ORGANIC VERSUS CONVENTIONAL METHODS OF FERTILIZATION AND WEED CONTROL IN A LONG TERM ROTATION OF CEREALS IN SEMIARID SPAIN

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ABSTRACT

Under semiarid conditions the response of cereal crops to chemical fertilizers and weed control practices with herbicides is often reduced. In fact, the economic profitability of agricultural production in many dryland regions is critically affected by high costs of inputs and low crop yields. As a solution, cropping systems like organic farming, obtaining similar yields and promoting environmental sustainability by reducing fertilizer and herbicides, could be an alternative to conventional systems. In this study, 23 trials were performed in five semiarid regions of Spain during 5 yr to compare different fertilizers and weed control methods on durum wheat (*Triticum durum* Desf.) and barley (*Hordeum vulgare* L.) yields. The following rotation pattern was developed on the experimental plots: fallow-barley-ground ploughed vetch (*Vicia sativa* L.)-durum wheat. Plots either received organic fertilizer, chemical fertilizer, or no fertilizer. In addition, three levels of weed control were applied in cereal plots: flex-tine harrow tillage, conventional herbicide, and no weeding. The results indicated that neither the fertilization nor the weed control have effect on the yield crop.

Key words: Sustainability, ecological agriculture, crop rotation, compost, flex-tine harrow.

In the last 30 yr, the profitability of extensive dryland agriculture in Spain has decreased gradually. While the price of grain has decreased, the costs of energy and inputs like chemical fertilizers and herbicides required for farming have increased. As a consequence, the economic viability of the majority of farms under conventional agricultural system critically depends on the European Union Common Agriculture Policy (CAP) support in the form of direct payments.

These problems have given rise to new productive models such as organic farming and integrated agriculture. These production systems can be profitable while providing environmental benefits by reducing or avoiding the use of chemicals and preventing other agricultural problems like pesticide resistance and soil residues (Pardo *et al.,* 2009a). Furthermore, the reduction in agrochemicals can improve the sustainability of the system in the long term. In this context, crop rotation and mechanical weed control are recommended to maintain crop productivity and reasonable weed densities.

In Spain, grain production levels on semiarid drylands cannot compete with central and northern Europe because of low rainfall (Angás *et al.,* 2006). However, organic farming could easily be developed in these drylands since chemical treatments have little impact over the yield (Lacasta and Meco, 2006; García-Martín *et al*., 2007), and sometimes they can be even negative (Van Herwaarden *et al.,* 1998). On the other hand, the effect of herbicide applications is limited because the soil conditions are not adequate under semiarid climate conditions. In other cases when rainfall is more abundant, herbicides controls weeds but the crop yields do not increase because of a low density of weeds (Lacasta and Meco, 2006). Therefore, farmers do not use herbicides if the humidity and agronomic conditions are not positive (Rodríguez-Pérez and Díaz-Salazar, 2002).

On the contrary, some authors have suggested that eliminating the use of chemicals will slowly impoverish

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the soil of nutrients (García-Martín *et al*., 2007) and will lead to a progressive proliferation of weeds (Nogueroles and Zaragoza, 1999) with the subsequent negative effects on crop production.

Even though organic production techniques may be easy to introduce, there is a need to develop alternatives for fertilization and weed control to correctly evaluate the impacts of their introduction under semiarid conditions in the long term. The evidence in Spanish and European literature are incomplete because the existent works are limited temporally (covering a small number of years) and spatially (very local studies).

The main objective of this paper was to study the effect of different types of fertilization and weed control –typical of conventional and organic production system–sover the cereal production in five semiarid dryland plots representative of Spanish agriculture, where the same crop types were maintained from 1996 to 2003.

MATERIAL AND METHODS

Trial locations, rainfall and soil types

The experimental trials began in 1996-1997, although the present analysis only includes the results of the last 5 yr. The trials were performed in five different regions where the rainfed agriculture is especially relevant. The specific locations of field experiments are the following: Huesca (42º06' N, 0º23' W, 430 m.a.s.l.), Navarra (42°27' N, 1°39' W, 380 m.a.s.l.), Soria (41º34' N, 3º1' W, 860 m.a.s.l.), Toledo (40º3' N, 4º26' W, 490 m.a.s.l.) and Zaragoza (42º17' N, 2º25' W, 454 m.a.s.l.). The annual average rainfall for all locations ranged between 391 and 560 mm, with a semiarid moisture index (Thornthwaite, 1948). Table 1 show the precipitation registered during the crop season (November to June) in trial locations. The possibility of repeating the experiment in five different locations is one of the most interesting and novel aspects of the study, because it allows to replicate the trial under different climatic conditions and soil types representing the characteristics of rainfed agriculture in Northern Spain. The relevant soil parameters of each trial are shown in Table 2.

Crop rotation and plant material

At present, the agriculture in all studied regions is based in a conventional production system, following a rotation fallow-cereal (durum wheat, *Triticum durum* Desf., or barley, *Hordeum vulgare* L.). For the purposes of our study and according to organic system principles, we modify the usual rotation by introducing vetch one of

Table 1. Precipitation registered during crop season in trials.

	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003
			mm		
Huesca	275	223	181	258	280
Navarra	314	180	254	231	355
Soria	314	247	130	315	-
Toledo	201	247	130	326	398
Zaragoza	302	257	80	228	336

Average rainfall during the experimental crop season 245 ± 63 mm.

Table 2. Soil characteristics in each trial.

Variables	Huesca	Navarra	Toledo	Soria	Zaragoza
Soil particles					
Sand (0.05-2 mm), %	6.62	21.07	30.01	47.71	39.68
Silt (0.002-0.05 mm), %	48.25	35.93	40.91	23.82	26.73
Clay (< 0.002 mm), %	45.11	43.01	29.08	28.47	33.43
Fertility parameters					
pH (H_2O)	8.33	7.99	6.83	8.15	7.95
Ce, dS m^{-1}	0.98	0.45	0.56	0.56	0.29
Organic matter, %	3.28	1.01	1.15	1.27	2.67
P (Olsen), mg kg^{-1}	11.69	14.97	11.09	15.01	21.90
K (ammonium acetate), mg kg^{-1}	243.56	196.10	119.01	199.91	327.01

the years and incorporating it on the soil by ploughing, in order to supply N to the soil. Furthermore, stubble and cereal straw were also incorporated in the soil after harvest to maintain or even increase organic matter in soil in a sustainable way.

In each location the trials were performed on two contiguous plots in order to have a winter crop every year, where a 4 yr rotation was established (Table 3). The data used in this study included the last 5 yr of the rotation (1998-2003, Table 3). This period was chosen because any possible differences in cereal output among treatments would be more obvious after the first 2 yr of the trial, which were necessary to reconvert from the previous conventional management.

The plant material used for trials was durum wheat 'Antón', during 1998-1999, 1999-2000 and 2002-2003. Barley 'Graphic' was used in 2000-2001, and 'Hispanic' in 2001-2002 in all locations. The vetch (*Vicia sativa* L.) in all years was the cv. Senda. The cereal and the vetch were sown in November and the harvest was in June-July, except in Soria, where it was extended to August. The vetch was ploughed in the soil in May.

Experimental design

The experimental design for the cereal unit in each location and year was a split-plot with four replicates in Toledo and Zaragoza, and three replications in Huesca, Navarra and Soria. There were two factors (fertilization and weeding) and three levels for each factor in an experimental plot of 91 m^2. The same type of fertilizer and weed control was used in the same physical space from the beginning of the experiment (year 1996) to evaluate the constant effect of both treatments through time. The adjacent plot remained as fallow or vetch, following the description in Table 3. The treatments of the different factors were the following:

Main factor (fertilization). F1: Control, without fertilization; F2: Organic fertilizer: 2500 kg ha^{-1} compost (sheep manure and cereal straw) applied at pre-planting (33.3% moisture, 57.4% organic matter, 27.8% C, 2.9% N, 1.4% P_2O_5, 5.1% K_2O and 0.89% Na). Compost was provided by Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT) in Soria, with adequate characteristics for organic farming; F3: Chemical fertilizer: 100-60-60 N-P_2O_5-K_2O kg ha^{-1} in 1998-1999 and 1999-2000 and 70-60-60 kg ha^{-1} in 2000-2001, 2001-2002 and 2002-2003. The fertilizer was applied at pre-planting with a rate of 32-60-60 N-P_2O_5-K_2O kg ha^{-1} and the rest of N was applied as top dress at tillering.

Secondary factor (weed control): E1: Control, without weed control; E2: Mechanical weed control with harrow: one superficial pass along the sowing lines with a light flex-tine harrow (Hatzenbichler, St. Andrä, Austria), at tillering of the cereal. The regulation was set for the maximum weed control while avoiding appreciable crop damage according to previous work (Pardo *et al*., 2009a); and E3: Chemical weed control: herbicides chosen according to the existing weeds, aiming for selectivity and efficiency at an authorized dose and at the right moment (Table 4). The herbicides were selected according weed flora, crop (barley or wheat) and growth stages of both weeds and crop. Herbicides were applied using a manual sprayer especially designed for these trials. The predominant weed species were *Papaver rhoeas* L., *Fumaria officinalis* L., *Anacyclus clavatus* (Desf.), *Veronica hederifolia* L., *Sinapis arvensis* L., *Convolvulus arvensis* L., *Galium aparine* L., *Polygonum aviculare* L., *Lolium rigidum* Gaudin and *Avena* spp.

Statistical analysis

The statistical analysis was performed according to the design established in each field using the SYSTAT 7.0 statistical package (SYSTAT, 1997). The data satisfy normality and variance homogeneity. When we detected a significant effect of the studied factor we separated the measurements using a Tukey test ($p < 0.05$).

RESULTS AND DISCUSSION

In this section we discuss the results corresponding to 23 of 25 total existing trials (5 yr × 5 locations). Data from Huesca 2001-2002 were eliminated because of poor emergence and data from Soria 2002-2003 because of excessive irregularity. In both cases technical problems were caused by machinery breaks. With respect to the rest of trials, 14 correspond to durum wheat crop (1999, 2000, and 2003) and nine correspond to barley crop (2001 and

Table 3. Crop rotations during the experimental trials.

	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003
Unit 1	Barley→	Vetch→	Durum wheat→	Fallow→	Barley→	Vetch→	Durum wheat
Unit 2	Fallow→	Barley→	Vetch→	Durum Wheat→	Fallow→	Barley→	Vetch

Bold text: data included in this work.

Table 4. Herbicide active ingredient and applied doses rates in trials.

	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003
Huesca	Tralkoxydim 25% (1.5 L ha^{-1})	-	-	-	2,4-D 48% (1.25 L ha^{-1})
Navarra	Diclofop-methyl 28% (2.5 L ha^{-1}) + Tribenuron 75% (15 g ha^{-1})	-	-	-	Tralkoxydim (1.5 L ha^{-1}) + Paraphinic oil 60% (0.75 L ha^{-1})
Soria	Tribenuron (25 g ha^{-1}) 2,4-D 27.5% + MCPA 27.5%	Tribenuron (25 g ha^{-1})	-	-	-
Toledo	Bromoxynil 7.5% + Ioxynil 7.5% + Mecropop 37.5% (2 L ha^{-1})				Bromoxynil (1.5 L ha^{-1}) + Ioxynil 12% + Mecoprop 36% (2 L ha^{-1}) + Paraphinic oil (0.75 L ha^{-1})
Zaragoza	Terbutryne 7% + Chlortoluron 43% (3.5 L ha^{-1})	-	Diclofop-methyl 36% + Diflufenican 2.5% + MCPA 25% (2 L ha^{-1})	Terbutryne + Chlortoluron 43% + Triasulfuron 0.25% (1.5 L ha^{-1})	Tralkoxydim (1.5 L ha^{-1}) + Ioxynil 12% + Mecoprop 36% (2 L ha^{-1}) + Paraphinic oil (0.75 L ha^{-1})

2002). To facilitate discussion of results, separately data obtained for fertilization and weed control treatments are presented.

Fertilization

In the majority of the cases, the results indicate that chemical or organic fertilizers were not effective to significantly increase crop yields (Table 5). In relation with unfertilized plot, chemical treatment only increased yields in five occasions, and in one case the yield significantly decreased. The effect of the organic fertilizer was lower also in relation to the unfertilized plot: yield only increased in two cases and the effect was never negative.

For durum wheat, data by location showed that only in the case of Navarra-2003 there were significant differences for the chemical fertilizer. The reason of having not important differences between fertilized and unfertilized plots for the alternative treatments considered could be found in the amount and distribution of rainfall. Certainly, yields obtained in these areas critically depend on the rainfall (Angás *et al*., 2006; Moret *et al*., 2007) and the effect of applied inputs is low (García-Martín *et al.,* 2007). Furthermore, the incorporation of cereal straw and the rotation with vetch may also explain the results. In fact, the rotation with buried vetch in the previous season appeared to have provided enough nutrients for the scarce yields obtained under these semiarid conditions. Some authors like Ernst (2006), Odhiambo and Bomke (2001) and Talgre *et al*. (2009) suggest that burying a leguminous plant can provide between 10 and 200 kg N ha^{-1} for the following crop. In Zaragoza location, for example, N present in vetch aerial biomass varied from 22 to 50 kg N ha^{-1} (Pardo *et al*., 2009b), without considering N in root biomass. Thus, the effect of the additional 100 kg N might be masked or exceed the quantity of N already in the soil if we consider the amount of N given by vetch. According to Campbell *et al*. (1991), Thorup-Kristensen *et al*. (2003), and Tonitto *et al*. (2006), when the potential crop yields are low, the inclusion of legumes in rotations can even compensate the total elimination of other fertilizers without abating yields. Some other studies located in semiarid areas of Europe (Betrán and Pérez-Bergés, 1997) and Australia (Van Herwaarden *et al.,* 1998) indicate that not positive response was observed to chemical fertilization (without previously ploughing a leguminous plant), and even the wheat yield decreases at higher doses of applied N.

Organic fertilizer significantly increased wheat yield (although with little differences in absolute values) in Navarra and Toledo (1999), with respect to chemical fertilizer (in Navarra also with respect to control plot). Thus, this treatment can be useful in some situations

Table 5. Yield according to location and fertilization treatment.

	1999 (wheat)	2000 (wheat)	2001 (barley)	2002 (barley)	2003 (wheat)
	kg ha^{-1}				
Huesca					
Control	512a	2830a	749a	-	891a
Organic	611a	2891a	793a	-	844a
Chemical	852a	2597a	734a	-	757a
Navarra					
Control	3263b	3078a	1478a	2907c	1140b
Organic	3557a	3193a	1555a	3064b	1179b
Chemical	3219b	3157a	3184b	3341a	1732a
Soria					
Control	2431a	3090a	652a	3216a	-
Organic	2780a	2329a	1019b	2942a	-
Chemical	3435a	3776a	1243b	4044a	-
Toledo					
Control	2309ab	2553a	477b	5212b	857a
Organic	2620a	2655a	596a	4733b	1108a
Chemical	1972b	2762a	317c	6159a	1159a
Zaragoza					
Control	1281a	2838a	818a	1596a	3077a
Organic	1041a	2941a	704a	1668a	3253a
Chemical	963a	2815a	684a	1176a	3068a

For every site and year, different letters indicate significant differences according to the Tukey test ($p < 0.05$).

although it is difficult to determine *a priori* whether it is better than the chemical fertilizer. In any case, increase in yield could be not enough to compensate the costs of treatment application (Pardo *et al*., 2009a).

Some authors underline that in dry years production is higher with compost than with chemical fertilizer, but the opposite occurs in wet years (Maiorana *et al*., 1992). On the contrary, in our case this expectation was not accomplished, because the best yield with organic fertilizer was obtained in Navarra (1999), under not especially dry conditions (Table 2). Other authors like Gonzalez *et al*. (1992) also obtained better yields under wet conditions, but with much higher fertilizer doses (20 t ha^{-1}).

With respect to barley trials (2001 and 2002), there were more situations (four in total) of positive response to chemical treatment than in the case of wheat. However, when production was especially low (Zaragoza 2001 and 2002, Huesca and Toledo 2001) yields were only equal or lower compared with compost or no fertilizer, showing that the amount of 100 kg N ha^{-1} could be excessive in very dry years (as it is explained above for the case of wheat). Yields were higher using chemical fertilizer when they were around 3000 kg ha^{-1} (Navarra 2001 and 2002, Toledo and Soria 2002). This result agrees with Angás *et al*. (2006), located in another semiarid area of Spain (Southern Lérida), where the yield improved by increasing the N dose, although the experiment was focus on a barley monoculture without vetch incorporation, thus one can expect that soil reserves are lost faster.

The compost had only a little effect in specific cases (Soria and Toledo 2001, Navarra 2002). This result is consistent with García-Martín *et al*. (2007), who did not find a positive response with the compost treatment in other semiarid areas of Southern Spain. However other analyses found an effect of the compost use in the long term (Eghball and Power, 1999), but that was not our case.

The results for barley presented here do not agree completely with the durum wheat results but the following points should be considered: first, barley was grown after a fallow period and 3 yr after vetch was incorporated, while the wheat was grown immediately after vetch. Thus, in theory barley had a lower amount of nutrients than wheat and then had a better response to the chemical fertilizer. Second, the biological cycle of barley is shorter than that of wheat so the former requires that nutrients should be available earlier. Finally, although it seems not very probable, unfertilized plots or just fertilized with compost could start to be deficient in nutritional elements after 7 yr, as suggested by García-Martín *et al*. (2007).

Summarizing previous discussion, and in spite of some particular cases, the global data of trials indicated that fertilization treatments studied do not appear to be justified for the conditions of the experiments. Under the semiarid climate of the studied sites the rotation and the nutrients remaining after the harvest were enough to maintain the relatively attainable low production levels through time (< 2500 kg). Focusing on the profitability of fertilizer treatments, only in one especially rainy year in Toledo location (2002) of 23 cases, the increase in crop yield with chemical fertilizer is justified (Pardo *et al*. 2009a). The use of compost is not profitable in any case.

Weed control

In the first 4 yr of experiments neither the application of herbicide nor the mechanical controls were effective to improve the yields (Table 6). Moreover, the treated plots did not achieve higher significant yields than the control plots in any case. The reason of this effect can be found in the scarce presence of weeds rendering weed control treatment unnecessary (or even negative) in the majority of the cases.

In general, mechanical weed control did not result effective, and harrowing even reduced production in two cases (Navarra 1999 and Zaragoza 2001) since it did not reduce weed density but could caused crop damages (there were not measured but they were observed in both trials). This result agrees with other authors who also registered a decrease in production with several mechanical treatments due to crop damages and/or ineffective weed control (Rasmussen and Rasmussen, 2000; Barberi *et al*., 2000; García-Martín *et al*., 2007).

In the first 4 yr the weed treatments were effective in some cases (data not shown) but yields were not increased by herbicide application or harrowing (Huesca 2001, Navarra 2001). In these cases the presence of high weed density did not diminish the final crop yields.

Table 6. Yield depending on weed control treatment in each location.

	1999 (wheat)	2000 (wheat)	2001 (barley)	2002 (barley)	2003 (wheat)
	kg ha^{-1}				
Huesca					
Control	826a	3065a	587a	-	809a
Mechanical	652a	2205a	896a	-	842a
Herbicide	497a	3049a	795a	-	843a
Navarra					
Control	3346a	3137a	2061a	3101a	1207b
Mechanical	3224b	3076a	2063a	2999a	1320b
Herbicide	3465a	3216a	2093a	3212a	1522a
Soria					
Control	2709a	3098a	995a	3629a	-
Mechanical	3061a	2401a	999a	2982a	-
Herbicide	2876a	3696a	921a	3591a	-
Toledo					
Control	2204a	2718a	492a	5390a	827b
Mechanical	2352a	2555a	420a	5244a	971b
Herbicide	2336a	2699a	486a	5469a	1327a
Zaragoza					
Control	1039a	2855a	781a	1442a	2887c
Mechanical	1092a	2832a	644b	1459a	3081b
Herbicide	1155a	2907a	781a	1538a	3429a

For every site and year, different letters indicate significant differences according to the Tukey test ($p < 0.05$).

Only in the last year (2003) for durum wheat, the lower weed density in the chemical or mechanical weeded plots achieved a higher yield in some sites (Toledo, Navarra and Zaragoza). An increased spring rainfall made the herbicides more efficient (data not shown), increasing yield in three locations. In Zaragoza, the mechanical treatment also increased yield, but less than the herbicide. This exceptional case –over 23 trials– underlines the difficulty of increasing output using this tool.

The previous results show the efficacy of the rotation cereal-fallow and cereal-ploughing vetch as green manure had a very positive effect impeding the presence of weeds associated to cereal. Thus initially weed densities were maintained at relatively low levels in the majority of the cases. Therefore even in the case that weed controls (chemical or mechanical) could eliminate weeds without damaging crops (which is almost impossible due to phytotoxicity or uprooting plants respectively), yields will rarely increase because of these low densities (see control plot results). On the other hand, mechanical control was not effective when weeds were too much developed and dry conditions reduced the effect of herbicide. As a result, both chemical and mechanical controls are clearly limited in productive terms and the ratio control-damage was not positive enough. Therefore, the weed control methods studied are not justified under our trial conditions.

In summary, in view of little reduction in yields resulting from not fertilizing and not weeding, the organic agricultural system can be an adequate alternative under the semiarid climate conditions of studied areas. In any case, the inputs reduction will conduct to economic savings. Moreover, if the crop yields can be sold at higher prices in ecological markets, farmers could improve the economic profitability of their exploitations (Pardo *et al.*, 2009a).

CONCLUSIONS

The chemical or organic fertilization methods increase yields rarely. Only when the precipitation regime is high the treatments are effective, but this is not frequent in semiarid regions. Furthermore, the weed control treatments (mechanical or chemical) are little effective to get better yields under trial conditions.

As a consequence, the proposed rotation cereal-vetch-cereal-fallow, which includes burying the stubble and cereal straw, is enough to achieve the adequate fertility levels and to maintain a limited density of weeds obtaining the usual crop productions in the region. With this management, the farmer may accomplish the European rules for organic products and, at the same time, increase the sustainability of the agricultural system by reducing the external inputs.

RESUMEN

Comparación de métodos convencionales y orgánicos de fertilización y control de malezas en una rotación de larga duración de cereales en secano, España. En condiciones de clima semiárido, la agricultura de cereal tiene una reducida rentabilidad debido a los escasos rendimientos y elevados costos de abonos y herbicidas. Dado que las condiciones climáticas impiden incrementar estos rendimientos, la viabilidad económica y la sostenibilidad ambiental de la agricultura en estas regiones pasan por reducir el costo de los insumos o por conseguir precios del producto superiores mediante la obtención de un certificado ecológico para su comercialización. En este artículo se presentan los resultados de 23 ensayos de un experimento de 5 años localizado en cinco zonas semiáridas representativas de la agricultura española de secano. El objetivo del trabajo fue comparar los efectos de diferentes métodos de fertilización y control de malezas –ecológicos y convencionales– sobre la producción. Para ello se diseñó una rotación compatible con las técnicas de agricultura ecológica: barbecho→ cebada (*Hordeum vulgare* L.)→ veza (*Vicia sativa* L.) como abono verde→trigo duro (*Triticum durum* Desf.). En las parcelas destinadas al cereal se estudiaron tres niveles de fertilización: testigo sin fertilizar, fertilización orgánica y química. Además, se aplicaron tres niveles de control de malas hierbas: testigo sin desmalezar, grada de varillas flexibles, y aplicación convencional de herbicidas. Los resultados mostraron que ni el tipo de fertilizante ni el control de malezas tuvieron efectos sobre los rendimientos, por lo que para estas áreas la agricultura orgánica puede ser una solución viable.

Palabras clave: Sostenibilidad, agricultura ecológica, rotación de cultivos, compost, grada de varillas flexible.

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