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Effect of Phosphorus-Containing Polymers on the Shoot Dry Weight Yield and Nutritive Value of Mavuno Grass

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Abstract: In an effort to improve fertility, recover degraded areas and increase support for the capacity of livestock on pasture, new forms of fertilizer are being developed. Polymer-coated monoammonium phosphate (MAP) is an innovative source of phosphorus (P) for maintaining forage grass productivity. The aim this study was to evaluate the agronomic efficiency of P rates with the presence and absence of the polymer on the productivity, development and nutritional value of hybrid signalgrass (*Urochloa* spp.) cv. Mavuno. The field research was conducted on a dystrophic Ultisol. The experiment was arranged in a randomized complete block design with four replications and treatments applied in a factorial scheme (2 × 4) + 1. The treatments included two P sources (uncoated MAP and polymers-coated MAP) at four rates (20, 40, 80 and 160 kg ha^{-1} of P_2O_5), and the control received no P fertilization. The measured variables showed no differences between sources with or without polymer. The maximum production of accumulated shoot dry weight yield (SDWY) of the 'Mavuno' grass was 20.2 Mg ha^{-1} with the dose of 114 kg ha^{-1} of P_2O_5. The value of crude protein and in vitro dry matter digestibility showed a quadratic response with maximum production of 76.5% and 15.9% for the P_2O_5 rates of 37.2 and 91.1 kg ha^{-1}, respectively, while the acid detergent insoluble fiber showed a linear increase up to the rate of 80 kg ha^{-1} of P_2O_5. No differences were observed in plant height, number of tillers, or the relative chlorophyll content between treatments.

Keywords: forage; nutritive value; *Urochloa*; tropical grass

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1. Introduction

Brazil holds a major share of the global cattle population [1]. They are raised mainly on pastures that occupy 21.2% of the national territory, consisting of 13.2% cultivated pastures, and 8.0% of native pastures [2], and are distributed across 2.6 million properties [3].

A diverse range of grasses are used in the development of pastures, such as species of the genus *Megathyrsus*, which are used in intensive and semi-intensive systems. These grasses are used in approximately 10% of the pastures in Brazil [4]. However, they require high soil fertility, are difficult to breed, require specific management knowledge, and are losing space to grass cultivars of the genus *Urochloa*. Grasses of the genus *Urochloa*, such as *U. brizantha*, *U. decumbens*, and *U. ruziziensis* occupy approximately 95 million hectares of cultivated pasture area in Brazil [5]. 'Mavuno' grass is a forage grass obtained via hybridization of *U. brizantha* and *U. ruziziensis*, and was developed by Wolf Seeds in 2016. Only a few studies have investigated the yield, management, and fertilization responses of this forage grass; therefore, further research is necessary [6].

Phosphorus (P) is essential for root structure development and tillering of forage grasses, and a lack of this element can reduce the quantity and quality of production in

pastures. Extremely low P availability hinders the formation and maintenance of pastures. The high P adsorption capacity under acidic conditions and high levels of aluminum (Al) and iron (Fe) oxides in soil result in the deficiency of this element [7].

However, it is necessary to develop strategies to reduce the negative effects of P fixation and improve the efficiency of phosphate fertilization; one such strategy involves coating P fertilizers with polymers. Several companies have developed techniques to coat fertilizer grains with polymers to enhance their utilization by plants [8]. These polymer-coated P fertilizers can reduce P loss due to adsorption by soil colloids and reduce its contact with Fe and Al oxides and clay, which can negatively affect P availability and uptake in the soil. Therefore, monoammonium phosphate (MAP) with polymer-coated P can be better utilized by plants [9,10].

The use of coating on phosphate fertilizer granules, especially with polymers, has been evaluated in several agricultural crops, many showing positive results [11–14], although some works did not verify effects of polymers [15]. There is limited information about their effects on forage plants, and these effects must be investigated as forage plants represent an important source of food in cattle production, especially in tropical regions characterized by acid reaction soils [9].

We hypothesized that MAP coated with polymers improves the forage and pasture quality of hybrid 'Mavuno' grass. Using MAP coated with polymers as a source of P during fertilization results in greater rooting and shoot dry mass yields. The aim of this study was to evaluate the agronomic efficiency of MAP coated with polymers on the nutrition, development, nutritive value, shoot dry weight yield and roots of 'Mavuno' grass.

2. Materials and Methods

2.1. Site

The experiment was carried out in Araçatuba (21°10′53″ S, 50°26′07″ W), São Paulo State, Brazil, at an altitude of 390 m. The climate is defined as Aw according to the Köppen classification [16]. The experiment was installed on an area with hybrid signalgrass (*Urochloa* spp.) cv. Mavuno cultivated for two years (since 2018). The average annual temperature and rainfall are 22 °C and 1206 mm, respectively, with an average maximum temperature of 31 °C and average minimum of 19 °C. Details on the climatic conditions during the experiment are shown in Figure 1.

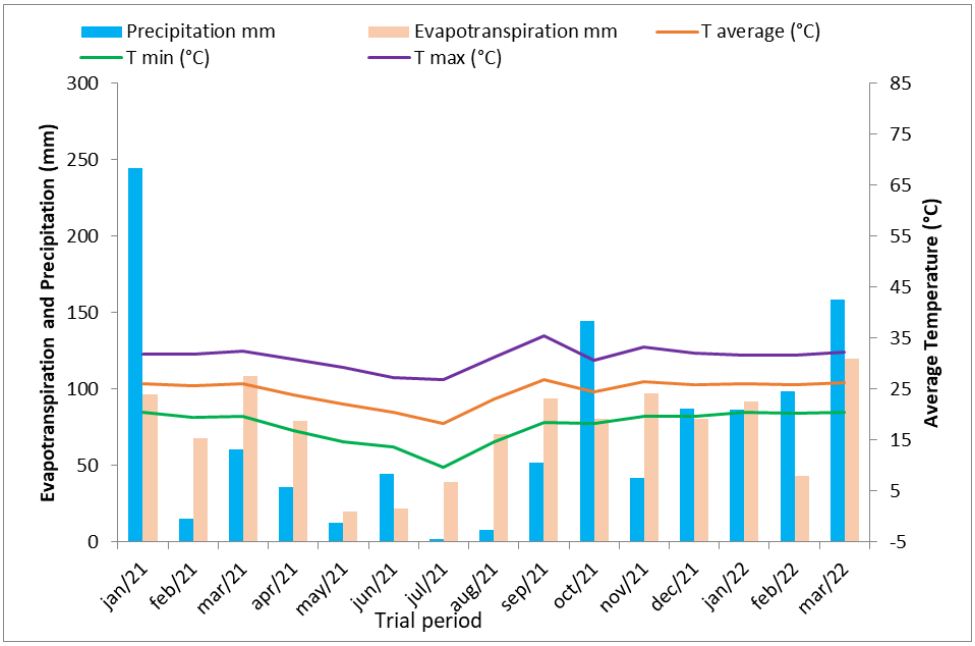

Figure 1. Maximum, average and minimum air temperatures (°C) and monthly accumulated rainfall (mm) during the experiment.

The soil is classified as a dystrophic Ultisol according to the Brazilian Soil Classification System [17]. A total of 15 soil samples were collected at a depth of 0–0.2 m. The soil properties were as follows: organic matter = 16 g dm^{-3}; pH = 5.1; P (phosphorus resin) = 4.0 g dm^{-3}; K^+, Ca^{2+}, Mg^{2+}, H + Al, Al^{3+}, SB, and cation exchange capacity = 0.6, 18.0, 11.0, 22.0, 29.6, and 51.6 $mmol_c$ dm^{-3}, respectively; base saturation = 57.0%, clay = 155 g kg^{-1}; silt = 110 g kg^{-1}; and sand = 735 g kg^{-1}. The liming requirement was determined using the base saturation method to reach 70% cation exchange capacity [18]. Dolomitic limestone (MgO > 12%) with 90% neutralizing power was used for soil remediation at the end of August 2020 at the time of pasture establishment in the area.

2.2. Experimental Design and Treatments

The experiment was arranged in a randomized complete block design with four replications and treatments in a factorial scheme (2 × 4) + 1, represented by two sources (uncoated MAP and polymer-coated MAP) at four rates (20, 40, 80 and 160 kg ha^{-1} of P_2O_5), and without P fertilization (control). The MAP without a coating had 11% nitrogen (N) and 52% P_2O_5, while polymer-coated MAP had 10% N and 49% P_2O_5. Owing to the polymer coating, the concentrations of N and P in the coated MAP were slightly lower than in the MAP without a coating.

N and potassium (K_2O) fertilization using urea (45% N) and potassium oxide (60% K_2O) was applied homogeneously across all plots at 40 and 60 kg ha^{-1}, respectively. Fertilizer applications were usually performed in the late afternoon and at mild temperatures. For each treatment, 40 kg ha^{-1} of N of urea (45% of N) was applied as fertilizer.

2.3. Harvest and Nutritive Value

During the experimental period, cuts were performed on average every five weeks in the rainy season (summer) and eight weeks in the dry season (winter). Seven cuts were conducted during the dry and rainy seasons to determine the shoot dry weight yield (SDWY) when the plants had partially reached a height of 0.5 m [19]. The shoots were harvested at 0.15 m above the soil surface [20]. The samples used to estimate the SDWY were collected with a sampler square with an area of 1.0 m^2, and a sickle (cleaver) was used to cut the interior of the plants to remove the grain (Figure 2).



Figure 2. Cutting day in the summer season.

Before each cut, plant height was measured using a millimeter ruler, and the relative chlorophyll index (SPAD) was obtained using a SPAD-502 Plus digital chlorophyll meter (SPAD—Development of soil and plant analysis) on newly expanded leaf slides. The tiller

number was counted in a 0.25 m^2 circle inside each plot and then multiplied by four to express the number of tillers per m^2.

After harvesting, the plant material was first weighed and approximately 200 g of leaf blade fraction was separated. Subsequently, the stem + sheath was identified, weighed, and dried in an oven with forced air circulation at a temperature of 55 °C for 72 h according to the methodology of Silva and Queiroz [21] (Figure 3). The dry material was weighed on a precision scale to quantify the yield of forage dry mass, and the samples were ground in a Wiley mill followed by sieving through a 1.0 mm sieve. The nutritive value (crude protein, neutral detergent fiber, and acid detergent fiber) was determined according to [22], and true in vitro dry matter digestibility (IVDMD) was determined according to [23]. Total N content was determined by sulfuric acid digestion followed by the semi-micro distillation Kjeldahl method [24].



Figure 3. Identification of stem + sheath.

The root systems were evaluated at the end of the experiment (Figure 4). The root biomass of the stratified pasture was determined at a depth of 0–0.2 m based on one sample per plot, using a cylindrical steel tube (0.5 m long and 0.1 m in diameter) with an opening to facilitate the stratification of samples. The roots were cleaned by successive washing in running water in 1.0 mm mesh sieves until it was no longer possible to identify any soil contamination. Subsequently, the root samples were dried in an oven with forced air circulation at 55 °C until a constant weight was achieved.



Figure 4. Root evaluation.

2.4. Statistical Analysis

The data were tested for normality of error and the variables SDWY, botanical composition, chlorophyll content (SPAD), and chemical-bromatological composition in the model of repeated measurements over time in split plots. For cumulative yield, the data were grouped according to summer (February–March 2021, January–March 2022) and winter (May 2021 and November 2021) seasons. Base 10 logarithm transformation of the root yield was applied, and the results were subjected to analysis of variance followed by Tukey's multiple comparison test ($p \leq 0.05$) using the SISVAR program [25]. Regression equations were applied only to the significant data [26].

3. Results

3.1. Shoot and Root Dry Weight Yield

Analysis of the observations revealed that the MAP sources with and without polymers did not show any significant differences in terms of the shoot dry weight yield (SDWY) accumulated, SDWY in the rainy and dry seasons, or the root dry weight yield (RDWY) of 'Mavuno' grass (Table 1). The P application rate had a significant effect on SDWY accumulation during the rainy season and on RDWY (Figure 5). However, in the wet season regression equation, the maximum SDWY was achieved with an application rate of 120 kg ha^{-1} of P_2O_5.

Table 1. Means of accumulated dry weight yield of shoots in the summer, winter, and total seasons, and root dry weight yield of Mavuno grass for different phosphorus sources and rates, in the presence and absence of polymers in dystrophic Ultisol.

Rates P_2O_5 (kg ha^{-1})	**SDWY Accumulated**	**SDWY Summer**	**SDWY Winter**	**RDWY *****
	------- (Mg ha^{-1}) ----------			(kg m^{-3})
0	15.19	11.18	4.01	8.52
20	18.09	13.90	4.19	6.87
40	18.78	14.06	4.42	6.50
80	19.11	14.38	4.42	9.30
160	19.63	15.10	4.53	8.33
Polymers				
Absence	18.09	13.74	4.34	7.52
Presence	18.24	13.70	4.53	8.02
Pr ≥ F				
Sources	0.7452	0.9086	0.5078	0.3317
Rates	0.0001 **	0.0001 **	0.4208	0.0265 *
Sources × Rates	0.6367	0.9473	0.5420	0.2179
Means	18.16	13.72	4.43	7.77
CV (%)	7.99	8.43	20.49	20.30

* significant at 5% probability ** significant at 1% probability. *** Root dry weight data were log 10 transformed. CV = coefficient of variation.

The SDWY accumulated in the 14 months of evaluation of 'Mavuno' grass varied as a function of the P application rates applied in the pasture (Table 1). No significant differences were found between phosphate sources and source-versus-rate interactions. SDWY ranged from 15.2 to 19.6 Mg ha^{-1} over the evaluation period, which consisted of two growing seasons and one dry season. The polynomial regression equation for P_2O_5 application rates showed $R^2 = 0.85$ (Figure 5a), demonstrating that 'Mavuno' grass responded well to P application at higher rates. The SDWY for the spring and summer period (wet season) ranged from 11.2 to 15.1 Mg ha^{-1}, while that of the dry season was 77% of this (Figure 5b). Figure 1 shows the precipitation and maximum and minimum temperatures during the experimental period and explains the seasonality of tropical forage yields. However, in the

wet season regression equation, the maximum SDWY was achieved with a P_2O_5 application rate of 120 kg ha^{-1}. In the dry season, the SDWY ranged from 4.0 to 4.5 Mg ha^{-1}.

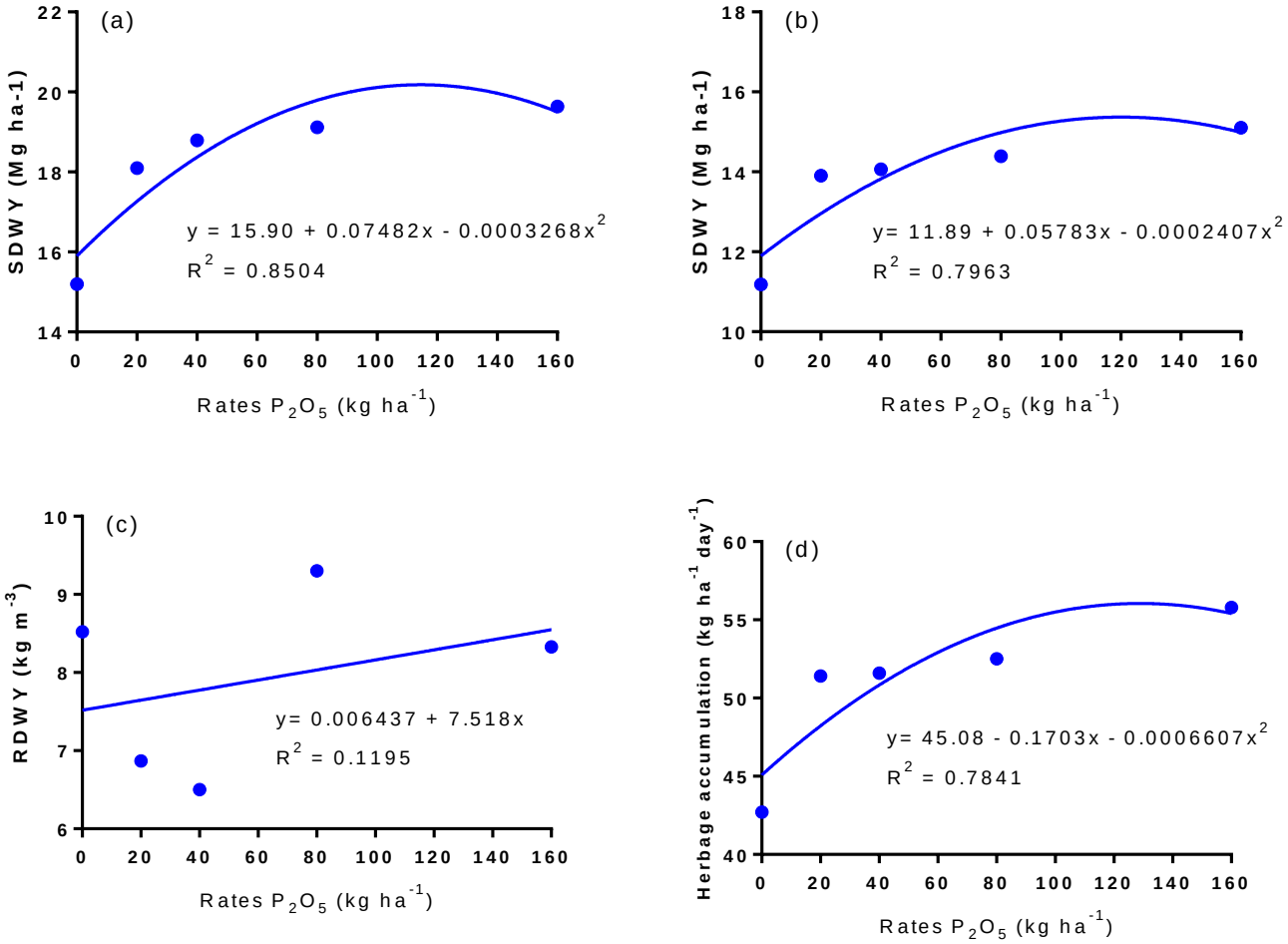

Figure 5. Regression equation means of accumulated SDWY (**a**), accumulated SDWY in the summer (**b**), root dry weight yield (RDWY) (**c**), and herbage accumulation (**d**) of 'Mavuno' grass as a function of phosphorus sources and rates, in the presence and absence of polymers in dystrophic Ultisol, Araçatuba, SP, 2022.

At the end of the experiment, the root system was sampled using a probe at a depth of 0–0.2 m. It was found that only two years after planting in the experimental area, the grass had formed a substantial quantity of roots in kg m^{-3}, which differed significantly depending on the P application rates applied. We verified that 80 kg of P_2O_5 haP2O5 applicatioP2O5 applicatio produced 13% more roots than the control treatment (Table 1 and Figure 5c).

The average SDWY varied as a function of the P_2O_5 application rate from 2.2 to 2.8 Mg ha^{-1}, and only the P application rates showed a significant effect (Table 2). No significant differences were found with respect to the P applied to the pasture. However, the regression equation indicates that the maximum mean SDWY was achieved with 114 kg ha^{-1} of P_2O_5. Figure 5d shows the effects of P_2O_5 application rates on herbage accumulation per hectare per day, which followed the same trend as SDWY.

3.2. Plant Height, Number of Tillers per Square Meter, and Relative Chlorophyll Index

The sources of MAP treatments did not show significant differences in grass height, number of tillers, SPAD units, or leaf blade percentage (Table 3), indicating that in the edapho-climatic conditions studied, the coated MAP had no advantage over conventional MAP.

Table 2. Mean dry weight yield of shoots per evaluation and herbage accumulated per hectare per day of Mavuno grass for different phosphorus sources and rates, in the presence and absence of polymers in dystrophic Ultisol.

Rates P_2O_5 (kg ha^{-1})	Mean Dry Weight Yield of Shoots (Mg ha^{-1})	Herbage Accumulated (kg ha^{-1} day^{-1})
0	2.17	42.7
20	2.58	51.4
40	2.68	51.6
80	2.73	52.5
160	2.80	55.8
Polymers		
Absence	2.58	50.9
Presence	2.60	50.7
Pr ≥ F		
Sources	0.7885	0.9287
Rates	0.0001 **	0.0001 **
Sources × Rates	0.7867	0.9396
Means	2.59	50.8
CV (%)	25.84	26.03

** significant at 1% probability. CV = coefficient of variation.

Table 3. Mean plant height, number of tillers per square meter, relative chlorophyll index and leaf blade percentage of Mavuno grass for different phosphorus sources and rates in the presence and absence of polymers in dystrophic Ultisol.

Rates P_2O_5 (kg ha^{-1})	Plant Height (cm)	Number of Tillers (Number m^{-2})	Relative Chlorophyll Index	Leaf Blade Percentage
0	46.48	188	28.9	72.4
20	52.18	168	30.3	70.9
40	51.51	188	30.7	72.1
80	52.11	200	30.7	73.0
160	52.69	208	30.4	72.1
Polymers				
Absence	51.64 a	208	30.3	72.0
Presence	50.35 b	204	30.1	72.2
Pr ≥ F				
Sources	0.0260 *	0.3947	0.5589	0.8017
Rates	0.0001 **	0.0044 *	0.0001 **	0.5130 ^{ns}
Source × Rates	0.1081	0.2567	0.2171	0.8829
Means	50.99	206.32	30.2	72.11
CV (%)	9.44	26.22	7.27	8.73

Means with the same lowercase letters in the column are not different using the Tukey test ($p \leq 0.05$). * significant at 5% probability ** significant at 1% probability. ^{ns} = not significant. CV = coefficient of variation.

The average height of the plants during the experiment was 46.5–52.7 cm, demonstrating that the height of the grass was within the ideal range for 'Mavuno' grass. The height varied significantly depending on P sources and application rates. However, there was no interaction between the P sources and rates (Table 3). The percentage of leaf blades was 70.9–73.0% and did vary significantly with sources, rates, or the interaction of P sources and rates.

The polynomial equation for P application rates as a function of plant height is shown in Figure 6a. A small variation was observed between the treatments, and a target height was maintained for the 'Mavuno' grass evaluation. The number of tillers did not differ significantly with P sources, and no interaction of P sources and rates was observed.

The values ranged from 168 to 208 tillers per m^2, and the polynomial equation for the P application rates is shown in Figure 6b.

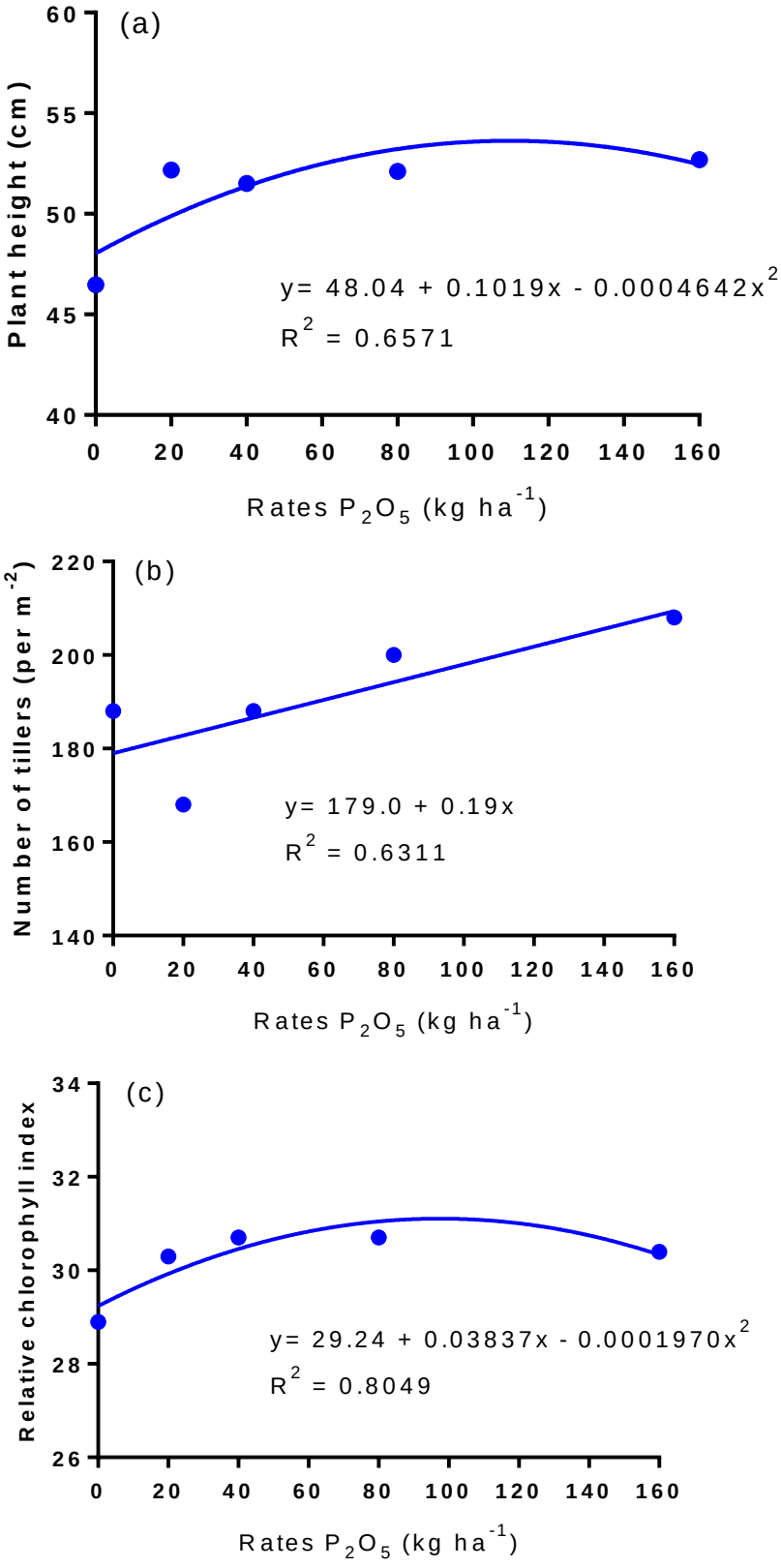

Figure 6. Regression equations for plant height (**a**), number of tillers per square meter (**b**), relative chlorophyll index (**c**) of Mavuno grass as function of phosphorus sources and rates in the presence and absence of polymers in dystrophic Ultisol.

SPAD did not vary significantly between sources and no interaction of P sources and rates was observed. The P application rates are represented by the polynomial equation shown in Figure 3. The values ranged from 28.9 to 30.7. The maximum SPAD was achieved with 95 kg of P_2O_5 ha^{-1}.

3.3. Nutritive Value

The neutral detergent insoluble fiber (NDF), acid detergent insoluble fiber (ADF), crude protein (CP), and true in vitro dry matter digestibility (IVDMD) are shown in Table 4. The results did not show significant differences with P sources and no interaction between P sources and rates was observed. However, significant differences in ADF, CP, and IVDMD were detected under different P application rates (Figure 7a–c). The P application rate had no significant effect on NDF (p = 0.1267). The ADF values ranged from 32% to 34%, which were not significantly different from those of the control treatment, except for the highest fertilizer dose (Figure 7a).

Table 4. Mean neutral detergent insoluble fiber (NDF), acid detergent insoluble fiber (ADF), crude protein (CP) content and in vitro true digestibility of dry matter (IVDMD) of Mavuno grass at different phosphorus sources and rates in the presence and absence of polymers in dystrophic Ultisol, Araçatuba, SP, 2022.

Rates P_2O_5 (kg ha^{-1})	**NDF**	**ADF**	**CP**	**IVDMD**
			%	
0	67.3	32.8	12.9	76.7
20	67.7	33.4	15.0	75.9
40	67.8	33.7	15.5	76.4
80	67.0	33.0	15.4	76.8
160	67.6	34.1	14.6	74.7
Polymers				
Absence	67.4	33.5	14.8	76.2
Presence	67.6	33.4	14.6	76.0
Pr ≥ F				
Sources	0.2514	0.5702	0.6866	0.5727
Rates	0.1267 ^{ns}	0.0016 **	0.0047 **	0.0001 **
Sources × Rates	0.5698	0.2146	0.4842	0.1064
Means	67.5	33.4	14.7	76.1
CV (%)	2.63	5.59	26.67	3.50

** significant at 1% probability. ^{ns} = not significant. CV = coefficient of variation.

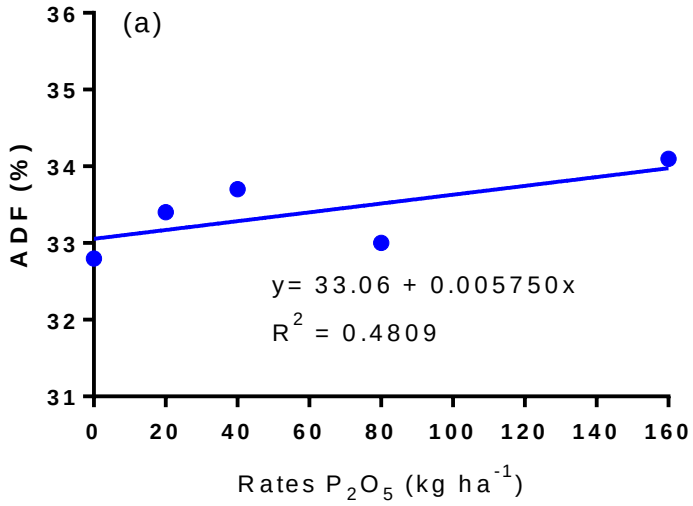

Figure 7. *Cont.*

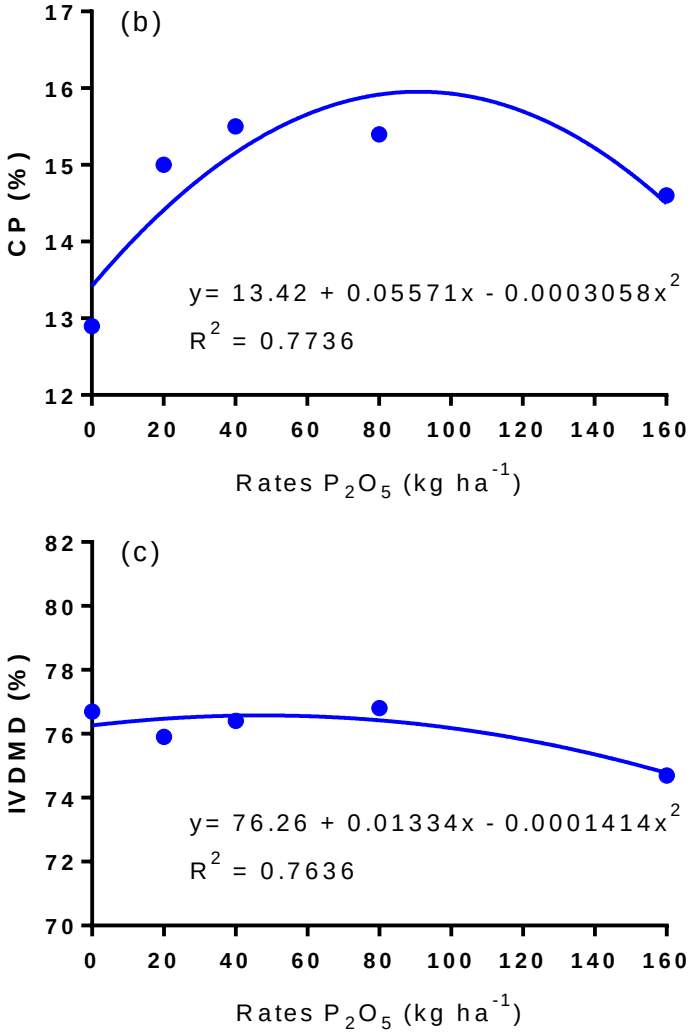

Figure 7. Regression equation of acid detergent insoluble fiber (ADF) (**a**), crude protein (CP) content (**b**) and in vitro true digestibility of dry matter (IVDMD) (**c**) of Mavuno grass as a function of phosphorus sources and rates in the presence and absence of polymers in dystrophic Ultisol.

P application rates had a significant effect on CP (p = 0.0047). The CP ranged from 13% to 15%, and by unfolding the polynomial regression equation, the CP responded to up to 91 kg ha^{-1} of P_2O_5 (Figure 7b). At each cut, the grass plots were fertilized with 40 kg N ha^{-1}. It was observed that 20, 40, and 80 kg ha^{-1} of P_2O_5 was associated with N fertilization.

4. Discussion

The SDWY and RDWY results indicate that there was no gradual release of P from the polymer-coated granules into the soil. This may be because its effectiveness was compromised by the rapid degradation of the polymer owing to the conditions imposed by edaphoclimatic factors, such as high temperature (Figure 1) and the type of soil, because moisture was not retained and this element was unavailable for a longer period.

A second reason could be the considerable increase in the base saturation values, as mentioned by [9] and [27], which could decrease the efficiency of the polymer-coated MAP by precipitating P in solution via the saturation of cation exchange sites with polymers. Gazola and collaborators [27] did not observe statistical differences between conventional and polymer-coated MAP in maize (*Zea mays* L.). Another study [28] reported higher yields of maize and common bean (*Phaseolus vulgaris* L.) under application of polymer-coated MAP compared with yields under conventional MAP.

Martins, et al. [29], working with coated MAP, observed that corn grain yield increased with increasing doses of P_2O_5 up to about 132 kg ha^{-1}, regardless of whether or not MAP was coated with polymers. In terms of grain yield, Fiorini et al. [30] did not detect responses in grain yield using policote-coated MAP compared with conventional MAP and suggested that this is due to the phosphorus content in the soil being very close to the value considered optimal in the soil.

According to Guelfi et al. [31] fertilizer technologies can reduce phosphorus losses in farming systems and lead to improvements in crop yields and quality. This increase in the efficiency of fertilization must always be linked to greater economic profitability and less environmental impact, obeying the principles of sustainability and the circular economy.

The efficiency of the polymer-coated fertilizer granules depends on the water solubility of the polymer. Thus, the process of nutrient release is regulated. Some authors [27,32] stated that the release and dissolution of these fertilizers depends on the type of coating, thickness, type of material, and factors such as soil moisture and temperature.

The maximum value of accumulated SDWY was 16.0 Mg ha^{-1} under an estimated application rate of 114 kg ha^{-1} of P_2O_5. These results agree with those of [13], who evaluated soybean (*Glycine max* L.) yield using MAP and polymer-coated MAP and observed increases of 10.0 and 8.5%, respectively. In the absence of P_2O_5 application, the grass produced 29.0% less forage compared with that under the highest P_2O_5 application rate.

For RDWY, the result was positive only at 80 kg ha^{-1} of P_2O_5. This result agrees with that of [33], who observed that the RDWY results of soybean plants did not differ significantly between coated and uncoated fertilizer, although a slight improvement was observed with the former. Similarly, the authors of [14], working with sugarcane (*Saccarum* spp.), observed no statistically significant effect, and the highest yield was observed with application of 80 kg of P_2O_5 ha^{-1}.

In an evaluation of Convert HD 364 grass (crossing hybrid of *U. brizanta*, *U. decumbens* cv Basilisk and *U. ruziziensis*) under grazing using the continuous stocking method at different grazing intensities, the authors of [20] reported an increase in the SDWY in the range of 4.6 to 9.0 Mg ha^{-1} at 75 kg ha^{-1} year^{-1} of P_2O_5. Silva et al. [20] observed that the annual forage productivities of 'Mavuno' grass and hybrid Mulato II (*U. ruziziensis* × *U. brizantha*) were similar and higher, respectively, compared with the productivity of grasses of the genus *Cynodon* (Tifton 85 and Jiggs).

The data agree with the results of [34], in which increased productivity was obtained in Tanzania grass (*Megathyrsus maximus*) pastures in soils with low P levels that were fertilized with triple superphosphate (43% of P_2O_5) and cut after 70 days. The results are also in agreement with those of [35] and [36], who evaluated the forage yield with *U. decumbens* in direct recovery through fertilization, and reported a significant increase in the SDWY and annual forage yield with P_2O_5 and N fertilization.

According to [37], 'Mavuno' grass is a good alternative forage species, with recommended heights of 0.3 and 0.4 m for management (under continuous grazing), as it has high yield potential and nutritive value.

The maximum number of tillers was obtained with 96 kg ha^{-1} of P_2O_5. Increasing P application had a significant effect on plant height. The effects on the percentage of leaf blades were positive for P application rates. The absence of interaction with SPAD indicated that the forage plant was already nourished by the existing P levels in soil and associated with nitrogen fertilization.

Similar results were obtained by [38] and [19] when evaluating the effect of inoculation with plant growth-promoting bacteria on the variable percentage of leaf blades in 'Mavuno' grass and *M. maximus* cv. BRS Zuri, respectively. A high percentage of leaf blades may represent greater digestibility and CP [39]. This percentage of leaf blades is considered to be appropriate for grasses of the genus *Urochloa*. Animal production in pastures is one of the important factors for the production of grazing cattle, as they select the leaf blade of the forage plant. The results of this study agree with those of [40], who did not find an

increase in the number of tillers in *U. brizantha* cv. Marandu inoculated with *A. brasilense* Ab-V5 + Ab-V6.

The authors of [5] evaluated the tillering of *Urochloa brizantha* cv. Xaraés inoculated with plant growth-promoting bacteria allied to 50 kg ha^{-1} of phosphorous and reported significant effects when compared with plants fertilized only with N. The inoculation promoted increments in the tillering of the grass as the doses of phosphorus increased. The results of the present study were consistent with those of [41], who investigated relative chlorophyll index in 'Marandu' grass inoculated with plant growth-promoting bacteria after cutting.

These data agree with those obtained by [35], who, while working with 'Mavuno' grass, observed that the SPAD readings showed no significant difference between treatments, indicating that the plants were already well nourished. Costa et al. [42] reported SPAD values of 31.8, 39.0, and 43.7 for 0, 50, and 100 kg ha^{-1} of N, respectively, in 'Marandu' grass. In article [43], it is mentioned that N is necessary for the synthesis and structure of chlorophyll molecules, and high N absorption leads to an increase in chlorophyll content. P is involved in photosynthesis and N fixation [44].

The neutral detergent insoluble fiber (NDF) values ranged from approximately 67% to 68% and were considered high for most tropical grasses. The author of [45] reported that NDF > 60% of dry matter limits the forage intake, and the mean values found in the present study were higher. The results of [46] support the findings of the current study. These authors state that tropical forages have high levels of NDF, generally >65% and may reach 80% after 30 days of growth. This is unfavorable for grasses because of the increase in fiber content, which limits forage intake and quality.

No effect of NDF was observed in this study. Regarding NDF, the lower its content, the greater the cell content in relation to the cell wall, leading to a better forage quality. Salman et al. [47] reported that NDF consists of cellulose, hemicellulose, lignin, and N bound to fiber. The NDF results in this study may result from the longer time interval between cuts. Some authors [48] found NDF values of 675.8 g kg^{-1} for the root grass *Chloris orthonoton* Doell after 30 days of growth. Similar results were obtained by [49], who found that NDF increased with increasing P application rates in Tanzania grass after 60 days of growth.

Duarte et al. [37] in his work using 100 kg ha^{-1} of N and inoculation with *A. brasilense* Ab-V5 + Ab-V6 in Zuri grass, reduced the ADF content by 2.0% and 7.3% in the third and fourth cuts, respectively, but with no statistical difference between the two inoculations. According to Duarte et al. [37], there was a statistical difference in NDF levels in the first, second and sixth evaluation cuts, in association with a dose of 50 kg ha-1 of N and inoculation with PGPB in Zuri grass. This is because of the greater cell content in relation to cell wall, of which the NDF is composed, and has N bound to the fiber, hemicellulose and lignin.

Considering the acid detergent insoluble fiber (ADF) levels, there were significant differences depending on the P rates, and it was demonstrated that ADF was within the ideal range. A higher ADF may directly influence consumption and lead to lower digestibility, and forages with ADF values of approximately 30% are generally considered ideal for animal consumption. Forage grasses with lower ADF levels are consumed in large quantities, while those with ADF values > 40% are consumed in smaller quantities [50]. ADF is the fraction of forage that is least digestible to ruminants. In study [47], it was found that ADF is mostly composed of lignocellulose. An increase in the ADF levels in 'Mavuno' grass, resulting in a high protein content, was observed as the applied dosage of P sources increased.

In an investigation of the influence of inoculation with bacteria on the biomass, accumulated N, and nutritional value in 'Mavuno' grass, the authors of [19] found that the concentration of ADF in the treatments did not differ significantly from that of the control. This indicates that the ADF values remained within the acceptable range. Oliveira and collaborators [51] observed an interaction between phosphate fertilization and CP in the

root grass *Chloris orthonoton* Doell after 30 days of growth. This is consistent with the results obtained by [52].

According to Duarte et al. [37], in association with a dose of 100 kg ha^{-1} of N, inoculation with *P. fluorescens* CCTB 03 in Zuri grass promoted increases of 13.4% and 21.7% in the content of crude protein in the fourth and fifth cuts, respectively, in comparison with the same fertilization without inoculation.

IVDMD values were found to be high in this study. These findings may be attributed to the high percentage of leaf blade in the leaf/stem ratio of the plants (Table 3). When tropical forage grasses are managed with cutting or grazing intervals of 4 to 5 weeks, it is possible to harvest forage with high nutritional value, and thus avoid losses due to senescence. For the 'Mavuno' grass, this was reflected in the high values of IVDMD.

In their work using 50 kgha^{-1} of N, Duarte et al. [37] found that inoculation with *A. brasilense* Ab-V5 + Ab-V6 in Capim Zuri promoted an increase in IVMSD of 3.1% in the third cut, a result statistically similar to that obtained with A. brasilense Ab-V5 and Ab-V6. At the dose of 100 kg ha-1 of N, the co-inoculation increased IVMSD by 3.8%.

In this study, the IVDMD values ranged from 74 to 77% (Figure 7c), and according to [46], P application has little effect on the dry matter digestibility of grasses. However, an increase in digestibility is expected when considering only the leaf blade fraction. In study [33], it was found that an increase in the fraction of N in the cell content, along with a proportional reduction in the cell wall, resulted in desirable IVDMD values. IVDMD is considered a desirable characteristic of forage plants as it provides ruminants with better nutrition.

5. Conclusions

The evaluations showed no difference between P sources with and without polymer coating. The maximum production of 'Mavuno' grass accumulated shoot dry weight yield (SDWY) was 20.2 Mg ha^{-1} with the dose of 114 kg ha^{-1} of P_2O_5. The values of CP and IVDMD showed a quadratic response with maximum production of 76.5% and 15.9% for the doses of 37.2 and 91.1 kg ha^{-1} of P_2O_5, respectively, while the ADF showed a linear increase up to the dose of 80 kg ha^{-1} of P_2O_5. No differences were observed between treatments for plant height, number of tillers or relative chlorophyll content.

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