Biomass and nitrogen accumulation in white oat (*Avena sativa* L.) under water deficit[1]

Anderson Prates Coelho[2], Rogério Teixeira de Faria[2], Fábio Tiraboschi Leal[2], José de Arruda Barbosa[2]; Leandro Borges Lemos[2]*

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ABSTRACT

Knowledge on nitrogen absorption rate by crops can indicate important managements, especially the definition of rates of this nutrient and the best time for topdressing application. This study aimed to evaluate and compare the accumulation of biomass and nitrogen in white oat cultivated under severe, moderate and no water deficit. Treatments consisted of levels of irrigation, with four repetitions. The treatments under severe water deficit (L1), moderate deficit (L3) and no deficit (L5) received 11%, 60% and 100% of the water volume evapotranspired by the crop (ETc). For each treatment, six plants were collected in each replicate. After collection, plants were separated into leaves, culm and reproductive structures (panicle + grains). Second and third order regressions were tested to model the behavior of biomass and nitrogen accumulation in white oat leaves, culms, reproductive structures and total over time. The maximum total nitrogen accumulation in white oat plants in the treatments L1, L3 and L5 was 50 kg ha^{-1}, 163 kg ha^{-1} and 246 kg ha^{-1}, respectively. Severe water deficit drastically reduced biomass and nitrogen accumulation in white oat. Severe water deficit causes earlier peak of biomass and nitrogen accumulation, reduces nitrogen accumulation rate and shortens cycle of white oats.

Keywords: export; extraction; irrigation; absorption rate; dry mass.

INTRODUCTION

White oat (*Avena sativa* L.) has high agricultural importance worldwide. The area cultivated with this crop in the world is 9.52 x 10^6 ha, with total production of 23.52 x 10^6 Mg and average yield of 2.47 Mg ha^{-1} (USDA, 2018). Brazil is the fifth largest global producer and has shown a substantial increase in the area cultivated with white oats over the last 10 years (Conab, 2018). This crop can be used for the production of grains, forage and straw in no-tillage system. The white oat is cultivated in Brazil during the winter season. Because this season is the driest in the main oat-producing regions in Brazil (Southeast and South), irrigation is essential to obtain high crop yields (Jat *et al.,* 2017).

In the world, there are several recent studies with white oat crop (Ahmad *et al.,* 2014; Sánchez-Martín *et al.,* 2014; Rasane *et al.,* 2015). However, due to country-specific conditions, such as climate, available cultivars and soil types, the results of these studies have few applications to Brazilian conditions. In Brazil, studies with the white oat crop are scarce in the literature and, when available, they are not recent (Frizzone *et al.,* 1995; Kolchinski and Schuch, 2003; Ceccon *et al.,* 2004), making it difficult to apply these results because, with the development of new cultivars, the cultivation practices tend to change over time (Escosteguy *et al.,* 2014).

Due to climatic factors, new diseases and pests, low yield and adaptation to different conditions, new white oat

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[2] Universidade Estadual Paulista, Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal, São Paulo, Brazil. anderson_100ssp@hotmail.com; rogerio.faria@unesp.br; lealft@bol.com.br; josearruda777@gmail.com; leandro.lemos@unesp.br

*Corresponding author: anderson_100ssp@hotmail.com

cultivars are constantly being developed. The high genetic variability among white oat cultivars (Montilla-Bascón *et al.,* 2013) requires specific agronomic recommendations, taking into account the genotype cultivated. Since the importance of white oat in Brazil has expressively increased, new studies are necessary to recommend agricultural managements, such as fertilization and irrigation. These managements include the improvement in topdressing nitrogen fertilization, especially in irrigated systems.

Nitrogen (N) is the nutrient extracted in largest amounts by white oat plants, which require on average 27 kg per ton of grains produced, of which 70% is exported to the grains. With the high exportation by the grains, N differs for instance from the second most extracted element by the crop, potassium (K), whose export is about 29% (Cantarella *et al.,* 1997). This fact leads to the need for replacing the large quantities of N via fertilizer to the soil, compared to other nutrients. In addition, due to its high mobility in soil (mass flow movement) and quantity required by crops, it is often the only nutrient applied in topdressing fertilization, unlike phosphorus and potassium, which are more absorbed by the diffusion process and are applied at planting and sowing.

Knowledge on nutrient absorption rate by crops can indicate important managements, especially the definition of rates of nutrients to be applied and the best time for application. Depending on the type of soil, sowing density, irrigation and cultivar, crop fertilization may have different recommendations from those with the currently used standards, such as earlier fertilization and application of higher rates (Rosolem *et al.,* 2012; Djaman *et al.,* 2013; Wang *et al.,* 2017a). Thus, research on the impact of water deficit on N absorption by white oat is necessary for correct recommendation of N fertilization in this crop, according to the production system adopted.

In addition to affecting the rate of nutrient absorption, water deficit can lead to morphological and physiological changes in plants (Wang *et al.,* 2017b; Jafari *et al.,* 2019). In moderate water deficit, morphologically plants tend to reduce leaf area, have leaf movements to minimize water loss and increase root system growth (Jafari *et al.,* 2019). As for physiology, in severe water deficit, plants present higher synthesis of abscisic acid hormone, which acts to reduce the crop cycle and generate greater partition of photoassimilates for grain production (Wang *et al.,* 2017a).

The hypotheses for the study are (i) severe water deficit in white oat drastically reduces biomass and nitrogen accumulation, and (ii) severe water deficit causes earlier peak of biomass and nitrogen absorption and shortens the cycle of white oat. The present study aimed to evaluate and compare biomass and nitrogen accumulation in white oat (*Avena sativa* L.) cultivated under severe, moderate and no water deficit.

MATERIAL AND METHODS

The experiment was conducted at the experimental farm of the School of Agricultural and Veterinarian Sciences, Unesp, Jaboticabal, SP, Brazil (latitude 21°14'44" S, longitude 48°17'00" W and altitude of 545 m). The climate of the region, according to Köppen's classification, is Aw, subtropical, relatively dry in the winter, with summer rains, average annual temperature of 22 ºC, coldest month temperature above 18 ºC and normal annual rainfall of 1,424 mm (Alvares *et al.,* 2013). The soil of the experimental area is classified as Latossolo Vermelho eutrófico (Embrapa, 2013) (Oxisol), and its physical and chemical attributes are presented in Table 1. Soil analysis was performed 90 days before experiment sowing.

The experiment was conducted from May 2, 2018 to August 11, 2018. White oat (cv. IAC 7) was sown on May 2, 2018, at density of 80 kg ha^{-1}, using seeds with 95% germination at spacing of 0.17 m between rows, in an area which had been under fallow since 2017, where white oat was cultivated between May and August 2017. Between 2013 and 2017, the area was cultivated with *Urochloa brizantha* cv. Marandu. Liming was carried out 30 days prior to the experiment, using a rate of 1.5 t ha^{-1} of limestone with PRNT (relative power of total neutralization) of 80. Fertilization at planting consisted of 20 kg ha^{-1} of N, 160 kg ha^{-1} of P_2O_5 and 160 kg ha^{-1} of K_2O. Topdressing fertilization was performed only with N (urea), at rate of 100 kg ha^{-1} of N split into two portions, the first one applied at the oat tillering stage (60% of the rate at 20 DAE) and the second one at the booting stage (40% of the rate at 45 DAE) (Escosteguy *et al.,* 2014).

In the study, treatments consisted of five levels of irrigation: L1, L2, L3, L4 and L5, which received 11%, 31%, 60%, 87% and 100%, respectively, of the water volume evapotranspired by the crop (ETc). Treatments were arranged in a strip-block experimental design, with four replicates. Biomass and nitrogen accumulation were compared using the treatments L1, L3 and L5, which represented severe, moderate and no water stress, respectively.

A "line-source sprinkler" experimental layout was used. This experimental layout allows distributing irrigation water with variable water depths as the treatment becomes distant from the central line of sprinklers (Lauer, 1983). In addition, before oat sowing, a field test was conducted to define the distribution fractions of the water applied by the sprinklers (Figure 1). In this test, collectors were positioned 1 m apart, up to the limit distance of water application by the sprinklers, in a line perpendicular to the irrigation line, with 4 replicates.

The water application intensity by the sprinklers was measured in the field, resulting in a rate of 12 mm $hour^{-1}$.

The coefficients of water application uniformity (CUC) and distribution (CUD) of the irrigation system were 89% and 84%, respectively. The experimental plots were 5 m long and 2.4 m wide. The first 0.5 m on each side of the plots were considered as borders.

Irrigation management was carried out based on crop water requirement, according to the FAO-56 method, using climatic data obtained daily in the automated agrometeorological station of FCAV/Unesp. Reference evapotranspiration (ETo) was estimated daily by the Penman-Monteith equation (Allen *et al.,* 1998). White oat crop evapotranspiration (ETc) was calculated as the product of ETo and the crop coefficients (kc), according to Allen *et al.* (1998).

Irrigation was always conducted when the water deficit in the treatment without water deficit (L5) was equal to 23 mm. This water depth was calculated based on the oat crop coefficient at each phenological stage and soil physical attributes (Table 1). This calculation used effective root depth of 0.40 m and soil water availability factor of 50% (Allen *et al.,* 1998).

Maximum and minimum temperatures, as well as the average for the period were 28.2 °C, 14.2 °C and 20.6 °C, respectively (Figure 2A). Cumulative rainfall and ETc along the oat cycle were 50.9 mm and 170.6 mm, respectively (Figure 2B). The irrigation depth for the treatment with 100% ETc (L5) was 140 mm, with values varying at the same proportion of the water application rate for the other treatments.

Along the white oat cycle, plants were collected close to the ground surface seven times to determine biomass and nitrogen accumulation by the crop as a function of water deficit. The collections were carried out in the treatments L1, L3 and L5 at 15, 28, 40, 50, 57, 71 and 90 days after emergence (May 6, 2018). For each treatment, six plants were collected in each replicate, forming a sample composed of 24 plants per treatment. After collection, plants were separated into leaves, culm and reproductive structures (panicle + grains), according to Soratto *et al.* (2013). Then, the samples were washed in running water, aqueous solution of neutral detergent at 1% and deionized water. The population of plants at the time of each collection was determined in each replicate, a variable used to estimate biomass and nitrogen accumulation in the treatments.

After being washed, the samples were dried in a forced air circulation oven at 65 ºC until constant weight, and then weighed to determine dry mass and estimate biomass accumulation. The samples were ground in Wiley-type mill to determine nitrogen content, according to the method proposed by Bataglia *et al.* (1983).

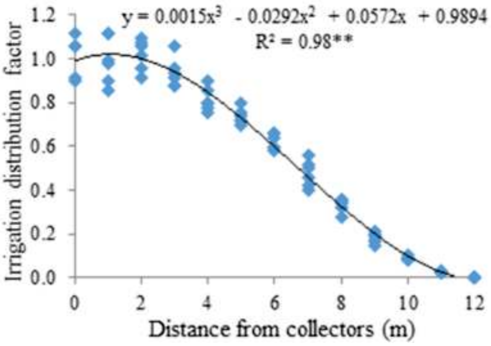
Second- and third-order regressions were tested to model the behavior of biomass and nitrogen accumulation

Table 1: Physical and chemical attributes of the soil in the experimental area

Layer (m)	BD*	θ* FC*	θ* PWP*	Total Sand	Clay	Silt	Soil texture
	(kg m^{-3})	(m^3 m^{-3})		(g kg^{-1})			
0.00-0.20	1.45	0.45	0.33	310	470	220	Clay
0.20-0.40	1.49	0.41	0.30	270	530	200	Clay

Layer	pH	OM*	P_{resin}	S	H+Al	Al	K	Ca	Mg	SB	CEC	V%
(m)	$CaCl_2$	(g dm^{-3})	(mg dm^{-3})	(mmol$_c$ dm^{-3})								
0.00-0.20	5.6	40	67	5	21	1	3.4	36	13	52.7	73.9	71
0.20-0.40	5.8	40	68	5	20	1	3.2	36	11	50.3	70.4	71

*BD: Bulk density; FC: Field capacity; PWP: Permanent wilting point; q: Volumetric moisture content (m^3 m^{-3}); OM: Organic matter; SB: Sum of bases; CEC: Cation Exchange capacity; V%: base saturation.



Distance (m)	Treatment	Irrigation distribution factor
0.00 – 2.40	L5	1.00
2.41 – 4.80	L4	0.87
4.81 –7.20	L3	0.60
7.21 – 9.60	L2	0.31
9.61 –12.00	L1	0.11

Figure 1: Fractions of distribution of the water applied by the sprinklers as a function of the distance or treatments from the irrigation line, with sprinklers spaced by 6 m in the line, obtained in field test.

in the leaves, culm, reproductive structures and total of white oat cultivated under severe (L1), moderate (L2) and no water deficit (L5) as a function of time. Regression analysis at 0.05 probability level was carried out for the best fit in each situation. The daily rate of accumulation of total N absorbed by white oat was obtained by the first derivative of the equations fitted for the total accumulation of each treatment.

RESULTS AND DISCUSSION

Based on the biomass accumulated in the culm, leaves and reproductive structures, it is possible to note that white oat cultivated under deficit irrigation levels (L1 and L3) showed a large reduction in its growth (Figure 3).

For culm and leaves, biomass accumulation decreases from a certain point. This occurs due to leaf senescence and lodging of some plants, a normal fact in field experiments evaluating nutrient accumulation (Soratto *et al.,* 2013). The maximum total biomass accumulation for white oat (Figure 3D) occurred at 71 DAE in the treatment L1, 78 DAE in L3 and 77 DAE in L5. Thus, the L1 treatment showed maximum biomass accumulation 7 days earlier than the others, demonstrating the effect of severe water deficit in promoting reduction in oat cycle. In the treatment with moderate water deficit (L3), such earlier maximum biomass accumulation was not observed.

In relation to N accumulation in the biomass, the L5 treatment showed maximum values of 62, 92, 144 and 246 kg ha^{-1} of N in the culm, leaves, reproductive structures and total accumulation, respectively. These values were 67% and 500%, 37% and 273%, 38% and 418% and 51% and 396% higher than those found in the L3 and L1 treatments, respectively (Figure 4). As observed for biomass, the treatment with highest water deficit showed maximum N accumulation at 66 DAE, whereas both L3 and L5 had maximum points at 72 DAE, indicating the reduction in oat cycle when cultivated under severe water deficit. The N accumulated in reproductive structures was on average 150% and 50% higher than that accumulated in the culm and leaves, respectively, considering all treatments. The maximum biomass and N accumulation for the treatments occurred between the milk and dough stages of white oat.

The maximum rate of total N accumulation was 0.94, 3.50 and 4.83 kg ha^{-1} day^{-1} for the treatments L1, L3 and L5, respectively (Figure 5). The accumulation rate in the treatment without water deficit (L5) was 38% and 414% higher than those in the treatments with moderate (L3) and severe (L5) water deficit, respectively. The maximum accumulation rate occurred at 32, 36 and 36 DAE of white oat in the treatments L1, L3 and L5, respectively, demonstrating once again that white oat cycle is shortened when it is cultivated under severe water deficit. Due to leaf abscission and lodging of plants at the end of the oat production cycle, the accumulation rate from 72 DAE was negative for all treatments, as previously discussed.

Despite the lower N accumulation compared to L3 and L5 treatments, the proportions of N accumulated by the leaves, culm and reproductive structures in the L1 treatment, relative to the total accumulated, remained very close to those of the other treatments along the entire cycle (Figure 6). At the end of the cycle, at 90 DAE, more than 70% of the total N accumulated was found in the reproductive structures of the crop, regardless of treatment. In addition, it was observed that the treatment without water restriction started forming the reproductive structures (40 DAE) earlier than the treatments with water deficit (50 DAE).

Despite receiving the same rate of N throughout the cycle, there was a large difference in total accumulation of biomass (265%) and N (396%) when white oat was maintained without water deficit (L5) and under severe water deficit (L1) (Figure 3). As nutrient absorption is influenced by water availability in soil, especially for nutrients absorbed in larger amounts through mass flow, such as N, the water deficit drastically affects nutrient accumulation in plants (Lisar *et al.,* 2012) and, consequently, crop yield (Djaman *et*

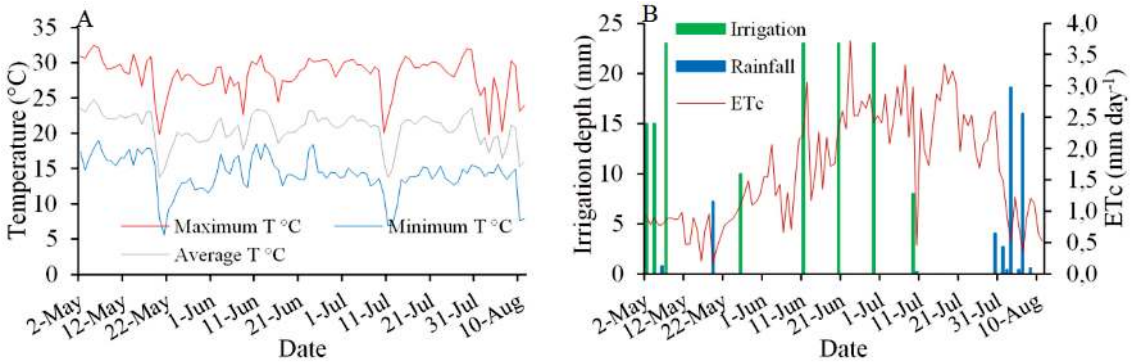


Figure 2: Daily maximum, minimum and average temperatures (A) and daily rainfall, evapotranspiration (ETc) and irrigation depth (B) for the experimental period from May 2, 2018 to August 11, 2018.

al., 2013). Since the rainfall for the experimental period was concentrated at the end of the cycle and was low (50 mm) (Figure 2), the effect of water deficit treatments on white oat growth can be confirmed.

It was observed that the smallest percentage difference in the maximum accumulation of biomass and N for treatments with severe and moderate water deficits, compared to the treatment without water deficit, occurred for the leaves (Figure 3B and 4B). Stressed plants tend to reduce proportionally more the growth of vegetative parts which are physiologically less important, such as the culms (Lisar *et al.,* 2012). As the leaves perform photosynthesis and are responsible for the production of photoassimilates, which serve for grain filling, stressed plants prioritize the growth of the photosynthetically active structures.

Thus, leaf production in stressed plants tends to be closer to the leaf production of non-stressed plants than the production of culms. This occurs because, if the water deficit stops, due to rainfall and irrigation for example, plants have a significant leaf area for the production of photoassimilates. However, when the water deficit remains until the end of the crop cycle, the losses of yield will be expressive, as observed in the present study, even if the relative reduction in the accumulation of leaves is lower. For the treatment under severe water deficit (L1), the percentage reduction in maximum accumulation of biomass (314%) and N (418%) in the reproductive structures (Figure 3 and 4), compared to the treatment without deficit (L5), was much higher than the percentage reduction in the accumulation for the leaves (37%).

The amount of N supplied by mineral fertilization to white oat during its cycle was 120 kg ha^{-1}, with 20 kg ha^{-1} at sowing and 100 kg ha^{-1} as topdressing. However, the maximum total N accumulation of the crop maintained

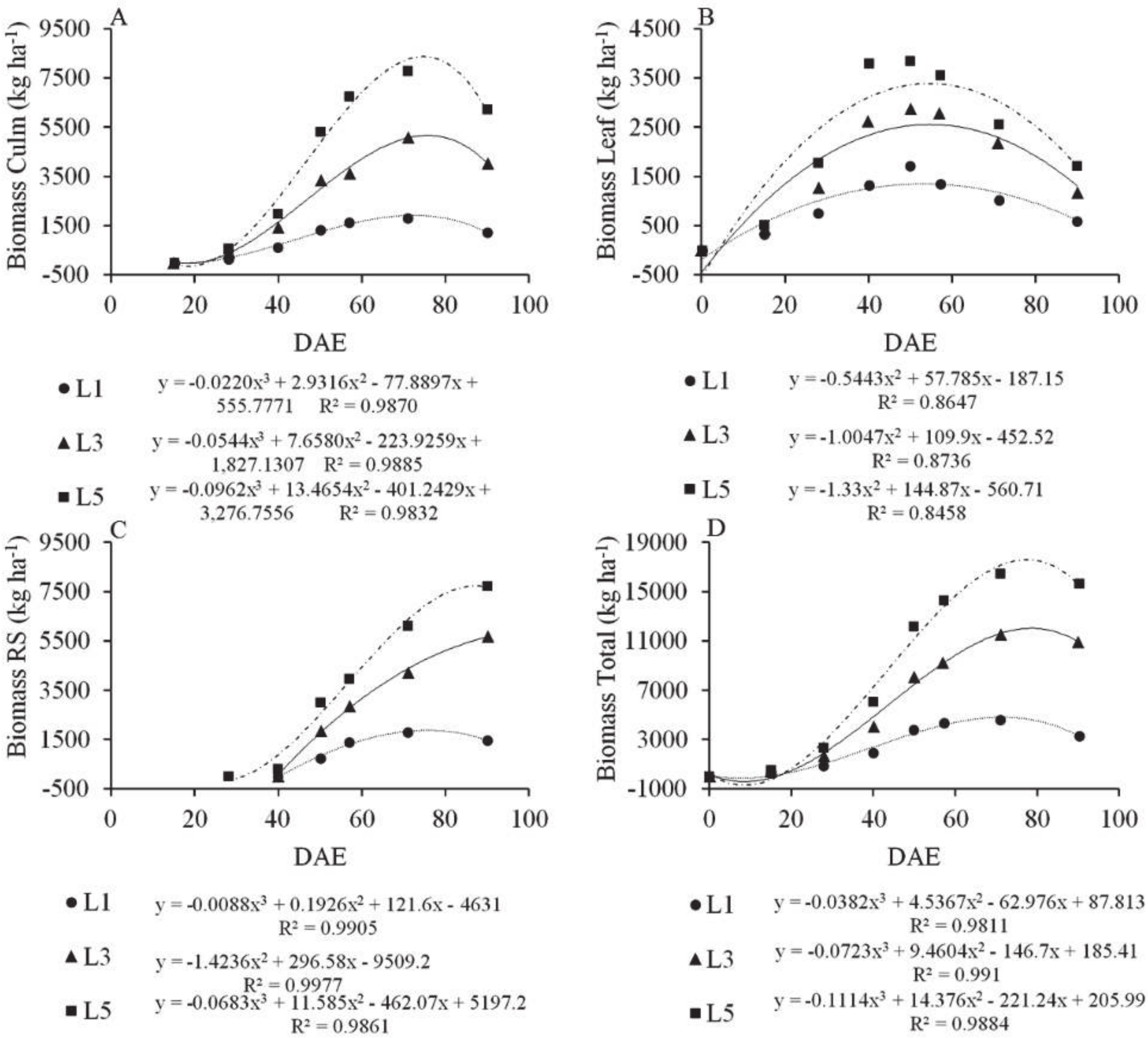


Figure 3: Biomass accumulation in the culm (A), leaves (B), reproductive structures – RS (C) and total (D) in white oat cultivated under levels of irrigation. L1: 11% of crop evapotranspiration (ETc); L3: 60% ETc; L5: 100% ETc; DAE: days after emergence; N: nitrogen

without water deficit (L5) was equal to 246 kg ha^{-1}. Considering that N fertilization had 100% efficiency, the soil provided for the crop at least 126 kg ha^{-1} of N. This quantity resulted from the amount of N already existing in the soil solution and the mineralization of organic matter, which is the main N reservoir in tropical soils (Silva and Mendonça, 2007). Some studies have associated the effects of exudates released by the roots of plants of the genus *Urochloa* to the mitigation of nitrification processes, reducing N losses by leaching (Gopalakrishnan *et al.,* 2009). Thus, as the experimental area had been cultivated with *Urochloa brizantha* for 4 years, the large amount of N provided by the soil for the white oat crop is justified.

For L1 and L3 treatments, the maximum total N accumulation was equal to 50 and 163 kg ha^{-1}, respectively. This demonstrates that the minimum amount of N provided by the soil for the L5 treatment was higher than the total amount of N absorbed by the L1 treatment and very close to that absorbed by the L3 treatment. Thus, when the crop is cultivated under deficit irrigation and under non-irrigated conditions, for soils with fertility similar to that of the soil in the present study, topdressing N fertilization can be performed at lower rates than when the crop is cultivated under supplementary irrigation. This fact demonstrates the importance of determining the maximum amount of N absorbed in each crop production system.

For white oat plantations maintained under high water deficit, for instance, besides the fact that the recommended N rates is lower than that for irrigated plantations, it is observed that topdressing N fertilization should be performed earlier compared to irrigated plantations (Figure 4D and 5). On the other hand, growing white oat under moderate deficit irrigation (L3) does not alter the moment of the peaks of biomass and N compared to the treatment

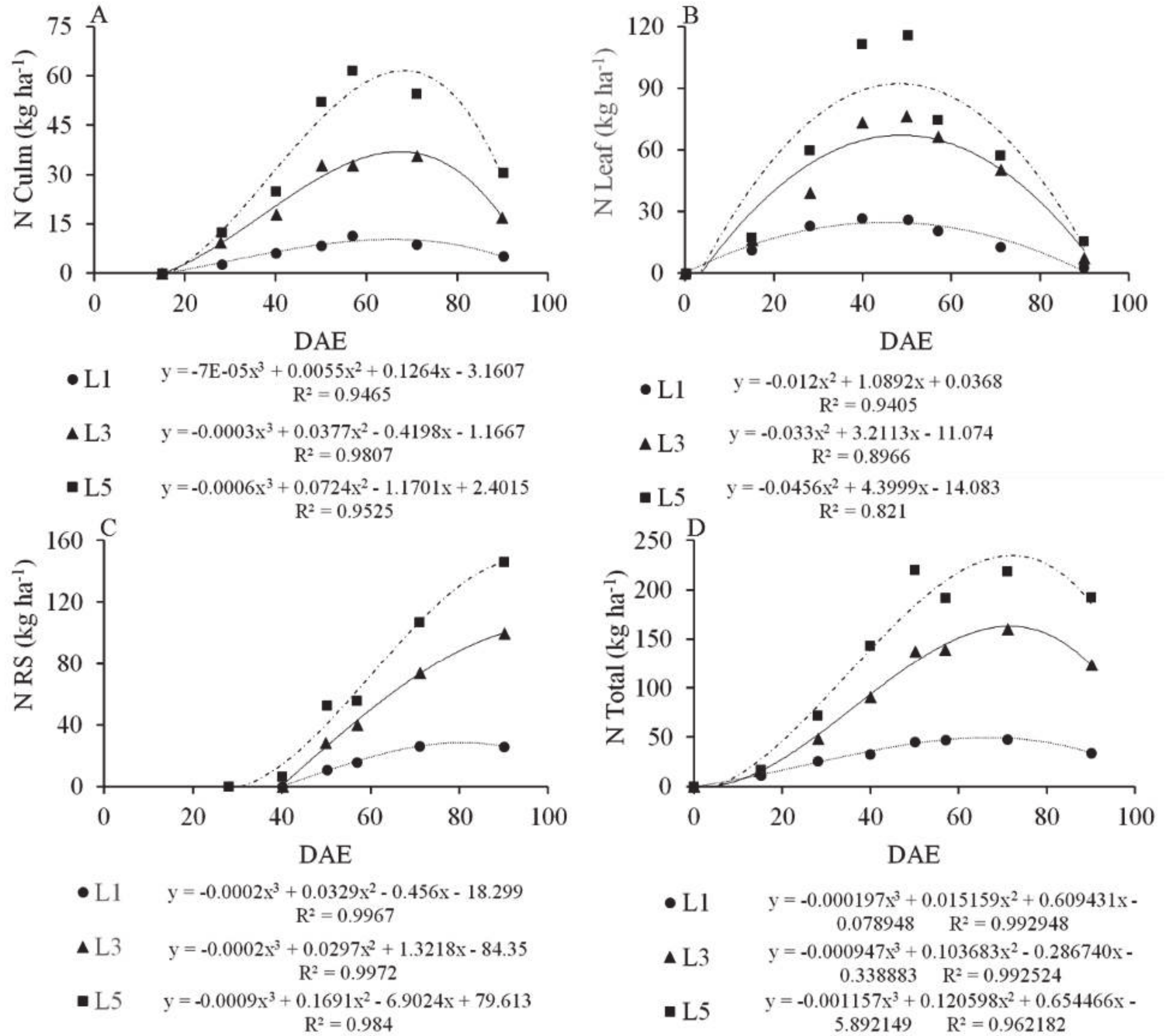


Figure 4: Nitrogen accumulation in the culm (A), leaves (B), reproductive structures – RS (C) and total (D) in white oat cultivated under irrigation levels. L1: 11% of crop evapotranspiration (ETc); L3: 60% ETc; L5: 100% ETc; DAE: days after emergence; N: nitrogen

without deficit (L5), so the same time should be adopted for topdressing N fertilization. Irrigation with moderate deficit is an interesting management, since it uses a smaller water volume for irrigation and, according to the present study, the growth of white oat is not drastically affected by this practice. Thus, for straw production in no-tillage system and forage production, deficit irrigation in white oat is a technically feasible technique.

Evaluating N extraction by wheat cultivars, Wang *et al.* (2017b) observed that the difference in the quantity of N extracted between the contrasting genotypes was 20% (30 kg ha^{-1}). For cotton, as the planting density increases, the peak of nutrient absorption occurs earlier and is superior to that of plantations with low density, suggesting an earlier topdressing fertilization and higher rates of fertilizers (Rosolem *et al.,* 2012). Djaman *et al.* (2013), evaluating nutrient accumulation in corn cultivated under irrigation levels, observed a difference of 100 kg ha^{-1} in the total N extracted by the crop when subjected to full irrigation and no irrigation. Corroborating the results found in the present experiment, these studies demonstrate the importance of the recommendation of fertilization for each production system. Depending on the cultivars, density in the plantations and irrigation levels, the recommendation of fertilization for the various crops should indicate different nutrient rates when compared to the standard recommendations. If performed adequately, these specific recommendations can lead to increased crop yields, higher fertilization efficiency and increased revenue for producers.

The percentage export of N to the reproductive structures (Figure 6) was close to the 74% recommended for oat by Cantarella *et al.* (1997), indicating a strong influence of the genetic factor on the redistribution of photoassimilates between plant structures. The reduction in the cycle of white oat cultivated under severe water deficit is due to the need for propagation when the species

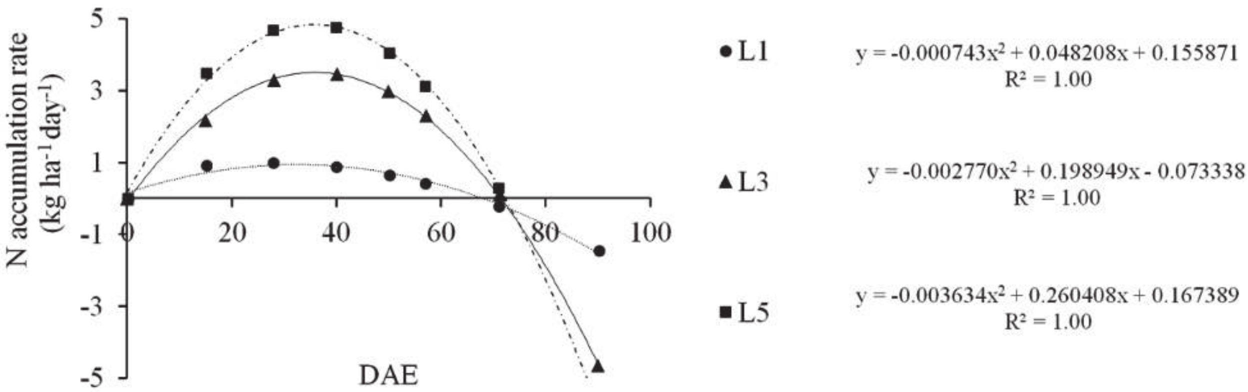


Figure 5: Total nitrogen accumulation rate by white oat. L1: 11% of crop evapotranspiration (ETc); L3: 60% ETc; L5: 100% ETc; DAE: days after emergence

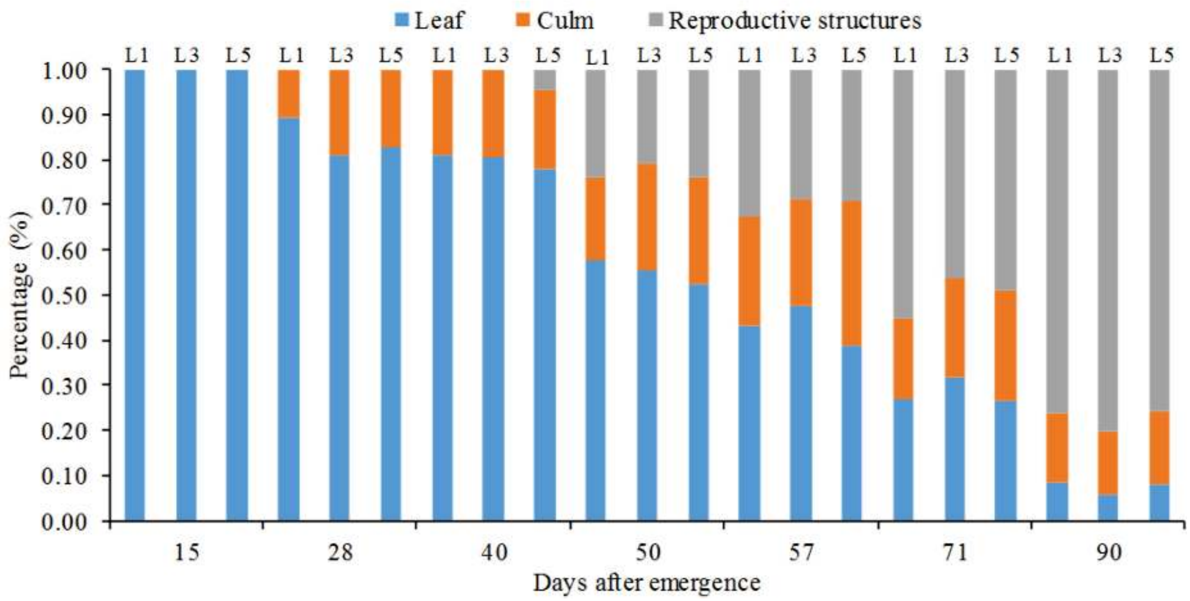


Figure 6: Percentage of the total nitrogen extracted by white oat cultivated under irrigation levels as a function of the quantity absorbed by the leaves, culm and reproductive structures. L1: 11% of crop evapotranspiration (ETc); L3: 60% ETc; L5: 100% ETc

are kept under unfavorable conditions to their growth, producing grains more quickly to generate new individuals (Lisar *et al.,* 2012).

CONCLUSIONS

Severe water deficit drastically reduces biomass and nitrogen accumulation in white oat (*Avena sativa* L.), reducing 72% and 80% the total accumulation of crop biomass and nitrogen, respectively. In addition, severe water deficit causes earlier peak of nitrogen absorption, reduces the daily accumulation rate and shortens the cycle of white oat. The proportion of nitrogen accumulated in leaves, culm and reproductive structures of white oat does not change according to water deficit.

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