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Scientific Paper

Loss of nitrogen, phosphorus, and potassium through surface runoff under simulated rainfall in different soil management systems

Perda de nitrogênio, fósforo e potássio via escoamento superficial sob chuva simulada em diferentes sistemas de manejo de solo

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ABSTRACT

The surface runoff in agricultural areas can carry soil chemical elements, causing environmental and economic problems. Nutrient losses through surface runoff can occur in both particulate and dissolved forms, influenced by soil use and management systems. In this context, the objective of this study was to quantify the losses of N (NH_4^+ and NO_3^-), P, and K in dissolved and particulate forms in samples from a simulated rainfall event of 60 mm h^{-1} with a duration of 20 minutes, after the onset of surface runoff. The study was conducted in experimental plots in a randomized block design, with four treatments and two replications. The treatments were defined as T1 (fallow with spontaneous vegetation), T2 (irrigated rice under conventional tillage), T3 (no-tillage irrigated rice in monoculture), and T4 (no-tillage rice in crop rotation). The rainfall was applied in pre-seeding of irrigated rice, crop 2022/2023. The results showed that the highest losses of NH_4^+ and NO_3^- occurred in treatments T2 and T3 compared to the others. Regarding nutrient loss, treatments T1 and T2 showed the highest losses of P and K, with a greater presence in the soil fraction (particulate).

Keywords: runoff; irrigated rice; no-tillage.

RESUMO

O escoamento superficial em áreas agrícolas pode carrear elementos químicos do solo, causando problemas ambientais e econômicos. As perdas de nutrientes por escoamento superficial podem ocorrer tanto na forma particulada quanto dissolvida, sendo influenciadas pelo uso e sistema de preparo do solo. Nesse contexto, o objetivo deste trabalho foi quantificar as perdas de N (NH_4^+ e NO_3^-), P e K nas formas dissolvida e particulada, em amostras de um evento de chuva simulada de 60 mm/h com duração de 20 minutos, após o início do escoamento superficial. O estudo foi conduzido em parcelas experimentais em delineamento de blocos casualizados, com quatro tratamentos e duas repetições. Os tratamentos foram definidos como T1 (pousio com vegetação espontânea), T2 (arroz irrigado em preparo convencional), T3 (semeadura direta em monocultivo de arroz irrigado) e T4 (semeadura direta em rotação de culturas). A chuva foi aplicada em pré-semeadura de arroz irrigado, safra 2022/2023. Os resultados evidenciaram que as maiores perdas de NH_4^+ e NO_3^- ocorreram nos tratamentos T2 e T3 em comparação com os demais. Em relação à perda de nutrientes, os tratamentos que apresentaram as maiores perdas de P e K foram T1 e T2, com maior presença na fração do solo (particulado).

Palavras-chave: escoamento superficial; arroz irrigado; semeadura direta.

INTRODUCTION

Soil degradation is one of the most relevant processes for agriculture, as it can lead to the loss or even depletion of nutrients in the soil. This process can occur due to various factors, whether natural or not, and intensifies with the anthropization of agricultural spaces. According to a Food and Agriculture Organization (FAO) report (FAO, 2021), it is estimated that human-induced soil degradation affects 34%, or 1.660 million hectares, of agricultural lands. As agriculture intensifies, the action of erosive processes on soils increases, reducing natural fertility and causing an increase in their salinity.

In Brazil, water erosion is one of the most important forms of soil degradation, causing average soil losses ranging from 0.1 to 136.0 t ha^{-1} $year^{-1}$, depending on land use and cover (ANACHE *et al.*, 2017). Furthermore, according to Silva *et al.*

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(2018), soil loss due to water erosion carries nutrients and other elements transported to water resources, which can cause environmental and sanitary problems.

The material carried by runoff can be transported in two main primary forms: dissolved and particulate. These forms are crucial to understanding the interaction of chemical elements while displacing nutrients from crops. The dissolved form refers to elements in the runoff's liquid phase. Surface runoff makes these elements more easily transported out of the agricultural area. On the other hand, the particulate form consists of sediment fractions, mainly represented by clay particles and organic matter, due to their low density (SCHICK *et al.*, 2000). The impact of raindrops disaggregates these particles and remains suspended in the runoff water, being carried along with it. These soil particles are deposited in lower regions and can reach water resources through surface runoff, mainly from agricultural areas that do not implement conservation agricultural practices (SILVA *et al.*, 2018).

In these areas, water erosion, besides contributing to the siltation of water bodies, has favored the transport of large quantities of nutrients from fertilizers through surface runoff, causing a more accelerated process of eutrophication (SOUZA *et al.*, 2013). Within these particles of eroded material, essential nutrients for agricultural crops can be found, which are displaced from this system, causing significant environmental and economic losses in productivity.

Several studies have been conducted to assess how different management practices influence erosive processes (CASSOL; LIMA, 2003; LEITE *et al.*, 2004; AMARAL *et al.*, 2008; KORKANÇ; DORUM, 2019) in order to identify which management systems yield better results in reducing losses due to water erosion. The management practices adopted in agricultural areas can positively or negatively influence soil and water losses and soil nutrients, exposing the soil surface to rainfall. Therefore, there is a hypothesis that conventional soil tillage leads to greater nutrient losses, especially in the particulate fraction.

Given the above considerations, this study aimed to quantify the loss of nutrients promoted by interrill erosion, carried by runoff in fallow, conventional, and no-tillage management systems, considering environmental variables such as the concentration of nitrogen (NH_4^+ and NO_3^-), phosphorus (P), and potassium (K) available, in a Typic Albaqualfs of lowlands located in the Pelotas region, RS, southern Brazil.

METHODS

Site description and experimental design

The experiment was conducted in the municipality of Capão do Leão, in the state of Rio Grande do Sul, located between latitudes 31°48'02" S and longitude 52°29'44" W, at an altitude of 12 meters above sea level. The study was carried out in experimental plots located at the Experimental Station of the Palma Agricultural Center (CAP), Universidade Federal de Pelotas (Figure 1).

The experimental area is in the physiographic region of the Southeastern Slopes of Rio Grande do Sul. The region's climate is classified as Cfa (humid subtropical climate with hot summers), according to the Köppen climate classification (ALVARES *et al.*, 2013). The average annual precipitation in the region is 1,369.46 mm (NUNES *et al.*, 2023). The most prevalent soil class in the study region is composed of Typic Albaqualfs (SEVERO, 1999; SOIL SURVEY STAFF, 2014). The main values of chemical and physical attributes are presented in Tables 1 and 2.

Site description and experimental design

Each experimental plot was delimited by galvanized iron sheets, with an area of 33 m² and dimensions of 11× 3 m, with the longest dimension oriented downhill (0.2 to 0.3% slope). The plots were bounded at the top and laterally with galvanized sheets measuring 0.20 m in height and 0.65 mm in thickness, with 0.10 m buried in the soil and 0.10 m above the surface. A space of 2.5 m was left between each plot (Figure 2).

The experiment was conducted in a randomized complete block design with four treatments and two replications. Different land use and management practices for lowland soils were adopted to identify the impacts of these systems on soil attributes and soil losses. Each treatment was defined with the following management practices:

T1: Fallow management with spontaneous vegetation;

T2: Conventional management, conducted with successive irrigated rice cultivation under conventional tillage and fallow in winter;

T3: No-till management, conducted with successive irrigated rice cultivation under no-till with clover and ryegrass in winter;

T4: No-till management, conducted with irrigated rice cultivation in rotation with soybeans under no-till with clover and ryegrass in winter.

The simulated rainfall was conducted in the plots using a portable rainfall simulator, following the operating principles similar to those described by Meyer and Harmon (1979), adapted by Faria Júnior *et al.* (2013). The VeeJet 80-150 sprinkler nozzle was positioned at a height of 3 m to provide the appropriate drop velocity (MEYER; HARMON, 1979). This nozzle operates at a pressure gauge of 41 kPa, is monitored by a pressure gauge, and is powered by a 1/3 HP electric centrifugal pump (Figure 3).

Data was collected through a simulated rainfall event during the pre-seeding period of summer crops, conducted in all eight plots. Soil preparation for irrigated rice seeding has already been completed in the conventional system. Subsequently, the application was conducted during the 2022/2023 summer season. The collection of runoff material began at the onset of surface runoff, totaling 20 minutes, and was carried out simultaneously with the runoff being collected from the gutter into the collecting containers.

The average precipitation used to calibrate the simulator was 60 mm h^{-1}. This value was adopted based on the intensity-duration-frequency (IDF) curve for Pelotas over a ten-year return period (DORNELES *et al.*, 2019). The precipitation intensity was monitored and calculated by distributing the contents of six 500 mL Becker flasks over a 1 m² plot within 15 minutes.

To calibrate the simulator, the Equation 1, presented by Faria Júnior *et al.* (2013), was used, with tests of 5, 10, and 15 minutes.

$$I = [(v/s)/T].60 \tag{1}$$

Where:

I: intensity, in mm h^{-1};

v: collected volume, in liters;

s: collector mouth area, in m²;

T: collection time, in minutes.

For runoff collection under simulated rainfall using the portable simulator, a square measuring 1 m² was delimited using galvanized sheets buried in the soil at a depth of 0.10 m and positioned 0.10 m above the ground. The simulator was installed near the bottom of each plot, where runoff (surface flow) resulting from the simulated rainfall was directed. At the bottom of each plot, a collecting gutter was installed to channel surface runoff by gravity, as shown in Figure 4.

The eroded material generated from surface runoff was collected using pre-identified and weighed 750 mL plastic pots. The collection period started when the onset of surface runoff was observed. As collections were made, the samples were stored in the pots, sealed with lids, and taken to the laboratory for further evaluation.

The analysis of electrical conductivity (EC) and pH was conducted immediately after collection at the event's site. For the collection of the total material resulting from surface runoff, three 80 mL pots were taken, which were stored in a refrigerated environment until transportation to the laboratory. Subsequently, the material was kept in a freezer at -4°C for subsequent nitrogen analyses.

To quantify phosphorus (P), the samples were filtered using a 0.45 µm filter paper and separated for analysis of the material dissolved in water and the sediment that remained retained. The dissolved material, i.e., the runoff water, was stored in a refrigerated environment until reading. The sediments retained on the filter were left exposed to the open air to dry for 48 hours. After this process, scraping, maceration, and weighing were conducted using precision scales (0.0001 g). For chemical analysis of the collected and filtered material, 1 g was separated for each replication of the treatments. Nutrient determinations were carried out on the particulate (sediment) due to the low sediment production in the simulated rainfall event.

Pot samples were removed from the freezer for nitrogen determination and allowed to thaw at room temperature. Subsequently, the contents were analyzed for NH_4^+ and NO_3^- content using Micro-Kjeldahl distillers, as described by Tedesco *et al.* (1995). Dissolved P content was determined by colorimetry, following the method described by Murphy and Riley (1962), while for particulate material the soil analysis methodology proposed by Tedesco *et al.* (1995) was adopted.

The statistical analysis was performed using multiple comparisons of means tests between the replications of each treatment. The R software (R CORE, 2022) was used to evaluate significant differences between means through analysis of variance (ANOVA) among treatments. The Tukey test was employed at a significance level of 0.05 for significant differences.

RESULTS AND DISCUSSION

From the pH and EC values obtained from the analysis conducted at the time of runoff, a significant difference at $p < 0.05$ was observed only for EC (Table 3). The highest values were observed in treatments T4 and T1, respectively.

The analysis of EC revealed statistically significant differences among the evaluated agricultural management treatments. Treatment T4 showed the highest mean value of EC (0,72 µS cm^{-1}), followed by treatment T1 (0,71 µS cm^{-1}). On the other hand, treatment T3 and treatment T2 exhibited lower mean values (0,63 and 0,56 µS cm^{-1}, respectively). These variations in EC values may indicate differences in the concentration of dissolved salts in the runoff water, consequently influencing the mobility of nutrients during water erosion. Higher EC values may suggest a greater presence of soluble salts, such as nitrate and ammonium, in the runoff water, which could result in significant losses of these nutrients during water erosion events.

The pH results of the runoff water, although not showing differences among the means values, were close to alkalinity. According to the study proposed by Kubitza (2003), an increase in water alkalinity tends to increase the concentrations of the non-ionized form of ammonia (NH_3^-), which is particularly toxic to fish when carried and deposited in water bodies. Furthermore, according to the same author, the percentage of this element, when present in water, triples when the pH increases from 7.0 to 7.5.

Figure 5 presents the mean values of ammoniacal nitrogen content obtained from the analysis of surface runoff samples under different treatments. When performing the analysis of variance of the mineral nitrogen content among treatments, no significant difference was observed at $p > 0.05$.

The analysis of nitrate and ammonia losses through water erosion revealed that both the conventional system under irrigated rice cultivation (T2) and the no-till rice monoculture system (T3) showed higher losses of these nutrients compared to the fallow system (T1) and the no-till system with crop rotation (T4). These results may be related to the practices employed in these management systems and also to the stage of decomposition of surface material in each treatment.

In treatments T2 and T3, the frequent use of nitrogen fertilizers and the lower diversity of crops contribute to a more significant accumulation of nitrate and ammonia in the soil. On the other hand, in treatment T4, the practice of alternating different crops promotes better nutrient absorption and utilization by the plant root system, thereby reducing the amount of nitrate and ammonia available for losses. Additionally, treatment T1, which does not receive any type of fertilization and has little spontaneous vegetative cover, maintained much lower values compared to the other treatments. Furthermore, according to Figure 5, the highest losses of ammonium occurred in the no-tillage system with rice straw (T3), as this system still had a higher concentration of surface straw. It is noteworthy that nitrogen can be lost in other ways, such as leaching in the soil. In this same treatment, there was a trend towards an increase in the presence of NH_4^+ in the samples, which may be related to the process of organic matter immobilization, probably due to the low mineralization of the rice straw from the 2021/2022 harvest, whose material was still present in the area.

Nitrate and ammonium can be present in both runoff water and eroded sediment, although their forms and availability may vary. When runoff water carries sediment, nutrients such as nitrate and ammonium can bind to sediment particles and be transported in this manner. The binding of nutrients to sediment can increase their stability and long-term availability in the environment. However, given the values presented, considering that the collected material was not filtered to distinguish between losses of nitrate and ammonium in runoff water and soil, it is difficult to determine the predominant source of these nutrients.

The values of nutrient losses were quantified, and the materials collected were categorized into dissolved in water and particulate in soil fractions, as shown in Table 4. When applying the variance test, a significant difference was found for all the analyzed elements, both in particulate and dissolved material.

The highest nutrient losses occurred in treatments T1 and T2, both in the dissolved and particulate forms. This response is due to the disaggregation generated by rainfall on bare soil. The representation of these values indicates the effect of surface disturbance and the transport of these nutrients, both in contact with sediment and water, in systems without surface cover.

The action of surface runoff in uncovered treatments favored the highest sediment losses in runoff water, allowing for the interaction of these nutrients with the water. Treatments T3 and T4 had lower values in particulate nutrient loss because little material was eroded. From this material, it is assumed that the lower results represent the nutrients carried by the organic fraction of the surface material found in these treatments, where fertilization was not performed to avoid interfering with the values found on the surface. In direct planting systems, high concentrations of these nutrients are found under the surface and can be lost more rapidly through surface runoff action (CASSOL *et al*., 2002; BERTOL *et al*., 2011).

According to Bertol *et al*. (2003), nutrient loss through surface runoff is influenced by its concentration in runoff water and sediments and by the total loss of water plus sediment. However, these concentrations can indicate how nutrient retention (P and K) occurs when incorporated into management practices. Ibáñez *et al*. (2004) suggest that nutrient losses through water erosion can lead to soil depletion at the erosion site and can also serve as a source for increased environmental contamination, especially in surface waters that may be transported away from the site.

It is crucial to recognize that nutrient losses through water erosion not only compromise soil fertility at the erosion source site but also contribute to environmental contamination, especially of surface waters. Therefore, strategies aimed at protecting the soil against erosion, such as using vegetative cover and no-till practices, are essential for mitigating nutrient loss, ensuring the sustainability of agricultural practices, and preserving natural resources.

CONCLUSIONS

The results highlight variations in EC among treatments, indicating a higher concentration of soluble salts in runoff water, intensifying the risk of nutrient loss during water erosion. However, further investigations are recommended to better understand this relationship and its implications for nutrient loss.

The conventional and no-till systems in rice monoculture obtained the highest losses of NH_4^+ and NO_3^-, demonstrating that the management practices adopted in each system, as well as the stage of decomposition of surface material, can influence the concentration of these nutrients and, consequently, their loss.

The soil disaggregation caused by rainfall in uncovered systems exposes the soil to erosion, favoring the transport of these nutrients both in contact with sediment and water.

AUTHORS' CONTRIBUTIONS

Melo, T. V.: Conceptualization, Data curation, Formal Analysis, Writing – original draft. Nunes, M.C.M.: Supervision, Formal Analysis, Project administration, Writing – review & editing. Martins Filho, E.M.S.: Data curation, Methodology, Project administration. Cadoná, E.A.: Data curation, Formal Analysis, Methodology, Supervision. Carlos, F. S.: Data curation, Project administration, Resources, Supervision. Miguel, P.: Supervision; Visualization.

REFERENCES

ALVARES, C.A.; STAPE, J.L.; SENTELHAS, P.C.; MORAES GONÇALVES, J.L.; SPAROVEK, G. Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, [S. l.], v. 22, n. 6, p. 711-728, 2013. https://doi.org/10.1127/0941-2948/2013/0507

AMARAL, A.J.; BERTOL, I.; COGO, N.P.; BARBOSA, F.T. Redução da erosão hídrica em três sistemas de manejo do solo em um cambissolo húmico da região do planalto sulcatarinense. *Revista Brasileira de Ciência do Solo*, Viçosa, v. 32, n. 5, p. 2145-2155, 2008. https://doi.org/10.1590/S0100-06832008000500035

ANACHE, J.A.A.; WENDLAND, E.C.; OLIVEIRA, P.T.S.; FLANAGAN, D.C.; NEARING, M.A. Runoff and soil erosion plot-scale studies under natural rainfall: A meta-analysis of the Brazilian experience. *Catena*, v. 152, p. 29-39, 2017. https://doi.org/10.1016/j.catena.2017.01.003

BERTOL, I.; MELLO, E.L.; GUADAGNIN, J.C.; ZAPAROLLI, A.L.V.; CARRAFA, M.R. Nutrient losses by water erosion. *Scientia Agrícola*, Piracicaba, v. 60, n. 3, p. 581-586, 2003. https://doi.org/10.1590/S0103-90162003000300025

BERTOL, O.J.; RIZZI, N.E.; FEY, E.; LANA, M.C. Perda de nutrientes via escoamento superficial no sistema plantio direto sob adubação mineral e orgânica. *Ciência Rural*, v. 41, n. 11, p. 1914-1920, 2011. https://doi.org/10.1590/S0103-84782011005000135

CASSOL, E.A.; LEVIEN, R.; ANGHINONI, I.; BADELUCCI, M.P. Perdas de nutrientes por erosão em diferentes métodos de melhoramento de pastagem nativa no Rio Grande do Sul. *Revista Brasileira de Ciência do Solo*, Viçosa, v. 26, n. 3, p. 705-712, 2002. https://doi.org/10.1590/S0100-06832002000300015

CASSOL, E.A.; LIMA, V.S. Erosão em entressulcos sob diferentes tipos de preparo e manejo do solo. *Pesquisa Agropecuária Brasileira*, Brasília, v. 38, n. 1, p. 117-124, jan. 2003. https://doi.org/10.1590/S0100-204X2003000100016

DORNELES, V.R.; DAMÉ, R.C.F.; TEIXEIRA-GANDRA, C.F.A.; VEBER, P.M.; KLUMB, G.B.; RAMIREZ, M.A.A. Modeling of probability in obtaining intensity-duration-frequency relationships of rainfall occurrence for Pelotas, RS, Brazil. *Revista Brasileira de Engenharia Agrícola e Ambiental*, v. 23, n. 7, p. 499-505, 2019. https://doi.org/10.1590/1807-1929/agriambi.v23n7p499-505

FARIA JÚNIOR, C.A.; NUNES, M.C.M.; SANTOS, F.A.S.; FREITAS, P.S.L.; DALLACORT, R. Construção e calibração de um simulador de chuva portátil. *Enciclopédia Biosfera*, Goiânia, v. 9, n. 17, p. 778-787, 2013. Available at: https://conhecer.org.br/ojs/index.php/biosfera/article/view/3062. Accessed on: Oct. 14, 2023.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO). *The state of the world's land and water resources for food and agriculture - Systems at breaking point*. Relatório Síntese 2021. Rome: FAO, 2021. https://doi.org/10.4060/cb7654en

IBÁÑEZ, A.; MARTÍNEZ, C.; RAMOS, M.C.; MARTÍNEZ CASANOVAS, J.A. Effects of composted cattle manure on erosion rates and nutrient losses. *In*: EUROSOIL, 2004, Freiburg, Germany. *Abstracts* [...]. Freiburg, 2004. CD-ROM.

KORKANÇ, S.Y.; DORUM, G. The nutrient and carbon losses of soils from different land cover systems under simulated rainfall conditions. *Catena*, v. 172, p. 203-211, 2019. https://doi.org/10.1016/j.catena.2018.08.033

KUBITZA, F. *Qualidade da água no cultivo de peixes e camarões*. Jundiaí: Degaspari, 2003.

LEITE, D.; BERTOL, I.; GUADAGNIN, J.C.; SANTOS, E.J.; RITTER, S.R. Erosão hídrica em um Nitossolo Háplico submetido a diferentes sistemas de manejo sob chuva simulada. I - Perdas de solo e água. *Revista Brasileira de Ciência do Solo*, Viçosa, v. 28, n. 6, p. 1033-1044, 2004. https://doi.org/10.1590/S0100-06832004000600012

MEYER, L.D.; HARMON, W.C. Mutiple intensity rainfall simulator for erosion research on row sideslopes. *Transactions of the American Society of Agricultural Engineering*, v. 22, n. 1, p. 100-103, 1979. https://doi.org/10.13031/2013.34973

MURPHY, J.; RILEY, J.P. A modified single solution method for the determination oh phosphate in natural waters. *Analytica Chimica Acta*, v. 27, p. 31-36, 1962. https://doi.org/10.1016/S0003-2670(00)88444-5

NUNES, M.C.M.; CARDOSO, D.P.; MELO, T.V.; DORNELES, V.R.; KNAPP, A.P.; COCCONELLO, S.T. Erosivity and seasonal rainfall for Pelotas-RS, Brazil with the RainfallErosivityFactor package and Modified Fournier Index. *Journal of South American Earth Sciences*, v. 132, 104649, 2023. https://doi.org/10.1016/j.jsames.2023.104649

R CORE (2022). *R:* Uma linguagem e ambiente para estatísticas Informática. Viena: Fundação R para Computação Estatística. Available at: https://www.R-project.org/. Accessed on: Oct. 14, 2023.

SCHICK, J.; BERTOL, I.; BALBINOT JÚNIOR, A.A.; BATISTELA, O. Erosão hídrica em cambissolo húmico alumínico submetido a diferentes sistemas de preparo e cultivo do solo. II. Perdas de nutrientes e carbono orgânico. *Revista Brasileira de Ciência do Solo*, v. 24, p. 437-447, 2000. https://doi.org/10.1590/S0100-06832000000200020

SEVERO, C.R.S. *Caracterização dos solos do centro agropecuário da palma, UFPEL, município de Capão do Leão-RS*. 97f. Dissertação (Mestrado em Solos) – Universidade Federal de Pelotas, Pelotas, 1999.

SILVA, D.C.C.; ALBUQUERQUE FILHO, J.L.; OLIVEIRA, R.A.; LOURENÇO, R.W. Proposta metodológica para análise espacial de nutrientes do solo em bacias hidrográficas. *Sociedade: Natureza*, v. 30, n. 3, p. 85-107, 2018. https://doi.org/10.14393/SN-v30n3-2018-5

SOIL SURVEY STAFF. *Keys to Soil Taxonomy*. 12. ed. Washington, D.C.: US. Department of Agriculture Natural Resources Conservation Service, 2014. Available at: https://www.nrcs.usda.gov/sites/default/files/2022-06/Soil%20Taxonomy.pdf. Accessed on: Feb. 14, 2024.

SOUZA, R.F. *Frações da matéria orgânica e perdas de solo, água e nutrientes no cultivo de hortaliças sob sistemas de manejo*. 76f. Dissertação (Mestrado em Agronomia) – Faculdade de Agronomia e Medicina Veterinária, Universidade de Brasília, Brasília, 2013.

TEDESCO, M.J.; GIANELLO, C.; BISSANI, C.A.; BOHNEM, H.; VOLKWEIIS, S.J. *Análise de solo, plantas e outros materiais*. 2. ed. Porto Alegre: Universidade Federal do Rio Grande do Sul, 1995. 174 p. (Boletim técnico, 5.)