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THE EFFECTS OF FORAGE REMOVAL ON BIOMASS AND GRAIN YIELD OF
INTERMEDIATE AND SPRING TRITICALES

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Abstract

The dual-purpose use of cereals can be a convenient management option if grain yield (GY) is not significantly reduced. The effects of clipping at the terminal spikelet stage on biomass and grain production of an intermediate ('Bienvenu') and a spring ('Oceania') triticale cultivar grown at two sowing rates (300 and 600 seeds per m²) were analysed in five different Mediterranean environments with no additional N application following clipping in terms of the changes induced on radiation and water capture and use and biomass partitioning. Clipped crops were able to recover completely in terms of the fraction of radiation interception (FIPAR) before anthesis, but the period in which plants exhibited a smaller leaf area resulted in a severe reduction – from 20 to 26% depending on the environment- in the total amount of radiation intercepted (IPAR, MJ m⁻²), and consequently, in biomass at anthesis (from 14 to 30%). Radiation use efficiency (RUE) between clipping and anthesis ranged from 0.89 to 1.42 g MJ⁻¹, and only contributed to the decrease in biomass when leaf nitrogen levels were reduced as a consequence of clipping. Evaporation increased (by 13 mm on average) and transpiration decreased (by 11 mm on average) following clipping, with contrasting but quantitatively small effects on evapotranspiration. Transpiration efficiency decreased by about 20% following clipping in most environments because clipping decreased biomass production more than evapotranspiration in environments that did not allow the triticale crops to reach leaf area index values greater than 3–4. GY varied from about 300 to 850 g m⁻² and was only affected by clipping in the two environments with favourable post-anthesis conditions where unclipped crops showed a higher harvest index (HI, 0.38 unclipped vs 0.36 clipped crops on the average of the two environments). In the environments where a severe water stress (transpiration lower than 18% of reference evapotranspiration) following anthesis led to similar amounts of IPAR under the two treatment conditions, the lower biomass at anthesis of clipped crops lead to a higher HI and no reduction in GY. No interaction between clipping and

1 cultivar was observed for FIPAR. Cultivar differences derived from their different phenologies and
2 were mainly expressed before clipping; the longer duration of the phase prior to clipping (from 0
3 to 18 days depending on the environment) resulted in the intermediate cultivar being superior in
4 terms of winter forage production (193 vs 135 g m⁻² on average). On the other hand, the
5 intermediate cultivar was less advantageous in terms of GY (270 vs 357 g m⁻²) in the environments
6 presenting the most severe terminal water stress. Sowing rate was only relevant in the pre-
7 clipping period when the higher sowing rate produced, on average, 40% more biomass than the
8 lower sowing density. Dual-purpose triticale can be a convenient management option in
9 Mediterranean environments subjected to severe terminal water stress because GY is not affected
10 and a variable amount of winter forage may be obtained.

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28 *Keywords:* triticale, dual purpose, radiation interception, radiation use efficiency,
29 evapotranspiration, transpiration efficiency.
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36 *Abbreviations:* GY, Grain Yield; FIPAR, Fraction of Intercepted Photosynthetically Active Radiation;
37 IPAR, cumulated Photosynthetically Active intercepted radiation; RUE, radiation use efficiency; TE,
38 Transpiration Efficiency.
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46 **1. Introduction**

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49 Dual-purpose use of cereals (in which the cereal is grazed by animals and harvested for grain in the
50 same season) is common where livestock and cereal crops are managed in the same area. Triticale
51 (x *Tricosecale* Wittmack) is one of the cereal species grown for dual-purpose use in Mediterranean
52 environments. This type of utilisation is particularly interesting under Mediterranean conditions,
53 because it guarantees a source of forage in a period when animal food requirements are high
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1 (Royo et al., 1997) and crop growth rates are low (Harrison et al., 2011) with low or no reduction
2 in grain production. It offers a wide range of varieties, from spring types, whose developmental
3 rate responds to temperature and day length, to winter and intermediate types, which are also
4 responsive to vernalisation. The phenological differences that exist among triticale cultivars,
5 including different times to maximum leaf area index (LAI), different rates of dry matter
6 accumulation (Royo and Blanco, 1999) and different growth habits (erect or prostrate), influence
7 their aptitudes to dual purpose use.
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10 Any change in grain yield (GY) following grazing/clipping can be viewed as the results of clipping
11 affecting the ability of crops to capture radiation and water, and/or the ability to convert them
12 into biomass (Bonachela et al., 1995a, b; Harrison et al., 2011b, c). A rapid and full recovery of
13 photosynthetic activity after the removal of aboveground biomass is important for obtaining a
14 good GY (Winter and Thompson, 1987). Given the same biomass, the GY of dual-purpose triticale
15 can also be affected by the altered partitioning of biomass into grain and straw (Bonachela et al.,
16 1995) because clipping affects dry matter accumulation in stems (Royo and Romagosa, 1996) and
17 green area duration (i.e., amount of biomass produced after anthesis) (Winter and Thompson,
18 1987).
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21 Most studies that have discussed the effects of grazing/clipping on the GY of small grain cereals
22 have reported dissimilar results with regard to the environmental conditions, management or
23 crop/cultivar (Harrison et al., 2011a and papers cited therein). As underpinned by Harrison et al.
24 (2011a), those papers lacked an approach that could be broadly applied (i.e., an analysis based on
25 a framework that allowed an interpretation of mechanisms by which leaf area removal affects
26 yield). Harrison et al. (2011b, c) performed such an analysis on bread wheat to analyse the effects
27 of different intensities and duration of grazing, thereby obtaining a useful dataset for modelling
28 the effects of grazing on GY (Harrison et al., 2012). In this paper, we adopted a similar type of
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1 analysis for triticale, based on the capture and use of resources. We focused our analysis on the
2 most critical period for dual-purpose cereals, i.e., the period of leaf area recovery, from clipping
3 to anthesis, and evaluated the interaction between clipping and phenology. The aim of this study
4 was to analyse the effects of clipping on biomass and grain production of winter and spring
5 triticales with regard to clipping-induced changes on the capture and use of radiation and water,
6 as well as on biomass partitioning.
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18 **2. Materials and methods**

19 *2.1. Experimental design*

20 Five field trials were conducted across two locations in Sardinia, Italy (Ottava, 41°N, 80 m asl, and
21 Ussana, 39°N, 97 m asl) in the 2011–2012 and 2012–2013 seasons, representing a subset of the
22 experiments used to analyse how dual-purpose use affects the phenology of triticales by Giunta et
23 al. (2015). The soil at Ottava consisted of a sandy- clay-loam that was overlaid on limestone
24 (Xerochrepts), with a soil water content of 31% on a volume basis at field capacity and of 13% at
25 the wilting point. The soil at Ussana consisted of loam, with a soil water content of 33% on a
26 volume basis at field capacity and of 17% at the wilting point. According to long-term data, the
27 climate at both Ussana and Ottava is typically Mediterranean, although the two sites differ in
28 rainfall and thermal regime. There is 19% less rainfall at Ussana than at Ottava, and the
29 temperature range is wider because of the higher maximum and lower minimum temperatures
30 that occur during the whole year (Table 1).
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Table 1. Long-term weather data for the two sites and weather data for the emergence-anthesis (EM-ANT) and anthesis-maturity period (ANT-MAT) of the five experiments. VPD, Vapor Pressure Deficit, T, transpiration, ETo reference evapotranspiration.

Site or environment	Period	Duration (d)	Maximum temperature (°C)	Minimum temperature (°C)	VPD (KPa)	Rainfall (mm)	ETo (mm d ⁻¹)	T/ETo
Ottava (58 years)	Oct-May		17.2 ± 1.0	8.8 ± 1.0	0.76 ± 0.21	473 ± 111	2.5 ± 0.4	
	Apr-May		20.1 ± 1.4	10.4 ± 1.3	0.90 ± 0.28	83 ± 46	4.0 ± 0.5	
Ussana (40 years)	Oct-May		18.9 ± 1.1	7.8 ± 0.7	0.60 ± 0.11	381 ± 123	2.2 ± 0.3	
	Apr-May		22.4 ± 1.8	9.6 ± 1.1	0.83 ± 0.21	72 ± 40	3.6 ± 0.5	
OTTOCT	EM-ANT	154	15.4	7.6	0.9	444	2.5	0.82
	ANT-MAT	101	20.3	11.1	1.2	148	4.6	0.38
OTTNOV	EM-ANT	143	15.5	7.7	0.9	185	2.7	0.56
	ANT-MAT	68	22.3	12.2	1.4	107	5.4	0.21
OTTJAN	EM-ANT	87	16.3	6.9	0.9	78	3.4	0.35
	ANT-MAT	61	25.0	14.7	1.7	80	6.0	0.28
USSDEC12	EM-ANT	107	16.7	3.9	0.6	187	2.5	0.53
	ANT-MAT	53	27.7	11.8	1.2	50	5.8	0.15
USSDEC13	EM-ANT	119	15.8	5.4	0.5	314	2.2	0.71
	ANT-MAT	54	24.2	11.8	0.9	18	4.8	0.18

Long-term data are means ± standard deviations

Two triticale cultivars with similar photoperiodic sensitivities but different vernalisation requirements were compared. Cultivar Oceania, which does not have a vernalisation requirement, can be classified as ‘spring type’ according to Loomis and Connor (1992), whereas cultivar Bienvenu, which has a quantitative response to low temperature, can be classified as ‘intermediate type’ according to the same authors. These plants were chosen among the most productive and well-adapted cultivars to the Mediterranean environment of Sardinia. During the 2011–2012 season, sowing was performed on 15 November 2011 and on 18 January 2012 at Ottava (‘OTTNOV’ and ‘OTTJAN’ environments), and on 28 December 2011 at Ussana (‘USSDEC12’). During the 2012–2013 season, sowing was carried out on 9 October at Ottava (‘OTTOCT’) and on 19 December (‘USSDEC13’) at Ussana.

Two seed-rate treatments were compared in each of the environments: 300 seeds per m², the common sowing rate for triticale in this type of environment, and 600 seeds per m². Seed density

1 was calculated for each cultivar from thousand-grain weight and percentage of germination. Half
2 of the plots were clipped at the terminal spikelet stage with a lawn mower ('clipped' treatment),
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4 so that their aboveground height did not exceed 2 cm. In each environment, a factorial
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6 combination of cultivar x clipping x sowing rate treatment was arranged in a randomised complete
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8 block design with four replications. Each plot was formed by eight 10 m long rows, separated from
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10 one another by 15 cm. The soil was dressed with 100 Kg ha⁻¹ P₂O₅ and 100 Kg ha⁻¹ N at sowing. All
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12 weeds, pests and diseases were chemically controlled.
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18 *2.2. Measurements*

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20 Emergence, booting, anthesis and physiological maturity were recorded by periodical inspections
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22 of the plots when more than 50% of plants in the plot had reached that phenological stage. The
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24 development of the apices of 5–10 main stems per plot was determined twice a week by
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26 destructive sampling to detect the stage of terminal spikelet, which corresponded to the end of
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28 terminal spikelet formation and was marked by the initiation of awns because of the elongation of
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30 the tip of the lemmas (Bonnett, 1936). The terminal spikelet stage was presumed to occur when it
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32 was exhibited by more than 50% of the plants sampled.
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38 Plant height (from the soil surface to the tip of the last leaf) was recorded on 10 random plants per
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40 plot at clipping, booting and anthesis. On one or two sampling occasions between clipping and
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42 anthesis, depending on the length of the period, SPAD-502 readings were taken from the middle
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44 portion of the blades of 30 uppermost fully expanded leaves per plot. On the same blades, the
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46 following parameters were determined: leaf area with an electronic leaf area meter; dry weight
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48 after oven drying at 80°C; and leaf nitrogen percentage (Carbon/Hydrogen/Nitrogen Determinator
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50 628 Series; LECO, St. Joseph, MI, USA). Using these data, leaf nitrogen level was expressed as g
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52 leaf⁻¹ and g m⁻² leaf. Within each environment, clipping was performed in each 'cultivar by rate of
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54 sowing' treatment immediately after observation of the terminal spikelet stage. Before clipping, a
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1 biomass sample of 0.60 or 0.72 m², depending on the environment, was hand-cut from all of the
2 plots. In addition to the sampling at the terminal spikelet stage, dry matter production was
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4 evaluated on different occasions during the growing cycle on samples of 0.6 m² of uprooted plants,
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6 excluding the roots. All of the biomass samples were oven-dried at 80°C for 48 hours before
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8 weighing.
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12 At physiological maturity, a sample of aboveground biomass of 0.72 m² was hand-cut from the
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14 internal rows, oven dried at 80°C for 48 hours, weighed and threshed. The harvest index (HI) was
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16 determined on these samples, and used to calculate the final biomass from the GY obtained on a
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18 plot basis with mechanical harvesting. In all of the environments and plots, the fraction of
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20 intercepted radiation (FIPAR) was measured on several occasions from emergence until the plants
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22 had yellow flag leaves. Measurements were made at noon with a tube solarimeter (Sun-Scan
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24 Canopy Analysis System SS1-UM-1.05. Delta-T Devices Ltd.; Cambridge, UK) allowing simultaneous
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26 measurements of photosynthetically active radiation above (using external sensor) and below
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28 (using a probe) the canopy. The probe was placed parallel to the soil surface at right angles to the
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30 row direction. It was positioned at ground level in the first samplings, and then subsequently
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32 positioned at increasing height from the soil in order to stay above the dead leaves. Indirect LAI
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34 measurements were obtained with this same instruments (Breda, 2003). Soil water content of the
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36 0–0.7 m layer was measured periodically with a Time Domain Reflectometer (TDR, TRASE model
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38 6050XI, Soil Moisture Equipment, Inc; Santa Barbara, CA, USA). Weather data (maximum and
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40 minimum temperatures, rainfall, solar radiation and air humidity) were recorded in meteorological
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42 stations located close to the fields.
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53 2.3. Derived measures and data analysis

54 FIPAR was calculated as the ratio between the differences of incident and transmitted to incident
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56 radiation. Cumulative radiation interception (IPAR, MJ m⁻²) was calculated as the sum of the daily
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1 values of IPAR obtained by multiplying the daily FIPAR (obtained by linear interpolation of the
2 measured data) by the daily values of solar radiation recorded at the meteorological station of
3 each experimental station. Radiation Use Efficiency (RUE, g MJ^{-1}) between clipping and anthesis
4 was calculated according to Sinclair and Muchow (1999) as the slope of the linear relationship
5 between biomass and IPAR in that period. Accordingly, transpiration efficiency (TE, $\text{g m}^{-2} \text{mm}^{-1}$)
6 was calculated as the slope of the linear relationship between biomass and amount of water
7 transpired between clipping and anthesis. The R^2 of those relationships was always greater than
8 0.91 for RUE, and greater than 0.81 for TE.
9

10 Weather data were used to calculate reference evapotranspiration (ETo) for each environment,
11 crop evaporation (E), crop transpiration (T) and soil water balance for each plot, according to the
12 dual crop coefficient method under soil water stress conditions proposed by Allen et al. (1998).
13

14 Daily FIPAR values and daily plant height data were used to take into account the effects of
15 clipping and correctly partitioning ET into E and T. The basal crop coefficient K_{cb} of Allen et al.
16 (1998) was considered equal to 0.15 for FIPAR values lower than 0.10. For FIPAR above 0.10, daily
17 K_{cb} values were calculated from the linear relationship between FIPAR and Kc assuming that the
18 tabular K_{cb} value of 1.1 for wheat (Allen et al., 1998) was reached when FIPAR was 0.98. These
19 daily K_{cb} values were then adjusted for climatic conditions and plant height (Allen et al., 1998).
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21 The degree of water limitation was quantified for each environment both before and after
22 anthesis through the ratio between the amount of water transpired (T) and the evapotranspirative
23 demand of the atmosphere (ETo): the lower the ratio, the higher the water stress.
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25 In four of the five environments TDR data were used to calibrate the soil water balance by
26 adjusting the rooting depth (Figure 1).
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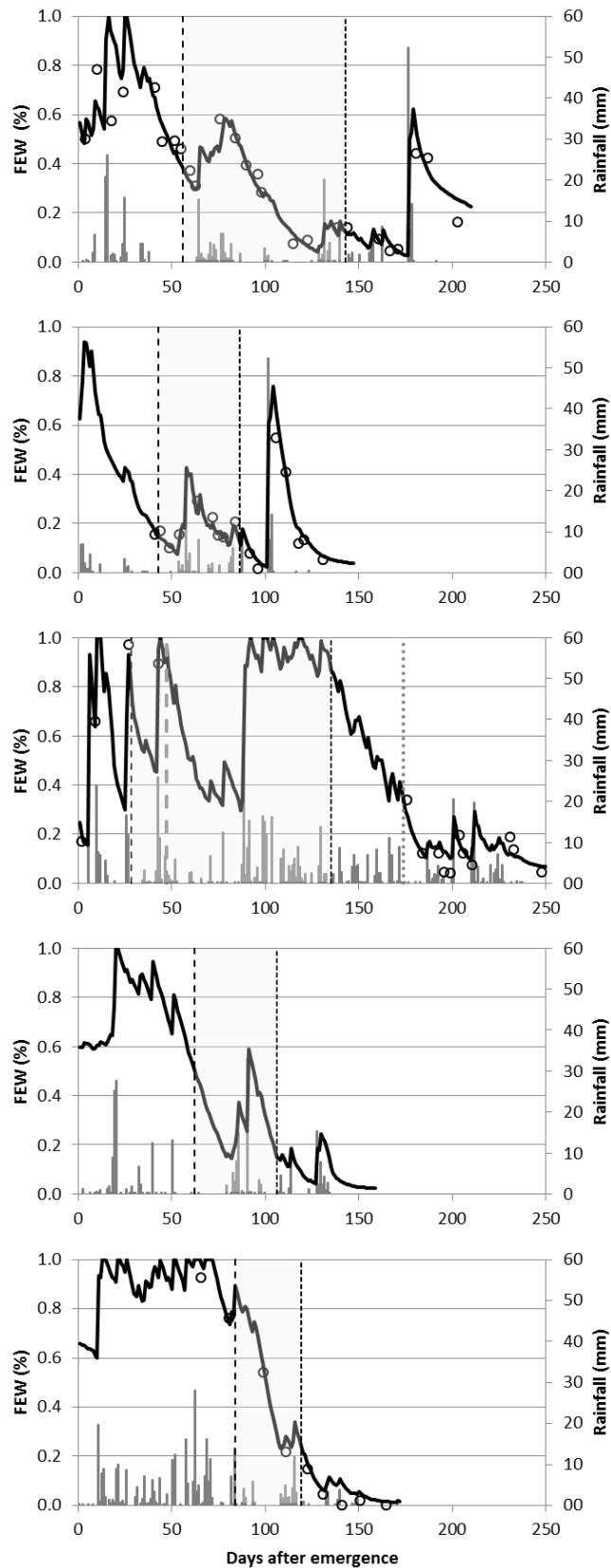


Fig. 1 Pattern of the fraction of extractable water (FEW) from emergence to maturity calculated through the soil water balance (black line) and TDR data (empty points). The grey bars represent daily rainfall, and the grey area represents the period from clipping to anthesis in the five environments (OTTOCT, OTTNOV, OTTJAN, USSDEC12 and USSDEC13 from the top to the bottom).

1 Analysis of variance (ANOVA) was performed separately for each environment. Only the main
2 effects were reported because the interactions were generally not significant. When reported,
3 means across all of the environments were compared using the Wilcoxon signed-rank non-
4 parametric test. The significance of difference between cultivars or clipping treatments in RUE and
5 TE was assessed according to Gomez and Gomez (1984). The package 'R' (R Core Team, 2014) was
6 used for the statistical analysis.
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21 **3. Results**

22 *3.1. Weather*

23 According to the long-term averages, the three Ottawa environments showed higher minimum
24 temperatures than the two Ussana environments (Table 1). The latter were also characterised by
25 higher water stress (i.e., lower T/ET_o after anthesis) compared with Ottawa. USSDEC12 was the
26 environment with the highest maximum temperatures and vapour pressure deficit (VPD) after
27 anthesis, which contributed to creation of the most stressful anthesis-maturity period as indicated
28 by the lowest T/ET_o ratio.
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41 *3.2. From emergence to clipping*

42 The main morphological differences between cultivars in this period were the growth habits,
43 which were prostrate for cultivar Bienvenu and erect for cultivar Oceania, as well as the leaf size,
44 which was larger in cultivar Oceania (39.9±1.4 cm² vs 27.9±1.5 cm² of cultivar Bienvenu). Biomass
45 at clipping ranged from less than 100 g m⁻² at OTTOCT to more than 300 g m⁻² observed for cultivar
46 Bienvenu at USSDEC13 (Table 2). On average, cultivar Bienvenu produced more biomass in this
47 period compared with cultivar Oceania (193±14 g m⁻² vs. 135 ±14 g m⁻², P=0.01), although this
48 difference was due to the superiority of the former in only two of the five environments tested.
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Table 2. Biomass production, total amount of available radiation, duration and intercepted radiation (IPAR) for the emergence-clipping period, the two cultivars and the two sowing rates in the five environments. Values are means \pm standard errors. P refers to the probability of cultivar and sowing rate effect according to the analysis of variance (ns, not significant)

<i>Environment</i>	<i>Cultivar</i>	Biomass	Available radiation	Duration	IPAR	<i>Sowing rate</i>	Biomass	Duration	IPAR
		g m^{-2}	MJ m^{-2}	days	MJ m^{-2}		g m^{-2}	days	MJ m^{-2}
OTTOCT	Bienvenu	92 \pm 12	391	47 \pm 0.0	139 \pm 6	300	68 \pm 5	38 \pm 3.3	95 \pm 12
	Oceania	74 \pm 5	263	29 \pm 0.3	78 \pm 5	600	95 \pm 11	37 \pm 3.6	117 \pm 12
	<i>P</i>	ns		<0.001	<0.001		0.009		0.002
OTTNOV	Bienvenu	194 \pm 12	473	65 \pm 0.5	216 \pm 15	300	127 \pm 19	56 \pm 4.0	162 \pm 11
	Oceania	121 \pm 14	330	47 \pm 0.0	159 \pm 7	600	188 \pm 16	56 \pm 3.3	213 \pm 16
	<i>P</i>	<0.0001		<0.001	<0.001		<0.0001		<0.001
OTTJAN	Bienvenu	125 \pm 5	678	46 \pm 0.0	146 \pm 12	300	109 \pm 11	43 \pm 1.3	116 \pm 13
	Oceania	115 \pm 13	560	40 \pm 0.0	130 \pm 12	600	128 \pm 9	43 \pm 1.2	153 \pm 8
	<i>P</i>	ns		<0.001	ns		ns		0.001
USSDEC12	Bienvenu	252 \pm 22	570	62 \pm 0.0	183 \pm 16	300	218 \pm 16	62 \pm 0.0	187 \pm 20
	Oceania	250 \pm 28	570	62 \pm 0.0	228 \pm 2	600	306 \pm 23	62 \pm 0.0	222 \pm 13
	<i>P</i>	ns		ns	ns		ns		ns
USSDEC13	Bienvenu	303 \pm 27	688	77 \pm 0.0	316 \pm 16	300	204 \pm 21	69 \pm 3.0	247 \pm 17
	Oceania	193 \pm 24	486	61 \pm 0.0	229 \pm 11	600	304 \pm 32	70 \pm 3.2	308 \pm 23
	<i>P</i>	<0.001		<0.001	<0.001		<0.001		0.002

Differences in biomass accumulation were driven by IPAR, as shown by the unique relationship calculated for the two cultivars between biomass and IPAR ($R^2=0.83^{***}$, $n=10$) that indicated a common RUE of $1.1 \pm 0.17 \text{ g MJ}^{-1}$. Therefore, the greater biomass of the cultivar Bienvenu was due to its greater IPAR, which resulted from a combination of a lower FIPAR compared with cultivar Oceania (Figure 2) but a longer duration of the emergence-clipping period. In fact, differences between cultivars in IPAR were associated with corresponding differences in the duration of the emergence-clipping period ($R^2=0.86^*$, $n=5$).

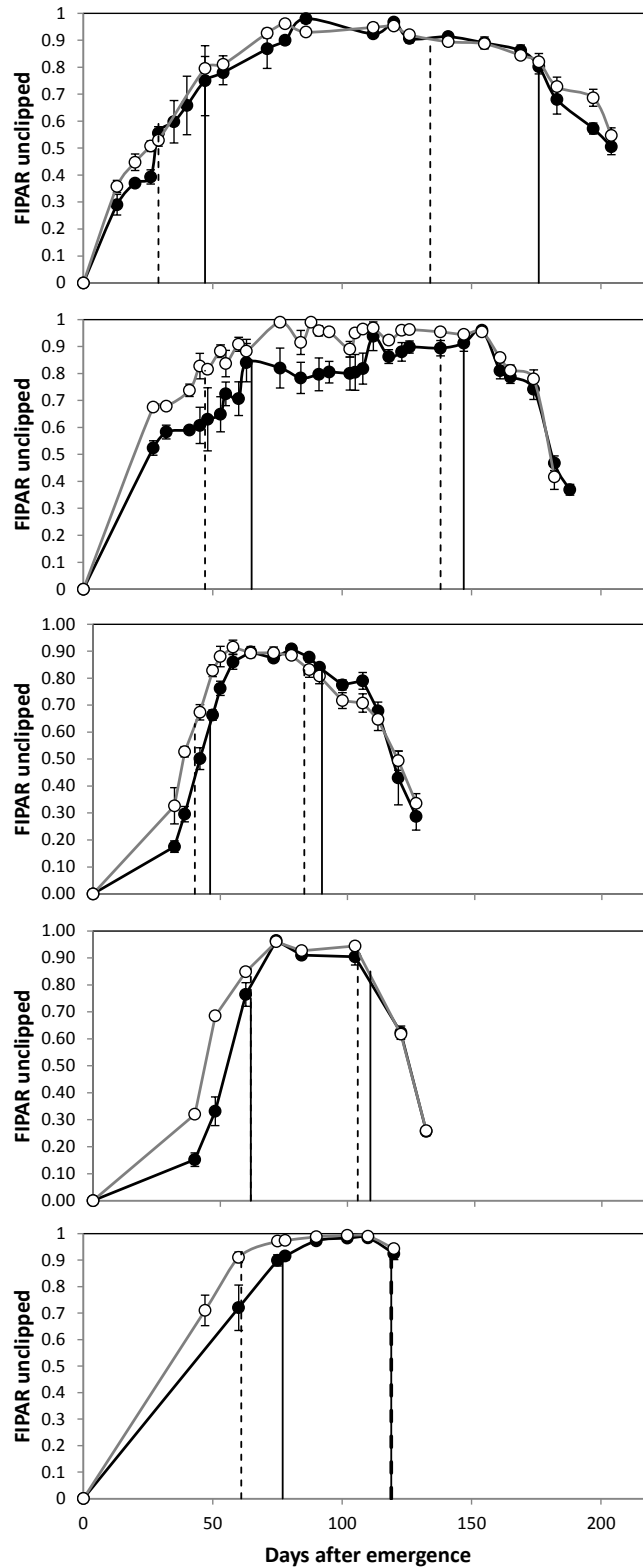


Figure 2. FIPAR patterns for the unclipped treatments in the period emergence-maturity for cultivar Bienvenu (closed symbols) and Oceania (open symbols) in the five environments (OTTOCT, OTTNOV, OTTJAN, USSDEC12 and USSDEC13 from the top to the bottom). Vertical lines, clipping and anthesis (dotted lines cultivar Oceania).

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It can be concluded that any difference in biomass between cultivars was driven by their phenology, which, in turn, resulted in a different availability of radiation (Table 2), and was not due to a difference in ability to capture radiation because of their different growth habits or leaf sizes. The higher sowing density produced, on average, 40% more biomass than the lower sowing density, and the difference was significant in three of the five environments (Table 2). A greater IPAR was the reason for the superiority of the '600' treatment over the '300' one.

3.3. From clipping to anthesis

ANOVA did not show any significant 'clipping x cultivar' interaction for the traits analysed. The lack of any interaction is also shown in Figure 3 where, in spite of their different habitus and phenology, both cultivars showed the same pattern of recovery in FIPAR after clipping. Therefore, cultivar and clipping effects were analysed separately. Figure 3 also shows that FIPAR recovery was almost complete, ranging from a minimum of 90% to 100% despite the short period available in some of the environments. On average, clipped crops intercepted less radiation than unclipped ones for 44% of the clipping-anthesis period. Both cultivars had an erect growth habit between clipping and anthesis, but cultivar differences in single leaf area were still large. In this period, cultivar Oceania had a leaf area of $31.9 \pm 1.7 \text{ cm}^2$, whereas the area of a Bienvenu leaf was $22.6 \pm 1.3 \text{ cm}^2$ on average. On average, no difference was detected between the spring (834 g m^{-2}) and intermediate cultivar (906 g m^{-2}) in the biomass produced between clipping and anthesis. This result masked the interaction between cultivars and environments, because cultivar Bienvenu produced more biomass than cultivar Oceania at OTTJAN and OTTOCT, but the opposite was true at OTTNOV and USSDEC13 (Table 3).

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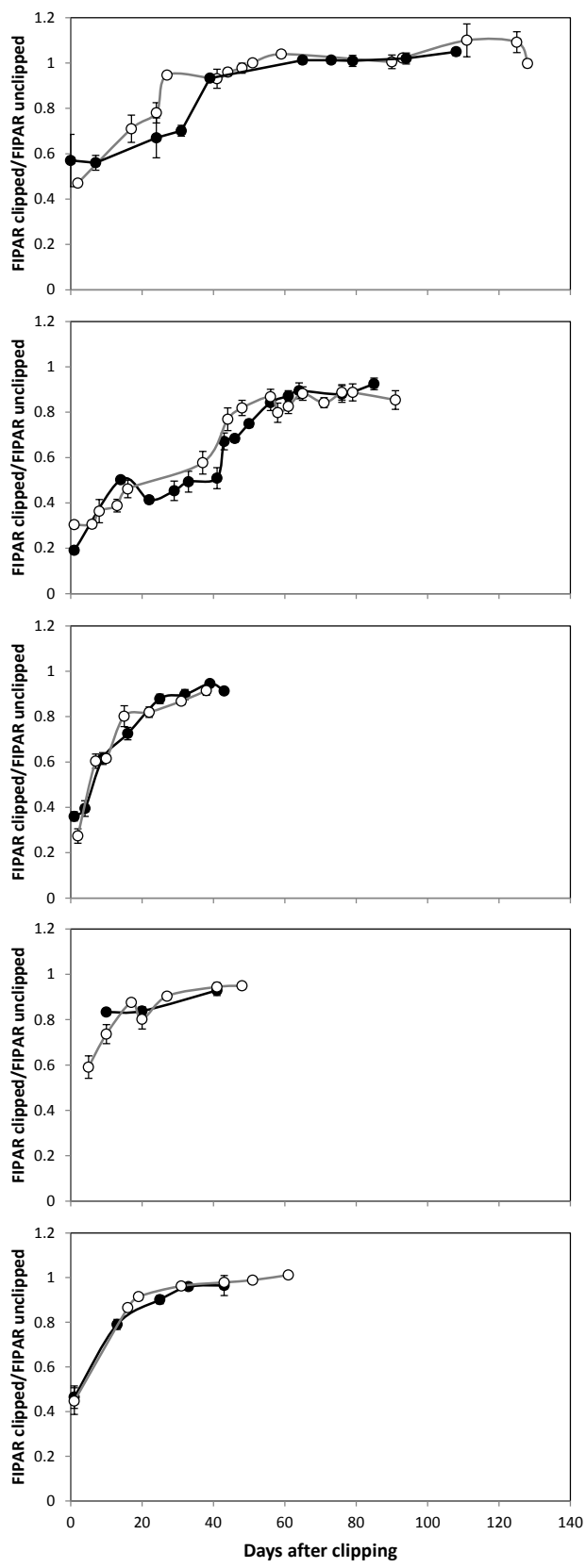


Figure 3. Recovery of FIPAR in the period clipping-anthesis for cultivars Bienvenu (closed symbols) and Oceania (open symbols) in the five environments (OTTOCT, OTTNOV, OTTJAN, USSDEC12 and USSDEC13 from the top to the bottom).

Table 3. Biomass production, total amount of available radiation, duration, intercepted radiation (IPAR) and radiation use efficiency (RUE), transpiration (T) and evaporation (E), for the clipping-anthesis period and the two cultivars in the five environments. Values are means \pm standard errors. P refers to the probability of cultivar effect according to analysis of variance (ns, not significant)

Environment	Cultivar	Biomass g m ⁻²	Available radiation MJ m ⁻²	Duration days	IPAR MJ m ⁻²	RUE g MJ ⁻¹	T mm	E mm	Transpiration efficiency g m ⁻² mm ⁻¹
OTTOCT	Bienvenu	1290 \pm 35	1185	127 \pm 1.4	1018 \pm 15	1.26 \pm 0.08	311 \pm 11	36 \pm 5	4.1 \pm 0.2
	Oceania	998 \pm 45	791	106 \pm 0.8	680 \pm 6	1.42 \pm 0.04	222 \pm 9	29 \pm 2	4.3 \pm 0.2
	P	<0.001		<0.001	<0.001	ns	<0.001	ns	ns
OTTNOV	Bienvenu	793 \pm 78	1287	83 \pm 1.4	848 \pm 58	0.95 \pm 0.04	111 \pm 9	35 \pm 10	6.7 \pm 0.5
	Oceania	991 \pm 60	1148	91 \pm 0.3	949 \pm 35	1.08 \pm 0.08	128 \pm 10	17 \pm 8	7.4 \pm 0.7
	P	0.0020		<0.001	<0.001	ns	<0.001	<0.001	ns
OTTJAN	Bienvenu	775 \pm 11	1207	44 \pm 0.0	668 \pm 10	1.17 \pm 0.05	93 \pm 7	14 \pm 3	8.2 \pm 0.4
	Oceania	689 \pm 11	1169	43 \pm 0.0	632 \pm 14	1.07 \pm 0.06	65 \pm 4	11 \pm 2	10.0 \pm 0.6
	P	0.0160		ns	ns	ns	<0.001	<0.001	0.0160
USSDEC12	Bienvenu	716 \pm 28	859	47 \pm 0.0	665 \pm 13	1.06 \pm 0.05	109 \pm 1	9 \pm 2	6.5 \pm 0.5
	Oceania	738 \pm 44	761	42 \pm 0.0	605 \pm 58	1.11 \pm 0.14	109 \pm 5	7 \pm 2	6.7 \pm 0.3
	P	ns		<0.001	0.0120	ns	ns	0.0230	ns
USSDEC13	Bienvenu	628 \pm 33	720	42 \pm 0.0	639 \pm 10	1.00 \pm 0.08	116 \pm 3	7 \pm 3	5.4 \pm 0.5
	Oceania	924 \pm 39	916	58 \pm 0.0	844 \pm 5	1.07 \pm 0.06	165 \pm 3	10 \pm 4	5.6 \pm 0.4
	P	<0.001		<0.001	<0.001	ns	<0.001	0.0100	ns

RUE was not the underlying reason for this interaction because no difference in RUE was observed between the two cultivars in the five environments. Thus, the observed differences in biomass between cultivars must have derived from the corresponding differences in IPAR, as demonstrated by the analysis of regression ($R^2=0.86^*$, $n=5$). Figure 2 highlights that cultivar differences in IPAR were not derived from different abilities to intercept radiation in any of the environments, except in relation to OTTNOV. In this case, the higher FIPAR of cultivar Oceania compensated for the less radiation available, thereby resulting in a greater IPAR compared with cultivar Bienvenu. The higher FIPAR of cultivar Oceania of the OTTNOV environment was derived from the sensibly higher LAI of this cultivar (Figure 4), which reached a maximum of more than 6, compared with approximately 5 in the cultivar Bienvenu.

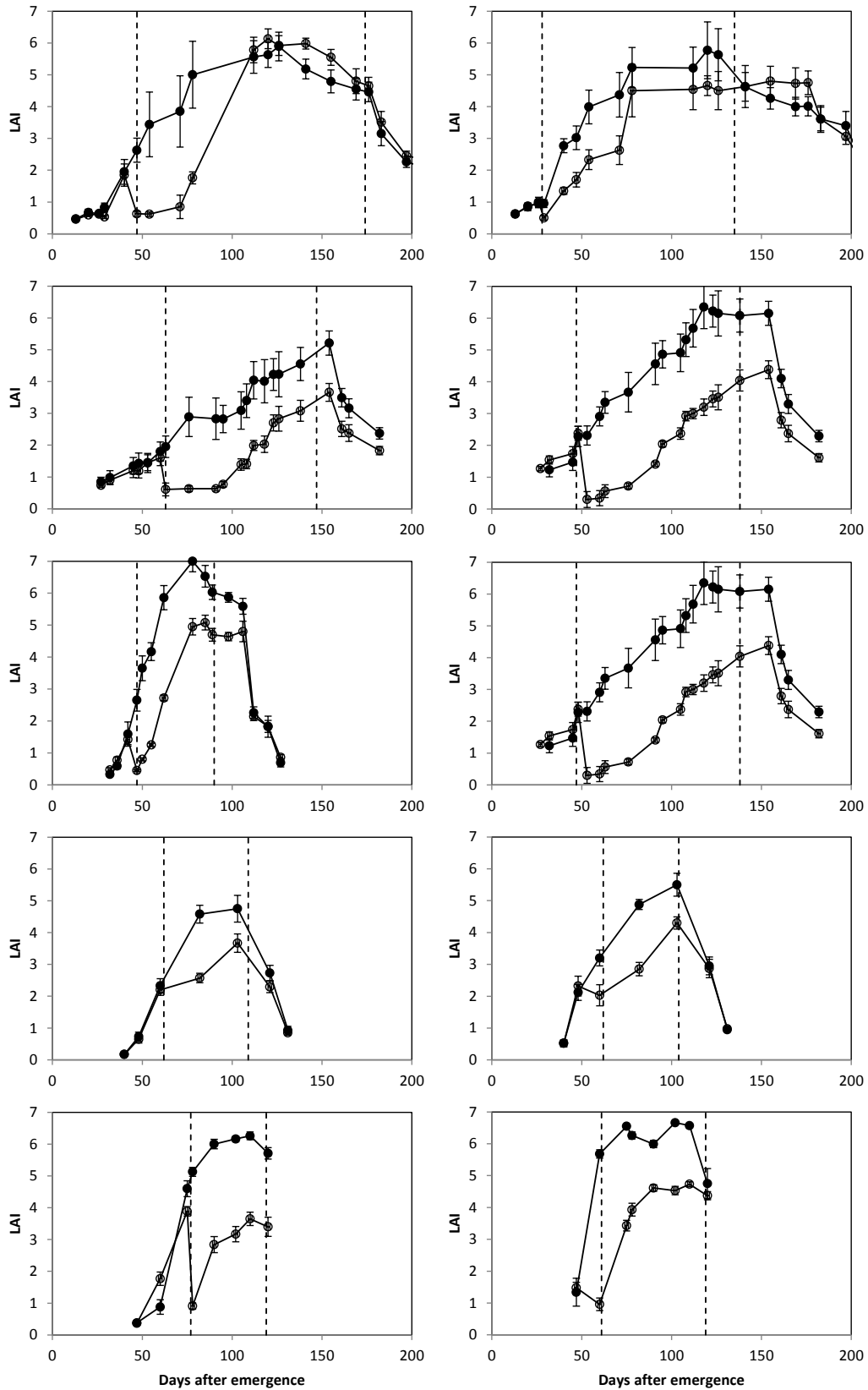


Figure 4. LAI pattern during the growing cycle for cultivar Bienvenu (on the left) and Oceania (on the right) in the five environments (OTTOCT, OTTNOV, OTTJAN, USSDEC12 and USSDEC13 from the top to the bottom). Closed symbols, unclipped treatment; empty symbols, clipped treatment. Vertical lines, clipping and anthesis.

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2 What differed between cultivars was the amount of radiation available as a consequence of a
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4 combination of different clipping-anthesis period durations and the different 'positioning' of these
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6 time periods within the year, particularly in the earliest sowing period in OTTOCT. In this
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8 environment, 1185 MJ m⁻² were available to cultivar Bienvenu across 127 days and only 791 MJ m⁻²
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10 were available to cultivar Oceania across 106 days. Therefore, a strong relationship was
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12 calculated between the difference between the two cultivars in IPAR and in the duration of the
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14 clipping-anthesis period ($R^2 = 0.99^{***}$, n=5). As in the previous emergence-clipping period, the
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16 different amount of biomass produced and IPAR by the spring and intermediate cultivars was a
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18 consequence of the different availability of radiation derived from their different phenology.
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20 E represented 6–24% of ET, with the highest proportion in OTTNOV due to the high frequency of
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22 rainfall immediately after clipping. Differences between cultivars in T were particularly marked in
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24 those environments where the greatest differences in duration of the clipping-anthesis period
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26 were observed. Therefore a positive relationship was calculated between cultivar differences in T
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28 and cultivar differences in the duration of the clipping-anthesis period ($R^2 = 0.90^*$, n = 5) and in
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30 IPAR ($R^2 = 0.94^{**}$, n=5). Clipping reduced the biomass produced between clipping and anthesis
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32 compared with the unclipped treatment across all of the environments, with the exception of
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34 OTTOCT (Table 4). In this environment, the longer clipping-anthesis period duration combined
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36 with the rapid and complete recovery of radiation interception (Figure 3) translated into a higher
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38 IPAR for the clipped treatment than the IPAR for the unclipped one. The very low biomass at
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40 clipping in the OTTOCT environment (Table 2) probably contributed to this pattern of interception
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42 recovery. In all of the other environments, the lower biomass of the clipped plots was derived
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44 from a lower IPAR, although the RUE was also lower in the clipped treatments in two of the
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46 environments (OTTNOV and OTTOCT).
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Table 4. Biomass production, duration, radiation intercepted (IPAR) and radiation use efficiency (RUE), transpiration (T), evaporation (E) and transpiration efficiency (TE) for the clipping-anthesis period and the two clipping treatments in the five environments. Values are means \pm standard errors. P refers to the probability of clipping effect according to analysis of variance (ns, not significant)

Environment	Clipping treatment	Biomass g m ⁻²	Duration days	IPAR MJ m ⁻²	RUE g MJ ⁻¹	T mm	E mm	Transpiration efficiency g m ⁻² mm ⁻¹
OTTOCT	Unclipped	1191 \pm 41	112 \pm 2.5	813 \pm 19	1.42 \pm 0.04	274 \pm 29	27 \pm 1	4.3 \pm 0.1
	Clipped	1084 \pm 35	119 \pm 3.1	864 \pm 9	1.16 \pm 0.07	259 \pm 25	38 \pm 4	3.8 \pm 0.2
	P	ns	<0.001	0.0060	0.0020	<0.001	0.0020	ns
OTTNOV	Unclipped	1081 \pm 80	84 \pm 1.8	1033 \pm 32	1.06 \pm 0.05	134 \pm 7	12 \pm 6	7.5 \pm 0.5
	Clipped	732 \pm 61	90 \pm 0.6	780 \pm 40	0.89 \pm 0.05	104 \pm 6	40 \pm 6	5.8 \pm 0.7
	P	<0.001	ns	<0.001	0.0120	<0.001	<0.001	0.0500
OTTJAN	Unclipped	848 \pm 8	43 \pm 0.1	744 \pm 18	1.11 \pm 0.06	88 \pm 10	8 \pm 1	8.6 \pm 0.5
	Clipped	621 \pm 8	43 \pm 0.1	553 \pm 16	1.13 \pm 0.05	70 \pm 7	17 \pm 2	8.3 \pm 0.7
	P	<0.001	ns	<0.001	ns	<0.001	<0.001	ns
USSDEC12	Unclipped	850 \pm 32	46 \pm 0.7	720 \pm 16	1.14 \pm 0.09	106 \pm 3	5 \pm 1	7.7 \pm 0.6
	Clipped	638 \pm 31	45 \pm 0.7	579 \pm 22	1.03 \pm 0.09	113 \pm 3	11 \pm 1	5.1 \pm 0.5
	P	<0.001	ns	<0.001	ns	<0.001	<0.001	0.004
USSDEC13	Unclipped	839 \pm 39	49 \pm 2.1	787 \pm 2	1.07 \pm 0.08	141 \pm 12	4 \pm 1	6.1 \pm 0.4
	Clipped	620 \pm 55	46 \pm 2.3	624 \pm 24	0.95 \pm 0.05	140 \pm 17	14 \pm 1	4.6 \pm 0.3
	P	<0.001	ns	<0.001	ns	ns	<0.001	0.008

In these environments, the lower RUE of the clipped treatments was associated with a lower leaf nitrogen content and SPAD index (Table 5).

Table 5. Leaf nitrogen status and SPAD Index for the clipping-anthesis period and the two clipping treatments in the two environments where RUE was affected by clipping. Values are means \pm standard errors. P refers to the probability of a clipping effect according to analysis of variance (ns, not significant).

Environment	Clipping treatment	Days after emergence	Leaf nitrogen			SPAD	
			(%)	(mg leaf ⁻¹)	(g m ⁻² leaf)		
OTTOCT	Unclipped	82	3.94 \pm 0.06	7.94 \pm 0.66	2.20 \pm 0.08	46 \pm 0.5	
OTTOCT	Clipped	82	3.86 \pm 0.07	6.98 \pm 1.41	2.16 \pm 0.09	45 \pm 0.5	
	P		ns	<0.001	ns	0.04	
	Unclipped	112	4.22 \pm 0.11	7.95 \pm 1.14	2.71 \pm 0.11	49 \pm 0.3	
	Clipped	112	4.32 \pm 0.13	6.54 \pm 1.61	2.56 \pm 0.14	47 \pm 0.3	
	P		0.03	0.01	ns	0.01	
OTTNOV	Unclipped	109	3.15 \pm 0.09	4.79 \pm 0.65	2.12 \pm 0.17	42 \pm 0.4	
OTTNOV	Clipped	109	2.80 \pm 0.04	3.70 \pm 0.50	1.97 \pm 0.02	39 \pm 0.4	
	P		<0.001	<0.001	0.02	<0.001	

It is likely that the longer duration of the clipping-anthesis period in these environments, coupled with the lack of any fertilisation following clipping, compromised the recovery of an adequate leaf

1 nitrogen status after clipping. As expected, clipping increased the amount of water lost by
2 evaporation from the soil surface and decreased the amount of water transpired in all Ottawa
3 environments. Clipping negatively affected TE in three environments because of the notable
4 decrease in biomass production induced by clipping, with the T of the clipped treatments being
5 lower or similar to that of the unclipped treatment. In the three environments where this greater
6 effect of clipping on biomass production than on T was observed, the maximum LAI of the clipped
7 treatments was around 4 compared with the higher maximum values observed in the other two
8 environments (Figure 4). No interaction between clipping and sowing rate was detected by
9 ANOVA, meaning a similar pattern and entity of leaf area recovery occurred at the two sowing
10 rates. The effect of sowing rate on the biomass produced and water used between clipping and
11 anthesis were negligible or absent given a maximum difference between sowing rate treatments
12 of 0.5 LAI units (data not shown).

3.4. GY and HI

32 The OTTOCT environment is omitted from this section because the very low temperatures around
33 the anthesis of cultivar Oceania caused an almost complete sterility of the spike and compromised
34 GY production. The intermediate cultivar Bienvenu produced a greater GY than the spring cultivar
35 Oceania at OTTJAN (Table 6), whereas cultivar Oceania was more productive at USSDEC12, the
36 most stressful environment in the post-anthesis period in terms of both T/ETo (0.15) and
37 maximum temperatures (28 °C) (Table 1). In the case of Bienvenu, the greater GY at OTTJAN was
38 derived from its greater biomass at maturity, despite its lower HI. In contrast, at USSDEC12,
39 cultivar Oceania showed a greater GY derived from a combination of both a greater biomass and a
40 greater HI. It is likely that the earlier anthesis of cultivar Oceania represented a great advantage in
41 this environment, characterised by severe water stress in the post-anthesis period, resulting in its
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higher HI. Cultivar ranking in biomass was not altered when the biomass clipped at terminal spikelet was added to the final biomass.

Table 6. Grain yield (GY) and HI, biomass at anthesis and at maturity (with and without the forage removed with clipping), and IPAR after anthesis for the two cultivars in the five environments. Values are means \pm standard errors. P refers to the probability of cultivar effect according to the ANOVA (ns, not significant)

Environment	Cultivar	GY g m ⁻²	Biomass at maturity g m ⁻²	HI	Total biomass (clipped included) g m ⁻²	Biomass at anthesis g m ⁻²	IPAR after anthesis MJ m ⁻²
OTTNOV	Bienvenu	734 \pm 80	2038 \pm 212	0.36 \pm 0.01	2116 \pm 186	1009 \pm 113	715 \pm 37
	Oceania	731 \pm 83	2009 \pm 242	0.37 \pm 0.02	2060 \pm 233	1111 \pm 171	816 \pm 32
	<i>P</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<0.001
OTTJAN	Bienvenu	764 \pm 55	1972 \pm 123	0.37 \pm 0.01	2051 \pm 86	895 \pm 78	697 \pm 20
	Oceania	678 \pm 42	1759 \pm 90	0.39 \pm 0.01	1852 \pm 70	801 \pm 56	745 \pm 28
	<i>P</i>	0.004	<0.001	0.043	0.005	0.015	<i>ns</i>
USSDEC12	Bienvenu	270 \pm 5	1173 \pm 72	0.24 \pm 0.01	1350 \pm 39	952 \pm 54	361 \pm 11
	Oceania	357 \pm 10	1296 \pm 65	0.28 \pm 0.01	1536 \pm 36	952 \pm 55	459 \pm 7
	<i>P</i>	<0.001	0.015	0.004	0.002	<i>ns</i>	<0.001
USSDEC13	Bienvenu	581 \pm 34	1912 \pm 131	0.30 \pm 0.01	2039 \pm 70	968 \pm 78	612 \pm 12
	Oceania	597 \pm 42	2132 \pm 41	0.30 \pm 0.01	2201 \pm 30	1060 \pm 68	696 \pm 19
	<i>P</i>	<i>ns</i>	0.013	<i>ns</i>	<i>ns</i>	<i>ns</i>	<0.001

Clipping negatively affected biomass at both anthesis and maturity in all of the environments, although no effect of clipping on biomass at maturity was detected in the two Ussana environments if the clipped forage was added to the final biomass (Table 7). Despite the generally remarkable effect of clipping on final biomass, GY was only reduced by clipping at OTTJAN and OTTNOV (i.e., environments where there was lower water stress post-anthesis) (Table 1), which was accompanied by a higher HI. In fact, these were the only environments where the unclipped treatments intercepted more radiation and produced more biomass post-anthesis compared with the clipped ones (data not shown). In contrast, the lower biomass of the clipped treatments was advantageous in the two environments – USSDEC12 and USSDEC13 – with the most severe water stress occurring after anthesis ($T/ET_o < 0.18$). In these conditions, clipped treatments intercepted the same amount of radiation and produced the same amount of biomass compared with

unclipped ones after anthesis, and thus compensated for their lower biomass at maturity with a higher HI.

Table 7. Grain yield (GY) and HI, biomass at anthesis and at maturity (with and without the forage removed with clipping), and IPAR after anthesis for the two clipping treatments in the five environments. Values are means \pm standard errors. P refers to the probability of clipping effect according to the ANOVA (ns, not significant)

Environment	Clipping treatment	GY g m ⁻²	Biomass at maturity g m ⁻²	HI	Total biomass (clipped included) g m ⁻²	Biomass at anthesis g m ⁻²	IPAR after anthesis MJ m ⁻²
OTTNOV	Unclipped	849 \pm 26	2323 \pm 113	0.37 \pm 0.01	2376 \pm 112	1267 \pm 116	862 \pm 37
	Clipped	589 \pm 15	1656 \pm 97	0.36 \pm 0.02	1803 \pm 125	883 \pm 56	666 \pm 32
	<i>P</i>	<0.001	<0.001	<i>ns</i>	<0.001	<0.001	<0.001
OTTJAN	Unclipped	787 \pm 29	2029 \pm 105	0.39 \pm 0.01	2043 \pm 124	950 \pm 49	749 \pm 20
	Clipped	624 \pm 9	1699 \pm 38	0.37 \pm 0.00	1844 \pm 52	739 \pm 21	690 \pm 28
	<i>P</i>	<0.001	<0.001	0.005	0.001	<0.001	0.041
USSDEC12	Unclipped	323 \pm 33	1328 \pm 67	0.25 \pm 0.02	1387 \pm 85	1036 \pm 10	398 \pm 11
	Clipped	311 \pm 24	1172 \pm 59	0.27 \pm 0.01	1407 \pm 80	890 \pm 9	412 \pm 7
	<i>P</i>	<i>ns</i>	<0.001	0.040	<i>ns</i>	<0.001	<i>ns</i>
USSDEC13	Unclipped	622 \pm 28	2110 \pm 52	0.29 \pm 0.01	2108 \pm 52	1110 \pm 18	664 \pm 12
	Clipped	533 \pm 8	1812 \pm 148	0.31 \pm 0.01	2082 \pm 115	858 \pm 40	610 \pm 19
	<i>P</i>	<i>ns</i>	0.005	<i>ns</i>	<i>ns</i>	<0.001	<i>ns</i>

No sowing rate effect on GY was observed, as a result of the opposite direction of the differences in biomass at maturity and HI (Table 8). Biomass production was penalized by the higher sowing rate in the environment with the highest water stress in post-anthesis. No effect of sowing rate was observed on the biomass at anthesis.

Table 8. Grain yield (GY) and HI, biomass at anthesis and at maturity (with and without the forage removed with clipping), and IPAR after anthesis for the two sowing rate treatments in the five environments. Values are means \pm standard errors. P refers to the probability of clipping effect according to the ANOVA (ns, not significant)

Environment	Clipping treatment	GY g m ⁻²	Biomass at maturity g m ⁻²	HI	Total biomass (clipped included) g m ⁻²	Biomass at anthesis g m ⁻²	IPAR after anthesis MJ m ⁻²
OTTNOV	300	710 \pm 42	1870 \pm 106	0.38 \pm 0.01	1909 \pm 112	1024 \pm 74	776 \pm 40
	600	756 \pm 46	2189 \pm 119	0.34 \pm 0.01	2273 \pm 117	1091 \pm 102	767 \pm 34
	<i>P</i>	<i>ns</i>	<0.001	0.003	<0.001	<i>ns</i>	<i>ns</i>
OTTJAN	300	708 \pm 26	1847 \pm 65	0.38 \pm 0.01	1926 \pm 75	874 \pm 41	696 \pm 22
	600	708 \pm 27	1892 \pm 71	0.37 \pm 0.01	1967 \pm 68	819 \pm 36	745 \pm 25
	<i>P</i>	<i>ns</i>	<0.001	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>
USSDEC12	300	315 \pm 16	1306 \pm 41	0.25 \pm 0.01	1423 \pm 34	966 \pm 32	405 \pm 16
	600	318 \pm 15	1161 \pm 44	0.28 \pm 0.01	1283 \pm 82	936 \pm 36	409 \pm 20
	<i>P</i>	<i>ns</i>	0.002	0.020	<i>ns</i>	<i>ns</i>	<i>ns</i>
USSDEC13	300	609 \pm 42	2005 \pm 102	0.31 \pm 0.01	2090 \pm 83	987 \pm 46	647 \pm 17
	600	562 \pm 32	1976 \pm 95	0.29 \pm 0.01	2105 \pm 82	1026 \pm 80	638 \pm 21
	<i>P</i>	<i>ns</i>	<i>ns</i>	0.050	<i>ns</i>	<i>ns</i>	<i>ns</i>

4. Discussion

Clipping was used in place of grazing because, the type or rate of defoliation has generally only minor effects on GY of dual-purpose cereal crops (Harrison et al. (2011) and papers cited therein), and clipping is highly comparable with the grazing of sheep (Francia et al., 2006; Dann et al., 1983). The wide variation in environmental conditions and in the length of the growing season created by the interaction of cultivar, year and the large range in sowing dates, generated very different LAI patterns. This allowed to better understand the impact of clipping on the processes of LAI recovery and on the capture and use of radiation and water, as well as on biomass partitioning.

Irrespective of the environment, of the short time available, and of their higher phyllochron (Giunta et al., 2015), clipped crops were able to make a complete recovery of radiation interception, in terms of FIPAR, before anthesis. This was partly due to the lack of clipping effects on the number of leaves left to emerge after anthesis (Giunta et al., 2015), given the strong

1 relationship between leaf number and LAI (Lawless et al., 2005). Nevertheless, the period with
2 reduced leaf area following clipping was mirrored by a severe reduction in IPAR, and consequently,
3 of biomass at anthesis. In some environments, the lower RUE between clipping and anthesis
4 contributed to this lower biomass at anthesis, in contrast to the observations reported by Harrison
5 et al. (2011c) on winter wheat. The lower RUE was probably due to the lower leaf nitrogen levels
6 of clipped crops, consistent with what has been proposed by Lawlor (2001) and Hay and Porter
7 (2006) on the base of the relationship between Rubisco and leaf nitrogen levels and the sensitivity
8 of carbon assimilation rate to Rubisco under light saturated conditions. The impossibility of
9 translocating the nitrogen assimilated before clipping during leaf area recovery likely makes
10 clipped crops more dependent on soil nitrogen availability. It is worth mentioning that Harrison et
11 al. (2011b) considered the RUE of the entire emergence-anthesis period, and that the soil nitrogen
12 availability in their experiments was likely superior to ours. This indicates that a decrease in RUE
13 can be avoided by a proper fertilisation. Hence, the lower nitrogen level of clipped crops could
14 have reduced any positive effect of clipping on RUE, which could have eventually been derived
15 from a better light distribution (Singer et al., 2007).

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As expected, clipping caused an increase in E and a decrease in T in most environments in the
recovery period, with contrasting but quantitatively small effects on ET, in accordance with the
results reported by Harrison et al. (2011c) and Bonachela et al., (1992b). TE between clipping and
anthesis decreased with clipping in most environments, signalling a greater impact of decreased
leaf area on biomass production than on ET. The LAI lower than 4 observed in the clipped crops
with a lower TE supports the suggestion made by Ritchie (1983) (i.e., that ET is nearly maximised
at LAIs approaching 3, whereas absorbed radiation continues to increase with LAIs exceeding 4 to
5). That is why the two processes of ET and photosynthesis, although both largely governed by
absorbed radiation, respond in quantitatively different ways to its availability. Therefore, it seems

1 that in our environments, the decrease in TE was not the result of an increase in E, as proposed by
2 Harrison et al. (2011c), but rather, of the drastic reduction in leaf area and biomass production
3 following clipping, according to Bonachela et al. (1995b).
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7 The lower biomass at anthesis of clipped crops can sometimes result in a lower GY, depending on
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9 the environmental conditions after anthesis, as observed by Bonachela et al. (1995a). The
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11 direction of change in GY was the same as that in HI, which was mainly determined by the post-
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13 anthesis conditions (Harrison et al., 2011a). GY was not reduced by clipping when the drought
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15 after anthesis was severe enough to increase HI to increase in the clipped crops. Severe drought
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17 (T/ETo lower than 0.18), while reducing the average HI compared with environments with more
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19 favourable post-anthesis conditions, was more penalizing for the unclipped crops as a
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21 consequence of their larger LAI and biomass. Giunta et al., (1995) demonstrated that, in these
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23 same environments, LAI values at anthesis of around 5–6 cause faster depletion of soil water
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25 compared with values of around 3–4. The consequent levelling-off of differences in LAI between
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27 clipped and unclipped treatments lead to similar IPAR and biomass after anthesis, finally resulting
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29 in a greater HI of clipped crops and similar GYs. Thus, in contrast to what was proposed by
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31 Harrison et al. (2011c), the greater susceptibility to water stress of unclipped crops was not
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33 mediated by a lower RUE in this period, but rather by a decrease in IPAR. The entity of the
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35 observed reductions in GY in the environments with more favourable post-anthesis conditions
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37 (i.e., 21% at OTTJAN and 31% at OTTNOV) are of the same order of magnitude as those reported
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39 by Royo and Tribò, (1997) and Royo and Pares (1996) for triticales grown in Mediterranean
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41 environments.
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54 In addition to current assimilation in the post-anthesis period, the variation in dry matter
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56 partitioning and in HI due to grazing could also result from a reduced amount of shoot dry matter
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58 available for retranslocation (Royo and Romagosa, 1996). We did not measure retranslocation, but
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1 when we estimated it according to Santiveri et al. (2004) (data not shown), we found that, in our
2 experiments, the contribution of retranslocation to GY was generally absent or very low. Therefore
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4 IPAR after anthesis confirms its key role in determining the effects of grazing on partitioning and
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6 on GY variation.
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10 Our results demonstrated the net prevalence of developmental differences over morphological
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12 ones throughout the entire growing season in establishing cultivar differences in biomass
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14 production. In other words, the availability of radiation as determined by the duration of
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16 interception has a greater impact than the ability to capture radiation as determined by
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18 morphological traits. Cultivar differences in duration were clear before terminal spikelet and led to
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20 general superiority of the intermediate cultivar in terms of biomass production. Both winter
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22 forage yield and cultivar differences were highly variable in this period depending on the
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24 environment, as also observed by Bonachela et al. (1995). The duration of the subsequent
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26 clipping-anthesis period was not always greater in the intermediate cultivar, which was also a
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28 consequence of the 'convergence' phenomenon (Hay and Kirby, 1991). Therefore, the amount of
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30 IPAR and of biomass produced in this period was clearly not determined by the spring or
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32 intermediate habitus.
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41 Morphological differences between cultivars **in leaf size and growth habits** were also irrelevant in
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43 determining their ability to recuperate IPAR after clipping. The relatively high sowing density
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45 adopted in this experiment might have contributed to this lack of difference, but usually
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47 morphological differences between spring and winter cultivars decline after clipping, in part
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49 because winter triticales display a higher tillering rate before terminal spikelet, but a higher tiller
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51 mortality than spring cultivars after terminal spikelet (Royo, 1997). The greater winter forage
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53 production of the intermediate cultivar was not related to GY reductions due to clipping, but the
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55 intermediate cultivar was penalised in terms of GY in the environments with the most severe
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1 terminal water stress. The greater susceptibility of late flowering cultivars to terminal water stress
2 is well documented in triticals and small grain cereals in general (Royo, 1996 and 1997). Sowing
3 rate was only relevant in the pre-clipping period, when the higher rate translated into more
4 biomass at clipping, in accordance with the results of Harrison et al. (2011a). The LAI of the lower
5 rate was high enough to avoid any substantial advantage of the higher rate during the recovery
6 period, but at the same time, it was not so high as to be detrimental after anthesis. Accordingly,
7 Giunta and Motzo (2004) did not find any effect of sowing density (300 vs. 700 plants m⁻²) on
8 biomass or GY of triticals grown in the same type of Mediterranean environment.
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28 **5. Conclusions**

29 Dual-purpose triticale can be a convenient management option in Mediterranean environments
30 that are subjected to severe terminal water stress ($T/ET_o < 0.18$), at least in the environments
31 evaluated in this study. Under these conditions, GY is not affected, but a variable amount of winter
32 forage may be obtained. The amount of IPAR was the main cause of the observed differences in
33 biomass, whether due to cultivar, clipping or sowing rate. In addition, differences in GY were
34 linked to the amount of IPAR after anthesis, regardless of biomass at anthesis. Clipping
35 differentially affected biomass production and ET in environments that **did not allow** the triticale
36 crops to reach LAI values greater than 3–4. The most important cultivar trait that should be taken
37 into account for dual-purpose utilisation is phenology, as it influences both winter forage yield and
38 GY. However, GY is affected by biomass partitioning more than by differences in leaf area recovery
39 after clipping.
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References

- Allen R. G., Pereira L. S., Raes D., Smith M. (1998) *FAO Irrigation & Drainage paper 56*.
- Bonachela S., Orgaz F., Fereres E. (1995a) Winter cereals grown for grain and for the dual purpose of forage plus grain I Production. *Field Crops Research*, 44, 1-11.
- Bonachela S., Orgaz F., Fereres E. (1995b) Winter Cereals Grown for Grain and for the Dual-Purpose of Forage Plus Grain .2. Water-Use and Water-Use Efficiency. *Field Crops Research*, 44, 13-24.
- Bonnett O. T. (1936) The development of the wheat spike. *Journal of Agricultural Research*, 53, 445-451.
- Dann P.R., Axelsen A., Dear B.S., Williams E.R., Edwards C.B.H. (1983). *Herbage, grain and animal production from winter grazed cereal crops. Australian Journal of Experimental Agriculture and Animal Husbandry*, 23, 154-161.

1 Francia E., Pecchioni N., Nicosia O. L. D., Paoletta G., Taibi L., Franco V., Odoardi M., Stanca A. M.,
2 Delogu G. (2006) Dual-purpose barley and oat in a Mediterranean environment. *Field Crops*
3 *Research*, 99, 158-166.
4
5

6
7 Giunta F., Motzo R. (2004) Sowing rate and cultivar affect total biomass and grain yield of spring
8 triticale (*×Triticosecale* Wittmack) grown in a Mediterranean-type environment. *Field Crops*
9 *Research*, 87, 179-193.
10

11
12
13
14
15
16 Giunta F., Cabiglieri A., Viridis A., Motzo R. (2015) Dual-purpose use affects phenology of triticale.
17 *Field Crops Research*, 183, 111-116.
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60
61
62
63
64
65

Giunta F., Motzo R., Deidda M. (1995) Effects of Drought on Leaf-Area Development, Biomass
Production and Nitrogen Uptake of Durum-Wheat Grown in a Mediterranean Environment.
Australian Journal of Agricultural Research, 46, 99-111.

Gomez K.A., Gomez A.A. (1984) *Statistical procedures for agricultural research*. 2nd edition. J.
Wiley and Sons, New York, 678 pp.

Harrison M. T., Evans J. R., Dove H., Moore A. D. (2011a) Dual-purpose cereals: can the relative
influences of management and environment on crop recovery and grain yield be dissected? *Crop*
& *Pasture Science*, 62, 930-946.

Harrison M. T., Evans J. R., Dove H., Moore A. D. (2011b) Recovery dynamics of rainfed winter
wheat after livestock grazing 1. Growth rates, grain yields, soil water use and water-use efficiency.
Crop and Pasture Science, 62, 947.

Harrison M. T., Evans J. R., Dove H., Moore A. D. (2011c) Recovery dynamics of rainfed winter
wheat after livestock grazing 2. Light interception, radiation-use efficiency and dry-matter
partitioning. *Crop and Pasture Science*, 62, 960.

1 Harrison M. T., Evans J. R., Moore A. D. (2012) Using a mathematical framework to examine
2 physiological changes in winter wheat after livestock grazing: 2. Model validation and effects of
3 grazing management. *Field Crops Research*, 136, 127-137.
4
5
6
7
8 Hay R. K. M., Kirby E. J. M. (1991) Convergence and synchrony - a review of the coordination of
9 development in wheat. *Australian Journal of Agricultural Research*, 42, 661-700.
10
11
12
13 Hay R., Porter J. (2006) *The physiology of crop yield*. Second Edn. Blackwell Publishing, Oxford, 314
14 pp.
15
16
17
18
19 Lawless C., Semenov, M.A., Jamieson, P.D. (2005) A wheat canopy model linking leaf area and
20 phenology. *European Journal of Agronomy*, 22, 14.
21
22
23
24
25 Lawlor D.W. (2001) *Photosynthesis*. BIOS Scientific Publishers.
26
27
28 Loomis R.S., Connor D.J. (1992) *Crop Ecology. Productivity and management in agricultural*
29 *systems*. Cambridge University Press, Cambridge, 538 pp.
30
31
32
33
34 R Core Team (2014). *R: A language and environment for statistical computing*. R Foundation for
35 Statistical Computing, Vienna, Austria. URL <http://www.R-project.org/>.
36
37 Hay R., Porter J. (2006) *The physiology of crop yield*. Second Edn. Blackwell Publishing, Oxford, 314 pp.
38
39
40
41
42 Ritchie, J.T. (1983) Efficient water use in crop production: discussion on the generality of relations
43 between biomass production and evapotranspiration. In: H.M Taylor, W.R. Jordan and T.R. Sinclair
44 (Eds.), *Limitations to efficient water use in crop production*, ASA, CSSA, SSSA. pp.29-43.
45
46
47
48
49
50
51 Royo C. (1997) Grain yield and yield components as affected by forage removal in winter and
52 spring triticale. *Grass and Forage Science*, 52, 63-72.
53
54
55
56 Royo C., Blanco R. (1999) Growth analysis of five spring and five winter triticale genotypes.
57 *Agronomy Journal*, 91, 305-311.
58
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55
56
57
58
59
60
61
62
63
64
65

Royo C., Lopez A., Serra J., Tribo F. (1997) Effect of sowing date and cutting stage on yield and quality of irrigated barley and triticale used for forage and grain. *Journal of Agronomy and Crop Science-Zeitschrift Fur Acker Und Pflanzenbau*, 179, 227-234.

Royo C., Pares D. (1996) Yield and quality of winter and spring triticales for forage and grain. *Grass and Forage Science*, 51, 449-455.

Royo C., Romagosa I. (1996) Effect of forage removal at the first detectable node stage on the growth of winter and spring triticale. *Grass and Forage Science*, 51, 170-179.

Royo C., Tribo F. (1997) Triticale and barley for grain and for dual-purpose (forage plus grain) in a Mediterranean-type environment .2. Yield, yield components, and quality. *Australian Journal of Agricultural Research*, 48, 423-432.

Santiveri F., Royo C., Romagosa I. (2004) Growth and yield responses of spring and winter triticale cultivated under Mediterranean conditions. *European Journal of Agronomy*, 20, 281-292.

Sinclair T.R., Muchow R.C. (1999) Radiation use efficiency. *Advances in Agronomy* 65, 215-265.

Singer J.W., Sauer T.J., Blaser B.C., Meek D.W. (2007) Radiation Use Efficiency in dual winter cereal-forage production systems. *Agronomy Journal*, 99, 1175-1179.

Winter S.R., Thompson E.K. (1987) Grazing duration effects on wheat growth and grain yield. *Agronomy Journal* 79, 110-114.