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LETUSA MOMESSO MARQUES

IMPACTS OF NITROGEN APPLICATION ON FORAGE GRASSES TO MAIZE IN NO-TILLAGE SYSTEM

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LETUSA MOMESSO MARQUES

IMPACTS OF NITROGEN APPLICATION ON FORAGE GRASSES TO MAIZE IN NO-TILLAGE SYSTEM

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To all those who work in science with

hope their contributions and discoveries

may change the world.

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“The real voyage of discovery consists not in seeking new landscapes, but in having new eyes”.

Adapted from PROUST, M. Remembrance of Things Past: The Captive. 1923.

ABSTRACT

The success of no-tillage system depends on the knowledge of the agricultural system as a whole. The use of grass *Urochloa* sp. as cover crop in agriculture results in slow organic material decomposition due to high biomass production and changes in soil microbe, in particular in biological processes related to nitrogen (N). Because N is a nutrient present in the main biochemical reactions in plants and microorganisms, N management requires special attention. Therefore, this research aimed to improve N-use efficiency from both agronomic and biological perspectives. The main objectives were to (i) assess the impact of N fertilizer and forage species on maize in the NT system, and (ii) determine the interactions between microbes x N x environmental factors. A field experiment was evaluated, in which palisade grass (*Urochloa brizantha*) and ruzigrass (*U. ruziziensis*) grown with four N management, included: (i) control zero-N (no N application), (ii) N applied on green cover crops at 35 days before maize seeding (35 DBS), (iii) N applied on cover crop residues at 1 day before maize seeding (1 DBS), and (iv) conventional method of N applied at sidedressing in maize growth), at a rate of 120 kg N ha^{-1} as ammonium sulfate. The hypothesis of *Chapter 1* that N applied on alive cover crops or cover crop residues could replace N-sidedressing application (conventional method) for maize was confirmed when: (a) N was applied on palisade grass at 35 DBS or its residues at 1 DBS, and (b) N was applied on ruzigrass residues at 1 DBS. Due to results of first chapter, another experiment was conducted with the objective of assessing whether either the early N application on alive cover crops or on cover crop residues or the conventional method of N application contributed to the recovery of total-N and fertilizer ^{15}N by maize, by cover crop residues, and in the soil over growing season. Although the hypothesis that N applied on palisade grass to achieve high grain yields of maize was previously confirmed, the results *Chapter 2* showed that the best option is applying nitrogen fertilizer as the current fertilizer recommended method (40 kg N ha^{-1} at maize seeding plus 120 kg N ha^{-1} sidedressed in V_6 growth stage) for enhance grain yields of maize and N recovery from fertilizer.

Keywords: *Brachiaria*. *Zea mays* L.. Crop residues. ^{15}N. Nitrogen uptake efficiency. Tropical agriculture.

RESUMO

O sucesso do sistema de plantio direto depende do conhecimento do sistema agrícola como um todo. O uso de gramíneas do gênero *Urochloa* como planta de cobertura resulta em lenta decomposição do material orgânico devido à alta produção de matéria seca e alterações nos microrganismos do solo, em particular nos processos biológicos relacionados ao nitrogênio (N). Como o N é um nutriente presente nas principais reações bioquímicas em plantas e microrganismos, o manejo deste nutriente requer atenção especial. Portanto, este trabalho de pesquisa teve como objetivo melhorar a eficiência do uso do manejo do N. O principal objetivo foi avaliar o impacto do adubo nitrogenado aplicado nas duas espécies de gramíneas ou nos seus resíduos para suprir a demanda e aumentar a produtividade de grãos do milho no sistema plantio direto. O experimento de campo foi conduzido durante três anos, no qual *Urochloa brizantha* e *U. ruziziensis* foram cultivadas com 4 manejos da adubação nitrogenada. Os manejos da adubação nitrogenada foram: (i) controle (zero aplicação de N), (ii) N aplicado 35 dias antes da semeadura do milho (35 DAS), (iii) N aplicado 1 dia antes da semeadura do milho (1 DAS), e (iv) método convencional (N aplicado em cobertura no crescimento do milho), com a dose de 120 kg ha^{-1} de N da fonte sulfato de amônio. A hipótese no *Capítulo 1* de que o N aplicado nas plantas de cobertura ou nos resíduos destas plantas de cobertura poderiam ser substituir a aplicação de N em cobertura do atual método convencional para cultura do milho foi confirmada quando o N foi aplicado na *U. brizantha* aos 35 DAS ou em seus resíduos 1 DAS e quando o N foi aplicado nos resíduos da *U. ruziziensis* 1 DAS. Devido aos resultados observados no primeiro capítulo, o *Capítulo 2* objetivou avaliar se a aplicação antecipada de N (nas plantas de cobertura ou nos resíduos das plantas de cobertura) e a aplicação de N no método convencional contribui para o teor total de N e a recuperação do ^{15}N do fertilizante pelo milho, pelos resíduos das plantas de cobertura e no solo ao final da safra. Embora a hipótese de que a aplicação de N na *U. brizantha* tenha sido confirmada anteriormente para atingir altas produtividade de grãos de milho, os resultados do segundo capítulo mostraram que a aplicação do N deve ser realizada como recomendado no método convencional (40 kg ha^{-1} na semeadura e 120 kg ha^{-1} em cobertura) para, além de atingir altas produtividade, recuperar maior quantidade do fertilizante nitrogenado aplicado.

Palavras-chave: *Brachiaria*. Plantas de cobertura. Fertilizante ^{15}N. Eficiência do uso do nitrogênio. Sistema semeadura direta.

LIST OF FIGURES

LIST OF TABLES

SUMMARY

GENERAL INTRODUCTION

Over time, the plant residues left on the soil surface in a no-tillage (NT) system gradually improve the physical, chemical, and biological characteristics of the soil (SILVA et al., 2014; TIRITAN et al., 2016; MORAES et al., 2019). Used frequently in tropical countries, this practice increases grain yields and improves environmental performance (DERPSCH et al., 2014; GUZMAN; GOLABI et al., 2017). In NT systems, food production costs are lower. It is easier to operate machines in fields, which improves soil sustainability, due to lower soil disturbances. However, the success of a no-tillage system depends on several important factors: growing crops in undisturbed soil, rotating crops and maintaining crop residues on the soil surface (DERPSCH et al., 2014; DUARTE et al., 2018).

Vegetal residues of cover crops are used in integrated livestock farming and grain food production systems (SILVA et al., 2015; MATEUS et al., 2016; MORAES et al., 2019; SCHUSTER et al., 2019). Use of these vegetal residues improves soil properties, inhibits the spread of diseases, reduces pests and weeds as well emissions of greenhouses gasses (FREITAS; LANDERS, 2014; MORAES et al., 2014; Mckenzie et al., 2016; SCHUSTER et al., 2019). The choice of the cover crop is very important and determines the success of the system (PARIZ et al., 2011). This is especially true in tropical soils due to the fact that plant characteristics impact biomass yield and the durability of soil coverage (LEITE et al., 2010; PAVINATO et al., 2017). Cover crop biomass contains nutrients extracted from deeper soil layers and plays an important role in nutrient cycling as a result of the release of nutrients during the decomposition process (CRUSCIOL; SORATTO, 2009; VERAS et al., 2016; ROSOLEM et al., 2017).

Legume and grass cover crops vary widely in their ability to cover the soil (CRUSCIOL et al., 2015; FAGERIA et al., 2016). Although legumes fix atmospheric nitrogen, grasses are better at scavenging nutrients. Among the cover crops, grasses are most widely cultivated and used for livestock as well as agricultural activities by farmers (COSTA et al., 2017; PARIZ et al., 2017; CATUCHI et al., 2019). The most commonly used grasses are from the *Urochloa* genus. These grasses produce a large amount of biomass, which has high soil protection properties and nutrient-cycling efficiency (BORGHI et al., 2013; PACHECO et al., 2017; TANAKA et al., 2019). When cultivated as a cover crop, forage grass is managed as an annual crop in the system to produce biomass (BORGHI et al., 2013). The high dry matter production potential and the high C:N ratio of *Urochloa* result in slow decomposition and increase the possibility of cultivation in warmer regions, even in regions were other cover crops have accelerated rates of decomposition (TIMOSSI et al., 2007; ROSOLEM et al., 2017). Other characteristics, such as vigorous and deep root systems, favor water deficiency tolerance and absorption of nutrients in deeper soil layers, aiding nutrient cycling (CRUSCIOL; SORATTO, 2009; ALMEIDA et al., 2018). Thus, grasses perform well in drought conditions where most of the grain crops or other cover crops do not grow well (CASTRO et al., 2015; CRUSCIOL et al., 2015).

Urochloa species are less demanding when it comes to soil fertility. The roots tolerate aluminum toxicity and low P availability in the soil, which occurs often in acidic tropical soils (ARROYAVE et al., 2018). In addition, the roots of these grasses suppress soil nitrification, which is one of the key microbial processes (SUBBARAO et al., 2009, 2015). *Urochloa* species release brachialactone, a biological nitrification inhibitor (BNI), that blocks ammonia monooxygenase (AMO) and hydroxylamino oxidoreductase (HAO) ammonia oxidizing enzymatic pathways (SUBBARAO et al., 2007, 2009). In the complex soil-plant-atmosphere system, the major processes in the soil are nitrogen fixation, soil organic matter (SOM) mineralization, ammonification, nitrification, and denitrification (WILCKE; LILIENFEIN, 2005; SUBBARAO et al., 2015; KUYPERS et al., 2018). Nitrogen plays a minor role in undisturbed temperate and tropical ecosystems, such as no-tillage systems, where nitrogen leakage is minimized and a large amount of nitrogen is retained in the soil (SUBBARAO et al., 2015). There are mechanisms of nitrogen conservation that involve short-circuiting mineralization, which microorganisms absorb nitrogen and return it to the soil, facilitating nitrogen accumulation in the soil when plants suppress nitrification and directly absorb organic nitrogen (SUBBARAO et al., 2015; KARWAT et al., 2017).

Nitrogen losses occur mainly through critical pathways of nitrification and denitrification (VAN GROENIGEN et al., 2015; ZHANG et al., 2015). *Urochloa* species cultivated in the no-tillage systems are expected to reduce nitrogen losses due to nitrate leaching and nitrous oxide emissions. One key role of tropical forage grasses has been suppressing leached nitrate and mitigating nitrous oxide emissions in pasture soils (BYRNES et al., 2017; KARWAT et al., 2017). However, there is a lack of information about forage grasses as cover crops in systems of grain food production. The nitrogen use efficiency (NUE) of fertilizer can be enhanced for grain crops when it is combined with nitrogen management on cover crops. Nevertheless, cover crop species affect the subsequent crops differently. This becomes important when investigating the influence of cover crops on the grass-maize system.

The organic nitrogen from the biomass of cover crops is degraded through mineralization and subsequently, nitrification in ammonium and nitrate in the soil (KUYPERS et al., 2018). The biomass of cover crops can drive shifts in soil microbial activity, resulting in mineral nitrogen. Since the plant roots take up nitrogen in the inorganic forms ammonium and nitrate (BOSCHIERO et al., 2018), the decomposition rates of nitrogen released in the soil determine synchrony/de-synchrony between soil nitrogen mineralization and plant nitrogen demand (PERVEEN et al. 2014; ROSOLEM et al., 2017). There is a huge potential to reduce nitrogen fertilizer use and nitrogen loss in agricultural system composed of *Urochloa* (KARWAT et al. 2017; MOMESSO et al., 2019; ROCHA et al., 2019).

The current recommended method of applying nitrogen fertilizer to annual crops is to divide the application over two periods. The first application occurs when seeding a crop and the second occurs when the crop is in its growing stage in a manner called ‘sidedressing’. However, an alternative method has been proposed which would actually supply the nitrogen fertilizer needed for annual crops, such as maize, during the cultivation of cover crops like *Urochloa*. The farmers would apply all the nitrogen either to cover crops or during pre-seeding of maize (BASSO; CERETTA, 2000; LARA CABEZAS et al., 2004, 2005; PÖTTKER; WIETHÖLTER, 2004), when the systems have high straw production (CERETTA et al., 2002). The early application of nitrogen could facilitate the main crop seeding, providing flexibility in the operational schedules of farmers. However, the application of all of the nitrogen on *Urochloa* cover crops does not supply the nitrogen to the subsequent maize crops due to the temporarily nitrogen immobilization. In systems composed of grasses grown in succession, microorganisms compete with plants for nitrogen in the soil during crop seeding due to increasing biological activity and consequent plant-microbe competition (MOMESSO et al., 2019).

An alternative and sustainable way to use nitrogen fertilizers could be to follow the initial recommended application of nitrogen fertilizer during maize seeding. However, instead of following the second half of the recommended application method, which says that nitrogen should be applied to growing crops (sidedressing), the nitrogen should actually be applied earlier to cover crops or on cover crop residues. Applying nitrogen directly to maize during seeding aims to reduce competition between the maize crop and microbes for nitrogen immobilization in the soil. The application of nitrogen during maize seeding minimizes the competition between plants and microbes and thus avoids nitrogen immobilization. Applying nitrogen to the cover crops or cover crop residues may be a good substitute for sidedressing when growing forage species. The use of fertilized *Urochloa* can be effective to gradually provide nitrogen to subsequent maize crops during residue decomposition due to the great potential of *Urochloa* to produce biomass and tighten nitrogen cycling.

There has been a growing interest in manipulating plant growth in order to increase NUE and grain yields in tropical food production (BOWATTE et al., 2015). The nitrogen fertilizer used in grass systems enhances grain yields of annual crops by improving biomass production in agricultural systems. In a no tillage system, this biomass gradually releases nutrients to subsequent crops. Keeping this in mind, the current thesis starts by assessing how the forage grass and the maize crop are affected by the timing of nitrogen fertilizer application. In *Chapter 1*, the effects of the timing of nitrogen application on decomposition rates of cover crops was monitored for 3 years during a field experiment. In this experiment, biomass production, nitrogen released by cover crops and the availability of mineral nitrogen in the soil was evaluated in order to enhance grain yields of maize. In *Chapter 2*, the fate of nitrogen fertilizers [$(^{15}NH_4)_2SO_4$] applied at different times to maize and forage grasses was examined. This thesis presents potential strategies to optimize the sustainable use of nitrogen fertilizer in maize-forage systems and examines how grasses can supply nitrogen to subsequent maize crops in tropical soils during decomposition.

palisade grass at 35 DBS and on its residues at 1 DBS resulted in similar maize grain yields as the conventional method of N application. Thus, the use of palisade grass as a cover crop allows for early N application and is an alternative to the recommended sidedressing application. However, when the cover crop is ruzigrass, N fertilization must not be applied while the grass is still growing. Beyond crop nutrition, our results raise questions concerning the impact of the timing of N fertilization on effective N-fertilizer uptake by maize and the environmental consequences of N fertilization for microbial communities in agro-food systems.

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system to supply N demand and raise grain yield of maize. Besides that, the timing of N application in agricultural system is an important factor in increasing the maize grain yield and forage production. This study reported the important knowledge that higher grain yields of maize were achieved when N was applied on palisade grass and its residues or on ruzigrass residues, resulting in similar grain yield obtained in conventional method. However, the fate of N fertilizer in the system was not completely understood. Although the hypothesis of N applied on palisade grass to reach high grain yields of maize was confirmed, the application of nitrogen fertilizer must be applied as current recommended method (40 kg N ha^{-1} at maize seeding plus 120 kg N ha^{-1} sidedressed in V_6 growth stage) to enhance grain yields of maize and high N recovery from fertilizer. The conventional method is still better option to avoid loss of fertilizer. Additional studies should be conducted to better understand the changes that occur in soil microbiology, soil biochemistry, root composition and N losses.

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FINAL CONSIDERATIONS

This study investigated during a period of three years (i.e. 2015-2018) the effects of grass cover crops and N management on grain yield, N-use efficiency and N recovery from fertilizer in maize. In no-tillage system, the N fertilizer applied on palisade grass (*Urochloa brizantha*) at 35 DBS or on its residues at 1 DBS, or on ruzigrass residues at 1 DBS resulted in similar grain yield of maize in conventional method of N application. However, since the earlier applications on cover crops had lower N recovery from fertilizer by maize grain, the application of nitrogen fertilizer must be applied as current recommended method (40 kg N ha^{-1} at maize seeding plus 120 kg N ha^{-1} sidedressed in V_6 growth stage) to enhance grain yields of maize and high N recovery from fertilizer.

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