This article is presented in Portuguese and English with "resumen" in Spanish.
Brazilian Journal of Applied Technology for Agricultural Science, Guarapuava-PR, v.4, n.2, p.226–244, 2011.

Bibliographic Review

Use of nitrogen fertilizer in corn: a review

Ricardo Shigueru Okumura [1]
Daiane de Cinque Mariano [1]
Paulo Vicente Contador Zaccheo [2]

Abstract

The management of nitrogen (N) has been one of the most studied agricultural practices in order to improve their efficiency of use, because 98% of N in the soil is in organic form, and only 2% arise from inorganic forms ammonium and/or nitrate. The N in the plant acts participating in the molecules of organic compounds such as amino acids and proteins, and also activating enzymes to carry out vital processes of the plant (primary metabolism), such as protein synthesis, ion absorption, photosynthesis, respiration, cell multiplication and differentiation. By having these characteristics nitrogen is the element that causes the greatest effect on the characteristics related to plant growth and development, which directly or indirectly affect the yield. From the economic and environmental standpoint, the dose of N applied is the most important decision in the management of fertilizers, and in this recommendation it should be taken into account soil and climatic conditions, cropping system, sowing time, the responsiveness of the genetic material, crop rotation, timing and mode of application, N sources, and operational economics. Thus, this study aims to review the importance of the nitrogen applied as top dressing in corn, emphasizing the periods of fertilizer application and the recommended and economic doses.

Keywords: *Zea mays* L.; nitrogen; productivity.

Introduction

Corn, which belong to the family Poaceae and genus *Zea*, has great world importance since its grains are used for animal and/or man food, thickeners and adhesives, production of oil, and recently Europe and United States have encouraged its use for the production of ethanol (SILVA et al., 2009), with this making the use of this cereal more expensive for direct and indirect food aims.

Corn is affected by a set of factors as the cultivar itself, soil, fertilization, climate, cultivation practices, plagues and diseases (FANCELLI and DOURADO NETO, 2004; FORNASIERI-FILHO, 2007). This makes it important and necessary the development of studies in the trial of solving several problems related to these factors, aiming to obtain high production, with high quality.

One of the variables which is determiner in the production is the obtaining and providence of nutrients to the crop, among which it is noteworthy nitrogen, for participating in the composition of the related amino acids, protein, chlorophyll and several essential enzymes which stimulated the growth and the development of the shoot and root system (MARSCHNER, 1995; MALAVOLTA, 2006), therefore it is the nutrient absorbed in more quantity by the corn crop and also the most limiting for it.

The management of nitrogen has been one of the most studied agricultural practices related to improve its efficiency of use. This necessity exists because most part of the soil nitrogen is found in organic combinations,

Received in: 13/04/2011 Accepted for publication: 05/08/2011

1– Student of the doctos's degree in Agronomy, Universidade Estadual de Maringá (State University of Maringá), Avenida Colombo, 5790, Bloco J45, CEP 87020-900, Maringá-PR. Scholaship by Capes and CNPq, respectively. E-mail: ricardo_okumura@hotmail.com;

2– Professor of the course of Agronomy, Universidade Estadual de Londrina (Federal University of Londrina), rodovia Celso Garcia Cid, PR 445 KM 380, CEP 86051-990, Londrina-PR.

being thus unavailable for vegetables (MALAVOLTA, 2006).

This work has as objective to make a review about the importance of nitrogen applied in cover in the corn crop, emphasizing the period of application of the fertilizer, and the recommended and economical doses.

The corn culture

Corn (*Zea mays* L.) is a monocotyledonous which belongs to the family Poaceae, genus *Zea*, scientifically named *Zea mays* L., and has its origins in America, possibly in Mexico, Center America or the Southeast of the United States. Soon after the discovery, corn was transported to Europe where it was cultivated in gardens until its value as food was known. From then it began to be planted in commercial scale and spread in the world from the latitude 58° North (Soviet Union) to 40° South (Argentina) (FANCELLI and DOURADO NETO, 2004; FORNASIERI-FILHO, 2007).

Corn grain has average composition of 60% of carbohydrates, 10% of protein, 4% of lipids, the remaining of minerals and vitamins (FORNASIERI-FILHO, 2007), considering that protein is constitute by albumins, globulins, prolamins and glutelins (FANCELLI and DOURADO NETO, 2004; FORNASIERI-FILHO, 2007). This constitution provides that this cereal is used for animal feed in nature, as forage conserved for the period of draught, in the manufacture of bran and also in human feed, as amide, floor or oil, besides being the raw material for more than 500 products (PONCIANO et al., 2003).

In relation to the world production of corn grain in the agricultural year 2009 it was produced the amount of 817 million tones (t), from which United States were responsible of 333 million of t, China of 163 million of t and Brazil of 51 million of t (FAO, 2010). According to FAO (2010), while the United States have cultivated and area of 32 million of hectares (ha) in which they obtained an average yield of 10.3 t ha^{-1} of grains, China obtained 5.4 t ha^{-1} of grains in an area of 30 million ha, Argentina 5.6 t ha^{-1} of grains in 2.3 million ha and Brazil with an area of 13.8 million ha reached an average grain yield of only 3.7 t ha^{-1}. This low yield is due to the fact that 43% of the area cultivated with the grain in the country is destined to subsistence, i.e., farmers use low technology, considering that 11% of the farmers use high technology for the production (VON PINHO, 2001).

The high yield in corn has been guaranteed by the adaptation of cultivars to varied situations of climate and soil, by genetic breeding, by the improvement of the chemical, physical and biological quality of the cultivated soils, besides the adoption of cultural practices, as the use of substantial quantities of nitrogen fertilizer. It is necessary, however, to take care, since the inappropriate supply of nitrogen may cause the limitation of the corn yield, besides causing environmental contamination and increase costs.

Nitrogen x Plant

The demand of N by plants is consequence of its structural function, since it is part of the molecule of organic compounds, as amino acids and proteins, and it is still activator of several enzymes (MALAVOLTA, 2006). The vegetable also depends on N to the performance of one or more vital processes of the plant, as synthesis of protein, ionic absorption, photosynthesis, respiration, multiplication and cell differentiation (MARSCHNER, 1995; MALAVOLTA, 2006), providing a green and abundant vegetation, increase in foliage and in the content of protein of the food plants, fast growth and aid to the soil microorganisms in the decomposition of the organic matter (MALAVOLTA, 2006).

Due to these characteristics, N is the element which causes more effects in the increase of production in the corn crop, according to which was proved by ARAÚJO et al. (2004), GOMES et al. (2007) and DUETE et al. (2008). Besides its effect over the yield, N interferes in many other characteristics of the plant related to the growth and development which, direct or indirectly, affect the crop yield. It can be found, in literature, quotes about the influence of N in the weight of one thousand grains (FERREIRA et al., 2001; AMARAL FILHO et al., 2005), in the number of ears per plant (FERNANDES et al., 2005), in plant height and weight of ears (ARAÚJO et al., 2004), in ear length (BÜLL, 1993), in stem diameter (MAR et al., 2003), in production of dry matter (ARAÚJO et al., 2004; DUETE et al., 2008) and in root growth (BÜLL, 1993).

The demand of N by corn range considerably with the different stages of plant development: it is minimum in the initial stages, increases with the increase in the growth rate and reaches a peak during the flowering until the beginning of grain formation. With this in mind, BOBATO (2006) and MALAVOLTA (2006) quantified the content of N in the index leaf, in the period of full bloom, phase recommended to diagnose the nutritional stage of the plant, obtaining the values of 34 g kg^{-1} of N and 28-35 g kg^{-1} of N, respectively, as being the appropriated for the crop.

Nitrogen x Soil

Approximately 98% of N in soil is found in the organic form, considering that 2% is presented in organic forms as ammonium (NH_4^+) and/or nitrate (NO_3^-), promptly available (MALAVOLTA, 2006), originated by the mineralization during the cultivation by enzyme hydrolysis produced by the activity of the soil microbiota (CORDEIRO and HOEK, 2007) and/or by application of nitrogen fertilization.

Other characteristic of N in soil is the influence that it suffers in the adopted in the management system, verifying that in the initial phase of adoption of the no-tillage system (NTS) there is a higher necessity of using nitrogen fertilizers, due to the process of immobilization by the microbial biomass of the soil, caused by the increase of the activity and by the low content of organic matter (OM) (SÁ, 1996). However, in a few years there is the recovery in the balance of the transformations which occur in soil, because there is deposition and accumulation of cultural residues in the soil surface (BEUTLER et al., 2001) and the absence of their incorporation to the soil contribute for the reduction of losses of OM by erosion and microbiological mineralization (AMADO et al., 2002; BAYER et al., 2004).

As a consequence of the increase of the content of OM there is the increase of the content of organic carbon, and with this the microbial activity is stimulated, resulting in products which act in the formation and stabilization of the aggregates (LIMA et al., 2003), increase in the cation exchange capacity (CEC) and of soil nutrients, specially N (AITA et al., 2001), being, thus, the main reservoir of this nutrient for the cultures in NTS (AMADO et al., 2002). Depending on the time of adoption and of the local conditions, the source of N character of the OM prevails in relation to the drain character, and may even have no answer for the application of nitrogen (BELOW, 2002).

According to COELHO et al. (2002), 70 to 90% of the researches conduced in Brazil under different conditions of soil, climate and management systems demonstrate positive responses of the corn crop to the fertilization with N.

According to FORNASIERI-FILHO (2007), a soil with content of 27 g dm^{-3} of OM in the layer of 0-20 cm, theoretically it is capable do provide the equivalent of 54 kg ha^{-1} of N, considering an average rate of mineralization of 2% of the organic N during the crop cycle, which enables to obtain 2700 kg ha^{-1} of corn grains. The same author affirms that, in soils which non limiting contents of OM, in favorable conditions of rain, the effects of the nitrogen fertilization are not very pronounced.

Period of nitrogen application

In the initial stages of crop development, the root system of the corn plants is underdeveloped and, therefore, a small portion of soil is exploited, with this, its nutritional demand is lower, however, researches have indicated that high concentration of N in the root zone are beneficial to provide the fast initial growth of the plant and increase in grain productivity (YAMADA, 1996). Besides that, the supply of N in the initial stages favors a higher absorption of phosphorus (MARSCHNER, 1995).

FORNASIERI FILHO (2007) suggests the division of the cycle of the corn crop in vegetative (V) and reproductive (R) phase, with sub-divisions of the vegetative phase numerically named as V_1, V_2, etc., until V_n, in which $_n$ represents the stage of last leaf before tasseling. By using as reference this division, FORNASIERI FILHO (2007) says that it is during the phenological stage V_4, in which plants have four leaves completely unfold, that the plant has its potential of production defined by the differentiation of the apex meristem. This justified the importance of the N available, observing the definition of the reproductive organs and leaves in the plant stem. In this phase, the deficiency of N reduces the number of egg cells in the beginnings of the ear (FANCELLI and DOURADO NETO, 2004).

The phenological stage V_8, in which plants presented eight leaves, is characterized by preceding the occurrence of increase in the rate of growth of the ears, observing good response to the use of nitrogen fertilizers, since in this period it occurs marked development of the root system and, consequently, increase in the absorption (FANCELLI and DOURADO NETO, 2004; FORNASIERI-FILHO, 2007).

The rate of absorption of N increases proportionally with the increase in growth until it reaches its maximum peak between the flowering and the beginning of the grain filling (FORNASIERI-FILHO, 2007).

In a general way, the absorption of N by corn is more intense in the period between 40 and 60 days after the germination, but the plant still absorbs a small quantity in the germination and after the beginning of the flowering, characterizing thus three phases for absorption: one phase in the slow initial growth (germination), one phase in the fast growth in which 70 to 80% of all the dry matter are accumulated and a last phase of absorption in which the growth is again slow, accumulating approximately 10% of total dry matter of plant (VASCONCELLOS et al., 1998).

CANTARELLA (1993) reports that even though the absorption of N by corn is more intense from 40 to 60 days after emergence, plant still absorbs approximately 50% of the N which it needs after the beginning of flowering. The author affirms that it is possible that there is advantage in one later application of part of the N in the cases of application of high doses of fertilizers, very sandy soils or irrigated areas.

It can be observed thus that the plotting and the period of application of the nitrogen fertilizer are alternatives to increase the efficiency of the fertilization with N by the corn crop and mitigate losses. This is supported by the better use of N, resulting of the synchronization between applications and the period of high demand of the nutrient (AMADO et al., 2002; SILVA et al., 2005).

SOUZA et al. (2001) evaluated the effects of the application of N in a single dose (150 kg ha^{-1} of N) or divided in different periods (stages V_4 and V_8), in the form of ammonium sulfate, verifying that the grain yield did not present significant differences for the periods of application, as well as the parceling of the N.

For SILVA (2005), in edaphoclimatic conditions of *cerrado*, the application of N in the stage V_4 provided higher grain yield (6756 kg ha^{-1}) in relation to the treatments which received N in the stage V_8 (6571 kg ha^{-1}).

MAR et al. (2003) studied different doses of N, in the form of urea, verifying that the best results were reached with the application of 1/3 of N in the seeding and 2/3 when corn was in V_8 (6549 kg ha^{-1} of grains) and the lowest yield was obtained where there was application of 1/3 in seeding and 2/3 in the stage V_{10} (3160 kg ha^{-1} of grains).

Other management which has been recommended in the south region of Brazil is the application of N in corn pre-seeding (SÁ, 1996), which has as objective to overcome the problem of the immobilization of N applied in seeding. The methodology consists in applying the N in the mechanical management of the winter crop, accelerating its decomposition and, thus, avoiding the competition between biomass and the crop by the nitrogen fertilizer placed in seeding (SÁ, 1996), providing increases in the content of N in soil and in the absorption by plants after the management of the cover crop, and may also influence in the rate of decomposition of vegetal residues. Thus, SÁ (1996) verified gains in yield with the anticipation of N in the corn seeding.

This kind of manage offers high risk, in function of the high doses of N recommended for the crop, and also of the occurrence of high rainfall after its application, which may cause the leaching of N. In studies developed by WOLSCHICK et al. (2003), it was verified that the application of 150 kg ha^{-1} of N in pre-seeding and 30 kg ha^{-1} of N in seeding resulted in yield similar to the application of 90 kg ha^{-1} of N, divided in seeding and two covers, under conditions of intense rainfall.

BORTOLINI et al. (2001) verified lower yield in corn when N was applied previously (150 or 60 kg ha^{-1} of N), in regime of excessive water availability.

CANTARELLA et al. (2003) observed that the application of N in pre-seeding reduced the corn yield in relation to the cover application, when there was regular distribution of rainfall, however, when rain was scarce, similar yield was observed for both periods of application.

It is important to emphasize that the ranges in the results of the experiments of nitrogen fertilization in corn come from the diversity of edaphoclimatic conditions which occur in the country (biotic and abiotic features), from the distinct conditions in which each study is developed. Another important factor which would affect the efficiency of the nitrogen fertilization in the experiments would be the genetic differences of the materials.

BEAUCHAMP et al. (1976), when evaluating different hybrids, observed that the concentration of N in leaves ranged in until 25% in the female flowering. These results showed the ability of genotyped in differing in the absorption of N of the soil, before and after the flowering.

Doses of nitrogen

Some caution must be taken to recommend the dose of N to be used, since if it is underestimated, it will happen a reduction of the yield, and, when super estimated, there will be a reduction in the producer yield by the unnecessary expense with fertilizers, besides affecting the environment, in consequence of the losses of N as a result of the excess available (ARGENTA et al. 2003).

From the economic and environmental viewpoint, the dose of N to be applied is the most important decision in the management of fertilizers. In this recommendation it must be considered the edaphoclimatic conditions, cultivation system (no-tillage or conventional system), period of seeding, responsiveness of the genetic material, crop rotation, period and form of application, source of N, economical and operational aspects (BOBATO, 2006). These factors affect the response of corn to N so that the curves of yield may range a lot in different places, as well as in fertile soils with high content of organic N in soil, consequently, nitrogen fertilization may not have effect or even reduce the production (BELOW, 2002).

RAIJ et al. (1981) conduced 25 experiments, in the state of São Paulo, evaluating the nitrogen fertilization in cover of the corn crop, concluding that there was positive relation in 16 of them, and in the dose of 120 kg ha^{-1} of N some experiments presented grain yield above 7000 kg ha^{-1}, verifying also that the average increase in yield for the set of experiments was approximately 1500 kg ha^{-1} of grains for applications of until 120 kg ha^{-1} of N.

According to BÜLL (1993) and YAMADA (1996), the use of 30-40 kg ha^{-1} of N in seeding and 80-140 kg ha^{-1} of N in cover in the stage V_4, may provide yield of 9000-12000 kg ha^{-1} of corn grains, in case that no negative effect occurs for the crop.

According to MALHI et al. (2001), it is necessary to be cautious in the recommendation of the dose, since the recovery of N from the fertilizers, by plants, is relatively low, reaching in many cases less than 50%. COELHO et al. (1991), using 60 kg ha^{-1} of N, obtained recovery of 60% of the N applied as urea in the corn crop. However, when the doses of N are higher, the recovery of N tend to decrease relatively, as it was observed by GROVE et al. (1980), who obtained 36% and 40% of recovery of N, applied in the corn crop, in the form of urea, in the doses of 120 and 140 kg ha^{-1} of N, respectively.

The low efficiency of recovery of the N of the fertilizer has been attributed mainly by volatilization, denitrification (LARA CABEZAS et al., 1997) and leaching. The losses of the fertilizer N by denitrification have been estimated in less than 10% of the corn crop (HILTON et al., 1994), by leaching it was just 4% of the applied (COELHO et al., 1991) and by volatilization it was seen losses which range from 31 to 78% of the total of N applied (LARA CABEZAS et al., 1997).

Economical doses of nitrogen

The prices of the corn accompany the movements of the offer, establishing fluctuations according to the periods of crop and intercrop. Among the main factors which influence in the process of formation of the price of the corn it is emphasized the offer and demand in the internal market and of the producer and exploiting countries, politics of financing of costs and management of minimum costs, cost of production, flow of formation of the commerce, politics of importation and interest and change rates.

In a general way, the Brazilian producer of corn has suffered losses of revenue in the last year, in function of the significant increases in the cost of production, mainly since corn does not have its price in dollar, as it happens in soybean, for example, while the inputs used in its cultivation accompany the exchange variation (SILVA et al, 2007).

SILVA et al. (2007) observed that the maximum economical yield of corn grains, in the first year of experiment with N applied in the phenological stage V_4 was obtained with the doses of 92, 112 and 130 kg ha^{-1} of N, in corn cultivated succession to crotalaria (8389 kg ha^{-1} of grains), fallow (7489 kg ha^{-1} of grains) and millet (7343 kg ha^{-1} of grains), respectively. For the phenological stage V_8, the yield was reached with 102, 122 and 107 kg ha^{-1} of N, in corn in succession to crotalaria (8327 kg ha^{-1} of grains), fallow (7357 kg ha^{-1} of grains) and millet (6423 kg ha^{-1} of grains), respectively.

In the second agricultural year, these authors verified that for the application of N in the phenological stage V_4, the yield was reached with the dosed of 121, 135 and 137 kg ha^{-1} of N, in corn cultivated in succession to crotalaria (8771 kg ha^{-1} of grains), fallow (7803 kg ha^{-1} of grains) and millet (7836 kg ha^{-1} of grains), respectively. For the phenological stage V_8, the yield was reached with the doses of 126, 131 and 128 kg ha^{-1} of N, in the millet in succession to crotalaria (8989 kg ha^{-1} of grains), fallow (7552 kg ha^{-1} of grains) and millet (6944 kg ha^{-1} of grains), respectively. The same authors verified that in economic terms, each kg of N in the form of urea invested provided, in average, the return of R$ 4.85; R$ 5.80 and R$ 5.48, respectively, for corn in succession to crotalaria, fallow and millet.

PAVINATO et al. (2008) with experiment of irrigated corn, found that the point of leveling (number of units which should be produced to cover the total cost of production, considering a pre-determined value of commercialization) ranged between 4.31 to 6.07 t ha^{-1} for the agricultural year 2003/04. Besides that, they observed that the costs with nitrogen fertilization were up to 29% of the total cost of production for both agricultural years. The same authors report that the crude revenue increases with the dose of N and reached a maximum with the doses of 243 and 248 kg ha^{-1} with coefficient of determination of 0.29 and 0.81, in 2002/03 and 2003/04, respectively. However, the maximum economic efficiency was obtained with the application of 156 and 158 kg ha^{-1} in the agricultural years of 2002/03 and 2003/04.

Final considerations

The response of the corn crop to nitrogen depends of factors such the adequate management of the nitrogen doses to be applied, nitrogen source, period of application of the fertilizer, besides the interference caused by the edaphoclimatic conditions and the soil microorganisms.

It is important to consider the phenological stages of the crop, the pace of absorption of N by corn, the climate conditions, the type of soil, the genotype used, aiming to reduce losses and increasing the efficiency of use of nitrogen and, with this, increasing yield and grain quality.

References

AITA, C.; BASSO, C.J.; CERETTA, C.A.; GONÇALVES, C.N.; DAROS, C.O. Plantas de cobertura de solo como fonte de nitrogênio ao milho. **Revista Brasileira de Ciência do Solo,** v.25, p.157-165, 2001.

AMADO, T.J.C.; MIELNICZUK, J.; AITA, C. Recomendação de adubação nitrogenada para o milho no RS e SC adaptada ao uso de culturas de cobertura do solo, sob sistema plantio direto. **Revista Brasileira de Ciência do Solo,** v.26, p.241-248, 2002.

AMARAL FILHO, J.P.R.; FORNASIERI FILHO, D.; FARINELLI, R.; BARBOSA, J. C. Espaçamento, densidade populacional e adubação nitrogenada na cultura do milho. **Revista Brasileira de Ciência do Solo,** v.29, n.3, p.467-473, 2005.

ARAÚJO, L.A.N.; FERREIRA, M.E.; CRUZ, M.C.P. Adubação nitrogenada na cultura do milho. **Pesquisa Agropecuária Brasileira,** v.39, n.8, p.771-777, 2004.

ARGENTA, G.; SILVA, P.R.F.; FOSTHOFER, E.L.; STRIEDER, M.L.; SUHRE, E.; TEICHMANN, L.L. Adubação nitrogenada em milho pelo monitoramento do nível de nitrogênio na planta por meio do clorofilômetro. **Revista Brasileira de Ciência do Solo,** v.27, p.109-119, 2003.

BAYER, C.; MARTIN NETO, L.; MIELNICZUK, J.; PAVINATO, A. Armazenamento de carbono em frações lábeis da matéria orgânica de um Latossolo Vermelho sob plantio direto. **Pesquisa Agropecuária Brasileira,** v. 39, p. 677-683, 2004.

BEAUCHAMP, E.G.; KANNENBERG, L.W.; HUNTER, R.B. Nitrogen accumulation and translocation in corn genotypes following silking. **Agronomy Journal,** Madison, v.68, n.2, p.418-422, 1976.

BELOW, F.E. **Fisiologia, nutrição e adubarão nitrogenada do milho.** Piracicaba: Potafós, p. 7-12, 2002. (Informações Agronômicas, 99).

BEUTLER, A.N.; SILVA, M.L.N.; CURI, N.; FERREIRA, M.M.; PEREIRA FILHO, I.A.; CRUZ, J.C. Agregação de Latossolo Vermelho distrófico típico relacionada com o manejo na região dos cerrados no estado de Minas Gerais. **Revista Brasileira de Ciência do Solo,** v.25, p.129-136, 2001.

BOBATO, A. **Índice nutricional do nitrogenio: uma ferramenta para o diagnostico do estado nutricional da cultura do milho.** Dissertação (Mestrado em Agronomia) – Universidade Federal do Paraná, Curitiba. 2006. 76f.

BORTOLINI, C.G.; SILVA, P.R.F.; ARGENTA, G.; FORSTHOFER, E.L. Rendimento de grãos de milho cultivado após aveia-preta em resposta a adubação nitrogenada e regime hídrico. **Pesquisa Agropecuária Brasileira,** v. 36, p.1101-1106, 2001.

BÜLL, L.T. Nutrição mineral do milho. In: BULL, L.T.; CANTARELLA, H. (eds) **Cultura do milho: fatores que afetam a produtividade.** Piracicaba: POFAFOS, 1993. p. 63-145.

CANTARELLA, H.; LERA, F.L.; BOLONHEZI, D.; LARA CABEZAS, W.A.R.; TRIVELIN, P.C.O. Antecipação de N em milho em sistema de plantio direto usando 15N-uréia. **In: Anais do** 29 Congresso Brasileiro De Ciência Do Solo, Ribeirão Preto: SBCS, 2003. 1 CD-ROM.

COELHO, A. M.; FRANÇA, G.E.; BAHIA FILHO, A.F.C.; GUEDES, G.A.A. Balanço de nitrogênio (^{15}N) em um Latossolo Vermelho-Escuro, sob vegetação de Cerrado, cultivado com milho. **Revista Brasileira de Ciência do Solo,** v.15, n.2, p.187-193, 1991.

COELHO, A.M.; FRANÇA, G.E.; PITTA, G.V.E.; ALVES, V.M.C.; HERNANI, L.C. **Cultivo de milho, nutrição e adubação.** Sete Lagoas: Embrapa. 2002. (Comunicado Técnico 44).

CORDEIRO, L.A.M.; HOEK, J.B.V.D. Nitrogênio na cultura do milho sob sistema plantio direto. **Revista Factuciência,** v.13, p.27-54, 2007.

DUETE, R. R. C.; MURAOKA, T.; SILVA, E. C.; TRIVELIN, P. C. O.; AMBROSANO, E. J. Manejo da adubação nitrogenada e utilização do nitrogênio (^{15}N) pelo milho em Latossolo Vermelho. **Revista Brasileira de Ciência do Solo,** v.32, p.161-171, 2008.

FANCELLI, A.L.; DOURADO NETO, D. **Produção de milho.** 2ª ed. Guaíba: Agropecuária, 2004. 360p.

FAO – Food And Agriculture Organization Of The United Nations. **Faostat.** Disponível em: <http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor>. Acesso em: 17 de março de 2011.

FERNANDES, F.C.S.; BUZETTI, S.; ARF, O.; ANDRADE, J.A.C. Doses, eficiência e uso de nitrogênio por seis cultivares de milho. **Revista Brasileira de Milho e Sorgo**, v.4, n.2, p.195-204, 2005.

FERREIRA, A.C.B.; ARAÚJO, G.A.A.; PEREIRA, P.R.G.P.; CARDOSO, A.A. Características agronômicas e nutricionais do milho adubado com nitrogênio, molibdênio e zinco. **Scientia Agricola**, v.58, n.1, p.131-138, 2001.

FORNASIERI FILHO, D. **Manual da cultura do milho.** Jaboticabal: Funep, 2007. 576p.

GOMES, R.F.; SILVA, A.G.; ASSIS, R.L.; PIRES, F.R. Efeito de doses e da época de aplicação de nitrogênio nos caracteres agronômicos da cultura do milho sob plantio direto. **Revista Brasileira de Ciência do Solo,** v.31, p.931-938, 2007.

GROVE, L.T.; RICHET, K.D.; MADERMAN, G.C. Nitrogen fertilization of maize on oxisol of the cerrado of Brazil. **Agronomy Journal,** v.27, p.261-265, 1980.

HILTON, B.R.; FIXEN, P.E.; WOODWARD, H.J. Effects of tillage, nitrogen placement, and wheel compactation on denitrification rates in the corn cycle of a corn-oats rotation. **Journal of Plant Nutrition,** v.17, p.1341-1357, 1994.

LARA CABEZAS, W.A.R.L.; KORNDORFER, G.H.; MOTTA, S.A. Volatilização de N-NH_3 na cultura de milho: I. Efeito da irrigação e substituição parcial da uréia por sulfato de amônio. **Revista Brasileira de Ciência do Solo,** v.21, n.3, p.481-487, 1997.

LIMA, C.L.R.; PAULETTO, E.A.; GOMES, A.S.; SILVA, J.B. Estabilidade de agregados de um Planossolo sob diferentes sistemas de manejo. **Revista Brasileira de Ciência do Solo,** v.27, p.199-205, 2003.

MALAVOLTA, E. **Manual de nutrição mineral de plantas.** Piracicaba: Editora Ceres, 2006. 631p.

MALHI, S.S.; GRANT, C.A.; JOHNSTON, A.M.; GILL, K.S. Nitrogen fertilization management for no-till cereal production in the Canadian Great Plains: a review. **Soil and Tillage Research,** v.60, n.3/4, p.101-122, 2001.

MAR, G.D.; MARCHETTI, M.E.; SOUZA, L.C.F.; GONÇALVES, M.C.; NOVELINO, J.O. Produção do milho safrinha em função de doses e épocas de aplicação de nitrogênio. **Bragantia,** v 62, n.2, p.267-274, 2003.

MARSCHNER, H. **Mineral nutrition of higher plants.** London: Academic Press, 1995. 889p.

PAVINATO, P.S.; CERETTA, C.A.; GIROTTO, E.; MOREIRA, I.C.L. Nitrogênio e potássio em milho irrigado: análise técnica e econômica da fertilização. **Ciência Rural,** v.38, n.2, p.358-364, 2008.

PONCIANO, N.J.; SOUZA, P.M.; REZENDE, A.M. Entraves da comercialização à competitividade do milho brasileiro. **Revista Paranaense de Desenvolvimento,** n.104, p.23-40, 2003.

RAIJ, B. van; FEITOSA, C. T. CANTARELLA, H. A análise de solo para discriminar respostas à adubação para a cultura do milho. **Bragantia,** v.40, n.6, p.57-75, 1981.

SÁ, J. C. M. **Manejo de nitrogênio na cultura de milho no sistema plantio direto.** Passo Fundo: Aldeia Norte, 1996. 23p.

SILVA, E. C. **Manejo da adubação nitrogenada e utilização do nitrogênio (^{15}N) da uréia, do milheto e da crotalária pelo milho sob semeadura direta em solo de cerrado.** Tese (Doutorado em Energia Nuclear na agricultura) - ESALQ/USP (Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo). Piracicaba, 2005. 111f.

SILVA, E. C.; BUZETTI, S.; GUIMARÃES, G. L.; LAZARINI, E.; SÁ M. E. Doses e épocas de aplicação de nitrogênio na cultura do milho em plantio direto sobre Latossolo Vermelho. **Revista Brasileira de Ciência do Solo,** v.29, p.353-362, 2005.

SILVA, E. C.; MURAOKA, T.; MONTEIRO, R. O. C.; BUZETTI, S. Análise econômica da adubação nitrogenada no milho sob plantio direto em sucessão a plantas de cobertura em Latossolo Vermelho. **Acta Scientiarum. Agronomy,** v.29, n.4, p.445-452, 2007.

SILVA, G.J.; GUIMARÃES, C.T.; PARENTONI, S.N.; RABEL, M.; LANA, U.G.P.; PAIVA, E. **Produção de haplóides androgenéticos em milho.** EMBRAPA Milho e Sorgo, 2009. 17p. (Documentos 81).

SOUZA, A.C.; CARVALHO, J.G.; PINHO, R.G.V.; CARVALHO, M.L.M. Parcelamento e época de aplicação de nitrogênio e seus efeitos em características agronômicas do milho. **Ciência e Agrotecnologia,** v.25, n.2, p.321-329, 2001.

VASCONCELLOS, C.A.; VIANA, M.C.M.; FERREIRA, J. J. Acúmulo de matéria seca e de nutrientes em milho cultivado no período inverno-primavera. **Pesquisa Agropecuária Brasileira,** v.33, p.1835-1945, 1998.

VON PINHO, R.G.V. Produção de milho no Brasil e no mundo: realidade e perspectiva. **In: Anais do** V Simpósio de Atualização em Genética e Melhoramento de Plantas: Genética e Melhoramento do Milho, Lavras: UFLA/FAEPE, 2001. p.3-13.

WOLSCHICK, D.; CARLESSO, R.; PETRY, M.T.; JADOSKI, S.O. Adubação nitrogenada na cultura do milho no sistema plantio direto em ano com pluviosidade normal e com "el nino". **Revista Brasileira de Ciência do Solo,** v.27, p.461-468, 2003.

YAMADA, T. **Adubação nitrogenada no milho: quanto, como e quando aplicar.** Piracicaba: POTATOS, 1996. p.15. (Informativo agronômico n. 47).