Are old varieties less productive than modern ones? Dismantling a myth.

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Abstract

Breeding programs of the Green Revolution based their success on increasing the production of harvestable biomass, in relation with non-commercial parts, of modern varieties (MV). Due to wheat's relevance in human food consumption, its varietal modification was especially intense and resulted in a remarkable harvest index increase, with the consequent decrease of straw production. The first-year results of a field experiment that compares old wheat varieties (OV) to modern ones under three different managements (traditional, organic and conventional), question the assumption that OV are less productive. They produced more biomass under organic and traditional management, and the same amount under conventional management. MV only sorted out as more productive for grain yield under conventional management. The greater OV capacity for producing biomass can have important advantages for Mediterranean rainfed organic farming in a climate change context, because it can allow maximizing soil organic carbon under low and medium inputs conditions, with benefits for mitigation and adaptation

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Introduction

The Green Revolution entailed a productive model change that involved the substitution of old varieties (OV) by modern varieties (MV) with higher yields, simultaneously to the increase in industrial fertilizers and fossil energy use. In the case of cereals, "high yielding" MV replaced OV, whose high straw production was not anymore useful, nor for feeding draught animals nor for edaphic fertilization, ignoring consequences of lower residue production on soil quality and agroecosystems sustainability (Guzmán and González de Molina, 2015).

Generally, rainfed cereal systems are abundant in Mediterranean areas. In Spain, they cover 37% of cropland area (MAGRAMA 2013). Productivity growth due to increases in external inputs is irrelevant in those semi-arid agroecosystems (Moreno *et al.* 2011). Under these semi-arid conditions, organic farming (OF) is more cost-effective, and more stable than conventional one (Lacasta and Meco, 2000). Additionally, a higher agroecosystem resilience is desirable for a more sustainable agriculture. For reaching this aim, many authors confirm the need for selecting better adapted varieties to OF (Fagnano *et al.* 2012; Sassi *et al.* 2014), since more productive varieties used in conventional farming are not suitable for OF (De Lucas and Sánchez del Arco, 2004). In such a way, the lower production usually assumed for OF in cereal systems (Arncken *et al.* 2012) could be compensated with an adequate selection for better adapted varieties.

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In the present study, we present the first-year results of a wheat field experiment where OV and MV have been assessed under three different agronomic managements: organic one third rotation, organic legume rotation, and conventional. As starting hypothesis, we consider that OV under organic conditions would be more productive than MV, whether considering grain yield or Net Primary Production (NPP). Under conventional farming conditions, MV would only overcome OV referring grain yield, but not NPP.

For testing our hypothesis, we have assessed differences on NPP, grain and straw yield, and the presence of weeds under the three managements above mentioned.

Material and methods

In order to assess and compare twelve wheat varieties, three essays have been carried out at three different locations of Andalusia (South of Spain) -Ronda and Sierra de Yeguas in Málaga province, and La Zubia, in Granada- during three growing seasons (2013-2016). Locations were separated a maximum of 187 km between Ronda and La Zubia, and a minimum of 69.5 km between Sierra de Yeguas and Ronda. The main soil physico-chemical properties are shown in Table 2. The same twelve wheat varieties were sown at every location. Six of them were durum wheat varieties (Triticum durum Desf.), and six where common wheat varieties (Triticum aestivum (L.) Thell.) (Table 1). Among durum and common wheat varieties, we chose three OV and three MV. OV were landraces grown during the first third of the 20th century in Andalusia, and their seeds came from the Phytogenetic Resource Centre of the National Agrarian Research Institute of Spain (CRF-INIA). MV were chosen among lately released varieties, considering their good reputation among farmers from the region. Each essay was representative of different soil fertility and agronomic management conditions, as described below. The results presented here refer to the first year of the field experiment (2013-2014).

Table 1: Wheat varieties grown at the field experiment

Durum wheat		Common wheat	
OV	MV	OV	MV
Rubio	Avispa	Barbilla Roja	García
BlancoVerdial	Simeto	Rojo Pelón	Chamoro
Recio	Vitrón	Sierra Nevada	Galera

OV= Old varieties; MV=Modern varieties

Trial 1 was located in Ronda. Wheat varieties were grown under organic management conditions (no fertilization and no weed control) in rotation with two fallow periods. This cereal rotation, called *one third* rotation, was characteristic of rainfed low productivity lands before the industrialization of agriculture in the region. This piece of land had been under organic management for more than 15 years and it is part of a dehesa landscape.

Trial 2, located in Sierra de Yeguas, was managed under organic conditions. Although no organic fertilization was applied throughout the experiment duration, it had occasionally been fertilized with manure previously, as this farm had been under organic management for the previous 15 years. One labour of manual weeding was done along February, eliminating only larger weeds. Crop rotation was wheat-legume (faba bean, Vicia faba). This rotation, called *ruedos*, is characteristic from areas with fertile soils, thus, with a higher productivity.

At trial 3, located in La Zubia, wheat varieties were grown under conventional agriculture conditions, based on synthetic inputs use. 570 kg ha-1 of a complex chemical fertilizer was applied before seeding and weeds were controlled by applying a broad-leaf herbicide (2 L ha-1 of MCPA 40% at the end of wheat tillering and the beginning of stem elongation).

Table 2: Soil physico-chemical properties of the field trials at the beginning of the experiment in 2013

Properties	Sierra de Yeguas		La Zubia		Ronda	
	Mean	SD	Mean	SD	Mean	SD
CEC*	31.19a	2.09	16.86b	1.89	10.55c	1.82
Ca exchange *	21.94a	1.79	13.83b	2.09	8.23c	1.26
Mg exchange*	5.80a	1.21	2.05b	1.62	1.76b	0.67
Na echange*	1.34a	0.16	0.50b	0.15	0.34b	0.01
K echange*	2.12a	0.11	0.48b	0.04	0.21c	0.03
Carbonate (%)	12.27a	7.09	18.62a	0.46	2.07b	0.31
Limestone (%)	4.61a	3.82	4.71a	0.97	0.12b	0.14
Assimilable P (ppm)	33.76a	9.92	27.08a	14.66	3.98b	1.19
MO (%)	2.39a	0.24	2.61a	0.38	1.03b	0.23
N org (%)	0.16a	0.01	0.17a	0.02	0.07b	0.01
Ph	8.18a	0.04	7.99a	0.11	7.66b	0.19
ph in ClK	7.46a	0.04	7.46a	0.06	6.53b	0.23
Assimilable K (ppm)	927.00a	60.93	208.40b	13.94	76.20c	3.77
Clay (%)	42.22a	2.54	16.42b	2.61	14.28b	2.33
Sand (%)	18.66a	3.12	28.76b	7.88	75.60c	2.91
Silt (%)	39.12a	1.89	54.82b	5.37	10.12c	1.88
Texture	Clay		Silt-loam		Sandy-loam	

Different letters in the same raw represent significant differences for each propriety at a significant level of 0.05 (Tukey test). SD=standard deviation; CEC=cation exchange capacity; OM=organic matter; *(meq/100g).

Fields were planted between October 25 and November 12 in all cases. In order to keep plots seeded with strictly one variety, we seeded by hand. Sowing rate was 200 kg ha-1 for wheat and 110 kg ha-1 for faba bean (in case). Sampling for ulterior analysis and harvest took place between June 5 and June 25, at the end of the cereal cycle.

Table 3: Data set from the experimental sites and farming conditions.

	Ronda	*Sierra de Yeguas*	*La Zubia*
Rainfall (mm)	611.5	386.4	325.4
Farming system	Organic	Organic	Conventional
Rotation	Wheat-fallow-fallow	Wheat-Faba bean	Monoculture
Fertilization	No	No	NPK (8:15:15) (570 kg ha^{-1})
			45.6 kg N ha^{-1}
			85.5 kg P ha^{-1}
			85.5 kg K ha^{-1}
Weed control	No	Manual weeding	Herbicide control (MCPA 40%) (2 l ha^{-1})
Irrigation	Rainfed	Rainfed	High water

Each experiment consisted of a split-plot design with four blocks separated with a non-seeded stripe 1 m width. Type of wheat (durum and common) was the main factor, while origin of wheat varieties (old and modern) was the subfactor. Plot size was 4x6 m. At La Zubia field, each block comprised 12 plots corresponding to the 12 wheat varieties assessed, while in the blocks at Ronda and Sierra de Yeguas experiments, there were 36 and 24 plots, respectively, in order to represent all phases of the rotations (crop and fallow plots). Cultivars were randomly arranged in each replicate of the experiment.

Variables studied were: Aerial Net Primary Productivity (NPP, related to total crop dry matter and total weed dry matter), total dry matter of the crop at the end of the cycle (grain dry matter, straw dry matter plus grain husk dry matter); grain yield; straw yield and weed yield at harvest time. We calculated the ratio between weed yield and NPP (weed:NPP ratio), as agroecosystem biomass allocated to weed.

Plots were sampled at the end of the wheat cycle with a sampling square of 0.25 m side, throwing it to the centre of the plots (to avoid the border effect), randomly and twice per plot. Cereal and weed plants in the square were cut at ground level. Wheat plants were separated into spike and stem. Wheat and weed biomass were dried at 70ºC using a laboratory drier oven (University of Jaén) to obtain dry weight. Fresh spikes were threshed to separate grain and grain husk before they were dried in the oven.

Split-plot variance analysis and Tukey test were carried out at a significance level of 0.05 with Statistix statistical software (Analytical Software, Version 10).

Results

We found some differences between durum and common wheat, but here we will focus on the results concerning OV and MV as they are more relevant for the aim of this communication. Data of variables assessed for wheat varieties are shown in Table 4. Notice that grain husk data are neither presented, nor discussed, so total crop biomass does not match grain and straw biomass sum. Finally, wheat variety and environment interaction has not been analysed yet. Statistical analyses are in process by the time of this communication.

Trial 1. One third rotation (Wheat-fallow-fallow).

We found significant differences between OV and MV within the following variables: NPP, total crop biomass at the end of the cycle, grain yield, straw yield and weed:NPP ratio. OV produced higher amounts of biomass than MV in all these variables but for weed:NPP ratio, in which MV showed a higher value. We did not find significant differences for the rest of the variables (Table 4).

Trial 2. Ruedos rotation (Wheat-Faba bean).

OV produced more NPP, total crop biomass at the end of the cycle and higher grain and straw yield than MV. Contrary, for MV we found larger amount of weed biomass and a greater ratio between weed and NPP (Table 4).

Trial 3. Conventional monoculture.

Because of technical problems, we could not sample weed biomass at the end of cycle. Data related to this variable and those for weed:NPP ratio are not reported as we could not asses weed biomass at La Zubia trial. Under conventional management, we found significant differences for grain yield, higher for MV (Table 4).

Discussion

The first-year results of this experiment question that OV are less productive than modern ones, as they produced more biomass under organic and traditional management, and the same amount of biomass under conventional management except for grain yield, which was the only variable for which MV had higher results. In other words, OV productive disadvantage is only true when referring to grain yield under conventional management. In contrast with our findings and for more humid farming conditions, Hildermann *et al.* (2009) did not find that grain yield of cultivars bred under low-input conditions outperformed grain yield of conventionally bred cultivars, and under no fertilization regime, they did not find significant differences among cultivars. As authors explain, this could be due to the conditions of the experiment site (DOK trial, Switzerland), like low weed pressure high inherent soil fertility and good water retention.

Table 4: Net Primary Production, total crop biomass, grain, straw and weed dry matter production (kg ha^{-1}) and weed:NPP ratio for OV and MV at the three field trials. Data for rotation crop or fallow are not presented.

	OV		MV		
	Mean	SD	Mean	SD	*P value*
Ronda					
NPP	1,249	562	893	432	0.0031*
Total crop biomass	992	454	593	360	0.0003*
Grain	256	219	153	175	0.0411*
Straw	597	194	374	186	0.0001*
Weed	257	170	300	177	0.3135
Weed:NPP	0.19	0.10	0.36	0.20	0.0009*
Sierra de Yeguas					
NPP	11,807	2,844	9,292	3,413	0.0060*
Total crop biomass	9,387	3,406	5,580	1,924	0.0000*
Grain	2,187	1,174	1,223	969	0.0005*
Straw	6,186	2,409	3,812	1,530	0.0002*
Weed	2,421	2,044	3,712	2,982	0.0386*
Weed:NPP	0.21	0.19	0.37	0.20	0.0001*
La Zubia					
NPP	17,800	4,957	17,192	5,498	0.6516
Total crop biomass	17,800	4,957	17,192	5,498	0.6516
Grain	2,401	807	3,300	1,612	0.0239*
Straw	13,805	4,876	12,305	4,851	0.1823
Weed	-	-	-	-	-
Weed:NPP	-	-	-	-	-

*Significant differences at a significant level of 0.05. NPP= Net Primary Production; OV= Old variety; MV= Modern variety; SD= Standard Deviation.

Our results suggest that breeding programs of the Green Revolution increased the grain yield of wheat varieties under modern management conditions, exclusively. Nonetheless, under organic farming conditions of a semi-arid climate, we did not find advantages for MV in this sense and, what is more, we found OV being more productive in terms of grain yield and more competitive against weeds, a fact that could be considered as an important advantage for organic farmers. Despite this weed biomass reduction, the total amount of biomass that can be incorporated to soil was higher for OV.

Other studies show a lower productivity of organic cereal production when compared to conventional management due to a lower nutrient availability and a greater presence of weeds. Our results indicate that these problems could be relatively ameliorated by employing a more suitable genetic material.

Moreover, this greater capacity for producing biomass of OV can have other important advantages for organic farming in arid conditions. In a climate change context, the greater straw yield under low and medium input use intensities can allow to maximize soil organic carbon, helping to mitigate climate change through carbon sequestration and to adapt to it through improved soil physical properties (Aguilera *et al.*, 2013). In Spain, the majority of the land devoted to cereal production has low and medium management intensity characteristics, due to the lack of water (Meco *et al.* 2011). Those rainfed cereal land areas cover over 5.4 million hectares (MAGRAMA, 2013). On the other hand, OV can increase grain yield in organic farming systems, decreasing their land cost (Guzmán *et al.* 2011). Besides, they can increase soil organic matter adding part of the residue biomass, without jeopardizing incomes from straw commercialization.

Suggestions to tackle the future challenges of organic farming

Greater straw production with OV can result advantageous for organic farmers, because once separated the straw needed as organic amendments to maintain soil fertility, they could dispose of a greater quantity of straw biomass susceptible of becoming animal feeding, for their own farms or as a market product for others farmers.

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