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REGIONE AUTÒNOMA DE SARDIGNA
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UNIVERSITÀ DEGLI STUDI DI SASSARI

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Scienze e Biotecnologie

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Indirizzo Produttività delle Piante Coltivate

Ciclo XXVII

Crop physiology of triticale in the context of dual purpose use

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ABSTRACT

Triticale is a crop used in the context of dual-purpose .The removal of above ground biomass at terminal spikelet stage can affect biomass production and grain yield (Chapt. 1), intercepted radiation and radiation-use-efficiency (Chapt. 2), kernel number per unit area (Chapt. 3)

Five field experiments were carried out in two locations and on different sowings dates. Treatments were represented by the factorial combination of two sowing rates, two triticale cultivars (one spring and one winter) and two clippinf treatments (clipped and unclipped).

Clipping affected final biomass and HI in opposite directions. The reduction in grain yield due to clipping was therefore less than proportional than the corresponding reduction in biomass and was strongly influenced by the combination ‘sowing date by cutlivar’.

In the rare cases in which clipping reduced the ability of the crops to produce biomass in the period between TS and anthesis, the cause was a lower leaf area. Radiation-use-efficiency was not affected by clipping consistently with the lack of any effect on leaf characteristics responsible for the photosynthetic rate.

Clipping can affect KNO, and grain yield as a consequence, both in winter and spring cultivars. This effect is not necessarily mediated by a lower amount of biomass allocated to the spikes of clipped crops. Much more relevant are the conditions around anthesis as long as they can affect grain set.

CHAPTER 1

GRAIN YIELD AND BIOMASS PRODUCTION IN DUAL-PURPOSE TRITICALE

Dual-purpose use of cereals (in which the cereal is grazed by animals and harvested for grain in the same season) is common where livestock and cereal crops are managed in the same area. Under Mediterranean conditions usually graze winter cereal represents a source of forage until stem elongation when animal food requirements are high (Royo *et al.,* 1997) and pastures growth rate is low (Harrison *et al.,* 2010).

In the context of dual-purpose, grain yield can be affected by plant species, sowing date, stocking rate and timing of grazing (Kelman and Dove, 2009) because delaying grazing after stage 30 (Zadocks *et al.,* 1974) may have a negative effect on grain production (Winter and Thompson, 1987; Royo *et al.,* 1997).

There are different ways to manage a graze land. If there is abundant biomass and the stocking rate is not high, animals will select young plants with soft tissue, and the result will be a heterogeneous canopy. Livestock staying in the field for a long time can have negative consequences to grain yield compared to the performance obtained when grazing is rapid (Harrison *et al.,* 2011). Some researchers say that sheep grazing can be comparable with clipping (Francia *et al.,* 2006), and we therefore choose clipping to study dual-purpose triticale in our experiment, meaning with 'clipping' a mechanical cutting.

Grain yield and biomass production can be affected by dual purpose, because this management can change:

- Canopy radiation interception. A moderate clip can increase radiation interception, because there may be an increase in radiation that can be used by lower canopy layers (Anten and Ackerly, 2001). However, an intensive defoliation can decrease the intercepted radiation and this may have a negative consequence on dry matter production (Teixeira *et al.,* 2007).

- Leaf area. The decrease in leaf area and dry matter production throughout the recovery period change in function of duration and termination of grazing (Winter and Thompson, 1987).
- Phenology. There could be a delay in anthesis depending on the timing of grazing, often associated with a reduction in grain yield (Royo *et al.,* 1997) because anthesis and grain filling can occur under drier and warmer conditions (Royo *et al.,* 1994; Giunta *et al.,* 2014). Dual purpose cereals are normally sown before the usual date so that clipping/grazing is brought backwards and the recovery period after clipping/grazing is favoured by likely warmer temperatures (Harrison *et al.,* 2011).

Triticale (*X Tricosecale,* Wittmack) is a versatile species used for the production of grain, silage, green forage and hay and for grazing (Bilgili *et al.,* 2009). It is also is one of many cereals used in the context of dual purpose. This species resists low winter temperatures, spring frost and stress caused by terminal high temperatures and low precipitations which are the main factors limiting the productivity of small grain cereals (Santiveri *et al.,* 2004). The biomass produced by this cereal during vegetative stages is very high, as dry matter during the recovery period (after grazing) allows the production of an abundant grain yield (Ramos *et al.,* 1996).

According to their phenology, triticale cultivars can be separated into two groups: winter and spring. These varieties differ in the vernalization requirements needed for floral differentiation in winter triticale (Varughese *et al.,* 1991), but also the time necessary to reach the maximum LAI and the rate of dry weight accumulation in the stems, in winter cultivars (Royo and Blanco, 1999).

The phenological differences existing among triticale cultivars influence their aptitude to dual purpose, because the environmental resources can be used in more or less efficient ways for producing dry matter and grain depending on developmental rate. Winter triticales can produce high biomass during their long vegetative stage, but a high biomass at anthesis is unwanted in Mediterranean environments because it can cause a rapid depletion of soil water reserves after anthesis (Fischer, 1979). In environments characterized by terminal droughts, the lower grain yields of winter compared to spring triticales derive from their long vegetative period which cause anthesis and grain filling to occur when weather conditions are the worst (Santiveri *et al.,* 2004). This can be the reason why thousand kernel weight is usually higher in spring than in winter triticales.

Comparisons between winter and spring triticale, in the context of dual purpose, highlight the ability of winter triticales to produce a greater LAI compared to spring ones as a consequence of the more tillers produced during their longer vegetative period (Royo *et al.,* 1996). On the other hand, many stems die after cutting and the resulting low number of spikes per m^2 negatively affect grain yield (Royo, 1997). Lower grain yield is due to delayed anthesis when temperatures are high (Miller *et al.,* 1993; Royo *et al.,* 1996) and precipitations are low (Dann *et al.,* 1983).

Triticale could be sown at different seed rates based on management (sowing date, utilization) and environmental conditions. In the context of dual purpose, increased seed rates means having more biomass available for grazing (Harrison *et al.,* 2011), although when animals are in the field this could cause uprooting plants and decreasing plant density. In environments with low rainfall low rates are preferred, but a correct choice of the rate should also take into account the rainfall distribution (Bassu *et al.,* 2013).

The aim of this chapter is not only to analyze and explain the difference in terms of biomass and grain yield in winter and spring triticale in the context of dual-purpose, but also to understand how the removal of biomass at terminal spikelet stage could change biomass production at anthesis and maturity, and how differences in biomass could modify grain yield in Mediterranean environments.

MATERIALS & METHODS

Experimental design

Five field trials were conducted in Sardinia, Italy, in 2011/12 and 2012/13.

Sowings were made at two locations (Ottava, 41°N, 80 m asl, and Ussana, 39°N, 97 m asl) and on several dates for a total of five 'environments' (location x sowing date x year) (Table 1.1).

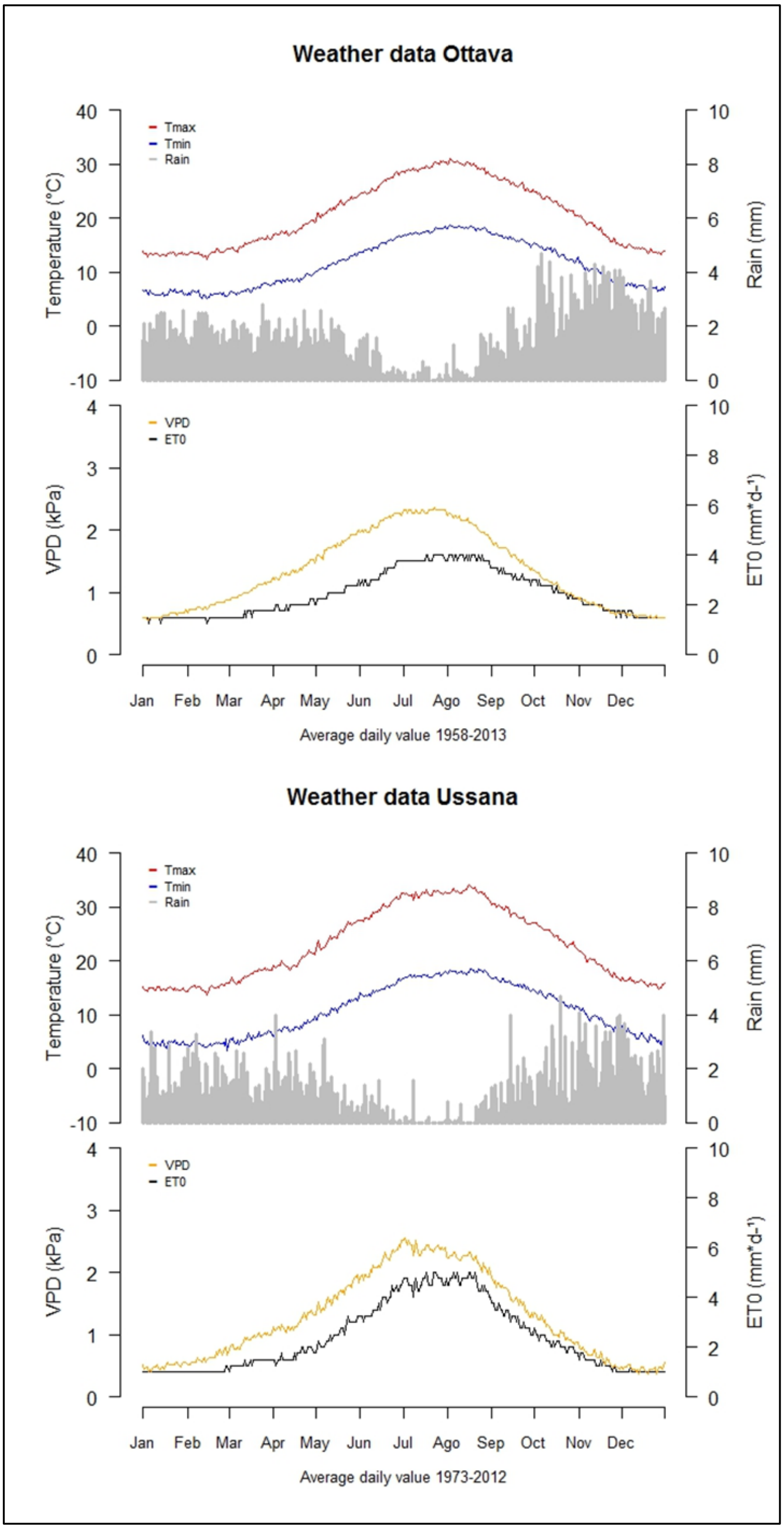
The soil at Ottava consisted of a sandy clay-loam of a depth of approximately 0.6 m that was overlaid on limestone (Xerochrepts). The depth of the soil at Ussana was of about 1.0 m.

The long-term mean annual precipitation at the two sites is, respectively, 557 mm and 441 mm. (Fig1.1). Sites also differed for their thermal environment, because Ottava has lower summer maximum temperatures and higher winter minimum temperatures than Ussana. The average minimum temperature during winter at Ottava is 6°C compared to 5°C at Ussana.

Site	**Location**			**Sowing date**	**Environment**
	latitude	longitude	altitude		
Ottava	40°	8°	80 m	9 Oct 2012	OttavaOCT
				15 Nov 2011	OttavaNOV
				18 Jan 2012	OttavaJAN
Ussana	39°	9°	110 m	27 Dec 2011	UssanaDEC2011
				19 Dec 2012	UssanaDEC2012

Table 1.1 Site description.

Fig. 1.1 Historic weather conditions in Ottava and Ussana.



Treatments consisted of two triticale cultivars, two sowing rates and two clipping treatments.

The two cultivars were ‘Bienvenu’ a winter triticale with a quantitative response to cold, and ‘Oceania’, a spring triticale. They were chosen among the most productive and well adapted cultivars of the two groups to the Mediterranean environment of Sardinia.

The two seed-rate treatments were 300 and 600 seeds per m². Seed density was calculated for each cultivar from thousand grain weight and percentage of germination. In UssanaDEC2012 there was only one seed rate, 300 seeds per m².

To study the effect of dual purpose utilization each experiment included unclipped (grain only) and clipped plots. In clipped plots aboveground biomass was mechanically cut at the height of 0.02 m at the terminal spikelet stage (Z30).

In each field trial treatments were combined in a complete factorial and laid out in randomized complete block design (RCBD) with four replications. The sowing bed was prepared by plowing to a depth of 0.25 m, which was followed by surface cultivation. Plots were sown with a cone-seeder. Plot size, number of rows and inter-row distance are reported in Table 1.2.

Table 1.2 Plot plan.

Environment	**Plot size**		**Row planter**	**Row spacing**
	Bienvenu	Oceania	(n°)	(m)
OttavaOCT	12 m²	12 m²	8	0.15
OttavaNOV	9 m²	18 m²	8	0.15
OttavaJAN	10 m²	10 m²	8	0.15
UssanaDEC2011	12 m²	12 m²	8	0.18
UssanaDEC2012	12 m²	12 m²	8	0.18

Nitrogenous and phosphorous fertilizers were applied as urea, ammonium nitrate and ammonium bi-phosphate at rates that varied from 82 to 150 kg ha^{-1} of N, depending on the environment, and at 92 kg ha^{-1} of P_2O_5. All weeds, pests and diseases were chemically controlled.

Measurements

Emergence, anthesis and physiological maturity were recorded by periodical inspections of the plots when more than 50% of plants in the plot had reached that phenological stage. The development of the apices of 5-10 main stems per plot was determined weekly by a destructive sampling to detect the stage of 'terminal spikelet' (TS), which corresponded to the end of terminal spikelet formation and was marked by the initiation of awns because of the elongation of the tip of the lemmas (Bonnett, 1936). The TS was assumed to occur when more than 50% of the plants exhibited it.

Dry matter production was evaluated on different occasions by hand-cutting samples of above-ground biomass of 0.6 m^2 from the internal rows (Fig.1.2.). These samples were oven-dried at 80 °C for 48 h.

The samples of above-ground biomass taken at physiological maturity was divided into stems, leaves and spikes before oven drying. Kernels were then mechanically separated from the chaff.

The harvest index (HI) was determined on this samples. Final biomass was calculated by the ratio between the grain yield obtained on a plot basis, and the HI obtaining from the maturity sample.

Weather data (maximum and minimum temperature, rainfall, solar radiation and air humidity) were recorded in a meteorological station located at each field.

Analyses of variance (ANOVA) was performed within environments. When the ANOVA revealed significant differences, means were separated by Least Significance Difference (LSD) using 0.05 (5%) probability level.

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Fig. 1.2 Experimental fields after emergence and sampling areas.

RESULTS & DISCUSSION

Accordingly to its lower long-term annual rainfall, Ussana rainfall in September and October is lower than Ottava. In the first site 85 mm versus 120 mm in the second. This is important especially in the context of dual purpose, because abundant rainfall in these months avoid sowings to be made in the most favorable period for dual-purpose (second-half of October – first half of November). This is the reason why in these environments the sowing date of dual-purpose triticale can vary between October and January, i.e. the range explored in our experiments.

During field experiments there were different weather conditions in all environments (Fig. 1.3; 1.4). The amount and distribution of rainfall between environments was different. OttavaOCT was the wettest environment, 610 mm in 261 days (from sowing to harvest), and OttavaJAN the driest, 193 mm in 170 days. The low total rainfall in the latter environment was characterized by a favorable distribution, as about 60 mm fell after anthesis. Also at Ussana there were differences in rainfall between the two environments, because UssanaDEC2012 had 340 mm in 188 days compared to UssanaDEC2011 with 247 mm in 177 days.

The coldest environment was UssanaDEC2011 having below zero minimum temperatures in February for many days. Also during the spring season at UssanaDEC2011 and UssanaDEC2012 there were the highest maximum temperatures.

VPD and ET_0 were greater in that environment where rainfall was low and generally increased at the end of the growing season due to high temperatures.

Fig. 1.3 Ottava weather trend during experimental trial

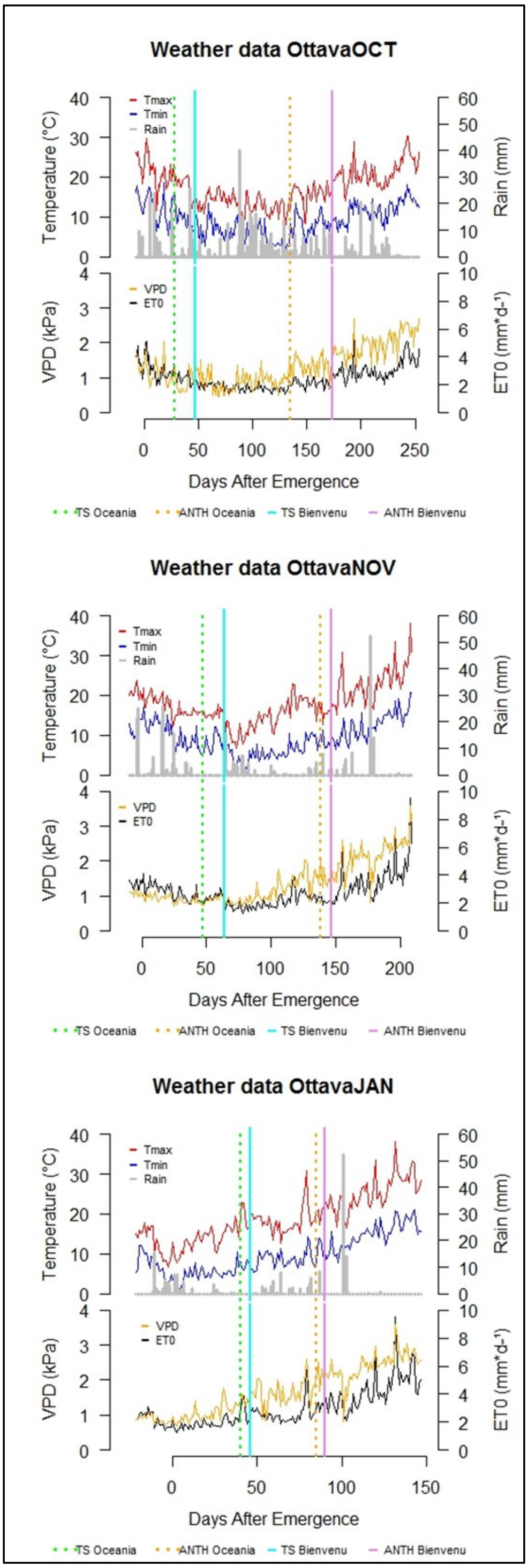
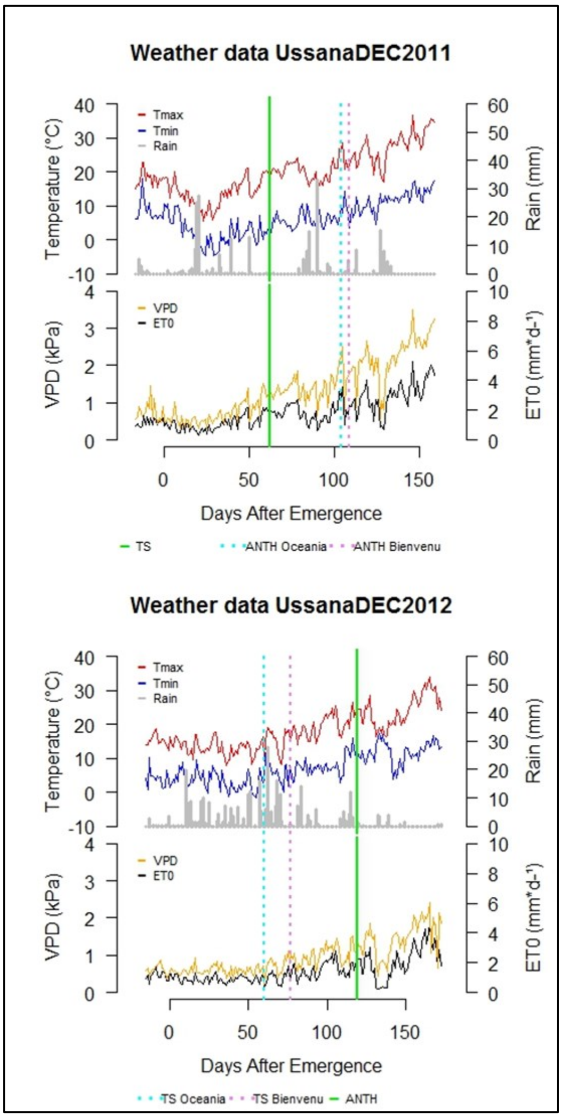


Fig. 1.4 Ussana weather trend during experimental trial



Phenological stages

The importance of the TS stage of development derives from the fact that the shoot apex emerges from the soil surface thus becoming vulnerable to grazing damage at this phenological stage (Giunta *et al.,* 2014). The TS stage defines therefore the duration of the pre-grazing/clipping period.

In Table 1.3 there are terminal spikelet and anthesis dates. The variation induced in this experiment in the duration of the period sowing-TS by acting on the combination location x sowing date x cultivar was of 51 days, from 38 to 89 Plants sown with 300 seeds per m² achieved this stage later than that plants sown with a higher rate. Slower development could have been caused by the different light quality, because with high plant density, there is a low red light/ far-red light (R/FR) which could accelerate stem growth rate (Ugarte *et al.,* 2010).

The terminal spikelet date is different between cultivars according to the differences between winter and spring triticale (Varughese *et al.,* 1991). Indeed this stage was reached earlier in Oceania compared to Bienvenu. Within the sowing-window considered, the earlier the sowing, the greater the differences between the winter and the spring cultivar in the time necessary to reach TS. This means that, while with the earliest sowings a facultative cultivar is preferable, the choice of a facultative or spring cultivar is relatively irrelevant for the duration of the grazing period with sowings from December onwards.

Anthesis date of dual-purpose crops is related to their grain yield, particularly in Mediterranean environments characterized by terminal droughts. In these environments a late anthesis results in more stressful environmental conditions during grain filling (Fischer, 1979).

There were no differences between sowing rates in anthesis date, whereas clipping affected anthesis date in some occasions. This, according to previous research, is because removing above ground biomass at terminal spikelet could change the time when anthesis is reached (Royo *et al.,* 1994; Royo *et al.,* 1997).

The winter cultivar was generally later than the spring one in anthesis and the magnitude of this difference varied with the sowing date. Differences between cultivars reached a maximum of 23 days in the earliest sowing of October and a minimum in the latest sowings of January. Bringing backward the sowing date, caused Oceania to reach flowering stage during winter, as happened in OttavaOCT, where anthesis occurred during the first ten days of March.

Table 1.3 Terminal spikelet and anthesis date

Environment	Sowing rate (n°*m-²)	Cultivar	Clip	Terminal Spkelet date	Anthesis date
OttavaOCT	**300**	**Bienvenu**	**Unclipped**	19-Dec	31-Mar
			Clipped		7-Apr
		Oceania	**Unclipped**	16-Nov	9-Mar
			Clipped		9-Mar
	600	**Bienvenu**	**Unclipped**	19-Dec	31-Mar
			Clipped		7-Apr
		Oceania	**Unclipped**	12-Nov	9-Mar
			Clipped		9-Mar
OttavaNOV	**300**	**Bienvenu**	**Unclipped**	1-Feb	18-Apr
			Clipped		20-Apr
		Oceania	**Unclipped**	9-Jan	10-Apr
			Clipped		12-Apr
	600	**Bienvenu**	**Unclipped**	24-Jan	18-Apr
			Clipped		20-Apr
		Oceania	**Unclipped**	9-Jan	10-Apr
			Clipped		12-Apr
OttavaJAN	**300**	**Bienvenu**	**Unclipped**	23-Mar	9-May
			Clipped		9-May
		Oceania	**Unclipped**	19-Mar	2-May
			Clipped		4-May
	600	**Bienvenu**	**Unclipped**	21-Mar	9-May
			Clipped		9-May
		Oceania	**Unclipped**	19-Mar	2-May
			Clipped		4-May
UssanaDEC2011	**300**	**Bienvenu**	**Unclipped**	16-Mar	2-May
			Clipped		2-May
		Oceania	**Unclipped**	14-Mar	27-Apr
			Clipped		27-Apr
	600	**Bienvenu**	**Unclipped**	16-Mar	2-May
			Clipped		2-May
		Oceania	**Unclipped**	9-Mar	27-Apr
			Clipped		27-Apr
UssanaDEC2012	**300**	**Bienvenu**	**Unclipped**	19-Mar	2-May
			Clipped		2-May
		Oceania	**Unclipped**	7-Mar	2-May
			Clipped		2-May

Biomass production

In every case in which significant differences were detected at ANOVA for biomass at the TS stage, Bienvenu produced more biomass than Oceania and plots with 600 seed per m^2 more than plots with 300 seeds m^{-2}, (Table 1.4).

The magnitude of the difference in the biomass produced by the two cultivars varied in accordance with the sowing time and the duration of the vegetative stage. Indeed the regression between biomass at this stage and the sampling date, revealed a positive association ($R^2 = 0.40$; $P<0.01$). This result was not surprisingly, given the mentioned wide variation in time to TS generated by the combination of the five environments with the different growth habit of the two cultivars. The greater biomass of cultivar Bienvenu was therefore related to the greater time needed by this cultivar to reach this phenological stage (see Table 1.2), and is in accordance with other authors, who say that winter types produce high biomass during the vegetative stage (Royo *et al.,* 1996; Santiveri *et al.,* 2004).

Dry matter production at TS was different between cultivars and sowing rate treatments only in OttavaOCT and OttavaNOV. In OttavaOCT average dry matter at TS was 93 g^*m^{-2} in Bienvenu, versus 58 g^*m^{-2} in Oceania compared to 167 g^*m^{-2} in Bienvenu and 106 g^*m^{-2} in Oceania obtained in OttavaNOV. In OttavaOCT average dry matter at TS was 95 g^*m^{-2} for 600 seed per m^2, versus 57 g^*m^{-2} for 300 seeds per m^2 compared to 162 g^*m^{-2} for 600 seed per m^2 and 111 g^*m^{-2} for 300 seeds per m^2 obtained in OttavaNOV.

Dry matter production up to ANT at Ottava was not affected by the sowing density treatment. The differences between cultivars were significant only in the extreme sowing dates of OttavaOCT and OttavaJAN. In these environments biomass production in the winter cultivar Bienvenu plots was higher than Oceania, confirming the difference between winter and spring cultivars observed by Santiveri *et al.* *(*2004). In OttavaOCT average dry matter at ANT was 1214 g^*m^{-2} in Bienvenu compared to 896 g^*m^{-2} in Oceania versus 940 g^*m^{-2} in Bienvenu and 823 g^*m^{-2} in Oceania obtained in OttavaJAN. Also in this case the duration of the period available for biomass accumulation was important in determining these differences, as carrying out a regression between dry matter at ANT and the sampling date a positive correlation (R^2 = 0.26; *P<0.01*) was found.

In the three Ottava environments, unclipped plots produced more dry matter than clipped plots. Unclipped plots produced on average 1100 g*m-^{2} and clipped plots produced 850 g*m-^{2}.

In UssanaDEC2011 Oceania had a higher dry matter production at ANTH than Bienvenu. Above ground biomass in Oceania was 1044 g*m-^{2} compared to 945 g*m-^{2} in Bienvenu. Dry matter production in unclipped plots was higher than clipped plots and similar to the average biomass obtained in Ottava in both clipped and unclipped treatments. In UssanaDEC2012, the absence of differences between cultivars could be due to anthesis date (Table 1.2), because both Bienvenu and Oceania reached this stage on May 2nd.

In Ottava, dry matter production at MAT at the higher sowing density was greater than dry matter production at the lower sowing density in the environments OttavaOCT and OttavaNOV. Differences between cultivars followed the trend observed at ANTH, therefore, Bienvenu had greater dry matter than Oceania in OttavaOCT and OttavaJAN. In OttavaOCT above ground biomass production was 1497 g*m-^{2} in Bienvenu compared to 1063 g*m-^{2} in Oceania; Bienvenu produced 1902 g*m-^{2} and Oceania 1686 g*m-^{2} in OttavaJAN. As happened in dry matter production at ANTH, also at MAT unclipped plots produced higher biomass than clipped plots in all Ottava environments.

In Ussana biomass produced at MAT was affected by cultivar and clip treatments in UssanaDEC2011 and UssanaDEC2012, and by sowing density in the first environment. In plots with 600 seeds per m^2, Oceania unclipped had a greater biomass production.

Table 1.4 Dry matter production at terminal spikelet (TS), anthesis (ANTH) and

Environment	Sowing rate ($n°*m^{-2}$)	Cultivar	Clip	Dry matter TS ($g*m^{-2}$)	Dry matter ANTH ($g*m^{-2}$)	Dry matter MAT($g*m^{-2}$)
OttavaOCT	300	Bienvenu	Unclipped	58 ± 1 ^{b}	1356 ± 111 ^{a}	1784 ± 50 ^{b}
			Clipped		982 ± 207 ^{b}	813 ± 47 ^{d}
		Oceania	Unclipped	56 ± 5 ^{b}	887 ± 56 ^{b}	1173 ± 138 ^{c}
			Clipped		806 ± 116 ^{b}	832 ± 34 ^{d}
	600	Bienvenu	Unclipped	129 ± 7 ^{a}	1440 ± 45 ^{a}	2022 ± 29 ^{a}
			Clipped		1078 ± 22 ^{ab}	1367 ± 87 ^{c}
		Oceania	Unclipped	61 ± 1 ^{b}	930 ± 1 ^{b}	1254 ± 58 ^{c}
			Clipped		960 ± 49 ^{b}	992 ± 63 ^{cd}
OttavaNOV	300	Bienvenu	Unclipped	141 ± 23 ^{b}	1094 ± 113 ^{ab}	1957 ± 108 ^{b}
			Clipped		793 ± 116 ^{b}	1717 ± 40 ^{bc}
		Oceania	Unclipped	81 ± 4 ^{c}	1207 ± 36 ^{a}	2322 ± 15 ^{a}
			Clipped		917 ± 107 ^{b}	1553 ± 27 ^{c}
	600	Bienvenu	Unclipped	193 ± 3 ^{a}	1315 ± 144 ^{a}	2428 ± 180 ^{a}
			Clipped		902 ± 29 ^{b}	1901 ± 68 ^{b}
		Oceania	Unclipped	131 ± 8 ^{b}	1509 ± 79 ^{a}	2365 ± 117 ^{a}
			Clipped		723 ± 58 ^{b}	1734 ± 12 ^{bc}
OttavaJAN	300	Bienvenu	Unclipped	133 ± 4 ^{a}	1101 ± 59 ^{a}	2134 ± 52 ^{a}
			Clipped		786 ± 38 ^{bc}	1703 ± 76 ^{c}
		Oceania	Unclipped	90 ± 12 ^{b}	944 ± 15 ^{b}	1686 ± 69 ^{c}
			Clipped		718 ± 22 ^{c}	1564 ± 77 ^{c}
	600	Bienvenu	Unclipped	124 ± 9 ^{ab}	1095 ± 86 ^{a}	2057 ± 40 ^{ab}
			Clipped		779 ± 6 ^{bc}	1714 ± 49 ^{c}
		Oceania	Unclipped	118 ± 15 ^{ab}	893 ± 6 ^{b}	1900 ± 46 ^{b}
			Clipped		737 ± 3 ^{c}	1592 ± 68 ^{c}
UssanaDEC2011	300	Bienvenu	Unclipped	202 ± 15 ^{NS}	1067 ± 40 ^{b}	766 ± 35 ^{cd}
			Clipped		849 ± 33 ^{cd}	641 ± 45 ^{e}
		Oceania	Unclipped	229 ± 17 ^{NS}	1246 ± 33 ^{a}	1065 ± 70 ^{a}
			Clipped		927 ± 33 ^{c}	714 ± 30 ^{de}
	600	Bienvenu	Unclipped		1059 ± 8 ^{b}	820 ± 3 ^{bd}
			Clipped		803 ± 33 ^{d}	850 ± 54 ^{bc}
		Oceania	Unclipped		1101 ± 43 ^{b}	1137 ± 32 ^{a}
			Clipped		899 ± 22 ^{cd}	915 ± 21 ^{b}
UssanaDEC2012	300	Bienvenu	Unclipped	286 ± 3 ^{a}	1122 ± 97 ^{a}	2342 ± 86 ^{a}
			Clipped		883 ± 51 ^{b}	1662 ± 157 ^{b}
		Oceania	Unclipped	191 ± 13 ^{b}	1100 ± 16 ^{a}	2222 ± 104 ^{a}
			Clipped		900 ± 29 ^{b}	2190 ± 119 ^{a}

Data means ± Standard Error.

In the same environment, within rows, means followed by the same letter are not significantly different according to LSD (0.05).

NS, nonsignificant. Not significantly different according to LSD (0.05).

physiological maturity (MAT)

Fig. 1.5 shows the pattern in average dry matter accumulation of the two clipping treatments during the growing season. When differences were detected, above ground biomass was always greater in unclipped plots compared to clipped plots, but the magnitude of the differences changed. In OttavaOCT (*a), b)*) in Bienvenu the differences between clipped and unclipped plots were more pronounced respect to Oceania. In OttavaNOV (*c), d)*) Oceania clipped had a faster recovery in biomass production after clipping than Bienvenu. This was likely a consequence of the faster development of spring compared to winter cultivars. According to Royo and Blanco (1999), this is because winter cultivars need more time to reach the maximum rate of dry weight accumulation in the stems. In OttavaJAN (*e), f)*) Bienvenu had greater dry matter production in particular at ANTH and MAT stage when compared to Oceania.

UssanaDEC2012 showed patterns of biomass accumulation similar to Ottava environments, whereas UssanaDEC2011 (*g), h)*) was the only environment where no increase in biomass was observed after anthesis. This could be partly attributed to the very low rainfall characterizing this environment (Fig. 1.3).

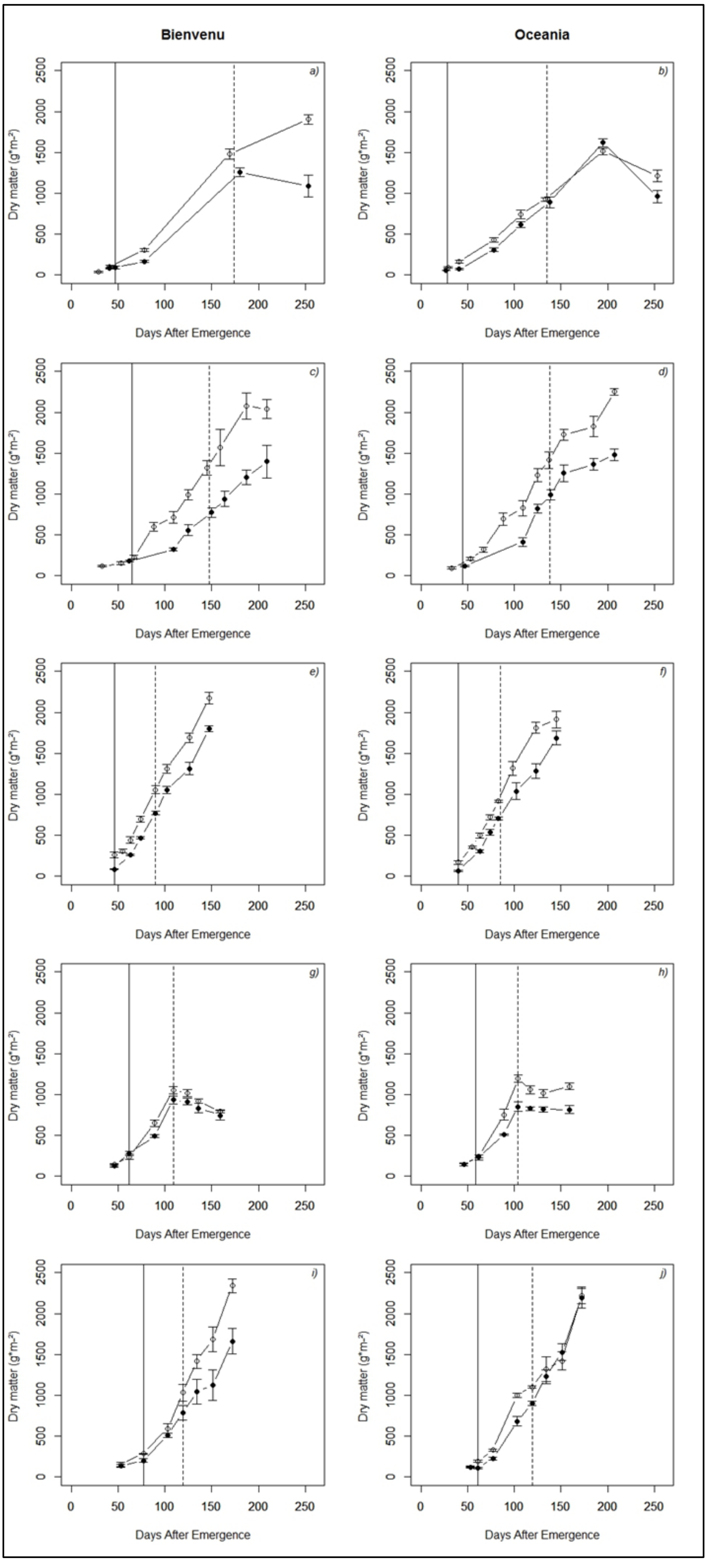


Fig. 1.5.
Dry matter production in Bienvenu (left column) and Oceania (right column) in
a) b) OttavaOCT,
c) d) OttavaNOV,
e) f) OttavaJAN,
g) h) UssanaDEC2011,
i) j) UssanaDEC2012.
Vertical entire line is the terminal spikelet date and dashed line is the average anthesis date between clipped (black points) and unclipped (white points) plots.

Grain yield and HI

In the Ottava environments, grain yield was affected by clipping at all environments, whereas differences between cultivars were apparent only in the extreme sowing dates of OttavaOCT and OttavaJAN. The sowing density did not affect grain yield.

The particularly low grain yield of the spring cultivar Oceania at OttavaOCT - 206 g*m-^{2} compared to 608 g*m-^{2} obtained in Bienvenu - was a consequence of its earlier anthesis. The October sowing was too early for this cultivar and caused anthesis to happen in winter, when there were very low temperatures (minimum temperature was around 3°C at anthesis). Low temperatures during anthesis in wheat negatively affect the fertility of pollen grains so reducing grain yield (Porter and Gawith*.,* 1999).

Unexpectedly, Bienvenu yielded more than Oceania also in the latest sowing date of OttavaJAN, where its grain yield was 751 g*m-^{2} versus 696 g*m-^{2} produced in Oceania plots. Generally, winter cultivar are considered not suited to late sowings in Mediterranean environments because they flower too late and are exposed to severe drought during grain filling. In this particular environments rainfall in spring was abundant and resulted in a superiority of the winter cultivar.

Grain yield was higher in unclipped plots than clipped plots, which is in accordance with the more biomass produced by unclipped plots.

Also in the Ussana environments sowing rate did not affect grain yield. Cultivar differences were observed in UssanaDEC2011, where Oceania plots (365 g*m-^{2}) had higher production compared to Bienvenu (291 g*m-^{2}). This greater grain yield could have been due to the low rainfall and high temperature that occurred in this environment at the end of the growing season. Spring cultivars had a better response to these weather conditions, because the absence of vernalization requirements, caused them to reach anthesis earlier than winter cultivars. In this specific environment, Oceania flowered 2-7 days before Bienvenu, depending on the sowing rate (Tab 1.3). According to previous research, it is important to “match cultivar phenology with environment type” to reduce negative effect of grain yield (Harrison *et al.,* 2011).

Interestingly, clipping generally did not affect grain yield in the most stressed environments, in contrast with what observed in other environment characterized by terminal drought (Virgona *et al.,* 2006). Evidently the reduced transpiration deriving from clipping did not mitigate the terminal drought stress. In UssanaDEC2012 there was a significant difference caused by clip treatments. Clipped plots had a lower grain yield (585 $g*m-^2$) than unclipped plots (709 $g*m-^2$).

In Ottava HI was affected by sowing rate in OttavaOCT, because plots sown with 300 seeds per m^2 had greater HI (0.39) compared to the plots which were sown with 600 seeds per $m-^2$ (HI =0.35). This can explain why the two sowing rates did not differ in grain yield: the greater biomass at ANTH in the treatment with the high sowing density was less ‘fertile’ because of less fertile spikes per m2 and/or, a lower spike fertility and/or a lower kernel weight.

In OttavaOCT, Oceania had a lower HI than Bienvenu. In this environment the HI of 0.14 in Oceania was very low also in absolute terms, cause the stress occurring during anthesis. Cultivars generally did not differ in HI apart from OttavaOCT environment where the HI of 0.14 in Oceania was sensibly lower than Bienvenu HI, and very low in absolute terms, cause the stress occurring during anthesis. Clipping affected HI only in few occasions: in both OttavaOCT and UssanaDEC2011 HI was higher in the clipped Oceania plots compared to the unclipped ones. This flattened the grain yield difference between clipped and unclipped Oceania plots.

Table 1.5 Grain yield and harvest index.

Environment	Sowing rate (n°*m^{-2})	Cultivar	Clip	Grain yield (g*m^{-2})	Harvest Index
OttavaOCT	300	Bienvenu	Unclipped	700 ± 47 ^{a}	0.37 ± 0.01 ^{a}
			Clipped	530 ± 55 ^{b}	0.39 ± 0.01 ^{a}
		Oceania	Unclipped	174 ± 16 ^{c}	0.10 ± 0.01 ^{c}
			Clipped	230 ± 13 ^{c}	0.18 ± 0.03 ^{b}
	600	Bienvenu	Unclipped	728 ± 34 ^{a}	0.34 ± 0.00 ^{a}
			Clipped	472 ± 34 ^{b}	0.36 ± 0.01 ^{a}
		Oceania	Unclipped	200 ± 35 ^{c}	0.09 ± 0.03 ^{c}
			Clipped	219 ± 22 ^{c}	0.17 ± 0.02 ^{b}
OttavaNOV	300	Bienvenu	Unclipped	828 ± 48 ^{b}	0.40 ± 0.01 ^{ab}
			Clipped	644 ± 47 ^{c}	0.37 ± 0.02 ^{ac}
		Oceania	Unclipped	871 ± 25 ^{ab}	0.38 ± 0.01 ^{ac}
			Clipped	640 ± 4 ^{c}	0.41 ± 0.01 ^{a}
	600	Bienvenu	Unclipped	944 ± 49 ^{a}	0.36 ± 0.02 ^{bd}
			Clipped	618 ± 18 ^{c}	0.33 ± 0.01 ^{d}
		Oceania	Unclipped	895 ± 35 ^{ab}	0.36 ± 0.00 ^{bd}
			Clipped	614 ± 23 ^{c}	0.34 ± 0.02 ^{cd}
OttavaJAN	300	Bienvenu	Unclipped	863 ± 18 ^{a}	0.39 ± 0.01 ^{ab}
			Clipped	659 ± 5 ^{cd}	0.37 ± 0.01 ^{bc}
		Oceania	Unclipped	735 ± 37 ^{bc}	0.42 ± 0.00 ^{a}
			Clipped	636 ± 26 ^{d}	0.36 ± 0.01 ^{c}
	600	Bienvenu	Unclipped	832 ± 22 ^{a}	0.38 ± 0.01 ^{bc}
			Clipped	649 ± 25 ^{d}	0.37 ± 0.00 ^{bc}
		Oceania	Unclipped	799 ± 51 ^{ab}	0.40 ± 0.01 ^{ab}
			Clipped	614 ± 14 ^{d}	0.38 ± 0.02 ^{bc}
UssanaDEC2011	300	Bienvenu	Unclipped	289 ± 26 ^{c}	0.39 ± 0.00 ^{b}
			Clipped	288 ± 22 ^{c}	0.39 ± 0.02 ^{ab}
		Oceania	Unclipped	386 ± 9 ^{a}	0.36 ± 0.01 ^{bd}
			Clipped	344 ± 14 ^{ab}	0.43 ± 0.02 ^{a}
	600	Bienvenu	Unclipped	300 ± 18 ^{bc}	0.32 ± 0.01 ^{e}
			Clipped	288 ± 21 ^{c}	0.35 ± 0.01 ^{ce}
		Oceania	Unclipped	366 ± 8 ^{a}	0.34 ± 0.00 ^{de}
			Clipped	362 ± 9 ^{a}	0.39 ± 0.01 ^{bc}
UssanaDEC2012	300	Bienvenu	Unclipped	729 ± 45 ^{a}	0.29 ± 0.00 ^{NS}
			Clipped	487 ± 74 ^{b}	0.31 ± 0.03 ^{NS}
		Oceania	Unclipped	688 ± 4 ^{a}	0.31 ± 0.01 ^{NS}
			Clipped	684 ± 49 ^{a}	0.31 ± 0.02 ^{NS}

Data means ± Standard Error.

In the same environment, within rows, means followed by the same letter are not significantly different according to LSD (0.05).

NS, nonsignificant. Not significantly different according to LSD (0.05).

CONCLUSIONS

The choice of a spring or a winter cultivar of triticale has an important impact on both the amount of biomass produced by TS and the grain yield obtaining after clipping, especially when plants grow under different weather conditions. Biomass at TS is strongly affected by the phenology of the cultivar via its effect on the duration of the sowing-TS period, i.e. the time available for biomass accumulation.

Grain yield is mainly influenced by the phenology of the cultivar utilized via the time of anthesis, as an incorrect combination cultivar x environment x sowing date can cause anthesis to happen to early (frost or cold stress) or too late (drought stress).

The environments sampled in this experiment suggest that the risk associated with early sowings of spring cultivars is greater than the risk associated with late sowings of winter cultivars. This is because an early-sown spring cultivar flowers in winter, when the probability of a cold stress is very high. Winter cultivars, on the contrary, are penalized by late sowings only when the post-anthesis period is particularly stressing.

The negative effects of clipping on grain yield are proportional to the corresponding decrease in biomass, whereas HI is usually improved by clipping, thus reducing the differences in grain yield between clipped and unclipped treatments.

In water-stressed environments, the water saved in pre-anthesis thanks to the reduction in leaf area index deriving from clipping does not represent an advantage for the subsequent grain filling period, but simply reduce the amount of biomass produced in pre-anthesis. In these conditions, on the other hand, the unclipped crops cannot fully express their potential grain yield.

In the context of dual purpose the biomass removed at terminal spikelet reduces biomass production and grain yield under Mediterranean conditions, but the size of this reduction is not the same in all environments, remarking the importance of the choice of the cultivar in function of weather conditions and sowing date.

Using high sowing density does not mean obtaining a greater grain yield at harvest, but this is good only for having a high biomass during vegetative stage, which could be important when crop is grazed. This is well explained by HI values, because low plant rate has greater HI compared to high plant density.

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CHAPTER 2

RADIATION INTERCEPTION AND RADIATION USE EFFICIENCY IN THE CONTEXT OF DUAL-PURPOSE UTILIZATION OF WINTER AND SPRING TRITICALES

In the context of dual purpose, a rapid recovery of photosynthetic activity after the removal of above ground biomass is important for obtaining a good grain yield. This physiological process is closely related to leaf area recovery (Dunphy *et al.,* 1984; Winter and Thompson, 1987). Leaf area development affects radiation interception and biomass production (Hay and Porter, 2006), and the higher number of stems and leaves per stem of winter triticales compared to spring ones (Royo *et al.,* 1996) has to be taken into account in the cultivar choice for dual-purpose..

The capacity of leaf area to intercept radiation is quantifiable in terms of the radiation extinction coefficient, which is closely linked to leaf angle and plant height (Green 1987; Hay and Porter, 2006). These morphological characteristics could be changed due to clipping (Dann, 1968) and depend on cultivar growth habit (winter or spring). Winter types usually have a prostrate posture before stem elongation, when spring cultivars have an erect posture. Given a same LAI, therefore differences in leaf growth habit can change the radiation distribution inside canopy layers that could change the radiation use efficiency (RUE) (Duncan, 1971; Sinclair and Muckow, 1999). RUE quantifies how efficiently the radiation intercepted by a crop is converted into biomass and is linked to the maximum leaf photosynthetic rate (Sinclair and Muckow, 1999). Motzo *et al.,* (2013) underlined the positive relationship existing between stomatal conductance and RUE in triticale crops.

It has been demonstrated that removing above ground biomass can increase the assimilation rate, because of improved leaf water status and increased leaf nitrogen concentration and photosynthetic enzyme activity (Harrison *et al.,* 2010). An increased photosynthetic activity after clipping is connected to a greater stomatal conductance (Harrison *et al.,* 2010) which can be attributed to a high water availability in clipped plants as a result of the lower transpiration due to leaf area reduction (Harrison *et al.,* 2010; Virgona *et al.,* 2006).

In those environments where water availability is not a limiting factor, nitrogen has an important role for leaf area development (Hay and Porter, 2006). In clipped plants, the removal of biomass decreases the nitrogen potentially available for leaf area development after clipping. This lower of nitrogen affects more leaf area development than specific leaf nitrogen (SLN) (Grindlay, 1997).

Sowing density could affect RUE, because lower population densities guarantee a greater nitrogen availability and a better radiation distribution within the canopy (Singer *et al.,* 2007; Whaley *et al.,* 2000). High sowing densities frequently cause water stress hastening post-anthesis senescence in environments where water availability decreases at the end of plant life cycle (Bonachela *et al.,* 1995). If plants are sown with low density, there will be a great survival of the stems. This implies a long lifetime of the leaf area that could capture a great quantity of radiation.

The aim of this chapter is to evaluate the effect of the growing habitus (winter or spring) on the quantity of intercepted radiation and on the RUE in dual-purpose triticale clipped at the stem elongation stage.

To the best of our knowledge there are no papers on the production of winter and spring triticale in the context of dual purpose which analyze biomass production in terms of intercepted radiation and RUE. Little research work has also been carried on the effect of clipping and growing habitus and their interaction on leaf characteristics and on leaf nitrogen concentration. However many researchers (Royo *et al.*, 1996) underline the importance of leaf area development on the performance of dual-purpose triticale and the differences between winter and spring triticale in this respect.

MATERIALS & METHODS

Details on experimental design and crop management are given in the first Chapter of this thesis (see Materials & Methods and Tables 1.2 – 1.3).

Specific measurements regarding this chapter are the following:

Intercepted radiation and LAI. At all environments, in all plots, radiation intercepted was measured at noon and on different occasions (from emergence to post-anthesis stage, until the plants had yellow flag leaf) using a tube solarimeter (Sun-Scan Canopy Analysis System SS1-UM-1.05. Delta-T Devices Ltd., Burwell, Cambridge, England) that was placed both above the canopy, and close to and parallel to the soil surface at right angles to the row direction. This instrument measures incident and transmitted radiation and estimates LAI.

SPAD. Leaf chlorophyll concentration was estimated with non-destructively samplings using a Minolta SPAD-502 leaf chlorophyll meter (Minolta Corp.,Ramsey, NJ). Measurements were taken on different occasions on the 10 uppermost fully expanded leaf blades up to anthesis, and on the green flag leaves after anthesis. .

Leaf area, leaf dry matter and leaf nitrogen content. Leaf area was measured on samples of 30 leaves (chosen among the last emerged leaves) with a planimeter on different occasions after clipping. After measuring, the sample was oven dried at 80°C for 48 hours for the dry weight measure. Total leaf nitrogen concentration was determined using a CHN determinator (CHN 628 LECO®)

Leaf porosity. Stomatal opening was measured with a viscous-flow porometer (Thermoline Scientific Equipment, Wetherill Park, Australia). This porometer measured the time, in 1/100 of a second, required to force a fixed volume of air through a leaf (Alvim, 1965). This measure of resistance to mass flow was used to calculate leaf porosity [(1/resistance) *100], which is linearly and strongly associated with leaf conductance as measured with a traditional transit-time porometer (Rebetzke *et al.,* 2000; Motzo *et al.,* 2013). Measurements were taken on different occasions in the last expanded leaf of ten stems per plot.

Derived measures and data analysis

The fraction of total solar intercepted radiation (FIR) was calculated as the ratio between the differences of incident and transmitted to incident radiation. Intercepted radiation in the period between terminal spikelet and anthesis (TS-ANTH) was calculated as the sum of the daily values of RI obtained multiplying the daily fraction of total solar intercepted radiation (obtained by fitting a polynomial curve to the measured data) by the daily values of solar radiation recorded at the meteorological station of each experimental station.

The dry matter produced by the unclipped plots between TS and anthesis (TS-ANTH) was calculated as the difference between dry matter at ANTH and dry matter at TS obtaining from the biomass samplings (see M&M section of Chapter 1).

RUE was calculated according to Sinclair and Muchow (1999) as the slope of the linear relationship between biomass and intercepted solar radiation cumulated between terminal spikelet and anthesis.

Specific leaf area (SLA, m^2 g^{-1}) was calculated dividing the leaf area measured with the planimeter by leaf weight. Specific leaf nitrogen (SLN, g N m^{-2}) was calculated dividing the leaf nitrogen concentration by SLA.

Statistical analysis was performed according with what reported in Chapter 1.

RESULTS & DISCUSSION

Radiation Use Efficiency (RUE)

Sowing density was not discussed among the treatments in this chapter because no differences were detected between the two sowing densities of 300 and 600 seeds per m², according to Stöckle and Kemanian (2009), who said that RUE is not affected by plant density and sowing rate.

In Ottava, Bienvenu produced more above-ground biomass than Oceania in the TS-ANTH period of the two extreme sowing dates of OttavaOCT and OttavaJAN (Table 2.1). In OttavaOCT the difference was particularly high due to the lower radiation intercepted by Oceania plots which could be due to its short TS-ANTH period (see Table 1.3). Clipping treatment affected dry matter production during TS-ANTH in OttavaNOV, where unclipped plots produced 1151 g m^{-2} compared to 934 g*m^{-2} in clipped plots.

In UssanaDEC2012, biomass produced in the TS-ANTH period was not affected by clipping but only by cultivar: Oceania plants produced 876 g*m^{-2} compared to Bienvenu, 706 g*m^{-2}. In UssanaDEC2011 there was cultivar x clip interaction where Bienvenu unclipped had a greater dry matter production.

Cumulated intercepted radiation and biomass produced during TS-ANTH in Ottava were affected by cultivar treatment in OttavaOCT and OttavaJAN, because Bienvenu intercepted more radiation than Oceania. In OttavaOCT intercepted radiation in Bienvenu plants was 1087 MJ*m^{-2} compared to 720 MJ*m^{-2} in Oceania. The lower biomass produced in Oceania could therefore be due to the lower amount of radiation intercepted, which in turn derived from its early anthesis. Clipping treatment affected intercepted radiation in OttavaNOV, where unclipped plots intercepted more radiation compared to clipped (1046 MJ*m^{-2} versus 813 MJ*m^{-2} in clipped plants). This could be due to the lower leaf area able to intercept radiation in clipped treatments.

In UssanaDEC2011 no treatment affected intercepted radiation, but in UssanaDEC2012 there was both a cultivar and a clip influence. Oceania and unclipped treatments intercepted more radiation than, respectively, Bienvenu and clipped treatments.

The resulting RUE did not show any ‘cultivar by clipping’ interaction (Table 2.1) and was not different between cultivars nor between clipping treatments (Fig. 2.1), being equal to 1.0 ± 0.04 g MJ^{-1} in Bienvenu clipped, 1.1 ± 0.04 g MJ^{-1} in Oceania clipped, and 1.2 ± 0.05 g MJ^{-1} for both cultivars, unclipped.

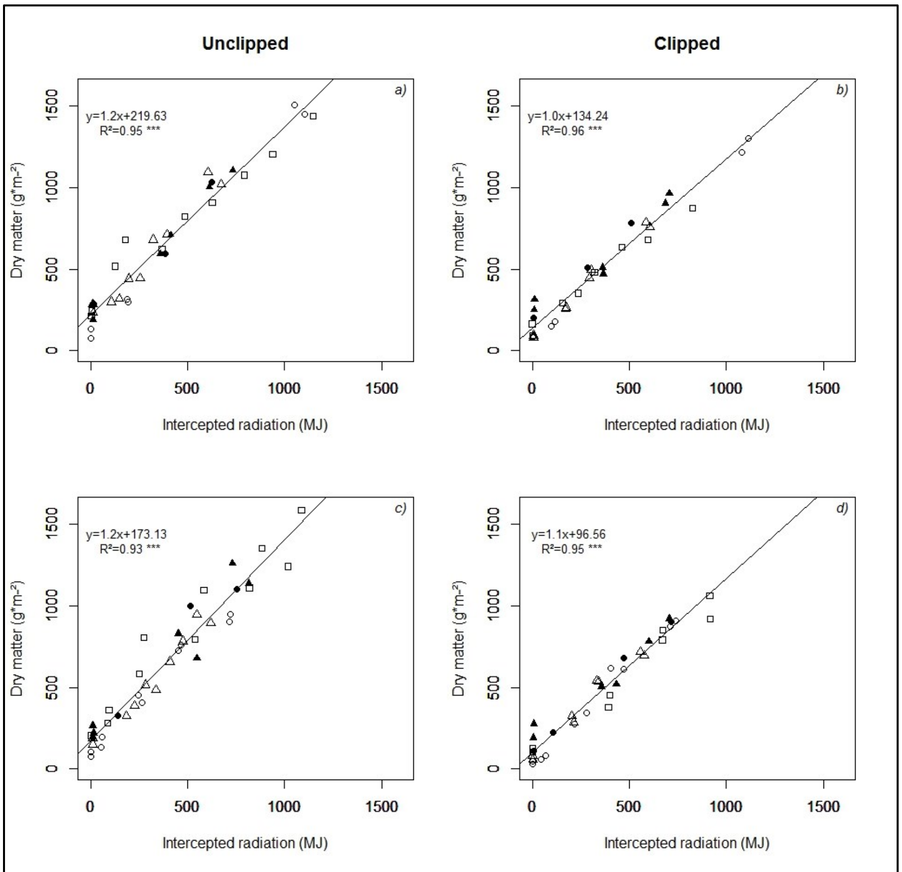
The few cases in which a reduced biomass production in the TS-anthesis period was observed following clipping were therefore not due to a lower efficiency to convert radiation but to the lower intercepted radiation resulting from clipping.

Table 2.1 Intercepted radiation, dry matter and RUE values obtained in the period between TS and ANTH.

Environment	**Cultivar**	**Clip**	**Intercepted Radiation TS-ANTH** (MJ*m^{-2})		**Dry matter TS-ANTH** (g*m^{-2})		**RUE** (g*MJ^{-1})	
OttavaOCT	**Bienvenu**	**Unclipped**	**1077** ± 32	a	**1374** ± 53	a	**1.3** ± 0.05	NS
		Clipped	**1096**± 15	a	**1258** ± 50	a	**1.1** ± 0.02	NS
	Oceania	**Unclipped**	**718** ± 12	b	**834** ± 21	b	**1.2** ± 0.06	NS
		Clipped	**722** ± 18	b	**891** ± 65	b	**1.2** ± 0.05	NS
OttavaNOV	**Bienvenu**	**Unclipped**	**1041** ± 66	a	**1092** ± 76	a	**1.0** ± 0.07	NS
		Clipped	**709** ± 67	b	**776** ± 58	b	**0.9** ± 0.05	NS
	Oceania	**Unclipped**	**1051** ± 25	a	**1210** ± 103	a	**1.1** ± 0.09	NS
		Clipped	**916** ± 34	a	**991** ± 64	a	**1.0** ± 0.08	NS
OttavaJAN	**Bienvenu**	**Unclipped**	**640** ± 29	a	**796** ± 35	a	**1.3** ± 0.10	NS
		Clipped	**595** ± 10	ab	**772** ± 21	ab	**1.2** ± 0.05	NS
	Oceania	**Unclipped**	**584** ± 21	ab	**749** ± 18	ab	**1.3** ± 0.09	NS
		Clipped	**567** ± 14	b	**706** ± 20	b	**1.2** ± 0.09	NS
UssanaDEC2011	**Bienvenu**	**Unclipped**	**673** ± 42	a	**817** ± 15	NS	**1.2** ± 0.07	NS
		Clipped	**696** ± 21	ab	**933** ± 53	NS	**0.9** ± 0.12	NS
	Oceania	**Unclipped**	**773** ± 39	ab	**954** ± 52	NS	**1.2** ± 0.17	NS
		Clipped	**653** ± 37	b	**850** ± 57	NS	**0.9** ± 0.10	NS
UssanaDEC2012	**Bienvenu**	**Unclipped**	**623** ± 5	b	**746** ± 108	ab	**1.2** ± 0.27	NS
		Clipped	**507** ± 6	c	**667** ± 23	b	**1.2** ± 0.04	NS
	Oceania	**Unclipped**	**755** ± 42	a	**910** ± 16	a	**1.3** ± 0.20	NS
		Clipped	**714** ± 12	a	**842** ± 14	ab	**1.1** ± 0.05	NS

Data means ± Standard Error.

In the same environment, within rows, means followed by the same letter are not significantly different according to LSD (0.05). NS, nonsignificant. Not significantly different according to LSD (0.05).



Significant codes at the ***0.001; **0.01; *0.05 probability level

Fig 2.1

RUE values of unclipped Bienvenu (*a*) and Oceania (*c*), clipped Bienvenu (*b*) and Oceania (*d*). The points represent dry matter and cumulated intercepted radiation corresponding to the sampling date in different environments: (white circle) OttavaOCT, (white square) OttavaNOV, (white triangle) OttavaJAN, (black triangle) UssanaDEC2011 and (black circle) UssanaDEC2012. The linear relationship does not have origin in 0 because when plants were cut down at the terminal spikelet stage, there was a residual biomass that could intercept radiation.

Leaf Area Index (LAI) and Fraction of Intercepted Radiation (FIR)

Fig. 2.2 and Fig. 2.3. clearly show the longer period available for radiation interception in the growing seasons of OttavaOCT and OttavaNOV (Fig. 2.2 *b, d*; Fig 2.3 *B, D*). OttavaNOV was the environment with the greatest difference in both LAI and FIR between clipped and unclipped treatments, in accordance with the significant effect of clipping on RI already discussed.

Bienvenu needed a longer time after clipping to recover its maximum LAI, compared to Oceania, consistently with what observed by Royo and Blanco (1999) in a comparison between winter and spring cultivars. These differences in canopy development did not affect the total amount of radiation intercepted between TS and anthesis, because Bienvenu intercepted more radiation than Oceania in OttavaOCT and OttavaJAN. Differences in LAI between clipped and unclipped plots, were greater in Oceania plots in OttavaNOV (Fig 2.3 *C*) where clipped plants were not able to recover a maximum LAI comparable with unclipped plots The same trend is observed for FIR (Fig 2.3 *D*).

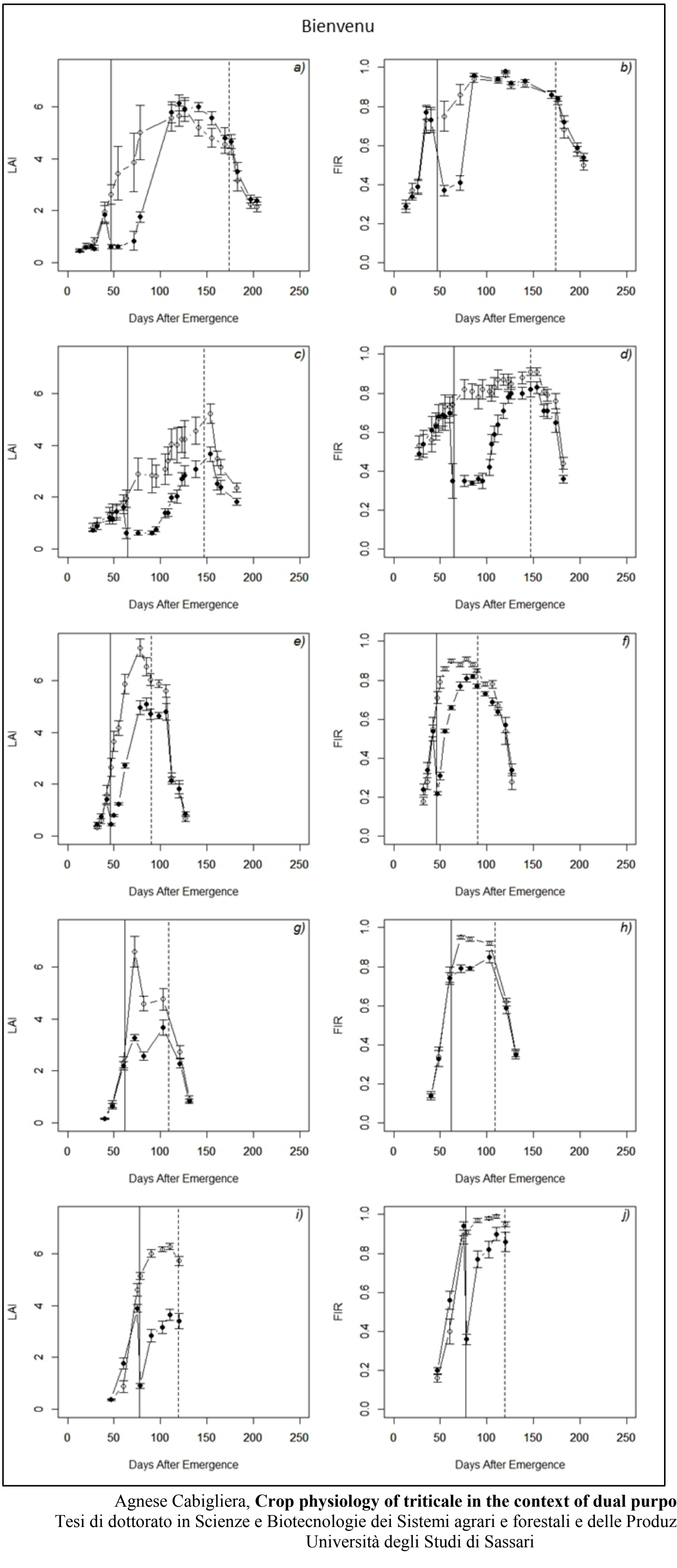


Fig 2.2
LAI (left column) and FIR (right column) measurements in Bienvenu in:
a) b) OttavaOCT,
c) d) OttavaNOV,
e) f) OttavaJAN,
g) h) UssanaDEC2011,
i) j) UssanaDEC2012.
Vertical entire line is terminal spikelet date and dashed line is the average anthesis date between clipped (black points) and unclipped (white points) plots.

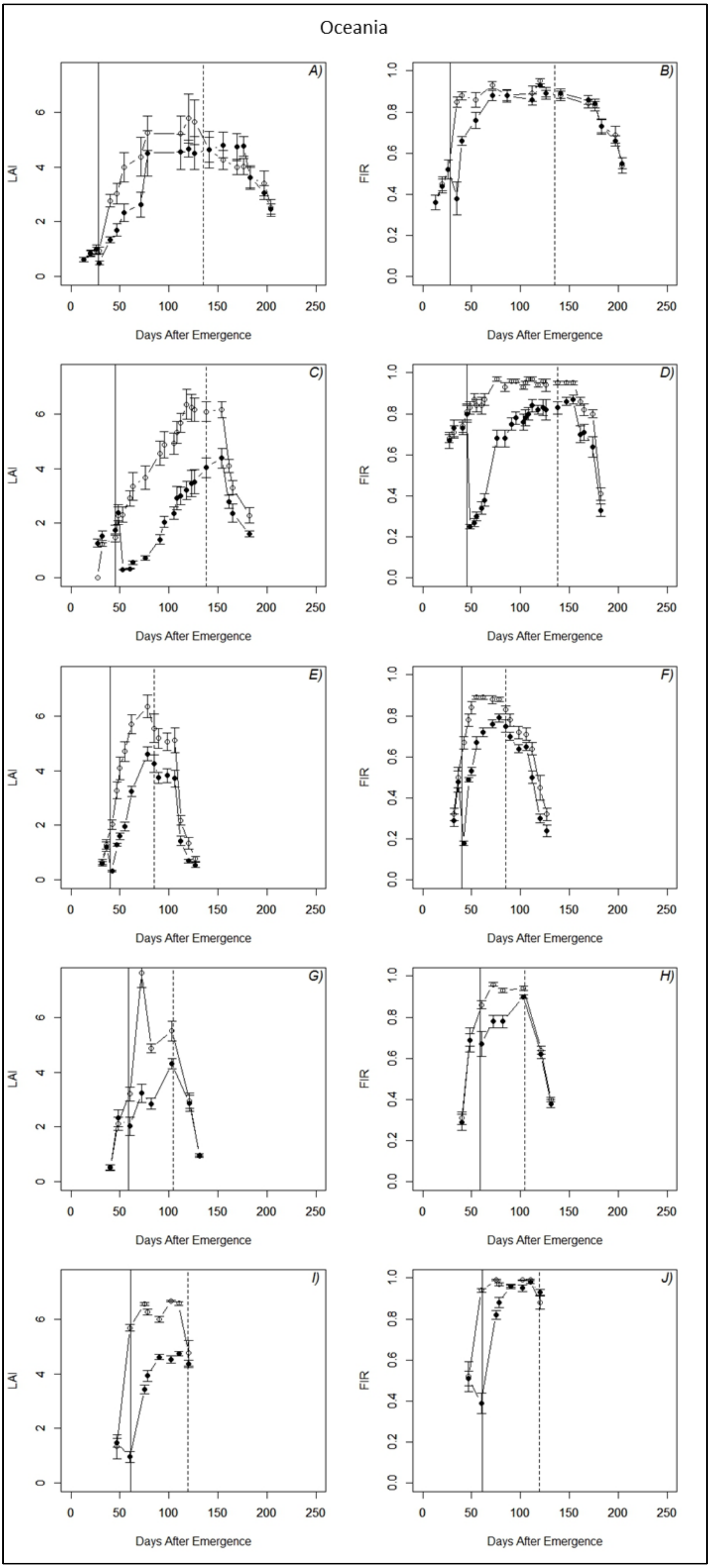


Fig 2.3
LAI (left column) and FIR (right column) measurements in Oceania in:
A) B) OttavaOCT,
C) D) OttavaNOV,
E) F) OttavaJAN,
G) H) UssanaDEC2011,
I) J) UssanaDEC2012.
Vertical entire line is terminal spikelet date and dashed line is the average anthesis date between clipped (black points) and unclipped (white points) plots.

Leaf porosity

The leaf porosity pattern was not different between clipped and unclipped treatments which follow the same direction with the same peak (Fig. 2.4), in contrast with Harrison et al. (2010) and Virgona et al. (2006) who reported an effect of clipping/grazing on stomatal conductance.

A great leaf porosity in Bienvenu (*a*) compared to Oceania (*b*) leaves is observed in OttavaOCT. At anthesis both cultivars had a similar leaf porosity value, but in pre-anthesis period, Bienvenu had a higher value. This could be connected to the rainfall distribution (Fig. 1.3) during terminal spikelet stage. Oceania plants reached TS when rainfall was less compared to rainfall during Bienvenu TS. This poor precipitation could have had a negative influence to water availability both in clipped and unclipped Oceania plots thus inducing some level of stomatal closure.

The relationship existing between leaf porosity and RUE (Condon *et al.,* 2008; Motzo *et al.,* 2013) is confirmed in this research, because the absence of differences in terms of RUE between clipped and unclipped plots is associated to the same leaf porosity in clipped and unclipped plants.

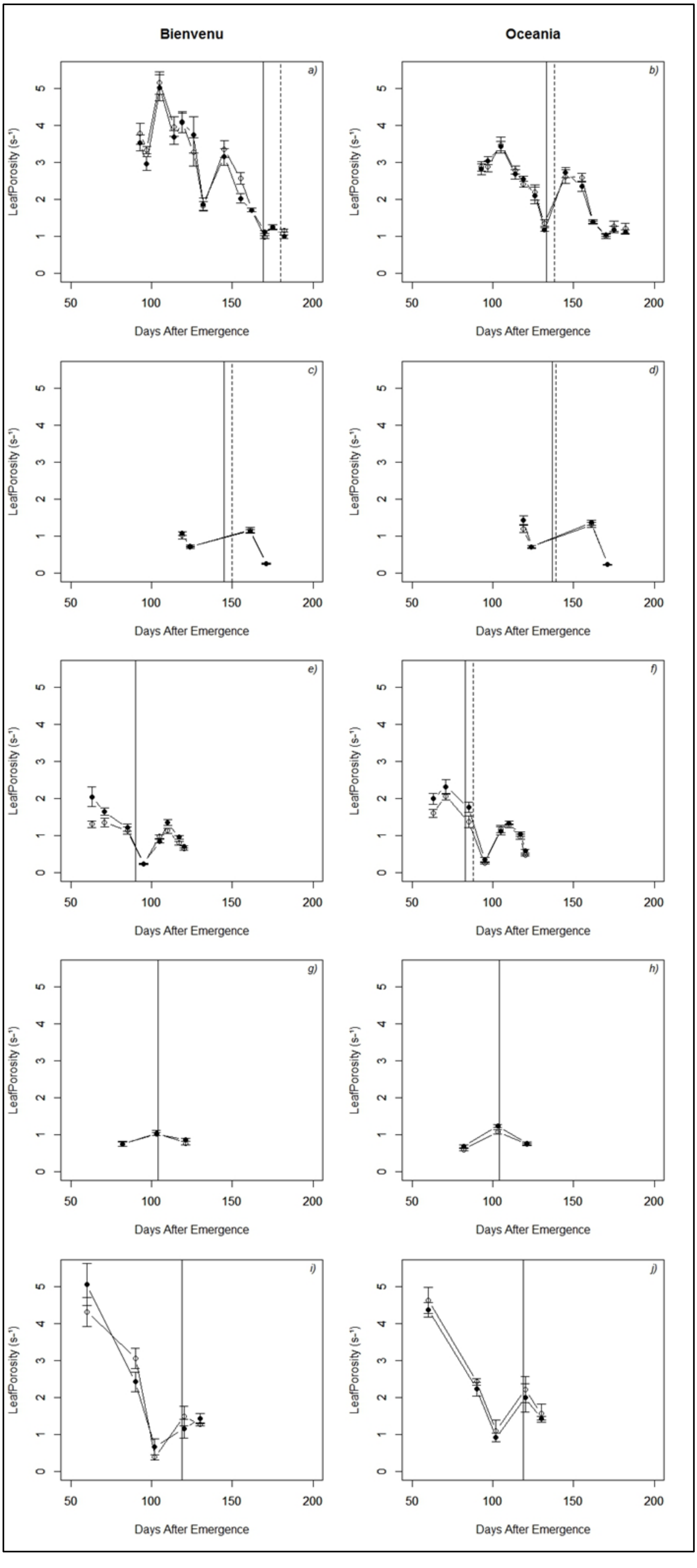


Fig 2.4
Leaf porosity in Bienvenu (left column) and Oceania (right column) in
a) *b*) OttavaOCT,
c) *d*) OttavaNOV,
e) *f*) OttavaJAN,
g) *h*) UssanaDEC2011,
i) *j*) UssanaDEC2012.
Vertical line is anthesis date for clipped (dashed line) and unclipped (entire line). One vertical line means that anthesis date for clipped and unclipped plots was the same.

SPAD readings

SPAD trend was not affected by clip treatment (Fig 2.5). This behavior was important because the cut at terminal spikelet removed the above ground biomass along with the nitrogen assimilated from sowing to this stage. There was no additional nitrogen fertilization in clipped plots that could justify the absence of nitrogen difference between treatments. The sharp decrease in SPAD after anthesis was due to leaf ageing.

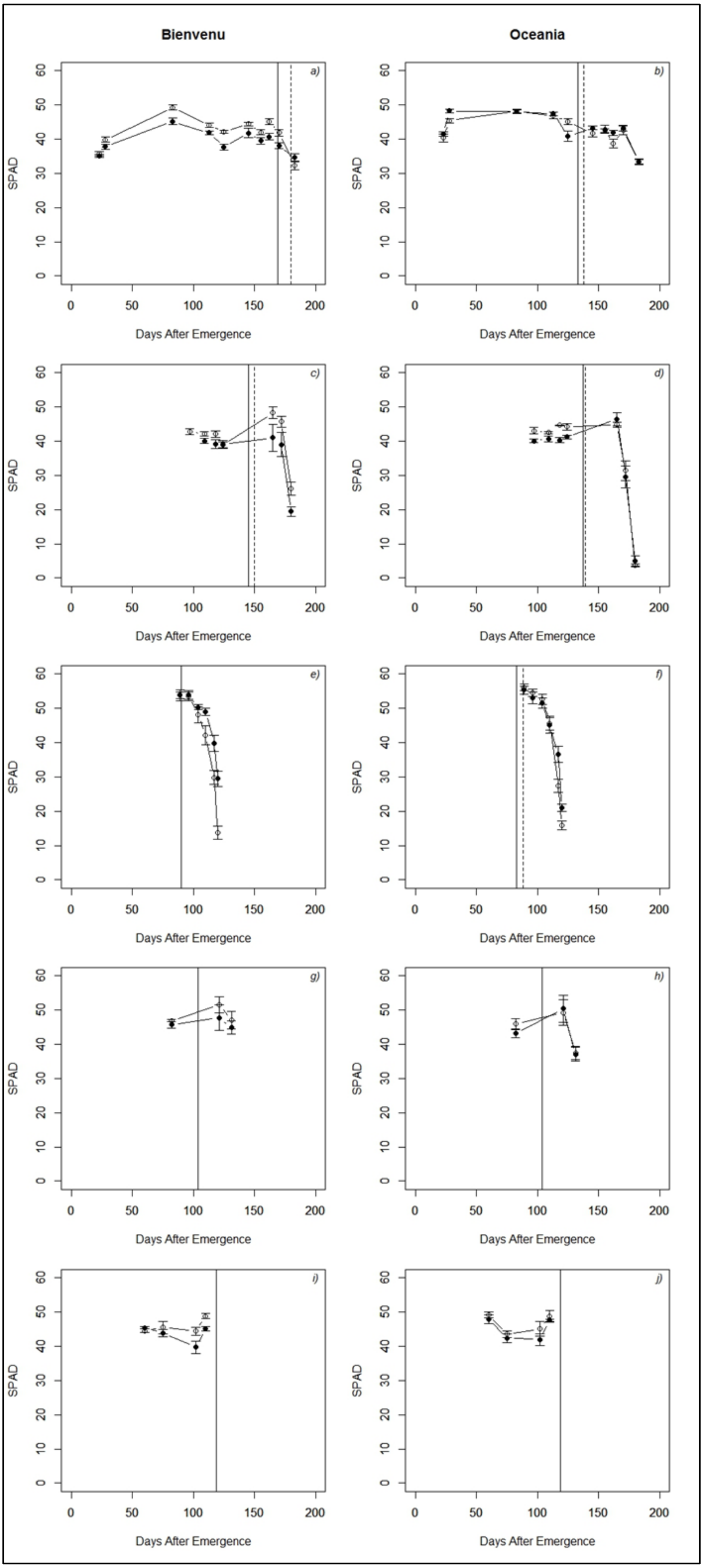


Fig 2.5
SPAD readings in Bienvenu (left column) and Oceania (right column) in *a*) *b*) OttavaOCT, *c*) *d*) OttavaNOV, *e*) *f*) OttavaJAN, *g*) *h*) UssanaDEC2011, *i*) *j*) UssanaDEC2012. Vertical line is anthesis date for clipped (dashed line) and unclipped (entire line). One vertical line means that anthesis date for clipped and unclipped plots was the same.

Specific Leaf Nitrogen (SLN) and Specific Leaf Area (SLA)

In OttavaNOV SLN and SLA have the same peak 109 days after anthesis, when Oceania unclipped reached the maximum SLN value (Fig. 2.6). At anthesis, both OttavaNOV and OttavaJAN had the same SLN and SLA values, SLN around 1.5 gN m-^{2} leaf area and SLA around 60 m^2 g-^{1}.

When there is a low nitrogen availability plants can reduce light interception, canopy photosynthetic rate or both (Stöckle and Kemanian, 2009) in order to reach a balance between resource capture and resource use efficiency (Sinclair and Horie, 1989; Grindlay 1997). In wheat plants if there is nitrogen deficiency, plants respond maintaining SLN and reducing leaf area (Stöckle and Kemanian, 2009).

Nitrogen leaf content was not affected by clipping. The same behavior was observed for specific leaf nitrogen and SLA, which means that leaf thickness did not change with the clipping. The absence of differences in SLN between clipped and unclipped plants highlighted the conservative behavior of triticale plants for this trait.

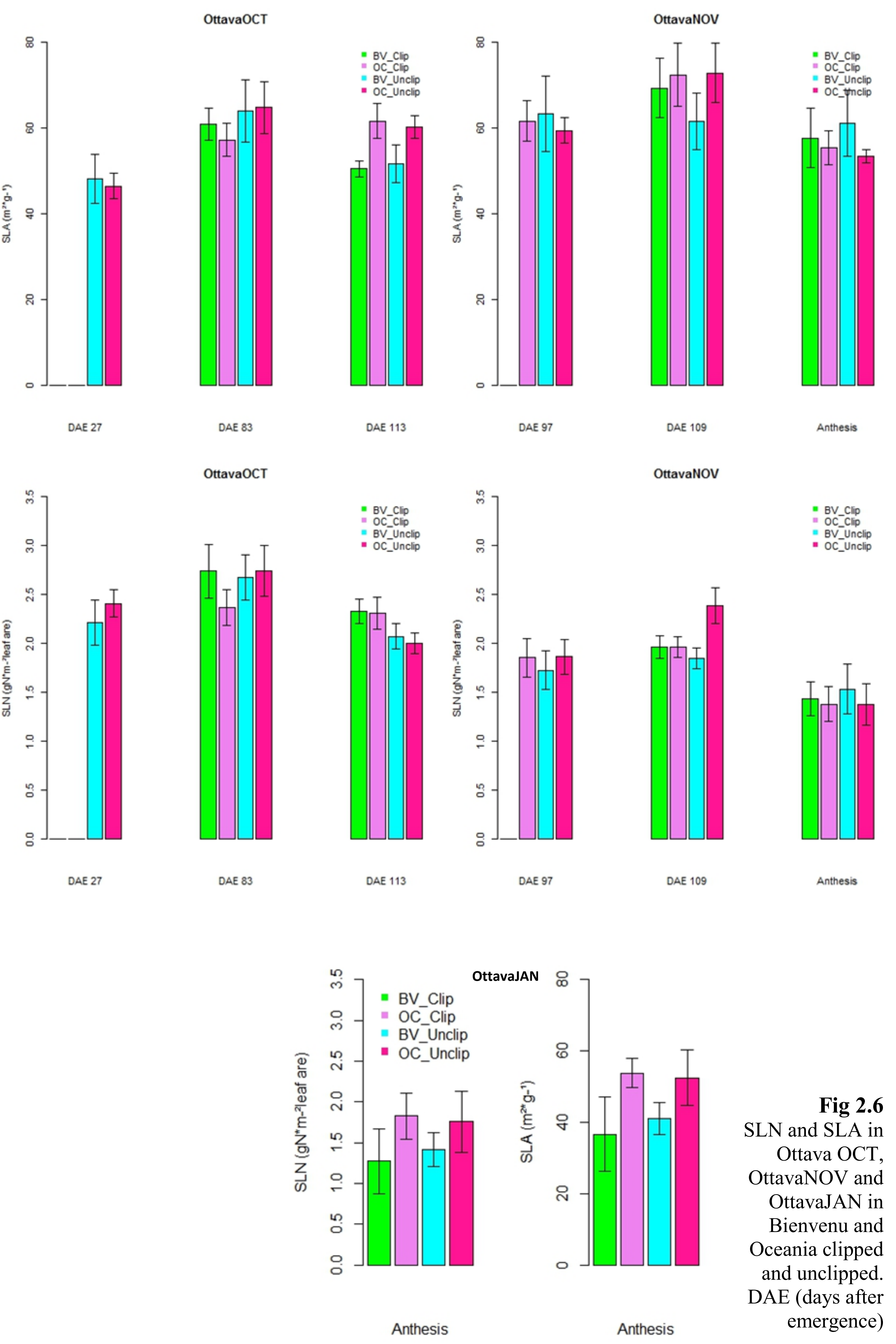


Fig 2.6 SLN and SLA in Ottava OCT, OttavaNOV and OttavaJAN in Bienvenu and Oceania clipped and unclipped. DAE (days after emergence)

CONCLUSIONS

A reduced biomass production as a consequence of clipping at TS was not the rule but the exception in the range of environments and cultivars explored in this experiment. In those few cases in which biomass production was negatively affected by clipping, this derived uniquely from a lower interception of radiation cause an insufficient recovery of leaf area index after clipping. Clipping does no change the efficiency of converting radiation into biomass of triticale, regardless of the growing habitus of the cultivar considered.

The conservative behavior of RUE was consistent with the lack of any effect of clipping on those leaf characteristics involved in the photosynthetic process. The reduction in leaf area caused by clipping only resulted in less interception whereas leaf porosity, leaf chlorophyll content, SLN and SLA did not change in spite of the lower nitrogen available to clipped plants from translocation of the nitrogen assimilated up to TS, compared to unclipped ones. The absence of differences in SLN between clipped and unclipped plants underlines the more conservative behavior of SLN compared to leaf area.

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CHAPTER 3

KERNEL NUMBER VARIATION IN THE CONTEXT OF DUAL PURPOSE UTILIZATION OF WINTER AND SPRING TRITICALE

In cereal crops, grain yield is made up of three components: ear population density, grain number per ear and individual grain weight. Every component is determined at different stages of the crop life cycle (Hay and Porter, 2006). The first two describe the number of kernels per unit area. Variation in in grain yield is generally associated with changes in kernel number (Sadras, 2007), but under unfavorable weather conditions during grain filling, variation in grain yield can be associated with grain weight (Dann *et al.,* 1983; Miller *et al.,* 1993; Royo *et al.,* 1996).

In the context of dual purpose the decrease in grain yield following grazing/clipping can be linked with a low kernel number and/or a low kernel weight, depending on weather conditions and cultivar grown (Harrison *et al.,* 2011). The negative effects on grain yield of removal of above ground biomass are a function of the phenological stage at clipping/grazing (Harrison *et al.,* 2011). A clipping delayed after stem elongation can cause a decrease in ear number per unit area with negative consequence to grain yield (Royo *et al.,* 1997). The lower grain yields of dual purpose triticale can also result from a decrease in kernel number per spike caused by a reduction in spikelet number per ear and kernel number per spikelet (Royo, 1997). In winter triticale, a delayed anthesis due to clipping could cause a low grain yield linked to a decrease in kernel size if grain filling is under unfavorable temperatures and low water availability which limit kernel growth (Royo, 1997).

Some researchers studied the relationship between kernel number and grain yield as a result of different assimilation (Fischer, 2008; Sinclair and Jamieson, 2006) during spike growth (Fischer, 1985). According to

Fischer's model (1984) kernel number is a function of biomass produced before anthesis, the proportion of this biomass accumulated in the spikes and the number of kernels per unit spike weight at anthesis. This model allows to determine a link between dry weight accumulation and kernel number. The model proposed by Fischer (1984) defines a critical period (from the emergence of the penultimate leaf on the main shoot until anthesis) during which spike accumulates most of its dry matter to produce grain. The variation in assimilation during this critical period does not cause only a change in the spike dry matter at anthesis, but also a different amount of reserves accumulated in stems which will be translocated to ears during grain filling (Fischer, 2008). Removing the biomass in dual purpose crops could change the components of this framework through a change in the amount of dry matter at anthesis and/or in the proportion allocated to spikes in those cases with a slow and/or incomplete recovery of leaf area after clipping. Delaying sowing does not mean a reduction in spike dry weight if the crop can intercept a high quantity of radiation before the emergence of the penultimate leaf (Fischer, 1985).

The aim of this chapter was to use Fischer's model to explain the variation in grain yield induced by clipping in winter and spring triticale grown at different sowing densities.

MATERIALS & METHODS

Details on experimental design and crop management are given in the first Chapter of this thesis (see Materials & Methods and Tables 1.2 – 1.3). UssanaDEC2012 was not included in this experiment.

Specific measurements regarding this chapter are the following:

Spike population density (SPNO, no m^{-2}). Number of spikes per unit area was calculated from the average value of spike number m^{-2} of all sampling from anthesis to maturity stage.

Number of kernels per spike (KperSP, no). This value was evaluated in a maturity sample of 10 spikes from each plot after hand-thrashing.

Kernel weight (mg). The weight of the kernels was measured on three samples of 250 seeds each randomly extracted from the grain harvested by each plot.

Kernel number per unit area (KNO, no m^{-2}). This value was calculated multiplying spike population density (SPNO) by number of kernels per spike (KperSP).

Spike dry weight at anthesis (SPANTH, g m^{-2}). This value was obtained from the anthesis biomass sample. Plants were divided into stems, leaves and spikes. Stems and spikes were counted and then oven dried at 80°C for 72 hours. Spikes dry weight was expressed on a unit surface basis.

Kernel number per spike dry weight at anthesis (KpergSPANTH, no g^{-1}). This value was calculated as the ratio between the kernel number per unit area (KNO) and spike dry weight at anthesis (SPANTH).

Total dry matter at anthesis partitioned to the spike (gSPANTH/gPANTH). This value was calculated as the ratio between the spike dry matter at anthesis and total plant dry matter at anthesis.

RESULTS & DISCUSSION

For both cultivars differences in KNO explained a great proportion of the differences in grain yield between treatments (Fig. 3.1). The relationship was stronger for Oceania ($r = 0.95$, $P<0.01$) than for Bienvenu ($r = 0.83$, $P<0.01$). A similar proportion of grain yield variation was explained in the cultivar Bienvenu by kernel weight ($r = 0.84$, $P<0.01$) consistently with its winter habit exposing its grain filling period to more stressful conditions (Royo *et al.,* 1996).

The variation in grain yield and KNO induced by environments and the treatments applied represented in Fig. 3.1. was first analyzed through the framework:

$$\text{Grain yield} = \text{SPNO} \times \text{KperSP} \times \text{kernel weight}$$

This numerical framework in mainly descriptive, and works only when its components are independent from one another, which is not always the case because particularly high SPNO can result in a decrease in KperSP, such as particularly high KNO can affect the kernel weight (Fischer, 2007). In our experiments SPNO was independent of KperSP.

In Ottava and Ussana SPNO was affected by plant density and clip treatments at all environments, but cultivar did not differ in SPNO at OttavaNOV (Table 3.1). Plots with 600 seeds per m-^{2} had a higher SPNO compared to plots with 300 seeds per m-^{2}, because spike population density was determined by plant population density (Hay and Porter, 2006). When cultivar differed in SPNO, Bienvenu had about 100 SPNO more than Oceania as a consequence of its winter habit which increased the duration of tillering (Hay and Porter, 2006). Removing above ground biomass at terminal spikelet affected SPNO as, in general, unclipped plots had 50 SPNO more than clipped plots.

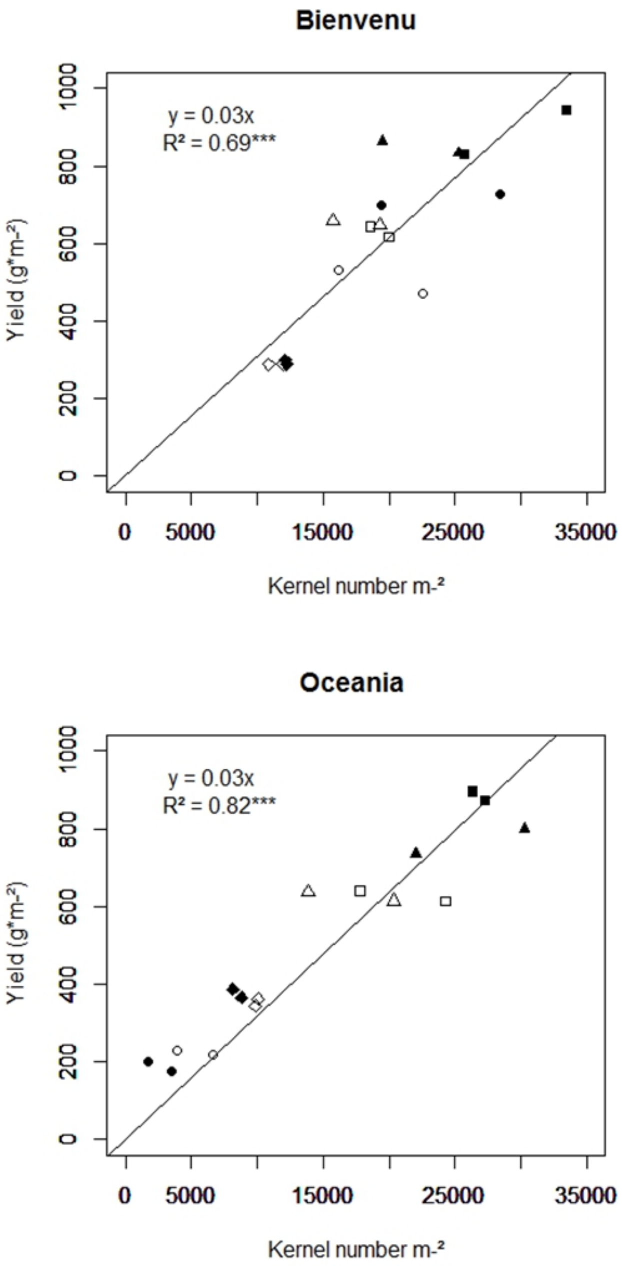

Fig. 3.1

Yield and kernel number per unit area in Bienvenu and Oceania in different environments (circle) OttavaOCT, (square) OttavaNOV, (triangle) OttavaJAN, (rhombus) UssanaDEC2011, in clipped (white) and unclipped (black) plots.

Significant codes at the ***0.001; **0.01; *0.05 probability level

This is in contrast with Royo (1997) who found no effect of forage removal on spike number likely because an additional nitrogen application was made after forage removal in her experiments.

The already mentioned cold stress which occurred at the anthesis of Oceania in OttavaOCT (Chapter 1 and 2) severely affected the spike fertility of this cultivar, which produced only 15 KperSP compared to 53 in Bienvenu, likely as a consequence of a remarkable pollen sterility (Porter and Gawith, 1999). A greater number of kernels per spike was recorded in Oceania at OttavaJAN compared to Bienvenu (50 versus 38). This is in accordance with previous studies (Royo *et al.,* 1995) where spring types have a high kernel number per spike compared to winter types. In OttavaNOV and OttavaJAN, KperSP was affected by clipping as unclipped plots had a high kernel number per spike compared to clipped plants. Sowing density changed KperSP value in OttavaNOV and UssanaDEC2011 where plots with 300 seeds per m^2 had a higher K per SP than plots with 600 seeds per m^2.

Kernel weight was affected by sowing rate and cultivar in OttavaOCT, OttavaNOV and UssanaDEC2011. Plots sown with 300 seeds per m^2 had a higher kernel weight than plots with 600 seeds per m^2, except in OttavaOCT where plots with 300 seeds per m^2 had a lower kernel weight than plots with 600 seeds per m^2, 42.6 mg versus 45.5 mg. When a cultivar effect was detected, Bienvenu had a lower kernel weight compared to Oceania. Thousand kernel weight is usually higher in spring than in winter triticale because the high biomass at anthesis which characterizes winter types exert a negative effect on kernel weight if plants are grown in Mediterranean environments (Santiveri *et al.,* 2004). In the context of dual purpose, a low kernel weight in winter cultivar is due to a delay of anthesis and maturity to periods with high temperatures (Miller *et al.,* 1993; Royo *et al.,*1996) and low water availability (Dann *et al.,* 1983). Removing above ground biomass affected kernel weight only in the higher sowing density of OttavaJAN where unclipped plots of both cultivars had a higher kernel weight compared to clipped plants. The higher population density of 600 could have been penalized in terms of kernel weight given the lower availability of carbohydrates to be translocated to the grains as a consequence of the heavy investments in structural carbohydrates (stems) after clipping.

In Ottava KNO was affected by sowing density at all environments. Plots with 600 seeds per m² had a high KNO compared to 300 seeds per m². This could be due to a great SPNO in plants sown with high seed density. The influence of cultivar was significant in OttavaOCT and UssanaDEC2011 where Bienvenu had a high KNO compared to Oceania. In OttavaOCT the difference was remarkable - 21640 KNO in Bienvenu compared to 3963 KNO in Oceania - and was the consequence of the impact of the cold stress at the anthesis of Oceania on KperSP. At UssanaDEC2011 the higher KNO of Bienvenu derived from its ability to produce more SPNO. Clipping affected KNO particularly in OttavaNOV and OttavaJAN where clipped plots had a lower KNO compared to unclipped ones. The lower KNO was accompanied by a 20% decrease in KperSP and a 10% decrease in SPNO.

When the whole set of data was used, SPNO and KperSP showed correlation of similar strength with KNO. In theory this means that environmental conditions during the whole period from beginning of tillering to anthesis, i.e. the period when SPNO and KperSP are determined, can affect KNO.

Table 3.1 Components of the yield and kernel number

Environment	Sowing rate (no m-^{2})	Cultivar	Clip	KNO (no m-^{2})	SPNO (no m-^{2})	K per SP (no)	Kernel weight (mg)
OttavaOCT	300	Bienvenu	Unclipped	**19389** ± 2083 ^{bc}	**355** ± 26 ^{cd}	**54** ± 2 ^{a}	**40.1** ± 0.32 ^{e}
			Clipped	**16137** ± 1225 ^{c}	**314** ± 19 ^{d}	**51** ± 1 ^{a}	**36.9** ± 0.21 ^{f}
		Oceania	Unclipped	**3542** ± 367 ^{d}	**308** ± 10 ^{de}	**13** ± 1 ^{cd}	**45.6** ± 0.55 ^{c}
			Clipped	**3970** ± 977 ^{d}	**266** ± 7 ^{e}	**25** ± 6 ^{b}	**47.9** ± 0.41 ^{b}
	600	Bienvenu	Unclipped	**28463** ± 4124 ^{a}	**530** ± 21 ^{a}	**56** ± 5 ^{a}	**42.8** ± 0.28 ^{d}
			Clipped	**22565** ± 348 ^{b}	**470** ± 4 ^{b}	**48** ± 1 ^{a}	**41.1** ± 0.56 ^{e}
		Oceania	Unclipped	**1736** ± 937 ^{d}	**386** ± 18 ^{c}	**4** ± 2 ^{d}	**48.2** ± 0.66 ^{b}
			Clipped	**6604** ± 706 ^{d}	**343** ± 4 ^{cd}	**20** ± 2 ^{bc}	**49.9** ± 0.92 ^{a}
OttavaNOV	300	Bienvenu	Unclipped	**25793** ± 388 ^{b}	**419** ± 14 ^{c}	**64** ± 1 ^{a}	**46.2** ± 0.45 ^{cd}
			Clipped	**18566** ± 2864 ^{c}	**328** ± 15 ^{d}	**51** ± 4 ^{bd}	**44.7** ± 0.35 ^{d}
		Oceania	Unclipped	**27309** ± 1151 ^{b}	**442** ± 24 ^{c}	**61** ± 4 ^{ab}	**50.1** ± 1.05 ^{a}
			Clipped	**17810** ± 1015 ^{c}	**360** ± 7 ^{d}	**52** ± 1 ^{bd}	**47.8** ± 0.44 ^{bc}
	600	Bienvenu	Unclipped	**33484** ± 1020 ^{a}	**569** ± 10 ^{a}	**60** ± 2 ^{ab}	**41.9** ± 0.47 ^{e}
			Clipped	**20000** ± 130 ^{c}	**522** ± 8 ^{ab}	**46** ± 5 ^{cd}	**41.8** ± 0.19 ^{e}
		Oceania	Unclipped	**26361** ± 1407 ^{b}	**520** ± 12 ^{ab}	**56** ± 3 ^{ac}	**48.0** ± 0.69 ^{b}
			Clipped	**24266** ± 1417 ^{b}	**497** ± 29 ^{b}	**42** ± 6 ^{d}	**46.7** ± 0.42 ^{bc}
OttavaJAN	300	Bienvenu	Unclipped	**19481** ± 686 ^{c}	**451** ± 1 ^{c}	**43** ± 2 ^{b}	**51.0** ± 0.70 ^{a}
			Clipped	**15715** ± 295 ^{de}	**441** ± 10 ^{c}	**37** ± 1 ^{cd}	**50.1** ± 0.46 ^{a}
		Oceania	Unclipped	**22051** ± 430 ^{bc}	**373** ± 7 ^{d}	**59** ± 1 ^{a}	**50.3** ± 0.76 ^{a}
			Clipped	**13880** ± 974 ^{e}	**346** ± 9 ^{d}	**40** ± 2 ^{bc}	**51.2** ± 0.88 ^{a}
	600	Bienvenu	Unclipped	**25267** ± 1632 ^{b}	**610** ± 23 ^{a}	**38** ± 2 ^{bd}	**46.9** ± 0.65 ^{bc}
			Clipped	**19346** ± 380 ^{cd}	**566** ± 11 ^{b}	**34** ± 0 ^{d}	**44.6** ± 0.16 ^{d}
		Oceania	Unclipped	**30268** ± 1878 ^{a}	**535** ± 17 ^{b}	**56** ± 2 ^{a}	**47.2** ± 0.38 ^{b}
			Clipped	**20370** ± 2086 ^{c}	**480** ± 16 ^{c}	**42** ± 3 ^{bc}	**45.3** ± 0.56 ^{cd}
UssanaDEC2011	300	Bienvenu	Unclipped	**12220** ± 44 ^{a}	**286** ± 8 ^{bc}	**41** ± 0 ^{ac}	**33.1** ± 1.38 ^{c}
			Clipped	**10880** ± 206 ^{ab}	**279** ± 5 ^{c}	**40** ± 1 ^{bc}	**32.8** ± 0.77 ^{c}
		Oceania	Unclipped	**8153** ± 412 ^{d}	**183** ± 3 ^{d}	**47** ± 1 ^{a}	**44.6** ± 0.43 ^{a}
			Clipped	**9861** ± 690 ^{bc}	**236** ± 13 ^{cd}	**43** ± 4 ^{ab}	**42.7** ± 0.65 ^{ab}
	600	Bienvenu	Unclipped	**12127** ± 473 ^{a}	**425** ± 14 ^{a}	**33** ± 2 ^{d}	**29.7** ± 1.02 ^{d}
			Clipped	**11982** ± 374 ^{a}	**433** ± 29 ^{a}	**30** ± 3 ^{d}	**29.6** ± 1.18 ^{d}
		Oceania	Unclipped	**8795** ± 776 ^{cd}	**280** ± 23 ^{c}	**36** ± 1 ^{cd}	**42.0** ± 0.28 ^{b}
			Clipped	**10065** ± 620 ^{bc}	**334** ± 27 ^{b}	**34** ± 0 ^{d}	**41.8** ± 0.30 ^{b}

Data means ± Standard Error.
In the same environment, within rows, means followed by the same letter are not significantly different according to LSD (0.05).
NS, nonsignificant. Not significantly different according to LSD (0.05).

KNO variation was also analyzed with the Fischer's model:

KNO = biomass at anthesis x gSPANTH/gPANTH x KpergSPANTH

as it can help to explain the causes of KNO variation due to treatments in terms of resource capture and use on a surface basis.

Spike dry matter per unit area at anthesis was affected by sowing density and cultivar treatments in OttavaOCT and UssanaDEC2011 (Tab. 3.2). Plots with 600 seeds per m^{-2} had the highest SPANTH, Bienvenu plants had a high SPANTH compared to Oceania. SPANTH was affected by clip treatment in both Ottava and Ussana environments. In Ottava environments unclipped plants had higher SPANTH compared to clipped plots whereas in UssanaDEC2011 the opposite was true.

In UssanaDEC2011 the proportion of dry matter allocated to spikes at anthesis was generally higher in Bienvenu than in Oceania, and in clipped compared to unclipped plots. The greater proportional allocation of dry matter to the spikes in clipped plants was probably due to the lower competitiveness of the tillers after clipping as manifested by their reduced height (data not shown).

Kernel number per spike dry weight at anthesis was affected by sowing density in Ottava. Plants with 600 seeds per m^{-2} had a higher KperSPANTH than plots with 300 seeds per m^2. KperSPANTH was affected by cultivar only in OttavaOCT, again as a consequence of the severe cold stress at the anthesis of Oceania. Removing above ground biomass at terminal spikelet did not change KperSPANTH.

The only component of the Fischer's model correlated with the variation in KNO was KperSPANTH. A strong and positive correlation was calculated between KNO and KperSPANTH in both Bienvenu ($r = 0.92$; $P<0.001$) and Oceania ($r = 0.96$; $P<0.001$). This means that the most critical period for KNO determination for both cultivars was the period around anthesis and the environmental conditions which, in this period, were responsible for a successful grain set.

Table 3.2 Kernel number per spike dry weight at anthesis, total dry matter at anthesis partitioned to the spike and spike dry weight at anthesis

Environment	Sowing rate (n°*m^{-2})	Cultivar	Clip	K per g SP ANTH (no g^{-1})	gSPANTH / gPANTH	SP ANTH (g*m^{-2})
OttavaOCT	**300**	**Bienvenu**	**Unclipped**	**150** ± 9 ^{b}	**0.11** ± 0.001 ^{c}	**156** ± 8 ^{ab}
			Clipped	**151** ± 2 ^{b}	**0.12** ± 0.001 ^{c}	**105** ± 5 ^{e}
		Oceania	**Unclipped**	**28** ± 3 ^{de}	**0.11** ± 0.002 ^{c}	**133** ± 6 ^{cd}
			Clipped	**35** ± 9 ^{cd}	**0.11** ± 0.001 ^{c}	**114** ± 3 ^{de}
	600	**Bienvenu**	**Unclipped**	**198** ± 18 ^{a}	**0.12** ± 0.001 ^{bc}	**169** ± 3 ^{a}
			Clipped	**159** ± 7 ^{b}	**0.14** ± 0.009 ^{a}	**143** ± 8 ^{bc}
		Oceania	**Unclipped**	**10** ± 5 ^{e}	**0.13** ± 0.004 ^{b}	**158** ± 15 ^{ab}
			Clipped	**55** ± 2 ^{c}	**0.11** ± 0.003 ^{c}	**108** ± 8 ^{e}
OttavaNOV	**300**	**Bienvenu**	**Unclipped**	**186** ± 29 ^{ab}	**0.21** ± 0.032 ^{ab}	**141** ± 26 ^{ab}
			Clipped	**122** ± 2 ^{c}	**0.29** ± 0.040 ^{a}	**125** ± 31 ^{b}
		Oceania	**Unclipped**	**145** ± 12 ^{bc}	**0.22** ± 0.018 ^{ab}	**181** ± 22 ^{ab}
			Clipped	**129** ± 17 ^{bc}	**0.25** ± 0.040 ^{ab}	**147** ± 21 ^{ab}
	600	**Bienvenu**	**Unclipped**	**220** ± 31 ^{a}	**0.18** ± 0.015 ^{b}	**147** ± 16 ^{ab}
			Clipped	**158** ± 17 ^{bc}	**0.25** ± 0.027 ^{ab}	**146** ± 10 ^{ab}
		Oceania	**Unclipped**	**151** ± 25 ^{bc}	**0.24** ± 0.029 ^{ab}	**207** ± 32 ^{a}
			Clipped	**176** ± 13 ^{ac}	**0.22** ± 0.034 ^{ab}	**122** ± 11 ^{b}
OttavaJAN	**300**	**Bienvenu**	**Unclipped**	**110** ± 7 ^{b}	**0.22** ± 0.004 ^{c}	**177** ± 5 ^{ab}
			Clipped	**126** ± 11 ^{ab}	**0.27** ± 0.020 ^{ab}	**133** ± 14 ^{c}
		Oceania	**Unclipped**	**119** ± 1 ^{b}	**0.23** ± 0.009 ^{bc}	**185** ± 4 ^{a}
			Clipped	**106** ± 16 ^{b}	**0.30** ± 0.026 ^{a}	**153** ± 11 ^{ac}
	600	**Bienvenu**	**Unclipped**	**144** ± 22 ^{ab}	**0.20** ± 0.005 ^{c}	**181** ± 16 ^{a}
			Clipped	**139** ± 7 ^{ab}	**0.22** ± 0.017 ^{c}	**133** ± 8 ^{c}
		Oceania	**Unclipped**	**164** ± 4 ^{a}	**0.19** ± 0.011 ^{c}	**163** ± 23 ^{ac}
			Clipped	**141** ± 24 ^{ab}	**0.23** ± 0.018 ^{bc}	**142** ± 7 ^{bc}
UssanaDEC2011	**300**	**Bienvenu**	**Unclipped**	**66** ± 4 ^{a}	**0.17** ± 0.008 ^{bc}	**179** ± 8 ^{b}
			Clipped	**67** ± 1 ^{a}	**0.17** ± 0.005 ^{bc}	**163** ± 3 ^{b}
		Oceania	**Unclipped**	**74** ± 2 ^{a}	**0.11** ± 0.002 ^{d}	**132** ± 8 ^{c}
			Clipped	**71** ± 8 ^{a}	**0.19** ± 0.029 ^{b}	**165** ± 18 ^{b}
	600	**Bienvenu**	**Unclipped**	**74** ± 5 ^{a}	**0.18** ± 0.011 ^{bc}	**171** ± 6 ^{b}
			Clipped	**53** ± 1 ^{b}	**0.25** ± 0.004 ^{a}	**211** ± 11 ^{a}
		Oceania	**Unclipped**	**65** ± 6 ^{ab}	**0.14** ± 0.006 ^{cd}	**157** ± 8 ^{bc}
			Clipped	**70** ± 1 ^{a}	**0.19** ± 0.018 ^{b}	**167** ± 11 ^{b}

Data means ± Standard Error.
In the same environment, within rows, means followed by the same letter are not significantly different according to LSD (0.05).
NS, nonsignificant. Not significantly different according to LSD (0.05).

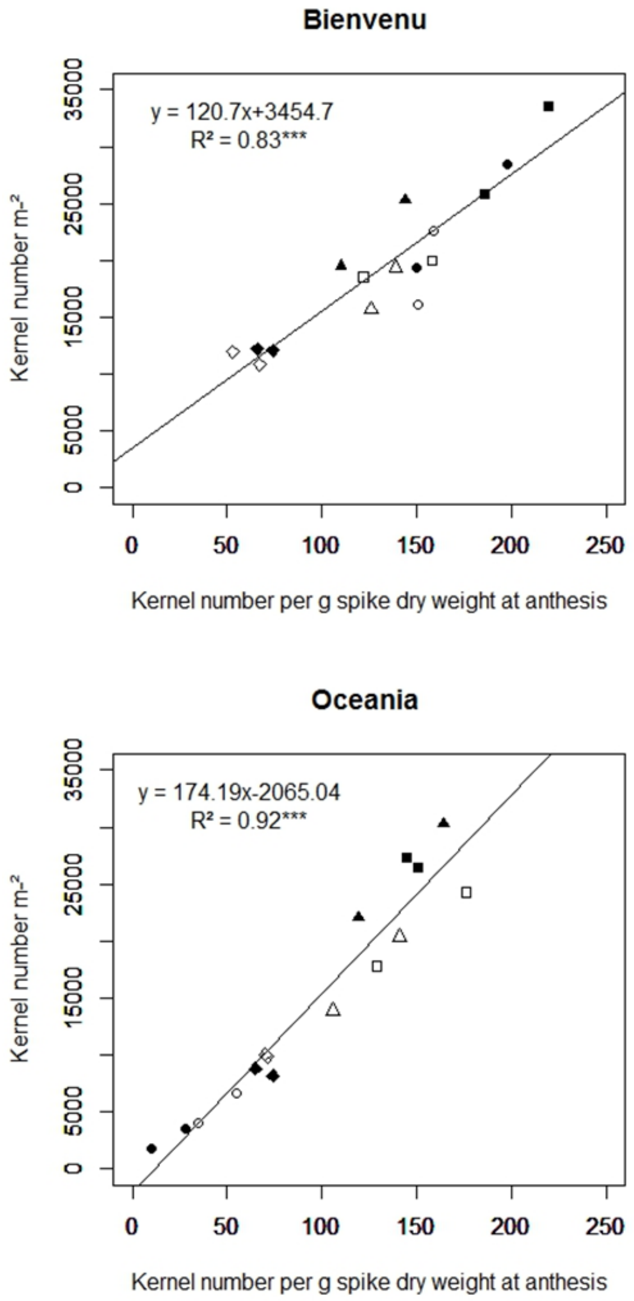

Fig. 3.2
Kernel number and kernel number per g spike dry weight at anthesis in Bienvenu and Oceania in different environment (circle) OttavaOCT, (square) OttavaNOV, (triangle) OttavaJAN, (rhombus) UssanaDEC2011, in clipped (white) and unclipped (black) plots.
Significant codes at the ***0.001; **0.01; *0.05 probability level

CONCLUSIONS

Clipping can affect KNO, and grain yield as a consequence, both in winter and spring cultivars. This effect is not necessarily mediated by a lower amount of biomass allocated to the spikes of clipped crops. Much more relevant are the conditions around anthesis as long as they can affect grain set. The consistent effect of sowing density on KNO determination suggests the lack of compensation between number and fertility of spikes, at least in the range of environmental conditions and cultivars explored.

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