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Intercropping of winter crops with perennial summer grasses in central Spain

"Trabajo Fin de Máster Universitario en Tecnología Agroambiental para una Agricultura Sostenible"

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MY SINCERE GRATITUDE

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SUMMARY

The intercropping of summer-growing perennial grasses with winter crops or "Pasture cropping" is a no-tillage technique that might adapt to the climatic conditions of the central region of Spain. This system would allow growing annual crops into perennial grasses when these become inactive to increase the overall productivity of the system (grass and/or grain) while improving several environmental features. The effects of such system on the establishment and production of winter crops, the behaviour of the perennial grasses, the development of weed populations and the levels of inorganic soil nitrogen were analyzed in order to determine its feasibility. Three cropping systems (Conventional cropping, pasture cropping with *Cynodon dactylon* and pasture cropping with *Eragrostis curvula*) were assessed over two winter crops (Barley and Vetch) during two years. There were no differences in the establishment of winter crops in any management assessed. In spite of this, pasture cropping reduced winter crops yields up to 50-60% in years with low rainfall in spring. Regarding weed control, pasture cropping showed a significant suppression on total weed density and biomass when rainfall was no limited. The growth of perennial grasses was limited by the severe drought conditions and high temperatures present during the summer in some of the study years. As a result, their summer dry biomass production was highly variable ranging from zero to approximately 6 Tons/ha. Pasture cropping management recorded a reduction in inorganic N content that ranged from 37% to 64% compared to conventional management, regardless of the perennial species used. In conclusion, the pasture cropping technique would not adapt to the environmental conditions of central Spain. Future work should be directed at investigating the effects of managing irrigation to avoid or reduce yield losses for competition between crop and pasture and the use of legume as a perennial crop instead a tropical grass.

Keywords: Intercropping; winter crops; *Cynodon dactylon; Eragrostis curvula*; no-tillage.

RESUMEN (ESPAÑOL)

El intercultivo de pastos perennes de verano con cultivos anuales de invierno o "Pasture Cropping", es una técnica de no laboreo que podría adaptarse a las condiciones climáticas de la región centro de España. Este sistema de producción permitiría la siembra de cultivos anuales sobre pasturas perennes cuando éstas últimas se vuelven inactivas, permitiendo incrementar la productividad global (forraje y/o grano) a la vez que se mejoran varios aspectos ambientales. Los efectos de este sistema en el establecimiento y la producción de cultivos de invierno, el comportamiento de las gramíneas perennes, el desarrollo de las poblaciones de malezas y los niveles de nitrógeno inorgánico del suelo fueron considerados para determinar la viabilidad del mismo. Se evaluaron tres sistemas de cultivo (Cultivo convencional, "Pasture Cropping" con *Cynodon dactylon* y "Pasture Cropping" con *Eragrostis curvula*) en dos cultivos de invierno (Cebada y Veza) durante dos años. No hubo diferencias en el establecimiento de los cultivos de invierno en ninguno de los manejos evaluados. A pesar de ello, el intercultivo de pastos redujo los rendimientos de los cultivos de invierno hasta un 50-60% en años con bajas precipitaciones en primavera. En cuanto al control de las malas hierbas, el sistema de "Pasture cropping" mostró una supresión significativa en la densidad total de malas hierbas y su biomasa cuando las precipitaciones no fueron limitantes. El crecimiento de los pastos perennes se vio restringido por las severas condiciones de sequía y las altas temperaturas presentes durante el verano en algunos de los años de estudio. Como resultado, su producción de materia seca en verano fue muy variable (desde cero hasta aproximadamente 6 Toneladas/ha). El intercultivo de pastos registró una reducción del contenido de N inorgánico que osciló entre el 37% y el 64% en comparación con el manejo convencional, independientemente de las especies perennes utilizadas. En conclusión, el sistema de "Pasture Cropping" no se adaptaría a las condiciones ambientales del centro de España. Futuros trabajos deberían dirigirse a investigar los efectos del riego deficitario para evitar o reducir las pérdidas de rendimiento por la competencia entre el cultivo y los pastos, como también al uso de legumbres como cultivo perenne en lugar de gramíneas tropicales.

Palabras clave: Intercultivo, Cultivos invernales, *Cynodon dactylon; Eragrostis curvula*, No laboreo

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1 INTRODUCTION AND OBJECTIVES

1.1 Introduction

One of the main contemporary challenges for the agricultural sector is the development of new or more efficient ways of producing food in quantity and quality for a growing population without affecting the environment and the general well-being of the population. In this sense, production models tend to become more complex and diverse, whether through crop rotation, changes in the way of working the soil (Conventional till vs No-till or minimal till), the use of cover crops, the integration of agricultural and livestock systems, among others (Davis et al. 2012; Franzluebbers 2007; Studdert et al. 1997; Tanveer et al. 2017). In summary, towards development of new or better "cropping systems" while minimizing environmental impact, understanding by this concept the crops and their sequences, as well as the management used in a particular field during a period of years (Nafzinger 2009). In this way, innovative cropping systems have emerged, such as the intercropping of summer perennial grasses with winter crops or "pasture cropping" with its different variants. Pasture cropping is a zero tilling technique consisting of sowing annual crops into living perennial pastures during their dormant stage (Lawes et al. 2014; Millar and Badgery 2009) (Figure 1).

Figure 1: Illustrative diagram of the pasture cropping system over time

Such management would be interesting in mixed production systems because it would allow the use of forage for livestock and at the same time obtaining an acceptable yield in a cash crop such as barley or wheat. This cropping system combines species with complementary growth periods to improve overall productivity and environmental benefits such as increasing soil cover, reducing erosive processes, improving soil structure and organic matter, increasing infiltration and water retention, reducing N lixiviation, sequestering CO_2 and helping to control weeds (Jones 1999; K. Descheemaeker et al. 2014; Lawes et al. 2014). However, in the Mediterranean climate of central Spain, the introduction of summer pastures into agricultural systems to implement pasture cropping is not an intuitive choice for farmers. The environmental requirements of these species, typical of humid and warm climates, contrast with the climatic conditions prevailing in the centre of the peninsula. Furthermore, from the point of view of crop rotation, the continuous sowing of grasses would not be a good alternative. Despite these concerns, this innovative technique is being used successfully in different regions of the Mediterranean climate in Australia, where more and more producers are beginning to implement it (Lawes et al. 2014, Mosely 2008, White 2012). The good performance of this technique lies in the ability of some grasses to persist during prolonged periods of drought and cold tolerance, staying asleep or with very low growth rates at the time of growth of winter crops (K. Descheemaeker et al. 2014). This would allow the cultivation of both perennial grass and crop in the same space, but different time. However, as temperatures increase during the spring, the pasture would be activated at the same time that the crop enters the grain filling stage, which could negatively affect the yield of crops and pastures (Ward et al. 2014). For these reasons, interaction with the local environment is very important leading to the question whether the intercropping of summer grasses and winter crops (pasture cropping) might adapt to the semi-arid Mediterranean climate of central Spain. In this sense, the available local experience is still very limited. Dorado et al. (2017) evaluated the potential of four summer grass species for use in pasture cropping systems in the locality of Arganda del Rey (Madrid) obtaining satisfactory results on the establishment and development of barley under this system, as well as the yields achieved and weed suppression. However, only two of the four pastures survived the first winter, other than reporting winter cereal results for just one year, thus requiring a greater depth in these cultivation techniques on a larger scale and in the long term. For these reasons, the objective of the present work was to analyse the performance of winter crops and pastures under pasture cropping management, as well as their effect on the weed community, starting from the results achieved by Dorado et al. (2017)

1.2 Objetives

The main objective of this study is to evaluate the feasibility of the Pasture cropping system in the central region of Spain. This general objective is developed in three components.

- 1) To evaluate the behavior of the main crops under this cropping system.
- 2) To characterize the behavior of pastures.
- 3) To evaluate weed control

These three general objectives are developed in the following specific objectives:

- - Obj.1. Determine if pasture cropping affects the establishment and yield of the main crops.
- - Obj. 2. Evaluate the dry matter production of pastures
- - Obj. 3. Assess weed density and biomass
- - Obj. 4. Analyse soil Nitrogen.
- - Obj.5. Identify barriers and opportunities for adoption of practices.

2 BACKGROUND

2.1 Global experiences

Seeding annuals crops into perennial pasture have been used since at least the 1960s (Millar and Badgery 2009). Farmers in Australia have rejuvenated this technique, with the development of the pasture cropping concept as a way of improve ecosystem sustainability without losing profitability in mixed farms. Such concept has been widely promoted and used to describe any form of sod seeding of cereal crops into pasture. However, there are variants within them. The most common system in Australia is to sow winter cereals directly into summer-growing (C4) native pastures (e.g., *Bothriochloa macra* and *Paspalidium jubiflorum*) to maximise their complementary growth phases and minimise direct competition. Pastures are grazed up to sowing the winter cereal, and then herbicide application prior to sowing may be used to reduce competition from emerging annual species. The system is primarily aimed at grain production, but it can also be used for forage production (Badgery 2009). Another variation is sowing winter cereal crops in dry conditions, before the autumn break, into perennial pastures of varying composition without the use of herbicides. The aim of this system is to provide additional winter and spring forage for grazing, and grain is harvested only on an opportunistic basis. The system relies on the cereal having a greater growth rate than germinating annual weeds (Badgery 2009).

This last alternative with some differences has been used in the USA since the 1970s (Reicosky et al. 1977; Hoveland, et al. 1977). Warm season perennial grass forages species, such as bermudagrass (*Cynodon dactylon* L.), bahiagrass (*Paspalum notatum* Flugge) and dallisgrass (*Paspalum dilatatum* Poir) are dormant or unproductive in Southeastern USA for 5 to 6 months of the year with their peak growing period in May-to-June. Therefore, overseeding winter annual crops such as rye or clover into perennial grasses extend the grazing season improving beef calf gains (Evers 2005, Hoveland et al. 1977). Other benefits of this practice are that cool season crops have a higher nutritive value resulting in better animal performance than warm season grasses, provide spring weed control, avoid erosion due to lack of deep tillage and, if a legume, add nitrogen to the pasture system (Evers 2005).

A variety of perennial species, such as lucerne (*Medicago sativa* L.), summer-active (C4) native and subtropical grasses and a range of cereal and pulse crops including wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), rye (*Secale cereale* (L.) M. Bieb.), triticale (6× *Triticosecale* Wittmack), annual ryegrass (*Lolium multiflorum* L.), faba-beans (*Vicia faba* L.), vetches (*Vicia sativa* L.), arrowleaf clover (*Trifolium vesiculosum* Savi), Berseem clover (*Trifolium alexandrinum* L.) crimson clover (*Trifolium incarnatum* L), and canola (*Brassica napus* L.), are candidates for pasture-cropping systems (Finlayson et al. 2012, Hoveland et al. 1977, Smith et al. 2014). The most common perennial grasses species utilized for pasture cropping are summarized in Table 1.

Table 1: Perennial grass species utilized for pasture cropping

Species	Reference
Bothriochloa macra	(Badgery 2009, Colin Seis 2012)
Paspalidium jubiflorum	(Badgery 2009)
Chloris gayana	(Finlayson et al., 2012; Lawes, et al 2014)
Panicum maximum cv. Gatton	(Descheemaeker et al., 2014; Lawes et al., 2014; Ward et al., 2014)
Panicum coloratum L. cv. Bambatsi panic	(Descheemaeker et al., 2014)
Cynodon dactylon	(Evers 2005, Hoveland et al. 1977)
Paspalum notatum	(Evers 2005)
Paspalum dilatatum	(Evers 2005)
Andropogon gerardii	(Glover et al., 2009)

A question that arises when analysing these cropping systems is undoubtedly under what environmental conditions they are conducted. Firstly, the environment must allow for the compatibility of temporary growth of both grasses and main crops. This is possible in Mediterranean climates, generally characterised by hot dry summers and cool moist winters, as well as in continental climates where seasons are well separated by temperature. In such climates, the growth of pastures would tend to be stopped when the sowing of winter crops approaches, being practically null during their growth. However, the Mediterranean climates would not be favourable for summer grasses, since the period of maximum growth of grasses coincides with the warmest months and therefore the most aggressive conditions of low rainfall and high temperature. In spite of this, numerous favourable experiences are cited in Mediterranean climates of Australia.

First evidence that summer-growing grasses can grow and persist in dry summer climates in Australia came from Western Australia (WA), where more than 50,000 ha has been established with pasture cropping on the more marginal sandy soils of the medium–low rainfall zone (Descheemaeker et al., 2014)

The Northern agricultural region of WA wheatbelt has an annual rainfall average of 430 mm, with 327 mm falling in the traditional May–October growing season. Approximately 100 mm of rainfall occurs outside the growing season annually. However, this varies in magnitude and timing, and substantial rainfall events (>20 mm) are not uncommon, but more unpredictable than the winter growing-season rainfall. For this reason, the farming system has evolved towards the use of reliable winter rainfall (Lawes et al. 2014). In this region, the C_4 grasses effectively utilized summer rainfall and may provide sporadic feed for livestock. The crop yield losses due to pasture cropping were generally small because the pasture remained dormant through winter and produced low levels of biomass at that time (Lawes et al. 2014).

The Mallee agro-ecological zone in South-eastern Australia is a low-rainfall environment (annual rainfall ~350 mm) where pasture cropping it is also being practised. In this region Descheemaeker et al. (2014) evaluated the pasture cropping system and concluded that the niche for summer-growing perennial pastures is restricted to areas that receive more than 150 mm of rainfall from October to April and to marginal soils where cropping is too risky. Under these conditions, grazing would be possible for 2–3 months in at least 40% of the years.

In Western New South Wales (NSW, Australia), the farmers Colin Seis and Daryl Cluff started in 1995 managing their farms under the pasture cropping concept and become one of the most known and successful cases regarding pasture cropping systems in Australia (Colin Seis 2012). The average annual rainfall in Winona (NSW) where Seis and Cluff run their farms is 650 mm and there is not a strong seasonal dominance in rainfall. Colin sowed commercial crops into the dominant pasture by direct drilling to minimise soil disturbance. Sheep were used to prepare paddocks to pasture crop and crops were usually sown with no herbicides (Colin Seis 2012).

The Mid Goulburn Broken Catchment Landcare Network reported on trials of pasture cropping in Northeast Victoria, an area with a markedly more seasonal rain pattern (winter rainfall) than the NSW Central West. These trials showed positive results from pasture cropping, including increased pasture production and total biomass production, increased native perennial pasture and increased ground cover. In trials where crops were harvested for grain, the grain production was low, but low input costs and good feed production led to all trial participants expressing the intention to continue working pasture cropping into their land management systems (Ham 2009). This trial report is particularly interesting because it resumes the experiences of six case studies in which pasture cropping was carried out looking for different objectives under various rainfall conditions. A summary of these trials is shown in the Table 2.

Table 2: Summary table for the "Trials by the Gecko CLaN in the Goulburn Broken and North East Catchments of Victoria"

Study case: Enterprise	Average rainfall (mm)	Rainfall during trials (mm)	Objetives
1: Beef Cattle	668	354 to 400	Fill summer feed gap, and decrease weeds by increasing groundcover throughout the year
2: Prime Lamb & Cropping	550	360 to 420	Increase biodiversity. Grow a crop if the season is good, or have winter feed for their stock in the years of lower rainfall
3: Prime Lamb & Cropping	520	350 to 400	Reduce costs, improve pastures and soils increasing long term sustentability
4: Prime Lamb & Cropping	525	247 to 340	Management tool to improve the whole system
5: Breeding Herd & Horse stud	700	440 to 555	Restore and renovate degraded paddock during years of drought and continuous grazing
6: Cattle	611	440 to 555	Improve pasture composition and dry matter production

Thomas et al. (2017), evaluated five southern Australian locations in order to define the agro-climatic regions where pasture cropping with C_4 grasses was most likely to succeed. They concluded that scenarios providing the best conditions for pasture cropping are those with growing season rain, rather than stored soil moisture, and also where C_4 grass growth can be slowed adequately during winter and spring by a combination of seasonal temperature and the application of herbicide at sowing. They concluded that only two locations from their study were favourable for cereal-C_4 grass pasture cropping. These sites were characterised by the coldest winters (June–September mean monthly maximum <20°C), the highest soil water contents at anthesis, and the least benefits to the crops from soil water stored during summer and autumn.

In the USA, although the systems under pasture cropping are mainly oriented to forage production for cattle, there are some positive experiences that seek to exploit both, grain and forage production. In the state of Kansas (Central USA), Glover et al. (2009) achieved viable yields of wheat grain and grass hay from pasture cropping systems. They pointed out that using appropriate wheat cultivars and nitrogen fertilization, yields up to 2000 kg/ha could be achieved .These yields levels were economically competitive with no-till wheat monocultures, which require higher herbicide inputs without producing an additional hay crop after wheat harvest. Kansas climate is characterised by cold winters with precipitation in form of snow that vary from 330 to 635 mm, and annual rainfall ranging from 380 to 1100 mm depending on the county (Goodin et al., 2004)

According to Reicosky et al. (1977), intercropping cool season annuals in dormant bermudagrass or bahiagrass in the fall have been used in the Piedmont (South-eastern U.S.) to reduce soil erosion while improving hay productivity. The average annual precipitation in this region goes from 940 to 1,145 mm at the northern and 1,145 to 1,525 mm at the southern (Ingram et al., 2013).

Other regions in Europe (Norway), South America and South Africa are also cited in some works as sites where pasture cropping is being adopted (Colin Seis 2012, Ham 2009) although no further information is available in the literature in terms of study cases or published articles from these countries.

Mixed farming–grain and graze–systems are inherently more complex that those based on either component individually (Price and Hacker 2009). Such systems has several pros and contras depending on the objectives pursued and the particular environmental conditions in each region. According to bibliography and worldwide experience it appears that pasture cropping would be more suitable to those cases where grasses growth patterns show a markedly winter dormancy and rain patterns are not strongly seasonal, allowing pastures and crops to use rain as it falls. Also, where soil present relatively low water holding capacity. As it was aforementioned the objectives pursued with this cropping technique are diverse, but it clearly works better when the aim is to restore degraded lands and to extend grazing periods in mixed-farms. The success of this system for harvesting grain and forage, is highly dependent on the specific environmental condition from each region and should be tested.

2.2 Experiences in Spain

The pasture cropping system in Spain was initially assessed in Arganda del Rey (Madrid) by Dorado et al. (2017) as a tool for Integrated Weed Management (IWM) in winter cereals since weeds emergence would be affected during the autumn months when the grass forms a vegetal cover. Following the general principles on which IWM is based, the prevention of weeds should be achieved through the rational use of herbicides and appropriate cultivation techniques (e.g., crop rotation, sowing dates, variety selection, etc.). But in addition to being a practice that fits the principles of the IWM, the authors hypothesized that such a system would maximize the productivity of cereals in semi-arid environments in central Spain and reduce the risks of erosion during the summer-autumn months.

Four grass species previously used in similar environments were tested in these studies based on a literature screaning: *Brachiaria* spp. (*B. ruziziensis* × *B. decumbens* × *B. brizantha*), *C. dactylon*, *E. curvula* and *Panicum maximum* Jacq., on which barley was sown by direct drilling. The sowing was performed after the autumn mowing of the grass. However, despite the good development of *Brachiaria* spp. and *P. maximum* during the year of implantation, these species did not survive the first winter, then keeping only two species in the experiment, *C. dactylon* and *E. curvula*.

Based on the results of their study, the authors concluded that the pasture cropping system helped in controlling weeds with a significant reduction in the parameters evaluated (weed density, weed biomass and number of species). This was possible without compromising a good establishment and development of the barley crop. Furthermore, concerning the cereal harvest parameters (spikes number and grain yield), no significant differences were observed in any treatment. These preliminary results were encouraging regarding the potential use of this technique. However, the environmental conditions explored during the years 2016 and 2017 in which the experiment was carried out registered adequate rainfall during the cereal growth period (~265 mm in both years) (Figure 2), being necessary to evaluate the pasture cropping system under more restrictive conditions.

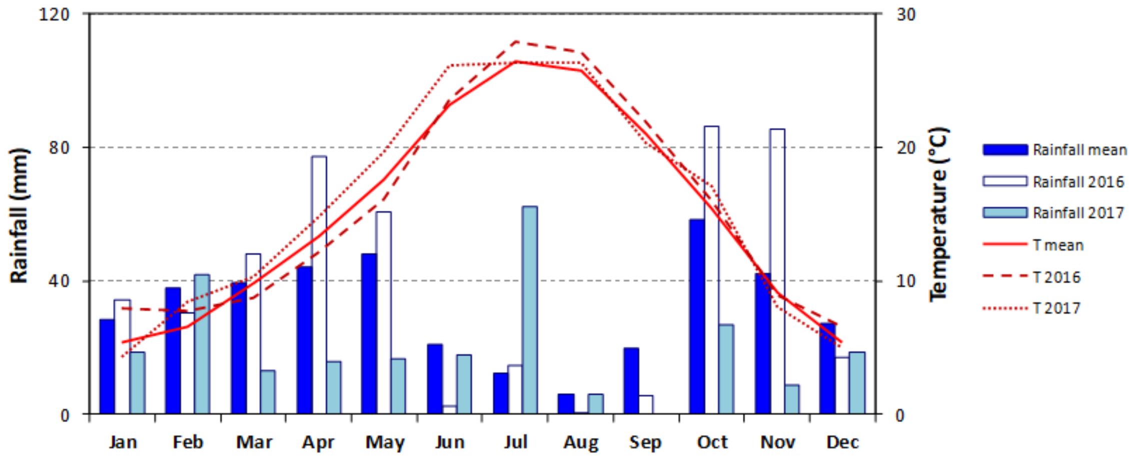

Figure 2: Monthly rainfall (mm) and temperature (ºC) for years 2016, 2017, as well as 15 years series for Arganda del Rey, Madrid

3 MATERIALS AND METHODS

3.1 Site and soil type

A multi-year field study was conducted from 2017 to 2019 at "La Poveda" research farm in Arganda Del Rey, Madrid (Lat. 40°18'49.4"N Long. 3°29'15.3"W). This farm is flat and its soil type is classified as a Xerofluvent (USDA classification), sand frank textural class in the first half meter, with a progressive increase in the proportion of sand up to reach 1.5 m, depth at which gravel begins to appear. The site has a semiarid Mediterranean climate with a dry and hot summer period, and the mean annual temperature and rainfall (over the last 15 years) in this area are 14.9 °C and 385 mm, respectively.

3.2 Experimental design

A factorial split-plot randomized complete block design with four replications was used for the experiment, with two winter crops (Barley and Vetch) treatments as the main plots and three management (Conventional, Intercropping with *E. curvula* and Intercropping with *C. dactylon*) treatments comprising the subplots (Figure 3 and Table 3). Each of the subplots measured 17 m × 10 m. Species and cultivar selection was based on results from Dorado et al. (2017).

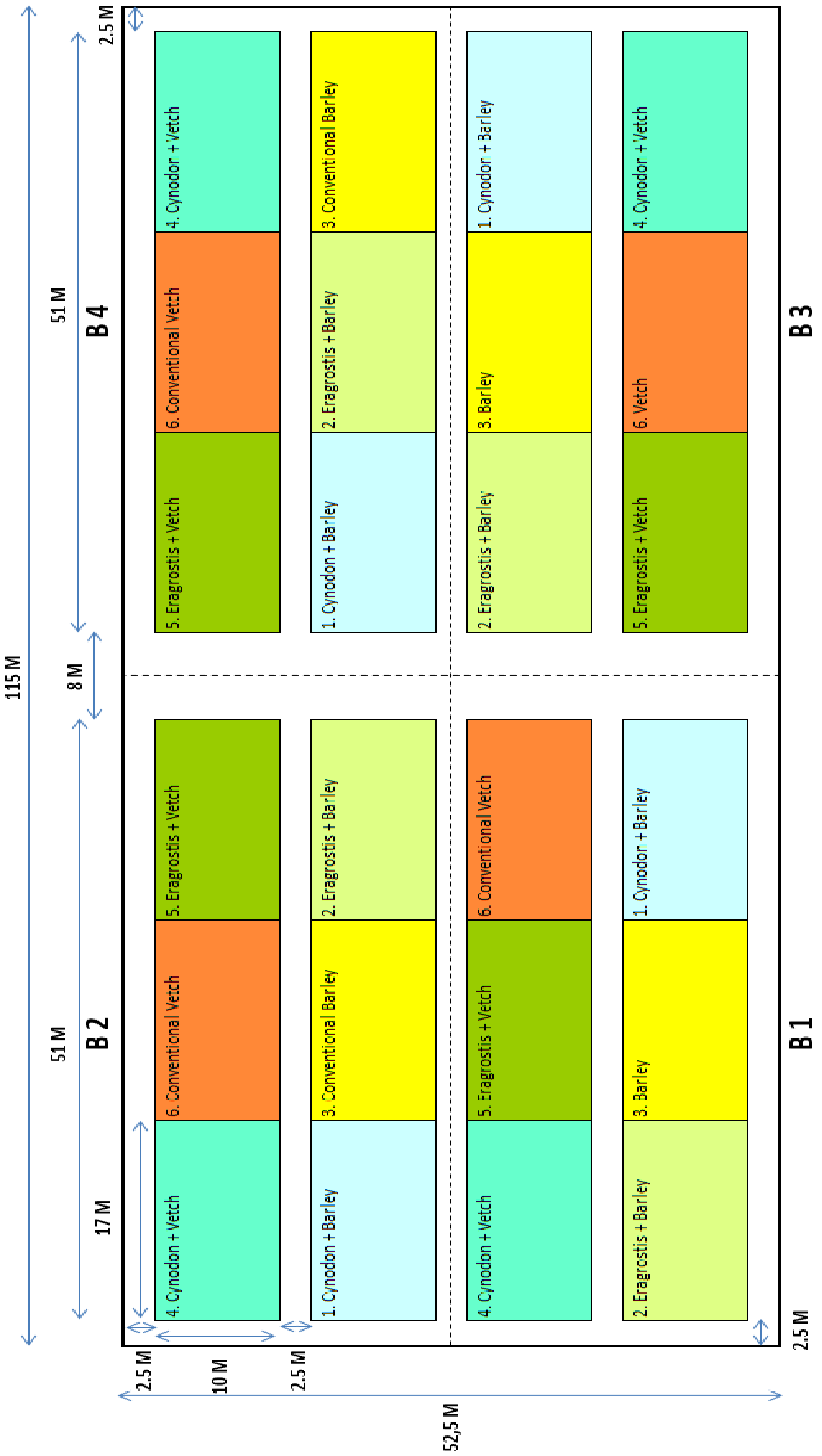

Figure 3: Experiment croquis

Table 3: Treatment ID, winter crop, perennial grass and treatment management

Treatment ID	Winter crop*	Perennial grass	Treatment management
Bar	Barley	*n.a. (crop only)*	Conventional
Bar:Cyn	Barley	*Cynodon Dactilon*	Pasture cropping
Bar:Era	Barley	*Eragrostis curvula*	Pasture cropping
Ve	Vetch	*n.a. (crop only)*	Conventional
Ve:Cyn	Vetch	*Cynodon Dactilon*	Pasture cropping
Ve:Er	Vetch	*Eragrostis curvula*	Pasture cropping

n.a.: Not applicable

3.3 Perennial summer grasses general description

3.3.1 *Eragrostis curvula* (Schrad.) Nees

The genus *Eragrostis* (family Poaceae) comprises more than 350 species distributed in different tropical and subtropical regions of the world. *Eragrostis curvula*, commonly called "Consol lovegrass " or “Pasto llorón”, is a perennial grass native from South Africa, which is widely sown in southern parts of the United States, Mexico, and Argentina (Figure 4). It is a densely tufted perennial, with erect or weeping stems, 0.5-1.2 m high. It has blue-green to grey-green foliage and its leaves are flat, 15-25 cm long and up to 7 mm wide. The ligule is about 1 mm long with a fringe of hairs and long lateral hairs. The inflorescence is an open, olive green panicle up to 15 cm long, which droops as it matures. The plant develops into a solid tussock and as it ages the inner stems die, leaving an unproductive centre of the plant. (López et al. 2018, Moore et al. 2006)

The objectives pursued with this grass are diverse going from rangeland regeneration and soil conservation to forage production for cattle in poor areas were other grasses does not succeed. Some of its most important attributes are its extraordinary tolerance to drought, its ability to grow in low fertility soils, its ability to consolidate erodible sandy soils. In addition, it has been documented that *E. curvula* incorporates a considerable amount of organic matter and improve soil structure (López et al. 2018, Moore et al. 2006). According to Echenique et al. (2008) its great aggressiveness allows it to compete and control important weeds. In central NSW Australia, *E.curvula* is recommended for controlling spiny burr grass (*Cenchrus spp*.), where it is grown with serradella (*Ornithopus sativus* Brot.) on acid, sandy soils (Johnston 1989). Among its main disadvantages are its low forage quality and weed reputation (Firn 2009, Moore et al. 2006)

Seasonal growth pattern, requirements and management

Eragrostis curvula starts actively growing from early spring, while summer growth depends on moisture availability. It then grows actively from the first rains in autumn to early winter. It continues to grow slowly in winter, unlike many sub-tropical grasses which are dormant (Echenique et al. 2008; Moore et al. 2006). Its fertility requirements are medium. It grows in a pH range of 7.0 to 8.5 and tolerates moderate salinity levels. Horizontal roots can expand up to a radius of one meter and facilitate competition for resources by avoiding the establishment of other plants. This species does not support poorly drained or floodable soils. It has a high tolerance to drought and adapts to a water regime of 350-800 mm/year. The optimum growth temperature is between 17° and 32°C. *Eragrostis curvula* is very resistant to low temperatures (between -15° and -20°C) and to fire (Paredes 2015). Consol lovegrass can be sown earlier in spring than other sub-tropical grasses or even dry sown, as it induces seed dormancy until the conditions (soil moisture, temperature) are favourable for germination. It has the ability to germinate at slightly lower soil temperatures than most subtropical grasses, with some germination at 10°C, increasing at 15°C with highest germination at 20°C. If initial establishment is poor, the plant density can be increased by periodically allowing the stand to set seed (Moore et al. 2006). It should be grazed regularly so that stock are always grazing young to medium regrowth. The grazing intensity should be sufficient to graze the area in less than three weeks, after which the paddock should be spelled for two to six weeks depending on rainfall (R.W.Strickland 1973)

Table 4: *Eragrostis curvula* summary chart

General features for *Eragrostis curvula*	
Rainfall	>350 mm
Drought tolerance	High to very high
Frost tolerance	Moderate to high
Soil type	Suited to a range, including coarse-textured soils and deep sands
Soil fertility requirements:	Will grow on infertile soils, but requires fertiliser for high production
Soil pH	7.0 to 8.5
Aluminium tolerance	High
Waterlogging and salt tolerance	Low to moderate
Forage quality	Medium to low
Groundwater recharge control	Good
Soil erosion control	Very good

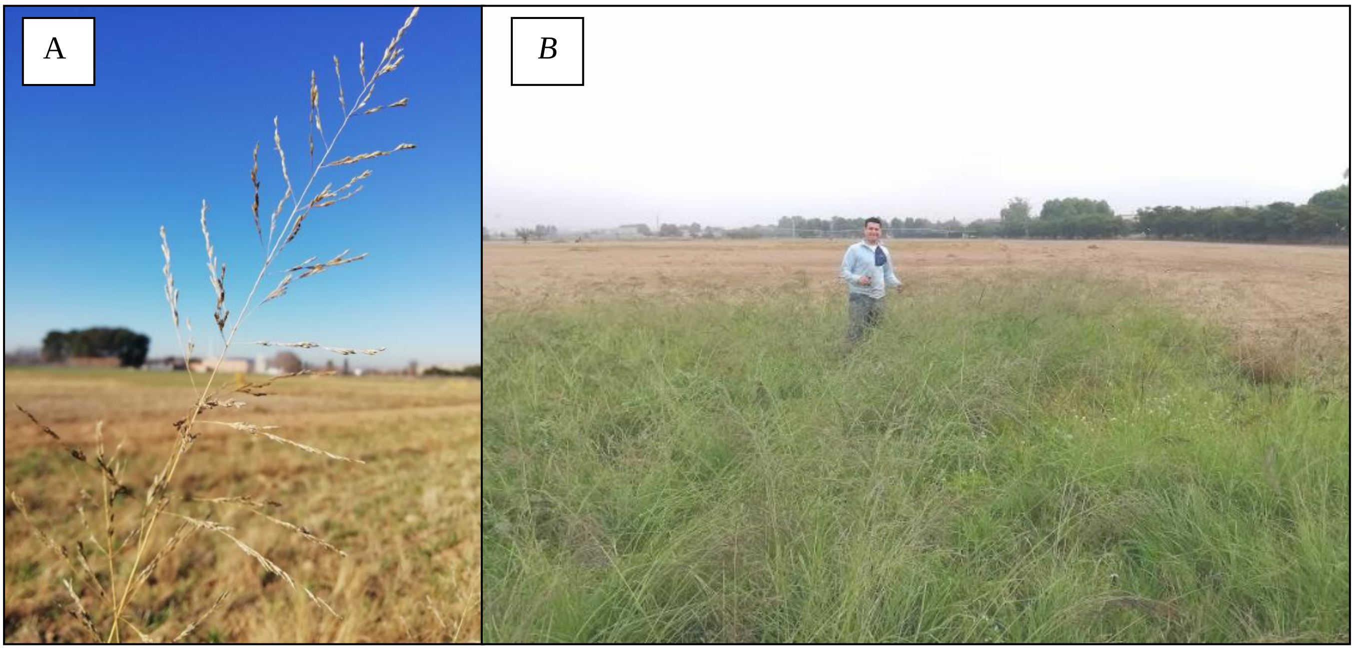

Figure 4: Images from *Eragrostis curvula*: A) mature spike in detail, B) general view of a plot in late November 2019

3.3.2 *Cynodon dactylon* (L.) Pers

Cynodon dactylon (family Poaceae), commonly called "Bermuda grass", is a perennial grass native from Africa and Southeast Asia. It is widely naturalized in tropical and subtropical regions of the world and has been widely used as a pasture grass. However, its main use is like turf grass (Moore et al. 2006). Also, it is consider as one of the most "serious" agricultural weeds in cropping systems (Pérez et al. 1999, Pérez et al. 2015). It is a low, creeping grass (<30 cm) that spreads by both rhizomes and stolons. It forms a dense sward under high fertility conditions. Its leaves are 2-5 cm long and 2-4 mm wide and have a ligule formed by a ring of hairs. Seed heads are digitate (finger-like) with 2-7 spikes on erect stems which turn purple or reddish-brown after flowering (Moore et al. 2006).

Its agronomic use is restricted for various reasons, including its invasive nature (high persistence, difficult eradication), and its difficult management in mixtures with legumes. Therefore, it is more frequently used for the establishment of recreational lawns and for the revegetation of slopes in hot and dry climates (Herbario Universidad de Navarra 2019). One of the most important attributes is its prostrate, creeping growth habit, which results in Bermuda grass being a useful plant for soil conservation and as a pioneer species on denuded areas. Other advantages are its ability to grow on poor rainfall environments (>350 mm) and to resist very high temperatures. A good tolerance to grazing and excessive traffic (quick recovery after trampling or cutting), high response to nitrogen fertilization, good disease resistance and adaptation to various drainage conditions are also features mentioned for *C. dactylon* (Laurencena, et al. 2009). Among its main disadvantages are its low to medium forage quality and weed reputation (Moore et al. 2006, Pérez et al. 2015)

Seasonal growth pattern, requirements and management

Bermuda grass is dormant in winter and grows actively from mid-spring to autumn until the first frosts. For good growth it requires warm temperatures with daily mean of about 24°C (Moore et al. 2006). Base temperature for bud sprouting ranging from 7.7°C to 10°C (Bedmar, 1997; Satorre et al. 1996) and new rhizomes are generated when temperatures exceed 15-20°C (Horowitz, 1972) Freezing point ranges from -2 to -3°C (Thomas 1969). Bermuda grass can be sown from seed or vegetatively propagated from runners. It should be grazed heavily as the feed quality and palatability decline with maturity.

Table 5: *Cynodon dactylon* summary chart

General features for *C. dactylon*	
Rainfall	>350 mm
Drought tolerance	Moderate to high
Frost tolerance	Moderate
Soil type	Adapted to well drained soils including deep sands
Soil fertility requirements	Moderate to high for good production, will persist under low fertility
Soil pH (Ca)	>4.0
Aluminium tolerance	Good
Waterlogging tolerance	Moderate
Salt tolerance	Moderate
Forage quality	Medium (good in enhanced cultivars)
Soil erosion control	Useful pioneer plant

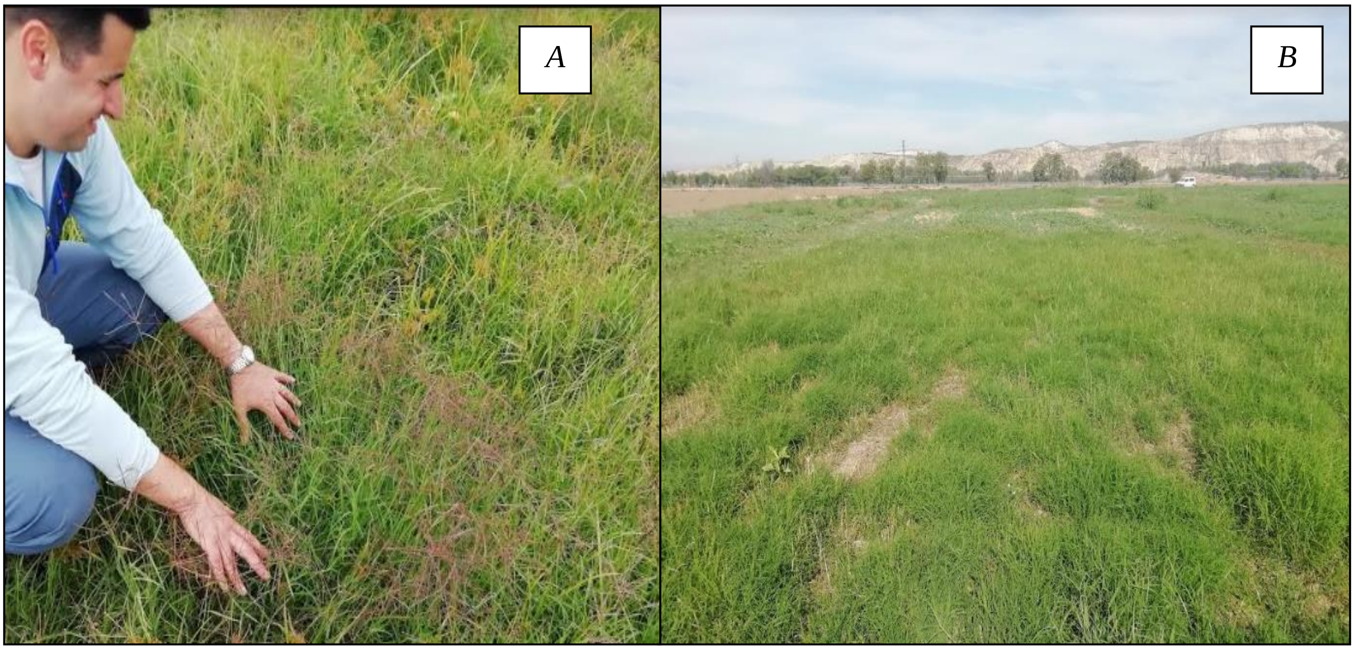

Figure 5: Images from *Cynodon dactylon*: A) spikes, B) general view of a plot in late November 2019

3.4 Establishment of the experiment

The first period was devoted to the preparation of the experimental site and no measurements were made. The sowing of the grasses in the intercropping plots was carried out manually at the beginning of spring in April 2017 at the rate of 8 kg/ha in *E. curvula* and 10 kg/ha in *C. dactylon*, supporting their establishment with irrigation up to September. In the conventional management plots, barley (cv. Hispanic, 180 kg/ha) and pea (*Pisum sativum* L.) as legume (140 kg/ha) were mechanically seeded in January 2017 to avoid leaving bare plots. Soil conditioning works prior to the sowing of pastures and crops included the passage of 1 disc harrow + 2 rotocultivators and a base fertilization of 350 kg/ha of a $8N–11P_2O_5–11K_2O$ complex, and at later application of 192 kg/ha of Ammonium Nitrosulphate 26% at tillering in all treatments.

3.5 Experimental start-up and general management

Once the grass was implanted and after autumn mowing, barley and vetch were sown using a direct drilling machine, on 28 November 2017 for the first cycle (2017-2018) and 5 December 2018 for the second cycle (2018-2019).

The crops under conventional management were sown on soil previously tilled with a rotary cultivator. The sowing density used was 80 kg seed/ha of vetch in mixture with 15 kg/ha of oats (the later used as a tutor) and 180 kg/ha of barley (cv. Hispanic). In the second cycle, post-emergence herbicides were applied to the crops (pinoxadem 42 g a.i./ha and tifensulfuron-methyl 50% + tribenuron-methyl 25% 30 g a.i./ha) in the case of barley and cletodim (360 g a.i. /ha) in the case of vetch.

The crops under the intercropping management were sown directly on the different pastures and no herbicides were used except for the last cycle in which treatment with carfrentazone (300 cc/ha) was applied to both pastures before sowing to achieve the drying of the green material. This herbicide application was necessary as a consequence of the favorable environmental conditions, causing grasses had not yet entered into latency.

Fertilizers were applied both years only in barley (conventional and pasture cropped) at two moments, prior to barley seeding (350 kg ha–1 of a 8N–11P2O5–11K2O complex) and at late tillering (192 kg ha–1 of Ammonium Nitrosulphate 26%).

3.6 Crop, grasses and weed measurements

Crop density was determined by counting plants in ten 0.25 m^2 quadrats in each subplot in mid January for 2018 and late February for 2019. Weed density was assessed in the same way at the end of winter (March 2018 and February 2019). Aboveground weed dry weight biomass was determined by cutting plants at ground level in six 0.10 m^2 quadrats per subplot in late April both years, drying at 104°C overnight, and weighing with a precision balance (0.01g). Aboveground pasture dry weight biomass was equally determined in three 0.25 m^2 quadrats per subplot in late june for 2018 and early May for 2019 before cereal harvest. Pasture sampling during summer was carried out when biomass appeared in response to summer or autumn rainfalls. Winter wheat grain yield was measured by manually harvesting four 0.25 m^2 in each subplot in June.

3.7 Soil measurements

Three soil samples per plot were taken to a depth of 0.75 m in 0.25 m intervals using an impact auger at four different times: i) before the sowing of winter crops in November 2018; ii) in February 2019 with crops in vegetative stages; iii) in May 2019 during crops reproductive stages; and iv) before harvest on June 2019. In this last date, only one block was sampled as a consequence of the extreme soil resistance to penetration because of drought. Soil cores were combined by depth to provide a composite profile of three samples taken randomly in each plot. Soil samples were placed in a plastic box and immediately firmly closed then transported, and refrigerated (4–6°C) in the laboratory. Within three consecutive days, a soil subsample from each box was extracted with 1 M KCl (~30 g of fresh soil: 150 ml of KCl), centrifuged, decanted, and a subsample of the supernatant volume was stored in a freezer until later analysis. Soil water content from samples was assessed by gravimetric methods. The soil NH_4^+-N and NO_3-N concentrations were measured by automated colorimetric determination using a flow injection analyzer (FIAS 400 PerkinElmer) provided with a UV-vis spectrophotometer detector.

3.8 Environmental conditions

The mean annual rainfall at Arganda del Rey for the last 15 years was 385 mm with growing season average rainfall (Nov–Jun) of 289 mm. Over the course of the study, 2018 and 2019 annual and growing season (parentheses) rainfall for Arganda del Rey was 440 (358) and 373 (140) mm. This represented 24% more rainfall during the winter crops growing season for the first year and 50% less in the second. In the case of pastures, it could be assumed that its growing season goes from April to October. Rainfall for this period was 165 mm in 2018 and 245mm in 2019. The long-term mean and monthly rainfall figures are presented in Figure 6.

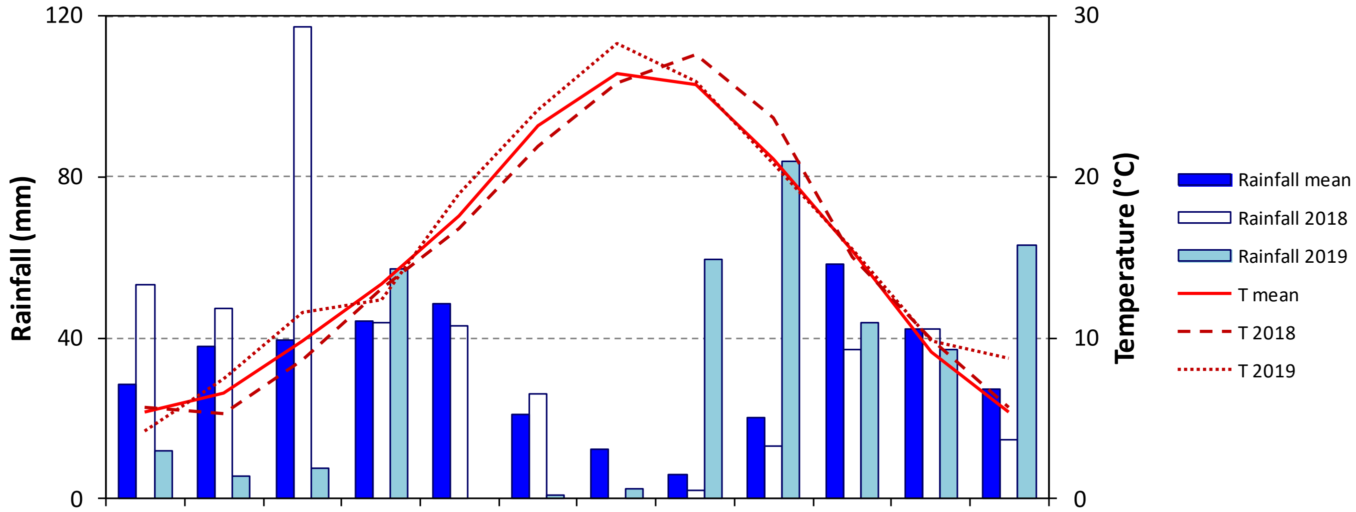

Figure 6: Monthly rainfall (mm) and temperature (ºC) for years 2018, 2019, as well as 15 years series for Arganda del Rey, Madrid

3.9 Statistical analysis

Years 2018 and 2019 were analysed individually for each variable under study.

Weed biomass data was analysed as a split plot design using a linear mixed-effects model with the "lme (nlme library)" procedure from R statistical software program with management, crop and their interaction in the model as fixed effect and replication, crop×replication (main plot) as a random effect. The same model specifications were used in weed density data but the analysis was made using a generalized linear mixed model with the glmer procedure (lme4 library) from R.

Yield data for vetch and barley and pasture dry matter production were analysed separately by the main crop as a complete random design using the "lme" procedure from R with management in the model as fixed effect and replication as a random effect. For crop establishment data the analysis was performed with identical model specifications using the glmer procedure from R.

Soil nitrogen data was analysed as a split plot design using a linear mixed-effects model with the "lme (nlme library)" procedure from R statistical software program with management, Time (or Date) and their interaction in the model as fixed effect and block and crop as a random effect.

Heteroscedasticity for different factors was modelled when necessary using the function of variance identity (varIdent) from statistical software R. In the analysis of the nitrogen data, the correlation structure for the different evaluation dates was modelled using the "corSymm" function of the statistical software R. Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC) were used to determine the best model for each variable. Then, inferences were made about the means of the treatments with the LSD test with a significance level of α=0.05. All analysis were performed with the InfoStat statistical software and its communication interface with R software (Infostat, 2018)

4 RESULTS

4.1 Crop establishment

Crop density was not affected by intercropping in either of the two years (Table 6). However, plant stand reached in 2018 was slightly higher than in 2019 probably due to unfavourable environmental conditions.

Table 6: Managements effects on crop densities (plants/m^2)

Management	Barley				Vetch				Vetch+Oat			
	2018		2019		2018		2019		2018		2019	
	D	*SE*	*D*	*SE*	*D*	*SE*	*D*	*SE*	*D*	*SE*	*D*	*SE*
Conventional	268^{a}	8,8	203^{a}	7,1	146^{a}	8,1	118^{a}	10	179^{a}	9,5	152^{a}	9,8
Cynodon Intercropping	258^{a}	8,5	182^{a}	6,8	112^{ab}	6,2	108^{a}	9,9	151^{ab}	8	131^{ab}	8,7
Eragrostis Intercropping	278^{a}	9,1	188^{a}	6,9	134^{a}	7,4	111^{a}	9,5	164^{a}	8,7	142^{a}	9,3

D: Density (plants/m^2); SE: Standard Error. Means within a crop and year followed by the same letter are not significantly different (P>0.05) according to LSD Fisher

4.2 Crop yield

4.2.1 Barley

The management factor was not statistically significant in 2018 over barley yield (p-value: 0.31, Table 7). However, average performance levels were subtly higher in the conventional system. In 2019 the differences between management were significant (p-value <0.0001) with pronounced reductions in yields compared to the previous season as a consequence of poor rainfall. Under these conditions, intercropping barley with *E. curvula* and *C. dactylon* reduced yields by 60 and 49%, respectively.

Table 7: Effect of the management system on barley yield (kg/ha)

Management	2018		2019	
p-value	0.3191		<0.0001	
	Y	*SE*	*Y*	*SE*
Conventional	4809.5	541.1	1019.7[a]	85.3
Cynodon Intercropping	4081.2	541.1	513.5[b]	85.3
Eragrostis Intercropping	4244.7	541.1	401.0[c]	85.3

Y: Yield (kg/ha); SE: Standard Error. Means within a year followed by the same letter are not significantly different (p>0.05) according to LSD Fisher

4.2.2 Vetch

The highest dry matter production during the first year was obtained with *E. curvula* intercropping producing yields close to 5,800 kg dry matter (DM)/ha, while the lowest yields were registered in the *C. dactylon* intercropping with values close to 3,400 kg DM/ha (Table 8). In the case of conventional vetch, the dry matter production was intermediate between the intercropping systems, about 4,700 kg DM/ha. In the last cycle, conventional vetch presented higher yields compared to intercropping systems. Within the intercropping treatments, *E. curvula* registered a greater decrease in dry matter compared to *C. dactylon.*

Table 8: Effect of the management system on vetch yield (kg dry matter/ha)

Management	2018		2019	
	Y	*SE*	*Y*	*SE*
Conventional	4,716[ab]	242.0	3,406[a]	269.9
Cynodon Intercropping	3,426[b]	798.5	2,821[b]	269.9
Eragrostis Intercropping	5,815[a]	782.9	2,495[c]	269.9

Y: Yield (Kg dry matter/ha); SE: Standard Error. Means within a year followed by the same letter are not significantly different (p>0.05) according to LSD Fisher

4.3 Pasture production

In 2018 there were no significant differences in pasture yields (Table 9). Both species had average production levels closed to 2,000 kg dry matter/ha. In 2019, yield production decreased drastically due to low rainfall conditions. In this context, *E. curvula* produced 87% more dry matter than *C. dactylon*. Summer pasture biomass was only assessed the last year with production levels of 6,300 and 4,460 kg dry matter/ha for *E. curvula* and *C. dactylon*, respectively since grass biomass in 2018 was practically depreciable.

Table 9: Pasture biomass (kg dry matter/ha) for pasture cropping management

	2018		2019	
	Y	*SE*	*Y*	*SE*
Cynodon Intercropping	2,040.5[a]	373.4	141.8[b]	59.5
Eragrostis Intercropping	1,999.8[a]	306.5	264.8[a]	59.5

Y: Yield (kg dry matter/ha); SE: Standard Error. Means within a year followed by the same letter are not significantly different (p>0.05) according to LSD Fisher

4.4 Weeds

4.4.1 Weed density

The management factor significantly affected weed density in 2018 (Table 10). There were no significant effects by crop factor or its interaction with management. The highest densities were observed in conventional cereal and vetch crops concerning pasture cropping. The reduction in weed density in intercropping was 82% and 92% for *C. dactylon* and *E. curvula*, respectively.

Table 10: Effect of the management system on weed densities in 2018

Management *p-value=0.0021*	2018	
	W	*SE*
Conventional	195.0[a]	43.1
Cynodon Intercropping	34.5[b]	7.2
Eragrostis Intercropping	15.2[c]	4.5

W: weed density (weeds/m2); SE: Standard Error. Means followed by the same letter are not significantly different (p>0.05) according to LSD Fisher

In 2019 the interaction between management and crop influenced weed density (p-value 0.0208; Table 11). Similarly to 2018, the highest weed densities were recorded in conventionally cultivated barley. Intercropped barley with pasture registered fewer weed plants/m^2, regardless of the grass species used. Vetch in *C. dactylon* intercropping presented a greater amount of weeds/m^2 than vetch in *E. curvula* intercropping. In spite of this, conventionally cultivated vetch did not differ from pasture cropping in the number of weeds/m^2.

Table 11: Effect of the interaction between management system and crop on weed densities in 2019

Management × Crop	2019	
	Barley	Vetch
p-value 0.0208	*Weeds/m^2*	
Conventional	56.4[a]	24.8[bc]
Cynodon Intercropping	35.6[bc]	37.6[ab]
Eragrostis Intercropping	20.9[bc]	15.4[c]
SE	9,4	

SE: Standard Error. Means followed by the same letter are not significantly different (P>0.05) according to LSD Fisher

When only the management factor was taken into account, the observed values in 2019 for intercropped treatments showed a general increase in weed density compared to conventional management in both years (Figure 7)

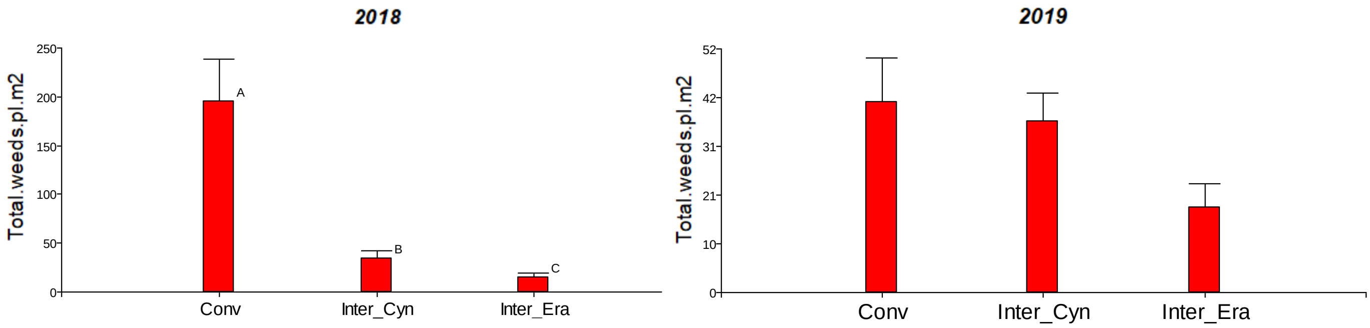

Figure 7: Weed density according to management system factor. Left: 2018; Right: 2019

In the spring of 2018, the area covered by pasture on intercropping plots was very high and uniform, decreasing substantially in 2019 to about 45% of the total soil surface on all plots (Figure 8). Despite both species of grasses had suffered a similar decrease in soil surface cover, the response of weeds was different. *Eragrostis curvula* produced a significantly higher decrease in weeds than *C. dactylon*, showing a greater competitive ability against weeds.

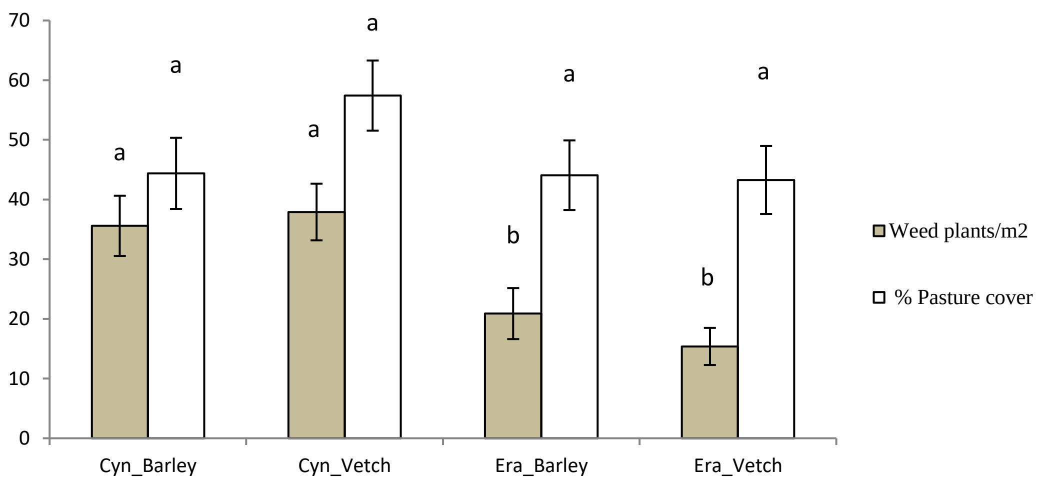

Figure 8: Weed density and grass cover (%) in pasture cropping treatments

4.4.2 Weed biomass

Weed biomass was only affected by the management system in 2018 (Table 12). Crops under conventional cultivation registered the higher weed biomass, despite there only were significant differences between conventional and intercropping with *E. curvula*. The average values showed a reduction in weed biomass with pasture cropping ranging from 17% to 60% in *C. dactylon* and E. curvula, respectively

Tabla 12: Effect of the management system on weed biomass in 2018

Management *p-value=0.045*	2018	
	Weed biomass (g/m^2)	*SE*
Conventional	23.6[a]	3.5
Cynodon Intercropping	19.1[ab]	3.7
Eragrostis Intercropping	9.2[b]	3.5

W: weed density (weeds/m^2); SE: Standard Error. Means followed by the same letter are not significantly different (p>0.05) according to LSD Fisher

In 2019, the interaction between management system and crop affected weed biomass (p-value <0.0001; Table 13 and Figure 9). Vetch intercropped with *C. dactylon* registered the highest weed biomass, followed by conventionally grown vetch. Barley in conventional cultivation and intercropped with *E. curvula* showed the lowest weed biomass values. Within the intercropping management, *E. curvula* proved to be more efficient against weeds with lower weed biomass in relation to *C. dactylon*.

Tabla 13: Effect of the interaction between management system and crop on weed biomass in 2019

Management × Crop	2019	
	Barley	Vetch
p-value <0.0001	*Biomass(g/m^2)*	
Conventional	7.2[d]	51.0[b]
Cynodon Intercropping	45.2[bc]	71.7[a]
Eragrostis Intercropping	20.8[d]	28.1[d]
SD	7.05	6.9

SE: Standard Error. Means followed by the same letter are not significantly different (p>0.05) according to LSD Fisher

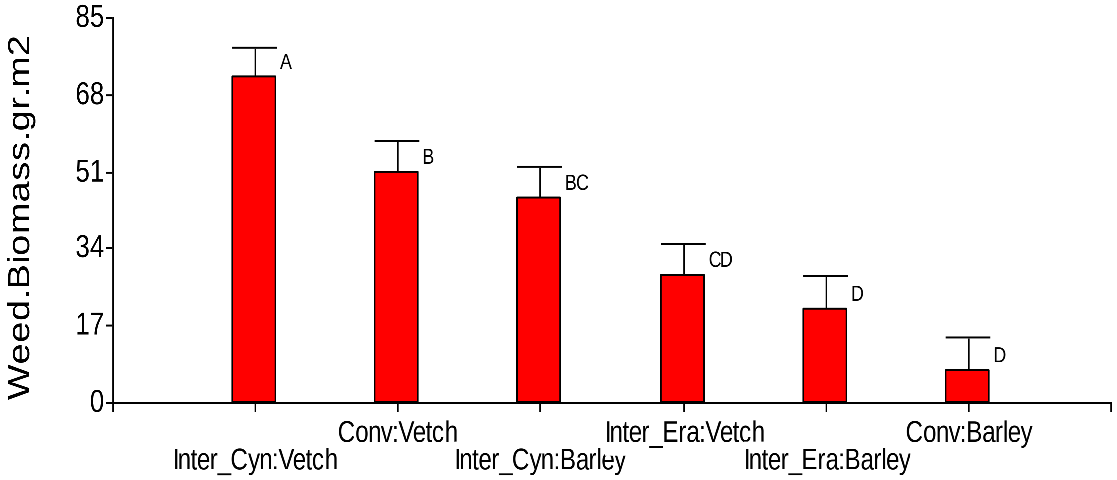

Figure 9: Weed biomass according to the interaction between management system and crop in 2019

4.5 Soil nitrogen

The inorganic nitrogen (N) content in the soil profile (0-75 cm) was higher in conventional management for all assessment dates (Figure 10). Pasture cropping management recorded a reduction in inorganic N content that ranged from 37% to 64% compared to conventional management, regardless of the perennial species used. A significant decrease in inorganic N was observed from December 2018 to May 2019 when the lowest values were recorded for the whole cycle. Subsequently, a tendency to increase inorganic N was observed towards the month of June.

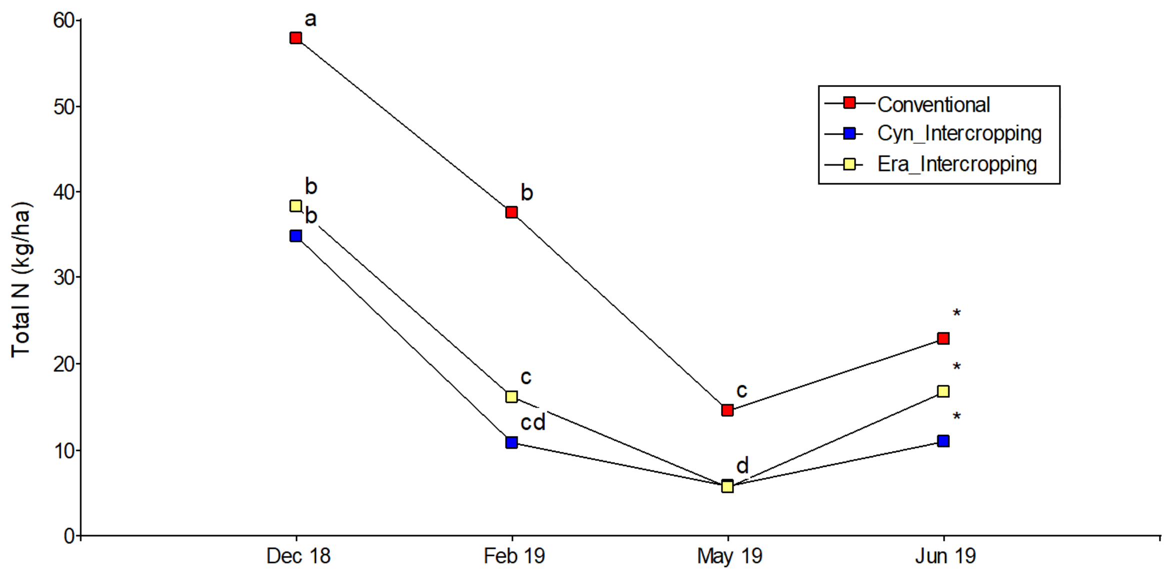

Figure 10: Inorganic N content (kg/ha) in the soil profile (0-75cm) as a function of management (Conventional, *Cynodon* intercropping and *Eragrostis* intercropping) for the different evaluation dates. Means followed by the same letter are not significantly different (P>0.05) according to LSD Fisher. (*) Only one block was sampled, these values only show a trend.

These differences in the inorganic N content of the soil profile were coming from the top 0-25 cm horizon and from the deeper 50-75 cm, where inorganic N follow a similar pattern with no marked differences between perennial species (Fig. 11). In the 25-50 cm horizon, differences between permanent pastures appeared, suggesting a higher N consumption by *Cynodon* than by *Eragrostis* (figure 11B). This higher consumption was visualized throughout the crop cycle, registering significant differences in February.

In all the layers evaluated, the N content was higher in conventional management for all dates.

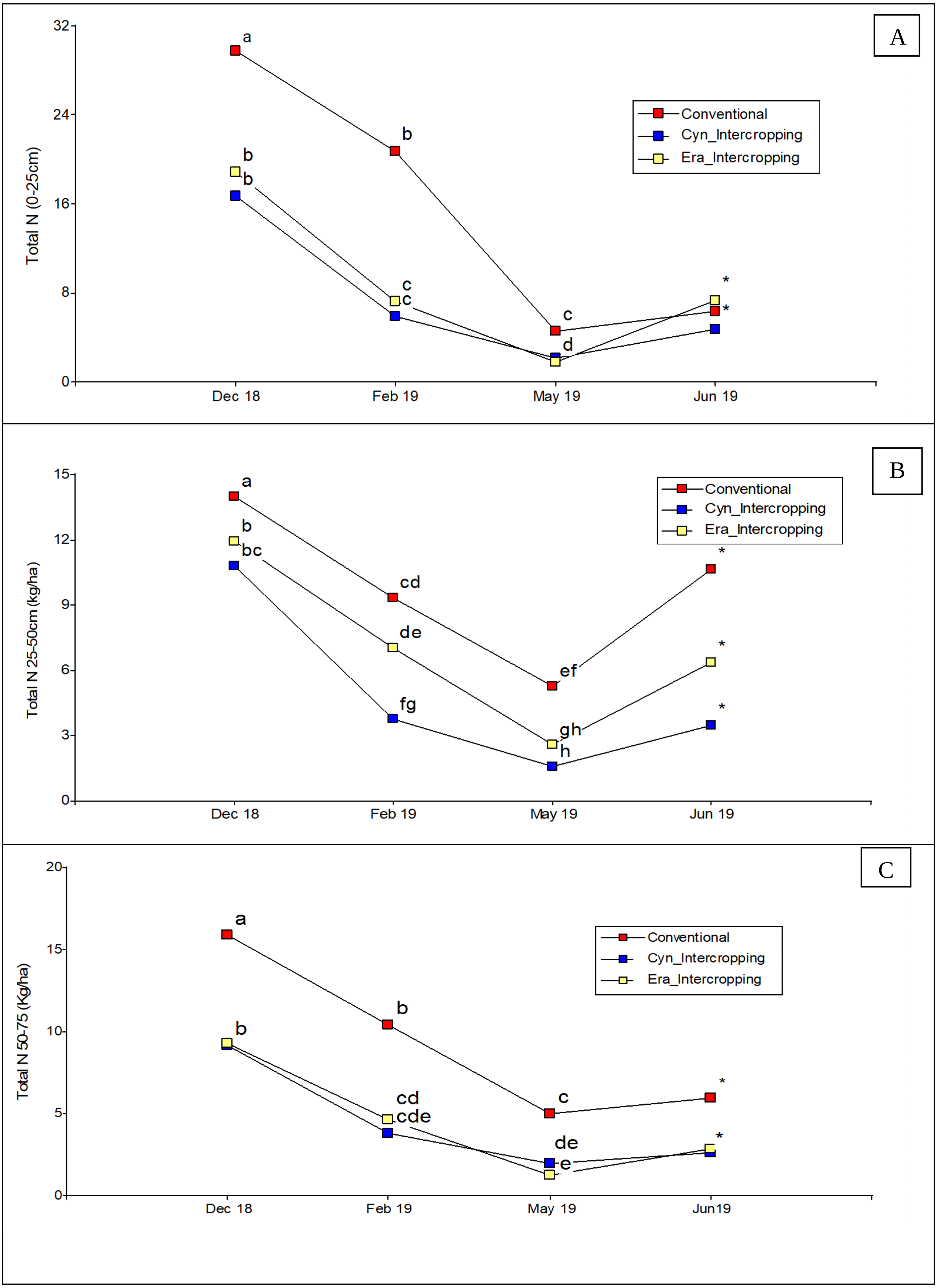

Figure 11: Soil inorganic N content (kg/ha) according to management (Conventional, *Cynodon* intercropping and *Eragrostis* intercropping) for the different evaluation dates and depths. A: 0 to 25cm; B: 25 to 50 cm, and C:50 to 75 cm. Means followed by the same letter are not significantly different (P>0.05) according to LSD Fisher. (*) Only one block was sampled, these values only show a trend.

When the accumulated N contents of 0-50 cm (0-25 + 25-50) and 25-75 cm (25-50 + 50-75) were considered, the trend was towards a higher in-depth consumption of *Cynodon* in comparison with *Eragrostis* in February (figure 12). Although the differences were not statistically significant, it was possible to visualize a higher overall N consumption in average values when the grass used was *Cynodon* (figure 12).

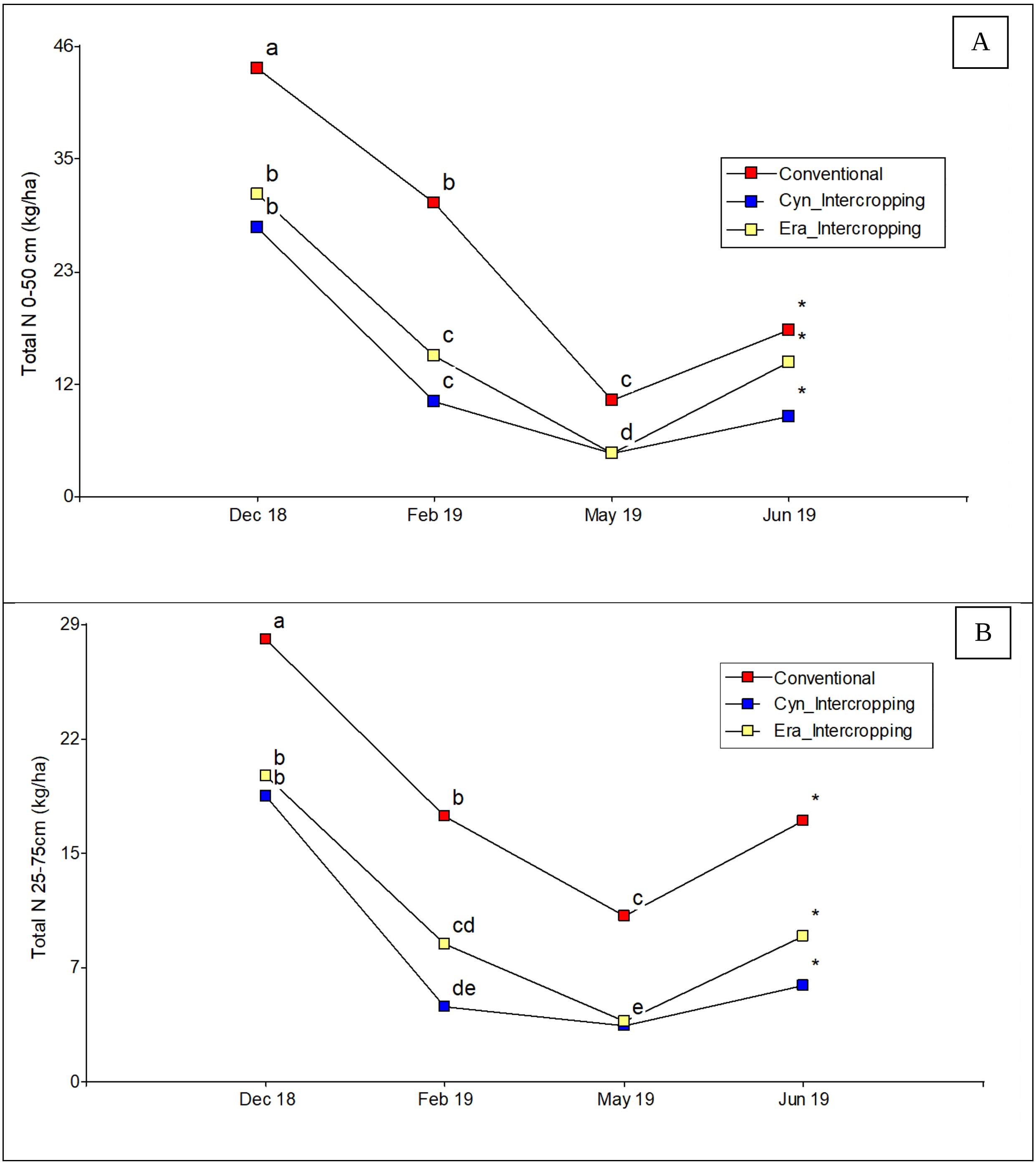

Figure 12: Soil inorganic N content (kg/ha) according to management (Conventional, *Cynodon* intercropping and Eragrostis intercropping) for the different evaluation dates and dephts. A: 0 to 50 cm; B: 25 to 75 cm. Means followed by the same letter are not significantly different (P>0.05) according to LSD Fisher. (*) Only one block was sampled, these values only show a trend

Figure 13 shows the inorganic N content (0-75cm) separate by crop. As expected, N content was higher in the legume crop sequence than in the cereal crop sequence. These increase in N availability is particularly relevant at the sowing time, when vetch crop registered 36% more inorganic N than barley (64 vs. 47 kg/ha). Also, It is interesting to note that in vetch crop, the differences for N content between the perennial grass species used were more evident, being possible to discriminate *Cynodon* against *Eragrostis* for the first 2 sampling dates.

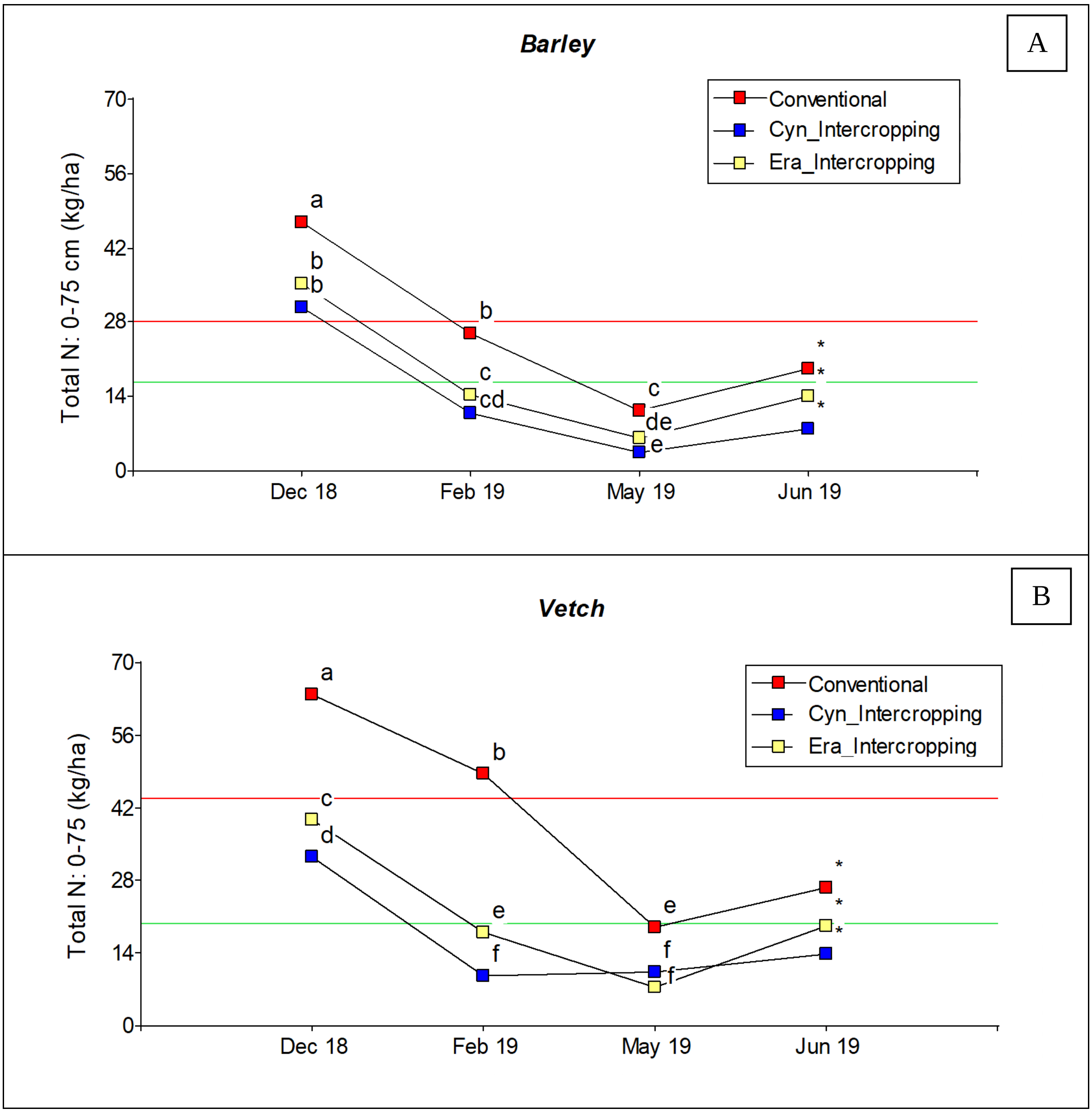

Figure 13: Inorganic N content (kg/ha) in the top 0-75 cm soil profile according to management (Conventional, *Cynodon* intercropping and *Eragrostis* intercropping) for the different evaluation dates. A: Barley; B: Vetch.; Green line: mean overall N content for intercropping treatments (*Cynodon*+*Eragrostis*); Red line: mean overall N content conventional treatments. Means within a crop followed by the same letter are not significantly different (P>0.05) according to LSD Fisher. (*) Only one block was sampled, these values only show a trend.

5 DISCUSSION

In the Mediterranean climate of central Spain, the adoption of summer pastures such as *E. curvula* or *C. dactylon* (the latter even considered an important weed) into agricultural systems for pasture cropping is not an easy election for farmers. The requirements of these grasses contrast with the climatic conditions prevailing in the centre of the peninsula. As it was mentioned, the good performance of this technique lies in the ability of the perennial species to persist during prolonged periods of drought and cold tolerance, staying asleep or with very low growth rates at the time of growth of winter crops (Descheemaeker et al. 2014). This condition is strickty influenced by temperature and rainfall throughout years. In this sense, the periods contemplated in this study allowed characterizing the performance of crops and pastures evaluated under markedly contrasting environmental conditions.

5.1 Crop performance

According to the results obtained, it is possible to sow winter crops over summer-growing perennial grasses without affecting the establishment of the crops in the central region of Spain. Regardless of the year or grass species used, the emergence of the cereal or the legume was not a limiting factor. The same results have been obtained on previous experiences by Dorado et al. (2017). In addition to this, it is mentioned by Finlayson et al. (2012) that pasture cropping is thought to be a useful way to maintain ground cover and reduce the consequences of cereal-establishment failure in lighter soils where there is a relatively high chance of crop establishment failure with conventional management due to low fertility and poor moisture-holding capacity. However, it is important to remark that prior to the sowing of winter crops in the last year, it was necessary to apply herbicide to desiccate the pastures since they still had some activity. This situation would be associated to the higher average temperatures registered during the previous months and water availability as a consequence of the abundant autumn rains in 2018. These conditions would have favoured the delay of vegetative stop of grasses as they still find a suitable environment for their growth. To avoid this inconvenience for crop establishment, Lawes et al. (2014) also used herbicides to supress the pastures before the direct drilling of the crops at the start of the winter growing season.

For pasture cropping to succeed, crop and pasture must coexist, and from an economic perspective, pasture should not excessively penalize crop yields, because crops support the profitability of this system (Finlayson et al. 2012). In this sense, our results indicates that such a management system would strongly affect the main crops yields when the available resources, especially water, are low. Yield losses on barley around 50-60% registered in the last cycle are similar to those cited by Millar and Badgery (2009) and Hagan et al. (2013) on wheat under pasture cropping systems and are considerably higher than those reported on barley by Lawes et al. (2014) and Thomas et al. (2017) of 26% and 12%, respectively. The greatest losses recorded in the current experiment would be the result of early competition for resources from grasses. In both years, pastures began their regrowth in mid-April coinciding with the spikes emergence of the cereal crop (data not shown). In this sense, the greater water availability for the first year would have been sufficient to supply the cereal and pasture requirements, with no statistical differences among management. Even though, in average values, it is possible to visualize a higher yield on the first cycle of conventional barley concerning intercropping, which would show that this competition was also present. Ward et al. (2014) studying soil-water dynamics in a pasture-cropping system in Southwestern Australia registered that treatments containing perennial pastures reduced soil-water contents during summer and autumn by 150 mm compared with the conventional management, which clearly demonstrate the competition between crop and grasses for water. The lower impact on barley yield in the experiences of Lawes et al. (2014) and Thomas et al. (2017) could be due to the lower growth of grasses during the crop period and that the delay in their activity until late spring. This separation between the growth of the pastures and the senescence of the cereal would explain to a large extent the differences observed with our data. Another explanation could be a low water use efficiency as a result of two species growing together for a variable period of time. Ward et al. (2014) pointed out that water use efficiency of grain production was significantly higher for barley and lupine under conventional cropping than pasture cropping and that the difference was driven by both lower yield in the pasture cropping treatments, and higher water use.

In the case of vetch, the variability registered in yields during the first cycle makes it difficult to explain the differences between treatments. The yield in conventional vetch did not differ from vetch under pasture cropping, regardless of grass species. On the other hand, differences between the two vetch pasture cropping were registered. Indeed, we found lower average productivity in the intercropping of vetch with *C. dactylon*. Given that during the first year rainfall was adequate and uniform throughout the vetch growing period, it is possible that *C. dactylon* exerts greater competition over vetch than *E. curvula*. Another possible hypothesis could be a lower vetch development as a consequence of an allelopathy generated by *C. dactylon*, affecting the biomass accumulation over time. It has been documented that *C.*

dactylon could have negative effects on some legumes. Aqueous extracts of its rhizomes decreased the seed germination and root growth of pea and that its residues decreased fresh weight of root and shoot in seedlings of soybean (Narwal 1994). Gamez Gonzalez et al., (2002) found that steam extract of *C. dactylon* reduced dry matter in bean, although wheat and oak was affected too. In addition, vetch has a slower initial growth rate when compared to barley and it may have been further reduced in the presence of a possible allelopathy. In this sense, Ferreira et al. (2008) found that seeds with high speed germination escaped the allelopathic effect of *Eragrostis plana*. These authors suggested that allelochemicals were released during the decomposition of residues and the seeds that delayed germination were exposed to the allelopathic effects. This could explain the null effect of perennial pastures on barley since its seeds has a rapid germination and establishment after sowing, while vetch with a slowly germination could suffer the allelopathic effect.

In the second cycle, characterized by very low rainfall, pasture cropping significantly reduced the production of biomass in relation to conventional management. This would be explained to a large extent by the competition towards the water-limiting resource by the pastures and crops. Similar results were found by Millar & Badgery (2009), who stated that legumes biomass were reduced by pasture cropping, but drought had a larger influence on biomass than treatment. In Lawes et al. (2014) experiences, lupin yield was limited between 0.06 and 0.4 t grain/t pasture biomass produced, even with good spring rains.

Another variable that would indicate the high stress level on pasture cropped vetch was the percentage of flowering measured on late spring which was a 75% higher in conventional vetch (Figure 14). This greater stress, clearly reflected in the flowering season, may have affected dry matter accumulation at harvest time. This variable was assessed according to Mischler (2010), because conventional vetch had more flowers than vetch pasture cropped at simple sight in order to quantify and register these observations.

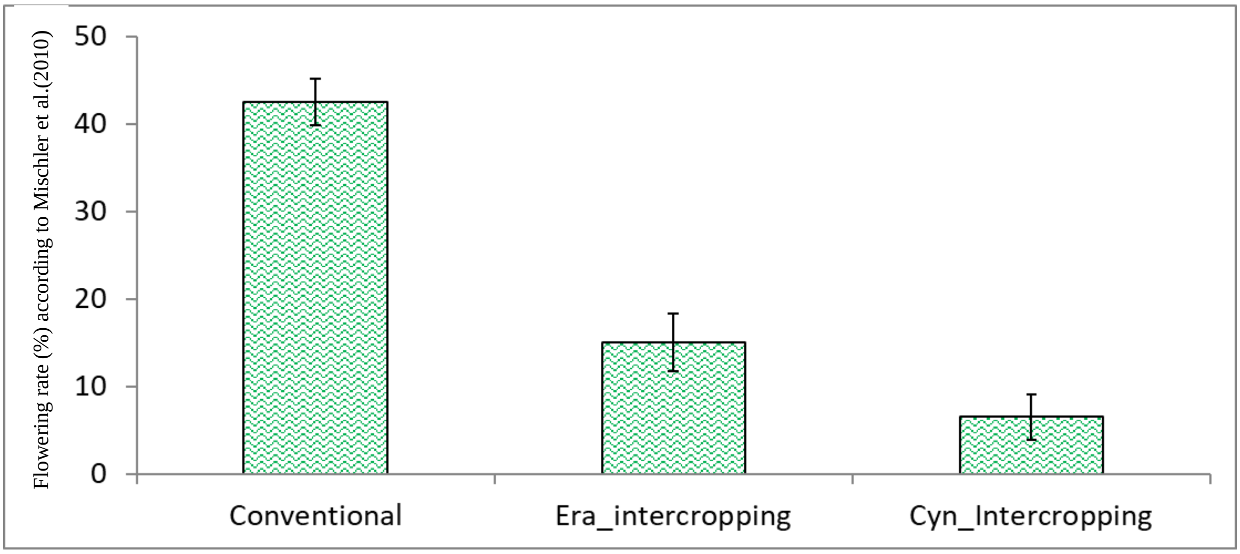

Figure 14: Percentage of flowers opened in vetch for different treatments in late spring. Bars showing the standard error.

5.2 Pasture performance

Pasture establishment is a critical stage where perennial grasses could experience emergence problems as it was observed by Corleto et al. (2009) in several tropical grasses in Mediterranean environments. In the current research, summer-growing pastures could be sown successfully during spring but as it was mentioned, irrigation was needed to support their establishment on first year, which could be a limiting factor on only rainfed farms.

Regarding pasture production, it was very variable and strongly associated with seasonal rainfall, coinciding with reported by numerous authors in relation to the behavior of perennial grasses under pasture cropping systems (Descheemaeker et al. 2014, Lawes et al. 2014, Millar and Badgery 2009). The greater generation of biomass in spring 2018 would be linked to the greater precipitations during the April-June period (~ 113 mm), especially those occurred in May and June (Figure 15), since in these months the competition for resources by winter crops is lower because these are in advanced phenological stages, close to harvest. In the same way, the low biomass production in spring of 2019 could be linked to the fact that the limited rains occurred in April with the crops beginning their reproductive stage. For this reason, both crops and pastures would have competed for this resource affecting either productivity. Summer biomass production was only relevant last year because of the abundant rainfall from late August to October (~ 184 mm). The production peaks reached in 2018 by the pastures (~2 t/ha) are similar to those obtained on Gatton panic (*Megathyrsus maximus* cv. Gatton) in pasture cropping systems by Descheemaeker et al. (2014) and Lawes et al. (2014) when the amount of summer-autumn rainfall was less than 150 mm. However, when rainfall is higher it is possible to reach peaks of 3.5 t/ha (Lawes et al. 2014) or even 7 t/ha (Descheemaeker et al. 2014), taking into account in the last case that the accumulated rainfall during grass growing season were close to 460 mm. These results are close to those obtained in the present experiment with better rainfall conditions. In this sense, late summer rainfall would be the most effective for the generation of pasture biomass, since spring rains would be used by crops and pastures, while precipitations concentrated towards the end of summer would only be used by pastures when temperatures would still be favourable for their growth.

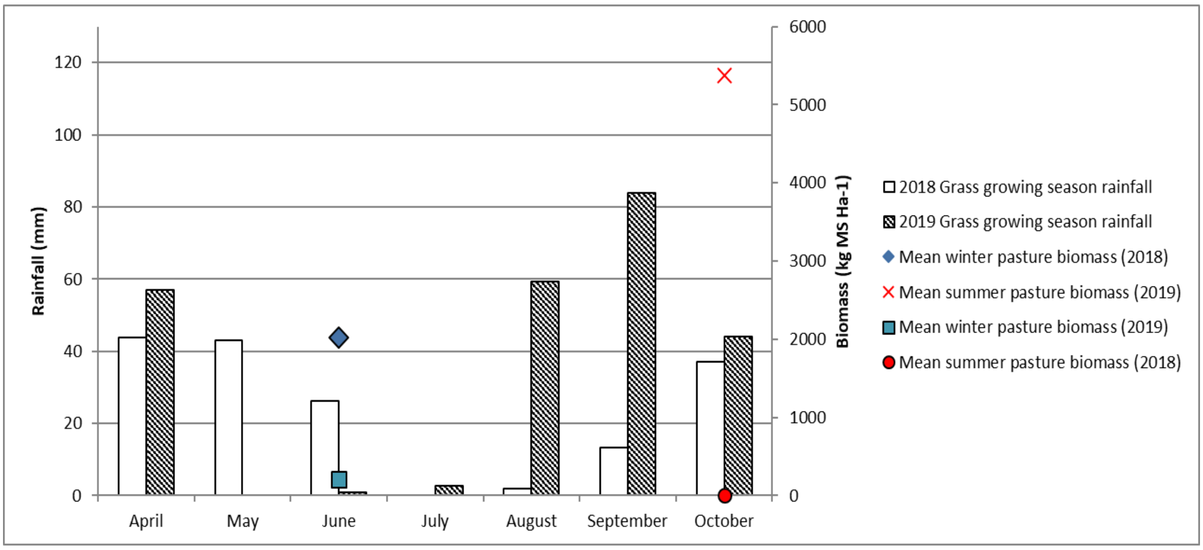

Figure 15: Grass growing season rainfall and average grass biomass in 2018 and 2019

However, despite the excellent establishment of the pastures (with cover levels close to 100% by first year), the soil cover provided by the pastures decreased throughout the experiment until reaching average values of 45% in both species. In this sense, in order to achieve an effective competition from grasses over weeds, pasture soil cover must be uniform and maintained between cycles. The lower is the pasture soil cover, the higher are the niches that weeds can explore and exploit and their density will progressively increase. In this sense, Colin Seis (2012) points out that providing the conditions for perennial pasture species to thrive will steadily suppress the weeds over time and that this suppression is achieved, not with herbicides, but with soil cover. Using herbicides can help in some circumstances but can also kill desirable species, such as the perennial pasture species. One of the causes that would explain the loss of cover of the pastures is their need for water during the summer for the synthesis of photoassimilates that would serve them as an energy reserve. As Nie et al. (2008) mention, the climate, and in particular rainfall, is an important factor that affects pasture persistence. According to them in regions with low summer rainfall, there appeared to be a trade-off between summer activity and persistence for temperate grasses, so that summer-dormant plants were more persistent than summer-active species. Descheemaeker et al. (2014), working in Australia under Mediterranean climatic conditions, concluded that the intercropping system was an option in areas with at least 150 mm of rainfall during the period of pasture growth. In our case, summer and autumn rainfall in 2018 were below this amount and that probably affect negatively the grass capacity to maintain soil cover. In other studies carried out in Italy, Corleto et al. (2009) successfully implanted *E. curvula* in different environments and maintained them for 3 years, but variable support irrigations were required during the summer. In such sense and for those cases where irrigation was feasible, the practice of supplementary irrigation during the summer could be an interesting tool to increase the persistence and biomass production of the pastures in Spain.

5.3 Effectiveness in weed supression

The results of this study have shown significant differences in weed suppression mainly depending on the year.. Indeed, pasture cropping under favourable humidity conditions would have a significant suppression on weed density and biomass (Tables 10 and 12). It is important to point out that during the first year there were no post-emergent applications of herbicides for weed control and the differences observed were due to management. However, when water conditions were as limiting as in 2019, the interaction between management system and crop becomes relevant. Although in the second cycle post-emergent herbicide treatments were carried out on the crops under conventional management, these were conducted after weed counting and did not affect the density recorded in each treatment. In this way, it is possible to observe the same behavior of barley as 2018, with higher weed densities in conventional management compared to pasture cropping. However, in the case of vetch, intercropping with *C. dactylon* showed the highest weed density, followed by conventional vetch and finally intercropping with *E. curvula*. The lower weed suppression in intercropping with *C. dactylon* would be explained by the lesser vetch development compared to barley on *C. dactylon* plots as a consequence of an allelopathy generated by this species, leaving niches available for the establishment of weeds. As it was discussed above (see crop performance) it is possible that *C dactylon* may exert negative effects on vetch. This results contrast with those observed by Templeton and Taylor (1975) who overseeded vetch into a dormant sward of *C. dactylon* resulting in legume dominance rather than weed dominance in early spring. However, the environment where they carried out their experiment was characterized by abundant rainfall (annual mean > 900 mm). It is well known that allelopathic compounds tend to be soluble and, therefore easily transported by washing to deeper soil layers. Further investigation on this issue should be explore.

Another possible explanation may lie in the fact that *C. dactylon* would not compete so well under low humidity conditions independently of the crop. However, the higher initial growth of barley relative to vetch would have favoured competition against weeds. This would explain the better performance of *C. dactylon* pasture cropped with barley than when pasture intercropped with vetch. Since the latter develops more slowly, the weed community would have colonized the available spaces better.

The interaction between management system and crop on weed biomass observed in 2019 would be explained to a large extent, as a consequence of the post-emergence herbicide treatments carried out in crops under conventional management. In the case of barley, the control spectrum of the herbicides used included mono- and dicotyledons, while in vetch it was only directed to monocotyledons as there were no herbicides available for the control of dicotyledons in vetch crop. Thus, genera such as *Papaver, Descurainia* and *Sonchus,* among others, continued their development within conventional vetch plots, but not in conventional barley. This would explain the differences in weed biomass over crops under conventional management despite herbicide treatments. On the other hand, it is remarkable the control of weeds provided by *E. curvula* in both crops, equivalent to the use of herbicides in conventional barley or even higher than conventional vetch. However, crops intercropped with *C. dactylon* showed the lowest effectiveness in weed suppression, probably due to the combination of *C. dactylon*'s lower competitive ability on the autumn-winter weed community and the absence of herbicide treatments that limited weed growth.

5.4 Nitrogen under pasture cropping

It is clear that the consumption of N in pasture cropping systems appeared to be a major limiting factor. Such consumption is notably higher when perennial pasture is present, being marked during the whole cycle. This is consistent with what has been studied in other pasture cropping systems (Badgery, 2009; Bruce et al. 2005; Millar & Badgery, 2009).

Also interesting is the greater initial N content in conventional management for the entire soil profile regarding pasture cropped treatments. This could be largely explained as a consequence of summer pasture activity. They would use part of the available N even with low growth rates while in conventional management the nitrogen would be used later by the main crop.

The decrease in N content over time is also expected and is linked to the increasing crop development. However, given the results obtained, much of the N consumption would be attributable to perennial grasses under pasture cropping management. In the present study they reduced the N content by approximately 50%. This lower N availability would be another factor explaining the strong reduction in barley and vetch yields achieved. These results coincided with those achieved by Badgery (2009) who observed that the grass dominant summer active pasture used much of the N that mineralised leading into the cropping phase. They registered nitrate-N content in the top 10 cm averaged 23.4 mg/kg in the No Till Cropping plots compared to 14.4 mg/kg in the Pasture Cropping plots. In their experiment, although both pasture cropping and no till plots received fertiliser (Pasture Cropping 50 kg DAP/ha, No Till 100 kg DAP/ha) at sowing, the amount was not sufficient to offset the effect of the perennial grass. However, this issue could be solved if additional N is incorporated. Glover, et al. (2009), states that pasture wheat intercrop systems (PWI) consistently achieved yields of 1.7 to 2.0 tons ha-1 of wheat with applications of 112 kg ha-1 of N fertilizer. They mentioned that these yield levels were economically competitive with no-till wheat monocultures. According to them, PWI systems produced 2.7 tons ha-1 grain yields with 224 kg ha-1 N fertilizer rates, even on very poor sites. However, they also said that the profitability of the PWI system is highly vulnerable to fluctuations in N fertilizer costs. In contrast, Lawes, et al. (2014) tested different pasture-cropping systems under low and high levels of N fertiliser and suggest that grain yield losses are lower in a low-input system and that competition between the species was reduced in a N limited environment.

The major differences between the conventional system and pasture cropping are located at the surface (0-25 cm) and the depth horizons (50-75 cm) (figure 11). In the case of the middle horizons (25-50 cm) the N contents are more variable, although it is possible to discriminate the pasture cropped plots with *Cynodon* as the most extractive ones. This phenomenon is better observed when the management strategies were analysed by crop (figure 13), particularly in vetch where total soil N was statically lower for *Cynodon*.

Despite the fact that in this experiment there was not a rotation between the legume and cereal crop, and that the objective was not to discriminate differences in N levels due to the rotation itself, it is also important to remark the incorporation of a legume like vetch in a crop sequence. As can be seen in figure 13, vetch started in December 2018 with N contents a 36% higher. This is relevant if we assumed that the trial site was relatively infertile and the incorporation of organic N becomes a good practice; since the sum of soil NH_4^+ and NO_3^-, measured at 0–25 cm depth, averaged 21,7 kg/ha and ranged from 19 to 35 kg/ha, depending on the management. These results are similar to those assessed by Lawes et al., (2014) working on infertile soils.

6 CONCLUSIONS

The pasture cropping technique not adapt to the environmental conditions of central Spain. At least, not in the way it was originally thought. The crop yield losses due to pasture cropping were high in low rainfall scenarios because the pasture start its regrowth at the same time that winter crops enter into reproductive stages. Under no irrigation management this issue threatens the sustainability of the entire system, compromising the productivity of the main crops. In addition, soil cover by pastures decreased in time as a consequence of poor rainfall as well, affecting weed control performance. Another consequence of this is that grasses may provide sporadic and unpredictable feed for livestock depending to summer rainfall. Additionally, Soil nitrogen is reduced in pasture cropping systems being necessary to fertilize it. However, this technique assisted in controlling weed showing a good weed suppression, especially in barley and under no water limited conditions. Future work should be directed at investigating the effects of managing irrigation to avoid or reduce yield losses for competition between crop and pasture and the use of legume as a perennial crop instead a tropical grass.

7 RISKS AND OPPORTUNITIES FOR THE ADOPTION OF THE PASTURE CROPPING SYSTEM

Conceptually, the technique of pasture cropping is ingenious and attractive–growing annual crops on perennial grasses when these become inactive to increase the overall productivity of the system (grass and/or grain) while improving several environmental aspects–sound promising. However, attempts to adopt it simply as a technique are unlikely to be successful if it is not deeply and effectively integrated with the whole farm system, especially when the main objective is to harvest the main crop. The strengths of the system itself and the external opportunities for starting with pasture cropping are numerous, but so are its weaknesses and threats, especially in the Mediterranean environment of central Spain. In fact, when these last negative factors are put in the balance the result ends up turning it against the system. One of the most critical points observed is the high dependence on appropriate environmental conditions of rainfall and temperature, which must ensure two aspects for the system to be maintained over time. The first is that the availability of resources, mainly rainfall but also nitrogen, should be supplied for both the pasture and crop components. This makes the system highly vulnerable in rainfed environments. The second aspect is that the environment must ensure adequate seasonality in order to avoid a longer permanence of the pastures towards winter, as well as early regrowth of the same. Changes in seasonality could affect the system since the growth period of the perennial grasses would be longer, increasing competition for resources with main crops. In this sense, the climatic forecasts for the Mediterranean region and specifically for Spain, show a tendency to desertification of certain regions as well as an increase in average temperatures (Vargas-Amelin and Pindado 2014), which presents a major threat. Therefore, the introduction of the pasture cropping system in Spain should consider the use of external inputs, such as irrigation, nitrogen fertilization and sometimes herbicides to dry the perennial grasses when the environmental conditions allow them to remain green close to the sowing of the winter crops. Neither should such a system be introduced on a large scale or as a single system within a farm. It can be directed to certain areas in order to take advantage of its benefits, such as the recovery of degraded soils (increasing levels of organic matter and soil structure, reducing erosion processes, etc). However, supporting such a system with external inputs (irrigation and nitrogen) to reduce competition between the perennial component and crops has yet to be evaluated. Another possible alternative to reduce competition for water use is to increase water use efficiency under controlled deficit irrigation-CDI (González-Altozano and Castel 2003). The CDI consists of reducing the water inputs only to certain moments of the crop cycle, in which such reduction does not significantly affect the production or the quality of the harvest. Then, to fully cover the demand of the plant for the rest of the crop cycle, particularly during the critical periods or phenological states of greater sensitivity to water deficit. The CDI could be directed at increasing the productivity of the winter crops and the perennial component (as well as its permanence in time). In the case of pastures, this supplementary irrigation would be most effective if concentrated towards the end of summer, since it would only be used by the grasses.

Additionally, it is well known that legume crops are capable of fixing atmospheric N and reducing fertilizer inputs in the following crops (Blackshaw et al. 2010). In this sense, the introduction of a perennial legume into an annual-based cropping system could also provide soil N, quality summer fodder, and assist in summer weed control as it was demonstrated by Humphries et al. (2004) overcropping wheat into Lucerne (*Medicago sativa* L.). So, replacing the perennial grasses for perennial legumes may locally improve pasture cropping systems, but it should be tested.

To summarize, many variables still need to be studied in depth to adjust the pasture cropping system to the Mediterranean environment of central Spain in order to take advantage of its strengths and opportunities while minimizing its weaknesses and threats

Strengths	Opportunities
- Increased soil cover - Improves soil structure - Increased Organic Matter - Increased infiltration - Increased water retention in the soil - Assist in controlling weed - Reduced NO_3 leaching - Reduced erosion - Increased CO_2 capture - It could improve global productivity	- Global trend towards more sustainable systems - Increased restrictions on the use of herbicides - Use of irrigation to reduce risks and increase overall productivity - Fundings to implement conservation systems - It can be used as a remediation tool for degraded environments
Weaknesses	**Threats**
- High dependence on environmental conditions - Variable impact on crop yield - It's not an intuitive practice - Complex system due to the interaction of pasture and cultivation - Loss of pasture cover - Variable impact on winter crop yields - Risk of perennial species becoming weeds - Difficulty in the implantation of the pastures - Variability in the production of pasture biomass - Need for nitrogen fertilization	- Loss of seasonality - Increase in average temperature - Decrease in average rainfall - Availability of access to No Till seeders - Farmers' willingness to change

Figure 16: Strengths, opportunities, weaknesses and threats for the adoption of pasture cropping system

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9 ANNEXES


Figure 17: Barley intercropped on *Eragrostis curvula* during the nascence


Figure 18:Barley successfully implanted on *E. curvula*

Figure 19:*Cynodon dactylon* in latency previous to sowing winter crops

Figure 20: Barley successfully implanted on *C. dactylon*

Figure 22: Vetch plants emerging from *C. dactylon* stubble

Figure 21: Vetch pasture cropped on *C. dactylon*. To its side, it can be seen vetch under conventional management.

Figure 24:Senescence of cereal and beginning of regrowth of pasture

Figure 23: Cereal before harvest. Grass already growing under the cereal.