Chemical and physical attributes of five Oxisols as predictors of shoot dry mass of white oats[1]

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ABSTRACT

In no-tillage systems, oats are one of the species most used as a cover crop in the subtropical region of Brazil. This study aims is to determine a set of chemical and physical properties of five Oxisols after surface liming, and to determine whether these properties are related to the shoot dry mass production of white oat (*Avena sativa* L.) variety IPR Aphrodite, in order to establish a model to predict its yield. For this purpose, a field experiment was conducted during 2015 and 2016 in Londrina County in the State of Paraná with samples of B horizon collected from five Oxisols with clay content ranging from 15–80 dag kg^{-1} arranged in microplots since 2004. Soil pH in $CaCl_2$, calcium, magnesium, potassium, potential cation exchange capacity (CEC), base saturation, microporosity, total porosity, field capacity, permanent wilting point, clay and sand of the Oxisols were the parameters that most influenced the dry mass production of white oats. Oxisol extrinsic factors such as values pH and base saturation, as well as the calcium and magnesium contents, positively altered with surface liming, boosting the production of oat dry mass production.

Keywords: *Avena sativa* L.; IPR Afrodite; no-tillage system; cover crop; soil acidity.

INTRODUCTION

Oat is one of the species most used as a cover crop within the southern region of Brazil , and this use is related to this plant's carbon and nitrogen ratio, high root volume and deep rooting in the soil profile (Muzilli, 2002). This species produces high shoot dry mass, which provides adequate protection of the soil surface because of its hardiness and tillering capacity (Ziech *et al.*, 2015). In addition, graniferous white oats are used for human and animal consumption, with the grains, silage, pre-dried silage and hay (Oliveira *et al.*, 2018) being used.

The white oat variety IPR Afrodite represents an efficient economical contribution to the production chain with probably high gians for growers (Riede *et al*., 2015). In addition, these authors point out that the food industry is furnished with high-quality grains for process several derivatives of this cereal, whereas shoppers have access to merchandise with higher quality , uniformity and flavour. In addition to food industry applications, IPR Afrodite white oats may be useful for conservation production systems by providing soil surface cover against raindrop impact and hydric erosion and by playing an important role in nematode management. In a greenhouse experiment, the white oat variety IPR Afrodite showed important role for nematode management which was found to be highly resistant to species of the genus *Meloidogyne* but moderately susceptible to the nematode *Pratylenchus brachyurus* (Riede *et al.*, 2015).

In a long-term no-tillage trials for evaluating soybean cropping systems in a Argissolo Vermelho Distrófico/ *Ultisol* with sandy texture (86 dag kg^{-1} of sand) in Umuarama County in northwestern Paraná (PR) state, Brazil, Bordin *et al.* (2020) verified that white oat is the best choice to precede soybean for increasing grain yield.

In the state of Paraná, to neutralize soil acidity in the no-tillage system, surface liming without mechanical limestone incorporation is recommended. (Oliveira & Pavan, 1996). In an Oxisol in Ponta Grossa, PR, Caires *et al.* (2006) observed that surface liming did not promote increases in black oat dry mass production. In contrast,

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Soratto & Crusciol (2008) found that in dry years, surface liming increased the grain yield of black oats. In addition, vegetable extracts from oats can assist in the mobility of basic cations at depths in the soil and can also soften the exchangeable Al of the soil (Diehl *et al.*, 2008).

Oat cultivation is traditionally used to adapt to a large vary of soil that change in chemical and physical attributes (Sorrells & Simmons, 1992). It is therefore important to know which soil attributes exert the greatest influence on the production of oats, thus helping in the management of the crop and in predicting its productivity. In a Cambissolo/*Inceptisol* in southern Brazil, Andognini *et al.* (2020) noted decrease in the dry mass of black oats with increasing soil compaction. On the other hand, in a Latossolo Vermelho Distroférrico/*Oxisol* cultivated with soybean on a common-black oat straw, Balbinot Junior *et al.* (2020) pointed out that oat root and shoot dry mass contributed to greater availability of water for soybean plants during water-deficit periods.

Oxisols represent the most common soil order in Brazil, constituting more than 50% of the arable area. In Paraná, Oxisols occupy approximately 30% (Bhering & Santos, 2008).

When using agrometerological models to estimate crop productivity, data collected from meteorological stations are usually used, which have limitations regarding the spatial representativeness of the results (Junges & Fontana, 2011). Simulating oat productivity in Rio Grande do Sul, Marolli *et al.* (2017) developed a mathematical model that showed efficiency in simulating the oat grain yield through meteorological parameter like thermal sum, radiantion and precipitation, nitrogen fertilization and growth regulator.

Chemical and physical attributes of the soil can directly influence crop production, thus being able to integrate models in the production estimate. (Affholder *et al.*, 2013).

Grain yield of the commercial variety Pérola showed positive linear correlation with aggregates indexes, microorganism biomass carbon and total soil organic carbon content of a Latossolo Vermelho Distrófico (Rhodic Haplustox) submitted to a no-tillage and these soil attributes along r explained 49% of variability (Stone *et al*., 2013).

Consideration of an isolated soil attribute as a determinant in crop production can generate errors due to the interrelationships among the attributes (Vezzani & Mielniczuk, 2009; Stone *et al*., 2013). Our hypothesis is that the shoot dry mass of white oat will be foretold from soil chemical and physical attributes. So, this study aims to identify a set of chemical and physical soil attributes and to correlate them with the shoot dry mass of white oat variety IPR Afrodite to analyse the result of surface liming on the cultivation of this grass in five Oxisols.

MATERIAL AND METHODS

The study was conducted in Londrina County, in northern Paraná, in southern Brazil, in microplots at the Research Station of the Rural Development Institute of Paraná, IAPAR – EMATER (IDR-Paraná) at latitude 23° 21' 30" S and line longitude 51° 10' 17" W and at a mean altitude of 570 m higher than sea level (Nitsche *et al.*, 2019). In 2004, B horizon samples from Oxisols from different sites in the state of Paraná (Londrina, Mauá da Serra, Arapongas and Ponta Grossa) (Figure 1) were collected and classified according to the Brazilian Soil Classification System (SiBCS) (Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA, 2018) besides the equivalence for Soil Taxonomy. These locations were selected because their soils exhibit a wide range in particle size distribution and consequently distinct chemical and physical attributes.

Oxisols in the current study were classified into: LAd, Latossolo Vermelho Distrófico (Rhodic Haplustox) – Ponta Grossa (25°06’70" S, 50°10’30" W), LVd, Latossolo Vermelho Distrófico – Mauá da Serra 1 (23°53’26" S, 51°11’32" W); (LVAd, Latossolo Vermelho-Amarelo Distrófico (Typic Haplustox) – Arapongas (23°22’32" S, 51°26’41" W); LAd: Latossolo Amarelo Distrófico (Typic Haplustox) – Mauá da Serra 2 (23°53’70" S, 51°11’30" W); and LVdf: Latossolo Vermelho Distroférrico (Rhodic Hapludox) – Londrina (23°11’19" S, 51°09’19" W).

In 2004, samples were collected from the B horizons of five Oxisols from different counties in Paraná (Figure 1) and conditioned on microplots with dimensions 10 m length by 1 m width and 0.7 m in depth in an open system (Figure 2). For the experiments conducted between 2004 and 2017, the plots were subdivided into microplots with dimensions 2 m length per 1 m width (Figure 2), in parallel bands with a factorial scheme (5 x 3 x 3 + 1). Three winter crops were grown on microplots; however, in the present study, only white oat cultivar IPR Afrodite was cultivated, with three replicates with additional treatment fallow plots in each soil class to study the effects of conservation practices of crop succession and liming in different soil classes on crop yield according to procedures described by Bertoni & Lombardi Neto (2010).

With the application of dolomitic limestone on a surface without mechanical incorporation on April 12, 2004 it was sought to neutralize 100% of the potential acidity (H+Al) of the soil. From 2004 to 2011, during autumn and winter, plots with wheat, forage turnip and a mixture of black oat (*A. strigosa* Schreb) cultivar IAPAR-61 Ibiporã + radish (*Raphanus sativus* L.) + common vetch (*Vicia sativa* L.) were established in all soil classes. In addition, in the summers, soybean was grown. From 2011 to 2014, in autumn and winter, the beds remained fallow, and maize was grown in the summers. For both periods, the no-tillage system was used.

Soil samples with preserved and unpreserved structure were collected on June 4, 2015, at depths of 0–0.10 and 0.10–0.20 m. Disturbed soil samples were dried at 60 ºC during a forced oven for 48 hours and disaggregated to undergo a 2-mm sieve.

The samples were sent to the Laboratory of Soils and Plant Tissue of IAPAR–Londrina, PR, for determination of the P (Mehlich), total organic carbon (by the wet combustion method) (Walkley & Black, 1934). Through atomic absorption spectrophotometry, exchangeable calcium (Ca), magnesium (Mg) and aluminum (Al) were determined, which were extracted with 1 mol L^{-1} KCl during a 1:10 soil: solution. Soil

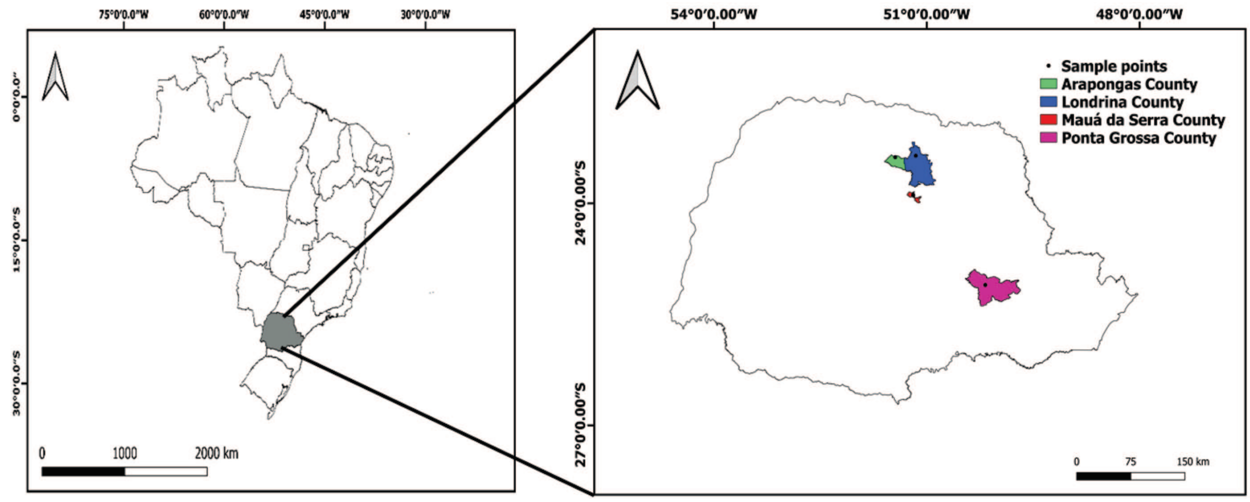

Figure 1: **Map of the state of Paraná identifying the locations where the soil samples were collected in 2004 to construct field microplots in an open system.**

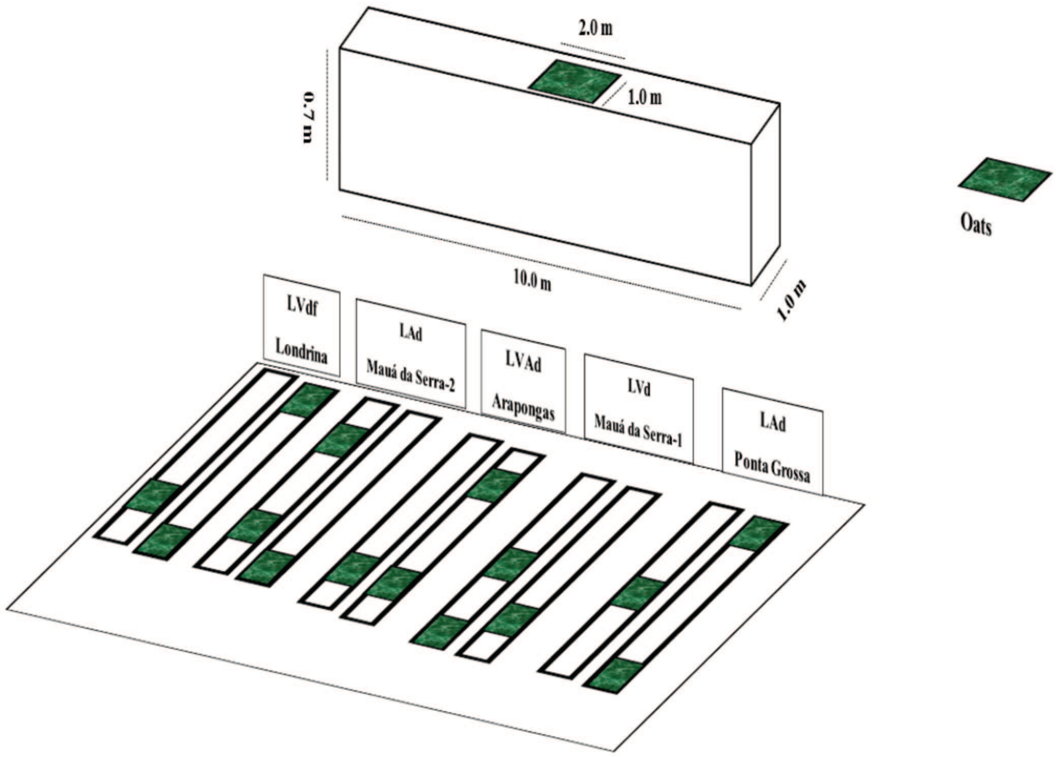

Figure 2: Experimental scheme of 15 plots cultivated with white oats in five soil classes in the state of Paraná. LVdf Londrina: Latossolo Vermelho Distroférrico (Rhodic Hapludox) of the Londrina County; LAd: Latossolo Amarelo Distrófico (Typic Haplustox) of the Maúa da Serra; LVAd: Latossolo Vermelho-Amarelo Distrófico(Typic Haplustox) of the Arapongas County; LVd: Latossolo Vermelho Distrófico (Rhodic Acrustox) and Lad Ponta Grossa: Latossolo Amarelo Distrófico (Typic Haplustox) of the Ponta Grossa County. White rectangle is the microplot. Green squares represents microplots cultivated with white oat cultivar IPR Afrodite.

pH was determined at 0.01 mol L^{-1} $CaCl_2$ in during a 1:2.5 soil: solution ratio; K (Mehlich). A mixture of sulfuric and hydrochloric acid ($Mehlich^{-1}$) was used to determine the available phosphorus and potassium contents. The determination of all chemical attributes of the soil were carried out according to the reference procedure used by IAPAR and described by Pavan *et al.* (1992).

The pipette method (Day, 1965) was used to carry out the textural analysis of the soil, using sodium hydroxide (NaOH - 0.1 mol L^{-1}) as a chemical dispersant, and mechanical dispersion was performed with the addition of 20 g coarse sand and slow stirring for 16 hours (Grohmann & Raij, 1977) in a reciprocal shaker at 180 cycles/min (Miyazawa & Barbosa, 2011).

Soil samples with preserved structure were slowly saturated in trays with water up to 2/3 of the height of the ring. Subsequently, they were subjected to matric potentials (-øm): -2, -4, -6, -8 and -10 kPa in an Eijkelkamp-Giesbeek® suction table and -33, - 100, -500 and -1,500 kPa in Richards Soil Moisture® extractors until they reached equilibrium so that the wet soil mass was determined. To determine the soil bulk density, the samples were taken to a oven at 105 – 110 °C for 48 h to obtain the soil dry mass and calculate the soil bulk density (Grossman & Reinsh, 2002). Through the product between the gravimetric water content and soil bulk density, the volumetric moisture was obtained (Topp & Ferré, 2002)..

The soil field capacity (FC) was calculated from the volumetric moisture determined for the -10 kPa matric potential and permanent wilting point (PWP) or for the residual volumetric water content determined at the -1,500 kPa matric potential. The total porosity, macroporosity and microporosity were determined according to Vomocil (1965) and Flint & Flint (2002).

The rate of limestone required to raise the base saturation to 70% was calculated based on the means obtained from the soil chemical analyses at 0–0.20 m depth. On June 26, 2015, liming was performed with dolomitic limestone (PRNT 77.60%), which was manually applied to the surface of the beds without physical incorporation into the soil.

In each soil class, three 2 m x 1 m plots of IPR Afrodite white oats (*Avena sativa* L.) were established, for a total of 15 plots. The planting furrows were prepared using a handheld rake with 0.05–m prongs, with furrows of approximately 0.03 m in depth obtained with clearly delimited planting rows spaced 0.17 m apart. Sowing was done manually on June 27, 2015 (Figure 3), with a sowing density of 98.08 kg h^{-1} being adopted.

Mineral fertilizer was applied to the soil surface between the rows of the crop with the mineral fertilizer formulation 30-04-10 at a dose of 250 kg ha^{-1} corresponding to 75 kg N ha^{-1}, 10 kg of P_2O_5 ha^{-1} and 25 kg ha^{-1} of K_2O. Also under the soil surface between the rows of the crop on July 27, 2015, top-dressing fertilization with 100 kg ha^{-1} of urea, which corresponds to 45 kg of N ha^{-1}.

The shoot dry mass yield of white oat was determined on September 18, 2015 (83 days after sowing), when the crop was in a vegetative stage with 50% flowering (Figure 3); to estimate the yield of white oat dry mass, samples were collected from an area of 0.25 m^2 per plot, then taken to drying in a forced-air oven at 65°C until stable weight was obtained(Hoogmoed & Derpsch, 1985).

For the statistical analyses, the attributes of the oxisols were considered only for the depth 0-0.10 m. Thus, the data for each attribute originates from three samples of each class of oxisol, totalling 15 samples. In each oxisol studied, the mean, maximum and minimum values were calculated, in addition to the coefficient of variation of the soil attributes; and oat dry mass yield. The same parameters were also calculated for all five oxisols. The attributes of all oxisols were individually correlated with the white oat dry mass yield for all soils.

The model for predicting white oat dry mass production according to the physical and chemical soil attributes was developed through multiple linear regression. However, the presence of multicollinearity may lead to high standard errors, thus preventing any estimations if the multicollinearity is perfect (Gujarati & Porter, 2011). Factor analysis was performed to solve the problem of multicollinearity by identifying the isolated dimensions of the dataset and then determining the degree to which each variable is explained by each dimension or factor.Soil attributes and white oat dry mass yield were correlated using Pearson's correlation, being used to extract significant attributes at 5% and 1% by the F test.The coefficient of Pearson (r) was classified as: (i) $0.00 < r < 0.19$, very weak; (ii) $0.20 < r < 0.39$, weak; (iii) $0.40 < r < 0.69$, moderate; (iv) $0.70 < r < 0.89$; and (v) $0.90 < r < 1.00$, very strong (Gujarati & Porter, 2011). Bartlett's test of sphericity and Kaiser-Meyer-Olkin (KMO) test were used to analyze these attributes.. Having reached the significance levels for used each test, factor analysis was performed using the Principal Component Analysis, extracting the factors via orthogonal Varimax rotation to obtain the best combinations.

Through the rotated component matrix, a factor load was assigned to each soil attribute relative to the factor. Fifteen factor scores were obtained; that is, composite measurements of each factor computed for each oat dry mass production were obtained, with the original variables being replaced by the factor scores. The linear regression was then performed according to the number of factors extracted, with a linear regression being used if only one factor was extracted, or a multiple regression when two or more factors were extracted. The oat dry mass was considered a response variable, and the factor scores for the extracted factors were used as explanatory variables.

To validate the model, it was tested with data obtained for the oxisol attributes evaluated before white oat cultivation and for the dry mass production obtained for the oats in the following year (2016) in the same plots previously described. In the 2016 autumn-winter crop, white oats were cultivated and managed similarly to the previous crop, being sown after soybean cultivation with a new surface application of limestone at the same doses applied to the previous crop (2015).

The efficiency of the model was assessed by the adjusted coefficient of determination (R^2), root mean square error (RMSE) and mean error (ME).

RESULTS AND DISCUSSION

The available phosphorus contents in the 0–0.10 m layer of the Oxisols (Table 1) exceeded the critical value of approximately 11 mg dm^{-3} for winter cereals (Vieira *et al.*, 2013), except for the lowest value observed in the *Latossolo Amarelo Distrófico* from Mauá da Serra-2 (Table 1). For the carbon contents of the Oxisols, mean values were low for the Lad, *Latossolo Amarelo Distrófico* from Mauá Serra-2 and between medium and high for the other soils (Pauletti & Motta, 2017).

The mean values of pH in $CaCl_2$ for the Oxisols indicate an average acidity, while the aluminium contents were very low according to criteria described by Pauletti & Motta (2017). According to these authors, low soil pH values and low alkalinity are the main soil chemical attributes that limit black oat yield in dry winter regions (Table 1).

With regard to the bases, the calcium contents are considered medium in the LAd – Mauá da Serra 2 and high and very high for the other Oxisols. The magnesium content is classified as medium in the LAd – Mauá da Serra 2 and high in the LAd – Ponta Grossa and (LVd, Latossolo Vermelho Distrófico) – Mauá da Serra 1, whereas it is very high in the (LVAd, Latossolo Vermelho Amarelo Distrófico) – Arapongas and (LVdf, Latossolo Vermelho Distroférrico) – Londrina (Pauletti & Motta, 2017).

Vegetable extracts from oats can assist in depth mobility of lime when applied to the soil surface in a no-tillage system . Diehl *et al.* (2008) observed that vegetable extracts of turnip followed by black oats showed higher amounts of water-soluble organic binders, titratable organic acids and organic anions than did extracts from the residues of wheat, corn and soybeans, and these higher values contributed to the ionic mobility of exchangeable bases in soils managed under a conservation production system.

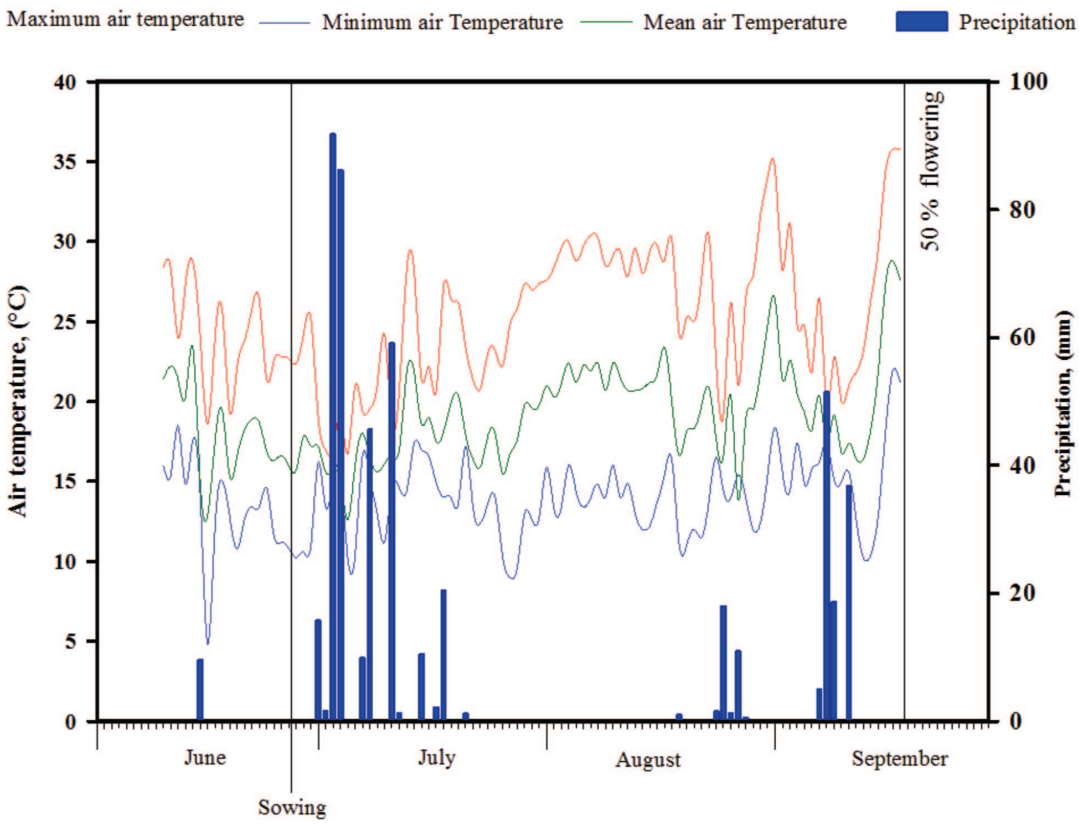

Figure 3: Daily values for maximum, minimum and mean temperatures and for precipitation during the period from June to September 2015, indicating sowing dates and time at 50% flowering of the white oat crop. Londrina, PR. Source: “Adapted from the Agronomic Institute of Paraná–IAPAR, 2015”

The mean level of potassium (Table 1) in the oxisols is considered medium in the LAd–Mauá da Serra-2, and LVAd–Arapongas and high in the other soils. The potential CEC indicates low values in the LAd–Mauá da Serra 2 and medium values for the other soils. For base saturation, its mean values are classified as medium in the LAd–Ponta Grossa, LVd- Mauá da Serra 1 and LAd–Mauá da Serra 2 and high in the others (Pauletti & Motta, 2017).

With regard to all soil classes, soil bulk density averaged 1.16 g cm^{-3} and ranged from 0.94 to 1.53 g cm^{-3} (Table 2). These values are typical for uncompacted Oxisols in Paraná. In the same Oxisols studied here, Araujo-Junior & Miyazawa (2012), through pedotransfer functions based on a compaction curve obtained through the Proctor test, suggested critical soil bulk density values critical for root growth and crop development in these Oxisols of 1.33 g cm^{-3} (LAd–Ponta Grossa), 1.22 g cm^{-3} (LVd–Mauá da Serra 1), 1.39 g cm^{-3} (LVAd–Arapongas), 1.52 g cm^{-3} (LAd–Mauá da Serra 2) and 1.25 g cm^{-3} (LVdf–Londrina). Thus, bulk density values reached critical levels only in the LAd–Mauá da Serra 2. Soil bulk densities below critical values, root development and soil airflow are not are not restricted. In contrast, root growth restrictions are probable for soil bulk densities higher than critical values.

The total soil porosity values were between 0.66 cm^{3} cm^{-3} (LVdf–Londrina) to 0.43 cm^{3} cm^{-3} (LVd–Mauá da Serra 2) this difference can be conditioned to textural, mineralogical and structural factors of oxisols. The total porosity of the soil is responsible for the transport and storage of the soil solution and air. Air-filled porosity higher

Table 1: Descriptive statistical measures of the chemical attributes of five Oxisols from the state of Paraná

Statistic	P	TOC	pH	Al	H+Al	Ca	Mg	K	CEC-T	V
	mg dm^{-3}	g dm^{-3}		cmol$_c$ dm^{-3}						%
[1]Latossolo Amarelo Distrófico (Typic Haplustox) – Ponta Grossa										
Mean	110.00	13.32	4.65	0.20	6.62	2.44	1.31	0.24	10.61	37.83
Maximum	134.70	14.06	4.75	0.25	7.20	2.57	1.32	0.30	11.26	39.34
Minimum	72.30	12.03	4.60	0.14	5.97	2.30	1.31	0.19	9.77	36.06
CV (%)	30.15	8.39	1.60	28.29	9.35	5.60	0.44	24.32	7.18	4.39
Latossolo Vermelho Distrófico (Rhodic Acrustox) – Mauá da Serra-1										
Mean	42.67	15.05	4.93	0.01	6.05	2.76	1.59	0.30	10.70	43.39
Maximum	61.10	17.45	5.00	0.02	6.20	3.07	1.68	0.33	11.28	45.04
Minimum	23.70	12.46	4.90	0.00	5.76	2.55	1.48	0.23	10.36	40.73
CV (%)	43.84	16.62	1.17	86.60	4.20	9.85	6.34	19.46	4.72	5.36
Latossolo Vermelho-Amarelo Distrófico (Typic Haplustox) – Arapongas										
Mean	37.07	13.82	5.20	0.06	4.86	3.45	2.18	0.15	10.64	54.37
Maximum	44.30	15.50	5.70	0.18	6.20	3.92	2.83	0.16	11.07	66.89
Minimum	24.60	12.11	4.80	0.00	3.42	2.67	1.48	0.14	10.33	41.01
CV (%)	29.25	12.26	8.81	173.21	28.66	19.67	31.06	7.53	3.63	23.84
Latossolo Amarelo Distrófico (Typic Haplustox) – Mauá da Serra-2										
Mean	17.97	6.62	5.00	0.01	3.18	1.89	0.95	0.10	6.12	47.70
Maximum	29.40	7.48	5.20	0.04	3.42	2.25	1.11	0.12	6.58	52.35
Minimum	9.50	6.15	4.80	0.00	2.94	1.42	0.69	0.07	5.60	38.93
CV (%)	57.20	11.27	4.00	173.21	7.56	22.53	24.06	26.03	8.05	15.94
Latossolo Vermelho Distroférrico (Rhodic Hapludox) – Londrina										
Mean	13.39	10.62	5.13	0.03	4.43	3.54	2.25	0.36	10.57	58.07
Maximum	14.50	11.57	5.30	0.06	4.60	3.92	2.39	0.43	11.13	60.89
Minimum	12.58	10.09	5.00	0.00	4.08	3.15	2.09	0.30	10.14	54.64
CV (%)	7.43	7.78	2.98	124.90	6.82	10.88	6.70	17.56	4.80	5.46
[2]All soils										
Mean	44.22	11.89	4.98	0.06	5.03	2.82	1.66	0.23	9.73	48.27
Maximum	134.70	17.45	5.70	0.25	7.20	3.92	2.83	0.43	11.28	66.89
Minimum	9.50	6.15	4.60	0.00	2.94	1.42	0.69	0.07	5.60	36.06
CV (%)	88.44	28.32	5.67	140.20	27.75	27.75	35.35	46.27	19.79	19.86

[1] n=3 samples at a depth of 0-0.10 m.[2] n=15 samples. P: available phosphorous; TOC: total organic carbon content; pH: soil pH determined in $CaCl_2$; Al: aluminium content; H + Al: potential acidity; Ca: calcium content; Mg: magnesium content; K: potassium content; CEC-T: potential cation exchange capacity; V: base saturation.

than 0.10 m^3 m^{-3} have been associated with best soil conditions for plant growth (Xu et al., 1992). (Xu et al., 1992). Macroporosity did not reach critical values in the oxisols (Table 2).

Soil microporosity is related to water storage and clay content, where greater field capacity and permanent wilting point are observed in the soil classes with greater microporosity and clay content, that is, LVd–Mauá da Serra 1 and LVdf–Londrina (Table 2). This relationship is present because these soils have a higher percentage of colloidal material, larger pore spaces and much greater adsorptive surface than soils with a coarser structure (Carvalho et al., 1999).

The selected oxisols vary regarding the particle size composition of the solid particles, with clay content ranging from 11.00 to 81.15 dag kg^{-1}, with very clayey to sandy-loam texture (Table 2).

The shoot dry matter production of the oat cv. IPR Afrodite in the five oxisols of the state of Paraná averaged 4,532.93 kg ha^{-1} (Table 2). Among the means, the lowest production was observed in the LAd–Mauá da Serra 2 and the largest in the LVd–Mauá da Serra 1 and LVdf–Londrina.

The highest white oat dry mass production was similar to those obtained by the common black oats cultivated in an oxisol from Londrina/PR (Derpsch et al., 1985), where a mean dry mass production of 5,090 kg ha^{-1} was obtained. In a study evaluating the dry mass yield of three white oat varieties that were managed at full flowering in an oxisol, Demétrio et al. (2012) obtained a production of 907; 1,185;

Table 2: Descriptive statistical measures of the physical-hydric attributes and dry mass production of white oat shoots in five oxisols of the state of Paraná

Statistic	BD	Ma	Mi	TP	FC	PWP	Clay	Silt	Sand	Dry mass
	g cm^{-3}	cm^3 cm^{-3}					dag kg^{-1}			kg ha^{-1}
[1]Latossolo Amarelo Distrófico (Typic Haplustox) – Ponta Grossa										
Mean	1.06	0.28	0.27	0.60	0.24	0.16	41.87	5.82	52.31	4099.20
Maximum	1.09	0.29	0.28	0.60	0.25	0.16	42.70	6.95	52.54	4531.20
Minimum	1.04	0.27	0.26	0.58	0.23	0.15	40.80	5.15	52.15	3874.80
CV (%)	2.57	4.61	4.38	1.73	4.12	4.29	2.32	16.90	0.38	9.13
Latossolo Vermelho Distrófico (Rhodic Acrustox) – Mauá da Serra-1										
Mean	1.01	0.28	0.34	0.64	0.31	0.23	72.70	7.62	19.68	5086.13
Maximum	1.05	0.31	0.35	0.66	0.32	0.24	73.65	8.15	20.20	5739.20
Minimum	0.94	0.27	0.32	0.62	0.29	0.21	71.65	6.85	19.35	4713.20
CV (%)	5.89	8.90	5.06	3.68	6.19	7.46	1.38	8.94	2.30	11.16
Latossolo Vermelho Amarelo Distrófico (Typic Haplustox) – Arapongas										
Mean	1.22	0.19	0.32	0.55	0.28	0.17	40.22	3.97	55.82	4853.07
Maximum	1.24	0.21	0.33	0.56	0.28	0.17	41.35	4.95	57.95	5984.80
Minimum	1.17	0.18	0.31	0.54	0.27	0.17	38.75	3.30	54.50	3378.40
CV (%)	3.04	8.83	2.34	2.47	2.58	2.54	3.31	21.92	3.34	27.54
Latossolo Amarelo Distrófico (Typic Haplustox) – Mauá da Serra -2										
Mean	1.49	0.16	0.23	0.44	0.19	0.09	15.73	1.18	83.08	3596.53
Maximum	1.53	0.18	0.26	0.45	0.21	0.09	18.85	1.75	87.25	3808.80
Minimum	1.46	0.14	0.21	0.43	0.17	0.09	11.00	0.55	80.60	3472.80
CV (%)	2.59	13.25	11.80	2.56	10.53	5.31	26.49	50.94	4.37	5.13
Latossolo Vermelho Distroférrico (Rhodic Hapludox) – Londrina										
Mean	1.02	0.20	0.37	0.66	0.34	0.25	80.78	10.32	8.89	5029.73
Maximum	1.04	0.22	0.37	0.66	0.35	0.25	81.15	12.15	9.68	5446.80
Minimum	0.99	0.17	0.36	0.65	0.33	0.24	80.40	9.30	7.45	4802.00
CV (%)	2.25	11.88	1.72	0.83	3.05	3.00	0.46	15.35	14.06	7.19
[2]All soils										
Mean	1.16	0.22	0.31	0.58	0.27	0.18	50.26	5.78	43.96	4532.93
Maximum	1.53	0.31	0.37	0.66	0.35	0.25	81.15	12.15	87.25	5984.80
Minimum	0.94	0.14	0.21	0.43	0.17	0.09	11.00	0.55	7.45	3378.40
CV (%)	16.60	24.23	16.79	13.76	20.99	32.40	48.85	57.63	62.94	18.63

[1]n = three samples collected from 0–0.10 m depth.[2] n=15 samples. BD – Soil bulk density, Ma - macroporosity, Mi - microporosity, TP - total porosity, FC - field capacity (at the matric potential -10 kPa), PWP - permanent wilting point (at the matric potential -1,500 kPa).

and 1302 kg ha^{-1} for the cultivars IPR 126, FAPA 2 and FUNDACEP FAPA 43, respectively.

Pearson's correlations analysis showed that the values of the pH, calcium and magnesium contents, as well as the base saturation of the oxisols, were determinants of white oat dry mass production (Table 3). The exchangeable cations like calcium which is constituent of plant cell walls and cell division, whereas magnesium participate in physiological processes like enzymatic activation, photosynthesis and DNA and RNA synthesis and also is a component of chlorophyll molecule (Taiz & Zeiger, 2013). In addition, calcium and magnesium uptake by oats is impaired by low pH and high aluminium concentrations (Silva et al., 2013). The authors also report that the uptake of magnesium and calcium by white oats is affected by increased aluminium in the solution. In a Latossolo Vermelho/Oxisol from southern Brazil, Castro & Crusciol (2013) observed increases in shoot dry matter yield of oats with the use of surface liming.

The potassium contents of the oxisols were positively correlated with white oat dry mass production (Table 3). This correlation was similar to that verified by Melo *et al.* (2011) in the black oats. Rozane *et al.* (2008) observed that the omission of potassium from a nutrient solution resulted in lower dry mass production of black oats, and the authors observed an even greater accumulation of calcium and magnesium in plants with full potassium treatment. In soils with reduced pH, the potassium uptake by oats can be impaired (Harper & Balke 1981).

The white oat dry mass production was positively correlated with the potential CEC of the oxisols (Table 3). This correlation was expected, since the base cations calcium, magnesium and potassium were also positively correlated with oat dry mass production. In sandy soils of the Eastern Region of Polônia, Usowicz & Lipiec (2017) demonstrated that the soil potential CEC and oat grain production were positively correlated.

Soil physical attributes, the microporosity and total porosity of the oxisols were positively correlated with white oat dry mass production (Table 3). The water and gas flows and availability in the soil depend on soil porosity, and those factors may affect the crop yield. In New Zealand clayey soils, Sojka *et al.* (1997) observed higher oat dry mass production in soil management systems that presented greater air soil permeability and hydraulic conductivity. The limitation of soil water infiltration is one of the variables that most often limits grain yield (Santi *et al.*, 2012).

The volumetric water contents at field capacity and at the permanent wilting point correlated positively with the oat dry mass production (Table 3). With regard to soil moisture, oats require more moisture than any other winter cereal (Castro *et al.*, 2012). In a study with different winter cereals (wheat, barley and oat), Usowicz & Lipiec (2017) observed that cereal production were more strongly positively correlated with the soil water content. In soils with fast water content release like sandy soils, cereal production depends not only on the total amount of rainfall

Table 3: Pearson correlations between soil attributes and shoot dry matter of white oat cultivar IPR Afrodite cultivated in five Oxisols in Paraná (n=15)

Attributes	Correlation		
	r	Classification	Probability
Available phosphorus content (mg dm^{-3})	-0.183	very weak	0.512
Total organic carbon (g dm^{-3})	0.364	weak	0.182
Aluminium ($cmol_c$ dm^{-3})	-0.448	moderate	0.020
pH ($CaCl_2$)	0.594*	moderate	0.094
Potential acidity ($cmol_c$ dm^{-3})	0.006	very weak	0.984
Exchangeable calcium content ($cmol_c$ dm^{-3})	0.745**	strong	0.001
Exchangeable magnesium content ($cmol_c$ dm^{-3})	0.807**	strong	0.000
Available potassium content ($cmol_c$ dm^{-3})	0.555*	moderate	0.032
Potential CEC ($cmol_c$ dm^{-3})	0.564*	moderate	0.029
Base saturation (%)	0.565*	moderate	0.028
Bulk density (g cm^{-3})	-0.487	moderate	0.066
Macroporosity (cm^3 cm^{-3})	0.168	very weak	0.550
Microporosity (cm^3 cm^{-3})	0.692**	strong	0.004
Total porosity (cm^3 cm^{-3})	0.534*	moderate	0.040
Field capacity (cm^3 cm^{-3})	0.702**	strong	0.004
Permanent wilting point (cm^3 cm^{-3})	0.678**	moderate	0.005
Clay (dag kg^{-1})	0.631*	moderate	0.012
Silt (dag kg^{-1})	0.437	moderate	0.103
Sand (dag kg^{-1})	-0.612*	moderate	0.015

*, ** significant values at 5% and 1% by the F-test, respectively.

but also on its temporal distribution relative to the plant growth stage (Lipiec & Usowicz, 2018).

The permanent wilting point of the oxisols was not negatively correlated with white oat dry mass production. In a study evaluating black oat root development and water uptake, Ehlers *et al.* (1987) observed a reduction in oat root development with increasing soil water tensionand stopped at approximately 1,900 kPa. Considering the permanent wilting point of 1,500 kPa in the present study, the oat crop possibly absorbed water at higher pressure.

The clay content of the oxisols was positively correlated with white oat dry mass production, whereas the sand content was negatively correlated (Table 3). These results are attributed to the influence of the clay and sand particles because the increase in the clay content in the soil increased the bases (calcium, magnesium and potassium) and the volumetric content of water in the soil, factors that condition the oat dry mass productionSoil attributes that were significant by Pearson's correlation were analysed using a factor analysis, where the data, cumulatively, showed that components 1 and 2 explained 90.442% of the existing variance (Table 4).

The chemical attributes of the oxisols, such as the K and T, along with the physical attributes, were the ones best explained by factor 1. The chemical attributes pH, Ca, Mg and base saturation were better explained by factor 2 (Table 4).

These results reflect that the attributes of the oxisols related to factor 1 were more intrinsic; that is, they did not present significant changes with liming, whereas the attributes related to factor 2 were more extrinsic with liming. Thus, oat production could be increased with an increase in the soil attributes of factor 2.

The utilization of soil potassium depends on the texture and may be higher in sandy soils due to the lower buffering capacity of K, as expressed by the CEC (Medeiros *et al.*, 2010; Maluf *et al.*, 2015). The soil porous system is mainly altered by machine traffic, a fact that did non-existen in this study. In a study evaluating the growth of maize roots under controlled machine traffic, Mazurana *et al.* (2013) observed that microporosity is little influenced by winter cover crops and machine traffic and is more influenced by intrinsic characteristics.

The availability of water to plants depends on soil intrinsic factors, such as their structure, texture, type and clay content. The water holding capacity soil profile is intrinsic to its matrix and does not depend on the plants (Petry *et al.*, 2007).

Considering all the soil attributes evaluated, the ones that jointly best explained the oat dry matter production by factor analysis were the potassium content, CEC, microporosity, total porosity, field capacity, permanent wilting point, clay and sand contents, pH, calcium, magnesium and base saturation, and the following multiple linear regression equation was fitted:

$$DM = 2.2221.54 + (7.26 \cdot (0.896 \cdot K + 0.833 \cdot CEC + 0.868 \cdot Mi + 0.978 \cdot TP + 0.912 \cdot FC + 0.957 \cdot PWP + 0.957 \cdot Clay - 0.962 \cdot Sand)) + (32.61 \cdot (0.956 \cdot pH + 0.748 \cdot Ca + 0.825 \cdot Mg + 0.973 \cdot V\%))\ R^2 = 0.61^{**}$$

where DM is the white oat dry mass (kg ha^{-1}), K is the available potassium content ($cmol_c\ dm^{-3}$), CEC is the potential cation exchange capacity ($cmol_c\ dm^{-3}$), Mi is the microporosity ($cm^3\ cm^{-3}$), TP is the total porosity ($cm^3\ cm^{-3}$), FC is the field capacity ($cm^3 cm^{-3}$), PWP is the permanent wilting point ($cm^3\ cm^{-3}$), Clay is the clay content (dag kg^{-1}), Sand is the sand content (dag kg^{-1}), Ca is calcium ($cmol_c\ dm^{-3}$), Mg is magnesium ($cmol_c\ dm^{-3}$), and V% is base saturation (%).

Obtaining a set of soil attributes that explains 61% shoot dry mass of white oat production is satisfactory because the yield of any crop is the result of the interactivity of climatic, plant and soil factors.

The model was tested to predict the shoot dry mass of white oat cultivar IPR Afrodite production in the next crop, after identifying and removing two outliers, and the model was thereby found to have a predictive accuracy of 74% (Figure 4).

The chemical and physical attributes of oxisols at the 0-0.10 m layer were therefore used to develop a model capable of estimating with good accuracy the dry mass production of white oats.

Table 4: Eigenvalues of factors, variance components and total variance explained by the chemical and physical attributes of the oxisols

Variance components	**Factors**	
	1	**2**
Eigenvalues	6.893	2.146
Proportion (%)	68.938	21.459
Cumulative proportion (%)	68.938	90.387
Variables	**Correlation with the factors**	
pH	-0.077	0.956*
Ca	0.560	0.748*
Mg	0.515	0.825*
K	0.896*	0.057
T	0.833*	0.088
V%	0.043	0.973*
Mi	0.868*	0.366
TP	0.978*	0.030
FC	0.912*	0.326
PWP	0.957*	0.245
Clay	0.957*	0.169
Sand	- 0.912*	-0.155

Bartlett's test of sphericity = $9.72^{\cdot 10\text{-}41}$ and Kaiser-Meyer-Olkin (KMO) test = 0.664. * Traits with higher factor loads (scores) selected within each factor.

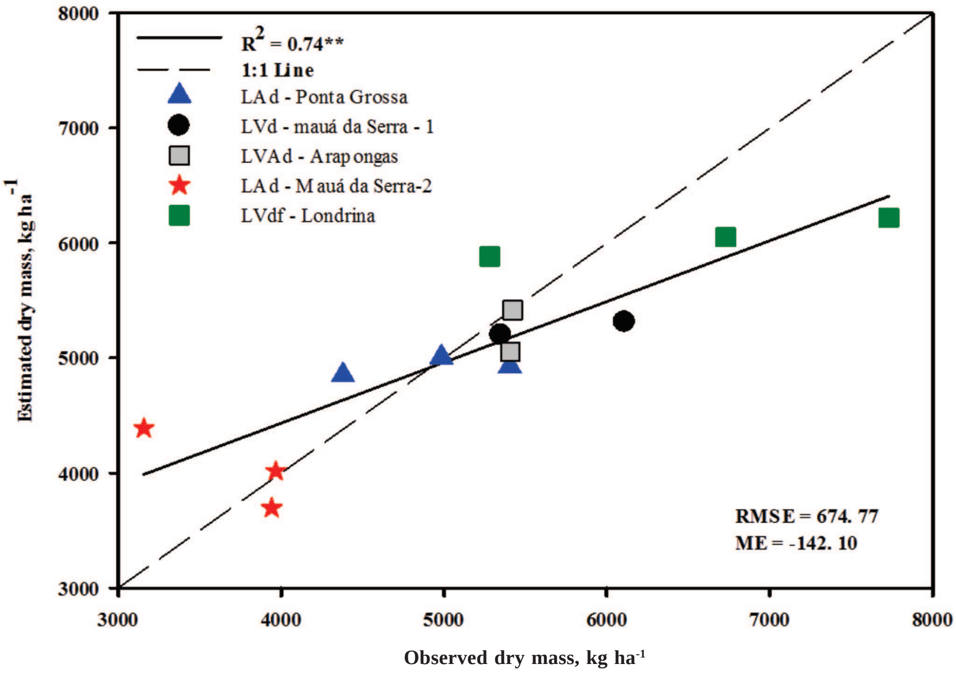

Figure 4: Regression of estimated and observed white oat dry mass production.

CONCLUSIONS

The soil chemical attributes pH in $CaCl_2$, Ca content, Mg content, K content, potential cation exchange capacity, and base saturation and soil physical attributes microporosity,total porosity, field capacity, permanent wilting point (PWP) and clay and sand contents of the Oxisols most affected white oat shoot dry mass production.

The soil chemical attributes pH in $CaCl_2$, Ca content and Mg content, in addition to the base saturation of the Oxisols, are extrinsic properties that are positively altered with surface liming, thereby increasing white oat dry mass production.

The multiple regression model that was composed based on factor analysis was efficient for predicting dry mass production of white oats in five oxisols managed with surface liming.

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