Scientific Paper

Effect of fertilization on the growth and development of the oat crop (Avena sativa)

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ABSTRACT: The effect of fertilization practices on crop productivity and the management of the soil resources has been a key focus of research in sustainable agriculture and global change. For this reason, the current experiment was conducted in order to determine the effect of organic and chemical (inorganic) fertilization on the oat crop (*Avena sativa* var. Cayuse) under field conditions. For such purpose, a completely randomized design was implemented. Different combinations of organic and inorganic fertilizers were applied (100% organic; 75% organic and 25% inorganic, 25% organic and 75% inorganic, 100% inorganic and a non-fertilized control) and their effects on growth and development were observed. The combination of organic and inorganic fertilizers did not show significant differences for biomass, yield, leaf area index (LAI) and crop growth rate compared with the plants that received 100% inorganic fertilizer. It is concluded that the combination of organic and inorganic fertilizers represents a reliable alternative in the short term to satisfy the nutritional requirements of forage oat crop based on the evaluated variables.

Keywords: biomass, compost, leaf area index.

INTRODUCTION

Oat (*Avena sativa* L.) is an important grass due to its feeding value, because according to Rodríguez and Sana (2007) it has significantly high concentrations of fermentable carbohydrates (starches), for which it is cultivated as forage for livestock feeding (Assefa and Ledin, 2001).

The application of fertilizers can provide the necessary nutrients for the plants in order to obtain high yields. Their use can increase productivity, taking into consideration that the source, the dose and season of application should be adequate to prevent excessive costs, damage to the plant and environmental problems (FAO, 2002). The conventional or chemical synthesis fertilization demands a large economic investment and can cause negative environmental effects on productive systems. For such reason, it is necessary to use alternatives, such as the application of organic fertilizers (Zuluaga *et al*., 2010); they can supply the nutritional requirements of crops, match the forage production with the one obtained using organic fertilizers (Tamayo *et al*., 2007; Zuluaga *et al*., 2010) and propitiate quality agronomic characteristics.

In addition, this type of fertilizers improves the nutrient availability in the soil (Bolaños and Rodríguez, 2009) and the medium in which the solubilizing microorganisms are established (Sattelmacher *et al*., 1991).

The objective of this study was to determine the effect of organic and inorganic fertilization and their combination on growth and development variables of *A. sativa* var. Cayuse.

MATERIALS AND METHODS

The trial was conducted in the campus Bogotá of the National University of Colombia, at a height of 2 640 m.a.s.l., daily temperature of 19 ºC, night temperature of 11 ºC and average relative humidity of 40 %. The experiment area measured 120 m^2 (6 m wide x 20 m long), distributed in four subplots (each 1,2 m wide) divided into five rows (each one 4 m long and 0,4 m wide). The planting was made in each row with 87,4 kg of seed/ha of oat var. Cayuse.

Treatments. For the adjustment of the treatments the soil analysis was taken into consideration, which showed loam-sandy texture and a total content of 0,45 % N, for which an application of 92 kg N/ha was necessary. The organic fertilizer was from the compost of a slaughterhouse, and had 1,14 % of N and a density of 0,54 g/cm^3; in the case of the chemical fertilizer, a full formula (15-15-15) was used.

The treatments consisted in: T1: 100 % organic fertilizer, T2: 75 % organic fertilizer and 25 % full formula fertilizer, T3: 25 % organic fertilizer and 75 % full formula fertilizer, T4: 100 % full formula fertilizer, C: control without fertilization.

In T1 the fertilizer was applied at the beginning of the experiment (6 t/ha). In T4 a total of 616 kg/ha was applied. The applications were made at three different moments: 40 % in pre-planting, 30 % 15 days after planting (dap) and 30 % 45 dap, according to the recommendations made by Florez (2005). The trial lasted 84 days.

Measurements. The vegetative development of the plants was characterized in each sampling through the phenological scale of the BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) for cereals, taking into consideration the stage in which the plant was, through the number of leaves and bunches (Zadoks *et al*., 1974). These data were directly compared with some growth variables, and the phenological stage of the plants was related to the dap.

Regarding growth, in each sampling the following direct measurements were made: fresh weight of the aerial part (FWAP); dry weight of the aerial part (DWAP), with tissue dried at 70 ºC during 72 h; and leaf area, calculated through the software ImageJ (Schneider *et al*., 2012).

With the data of the leaf area and the dry weight of the aerial part the growth variables were calculated (table 1): leaf area index (LAI), leaf area ratio (LAR), relative growth rate (RGR), crop growth rate (CGR) and net assimilation rate (NAR), according to Hunt *et al*. (2002), which are derived from the direct measurements (Melgarejo *et al*., 2010). The yield was quantified as forage production per hectare and number of bunches per square meter.

Experimental design and statistical analysis. A completely randomized design was used with five treatments and four repetitions per treatment. The sampling unit consisted in a rectangle of 150 cm^2 (50 cm x 30 cm), which was randomly thrown in each plot to sample all the plants which were included in that area. The samplings were conducted at 18, 32, 53 and 70 dap.

The statistical analysis was carried out through the software R (Hornik, 2016), with a *p* value of 0,05; and Tukey's multiple comparison test was used in case of existing significant differences.

RESULTS AND DISCUSSION

The plant development at 70 dap was different among treatments. In T4, T3 and T2 the plants had around twenty three leaves (BBCH19), while in T1 and in the control they had fifteen leaves (BBCH 15). Significant differences were found in the biomass accumulation in T4 with regards to T1 and the control (fig. 1). There was no difference among the treatments that included some proportion of inorganic fertilization and the control, at 53 dap.

Table 1. Formulas used in the determination of the growth indexes

Growth rate	Formula
Leaf area index (LAI)	$\frac{L_A}{G_A}$
Crop growth rate (CGR)	$\frac{W_2 - W_1}{(t_2 - t_1)(G_A)}$
Leaf area ratio (LAR)	$\frac{\frac{L_{A2}}{W_2} + \frac{L_{A1}}{W_1}}{2}$
Net assimilation rate (NAR)	$\frac{W_2 - W_1}{t_2 - t_1} * \frac{\ln L_{A2} - \ln L_{A1}}{L_{A2} - L_{A1}}$
Relative growth rate (RGR)	$\frac{\ln W_2 - \ln W_1}{t_2 - t_1}$

L_A: leaf area, G_A: soil area, *W*: weight, *t*: time, *ln*: natural logarithm.

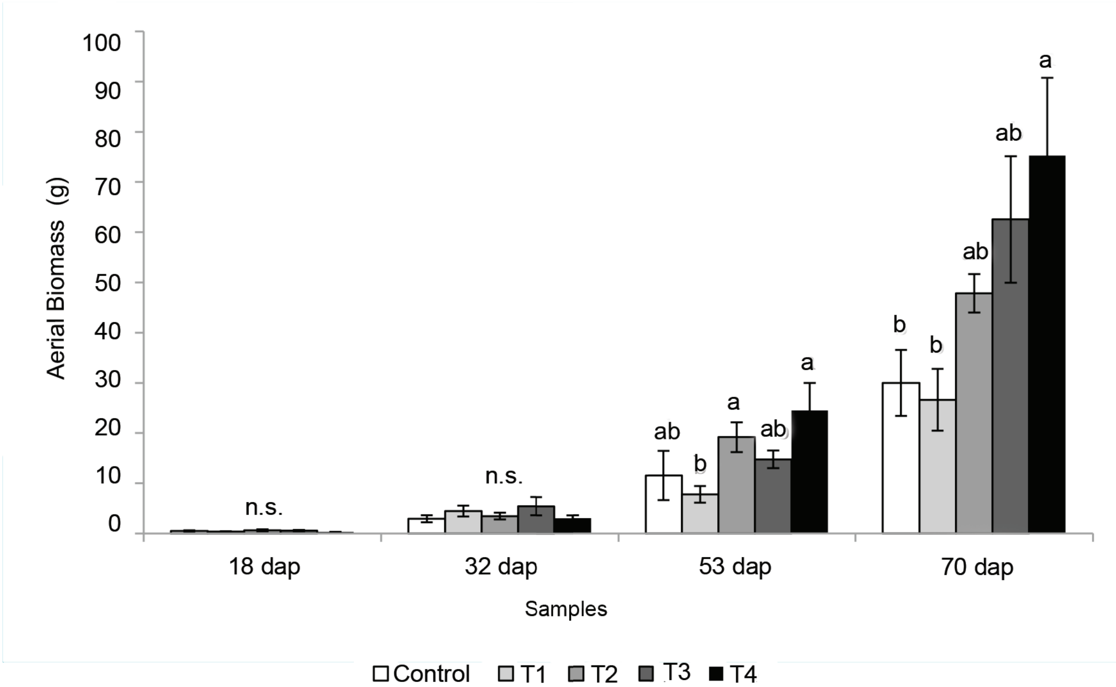

Figure 1. Aerial biomass of *A. sativa* with different combinations of organic and inorganic fertilization. (The letters represent the different groupings obtained according to Tukey's multiple comparison test (p < 0,05)).

These results can be directly related to the N availability of the inorganic fertilizers compared with the organic fertilizers. Fast-release inorganic fertilizers are easily solubilized in the soil, for which their effect on plant nutrition is direct and fast. On the other hand, organic fertilizers release some nutrients more slowly, because this process depends directly on the microbial activity in the soil and on some abiotic factors; this hinders guaranteeing the nutritional needs of crops immediately after their application (Chen, 2006; Chang *et al*., 2010). Oat, like many grass species, shows a favorable response in growth when adding N, for which it is common that the accumulation of biomass in the plants increases (Fontanetto *et al*., 2008).

The forage oat yield at 70 dap was significantly higher in T4 than in T1 and in the control. T2 and T3 did not show significant differences with regards to the others (fig. 2). At the same time, the yield of bunches per square meter showed a similar performance to the one described (fig. 3). This indicates that the crop response in yield was significantly higher when the nutritional supplement of NPK was supplied through 100 % inorganic fertilization. Nevertheless, the combined organic-inorganic fertilization (T2 and T3) generated an intermediate result.

Ahmad *et al*. (2011) concluded that the use of inorganic fertilizers favored more the production of forage oat than the organic fertilizers. These authors also reported that the combination of organic and inorganic fertilizers can partially supply the nutritional demand of the crop with relation to the yield. In this sense, Montemurro *et al*. (2006) reported that in *Dactylis* sp. the combined organic and inorganic fertilization caused an increase in the forage yield, but this result was slightly lower than the one obtained with inorganic fertilizers.

The results obtained with T3 (fig. 3) coincide with the ones reported by Jayanthi *et al*. (2002), who stated that the combined organic and inorganic fertilizers increase the number of bunches. On the other hand, Lakho *et al*. (2004) reported that a significant increase can be obtained in the yield of forage corn by including organic fertilizers within the management of inorganic fertilizers. The above –stated facts indicate that a partial inclusion of organic fertilizers within the management strategies of the forage crop fertility can favor their yield.

Regarding the CGR (fig. 4), an increase was observed through time in all the treatments; T4 and T2 showed significant differences with regards to T1 between 32 and 53 dap, while T3 and the control

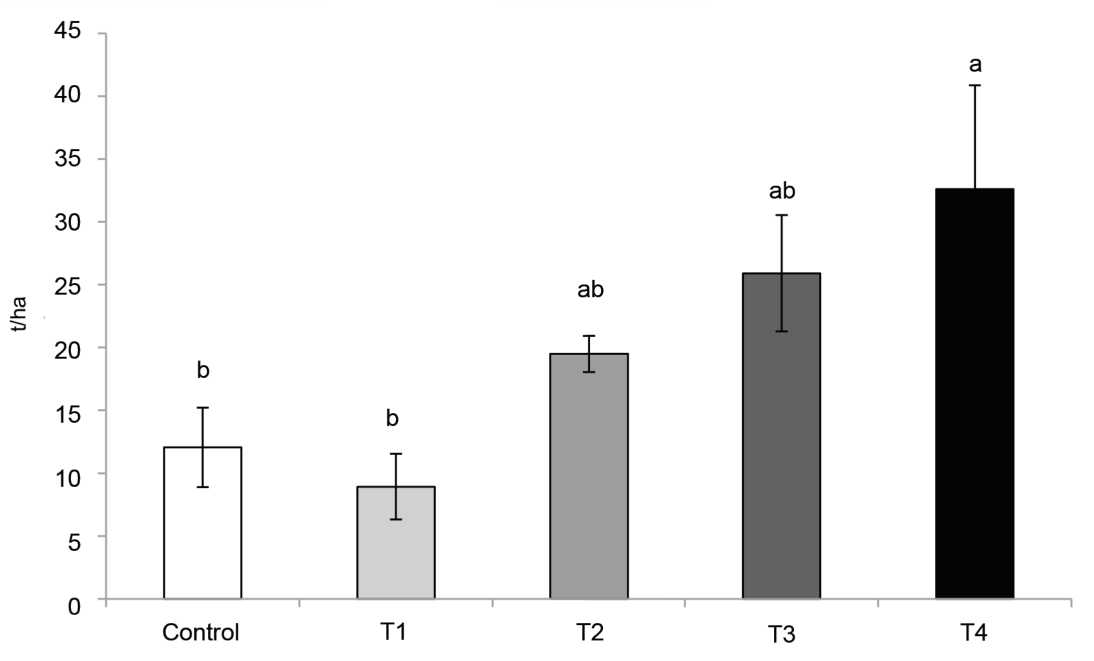

Figure 2. A. sativa yield with different combinations of organic and inorganic fertilization on different sampling days (18, 32, 53 and 70 dap).
Different letters differ at p < 0,05 (Tukey).

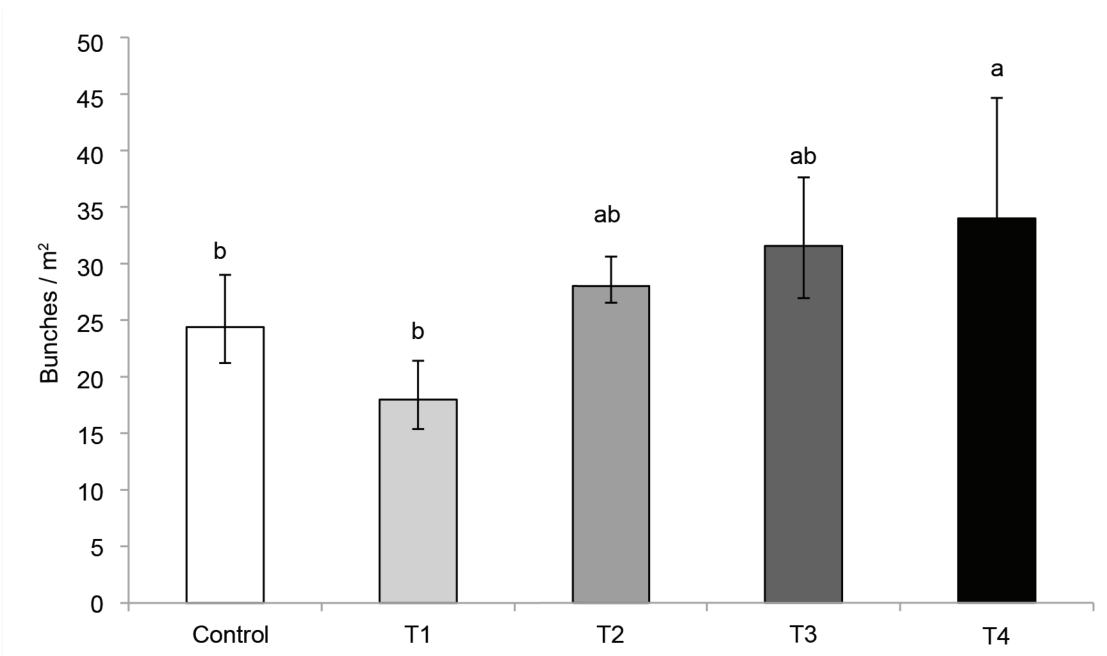

Figure 3. Number of bunches/m2 of A. sativa with different fertilization combinations.
Different letters differ at p < 0,05 (Tukey).

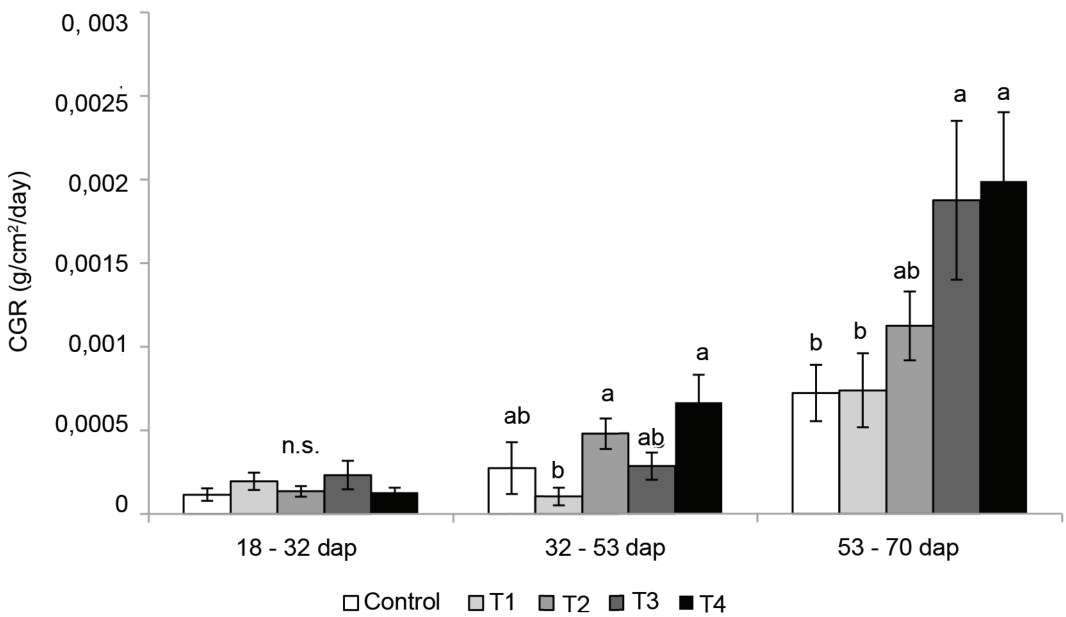

Figure 4. Growth rate of the crop.
Different letters differ at p < 0,05 (Tukey).

had a similar result for this variable. Likewise, T4 and T3 differed significantly compared with T1 and the control between 53 and 70 dap. Such performance can be explained by the delivery of nutrients from each fertilizer in time, according to the mineralization processes that occur in the soil (Chen, 2006; Chang *et al*., 2010). This can be one of the reasons why the treatments of organic fertilization showed low CGR values.

The leaf area index, which represents the projection of the leaf area on the soil plane –that is, the area of the set of leaves per soil unit– (Calvo *et al*., 2005), is important in the photosynthetic processes (Liang *et al*., 2014). In this study it was observed that since 53 dap there were significant differences in the LAI between T3 and T1 and the control (fig. 5), which was maintained until 70 dap. Similarly, the CGR showed significant differences between 32-53 dap and 53-70 dap. The performance of these two variables at 70 dap for each treatment is comparable with that of the accumulation of biomass and yield (figs. 1 and 2). The above-described result indicates that the significant differences in the leaf area production among the treatments could have generated a differential increase in the biomass production per area unit in the crop. Thus, the LAI and CGR showed that there was a relation between the leaf area gain and the biomass gain. In addition, it was observed that the different treatments maintained a similar increase rate for both indexes.

The above-presented interpretation comprises the increase in the leaf area of the crop and the total biomass production for each treatment, key factors implied in the carbon gain of the plants. In this study the carbon gain was characterized through the NAR. Nevertheless, it was not possible to establish a clear relation among the results of the NAR (fig. 7) with regards to those of the LAI and the CGR (figs. 4 and 5), with the exception of the significant differences found between 32 and 53 dap. This indicates that the proportional relation between the leaf area and the biomass gain (without taking into consideration the soil area) in time did not maintain a similar performance to the one described for the CGR and LAI, which can explain the low similarity with the carbon gain.

The NAR depends directly on the leaf area and the arrangement and age of the leaves, as well as on the internal metabolism of the plant and its response to external factors through the respiratory activity (Hunt *et al*., 2002). There were significant differences only between 32 and 53 dap, periods in which the carbon gain was higher for the plants in T4 with regards to T3 and T1. The increase of the NAR can be ascribed to fertilization, because according to Lopes *et al*. (2011) this practice is directly involved in the higher development of the leaf tissue.

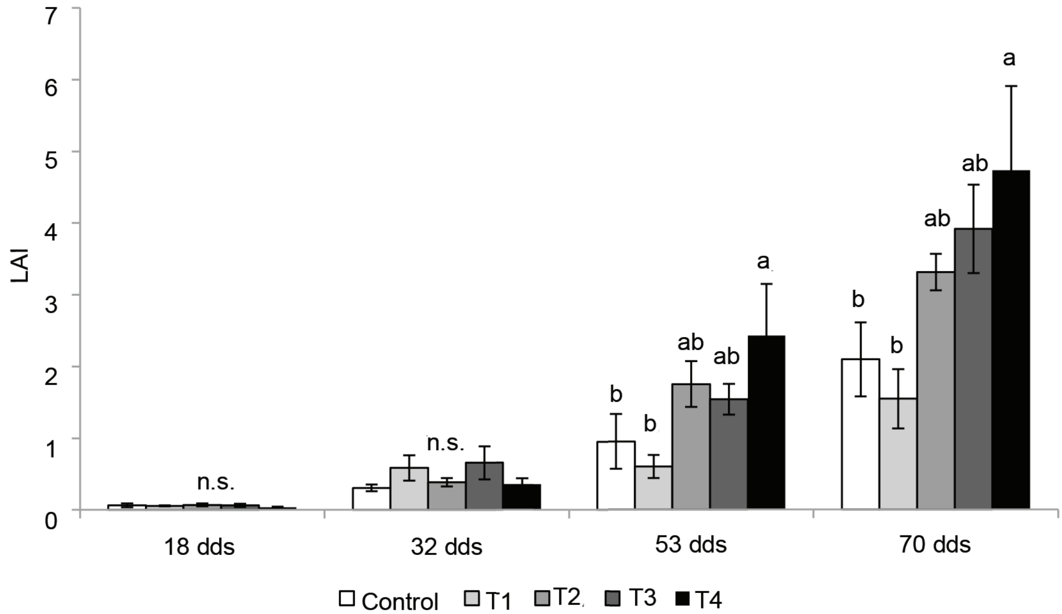

Figure 5. Leaf area index of A. sativa.
Different letters differ at p < 0,05 (Tukey).

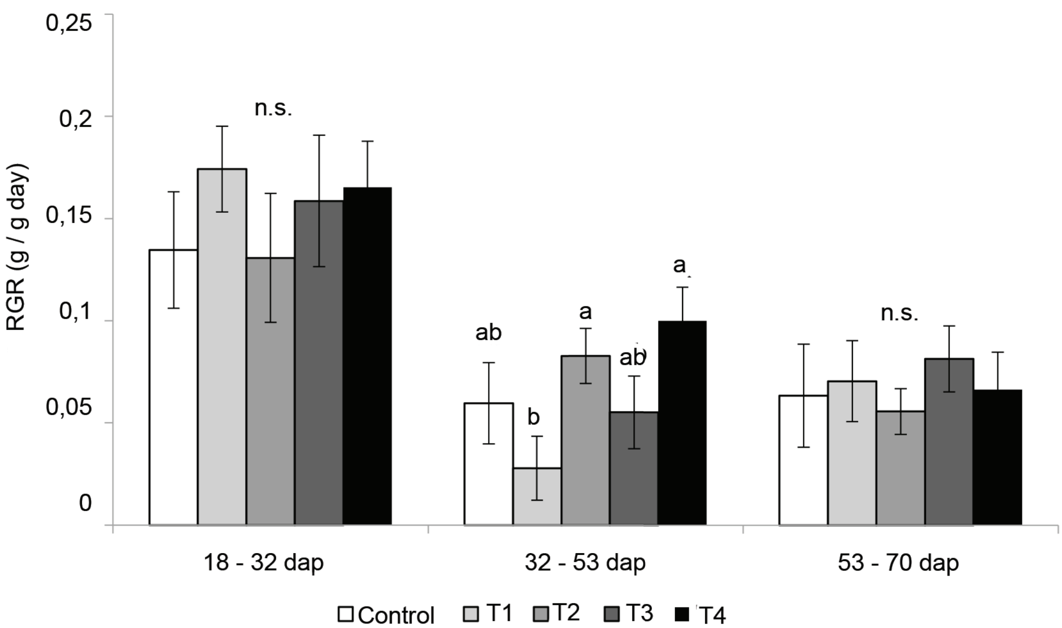

Figure 6. Relative growth rate.

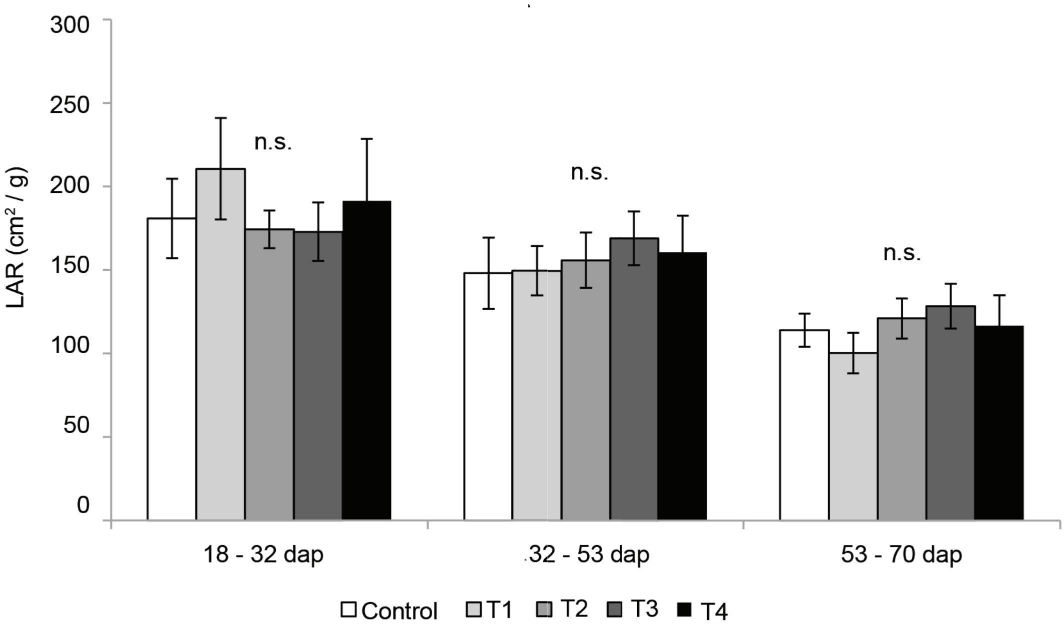

Figure 7. Net assimilation rate.
Different letters differ at p < 0,05 (Tukey).

The RGR only showed significant differences between 32 and 53 dap, period in which T4 and T2 showed better results compared with T1 (fig. 6). In the variation of the RGR different internal factors are involved, such as the development stage of the plant, and external biotic as well as abiotic factors (Shipley, 2006). Some reports indicate that the type of fertilization can have a great impact on plant growth (Chen, 2006; Derkowska *et al*., 2015), which could have influenced the results of this study.

The NAR represents the net carbon gain produced through photosynthesis with regards to its intake in respiration, both expressed per leaf area unit in time (Carranza *et al*., 2009). The relative growth rate is the result of complex processes in the plant, determined by physiological, morphological, genetic and environmental aspects. It should be stated that there are different methodologies related among themselves, for the quantification and modeling of the RGR in the studies with plants (Pommerening and Muszta, 2016). Thus, the method used in this study is based on the periodic relative increase in the plant growth.

The performance of the NAR can be directly related to that of the RGR, because both showed the same proportions of increase and maintained the significant differences with regards to other treatments, with the exception of T3 between32 and 53 dap (figs. 6 and 7). At the same time, it was observed that the LAR did not show differences among the treatments at any sampling moment (fig. 8). The relative growth rate expresses the increase in dry matter per unit of biomass in time, by the plants. This index is the product between the net carbon gain and the fraction of the total dry weight of the plants corresponding to the aerial part. Based on this, it is possible to explain the similarity of the RGR with regards to the NAR, because the LAR was homogeneous in the different treatments and, thus, did not have a large impact on the RGR. This result is comparable to the one obtained by Shipley (2006), who reported that the NAR is generally the best index to predict the variation of the RGR when the plants grow under high solar radiation conditions.

According to the results it is concluded that the combination of organic and inorganic fertilizers represents an alternative to guarantee the nutritional requirements to the forage oat under similar conditions to the ones in this study.

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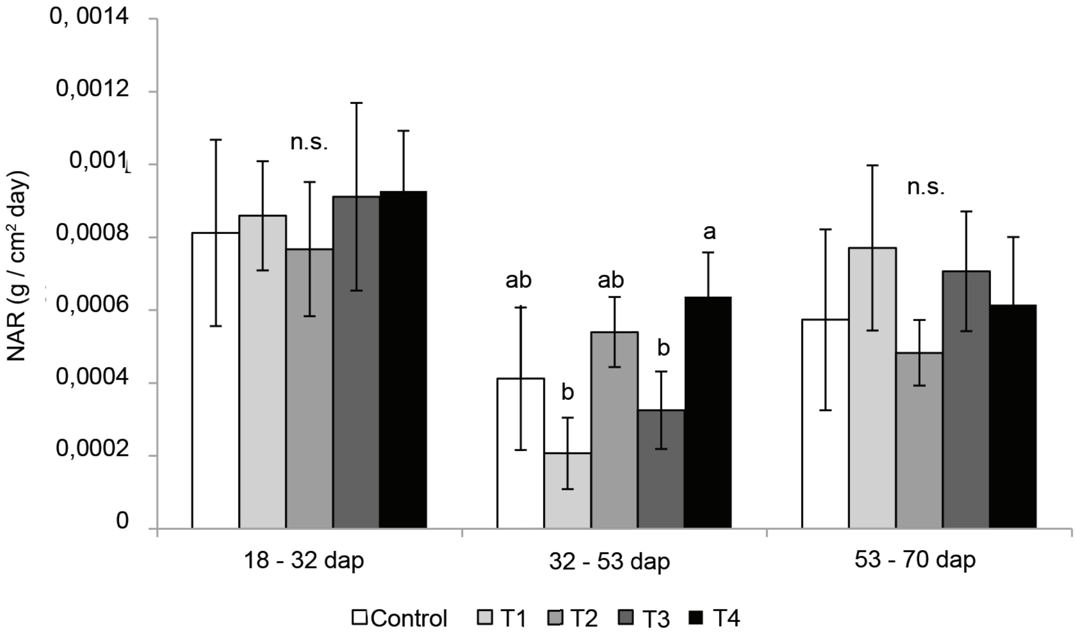

Figure 8. Leaf area ratio.
Different letters differ at $p < 0,05$ (Tukey).

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