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Radiation interception and biomass and nitrogen accumulation in different cereal and grain legume species

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ABSTRACT

The increasing interest in the sustainability of agricultural systems has emphasised the importance of incorporating legumes into cereal production, in spite of their lower and less reliable grain yields. The basis of the poor performance of legumes has been analyzed in a 2-year comparison between varieties of pea, faba bean, durum wheat and triticale, in terms of resource capture and use. The cereals developed a full canopy 350 °Cd earlier than did the grain legumes, and the triticale more rapidly than the durum wheat. This difference, and the 11-day longer duration of the growing cycle of cereals allowed them to intercept more photosynthetically active radiation (PAR) than grain legumes. This, combined with their higher radiation use efficiency (2.35 ± 0.07 vs 2.10 ± 0.05 g MJ^{-1}), resulted in a biomass greater, on average, by about 500 g m^{-2}. Within the cereals, triticale accumulated 34% more biomass than durum wheat. Radiation interception and nitrogen uptake are closely tied in both cereals and grain legumes. There was no difference between cereals and legumes in the relationship between the amount of nitrogen assimilated and the fraction of intercepted PAR (FIPAR), but there were differences in the form and in the parameters of the relationship between nitrogen assimilated and PAR intercepted. Below a FIPAR of 0.8, the relationship between FIPAR and N uptake is crop independent, underlining the influence of FIPAR on N uptake. The significance of this FIPAR level is that by the time it has been achieved, the plants will have accumulated most of the N present in their biomass at maturity.

1. Introduction

The incorporation of legumes into the cropping cycle is being increasingly promoted as a way of improving the sustainability of cereal production, specifically in the context of containing the environmental damage caused by the excessive use of inorganic nitrogenous fertiliser. Legume/wheat rotations both reduce fertiliser input and the build-up of pathogens in the soil (Loomis and Connor, 1992). However, the economic yield of legume crops is lower and less stable than that of the cereals (King, 1984; Reeves et al., 1984; Giunta et al., 2003). In a comparison of various grain legume and cereal species, Giunta et al. (2003) showed that the higher yield potential of the cereals over the legumes is related to their greater capacity to accumulate biomass, while harvest index (HI) as a parameter was only able to explain differences between particular cereal or legume species.

The contrasting performance of these two botanical species groups can be analysed in more detail by considering resource capture, use and partitioning, assuming that the capture of radiation plays a key role in both dry matter and nitrogen accumulation (Hay and Porter, 2006). The usefulness of this approach in analysing species with very different growth patterns has been demonstrated by Scott et al. (1994) in a comparison between wheat and sugar beet. When water is non-limiting, both carbon and nitrogen capture and use are closely linked with one another through the development of leaf area and the pattern of intercepted radiation (Lemaire et al., 2007). Thus, in several field experiments, the rate of nitrogen uptake has been shown to match the growth rate of the crop, and is determined by the quantity of intercepted radiation (Grindlay, 1997). The dependence of the rate of nitrogen fixation in legumes on the amount of energy derived from photosynthesis can be used to explain Williams et al. (1990) finding that total leaf area was associated with the amount of nitrogen fixed across a range of groundnut genotypes.

In this present study, we have compared various well-adapted cereal and legume species for their ability to accumulate biomass and nitrogen under field conditions in an irrigated Mediterranean environment, by analyzing the relationship between patterns of radiation interception, carbon assimilation and nitrogen uptake.

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2. Materials and methods

A 2-year experiment (2002/2003 and 2003/2004) was carried out at Sassari (41°N; 8°E; 80 m above sea level) and Oristano (40°N; 8°E; 15 m above sea level). At the former site, the materials were sown on three separate dates (SA03: 27 December 2002, SA04/1: 20 November 2003, SA04/2: 17 February 2004), and at the latter, one date (OR04: 18 November 2003). At Sassari, the soil is a sandy-clay-loam with a depth of about 0.6 m, overlying layers of limestone (typic Xerochrepts); the mean nitrogen concentration is 0.17%, and the C/N ratio is 11.5. At Oristano, the soil is a 2-m deep clay-loam, with a mean nitrogen concentration of 0.08% and a C/N ratio of 10.7. At both sites, the climate is typically Mediterranean, with long-term mean annual rainfall amounts of, respectively, 538 and 561 mm.

2.1. Treatments and design

Two grain legumes (faba bean, *Vicia faba*, and pea, *Pisum sativum*) and two cereal species (durum wheat, *Triticum turgidum* L. subsp. *durum* and triticale, *Triticosecale* Wittmack) were grown in the four sowing date/location combinations SA03, SA04/1, SA04/2 and OR04. Two faba bean (the early flowering 'Sicilia' subsp. *equina* and 'Sikelia' subsp. *minor*, a tall selection from a local population) and two pea ('Brevent' and the semi-leafless 'Pinochio') varieties were chosen. The cereal varieties were the Italian semi-dwarf durum wheat 'Claudio' and the spring hexaploid triticale breeding line '140', which is an early flowering, high yielding type. The experimental design consisted of a completely randomized design with four replications.

2.2. Crop management

The seed bed was prepared by ploughing to a depth of 0.25 m, followed by a secondary tillage with a field cultivator equipped with spike-toothed harrows running at about 10 cm depth. In both seasons, the previous crop was a cereal, and all plots received a basal application of 90 kg ha^{-1} of P_2O_5 before sowing. Nitrogen fertilization was only applied to the cereal plots, which at Sassari and Oristano, respectively, received 90 and 120 kg ha^{-1} of nitrogen. At OR04, 30 kg ha^{-1} additional nitrogen was applied after sowing. The sowing rate was 350 viable seeds m^{-2} for the cereals, 80 viable seeds m^{-2} for pea, and, respectively, 40 and 20 viable seeds m^{-2} for the faba bean varieties 'Sikelia' and 'Sicilia'. Each plot consisted of 16 rows 6.25 m long, 0.20 m apart. Water was applied via drip irrigation (SA03 only), providing 60 mm between the end of March and the beginning of May. Abundant rainfall in spring 2004 obviated any need for irrigation. Weeds, pests and diseases were controlled chemically with, respectively, Pendimethalin in pre-emergence, deltametrina ('Decis') and propiconazole ('Tilt').

2.3. Measurements

A developmental stage was recorded as having been reached when 50% of the plants in a given plot were at this stage. For the cereals, time to reach booting (awns emerging 1 cm beyond the flag leaf sheath), anthesis (anthers exerted from the spikelets) and physiological maturity (yellow peduncle, Singh et al., 1984) were recorded, while the developmental scale proposed by Knott (1987) was used for the grain legumes. These consisted of time to first open flower (stage 203), pod set (stage 204), pod swell (stage 206) and yellow, wrinkled pod (stage 209).

Incident and transmitted photosynthetically active radiation (PAR) were measured on clear days around noon using a SunScan Canopy Analysis System SS1-UM-1.05 (Delta-T Devices). A portable probe was used to measure PAR both above the canopy (I_o) and at the soil surface (I_S), by placing the probe at right angles to the row and parallel to the surface at three locations along the plot. The fraction of intercepted PAR (FIPAR) was calculated as

Table 1
Principal phenological events and length of the growing cycle

Cereals	Emergence (das)	Booting (das)	Heading (das)	Anthesis (das)	Yellow peduncle (das)	Growing cycle (days)
Triticale	12	97	106	122	160	148
Durum wheat	12	115	122	132	164	152
Grain legumes	**Emergence (das)**	**1° Flower (das)**	**1° Pod (das)**	**Pod swell (das)**	**Yellow pod (das)**	**Growing cycle (days)**
Pea cv Brevent	16	98	113	127	153	138
Pea cv Pinochio	16	98	112	123	147	132
Faba bean cv Sicilia	18	76	109	131	158	140
Faba bean cv Sikelia	18	109	132	145	165	147

Data represent mean numbers of days after sowing (das) across the four environments. Phenological stages for grain legumes refer to Knott (1987). The length of the growing cycle correspond to the period from sowing to yellow peduncle for cereals, and from sowing to yellow pod for grain legumes.

Table 2
Grain yield, biomass and nitrogen (N) content at harvest

Cultivar	Grain yield (g m^{-2})	Final biomass (g m^{-2})	Straw (g m^{-2})	H.I.	Total N (g m^{-2})	N in grains		N in straw	
						(%)	(g m^{-2})	(g m^{-2})	(%)
140	537 *a*[b]	1514 *a*	977 *a*	0.35 *c*	12.5 *b*	1.8 *d*	9.4 *b*	3.0 *b*	0.3 *c*
Claudio	399 *b*	1157 *b*	759 *b*	0.35 *c*	8.7 *c*	1.7 *d*	6.8 *c*	1.9 *b*	0.2 *c*
Brevent	388 *b*	871 *c*	484 *de*	0.47 *a*	20.1 *a*	3.8 *c*	14.9 *a*	5.1 *a*	1.0 *b*
Pinochio	371 *b*	924 *c*	553 *d*	0.41 *b*	19.5 *a*	3.8 *c*	13.8 *a*	5.6 *a*	1.0 *b*
Sicilia	332 *b*	759 *c*	427 *e*	0.43 *b*	19.1 *a*	4.3 *a*	14.1 *a*	5.0 *a*	1.2 *a*
Sikelia	155 *c*	800 *c*	645 *c*	0.20 *d*	12.7 *b*	4.1 *b*	6.4 *c*	6.3 *a*	1.0 *b*
F-Test for cultivar	***[a]	***	***	***	***	***	***	***	***

[a] ***, significant at $P \leq 0.001$; **, significant at $P \leq 0.01$; *, significant at $P \leq 0.05$; ns, not significant at the analysis of variance.
[b] Cultivar means sharing the same letter do not differ significantly from one another (SNK test at $P \leq 0.05$).