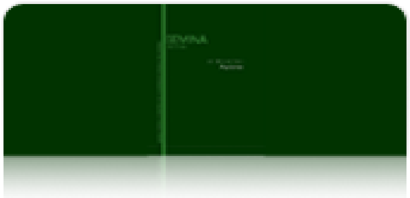

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Universidade Estadual de Londrina
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Restelatto, Rasiel; Glasenapp de Menezes, Luís Fernando; Paris, Wagner; Ricardo Sartor, Laércio; Newton Martin, Thomas; Bejarano Herrera, Wilfrand Ferney; Pavinato, Paulo Sérgio

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Sorghum and black oat forage production and its nutritive value under phosphate levels

Produção e valor nutritivo do sorgo forrageiro e da aveia preta sob doses de fósforo

Rasiel Restelatto[1]; Luís Fernando Glasenapp de Menezes[2]; Wagner Paris[2*]; Laércio Ricardo Sartor[2]; Thomas Newton Martin[3]; Wilfrand Ferney Bejarano Herrera[4]; Paulo Sérgio Pavinato[5]

Abstract

Phosphorus (P) is one of the most limiting mineral elements for biomass and grain production in tropical soils. This study was undertaken to assess the influence of P on herbage accumulation (DM) and the nutritive value of forage sorghum (*Sorghum bicolor*) and black oat (*Avena strigosa*) in succession. Evaluated treatments were P fertilization levels of 0, 50, 100, 150 and 200 kg of P_2O_5 ha^{-1} distributed in a randomized complete block design with three replicates. The treatments were applied at sorghum seeding in the summer 2010/2011 and 2011/2012. Black oat was seeded following sorghum in 2011 with no additional P fertilization. Herbage production and its nutritive value were assessed by successive cuts. The greatest sorghum DM yields were obtained at the highest phosphate level tested (200 kg P_2O_5 ha^{-1}), with residual response in subsequent black oat. There was no effect of P fertilization levels on the nutritive values of both crops, considering crude protein (CP) levels, in vitro dry matter digestibility (IVDMD), neutral detergent fiber (NDF) and acid detergent fiber (ADF), what demonstrates that P addition has no effect in forage nutritive value, especially when the soil P levels are classified as medium or high. The plant P recovery efficiency decreased when increasing P fertilization levels for both sorghum and black oat. The level of 50 kg P_2O_5 ha^{-1} $year^{-1}$ presented the greatest P recovery by plants, which supports the idea of less fertilizer use with more efficiency.
Key words: Animal feed. Phosphate fertilization. Recovery P. Tropical regions.

Resumo

O fósforo (P) é um dos elementos minerais mais limitantes na produção de biomassa e de grãos em solos tropicais. Este estudo teve como objetivo avaliar a influência do P na produção de matéria seca (MS) e no valor nutritivo do sorgo forrageiro (*Sorghum bicolor*) e da aveia preta (*Avena strigosa*) em sucessão. Os tratamentos foram constituídos com doses de P nos níveis de: 0, 50, 100, 150 e 200 kg de P_2O_5 ha^{-1}

[1] Discente de Doutorado, Programa de Pós-Graduação em Zootecnia, Universidade Federal do Paraná, UFPR, Curitiba, PR, Brasil. E-mail: restelattor@yahoo.com.br

[2] Profs., Departamento de Zootecnia e Agronomia, UTFPR, Dois Vizinhos, PR, Brasil. E-mail: luismenezes@utfpr.edu.br; wagparis@yahoo.com.br; laerciosartor@utfpr.edu.br

[3] Prof., Departamento de Agronomia da Universidade Federal de Santa Marina, UFSM, Santa Maria, RS, Brasil. E-mail: martin.ufsm@gmail.com

[4] Discente de Doutorado, Departamento de Ciência do Solo, Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo, ESALQ, Piracicaba, SP, Brasil. E-mail: wfbejaranoh@usp.br

[5] Prof., Departamento de Ciência do Solo, Escola Superior de Agricultura Luiz de Queiroz, ESALQ, Piracicaba, SP, Brasil. E-mail: pavinato@usp.br

[*] Author for correspondence

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distribuídos em um delineamento em blocos casualizados com três repetições. Os tratamentos foram aplicados no momento da semeadura, na cultura do sorgo no verão 2010/2011 e 2011/2012. A aveia foi semeada após o sorgo em 2011, sem a aplicação de P. A produção de forragem e o valor nutritivo das culturas foram avaliados por cortes. As maiores produções de MS do sorgo foram obtidas quanto foi aplicado a maior dose do fosfato (200 kg P_2O_5 ha^{-1}), com uma resposta residual na cultura subsequente da aveia preta. Não houve efeito dos níveis de P nos valores nutritivos de ambas as culturas, tanto nos teores de proteína bruta (PB), como na digestibilidade *in vitro* da matéria seca (DIVMS), na fibra em detergente neutro (FDN) e na fibra em detergente ácido (FDA), demonstrando que a utilização de fertilizantes fosfatados não tem efeito no valor nutritivo das forragens, especialmente quando os níveis de P do solo estão médios a altos. A eficiência de recupera ção P pelas plantas diminuiu quando as doses de P aumentaram tanto no sorgo como na aveia preta. A dose de 50 kg de P_2O_5 ha^{-1} ano^{-1} foi a que apresentou a maior recuperação de P pelas plantas, apoiando a ideia sob uma menor utilização de fertilizantes com maior eficiência.

Palavras-chave: Adubação fosfatada. Alimentação animal. Recuperação de P. Regiões tropicais.

Introduction

Brazil has the second largest commercial beef cattle herd in the world, is the greatest beef cattle exporter, and is the fifth largest milk producer in the world (ANUALPEC, 2014). Most of our beef cattle herd in Brazil is located on annual and perennial pastureland. However, Vaz and Lobato (2010) reported that Brazilian livestock data still fall short of our maximum capability, due to mis-match of forage sources, wrong feed planning, and a lack of management knowledge by the farmers.

Southern Brazil, a subtropical region with four well-defined seasons, is characterized by a great number of forage species with high potential as ruminant feed. Black oat (*Avena strigosa*), the temperate annual forage suitable for temperate and subtropical regions, annual, with high tillering and nutritive value, is an excellent alternative for cattle feed during the autumn/winter seasons, due to its adaptability to low temperatures and its high forage quality (SKONIESKI et al., 2011). Otherwise, during the spring/summer seasons maize (*Zea mays*), millet (*Pennisetum americanum*), sudan grass (*Sorghum sudanense*), sorghum (*Sorghum bicolor*), Alexander grass (*Uruchloa plantaginea*) and sunflower (*Helianthus annuus*) are the mostly used forages by cattle producers, because of its significant productive capacity and high nutritive value (SARTOR et al., 2011; WORTMANN et al., 2010). Thus, crop rotation using sorghum/black oat has emerged as a source of great potential for dairy or beef cattle feed in southern Brazil.

The nitrogen (N) and phosphorus (P) are the main elements required in fertilizers to supply crop production. These nutrients not only affect crop yields, but also the forage nutritive value (BARBANTI et al., 2011). Besides, P deficiency has limited the establishment of pastures in tropical and subtropical regions in Brazil (CARVALHO, 1985). This deficiency reduces initial growth, and delays the establishment of pastures, reducing their competitiveness against weeds. However, once in the plant, P promotes root growth, better cell division, photosynthesis, stocking of sugar and starch, and also affects the absorption and metabolism of several other nutrients, especially N (NOVAIS; SMYTH, 1999).

The hypothesis is that there is increase in herbage accumulation and improvement in nutritive value with P supplementation, since the potential of P adsorption/retention is high in clayey soils of Brazil. The objective of this study was to evaluate the effect of P fertilization levels on sorghum and oat herbage accumulation and nutritive value over a 18 month period.

Materials and Methods

Local description

The soil of the experimental area is classified as a Rhodic Hapludox. Chemical parameters of the soil prior to the first crop season are presented in Table 1. Overall, fertility parameters are at adequate levels, classified as high available P level at 0-10 cm and medium at a depth of 10-20 cm (CQFS RS/SC, 2004).

Crop cultivation cycles

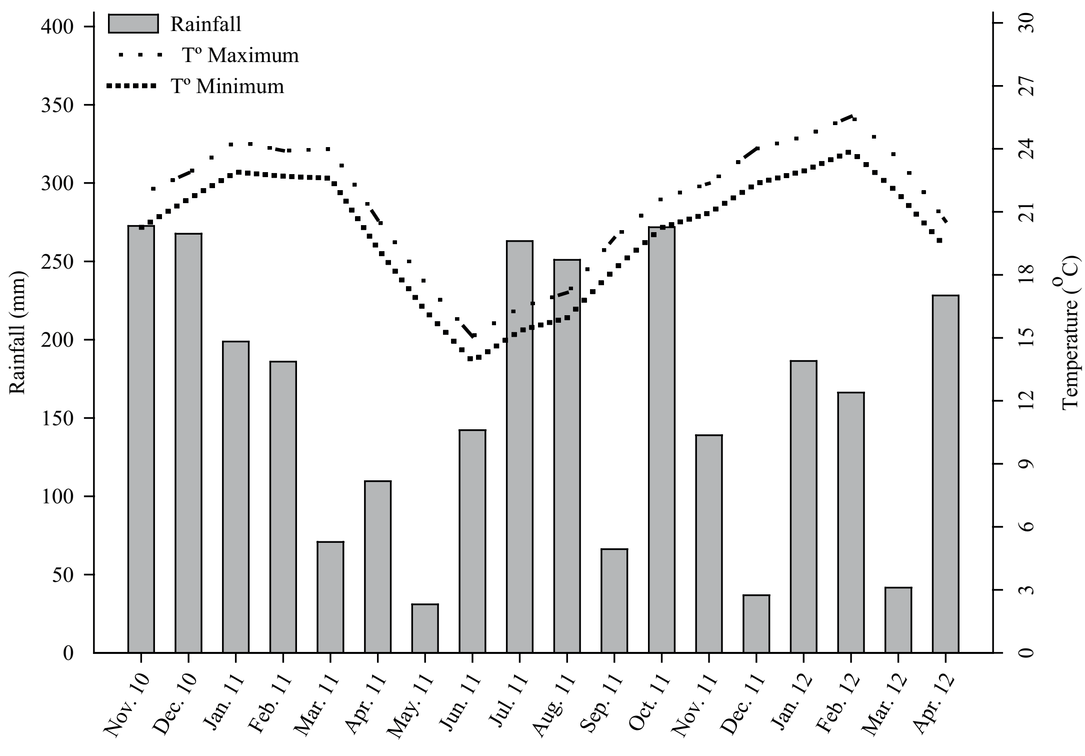
Three consecutive crops were cultivated: sorghum (summer 2010/2011); black oat (winter 2011) and sorghum again (summer 2011/2012). The forage sorghum cultivar used was 'Jumbo' (the hybrid derived from *Sorghum bicolor* and *Sorghum sudanensis*) and the black oat cultivar was 'Iapar 61'. The first sorghum cycle was from November 2010 to April 2011, with sowing date 11/15/2010. The winter black oat cycle was from May to October 2011, with sowing date 05/12/2011. The second sorghum cycle was from January to April 2012, with sowing date 01/31/2012. This delay in sowing date was due to an unusually dry period between November and December 2011, as shown in Figure 1, which prevented earlier crop establishment.

Table 1. Chemical soil parameters prior to sorghum cultivation in 2010. Dois Vizinhos, Paraná, Brazil.

Depth	pH	OM*	P-Mehlich	K	Ca	Mg	Al	H+Al	SB	T	V
(cm)	$CaCl_2$	%	mg dm^{-3}				$cmol_c$ dm^{-3}				(%)
0-10	4.90	3.48	8.62	0.30	5.13	2.34	0.06	5.35	7.77	13.12	59.2
10-20	4.50	3.22	4.20	0.15	3.59	1.69	0.28	5.76	5.43	11.19	48.5

*OM: Organic matter; H+Al: exchangeable acidity; SB: Sum of basis (Ca+Mg+K); T: cation exchange capacity; V: basis saturation index.

Figure 1. Mean monthly rainfall, mean maximum and minimum temperatures from November 2010 to April 2012, at the experimental area of UTFPR, Dois Vizinhos, PR, Brazil.



Experimental design and treatments

The plots were allocated in a randomized block design with three replicates; each plot was 5 x 5 m, totaling 25 m^2. For both sorghum cycles, row spacing was 40 cm, with a density of 15 kg ha^{-1} of viable seed, testing the treatments with 0, 50, 100, 150 and 200 kg P_2O_5 ha^{-1}, as triple superphosphate (45% P_2O_5 soluble), broadcasted at sowing. For black oat, row spacing was 20 cm, with a density of 40 kg ha^{-1} of viable seed, testing only the residual phosphate effect from the previous sorghum cycle. Dosages of 25 kg N ha^{-1} and 60 kg K_2O ha^{-1} were applied at sowing to both crops by using urea and potassium chloride. Two additional dosages of 25 kg N ha^{-1} were applied at the first and third cut for each of the three crop cycles evaluated (CQFS RS/SC, 2004).

Forage management and sampling

Forage sorghum sampling was performed by manual cutting in two rows of 0.50 m per plot, equivalent to 0.40 m^2. These samples were taken when the crop reached an average 0.70 to 0.80 m height, leaving a residual plant stalk of 0.20 m (simulating rotative grazing system). The remaining plot area was cut and removed manually. For black oat, forage sampling was assessed when the crop reached the recommended height for grazing, about 0.25 to 0.30 m (MIGLIORINI et al., 2010). Black oat samples were obtained manually by sickle cut at 0.10 m above ground level (simulating rotative grazing system), from two lines of 0.50 m totaling 0.20 m^2 per plot, the remaining plot was harvested by a mechanical cutter, at the same sampling height.

The herbage samples harvested in each cut was fresh-weighed, oven-dried at 60°C for 72 h to determine DM yield and then ground in a Wiley mill through a 1-mm sieve for subsequent laboratory analysis. The nutritive value of each cut was assessed from these samples.

Nutritive forage evaluation

The nutritive value of the samples was determined in Food Analysis Laboratory at the Federal Technological University of Paraná - Campus Dois Vizinhos and the levels of crude protein were determined by *kjeldahl* method (AOAC, 1990), neutral detergent fiber (NDF) and acid detergent fiber (ADF), according to the Van Soest et al. (1991), adapted for use of the Ankon 200 fiber digester and in vitro dry matter digestibility (IVDDM) according to Tilley and Terry (1963) adapted for use of artificial rumen (HOLDEN, 1999) and developed by Ankon®.

Phosphate recovery efficiency

The concentration of P in DM was determined according to Tedesco et al. (1995). After sulfuric digestion, P was measured by analytical method of blue-molybdate in colorimeter. The concentration was multiplied by DM yield to find the total nutrient accumulated. The recovery efficiency of applied P (RAP) was estimated by the accumulated amount of DM per unit of total nutrient applied which is calculated by the following equation, according to Fageria et al. (1998):

$$RAP = \frac{QP_f - P_0}{(\ Q_f\ )(kg.kg^{-1})}$$

Where, QP_f is the P accumulated in kg ha^{-1} with fertilization; P_0 is the P accumulated in kg ha^{-1} without fertilization; Q_f is the amount of applied fertilizer in kg ha^{-1}.

The cumulative herbage produced of each crop and the individual herbage accumulated in each cut of each crop were subjected to analysis of variance using SAS 8.1 (SAS Institute, 2001) at a significance level of 5%. The mean of nutritive parameters of each crop and the nutritive parameters of each cut were also subjected to analysis of variance. When significant, polynomial regressions were tested considering the highest significance degree. It was not compared year in the model since the weather had negatively influenced the establishment of sorghum in the second year and the final general results were distinct each year.

Results and Discussion

The sum of total herbage production (DM) of sorghum in 2010/2011 (Figure 2a) and 2011/2012 (Figure 2b) and black oat in 2011 (Figure 2c) were positively influenced by phosphate addition ($p<0.05$). There was a linear response in DM yield for sorghum, reaching a maximum of 11.49 Mg ha^{-1} in 2010/2011 and 6.09 Mg ha^{-1} in 2011/2012, under the highest P rate (200 kg P_2O_5 ha^{-1}). The mean DM yield during the second year was much lower than the first due to the sowing delay of 77 days, caused by the lack of rain in November and December 2011, as already mentioned in the methodology, that is the reason why was not compared years.

According to Mesquita et al. (2006), soil nutrients are essential for specific functions in plant metabolism. Thus, when the availability of one of these nutrients is low in the soil, it changes the plant metabolism and decreases forage quality and production. In our study, sorghum and black oat DM yield were improved by phosphate fertilization, even though the soil P levels were medium/high before planting, what may suggest a review in the current recommendations. This is supported by the results of Cruz et al. (2009), whom evaluated the response of two sorghum hybrids to P dosages, reaching a production of 6.48 to 8.73 Mg ha^{1} of DM for the cv BR304 and 6.15 to 8.75 Mg ha^{1} of DM for cv BRS310 at dosages of 0 to 75 kg P_2O_5 ha^{-1}, respectively, in soils under similar conditions to our study.

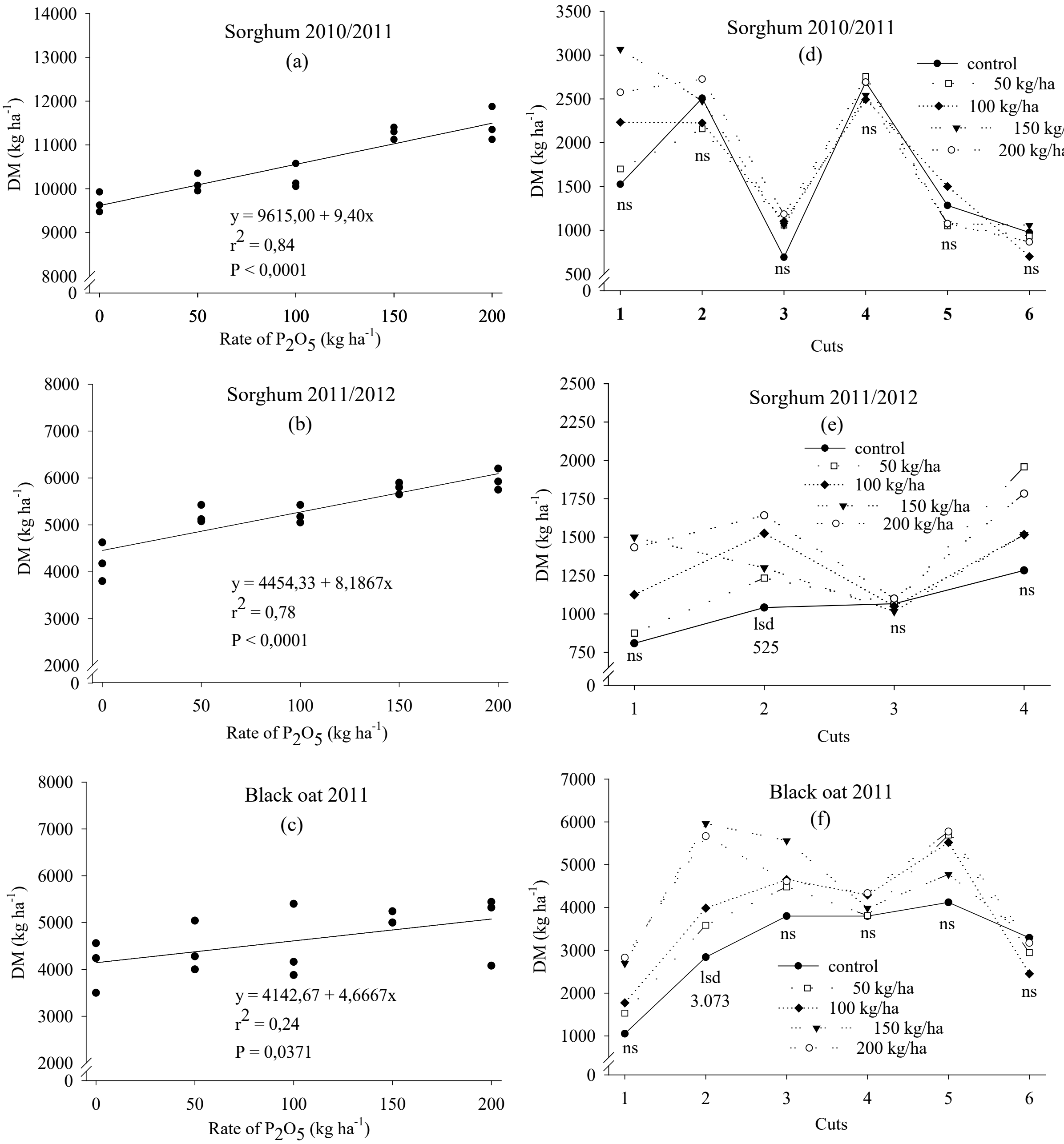
For black oat, a linear response in DM yield (Figure 2c) was also observed, reaching a peak of 5.08 Mg ha^{-1} under 200 kg P_2O_5 ha^{-1} applied in the sorghum, which in fact shows a great residual effect of phosphate fertilizer in this soil.

Evaluating each cut during the crop season, it was not detected influence in DM yield of sorghum by P levels in the year 2010/2011 (Figure 2d), but in 2011/2012 in the 2nd cut a significant effect was detected, where 200 kg P_2O_5 ha^{-1} presented the highest values (Figure 2e). This was also observed in the results of the 4th cut, although not significant as in the 2nd one. The black oat (Figure 2f) was influenced by phosphate only in the 2nd cut, where 150 and 200 kg P_2O_5 ha^{-1} had better results than the others, without any difference between levels in other cuts.

According to Pavinato et al. (2008) and other authors, crops requirement for P is lesser than N and K for an adequate development, but P still one of the most used nutrient applied via fertilizers in Brazil. This is explained by the low availability of this element in Brazilian soils and its strong interaction between clay colloids and phosphate ions, which reduces P availability, supporting the results found here and in the literature, which shows that rising P dosages has increased DM yields due to the residual effect in soil.

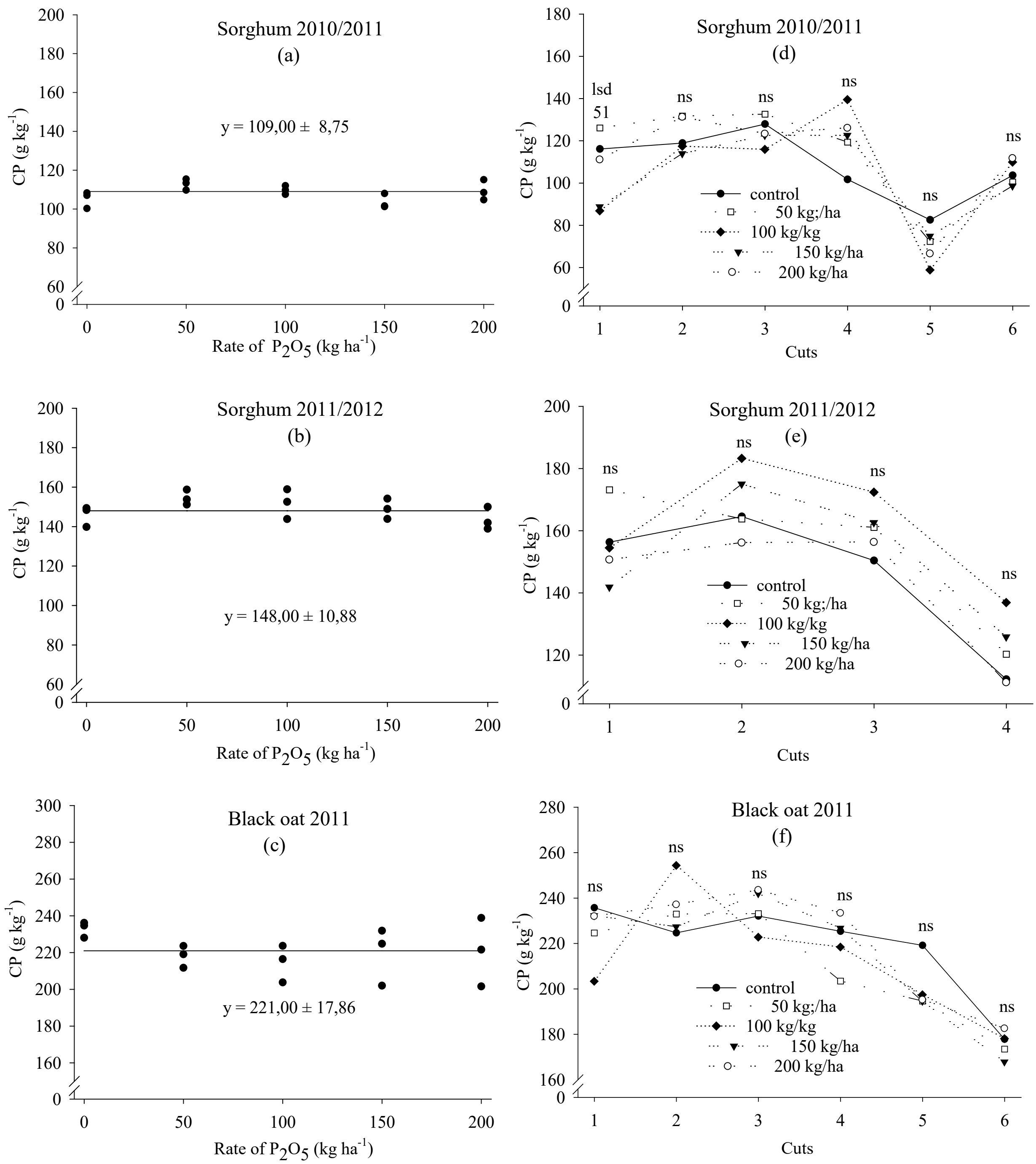
The nutritive value of forage can be estimated by various parameters. However, CP concentration is one of the most important as it directly influences forage consumption, milk and meat production by ruminants. The levels of crude protein (CP) by cut, and means by level on sorghum and black oat under phosphate fertilization are presented in Figure 3. For both crops phosphate levels were unable to affect the CP concentration (Figure 3a, 3b and 3c), reporting that soil available P at a medium level is enough for keeping high CP in the forage.

Figure 2. Cumulative DM yield and DM yield by cut of forage sorghum in 2010/2011 (a and d) and 2011/2012 (b and e) under phosphate levels, and black oat in 2011 (c and f) under the residual effect of P applied in sorghum in 2010/2011.



Van Soest (1994) has mentioned that pasture with CP concentrations below 70 g kg^{-1} of DM has a negative effect on consumption and animal development. CP concentration of sorghum, mean values of 109 and 148 g kg^{-1} of DM for the first and second year, respectively (Figure 3a and 3b), were much higher than the minimum levels stipulated by Van Soest (1994). Corroborating, Lima et al. (2008) evaluated the quantity and quality of crop residues produced by *Sorghum bicolor* (L.) cv. A; *Sorghum bicolor* (Guinea) cv. B; *Pennisetum glaucum* (L.) cv. BN2; *Panicum dichotomiflorum* and spontaneous vegetation, obtaining CP concentration of 121, 119, 83, 94 and 68 g kg^{-1} of DM, respectively, under 20 kg P_2O_5 ha^{-1}. The authors concluded that in addition to management and fertilization, the type of species is the most important in forage quality produced, with sorghum presenting the best results for CP.

Figure 3. Mean CP level and CP level by cut of forage sorghum during 2010/2011 (a and d) and 2011/2012 (b and e), under phosphate levels, and black oat in 2011 (c and f) under residual effect of P applied in sorghum in 2010/2011.



Working with *Sorghum bicolor* and *Sorghum almunn* in Italy, Gherbin et al. (2006) also reported a similar data of the present work in the first year, with mean levels of 112 and 121 g CP kg^{-1} of DM respectively. Moreover, no influence of P fertilization on sorghum CP concentration was observed. Simili et al. (2008) working with sorghum cv. AG 2501C in Brazil, reported values of 152, 160 and 159 g CP kg^{-1} DM under 0, 80 and 160 kg P_2O_5 ha^{-1}, pretty close to the ones obtained here in 2011/2012.

According to individual forage cuts, generally the more advanced the crop cycle, the lower the CP concentration (Figure 3d, 3e and 3f). Only in the 6th cut of sorghum in the year 2010/2011 the levels of CP were incremented in relation to the previous cut (Figure 3d). Regarding phosphate dosages, sorghum in 2011/2012 (Figure 3e) and black oat (Figure 3f) were not affected by P dosages in CP concentration. Only the first cut of sorghum in 2010/2011 (Figure 3d) was significantly affected by tP dosage, with a better CP at 50 kg P_2O_5 ha^{-1}.

Phosphate residual effect was not detected in the CP concentration in black oat, with a mean value of 221 g CP kg^{-1} DM (Fig. 3c). Cecato et al. (2001) evaluated eighteen oat cultivars fertilized with phosphate, reaching values between 171 and 223 g CP kg^{-1} DM in the first harvest, very similar to our results, also do not answering to phosphate fertilization, like our results. We detach here that the CP concentration always decline with the plant age, as observed in figure 3f. Ross et al. (2005) also found a decline from 310 to 180 g CP kg^{-1} DM for oats-clover mix at 35 and 88 days after planting, respectively, the same observed by other results in literature.

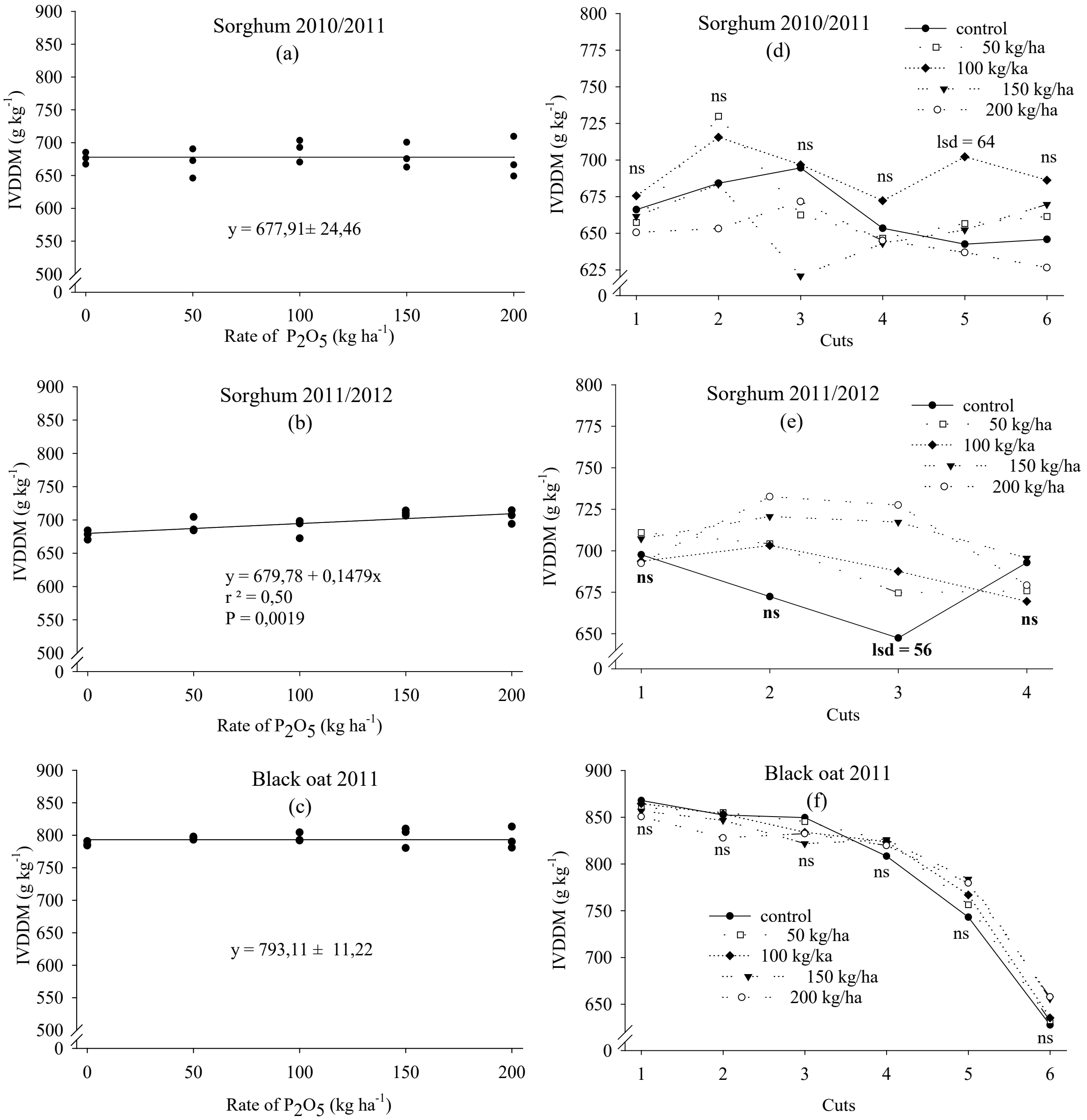
There was no effect of phosphate dosage on IVDMD levels for sorghum in 2010/2011 and black oat in 2011 (Figure 4a and 4c). A linear effect was observed for sorghum in 2011/2012 (Figure 4b), with a slight increase in IVDMD according to the P dosage ($p<0.05$). Tomich et al. (2006), evaluating the forage IVDMD of sorghum cv. BRS 800 and Sudan sorghum cv. AG 2501C, reported values up to 656 and 639 g kg^{-1} DM respectively, slightly below those found here, also without any effect of phosphate fertilization.

When the IVDMD level by cut were considered, sorghum in 2010/2011 presented very similar values of digestibility between the first and last cut (671 and 681g kg^{-1} respectively), and only the 5th cut was significantly affected by dosage, with the greatest response at 100 kg P_2O_5 ha^{-1} (Figure 4d). In 2011/2012 average sorghum digestibility between the first and last cut was also very similar (710 and 685g kg^{-1} respectively), with a significant effect in the 3rd cut, wherein the dosage of 200 kg P_2O_5 ha^{-1} presented the highest IVDMD level (Figure 4e). For black oat, the older the plant the lower the IVDMD levels observed (Figure 4f).

Restle et al. (2002) comparing different forages used in southern Brazil found IVDMD values of 675 g kg^{-1} DM for sorghum in the 1st cut, decreasing to 463 g kg^{-1} DM in the 5th cut, concluding that the plant stage and grazing cycle are the main factors influencing forage digestibility. However, our results (671, 672, 663, 668, 654 and 681 g IVDMD kg^{-1} DM from the 1st up to the 6th in 2010/2011 (Figure 4d) and 710, 690, 690 and 684 g IVDMD kg^{-1} DM from the 1st up to the 4th cut in 2011/2012 (Figure 4e), do not substantially declined according to plant age.

By assessing the IVDMD levels observed here and in the literature, it can be concluded that in high-fertility soils, with adequate-water supply throughout the crop cycle, P dosages do not affect IVDMD levels. In areas or periods of low water supply, especially in the early stage of crop development, P levels may provide higher forage digestibility, as observed in the second crop season (Figure 4b and 4e). A plausible explanation is that more available P promotes a more abundant root system development, exploring deeper soil layers in situations of water deficiency, do not compromising the forage production during short periods of deficiency (PAVINATO et al., 2008).

Figure 4. Mean IVDDM level and IVDDM level by cut of forage sorghum in 2010/2011 (a and d) and 2011/2012 (b and e), under phosphate levels, and black oat in 2011 (c and f) under residual effect of P applied in sorghum in 2010/2011.

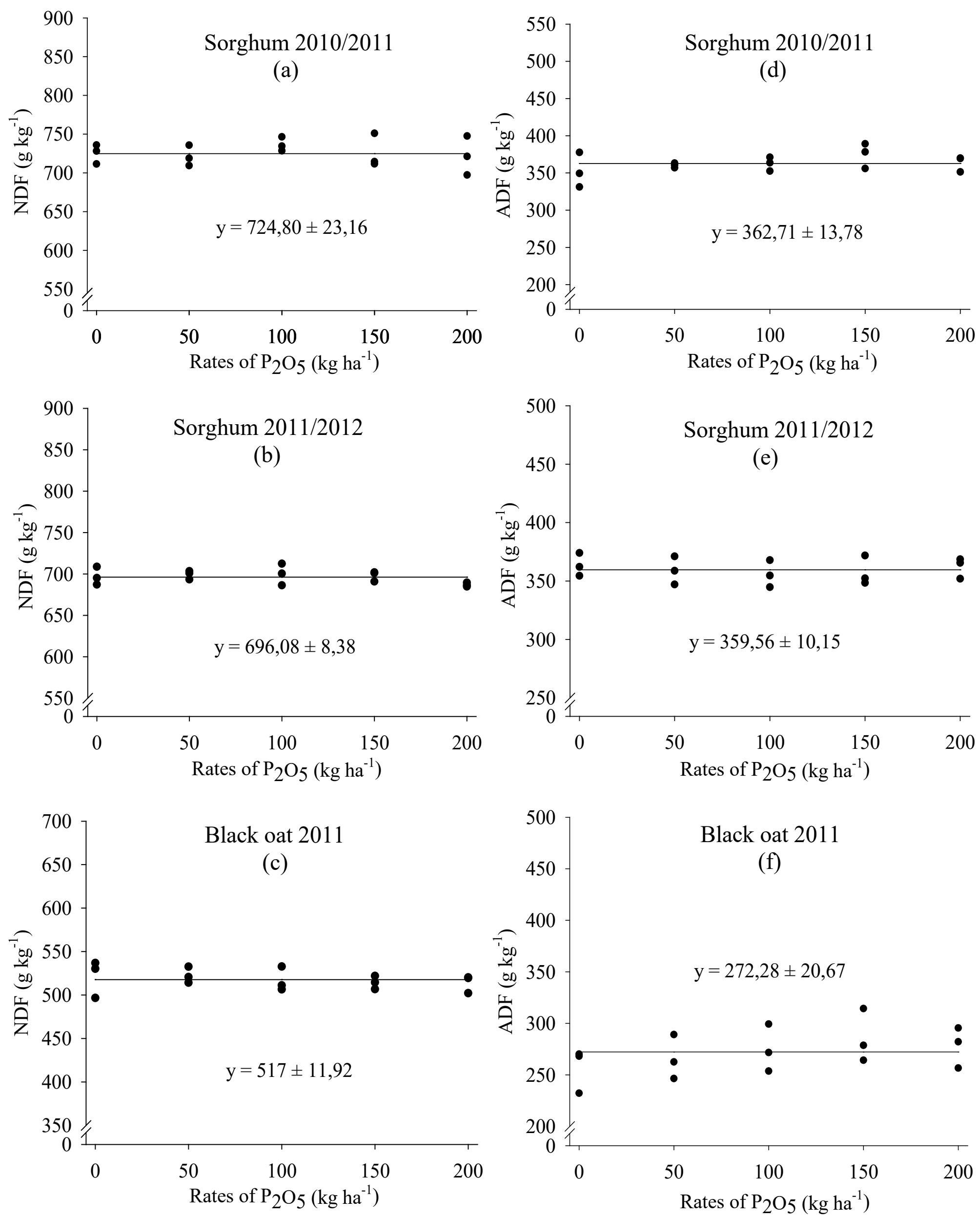


For black oat, the IVDMD levels were not influenced by residual P fertilization, with a mean of 793.1 g kg^{-1} of DM (Figure 4c). When evaluating the IVDMD by cut, Neres et al. (2012) found IVDMD levels of 843, 825 and 794 g kg^{-1} DM in the 1st, 2nd and 3rd cut, respectively, similar to those found here (865, 849, 838, 819, 778 and 668 g IVDMD kg^{-1} DM from the 1st up to the 6th cut, respectively (Figure 4f)). According to Mott (1974), high forage IVDMD values (700 to 800 g IVDMD kg^{-1} DM) observed in winter annual crops are due to seasonal conditions, with low solar radiation compared to the spring/summer. Consequently, there is smaller growth, lower amounts of NDF and

ADF, improving the digestibility, corroborating to the results presented here.

Similar to the CP and IVDMD results, the mean NDF and ADF levels in sorghum were not influenced by phosphate fertilization. The NDF levels in forage sorghum reached average values of 725 g kg^{1} of DM (Figure 5a) and 696 g kg^{-1} of DM (Figure 5b) in 2010/2011 and 2011/2012, respectively. The average ADF levels were 363 g kg^{-1} of DM (Figure 5d) and 360 g kg^{-1} of DM (Figure 5e) for the respective seasons. Souza et al. (2010) also reported no effect of P_2O_5 application on the NDF content in Tanzania grass (*Panicum maximum*), with mean levels of 740, 740 and 722 g kg^{-1} DM under the levels of 0, 50 and 100 kg of P_2O_5 ha^{-1}, respectively.

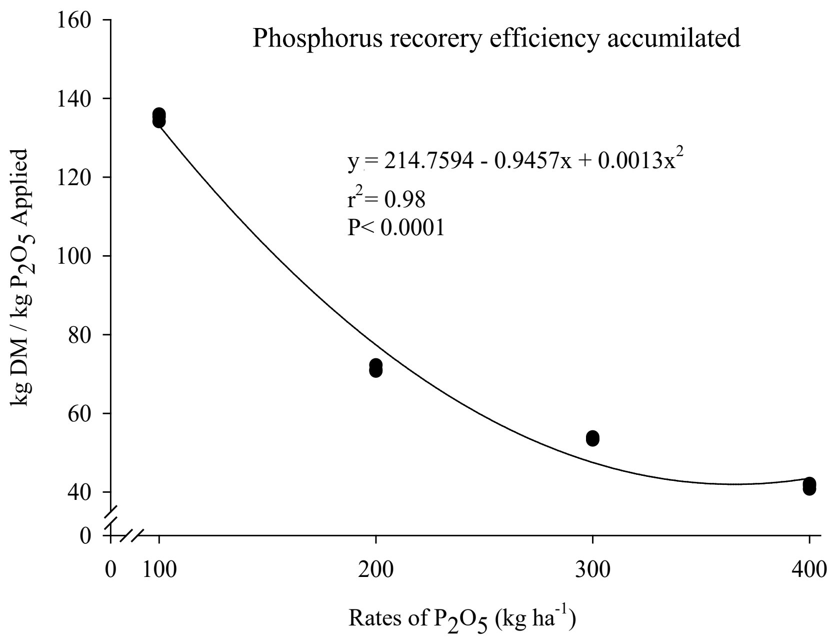
Figure 5. Mean levels of NDF and ADF of forage sorghum in 2010/2011 (a and d) and 2011/2012 (b and e) under phosphate levels, and black oat in 2011 (c and f) under residual effect of P applied in sorghum in 2010/2011.



Additionally, the NDF and ADF of black oat were not affected by residual phosphate (Figure 5c and 5f). Ross et al. (2005) found NDF levels of 520 g kg^{-1} DM and ADF levels of 305 g kg^{-1} DM of black oat, similar to the mean NDF levels found here, and slightly higher for ADF. Also, Moreira et al. (2001) reported mean NDF levels of 482 g kg^{-1} DM and mean ADF levels of 277 g kg^{-1} DM. As observed here and already mentioned in literature, the NDF and ADF can vary greatly depending on the crop cycle, temperature and carbohydrate contents, but P fertilization has no effect on these parameters.

The recovery P efficiency by plant, considering the sum of three consecutive crop seasons, was evaluated at the end of the experiment. As observed in Figure 6, recovery P efficiency under phosphate fertilizer application was higher at lower dosages, reaching 138 kg DM kg^{-1} P_2O_5 applied, and decreased according to fertilizer dosage, as expected. Lower recovery P efficiency was observed at the higher dosages (lower peak, 43 kg DM kg^{-1} P_2O_5, under a cumulative dosage of 364 kg P_2O_5 ha^{-1}), which may be explained by the initial soil P level, capable of supplying plant demand in a short time.

Figure 6. Phosphorus recovery efficiency by DM after three cycles (sorghum in the summer of 2010/2011 and 2011/2012 and black oat in the winter of 2011), under phosphate accumulated dosage levels.



Considering all the phosphates applied in tropical soils, plants can utilize only around 10-20% of the total (NOVAIS; SMYTH, 1999) due to soil adsorption processes, so the efficiency of plant P use depends on the soil chemical, physical and biological parameters and forage capacity (mainly root depth) to absorb this macronutrient. The efficiency of nutrient use/recovery is an essential diagnosis when working with P levels. The recovery efficiency was significantly influenced by P levels with a quadratic effect. However, we mentions that our original soil P levels were considered adequate for crop development, what may compromise our conclusions about forage answer to phosphate fertilization, especially about forage nutritive values.

Conclusions

It was observed increasing response to phosphate application in sorghum forage accumulation, with residual response in subsequent black oat forage production. However, the P recovery efficiency was reduced gradually according to the dosage applied, as expected, with less fertilizer use with better efficiency, since the DM yield was not substantially reduced under low or no P fertilization.

The nutritive parameters, such as CP, IVDMD, NDF and ADF, were not substantially affected by phosphate fertilization for either crop, what demonstrates that P fertilization has no effect in forage nutritive value, especially when the soil P levels are adequate for crop development.

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