Precision Agriculture: Forage chopper noise level as an estimator of corn silage production in small farms

Wilson Souza[1], *UNESP-FCAVR, Rua Nelson Brihi Badur, 430, Registro, SP, BR.*
[1]*wilson.souza@unesp.br*
A. Silva[2], *UNESP-FCAVR, Rua Nelson Brihi Badur, 430, Registro, SP, BR.*
L. Fernandes[2] *UNESP-FCAVR, Rua Nelson Brihi Badur, 430, Registro, SP, BR.*

Abstract.
The objective of the work carried out in the Registro County, SP, Brazil, in the year 2021, was to study the forage chopper noise level as an estimator of corn silage production in small farms. The corn crop study and characterization were measured plant height (PH), height of first ear insertion (HEI) and green mass of plants (GM) were studied. The Sound Pressure Level (SPL) produced by the forage machine during ensiling was collected by decibel meter equipment, considering it as a potential yield estimator during harvest. The data showed to exist potential for use of the SPL as an estimator of GM production in corn, correlating positively. It is concluded that the study contributes to the progress in this evaluation, as it is easy to obtain, the possibility of high sampling density and applicable in small and medium-sized properties as a precision agriculture tool.

Keywords.
Sound Pressure Level, forage harvester, mechanization.

Introduction

Sustainable production involving the Crop-Livestock Integration (ILP) with corn, associating the production of green ears for in natura consumption and harvesting the entire plant for silage, can increase the producer's income and improve the quality of production environments. According Gonçalves & Franchini (2007), the adoption of ILP is of great importance in the recovery of degraded pastures with the introduction of crops such as corn, soybeans, rice in intercropping and rotation, expanding the production of phytomass for animal feed and soil cover in several Brazilian biomes.

Recent research studies the behavior of production systems in a specialized way, aiming to identify specific management sites, adopting techniques related to precision agriculture, such as superimposing maps of the variables collected with Geographic Information Systems tools and satellite images (Santos et al. al., 2014), use of univariate and multivariate statistics (hierarchical cluster analysis, principal component analysis) (Demarch et al., 2014; Santos et al, 2015) univariate and multivariate geostatistics, fuzzi algorithms (Alves et al., 2013), among other techniques.

The Proceedings of the 16th International Conference on Precision Agriculture. Souza, W. J. O. & Coauthor, Silva. A.N. & Fernandes. L. R. (2024). Precision Agriculture: Forage chopper noise level as an estimator of corn silage production in small farms. In Proceedings of the 16th International Conference on Precision Agriculture (unpaginated, online). Monticello, IL: International Society of Precision Agriculture.

Data collection with embedded systems is an important facilitator in the advancement and adoption of these PA techniques to quantify the georeferenced crop productivity. However, mechanized forage harvesting has limitations for to quantify productivity with systems mapping productivity (SMP), such as those available on grain harvesters (Zandonadi et al, 2021).
A characteristic observed during the operation of forage harvesters is the oscillation in the intensity of the sound emitted during plant processing, caused by variation in the volume of processed material. The sound intensity (I) is defined as the average value of the energy flux per unit area perpendicular to the propagation direction, measured in Watt per m^2 (Wm^{-2}) and can be expressed by Equation 1.

$$I = \frac{Power}{Area} \quad (1)$$

The sound intensity level (SIL) is a relative quantity, considering the intensity I_0 *=10-12* Wm^{-2} as a reference, being expressed in decibels as Equation 2.

$$NIS = 10 \log \frac{I}{I_0} \quad (2)$$

The sound pressure level (*Sound Pressure Level – SPL*) determines the intensity of the sound and represents the logarithmic relationship between the pressure variation (P) caused by the vibration and the pressure that reaches the hearing threshold (Saliba, 2004). At a given point in space it is a relative magnitude, having as reference the value of *P0 = 20 μPa* (2×10^{-5} Nm^{-2}), being expressed in decibel (dB). The square of the average sound pressure variation (P) is proportional to the Sound Intensity (Equation 3), relating the Sound Intensity level (SIL) to the Sound Pressure Level (SPL), as shown in Equation 4 and expressed in Equation 5.

$$\frac{I_1}{I_2} = \frac{P_1^2}{P_2^2} \quad (3)$$

$$NIS = 10 \log \frac{l}{l_0} = 10 \log \frac{P^2}{P_0^2} = 20 \log \frac{P}{P_0} \quad (4)$$

$$SPL = 20 \log \frac{P}{P_0} \quad (5)$$

The objective of this work was to study the SPL of forage machine during ensiling as estimator potential of forage production, as well as its relationship with maize plant variables associated with green mass production. The tested hypothesis is that the variation in the amount of green mass, plant height and height of insertion of the first ear results in variations in the SPL, correlating significantly.

Material and Methods

The work was carried out in a commercial production area of Vale do Ribeira in the Registro County, SP, Brazil, in the year 2021. The area is located at the geographic coordinates (UTM) 224437.309 E, 7296984.882 N (23 J) and average altitude of 23m, the climate is Cfa (Köppen classification), with average annual rainfall of 1415 mm, average annual temperatures of 21.5˚C and relative humidity of 83.1%.
The perimeter of the 800 m^2 area (0.08ha) was delimited with a Garmin 60Cx GPS, with 30 points marked in an irregular grid, intended for data collection during the corn crop cycle.
The preparation of the area for implantation of the crop consisted of previous mowing and desiccation 20 days later. On 03/18/2021, 200L ha^{-1} of spray solution was applied, consisting of 4L ha^{-1} of glyphosate (p.c.), 2.5L ha^{-1} of 2,4-D (p.c.) and 2% urea (46% N), using an sprayer electrically driven pump with 4 m working width, with 0.5 m spacing between nozzles (8 nozzles),

pulled by a Massey Ferguson tractor model MF 4265 (60 hp engine power), with front-wheel drive assist (FWD).

Direct seeding was carried out on 03/27/2021 with a single-unit seeder, pulled by the same tractor. Biomatrix 3066 Pro 3 transgenic hybrid corn seeds were used, with the machine adjusted to obtain a population of 55,000 plants ha^{-1}, at a depth of 0.04 to 0.05 m and spacing between rows of 0.8 m. Sowing fertilization was carried out according to the recommendations of Raij et al (1996): 120 kg ha^{-1} of formula 8-28-16 (sowing), two top-dressing fertilizations (04/14/2021 and 05/15/ 2021) with 83 kg ha^{-1} of urea (46% N). On the same date, weed control was carried out with glyphosate (4L ha^{-1} p.c.) and 2,4-D (2.5L ha^{-1} p.c.) with a knapsack sprayer with 1 nozzle, set to 200 L ha^{-1} of syrup.

In maize, the Sound Pressure Level (SPL), plant height (PH), first ear insertion height (HEI) and green mass production of maize plants (GM) were studied. The SPL produced by the forage machine during ensiling was measured with an Instrutherm decibel meter, model DEC-416, measurement range from 30 to 130 dB, A and C weighting, fast and slow time weighting, at a distance of 1.5 m of the machine, recording the maximum SPL value (dB) during the processing of 5 corn plants.

The preparation of the area for implantation of the crop consisted of previous mowing and desiccation 20 days later. On 03/18/2021, 200L ha-1 of spray solution was applied, consisting of 4L ha-1 of glyphosate (p.c.), 2.5L ha-1 of 2,4-D (p.c.) and 2% urea (46% N), using an electrically driven 4 m boom sprayer, with 0.5 m spacing between nozzles (8 nozzles), pulled by a Massey Ferguson tractor model MF 4265 (60 hp engine power), with front-wheel drive assist (FWD).

Direct seeding was carried out on 03/27/2021 with a single-unit seeder, pulled by the same tractor. Biomatrix 3066 Pro 3 transgenic hybrid corn seeds were used, with the machine adjusted to obtain a population of 55,000 plants ha-1, at a depth of 0.04 to 0.05 m and spacing between rows of 0.8 m. Sowing fertilization was carried out according to the recommendations of Raij et al (1996): 120 kg ha-1 of formula 8-28-16 (sowing), two top-dressing fertilizations (04/14/2021 and 05/15/ 2021) with 83 kg ha-1 of urea (46% N). On the same date, weed control was carried out with glyphosate (4L ha-1 p.c.) and 2,4-D (2.5L ha-1 p.c.) with a knapsack sprayer with 1 nozzle, set to 200 L ha-1 of syrup.

In maize, the Sound Pressure Level (SPL), plant height (PH), first ear insertion height (HEI) and green mass production of maize plants (GM) were studied. The SPL produced by the forage machine during ensiling was measured with an Instrutherm decibel meter, model DEC-416, measurement range from 30 to 130 dB, A and C weighting, fast and slow time weighting, at a distance of 1.5 m of the machine, recording the maximum SPL value (dB) during the processing of 5 corn plants.

The production of green mass (GM) was measured by harvesting 5 plants at each georeferenced point, which were taken to LAMMEC/UNESP, chopped with a single-phase stationary forage chopper, Trapp, model TRF50, with a 1.5 hp electric motor (127/220V), at which time the SPL was measured. The insertion height of the first ear was determined by measuring the distance between the ear and the ground level with a measuring tape, as well as the plant height, from the last leaf issued to the ground.

Data were submitted to descriptive analysis and Anderson-Darling normality test (PIMENTEL-GOMES & GARCIA, 2002). The data were also submitted to geostatistical analysis (SOARES, 2006), with the Vesper program version 1.6 (Minasny et al., 2006). The structure and spatial dependence of the sampling points were evaluated using experimental semivariograms (Vieira, 2000). The degree of spatial dependence was classified according to the methodology proposed by Cambardella et al. (1994).

Results

The data obtained in the experiment during the 2021 harvest were subjected to descriptive statistical analysis, shown in Table 1, and Pearson correlation analyzes between the variables, shown in Table 2.

Table 1. Descriptive statistical analysis of the data obtained in the green corn crop in the year 2021 in Registro County, SP, Brazil.

Variable	SPL (dB)	GM (t/ha)[1]	HEI (m)	PH (m)
N	30,0	30,0	27,0	27,0
M	96,43	13,17	0,88	2,10
EP_M	0,296	0,742	0,030	0,055
s	1,6190	4,064	0,1535	0,2875
s^2	2,6210	16,513	0,0236	0,0827
CV	1,68	30,85	17,50	13,70
Mín.	91,70	7,170	0,493	1,237
Q1	95,900	10,133	0,7850	1,9233
Med.	96,550	12,730	0,923	2,200
Q3	97,425	15,605	0,993	2,323
Máx.	99,30	25,37	1,10	2,48
Ass.	-1,17	0,94	-0,90	-1,29
Curt.	2,23	1,66	0,56	1,80
Anderson-Darling Normality Test				
AD	1,039	0,430	0,574	0,848
valor-p	0,008**	0,288^{NS}	0,123^{NS}	0,025*

*[1] considering population of 55.000 plant ha^{-1}; SPL = sound pressure level of forage chopper; M = average; EP_M = mean standard error; s = standard deviation; s^2 = variance; CV = variation coefficient (%); Med. = median; Ass. = asymmetry; Curt. = kurtosis; AD = value of Anderson-Darling Test; ** = significative value at 1% (valor-p < 0,01); * = significative value at 5% (valor-p < 0,05); NS = no significative.*

The descriptive analysis of the data showed that the average sound pressure level was 96.43 dB, ranging from 91.70 dB (min.) to 99.30 dB (max.), the average production of 13.17 t ha^{-1} of green mass (VM) of plants, varying between 7.17 and 25.37 t ha^{-1} of GM of maize for silage (CV = 30.85%), average height of insertion of the first ear (HEI) of 0.877 m , varying between 0.49 and 1.10 m (CV = 17.5%) and average plant height (PH) of 2.099 m, varying between 1.2 and 2.48 m with CV of 13.7%. The Anderson-Darling (AD) Normality test showed that the SPL data were the only ones with normal distribution, as shown in Table 1.

Analyzing the Pearson correlations *(ρ)* between the variables (Table 2), it is noted that GM x SPL and PH x HEI were the ones that presented the highest correlations.

Table 2. Result of Pearson's correlation analysis between the variables studied in the corn silage experiment in the 2021 harvest, in Registro County, SP, Brazil.

X	Y	N	r	IC de 95% para ρ	Valor-p
GM (t ha^{-1})	SPL (dB)	27	0,656	(0,368; 0,829)	0,000
HEI (m)	SPL (dB)	27	0,314	(-0,075; 0,620)	0,110
PH (m)	SPL (dB)	27	0,142	(-0,252; 0,495)	0,481
HEI (m)	GM (t ha^{-1})	27	0,254	(-0,139; 0,578)	0,201
PH (m)	GM (t ha^{-1})	27	0,041	(-0,345; 0,414)	0,841
PH (m)	HEI (m)	27	0,730	(0,484; 0,869)	0,000

The 27 pairs of data used in the correlational analysis showed linear adjustments, expressed by the Equations SPL = 0.192.GM + 94.075 (r^2 = 0.430; p < 0.01) (Figure 1) and HEI = 0.3897.PH + 0.0592 (r^2 = 0.5329; p < 0.01) (Figure 2).

The sound pressure level (SPL) data were studied regarding spatial distribution, since the collection of plants was carried out at georeferenced points in the experimental area. The geostatistical analysis showed that the SPL (dB) and GM (t ha^{-1}) data (Table 3) better fit the exponential and spherical semivariogram, respectively. The data also showed that SPL showed weak spatial dependence (DSD < 0.001), while GM showed moderate spatial dependence (DSD = 0.731) as proposed by Cambardella et al. (1994).

Table 3. Semivariogram parameters adjusted for Sound Pressure Level (SPL, in dB) and Green Mass production of maize during ensilage (GM, in t ha^{-1}) in the agricultural year 2021, in Registro County, SP, Brazil.

VARIABLE	MODEL	C_0	C_0+C	A_0	RMSE	AIC	DSD
SPL (dB)	Exponential	0,00	0,979	2,454	0,6903	78,54	< 0,001
GM (t ha^{-1})	Spherical	10,43	14,266	15,72	5,020	189,60	0,731

Analyzed variables, adjusted on statistical models, C_0 = nugget effect; C_0+C = sill; A_0 = range (autocorelation); RMSE = root mean square error; AIC = value of the semivariogram model selection criteria (Akaike criteria); DSD = degree of spatial dependence.

Discutions

The sound, measured by the sound pressure level (SPL) presented values compatible with those observed in agricultural machines in operation (Magalhães et al., 2012; Silva et al., 2017), usually with a focus on occupational health. In this work, the values compatible with those expected and the low coefficient of variation (CV = 1.68%) seem to indicate that the SPL presented stability in the values, as well as the normal distribution obtained (*p-value* 0.008), desirable characteristics to use the parameter as an estimator of another, which together with the ease of measurement can contribute to the development of a methodology for estimating the production of green mass during the forage harvest.
The Figure 1 illustrates the positive and significant correlation between the variables SPL and GM (r = 0.656; *p-value* < 0.001) and they oscillate according to the volume of biomass that passes through the sinner system. According to Fernandes (2002), this behavior is compatible with fluctuating noises, those that present large variations in level as a function of time.
The relationship between green mass (GM) and insertion height of the first ear was also evaluated (Figure 2), the coefficients of variation were higher (13.70% and 17.5%, respectively) and showed a positive and significant correlation (r = 0.730, *p-value* < 0.05). The insertion height of the first ear is related to the plant height, but it was not expected to be related to the SPL, which was confirmed in this work, since the HEI x SPL relationship were not significant (*p-value* > 0, 01) and with a low correlation coefficient (Table 2). However, according to Kopper et al. (2017) the PH has a high influence on corn grain yield, with ears inserted at greater heights (taller plants), tending to produce more.

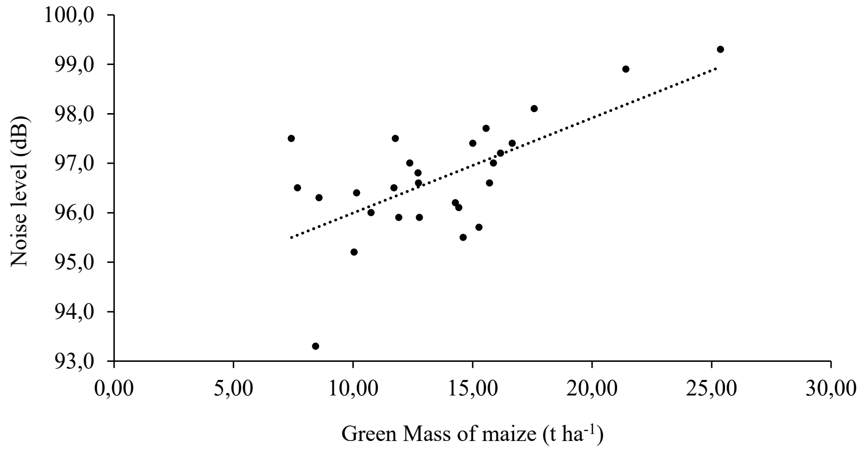

Figure 1. Correlation between green mass production of corn and sound pressure level during the ensiling process in the 2021 harvest, in Registro, SP, Brazil.

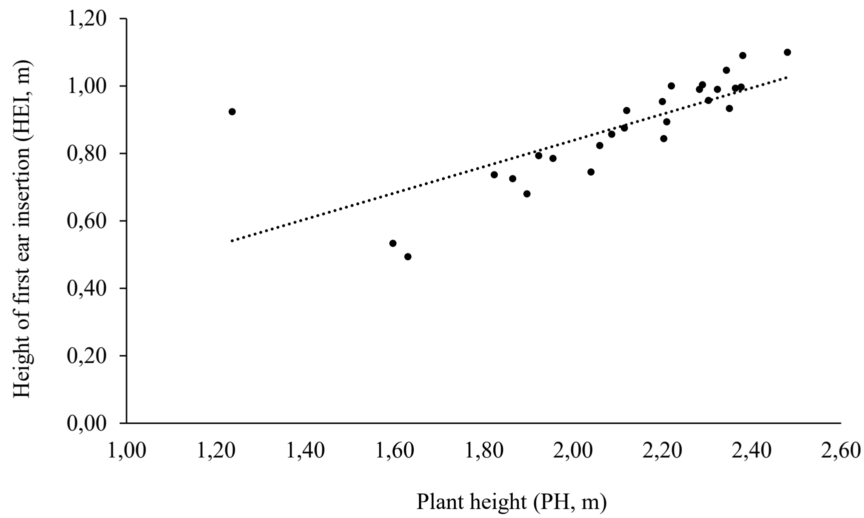

Figure 2. Correlation between green corn plant height (PH, m) and insertion height of the first ear (HEI, m) in the 2021 harvest, in Registro County, SP, Brazil.

The sound pressure level (SPL) data were studied regarding spatial distribution since the collection of plants was carried out at georeferenced points in the experimental area. The fact that SPL is significantly correlated with the production of green mass in this experiment makes it interesting to verify the spatial behavior of the variables in the area under study. The semivariogram shown in Figure 3 shows that the variance is explained because of the data obtained (Nugget Effect C_0 = 0.0) and the estimated range (A_0) proved to be consistent with the form of sound propagation. Magalhães et al. (2012) studied the noise levels emitted by a tractor on its four sides and in positions from the operator's station (0,0 m) up to 15m and verified a reduction in the values of the emitted noise, corroborating with what was observed in this work.

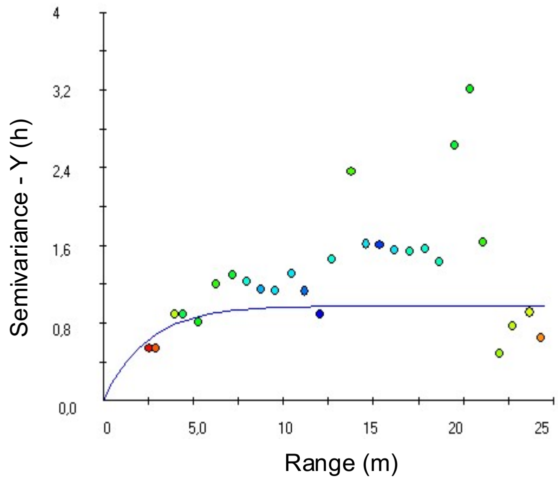

Figure 3. Semivariogram of Sound Pressure Level (SPL, in dB) adjusted to the Exponential model, in Registro County, SP, Brazil.

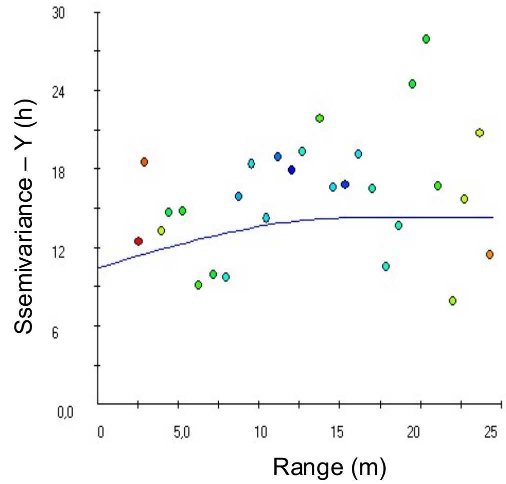

Figure 4. Green mass semivariogram of plants in ensilage (GM, t ha^{-1}) adjusted to the spherical model, in Registro County, SP, Brazil.

To GM, it was found that the mathematical model to which the data best fitted (Figure 4) was the spherical model and showed moderate spatial dependence (0.35 < DSD < 0.75). Studies relating the production of green mass during ensiling and the sound pressure level are non-existent in the literature, but this research demonstrates that there is the possibility of using the SPL as an estimator of the productivity of GM, with the accomplishment of new researches on the subject.

Conclusions

According to the data and performance conditions, the work showed that: (a) there is a possibility of the SPL being an estimator of the corn VM productivity in ensilage, due to the positive and significant correlation between both; (b) the geospatial distribution of SPL decreases with increasing distance from the machine; (c) Plant height and first ear insertion height were not related to SPL.

Acknowledgements

To farmer Mr. Carlos Samitsu for permission to carry out the research on your Farm and to the students who are members of LAMMEC/FCAVR-UNESP for their collaboration in field activities.

References

Cambardella, C.A., Moorman, T.B., Parkin, T.B., Karlen, D.L., Novak, J.M., Turco, R.F., & Konopka, A.E. (1994). *Field scale variability of soil properties in central Iowa soils. Soil science society of America journal*, 58, 1501-1511.

Fernandes, J.C.O. (2002). *Ruído Ambiental: Seus Efeitos e seu Controle.* Apostila do Departamento de Engenharia Mecânica da UNESP - Campus de Bauru.

Kopper, C.V., Meert, L., Krenski, A., Borghi, V.A., Oliveira Neto, A.M., Figueiredo, A.S.T. (2017). *Produtividade de milho segunda safra em função de diferentes velocidades de semeadura e densidade de plantas*. Pesquisa agropecuária pernambucana, 22, e 201701. Avaliable at: http://dx.doi.org/10.12661/pap.2017.003.

Magalhães, A.T., Cortez, J.W., Naga-hama, H.J. (2012). *Nível de ruído de um trator agrícola em função da rotação, da distância, da velocidade e da condição do solo obtido por meio de decibelímetro com e sem proteção de vento*. Energia na Agricultura, 27, 27-44.

Minasny, B., McBratney, A.B., Whelan, B.M. 2002. (2006). VESPER Version 1.6 Australian Centre for Precision Agriculture, McMilan Building A05, The University of Sydney, NSW.

Pimentel-Gomes, F.; Garcia, C. H. (2002). Estatística aplicada a experimentos agronômicos e florestais: exposição com exemplos e orientações para uso de aplicativos. Piracicaba: Fealq.

Raij, B. V. (1996) *Recomendações de adubação e calagem para o Estado de São Paulo. Campinas: IAC*.

Saliba, T. M. *Manual Prático de Avaliação e Controle do Ruído*. São Paulo: LTr, 2004

Silva, A.C., Furtado Júnior, M.R., Ribeiro, L.C., Fernandes, H.C., Teixeira, R.R.D. (2017). Ruído e vibração no posto de operação de um trator agrícola em função da pressão dos pneus e velocidade operacional. Engenharia na Agricultura, 25, 454-458. Available at: https://doi.org/10.13083/reveng.v25i5.842.

Soares, A. (2006). *Geoestatística para as ciências da terra e do ambiente*. IST Press, p. 214.

Veiga, R. K.; Gontijo, L. A.; Masiero, F. C.; Venturi, J. (2021). Análise e distribuição espacial do ruído no posto de trabalho do operador e nas proximidades de máquinas agrícolas e florestais. Ciências Florestais, 31, 43-65. Available at: https://doi.org/10.5902/1980509816116.

Vieira, S. R., Novais, R. D., Alvarez, V. H., & Schaefer, C. E. G. R. (2000). *Geoestatística em estudos de variabilidade especial do solo*. Tópicos em ciência do solo. Viçosa: Sociedade Brasileira de Ciência do Solo,1, 1-53.

Toginho Filho, D. O. (2012). *Catálogo de Experimentos do Laboratório Integrado de Física Geral Departamento de Física* · Universidade Estadual de Londrina.