A Six-Year Rotation LTE to Analyse the Effect of Climate Variability and Management Intensity on Crop Yield

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Introduction

Low-input cropping systems may produce substantial benefits to farmers and the environment, such as: (i) reduced energy consumptions (Alluvione et al., 2011), (ii) lower costs, (iii) decreased nutrient losses from soil as leachates and gas and (iv) lower GHG emissions linked to input production (Lehuger et al., 2011). The experience of long-term field experiments (LTE) can help delineate future approaches to cope with variability and uncertainty of climate at local scale and support the design of efficient low-input cropping systems. This work analyses the responsiveness of two management systems, in term of crop yield, to the combined effect of management intensity (Low – L and High – H) and weather fluctuations in a long-term rainfed experiment set up in Pisa (Central Italy) in 1992. The experiment, designed according to a system approach, considered the effect of the combination of cultural practices (tillage, fertilization, weed and pest management) on the yield of four arable crops in a six-year rotation, including one year of set-aside. The L system was designed upon the framework of the Council Regulation (EEC) No 2078/92. This study aims to assess the effect of (i) long term management, (ii) meteorological conditions and (iii) their interaction on the yield of each crop in rotation on yearly bases.

Materials and Methods

The field trial is a LTE on crop management system (CIMAS, Conventional vs. Integrated Management Systems) established in 1992. This work is based on data collected from 1994 to 2005 with no changes in the crop sequence. The LTE was located in San Piero a Grado (PI), at the Centre of Agro-Environmental Research "Enrico Avanzi" (CiRAA) of the University of Pisa, in the coastal plain of northern Tuscany, central Italy. The soil has a clay loam texture with a pH of 8.3. The high-input system (H) was characterized by conventional agricultural practices: deep tillage, pre-and post-emergence herbicides and fertilization levels based on the expected N and K uptakes by whole crop and the potential P removal by the harvestable biomass increased by 75%, due to the low P availability induced by the high soil pH value. The integrated low-input system (L) was characterized by reduced tillage and reduced use of agrochemicals. The N and P fertilization rates were based on the expected removal by harvestable biomass, while K was not applied considering its high availability in the soil. Both H and L were performed on a six-year rainfed crop rotation in which all crops were present in each year. The crop sequence was: sugar beet (*Beta vulgaris* L. var. saccharifera) (sb), durum wheat (*Triticum durum* Desf. cv. Grazia) (wheat after sugar beet, Wsb), sorghum (*Sorghum vulgare* Pers. var. NK 121), sunflower (*Helianthus annuus* L. var. Ketil) (sf), durum wheat (wheat after sunflower, Wsf) and set-aside, managed with a cover crop in L (*Phacelia tanacetifolia*). The crop rotation was replicated in two blocks. In every year, each phase of the crop rotation was located in two adjoining plots, one assigned to H and the other to L. At harvest time, four areas for each plot were selected randomly to determine crop productivity. The sampling area was 4 m^2 for sugar beet, sorghum and sunflower, and 1 m^2 for durum wheat. Linear mixed models, built according to the procedure outlined by Onofri et al. (2016), were used to analyse the effect of the management system (MS) on the yield of each crop. Furthermore, recursive partitioning analysis was carried out for each crop with the R package "party", using crop yield as variable, sowing and harvest months as factors in addition to the factors of the linear mixed model that turned out to significantly affect crop yield. Finally, the effect on yield of meteorological indices, computed on monthly basis, was analysed through a sparse redundancy analysis using the R package "sRDA" (Csala et al., 2017).

Results

MS did not show significant effects on the dry yield of sugar beet, sorghum and sunflower, while year affected significantly crop productivity (Table1). A significant MS x year interaction was observed in durum wheat, being the yield higher in H than in L only in 2001 and 2002.

Table 1. Annual mean (n= 8) and overall mean (n= 96) dry yield (t DM ha^{-1}) of sugar beet, sorghum and sunflower in high (H) and low-input (L) management systems. Durum wheat grain yields are the mean of the two rotation phases, n= 16 for the annual mean and n= 192 for the overall mean. Significance per row and per column shows the differences according to MS within each year.

	Sugar beet		Durum wheat			Sorghum		Sunflower	
Year	H	L	H	L		H	L	H	L
1994	14.0±0.8	11.6±0.8	3.3±0.2	2.8±0.2		6.8±0.2	6.5±0.4	5.1 ±0.2	4.7 ±0.2
1995	13.5±0.8	12.0±0.5	2.2±0.2	2.3±0.1		6.1±0.3	5.5±0.4	2.7 ±0.3	2.8 ±0.2
1996	8.3±0.5	7.4±0.4	4.6±0.2	4.1±0.2		7.9±0.7	8.3±0.9	3.0 ±0.1	2.9 ±0.1
1997	14.1±0.5	15.0±1.1	2.5±0.1	2.1±0.2		6.9±0.3	5.9±0.4	4.7 ±0.2	4.7 ±0.2
1998	11.5±1.1	10.0±0.6	4.8±0.2	5.4±0.2		7.7±0.1	7.5±0.5	4.8 ±0.3	4.3 ±0.3
1999	18.3±2.1	15.4±1.0	5.1±0.1	5.0±0.1		7.1±0.4	7.3±0.3	3.9 ±0.1	4.4 ±0.3
2000	19.5±0.7	15.4±0.6	4.6±0.2	4.0±0.2		6.8±0.4	6.9±0.2	4.6 ±0.1	4.2 ±0.2
2001	14.5±1.3	12.7±1.2	3.7±0.2	2.2±0.2	***	6.9±0.9	5.8±0.4	2.7 ±0.2	3.2 ±0.4
2002	15.3±0.7	16.8±1.8	6.3±0.3	4.1±0.2	***	8.6±0.2	8.9±0.2	4.9 ±0.2	5.0 ±0.2
2003	12.0±1.3	12.5±1.2	3.8±0.1	4.3±0.2		3.1±0.2	3.5±0.3	2.4 ±0.3	2.8 ±0.3
2004	9.0±0.6	9.1±0.6	4.9±0.1	5.0±0.2		7.2±0.4	7.8±0.3	4.3 ±0.2	3.8 ±0.2
2005	10.4±1.1	11.7±1.0	5.7±0.3	4.7±0.2		8.2±0.6	7.9±0.4	4.3 ±0.3	4.4 ±0.3
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Avg	13.3 ±0.4	12.5 ±0.4	4.3 ±0.1	3.8 ±0.1		6.9 ±0.2	6.8 ±0.2	3.9 ±0.1	3.9 ±0.1

The recursive partition analysis indicated that sowing durum wheat in November positively affected grain yield (data not shown). Early sowing showed positive effects on sugar beet and sunflower, but not on sorghum. Moreover, when sugar beet was sown in March instead of February, delayed harvest showed a positive effect on the final yield. The sRDA indicated how the climate variability affected the final yield of the four crops (data not shown), regardless of the management intensity and how the occurrence of drought and heat in specific crop development stages may be detrimental for the productivity of warm-season crops under rainfed conditions. Moreover, we highlighted the negative effect of rainfall excess at sowing and during early stages, in particular on durum wheat.

Conclusions

This study shows that higher intensification of agricultural inputs did not result in a relevant increase of yields in the target environment. Moreover, in both management systems (H and L), crops were highly subjected to the inter-annual weather variability. Warm-season crops, under a rainfed management, showed to be particularly susceptible to water scarcity occurring in combination with peaks of maximum temperatures in summer months. Water excess after seeding and the risk of drought starting at the anthesis negatively affected the yield of durum wheat, thus decreasing the efficacy of higher fertilization rates in H. Our results show that a more rational use of inputs, coupled with an appropriate planning of operation schedule, is more effective than high-input management in highly variable Mediterranean climate, allowing to reduce the risk of environmental impacts and to increase the gross margin of farmers by reducing the costs of main inputs.

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