACT

The integration of cover crops (CC) into annual crop rotations improves the provision of multiple ecosystem services in time and represents an alternative paradigm to achieve sustainability goals. In spite of the benefits that several authors have exposed, CC are seldom included in rotations because their water consumption could affect cash crops development. We evaluated the possibility of including CC in the agricultural area of Rio de la Plata grasslands and identified its optimal duration depending on both environmental conditions and crop rotations. Fallow areas were located based on NDVI time series derived from MODIS satellite images and the influence of CC on the subsequent cash crop was evaluated based on modeled changes in soil water contents at the sowing date of the cash crop. Our land use classifications revealed that single crop rotations, mostly summer crops with winter fallow periods, occupy a large proportion (89%) of the agricultural portion of the Rio de la Plata grasslands studied. In most of the region, sowing CC of 3 to 5 months of length during fallow periods had little impact on soil water contents at the sowing date of the following cash crop. As expected, the optimal CC duration in the different sub-regions increased with the average rainfall occurred during the fallow period. The possibility of sowing CC without affecting cash crops yields opens the opportunity for intensifying crop sequences in the region, oriented to mitigate environmental concerns raised by monocultures and agricultural simplification.

1. Introduction

Simplification and intensification of agricultural systems (e.g. continuous agriculture and monocultures) challenges the sustainability of crop production, both at national and global scales. Several practices aimed to increase productivity affect ecosystem components and processes, disrupting numerous regulating and supporting ecosystem services, including nutrient cycling, climate and water regulation, pollination services, weed resistance and pest and disease regulation (Palm et al., 2014; Power, 2010). This trends have demanded continuous research in cropping systems where ecosystem services are preserved and production is sustained in the long-term (Foley et al., 2003; Malézieux et al., 2009; Oliver et al., 2010).

Recently, an alternative paradigm to mainstream agricultural practices has been proposed to meet the challenge of increasing productivity but maintaining the supply of ecosystem services and therefore achieving sustainability goals. This, "ecological intensification" paradigm proposes the use of ecological principles to guide the management of agricultural systems for increasing both provisioning services (e.g. food, fiber) but also regulating, supporting and cultural ecosystem services (Tittonell, 2014). Under this view, it has been suggested that trade-offs between agricultural production and ecosystem services can be avoided and that 'win–win' scenarios are possible. Examples of ecological intensification include organic agriculture, diversified farming systems, nature mimicry and some forms of conservation agriculture (Tittonell, 2014). Practices such as intercropping, double cropping or cover crops have been proposed in conservation agriculture to increase sustainability (Bommarco et al., 2013; Doré et al., 2011), because several works show that the integration of cover crops into annual crop rotations improves the provision of multiple ecosystem services in time, such as N regulation, soil aeration, weed and pest control, etc. (Schipanski et al., 2014). Moreover, the reduction of fallow periods allows mimicking the functioning and structure of natural systems and therefore reducing the environmental impacts of agricultural land use changes (Jackson and Jackson, 1999).

A large body of knowledge is being rapidly developed on cover

Abbreviations: SWCsd, soil water content at the cash crop sowing date; PSWCsd, probability of finding the same SWCsd after fallow

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crops and their impacts on agricultural systems. Several authors have studied how to improve structural and functional attributes of agroecosystems by sowing Cover Crops (CC). The inclusion of CC generally increases soil organic matter (Ding et al., 2006; Duval et al., 2016; Sainju et al., 2006; Venkateswarlu et al., 2007) and improves physical properties (Chen et al., 2014; Hermawan and Bomke, 1997; Sasal and Andriulo, 2005; Varela et al., 2011). Moreover, CC could improve nutrient cycling through the inclusion of N-fixing legumes, decreasing leaching by nutrient immobilization through grasses or resorting to both methods simultaneously (Bergkvist et al., 2011; Büchi et al., 2015; Kramer et al., 2002; Plaza-Bonilla et al., 2015; Rosecrance et al., 2000; Sainju et al., 2005; Teixeira et al., 2016). In general, single cash crops use only a small proportion of potentially available resources (Caviglia, 2004). Thus, shortening fallow periods with CC could be useful to increase capture and resource use efficiency (e.g. radiation and water) in order to increase ecosystem services.

In spite of the benefits exposed, CC are seldom included in rotations because their water consumption could affect cash crops development. Soil water content (SWC) at the cash crop sowing date (SWCsd) is a good variable to evaluate this effect. Restrictions in cash crop development due to water availability do not occur if SWCs remains unchanged (or increases) after fallow periods. Both locally and globally, different effects of CC in SWC have been found, depending on the length of fallow period (or CC duration) and precipitation regimes. Some authors found that CC lead to a significant decrease in SWCsd as compared to bare soil fallow periods but with a small impact on cash crops yields (Nielsen and Vigil, 2005; Restovich et al., 2012; Rimski-Korsakov et al., 2015). Other authors even propose that SWCsd may increase, because soil evaporation decreases due to increased soil cover and mulching (Quiroga et al., 2005). In summary, the potential effect of CC on SWCsd will depend on environmental conditions and CC duration (Verburg et al., 2012).Therefore, mapping fallow periods and their duration, as well as environmental conditions is key for potentially including CC of different durations into current crop rotations.

Several regions of the world lack crop or vegetation cover during part of the year, allowing fallow periods of different duration and offering opportunities for including CC (Siebert et al., 2010). The *Rio de la Plata* grasslands (including the *Pampas* of Argentina and *Campos* of Uruguay and Brazil), is one of the world's largest croplands where accelerated land use changes are challenging the sustainability of crop production and food security worldwide. During most of the twentieth century traditional cropping systems of the *Rio de la Plata* grasslands included perennial pastures in similar proportions to annual crops (García-Préchac et al., 2004; Hall et al., 1992; Soriano et al., 1991). However, since the 90s, cropland area has increased at the expense of a reduction in pastures area (Baldi and Paruelo, 2008; Viglizzo et al., 2011). Furthermore, cropping sequences became simpler, with a predominance of soybean and limited crop diversity, raising concerns about the sustainability and environmental risks associated to crop production in a region which is relevant for the world grain and oil market (FAO, 2014). Currently, a large proportion of the agricultural area of the *Rio de la Plata* grasslands is potentially under fallow periods at some time during the year (either during summer or winter) (Paruelo and Guerschman, 2005; Restovich et al., 2012). However, there is no detailed information on their spatial distribution or interannual variability, because National agricultural statistics (http://www.siia.gov.ar/sst_pcias/estima/estima.php) and National Census (http://www.indec.gov.ar/cna_index.asp), only report single crop areas, and do not report areas under fallow or double crops.

Satellite images can be used to determine changes in agricultural land uses and therefore help identifying fallow periođs location and duration (Baeza et al., 2014; Kerr and Ostrovsky, 2003). Different wavelengths are recorded by sensors on board satellites that can describe biophysical properties of ecosystems (Myneni et al., 1995). The Normalized Difference Vegetation Index (NDVI) is a widely used index, which integrates two key aspects of the spectral behavior of photosynthetic tissues: low reflectance in red wavelengths and high reflectance in the near infrared portion (due to chlorophyll absorption and leaf mesophyll structure, respectively) (Myneni et al., 1995; Paruelo, 2008). NDVI has been related to leaf area and thus used to describe cropś phenology based on images time-series (Sakamoto et al., 2010). Several authors used this approach to perform land use classifications, identifying different crop types and fallow periods (Friedl et al., 2002; Guerschman et al., 2003; Han et al., 2008; Siebert et al., 2010; Wardlow et al., 2007).

Our objective was to evaluate the possibility of including CC in the agricultural area of *Rio de la Plata* grasslands and to identify its optimal duration depending on both environmental conditions and crop rotations. To achieve this objective, we: (1) spatially identified fallow periods and classified them into winter or summer fallows; (2) determined sub-regions with a similar proportion of summer, winter or double crops; and (3) evaluated soil water content on the cash crop sowing date (SWCsd) after fallow periods or after CC with different durations within each sub-region.

2. Materials and methods

2.1. Study area

Our study area covers most of Rio de la Plata grasslands in Argentina and Uruguay (Soriano et al., 1991). This huge region has more than 120 million hectares and extends between 30° and 39° south latitude parallels and 50° and 66° west longitude meridians. It represents the agricultural central area of Argentina and west coast of Uruguay (Fig. 1). In this region field crop production has increased since the last quarter of the 19th century and nowadays is the key agricultural activity in the region, with the widespread use of no-till farming, agrochemicals and transgenic crops. Currently, soybean is the main crop in the region, followed by maize, wheat, sunflower and other minor crops (FAO, 2014).

The region is a vast plain with a warm and temperate climate. Rainfall occurs throughout the year, decreasing from north to south and east to west from 1200 to 600 mm annually (Cabrera, 1976). Rainfall has a seasonal pattern with a summer maximum and lower amounts of precipitation in spring and autumn, with a minimum in winter (Hall et al., 1992). The high variability of rainfall events is mainly explained by the ENSO phenomena (Podestá et al., 2002). Mean annual temperature varying from 17 °C in the north to 14 °C in the southern portion of the region, being 6 to 8 °C higher in summer and about 5–6 °c less in winter (Hall et al., 1992). Soils are mainly based on loess "Pampeano" deposits, with high proportions of silt and high natural fertility. Dune ripples, sandy soils and loosely structured surface horizons predominate in the west wile silt and clay textured soils are common in the central and eastern Buenos Aires. In Entre Rios and Uruguay (northeast of the study area) soils are predominantly clay-rich (Vertisols) with a highs water erosion risk and low drainage (Panigatti, 2010; Soriano et al., 1991).

2.2. Evaluation of the inclusion of CC in fallow periods

We evaluated the possibility of including CC in the agricultural area of Rio de la Plata grasslands and identified their optimal duration by means of three steps. First, we used temporal-series of MODIS sensor to identify spatially fallow periods and classified them into winter or summer fallows in the 2001–2010 period. Second, we delimitated different sub-regions that had similar proportions of winter, summer and double crops to analyze the variation of the area occupied by fallow periods along the same period. And third, we performed water balances using both climatic and soil characteristics found in different weather stations located in each sub-region. From these water balances, we evaluated the probability of finding the same SWCsd after fallow or after CC with different durations within each sub-region. Finally, we

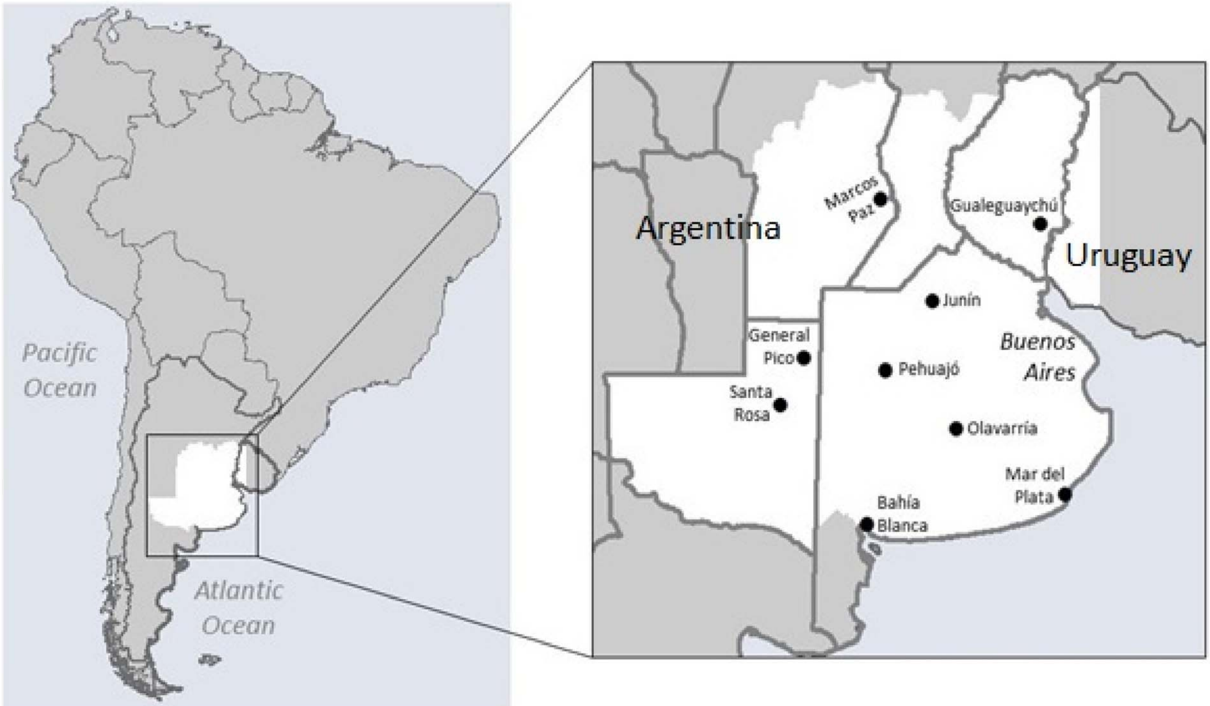

Fig. 1. Map of the study area. Black dots show weather stations where water balances were performed in the study.

used the water balance results to adjust linear regressions between the longest duration of CC that did not significantly change SWCsd with rainfall accumulated during the fallow period.

2.2.1. Mapping fallow periods

Fallow periods in the study area were located based on NDVI time series derived from MODIS satellite images to determine the potential area where a second crop in the year could be sown. Specifically, the product MOD13Q1 (http://modis.gsfc.nasa.gov/) was used in our work, because it has an appropriate spatial and temporal resolution (approximately 250 m and 23 good quality images per year). We used a large data base assembled by the LART-FAUBA (Laboratorio de Analisis Regional y Teledetección de la Facultad de Agronomía, Universidad de Buenos Aires) that compiles average NDVI time series for pixels contained inside polygons associated to different land uses (i.e. soybean, maize, wheat). Based on field trips performed from 2005 to 2009, 1981 ground control points were located, and land uses registered. Land uses were grouped into 4 classes: Winter Crops, Summer Crops, Double Crops and Non-croplands areas. Within cropland classes, winter and summer crops presented a fallow period (in summer and winter, respectively) but not double crops.

Based on NDVI time series of each ground control point and we performed a supervised land use classification algorithm based on NDVI time series and using two third of our recorded ground control points. The decision trees classifiers were developed with the See5 software (http://www.rulequest.com/see5-info.htmlhttp://www.rulequest.com/see5-info.html) (see Supplementary material for details). We first separated cropping areas (winter, summer and double crops) from non-croplands areas with a decision tree that included several nodes (see Supplementary material for details). Within the croplands area previously classified, a second tree was trained that separated single crops (winter and summer) from double crops. Finally, a last decision tree separated winter crops and summer crops within single crops classes (see Supplementary material for details). These decision trees were used to classify the study region in all years from 2001 through 2010. A filter was used to remove polygons smaller than 20 ha obtained in the classifications. In addition, a Non-croplands class was assigned to water and cities, based on MODIS product MCD12Q1, with a 500 m spatial resolution.

We evaluated our classifications by two independent sources. First, we constructed confusion matrices to assess our classification accuracy, using one third of the land use dataset, which was previously separated and not used in the training process of the decision trees. Second, we compared our results with sown crop areas reported by National statistics (Sistema Integrado de Información Agropecuaria SIIA, http://www.siia.gov.ar/sstpcias/estima/estima.php) and compared our estimates on a county basis. We used only the most common winter (wheat and rape) and summer crops (soybean, corn, sunflower and sorghum). For this comparison, we added our double crop areas to both summer and winter crop‘s area, because National Statistics do not report double crop areas but they are included in both summer and winter crops.

Using our classifications, we delimitated different sub-regions that had similar proportions of winter, summer and double crops to analyze their variation along the period from 2001/2002 to 2009/2010 campaigns. We created synthetic images of 4800 ha pixels (each pixel included 900 pixels of our original classification with MODIS) where the percentage of each cropland class in each new pixel was estimated from our classification. Using these synthetic images, we performed a maximum likelihood classification to separate homogenous sub-regions with similar proportions of each land use class. In each sub-region, we calculated the area occupied by each land use class and we analyzed its variation between growing seasons from 2001/2002 to 2009/2010.

2.2.2. Water consumption by cover crops

The influence of CC on the subsequent cash crop was evaluated based on modeled changes in soil water contents at the sowing date of the cash crop (SWCsd) in nine sites (weather stations) distributed across our study region (Fig. 1). Therefore, we estimated the probability of finding the same SWCsd after fallow, which we called PSWCsd. To estimate PSWCsd we performed water balances at all sites (based on long-term weather series, > 40 years) for summer crops alone (soybean, corn and sunflower) and also for summer crops followed by CC with different durations. CC influence on the PSWCsd of winter crops (wheat), was only evaluated in Mar del Plata, Santa Rosa and Bahia

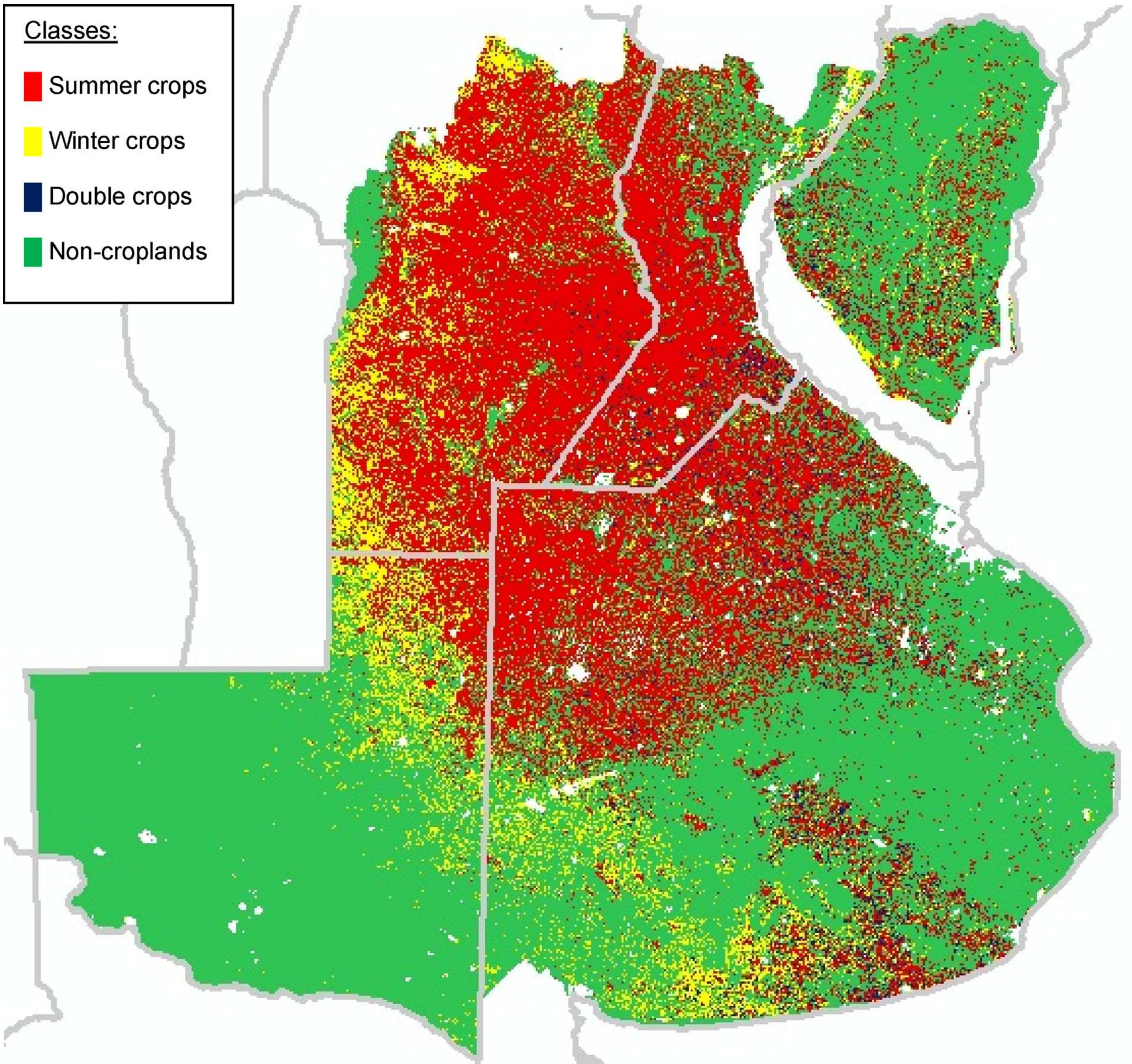

Fig. 2. Land use classifications for 2009–2010 growing season. Classifications were made using decision trees algorithms and spectral signatures of MODIS-NDVI.

Table 1
Decision trees evaluation. Confusion matrices and % error estimated by See5 software.

1st tree (Error = 2.8%)		Non-croplands (%)	Croplands (%)
	Non-croplands	98.0	2.0
	Croplands	4.3	95.7
2nd tree (Error = 5.7%)		Double crops (%)	Single crops (%)
	Double crops	89.9	10.1
	Single crops	3.2	96.8
3th tree (Error = 3.8%)		Summer crops (%)	Winter crops (%)
	Summer crops	100.0	0.0
	Winter crops	14.7	85.3

Blanca because winter crops were rare in the other sub-regions. In all situations, we compared SWC average of 15 days around the cash crop sowing date. To estimate water consumption by crops we used the BHOA model (Fernández-Long et al., 2012), a coupled evapotranspiration-soil water balance model based on the Kc curves provided by FAO (Allen et al., 2006). We did not use simulation models, such as DSSAT, CropsSys and APSIM because model parameters for CC have not been developed for the region, whereas the BHOA model has shown very good performance in SWC estimation at regional scale (Carnelos et al., 2014).

Water balances were based on Thornthwaite and Mather (1955) and including changes based on Forte Lay et al. (1995). Potential evapotranspiration was calculated with the Penman-Monteith model (Allen et al., 1998). Daily rainfall, maximum and minimum temperatures, solar radiation, wind intensity and vapor pressure, were obtained from weather stations of the Servicio Meteorologico Nacional. Soil parameters for the water balance (field capacity and wilting point) were taken from published articles when available (Damiano and Taboada 2000; Damiano, 2010; Hurtado, 2008; Spescha, 2008) or estimated based on a soil water characteristic model (Saxton and Rawls, 2006) (Supplementary material). Crop evapotranspiration was estimated by crop coefficients (Kc) for each day using the Kc curve method as proposed by (Allen et al., 2006). This method requires establishing Kc values across four periods during the growing season of the crop (initial, crop development, mid-season and end of season). Kc values for all periods for soybeans, corn, sunflower and wheat, were obtained from Allen et al. (1998) (Supplementary material). The different durations of crop phases were estimated considering emergency and physiological maturity dates reported for each site by the Oficina de Riesgo

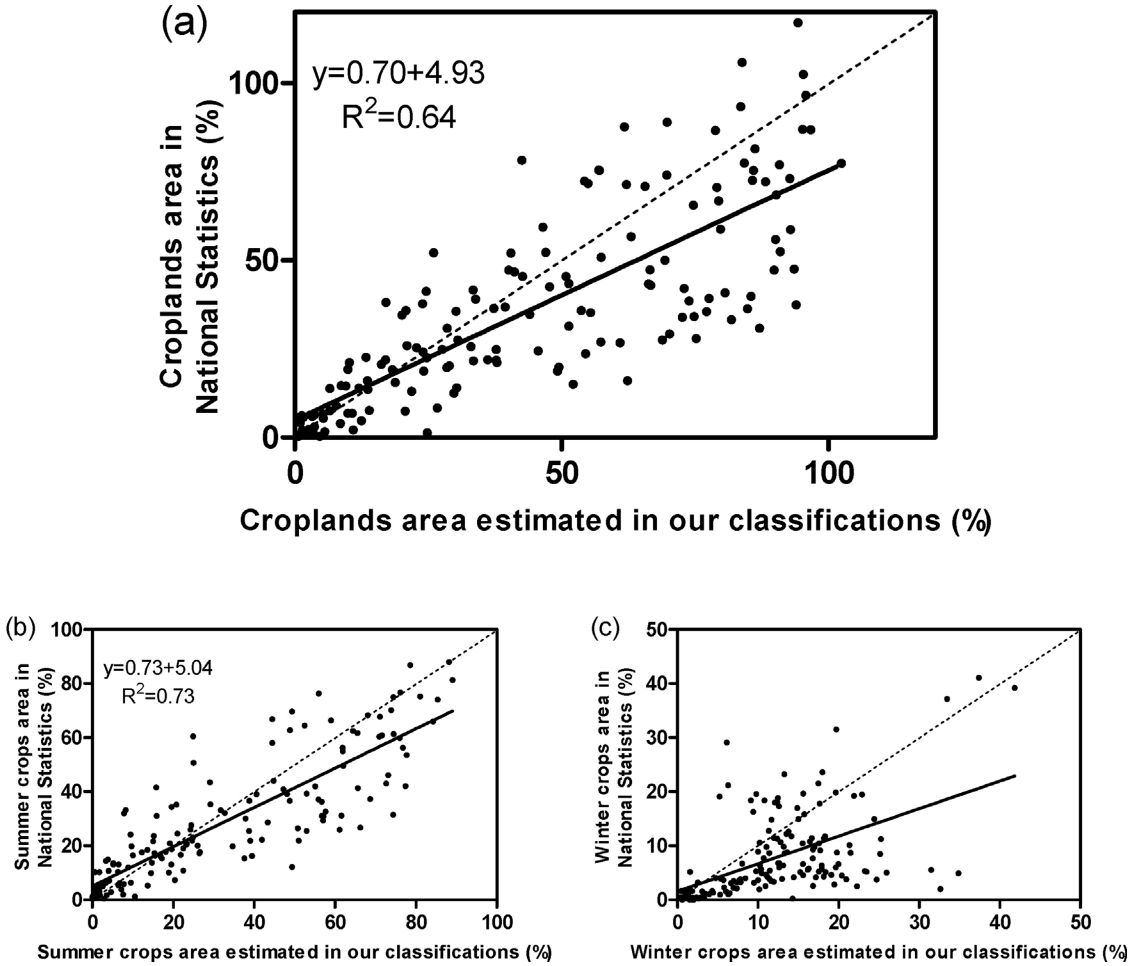

Fig. 3. Correspondence between the% of agricultural area (a), summer crops (b) and winter crops (c) in each department according to the classifications of the present study, and percentages reported by National Statistics.

Agropecuario (ORA) (www.ora.gov.ar). Kc curve periods were established from these dates, while the duration of each period was calculated from the relative duration established by Allen et al. (1998). The Kc curves of CC were estimated considering that the initial period began 10 days after the cash crop was harvested and had 22 days of duration, while the development period lasted 28 days and the mid-season period was modified to give CC durations ranging from two to six and a half months, depending on fallow periods. The final period of the Kc CC curve was not considered since CC are usually suppressed before they reach this phase. Finally, we considered a Kc = 0.2 for fallow periods (see Supplementary material for details).

We defined the duration of the CC considering all years in the weather dataset of a site, when the PSWCsd was higher than 90% of the years. We estimated the maximum duration of the CC by comparing long-term average SWCsd 15 days before and after sowing the cash crops. The longest duration of CC was set in the maximum length that did not change significantly SWCsd and was called "Possible CC duration" (PSWCsd > 90%). Finally, linear regressions were adjusted between "Possible CC duration" and the rainfall accumulated during the fallow period, using the Pearson coefficients.

3. Results

3.1. Spatial location of fallow periods

Our land use classifications revealed that single crops occupy a large proportion (89%) of the agricultural portion of the Rio de la Plata grasslands studied (Fig. 2). These were usually summer single crops, since winter single crops were only found in the southwest portion of the region (Fig. 2). Moreover, double crops were scarcely present in the area and therefore, fallow periods occurred more frequently than expected. These results were consistent along all 9 years studied (2001–2010), since land use classifications obtained in different years were very similar and no significant trends were observed within summer, winter and double crops in the different sub-regions, despite of annual oscillations (Slope = 0, $p < 0{,}01$) (Figs. 1 and S7–S14 in Supplementary material).

Both independent evaluation sources showed that our classification accuracy was adequate. On the one hand, overall errors of the decision trees classifiers were always lower than 6% (overall accuracy). Our second decision tree showed that only 10% of the double crops were potentially misclassified as single crops (Table 1). On the other hand, our classification was in agreement with agricultural areas reported by national statistics in the region ($r^2 = 0.64$, n = 153, $p < 0.01$) and correlations were even better for summer crops ($r^2 = 0.73$, n = 153, $p < 0.01$) (Fig. 3 a-b). However, our estimates of winter crops showed lower areas than national statistics, suggesting a possible overestimation in our classifications. Most of the departments in which we overestimated winter crops had greater proportions of summer crops, and therefore the probability of underestimating double crops in the agricultural area was relatively low.

Five distinct sub-regions were separated based on the proportion of the land occupied by summer, winter or double crops (Fig. 4). Double cropping was the less abundant class in all sub-regions, but it existed in low proportions in all of them (note that blue areas are barely visible in Fig. 2). However, double crops were more common in sub-regions1, 2

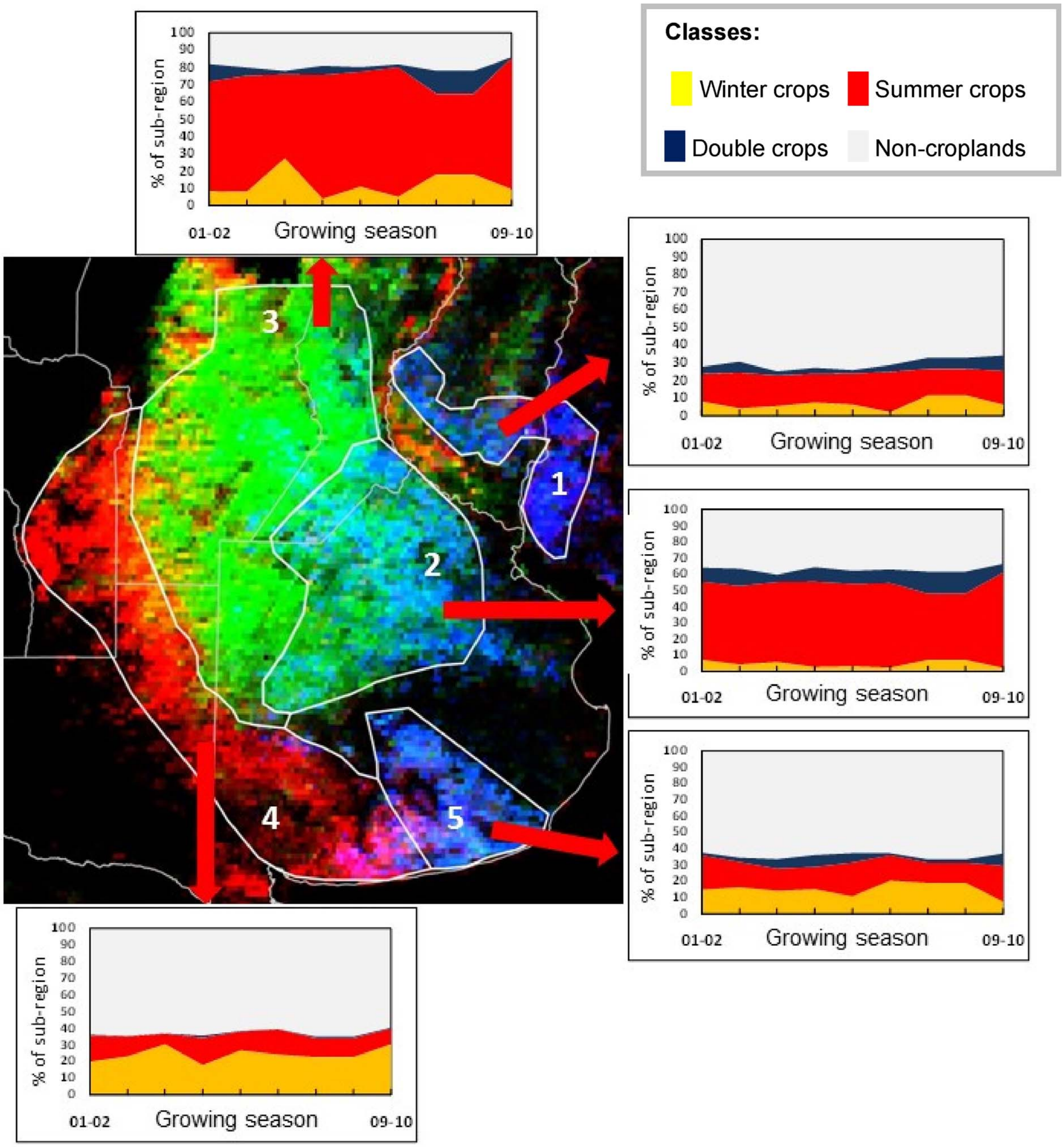

Fig. 4. Map showing sub-regions with similar proportions of summer, winter and double crops. Insets show for each sub-region temporal variations in the proportion of the land occupied by each land use type from 2001 through 2010.The map corresponds to a false color composite made with the three synthetic images with percentage of land use types (red band for winter crops, green band for summer crops and blue band for double crops). Each sub-region was identified by a number and white lines represent their estimated boundaries. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and 5. These sub-regions included the east of Uruguay, Entre Rios and northeast and southeast of Buenos Aires province (areas with rainfall higher than 800 mm year^{-1}). Only sub-region 1 had double crops present in more than 25% of the agricultural area in at least one campaign. Therefore, all sub-regions presented large fallow periods during the year and this pattern was relatively constant in all growing seasons analyzed (Fig. 4). Winter fallows were dominant in sub-region1, 2 and 3 and summer fallows dominated in sub-region 4, while the proportion of summer and winter fallow periods were similar within sub-region 5.

3.2. Potential effects of cover crops on soil water contents

Our results showed that in most of the region, sowing CC of 3 to 5 months of length during fallow periods had little impact on soil water contents at the sowing date of the following cash crop (SWCsd) (Fig. 5). Although CC decreased the probability of finding the same amount of SWC at the cash crop sowing date (PSWCsd), reductions were always significant (with a probability higher than 90%) only in the southwest portion of the region (sub-region4). In all sub-regions PSWCsd decreased with longer CC duration, but steeper decreases were observed in sub-regions 3 and 4 (Fig. 5). In regions 1, 2 and 5, PSWCsd was higher than 90% for cover crops of up to 4–5 months of length, suggesting that the incorporation of cover crops or double cropping in these sub-regions is highly viable. All crops studied showed similar results, but corn had the highest differences between sub-regions and sunflower allowed potentially longer CC durations.

When analyzing all crops together and all locations, the optimal CC

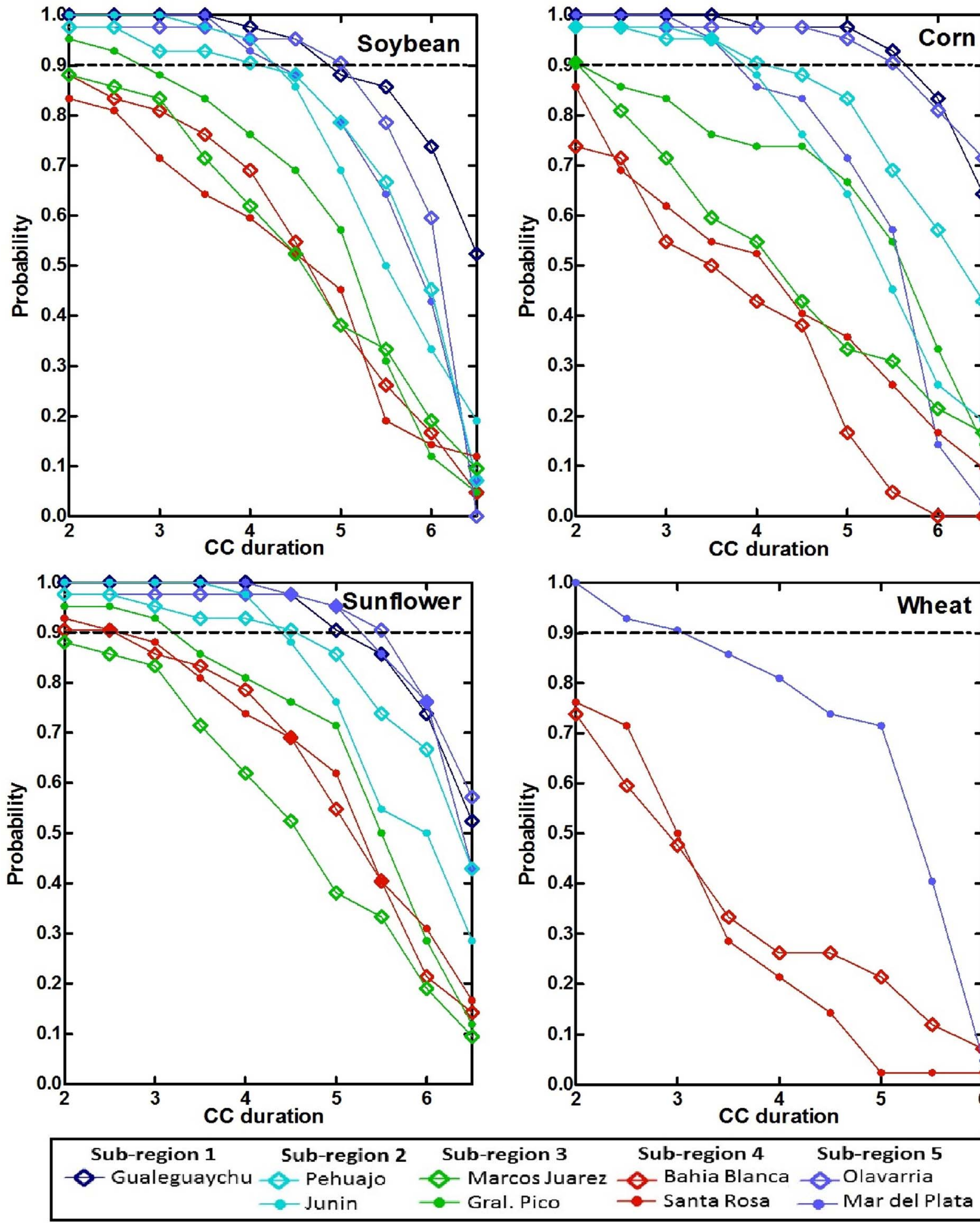

Fig. 5. Relationship between the cumulative probability of having the same soil water content at the sowing data of the cash crop (PSWCsd), and the duration of a cover crop planted during the fallow period. Each line represents a weather station studied and colors identify sub-regions (see Fig. 4). The horizontal dashed line indicates the 90%probability of having the same amount of soil water with or without planting a cover crop. Each panel shows the results for different crops (soybean, corn, sunflower or wheat).

duration (with PSWCsd > 0.90) was significantly related with the average rainfall occurred during the fallow period (Fig. 6). The regression model (CC duration = $-1 + 0.01_{(\text{months/mm})}$ * Cumulative rainfall during fallow $_{(\text{mm})}$) indicates that CC can be sown when cumulative rainfall during the fallow period is at least 100 mm, although durations of 3 months or more are feasible with 350 mm or higher rainfall during fallow periods. In addition, in most regions, the longest CC durations were observed when the cash crop sown was sunflower, followed by soybean and maize (see shapes in Fig. 6).

4. Discussion

Land use classifications arising from our work showed that a large proportion of the agricultural area of the Río de la Plata grasslands has single crops and therefore the existence of fallow periods in the region is greater than previously thought (Caviglia, 2004; Paruelo and

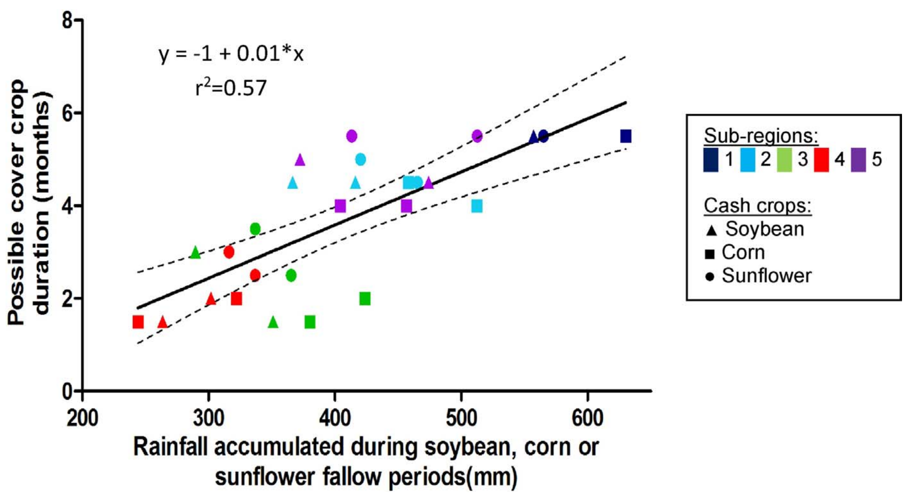

Fig. 6. Relationship between the possible duration of a cover crop and rainfall accumulated during the fallow periods before planting the cash crop (soybean, corn or sunflower). Possible cover crop duration is based on a 90% or higher probability of maintaining the same level of SWCsd after planting CC than without planting them. Colors represent the different sub-regions and different dots (circles, squares, triangles) characterize cash crops. Solid line shows the model fit for all crops and dotted lines show the confidence interval. Cumulative rainfall during fallow in each weather station is the average from the period between 1970 and 2011. Information about start and end of fallow periods was obtained from ORA statistics (www.ora.gov.ar).

Guerschman, 2005; Restovich et al., 2012). Our spatially explicit land use classification allowed determining single or double crop rotations, not documented in national statistics. National statistics currently report single winter or summer crops, which makes impossible to determine crop sequences by location or areas with double cropping (SIAA, http://www.siia.gov.ar/sstpcias/estima/estima.php). Therefore, our classification shows that a large portion of the central Pampas (sub-region 3 in our classification), one of the largest agricultural areas of the world, remains with no vegetation during late fall, winter and early spring, representing an opportunity for ecological intensification of crop sequences in the region (Caviglia, 2004; Novelli et al., 2017; Piñeiro et al., 2014).

Our work also showed that sowing a second crop in the year on current fallow periods would not substantially alter soil water contents at the beginning of the cash crop in most of the region. The CC duration that does not produce changes in the SWCsd was related to the precipitation occurring in fallow (Fig. 6). For this reason, eastern sub-regions (1, 2 and 5) where rainfall is higher, allowed CC duration of 4 months or more (Fig. 6). Our findings are contrary to the common perception by farmers, which maintain long fallow periods in the winter to capture water in the soil and delay it for the summer crops. However, the lack of promotion and knowledge of CC benefits could be limiting its adoption, as well as the lag periods often necessary until their benefits are observed by farmers (Duval et al., 2016; Restovich et al., 2012; Rimski-Korsakov et al., 2015; Villamil et al., 2006). However, is notably that double cropping with cash crops, for example based on a wheat-soybean rotation, is also highly absent in the region. High soybean prices and low wheat prices could have discouraged this option (Monzon et al., 2007), because soybean sowing dates are delayed in double cropping sequences, which has been shown to decrease soybean yields in southwestern Pampa (Calviño et al., 2003). However, winter CC may still be suitable because they can be sown earlier and also suppressed earlier than wheat crops, not affecting summer cash crop's growing season.

Our estimates of water consumption by CC are conservative and do not consider potential positive effects of CC on soil water conservation. The effects of CC on PSWCsd depends on the amount and the distribution of rainfall, soil water storage capacity and atmospheric demand (Verburg et al., 2012). To be conservative we considered the highest Kc of CC, therefore setting the maximum evapotranspiration potentially achieved by a potential CC, either legumes, grasses, etc. Cash crops and CC can also use underground water, therefore alleviating water competition and, in some cases, CC may even decrease water tables allowing a better cash crop development (Nosetto et al., 2009). Furthermore, the contribution of CC biomass residues usually reduces evaporation losses and increase rainfall catchment, sometimes increasing SWCsd as compared to fallow periods (Baumhardt and Jones, 2002; Quiroga et al., 2005). All these evidences and a potential increase in precipitation over the region due to climate change (Trenberth, 2011; Vera et al., 2006), suggest that sowing crops in winter in this large agricultural region can have positive environmental impacts, without affecting crop yields. In this line, Uruguayan government has recently implemented a new soil conservation law, that requires double-cropping sequences to avoid erosion loses, representing a key advantage for ecological intensification in the region (Hill and Clérici, 2013).

The possibility of sowing CC without affecting cash crops yields opens the opportunity for intensifying crop sequences in the region, oriented to mitigate environmental concerns raised by monocultures and agricultural simplification. CC are sown to decrease soil erosion, but can also supply other benefits related to different ecosystem services. For example, CC can increase soil organic matter, suppress weeds, decrease soil compaction or fix N from the atmosphere, among others, and thus have been called "Service Crops" to highlight their multiple ecosystem functions or services (Piñeiro et al., 2014). The capture of energy and nutrients by CC during fallow periods is a central point contributing to the ecological intensification of cropping systems (Tittonell, 2014). This energy can be used to recover ecosystem degradation via multiple pathways (Caviglia, 2004). For example, crops that produces large amounts of roots biomass can be used to reduce soil compaction but also increase soil organic matter formation and stabilization (Chen and Weil, 2010; Mazzilli et al., 2015; Rimski-Korsakov et al., 2015). Cover crops can also capture nutrients in fallow periods, avoiding their losses and decreasing fertilizer use (Sainju et al., 2005). Furthermore, sowing legumes as CC also increases nitrogen additions and decreases inorganic N fertilizer applications (Bergkvist et al., 2011; Kramer et al., 2002). A growing body of evidence suggests that increasing energy and resource capture within ecosystems via CC or service corps, produces higher cash crops yields but also reduces the negative environmental impacts of agricultural production (Bommarco et al., 2013; Doré et al., 2011; Schipanski et al., 2014; Tittonell, 2014). Managing these multifunctional and diverse landscapes will be a challenging issue for agricultural research in the coming years (Dale and Polasky, 2007; Petersen and Snapp, 2015; Tilman et al., 2002; Tittonell, 2014).

5. Conclusion

Our land use classifications revealed that single crops occupy a large proportion of the agricultural portion of the Rio de la Plata grasslands studied and these were usually summer single crops. In most of the region, sowing CC of 3 to 5 months of length during fallow periods had little impact on soil water contents at the sowing date of the following cash crop. The optimal CC duration in different sub-regions was significantly related with the average rainfall occurred during the fallow period. The possibility of sowing CC without affecting cash crops yields opens the opportunity for intensifying crop sequences in the region, oriented to mitigate environmental concerns raised by monocultures and agricultural simplification.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2017.07.028.

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