Original Article

EVALUATION OF NO-TILLAGE OF COMMON BEAN IN A NATIVE FIELD IN THE HIGH JEQUITINHONHA VALLEY, MINAS GERAIS STATE, BRAZIL

AVALIAÇÃO DO PLANTIO DIRETO DE FEIJÃO EM CAMPO NATIVO NO ALTO VALE DO JEQUITINHONHA, MG

Enilson de Barros SILVA[1]; Juan Paulo Xavier de FREITAS[2]; Luís Reynaldo Ferracciú ALLEONI[3]; Alexandre Christófaro SILVA[4]; Wellington Willian ROCHA[5] Sheila Renata SANTOS[2]

1. Associate Professor, Doctor, Departamento of Agronomy, Universidade Federal dos Vales do Jequitinhonha e Mucuri - UFVJM, Diamantina, MG, Brazil. ebsilva@ufvjm.edu.br; 2. Master in Vegetable Production - UFVJM, Diamantina, MG, Brazil; 3. Associate Professor, Doctor, Departament of Soil Science, ESALQ/USP, Piracicaba, SP, Brazil; 4. Associate Professor, Doctor, Departament of Foresty - UFVJM, Diamantina, MG, Brazil; 5. Adjunct Professor, Doctor, Departament of Agronomy, UFVJM, Diamantina, MG, Brazil.

ABSTRACT: High Jequitinhonha Valley is a region of Minas Gerais State, Brazil, where agriculture is underdeveloped and the agricultural systems have low efficiency and yield rates. As a result, environmental degradation rates are high, and it is thus necessary to adjust the soil management techniques. This study aimed to evaluate the no-tillage of common bean with the direct desiccation of a sandy soil native field of High Jequitinhonha Valley, Minas Gerais State, Brazil. The study followed a randomized block design, with two replicates (treatments: conventional tillage and no-tillage) in five blocks. The following outcomes were evaluated: the chemical properties of a Quartzarenic Neosol (Entisol), the nutritional status and yield of common bean farmed under conventional tillage and no-tillage via the direct application of desiccant to the natural vegetation during three crop cycles. The adoption no-tillage in the native field improved the chemical attributes of the sandy soil, with altered the nutritional status and increased the yield of the common bean after three crop cycles under the conditions of High Jequitinhonha Valley, Minas Gerais State, Brazil. The soil contents of organic carbon, P, Ca, Mg, and CEC in the 0-0.1 m soil layer were higher under no-tillage than conventional tillage. The leaf contents of N, Mg, S, and Zn increased whereas the leaf contents of P, K, Fe, and Mn decreased throughout the crop cycles. Deficiencies of P, Fe, and Mn were observed in the common bean leaves during the last crop cycle under no-tillage.

KEYWORDS: Disc plow. Yield, Soil fertility. Nutritional status.

INTRODUCTION

High Jequitinhonha is part of the Brazilian Cerrado biome (savannah) in Minas Gerais State, Brazil, and its relief is formed by large plateaus and tablelands, interspersed by deep and narrow valleys, with little fertile land and undergrowth and shrubby vegetation, where agricultural practices are very limited (GONÇALVES, 1997). Quartzarenic Neosol (Entisol) is found in the 'Serra do Espinhaço Meridional', where it is shallow, sandy, rocky, and acidic, with limitations for conventional agricultural practices (SILVA, 2005).

Under the conditions of High Jequitinhonha Valley, the agricultural systems for soil management are very important in common bean (*Phaseolus vulgaris* L.), as this is a subsistence crop. Some sites display low yield and high environmental degradation rates. This problem is mainly due to inappropriate soil management resulting from excessive soil tillage, usually performed via the intensive use of harrows or disc plows that pulverize the plow layer and compact the subsurface layer.

Under conventional tillage, there are various implements available for tillage, which incorporate and mix the material throughout the soil layers and alter the soil chemical, physical, and biological properties (FALLEIRO et al., 2003; COSTA et al., 2006; RANGEL; SILVA, 2007). Soil tillage under conventional tillage systems alters the soil by reducing the organic matter (OM) contents; it increases aeration and contact between organic residues and soil microbiota (AMADO et al., 2002), consequently reducing the cation exchange capacity (CEC), as OM is mainly responsible for CEC in tropical and subtropical soils (ALMEIDA et al., 2008). Under conventional tillage, increased soil acidity may be attributed to the decomposition of organic residues and leaching of exchangeable bases (Ca, Mg, and K) in the plow layer due to reduced soil CEC (CIOTTA et al., 2002, CIOTTA et al., 2003). The available soil P decreases under conventional tillage because soil tillage increases

Received: 09/02/12
Accepted: 05/06/13

the contact between phosphate ions and the surfaces of inorganic colloids, favoring adsorption (PAVINATO; ROSOLEM, 2008).

Thus, due to the increased soil protection, restricted mobilization of the topsoil, and accumulation of organic matter and nutrients in the surface soil layer under soil management systems involving less soil disturbance, such as no-tillage (SILVEIRA et al., 2000; CIOTTA et al., 2002; FALLEIRO et al., 2003; MATIAS et al., 2009), the recovery of the physical and chemical attributes usually deteriorated by conventional cropping systems favored under these systems (SILVEIRA; CUNHA, 2002; BAYER et al., 2004; FRANCHINI et al., 2007; LIMA et al., 2007). No-tillage systems increases the OM (SILVEIRA; STONE, 2001; MURAGE et al., 2007), where the remaining organic residues on the surface release organic compounds that stimulate the formation and stability of soil aggregates, thus improving the soil structure (BAYER et al., 2004; FRANCHINI et al., 2007; PAVINATO; ROSOLEM, 2008). Plant residue contains nutrients in the form of labile OM, which may become available for crops via the following methods: mineralization (SANTOS; TOMM, 2003; AMADO et al., 2002), variations in soil pH and in cation exchange capacity (SILVEIRA et al., 2000; CIOTTA et al., 2002; SOUZA; ALVES, 2003), increased exchangeable bases and surface accumulation of soil P (SILVEIRA; CUNHA, 2002; FALLEIRO et al., 2003; THOMAS et al., 2007), and reduced toxic Al as compared to under conventional tillage (SILVEIRA; STONE, 2001, MATIAS et al., 2009).

The implementation of no-tillage in native field soil without straw production, which is recommended for direct seeding to start the system (COSTA et al., 2006), makes it is necessary to build up soil fertility that first occurs in the surface layer in the short-term and then moves deeper throughout the crop cycles. Therefore, adoption no-tillage provides improved soil fertility, thus promoting a higher yield capacity, with higher economic return for farmer (BARBOSA FILHO et al., 2005), and it is an essential strategy for maintaining the sustainable use of agricultural soil (SORATTO; CRUSCIOL, 2008).

The use of sandy soil by small-scale farmer without conservation practices leads to soil loss by water and wind erosion. The reality should be studied for providing better sandy soil for agricultural production in a sustainable manner, aiming to keep small-scale farmer in the municipalities, and consequently, in the region of the High Jequitinhonha Valley. This study therefore aimed to evaluate no-tillage in common bean with the direct desiccation of a sandy soil native field of High Jequitinhonha Valley, Minas Gerais State, Brazil).

MATERIAL AND METHODS

The experimental area is located in the region of the High Jequitinhonha Valley in Diamantina, Minas Gerais State, Brazil (18° 12’ S, 43° 34' W, altitude of 1,350 m with mean annual rainfall of 1,082 mm and mean temperature of 19.4°C). The region's climate is typically tropical, Cwb according to the Köppen classification. The soil of the experimental area is a Quartzarenic Neosol (Entisol), ‘Campo Limpo’ (pure grassland) phase, wavy relief, with 7.0% slope and sandy texture (EMBRAPA, 2006). To characterize the soil, composite samples were collected at a 0.20 m depth and then air-dried and sieved (2.0 mm-sieve); the results of their chemical analyses (SILVA, 2009) and their soil texture (EMBRAPA, 1997) are presented in Table 1.

Table 1. Results of the chemical and soil texture analyses before implantation the experiment.

pH $_{água}$	P	K	Ca	Mg	Al	T	m	V	OC	Sand	Silt	Clay
	--- mg dm^{-3} ---		-------- mmol$_c$ dm^{-3} ---------				----- % ------		--------------- g kg^{-1} --------------			
5,3	2,0	28	2	2	6	33	56	14	4,3	880	60	60

pH $_{water}$: Soil-water ratio 1:2.5. P and K: Mehlich-1 extractor. Ca, Mg, and Al: 1 mol L^{-1} KCl extractor. T: Cation exchange capacity, pH 7.0. m: Aluminum saturation. V: Base saturation. OC: organic carbon by the Walkey-Black method according to the method described in Silva (2009). Soil texture with determination of the fractions (sand, silt, and clay) by the pipette method (EMBRAPA, 1997).

The study followed a randomized block experimental design, with two replicates (treatments: conventional tillage and no-tillage) in five blocks. The soil preparations were as follows: conventional tillage (CT) with a disc plow (three discs, 0.711 m diameter and 0.30 m working depth) + disc harrow (24 discs, 0.356 m diameter and 0.05 m working depth) and no-tillage (NT) using a brushcutter and desiccant to the natural vegetation. The experimental area was 1,440 m^2, and the experimental plot was 20 m^2 (2 x 10 m), with a useable plot of 8 m^2 (1 x 8 m), where 15 m was maintained between the plots for the tractor to maneuver, regardless of the treatment.

The following three common bean crop cycles were grown: the first (C1) between April and June 2006; the second (C2) between November 2006 and January 2007; and the third (C3) between December 2008 and February 2009. The rainfall and maximum and minimum temperature data during the experimental period between April 2006 and February 2009 (Figure 1) were obtained in the Diamantina Meteorological Station (Estação Meteorológica de Diamantina), Minas Gerais State, Brazil (INMET, 2009).

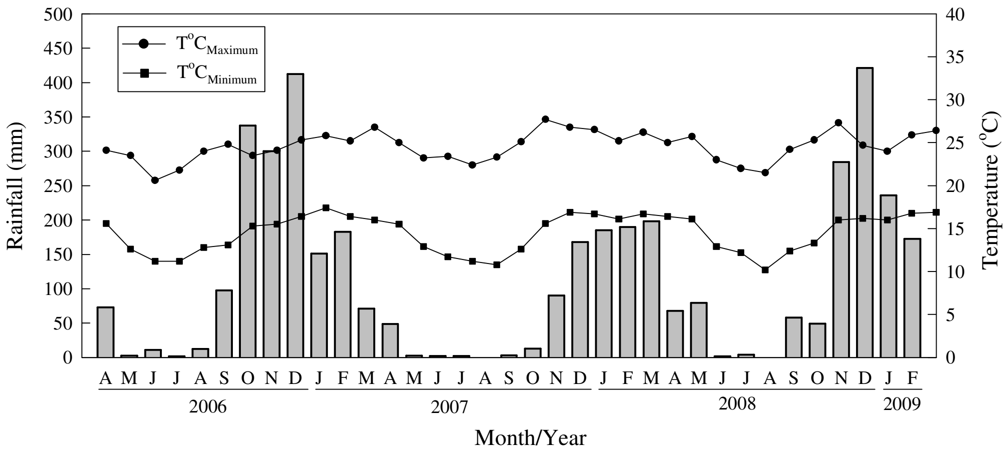

Figure 1. Monthly rainfall distribution and maximum and minimum temperature in Diamantina, Minas Gerais State, Brazil, during cultivation common bean. Source: Inmet (2009)

The experimental area before C1 contained the following native plant families: Fabaceae, Asteraceae, Malpiguiaceae, Lamiaceae, Rubiaceae, Eriocaulaceae, Orchidaceae, Cyperaceae, Poaceae, and Bromeliaceae. Between common bean crop cycles, the experimental area remained fallow, during which the following species prevailed: *Solanum americanum, Bidens pilosa, Acanthospermum hispidum, Digitaria sanguinalis*, and *Emilia fosbergii, Tagetes minuta.* The families and species listed were used to indicate which were included under CT and which were desiccated under NT during common bean crops.

First, the native vegetation within the CT treatment plot was cut using a brushcutter via mechanical traction. The common bean was sowed using a conventional planter (seeder-fertilizer). The natural vegetation within the NT treatment plot was mowed, and glyphosate herbicide was applied (960 g a.i. ha^{-1}), which was equivalent to 2.0 L ha^{-1} of the commercial product. During the second bean crop cycle within the NT treatment plot, 30 kg ha^{-1} of N (SÁ, 1999) was applied in the form of ammonium sulfate on straw at 30 days before sowing to reduce N immobilization peaks due to soil microbiota (SÁ, 1999). The common bean was sowed using a no-tillage multi-row planter.

Dolomitic limestone (lime) was applied with 90% total neutralizing power (TNP), which was calculated in an attempt to increase the base saturation (V%) to 50% using the increasing base saturation method (ALVAREZ V.; RIBEIRO, 1999). The amount of lime needed was 1.8; 1.8, and 1.1 t ha^{-1} in crop cycles C1, C2, and C3, respectively. A half-dose of lime was applied before plowing, and the remaining half-dose was applied before using the disc harrow at 90 days before sowing the common bean in the CT treatment plot and on the soil surface in the NT treatment plot. The amount of lime applied was chosen for incorporating the lime at a 0.30 m soil depth by disc plow under CT and a 0.05 m soil depth by surface application under NT. The following amounts of lime were applied under CT and NT, respectively: 3.0 and 0.5 in the C1; 3.0 and 0.5 in the C2; and 1.8 and 0.3 t ha^{-1} in the C3.

The common bean ("Carioquinha" cultivar) population was 240,000 plants per ha, in rows spaced 0.5 m apart and with 12 seeds per meter. Corrective phosphorus fertilizer was applied as a single superphosphate (8 kg ha^{-1} of P_2O_5 for each 10 g kg^{-1} of clay) (LOPES; GUILHERME, 1992) one day before planting the C1 and C2 crop cycles, incorporating it to a 0.05 m depth with the disc harrow.

The fertilizer applications were based on that recommended for the common bean according to the second level of technological culture (CHAGAS et al., 1999) in each crop cycle. The crop was fertilized at sowing, with 80 kg ha^{-1} of P_2O_5 (single superphosphate) applied to the furrows. Topdressing was performed with 30-0-30 kg ha^{-1} of

$N-P_2O_5-K_2O$ (ammonium sulfate and potassium chloride) at 25 days after emergence, except for N in the C2 crop cycle. Together with N and K topdressing, 1 kg ha^{-1} of B (boric acid) and 2 kg ha^{-1} of Zn (zinc sulfate) were applied. The cultural practices were according to that recommended by Paula Júnior; Venzon (2007).

At the harvest of each common bean crop cycle, the crop yield, with the moisture content of the grain corrected to 12%, and the soil chemical attributes in the composite samples taken at soil depth layers of 0-0.1, 0.1-0.2, 0.2-0.3, and 0.3-0.4 m per useable plot were evaluated. The following measurements were conducted to determine the soil chemical attributes: pH in water; P and K (Mehlich-1); Ca, Mg, and Al (1 mol L^{-1} KCl); potential acidity (H + Al) by calcium acetate; and organic carbon, using the Walkey-Black method (SILVA, 2009). To evaluate the nutritional status of the common bean, samples were taken from the leaves during flowering from each useable plot, and the nutrient contents were obtained according to methodology of Malavolta et al. (1997).

The data on grain yield and nutrient contents in the common bean leaves were subjected to analysis of variance and consisted of the following factors: blocks, soil management system (CT and NT), and common bean crop cycle (C1, C2, and C3). For soil chemical analyses, in addition to the previous factors, the sampling depths were added to the analysis of variance. The mean factors studies were compared by Tukey's test at 5%.

RESULTS AND DISCUSSION

In the C1 crop cycle, the grain yield was low in the cropping systems as compared to the other common bean crop cycles ($P < 0.05$) (Figure 2), which may be explained by the low rainfall during this crop cycle (Figure 1), equaling the effect of the cropping systems. Common bean yield is affected by the water regime, which may affect the root growth and, consequently, nutrient absorption and translocation (GOMES et al., 2000).

The same soil preparation procedures used in C2 were used in C1, but there was increased grain yield under NT ($P < 0.05$) (Figure 2) because 30 kg ha^{-1} of N was applied over the straw before sowing, according to the recommendation of Sá (1999). This early N application most likely reduced the C/N ratio of the straw remaining on the soil surface. At the start of decomposition, there is a trend of higher nutrient immobilization, especially N, as the amount of N available in the straw is inadequate for microbial decomposition, which involves immobilization and reduced N availability for crops (TEIXEIRA et al., 2009). The higher yield in C2 compared to C1 should be due to the rainy growing season, when there was higher rainfall for the common bean crop (Figure 1) and most likely better N mineralization due to higher OM decomposition by soil microbiota (MARQUES et al., 2000; AMADO et al., 2002) under both cropping systems.

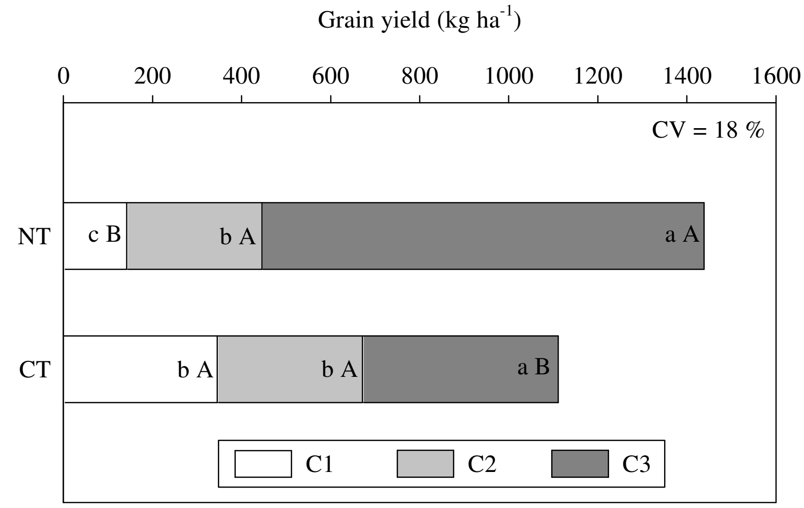

Figure 2. Grain yield in conventional tillage (CT) and no tillage (NT) in three common bean crop cycles (C1: Apr to Jun/2006, C2: Nov/2006 to Jan/2007 and C3: Dec/2008 to Jan/2009). Means with uppercase letters between and lowercase letters within the bar do not differ by Tukey test at 5%.

There was lower grain yield under CT as compared to NT in the C3 crop cycle (Figure 2). Plowing (CT) turns the soil more and tends to pulverize it (SILVEIRA; CUNHA, 2002), decreasing the OM levels (AMADO et al., 2002), which reduces the cation exchange capacity (CEC) and, consequently, the leaching of exchangeable cations into the plow layer (CIOTTA et al., 2002; CIOTTA et al., 2003). The NT provided higher grain yield (Figure 2), which may most likely be explained by the higher maintenance of nutrients readily available for plants and soil organic matter (SILVEIRA; CUNHA, 2002; BAYER et al., 2004; FRANCHINI et al., 2007; MURAGE et al., 2007).

The grain yield increased throughout the crop cycles under both systems, but especially in NT (Figure 2), with an increase of 27 % for CT and of 600 % for NT between the first and third common bean crop cycles. This increase of yield under NT is due to the gradual increase of the degree of soil fertility in the surface layer as compared to under CT (SILVEIRA; CUNHA, 2002; FALLEIRO et al., 2003; THOMAS et al., 2007).

The CT and NT cropping systems affected the chemical properties at the soil depths evaluated ($P < 0.05$). In C1, higher pH values were detected in the surface soil layer, decreasing with depth, where there were higher values under CT as compared to NT (Table 2). The higher soil pH values under CT may reflect the effect of the tool used for turning the soil and for incorporating lime into the soil (PRADO; ROQUE, 2002; PRADO; NATALE, 2004). The NT system had lower pH values at all depths due to lime surface application.

Table 2. Soil chemical attributes along depth under conventional tillage (CT) and no-tillage (NT) systems in three common bean crop cycles.

Depth	C1		C2		C3		CV (%)
(m)	CT	NT	CT	NT	CT	NT	
			pH water				
0.0-0.1	5.6aA	5.1aB	5.6aA	5.6aA	4.9bA	4.8aA	
0.1-0.2	5.2bA	4.7bB	5.7aA	5.3bB	5.0bA	4.6aB	
0.2-0.3	5.2bA	4.7bB	5.5aA	5.3bB	5.0bA	4.6aB	5.0
0.3-0.4	5.0bA	4.7bB	5.0bA	4.8cA	5.4aA	4.4bB	
			Al (mmol$_c$ dm^{-3})				
0.0-0.1	1.0aB	8.0aA	2.0aB	6.0aA	3.0aB	5.0aA	
0.1-0.2	4.0aB	8.0aA	2.0aB	6.0aA	3.0aB	5.0aA	
0.2-0.3	3.0aB	7.0aA	3.0aB	6.0aA	3.0aB	6.0aA	11.0
0.3-0.4	2.0aB	8.0aA	3.0aB	7.0aA	2.0aB	6.0aA	
			Ca (mmol$_c$ dm^{-3})				
0.0-0.1	15.0aA	4.0aB	5.0aA	5.0aA	13.0aA	7.0aB	
0.1-0.2	9.0bA	2.0aB	4.0aA	4.0aA	10.0bA	7.0aB	
0.2-0.3	7.0bA	2.0aB	4.0aA	3.0aA	8.0bA	6.0aA	18.0
0.3-0.4	7.0bA	2.0aB	3.0aA	3.0aA	7.0bA	6.0aA	
			Mg (mmol$_c$ dm^{-3})				
0.0-0.1	8.0aB	3.0aB	4.0aA	3.0aA	5.0aA	4.0aA	
0.1-0.2	5.0bA	2.0aB	4.0aA	3.0aA	5.0aA	4.0aA	
0.2-0.3	5.0bA	2.0aB	3.0aA	2.0aA	6.0aA	3.0aB	26.0
0.3-0.4	5.0bA	2.0aB	2.0aA	1.0aA	5.0aA	3.0aB	
			P (mg dm^{-3})				
0.0-0.1	35aA	32aA	35aB	48aA	22aB	35aA	
0.1-0.2	31bA	3bB	21bA	3bB	15bA	4bB	
0.2-0.3	17cA	2bB	14cA	3bB	16bA	3bB	18.0
0.3-0.4	2dA	2bA	8dA	2bA	7cA	2bB	
			K (mg dm^{-3})				
0.0-0.1	38aB	50aA	23aB	38aA	51aA	57aA	
0.1-0.2	31bA	32bA	21aA	27bA	11bA	13bA	
0.2-0.3	31bA	29bA	19aB	29bA	13bA	11bA	18.0
0.3-0.4	26cA	19cB	14bA	17cA	6cA	10bA	
			CEC a pH 7,0 (mmol$_c$ dm^{-3})				
0.0-0.1	33bA	25aB	33aA	34aA	52aB	63aA	
0.1-0.2	32bA	24aB	32aA	23bB	52aA	52bA	
0.2-0.3	39aA	23aB	25bA	21bA	47bB	55bA	6.0

0.3-0.4	36aA	26aB	22bA	23bA	41bB	50bA	
			OC (g dm^{-3})				
0.0-0.1	4.4bA	5.0aA	5.7aA	6.2aA	5.6aB	8.2aA	
0.1-0.2	4.4bA	4.4aA	4.4bA	4.8bA	5.4aA	4.8bB	
0.2-0.3	5.6aA	4.4aB	4.6bA	4.4cA	4.6bA	4.0bB	6.0
0.3-0.4	5.5aA	4.1aB	4.7bA	4.1cA	3.8bA	3.8bA	
			V %				
0.0-0.1	73aA	33aB	29aA	26aA	37aA	20aB	
0.1-0.2	46bA	28aB	27aA	33aA	29bA	22aB	
0.2-0.3	33cA	29aA	30aA	27aA	30bA	17bB	19.0
0.3-0.4	35cA	17bB	24aA	19bB	30bA	19bB	

Means followed by the same lowercase letter in the columns and uppercase letter in the rows, in each common bean crop, do not differ by Tukey test at a 5%. Common bean crops: C1: Apr to Jun/2006, C2: Nov/2006 to Jan/2007, and C3: Dec/2008 to Jan/2009.

In C2, the soil pH values were the highest among the three common bean crop cylces (Table 2). These results reflect a reduced reaction of the lime applied to the soil in C1 due to low rainfall (Figure 1). This result only occurred in C2 because there was a higher amount of water available for solubilization and reaction of the corrective (lime) in the soil during this crop cycle. Additionally, the water regime of local may affect the reaction speed of the lime in the soil over time (NATALE et al., 2007).

In C3, there was reduced soil pH at the different depths compared to in C2, where it was more pronounced under NT (Table 2). The pH in water is affected by reactions of the ammonium fertilizer (CIOTTA et al., 2002) and the export of nutrients such as Ca, Mg, and K via harvests (SILVEIRA et al., 2010). Additionally, the decomposition of vegetable residue under NT releases organic acids (SIDIRAS; PAVAN, 1985) from weeds that grow in the fallow between crop cycles at the experimental area. It is noteworthy that under CT, there were higher pH values at a 0.3-0.4 m depth (Table 2), which reflects the higher efficiency of the plow in inverting the plowed soil (SILVEIRA; STONE, 2001), which incorporates lime into deeper soil layers (PRADO; ROQUE, 2002; PRADO; NATALE, 2004).

The Al exchangeable followed the trends discussed for soil pH with differences between cropping systems and soil sampling depths (Table 2). The differences are small, and the values are in the ‘low’ class according to the classification proposed by Alvarez V. et al. (1999). The soil under NT had higher Al levels at all of the depths as compared to under CT, with reduction among the common bean crop cycles (Table 2). Under NT, the lime applied before each common bean crop cycle was not incorporated, but it may promote the increased ionic strength of the solution and increased pH values, affecting Al speciation and solubilization in the soil (CIOTTA et al., 2002; FALLEIRO et al., 2003; MATIAS et al., 2009) throughout the crop cycles. In contrast, under CT, the lime was incorporated and neutralized in the soil Al according to the working depth of the plow (SILVEIRA; STONE, 2001).

In C1, the higher Ca and Mg levels were related to the lime incorporation depth under CT, whereas there was no difference in the depth under NT (Table 2). The lime incorporation caused by the plow under CT promotes uniform soil nutrient levels (SILVEIRA et al., 2000; PRADO; ROQUE, 2002; MATIAS et al., 2009). In the case of NT, the non-tillage of the soil (FALLEIRO et al., 2003) and low Ca mobility in the soil (SILVA; SILVEIRA, 2002) are possible reasons behind the lack of a difference in the Ca and Mg levels by depth. Another relevant aspect is the fact that this cropping system did not undergone previous crop cycles under CT, as it was directly established on a native field.

In C2, the same trend for the Ca and Mg levels found in C1 was observed, but the levels were lower (Table 2). The lower Ca and Mg levels result from the higher volume of rainfall that occurred during C2 (Figure 1) and that resulted in higher grain yield (Figure 2) by promoting the higher extraction of these nutrients from the soil.

In C3, the Ca and Mg values were higher in the surface layer under NT as compared to the previous crop cycles, with the same trend being observed for CT (Table 2). These results are attributed to the non-tillage of the soil and nutrient recycling by the plants (FALLEIRO et al., 2003), especially the weeds that grew in the fallow between the crop cycles.

The soil P levels are high in the surface layers according to the interpretation by Alvarez et al. (1999), especially in the crop cycles C1 and C2 (Table 2), due to corrective phosphate fertilizing with single superphosphate the day before sowing common bean under CT and NT. Under NT, the available P levels were higher in the surface soil layer (0-0.1 m) (Table 2). Under CT, the soil tillage provided a uniform P distribution in the plow layer (SILVEIRA; STONE, 2001; FALLEIRO et al., 2003); this result was also found for NT due to the lack of soil tillage and the fact that this element was immobile in the soil, especially in the first 0.05 to 0.10 m (SILVEIRA; CUNHA, 2002; FALLEIRO et al., 2003; THOMAS et al., 2007). This P accumulation in the surface layer results in the saturation of phosphate absorption sites from soil colloids, thus increasing the P availability for plants (PAVINATO; ROSOLEM, 2008).

The K content was higher at a 0-0.1 m soil depth, decreasing with depth among the cropping systems and common bean crop cycles (Table 2). Similar results were found by Oliveira et al. (2001) and Falleiro et al. (2003). It is noteworthy that the K contents become uniform under CT as a function of the disc plow working depth, especially in the common bean crop cycle C2, until a depth of 0.30 m (Table 2). Soil tillage by the agricultural tools causes nutrient dilution due to mixing in the soil volume (SILVEIRA et al., 2000).

In C3, the K accumulated in the surface layer, with higher content under NT (Table 2). The highest K content, at the 0-0.1 m layer, is due to the non-tillage of the soil (FALLEIRO et al., 2003) and fertilization in the seeding row. Additionally, the vegetable residue is left on the soil surface, which allows the K to accumulate in the more superficial soil layers (SANTOS; THOMM, 2003).

The CEC at pH 7.0 (T) was affected by the soil sampling depth and cropping systems in each common bean crop cycle (Table 2). In C1 showed increased T values at a 0.3-0.4 m depth after using the disc plow under CT, where there was also higher OC content (Table 2). The inversion of the soil layers by a disc plow regulated to turn the soil to a 0.30 m depth resulted in the incorporation of weeds and crop residues from the surface to deeper layers, thus contributing to the accumulation of organic matter (BAYER; BERTOL, 1999; FALLEIRO et al., 2003). Under NT, there was no difference in the T values due to the non-tillage of the soil (SILVEIRA et al., 2000; MATIAS et al., 2009), as no plant matter was incorporated. In addition, the NT system in C1 was directly established on natural vegetation, thus resulting in a low decomposition rate and, consequently, the low addition of organic material to the soil.

In C2, soil tillage with the disc plow under CT promoted the inversion of the T values and OC levels as compared to in C1 (Table 2). The inversion of the soil layers in this crop cycle returned the organic matter that was incorporated deeper in C1 to the superficial soil layers. The NT system exhibited a higher T value at a 0-0.1 m depth as compared to C1, as there was also increased OC at this depth, despite the lack of vegetation accumulation at the experimental area due to the short time interval between C1 and C2. The increased CEC under NT may be attributed to the increased soil OM content (CIOTTA et al., 2003; FALLEIRO et al., 2003), especially of the humic acid fraction, mainly responsible for forming negative charges in the soil (BAYER; BERTOL, 1999).

In C3, the T values were higher in the superficial soil layers, and inversion of the values did not occur as compared to C2; the OC contents in the soil under CT behave similarly (Table 2). During this crop cycle, soil tillage for the third time with the disc plow may have contributed to homogenizing the organic matter levels. During soil tillage, the majority of the increase in the OM obtained with no-tillage systems may be lost (BRUCE et al.; 1995). The NT system maintained the same trend as the previous common bean crop cycles.

There was a positive relationship between increasing T and OM accumulation throughout the common bean crop cycles, which was the most pronounced in the last crop cycle (C3) (Table 2). The longer fallow duration (19 months) and growth of plant species that are easily decomposed compared to natural vegetation during the establishment of NT was the origin of this OM accumulation, not only under NT but also under CT. Fallow on a site without soil tillage and leaving crop residues on the soil surface increases the soil OM content (ALMEIDA et al., 2008), which is complemented by root decomposition (DE MARIA et al., 1999).

Regarding base saturation (V %), there were differences between the soil sampling depths from each cropping system and common bean crop cycle (Table 2). In C1, the CT system (with soil tillage) obtained higher V % values until the depth where lime was incorporated into the soil (PRADO; ROQUE, 2002; PRADO; NATALE, 2004) by the disc plow. Under NT, in which there was no soil tillage (CIOTTA et al., 2002; FALLEIRO et al., 2003; MATIAS et al., 2009), there were lower V % values than with CT in all of the common bean crop cycles. In C2 and C3, the V % values are below that recommended for the common bean (50 %) (ALVAREZ V.; RIBEIRO, 1999) due to the higher extraction of exchangeable bases (Ca, Mg, and K) by the crop to provide higher yield (Figure 2) in response to higher water availability during the crop cycles (Figure 1).

Generally, there was evolution of the nutritional status of the common bean (Table 3), which was reflected in increased grain yield (Figure 2) throughout the three crop cycles. The cropping systems affected the macro (N, P, K, and Mg) and micronutrient (Fe, Mn, and Zn) leaf levels, especially in the last crop cycle (C3) (Table 3). Among the other nutrients, the leaf Ca and S levels remained close to the lower limit, whereas the B and Cu levels were within the adequate range for the common bean proposed by Martinez et al. (1999).

Table 3. Nutrient contents in common bean leaves under conventional tillage (CT) and no-tillage (NT) systems in three crop cycles.

Cropping system	Common bean crop[1]			Reference [2]
	C1	C2	C3	
	------ N, $g\ kg^{-1}$ - CV = 12 % ------			
CT	30 b A	32 b A	38 a A	
NT	22 b B	32 a A	31 a A	30 - 35
	------ P, $g\ kg^{-1}$ - CV = 15 % ------			
CT	3.5 b A	4.0 a A	3.9 a A	
NT	3.9 b B	4.4 a A	2.7 c B	4.0 - 7.0
	------ K, $g\ kg^{-1}$ - CV = 6 % ------			
CT	25 a A	26 a A	22 b A	
NT	27 a A	27 a A	23 b A	27 - 35
	------ Ca, $g\ kg^{-1}$ - CV = 9 % ------			
CT	20 a A	24 a A	23 a A	
NT	21 a A	25 a A	21 a A	25 - 35
	------ Mg, $g\ kg^{-1}$ - CV = 18 % ------			
CT	3.0 b A	3.0 b A	6.3 a B	
NT	3.0 b A	3.1 b A	7.4 a A	3.0 - 6.0
	------ S, $g\ kg^{-1}$ - CV = 15 % ------			
CT	1.3 b A	1.5 b A	2.6 a A	
NT	1.4 b A	1.6 b A	3.5 a A	1.5 - 2.0
	------ B, $mg\ kg^{-1}$ - CV = 5 % ------			
CT	100 a A	105 a A	112 a A	
NT	104 a A	109 a A	105 a A	100 - 150
	------ Cu, $mg\ kg^{-1}$ - CV = 18 % ------			
CT	8.0 a A	8.0 a A	10.5 a A	
NT	8.3 a A	8.2 a A	10.7 a A	8 - 10
	------ Fe, $mg\ kg^{-1}$ - CV = 7 % ------			
CT	300 a A	320 a A	276 b A	
NT	315 a A	335 a A	192 b B	300 - 500
	------ Mn, $mg\ kg^{-1}$ - CV = 9 % ------			
CT	200 a A	205 a A	195 a A	
NT	202 a A	207 a A	160 b B	200 - 300
	------ Zn, $mg\ kg^{-1}$ - CV = 10 % ------			
CT	40 a A	46 a A	53 a B	
NT	41 b A	47 b A	68 a A	45 - 55

Means followed by the same lowercase letter in the rows and uppercase letter in the columns do not differ by Tukey's test at a 5%. [1] C1: Apr-Jun/2006, C2: Nov/2006-Jan/2007, and C3: Dec/2008-Jan/2009. [2] Martinez et al. (1999).

The leaf N content was lower in C1 (Table 3) due to reduced rainfall as compared to the crop cycles C2 and C3 (Figure 1), i.e., there was not enough moisture for N absorption by common bean roots. Water availability during the vegetative phase favors plant development and nutrient absorption (GOMES et al., 2000). In C1, the highest N contents were obtained under CT and the lowest content under NT, due to the immobilization of the N applied to the crop and that in the fertilizer from soil microorganisms (TEIXEIRA et al., 2009), thus reducing the N availability for common bean under NT. In C2, the leaf N contents remained within the critical range proposed by Martinez et al. (1999) due to the higher rainfall that occurred at the site (Figure 1). Under NT, the application of 30 kg ha^{-1} of N provided an adequate N content in this cropping system as compared to under CT. In C3, the N absorption by common bean was higher, whereas under CT, the leaf N content was above the critical range established by Martinez et al. (1999) and the levels found by Binotti et al. (2010) as compared to those under NT (Table 3). The decomposition of the vegetable residue incorporated by the disc plow (BAYER; BERTOL, 1999; FALLEIRO et al., 2003) under CT may release N for common bean.

Although corrective phosphorous fertilizer was applied before sowing in C1 and C2, the leaf P content remained below the adequate range proposed by Martinez et al. (1999) for the crop in C1, but with adequate content in C2 that did not differ between the cropping systems (Table 3). The difference in P content between C1 and C2 may be attributed to the better water availability for the common bean in C2 (Figure 1), which promotes higher P diffusion into the soil (KIKUTI et al., 2006).

In C3, the lower P content was obtained under NT, and it remained at contents below the adequate range for bean plants (Table 3), although there was good water availability for the common bean development (Figure 1), which was different from what occurred in C2. This lower P availability is likely due to immobilization by soil microbiota (SOUZA et al., 2008), despite the high P content in the surface soil layer (Table 2).

The K levels in the common bean leaves always remained close to the lower limit of the critical range proposed by Martinez et al. (1999) in the three crop cycles and with small differences between the cropping systems, whereas the Mg levels remained within or above the critical range in the two first (C1 and C2) and last (C3) crop cycles (Table 3). The Mg most likely competitively inhibited the K for absorption sites on the roots (MALAVOLTA et al., 1997), as confirmed by the low K availability and high Mg availability in the soil among cropping systems (Table 2) due to the application of dolomitic limestone before each crop cycle.

The Fe and Mn contents varied in the common bean leaves depending on the soil preparation systems in the crop cycles C1 and C2, reaching the critical value proposed by Martinez et al. (1999). In C3, the levels did not reach the adequate range for the crop among the cropping systems, where a lower content was found under NT (Table 3). This content should be due to the non-supply of this nutrient in the fertilizers throughout the common bean crop cycles and the possible formation of organic complexes of the OM contained in this soil with Fe (SANTOS; RODELLA, 2007), as there was OM accumulation (Table 2) due to the lack of soil tillage (SILVEIRA et al., 2000; MATIAS et al., 2009).

In crop cycles C1 and C2, the Zn contents in the common bean leaves did not differ between the planting cropping and remained below and within the critical range proposed by Martinez et al. (1999) (Table 3), respectively. Using dolomitic limestone provided increased Mg content in the soil (Table 2), which inhibits Zn absorption (MALAVOLTA et al., 1997), as these elements exhibit a similar valence, ionic radius, and degree of hydration (KABATA-PENDIAS; PENDIAS, 1984). In C1, the low rainfall hindered the diffusion of Zn into the soil (MALAVOLTA et al., 1997). In C3, the Zn levels remained above that established for the common bean under NT due to increased OM throughout the crop cycles (Table 2) and by the residual effect of the Zn fertilizer applications to the common bean crop.

CONCLUSIONS

Adoption no-tillage in a native field promoted improved chemical attributes of the sandy soil, with altered nutritional status and increased grain yield after three crop cycles under the conditions of High Jequitinhonha Valley, Minas Gerais State, Brazil.

No-tillage increased the levels of organic carbon, CEC, P availability, and exchangeable bases (Ca and Mg) in the 0-0.1 m layer as compared to under the conventional tillage system.

The leaf levels of N, Mg, S, and Zn increased, whereas the levels of P, K, Fe, and Mn decreased throughout the crop cycles, with deficiencies of P, Fe, and Mn in the common bean leaves during the last crop cycle under no-tillage.

ACKNOWLEDGEMENTS

The CNPq for financial support, the CAPES, the scholarship masters the second author, and the UFVJM, the infrastructure necessary for the experiment.

RESUMO: O Alto Vale do Jequitinhonha é uma região do estado de Minas Gerais onde a agricultura é pouco desenvolvida, e os sistemas agrícolas possuem eficiências e índices de produtividade baixos. Como resultado, as taxas de degradação ambiental são altas, sendo necessário ajuste nas técnicas de manejo do solo. Objetivou-se avaliar o plantio direto do feijoeiro com dessecação direta do campo nativo de um solo arenoso do Alto Vale do Jequitinhonha (MG). O delineamento experimental foi em blocos casualizados, com duas repetições dos tratamentos (preparo convencional e plantio direto) por cinco blocos. Foram avaliados os atributos químicos de um Neossolo Quartzarênico, o estado nutricional e a produtividade do feijoeiro em sistema convencional de preparo do solo e de plantio direto com aplicação de dessecante direta da vegetação natural em três cultivos. A adoção do plantio direto sob campo nativo promoveu melhoria nos atributos químicos do solo arenoso, com alteração do estado nutricional e aumento da produtividade do feijoeiro após três cultivos nas condições do Alto Vale do Jequitinhonha, MG. Os teores de carbono orgânico, P, Ca, Mg e CTC na camada de 0 a 0,1 m foram maiores no sistema plantio direto do que no preparo convencional do solo. Os teores de N, Mg, S e Zn nas folhas aumentaram enquanto os teores de P, K, Fe e Mn diminuíram no decorrer dos cultivos. A deficiência de P, Fe e Mn nas folhas do feijoeiro ocorreu no último cultivo no sistema de plantio direto.

PALAVRA-CHAVE: Arado de disco. Produção. Fertilidade do solo. Estado nutricional.

REFERENCES

ALMEIDA, V. P.; ALVES, M. C.; SILVA, E. C.; OLIVEIRA, S. A. Rotação de culturas e propriedades físicas e químicas em Latossolo Vermelho de cerrado sob preparo convencional e semeadura direta em adoção. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 32, n. 3, p. 1227-1237, 2008.

ALVAREZ V., V. H.; NOVAIS, R. F.; BARROS, N. F.; CANTARUTTI, R. B.; LOPES, A. S. Interpretação dos resultados das análises de solos. In: RIBEIRO, A. C.; GUIMARÃES, P. T. G.; ALVAREZ V., V. H. (ed.). **Recomendações para o uso de corretivos e fertilizantes em Minas Gerais.** Viçosa: CFSEMG, 1999. p. 25-32.

ALVAREZ V., V. H.; RIBEIRO, A. C. Calagem. In: RIBEIRO, A. C., GUIMARÃES, P. T. G.; ALVAREZ V., V.H. **Recomendações para o uso de corretivos e fertilizantes em Minas Gerais.** Viçosa: CFSEMG, 1999. p. 43-60.

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**, Viçosa, v. 26, n. 1, p. 241-248, 2002.

BARBOSA FILHO, M. P.; FAGERIA, N. K.; ZIMMERMANN, F. J. P. Atributos de fertilidade do solo e produtividade do feijoeiro e da soja influenciados pela calagem em superfície e incorporada. **Ciência e Agrotecnologia**, Lavras, v. 29, n. 3, p. 507-514, 2005

BAYER, C.; BERTOL, I. Características químicas de um cambissolo húmico afetadas por sistemas de preparo, com ênfase à matéria orgânica. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 23, n. 3, p. 687-694, 1999.

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,** Brasília, v. 39, n. 7, p. 677-683, 2004.

BINOTTI, F. F. S.; ARF, O.; CARDOSO, E. D.; SÁ, M. E.; BUZETTI, S.; NASCIMENTO, V. Fontes e doses de nitrogênio em cobertura no feijoeiro de inverno irrigado no sistema plantio direto. **Bioscience Journal,** Uberlândia, v. 26, n. 5, p. 770-778, 2010.

BRUCE, R. R.; LANGDALE, G. W.; WEST, L. T.; MILLER, W. P. Surface soil degradation and soil productivity restoration and maintenance. **Soil Science Society of American Journal**, Madison, v. 59, n. 3, p. 654-660, 1995.

CHAGAS, J. M.; BRAGA, J. M.; VIEIRA, C.; SALGADO, L. T.; JUNQUEIRA NETO, A.; ARAÚJO, G. A. A.; ANDRADE, M.J.B.; LANA, R.M.Q.; RIBEIRO, A.C. Feijão. In: RIBEIRO, A.C.; GUIMARÃES, P. T. G.; ALVAREZ V., V. H. (Ed.). **Recomendações para o uso de corretivos e fertilizantes em Minas Gerais.** Viçosa: CFSEMG, 1999. p. 306-309.

CIOTTA, M. N.; BAYER, C.; ERNANI, P. R.; FONTOURA, S. M. V.; ALBUQUERQUE, J. A.; WOBETO, C. Acidificação de um latossolo sob plantio direto. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 26, n. 4, p. 1055-1064, 2002.

CIOTTA, M. N.; BAYER, C.; FONTOURA, S. M. V.; ERNANI, P. R.; ALBUQUERQUE, J. A. Matéria orgânica e aumento da capacidade de troca de cátions em solo com argila de atividade baixa sob plantio direto. **Ciencia Rural**, Santa Maria, v. 33, n. 6, p. 1161-1164, 2003.

COSTA, E. A.; GOEDERT, W. J.; SOUSA, M. G. Qualidade do solo submetido a sistemas de cultivo com preparo convencional e plantio direto. **Pesquisa Agropecuária Brasileira**, Brasília, v. 41, n. 7, p. 1185-1191, 2006.

DE MARIA, I. C.; NNABUDE, P. C.; CASTRO, O. M. Long term tillage and crop rotation effects on soil chemical properties of a Rhodic Ferralsol in southern Brazil. **Soil and Tillage Research**, Amsterdam, v. 51, n. 1, p. 71-79, 1999.

EMBRAPA. Centro Nacional de Pesquisa de Solos (Rio de Janeiro, RJ). **Sistema brasileiro de classificação de solos.** Brasília: Produção de Informação, 2006. 306p.

EMBRAPA. Centro Nacional de Pesquisa de Solos (Rio de Janeiro, RJ). **Manual de métodos de análise do solo.** Brasília: Produção de Informação, 1997. 212p.

FALLEIRO, R. M.; SOUZA, C. M.; SILVA, C. S.W.; SEDIYAMA, C. S.; SILVA, A. A.; FAGUNDES, J. L. Influência dos sistemas de preparo nas propriedades químicas e físicas do solo. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 27, n. 6, p. 1097-1104, 2003.

FRANCHINI, J. C.; CRISPINO, C. C.; SOUZA, R. A.; TORRES, E.; HUNGRIA, M. Microbiological parameters as indicators of soil quality under various tillage and croprotation systems in southern Brazil. **Soil and Tillage Research**, Amsterdam, v. 92, n. 1-2, p. 18-29, 2007.

GOMES, A. A.; ARAÚJO, A. P.; ROSSIELLO, R. O. P.; PIMENTEL, C. Acumulação de biomassa, características fisiológicas rendimento de grãos em cultivares de feijoeiro irrigado e sob sequeiro. **Pesquisa Agropecuária Brasileira**, Brasília, v. 35, n. 10, p. 1927- 937, 2000.

GONÇALVES, R. N. **Diagnóstico ambiental da bacia do Rio Jequitinhonha.** Salvador: IBGE, 1997. 64p.

INMET. Instituo Nacional de Meteorologia. Disponível em: http://www.inmet.gov.br. Acesso em: 30 mar. 2009.

KABATA-PENDIAS, A.; PENDIAS, H. **Trace elements in soils and plants.** Boca Raton, CRC Press, 1984. 315 p.

KIKUTI, H.; ANDRADE, M. J. B.; CARVALHO, J. G.; MORAIS, A. R. Teores de macronutrientes na parte aérea do feijoeiro em função de doses de nitrogênio e fósforo. **Bragantia,** Campinas, v. 65, n. 2, p. 347-354, 2006.

LIMA, H. V.; OLIVEIRA, T. S.; OLIVEIRA, M. M.; MENDONÇA, E. S.; LIMA, P. J. B. F. Indicadores de qualidade do solo em sistemas de cultivo orgânico e convencional no semi-árido cearense. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 31, n. 5, p. 1085-1098, 2007.

LOPES, A. S.; GUILHERME, L. R. G. **Interpretação de análise do solo:** conceitos e aplicações. São Paulo: Anda, 1992. 64p. (Boletim técnico, 2)

MALAVOLTA, E.; VITTI, G. C.; OLIVEIRA, S. A. **Avaliação do estado nutricional das plantas:** princípios e aplicações**.** 2.ed. Piracicaba: POTAFOS, 1997. 319 p.

MARQUES, T. C .L. L. S. M., VASCONCELLOS, C. A.; PEREIRA FILHO, I.; FRANÇA, G. E. CRUZ, J. C. Evolvimento de dióxido de carbono e mineralização de nitrogênio em Latossolo Vermelho-Escuro com diferentes manejos. **Pesquisa Agropecuária Brasileira**, Brasília, v. 35, n. 3, p. 581-589, 2000.

MARTINEZ, H. E. P.; CARVALHO, J. G.; SOUZA, R. B. Diagnose foliar. In: RIBEIRO, A.C.; GUIMARÃES, P. T. G., ALVAREZ V., V.H. **Recomendações para o uso de corretivos e fertilizantes em Minas Gerais.** Viçosa: CFSEMG, 1999. p. 143-168.

MATIAS, M. C. B.; SALVIANO, A. A. C.; LEITE, L. F. C.; GALVÃO, S. R. S. Propriedades químicas em Latossolo Amarelo de Cerrado do Piauí sob diferentes sistemas de manejo. **Revista Ciência Agronômica**, Fortaleza, v. 40, n. 3, p. 356-362, 2009.

MURAGE, E. W.; VORONEY, P. R.; KAY, B. D.; DEEN, B.; BEYAERT, R. P. Dynamics and turnover of soil organic matter as affected by tillage. **Soil Science Society of America Journal**, Madison, v. 71, n. 4, p. 1363-1370, 2007.

NATALE, W.; PRADO, R. M. P.; ROZANE, D. E. R.; ROMUALDO, L. M. Efeitos da calagem na fertilidade do solo e na nutrição e produtividade da goiabeira. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 31, n. 6, p. 1475-1485, 2007.

OLIVEIRA, J. O. A. P.; VIDIGAL FILHO, P. S.; TORMENA, C. A.; PEQUENO, M. G.; SCAPIM, C. A.; MUNIZ, A.S.; SAGRILO, E. Influência de sistemas de preparo do solo na produtividade da mandioca (*Manihot esculenta*, Crantz). **Revista Brasileira de Ciência do Solo**, Viçosa, v. 25, n. 2, p. 443-450, 2001.

PAULA JUNIOR, T. J.; VENZON, M. **101 culturas:** manual de tecnologias agrícolas. Belo Horizonte: EPAMIG, 2007. 800p.

PAVINATO, P. S.; ROSOLEM, C. A. Disponibilidade de nutrientes no solo - decomposição e liberação de compostos orgânicos de resíduos vegetais. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 32, n. 3, p. 911-920, 2008.

PRADO, R. M.; NATALE, W. Uso da grade aradora superpesada, pesada e arado de disco na incorporação de calcário em profundidade e na produção do milho. **Engenharia Agrícola**, Jaboticabal, v. 24, n. 1, p. 167-176, 2004.

PRADO, R. M.; ROQUE, C. G. Uso alternativo da grade aradora superpesada na correção da acidez do solo em profundidade e na produção da aveia preta. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 26, n. 1, p. 275-281, 2002.

RANGEL, O. J. P.; SILVA, C. A. Estoques de carbono enitrogênio e frações orgânicas de Latossolo submetido adiferentes sistemas de uso e manejo. **Revista Brasileira de Ciência do Solo,** Viçosa, v. 31, n. 6, p. 1609-1623, 2007.

SÁ, J. C. M. Manejo da fertilidade do solo no sistema plantio direto. In: SIQUEIRA, J. O.; MOREIRA, F. M. S.; LOPES, A. S. (Ed.) **Inter-relação fertilidade, biologia do solo e nutrição de plantas.** Lavras: SBCS, 1999. p. 267-321.

SANTOS, G. C. G.; RODELLA, A. A. Efeito da adição de fontes de matéria orgânica como amenizantes do efeito tóxico de B, Zn, Cu, Mn e Pb no cultivo de *Brassica juncea.* **Revista Brasileira de Ciência do Solo**, Viçosa, v. 31, n. 4, p. 793-804, 2007.

SANTOS, H. P.; TOMM, G. O. Disponibilidade de nutrientes e teor de matéria orgânica em função de sistemas de cultivo e de manejo de solo. **Ciência Rural**, Santa Maria, v. 33, n. 3, p. 477-486, 2003.

SIDIRAS, N.; PAVAN, M. A. Influência do sistema de manejo do solo no seu nível de fertilidade. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 9, n. 1, p. 249-254, 1985.

SILVA, A. C. Solos. In: SILVA, A. C.; PEDREIRA, L. C. V. S. F.; ABREU, P. A. A. **Serra do Espinhaço Meridional: paisagens e ambientes.** Belo Horizonte: O Lutador, 2005. p. 61-77.

SILVA, C. C.; SILVEIRA, P. M. Influência de sistemas agrícolas em características químico-físicas do solo. **Ciência Agrotecnologia**, Lavras, v. 26, n. 3, p. 505-515, 2002.

SILVA, F. C. **Manual de análises químicas de solos, plantas e fertilizantes**. 2.ed. Brasília: Embrapa Informações Tecnológicas, 2009. 627p.

SILVEIRA, P. M.; CUNHA, A. A. Variabilidade de micronutrientes, matéria orgânica e argila de um Latossolo submetido a sistemas de preparo. **Pesquisa Agropecuária Brasileira**, Brasília, v. 37, n. 9, p. 1325-1332, 2002.

SILVEIRA, P. M.; CUNHA, P. C. R.; STONE, L. F.; SANTOS, G. G. Atributos químicos de solo cultivado com diferentes culturas de cobertura. **Pesquisa Agropecuária Tropical**, Goiânia, v. 40, n. 3, p. 283-290, 2010

SILVEIRA, P. M.; STONE, L. F. Teores de nutrientes e de matéria orgânica afetados pela rotação de culturas e sistema de preparo do solo. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 25, n. 2, p. 387-394, 2001.

SILVEIRA, P. M.; ZIMMERMANN, F. J. P.; SILVA, S. C.; CUNHA, A. A. Amostragem e variabilidade espacial de características químicas de um latossolo submetido a diferentes sistemas de preparo. **Pesquisa Agropecuária Brasileira**, Brasília, v. 35, n. 10, p. 2057-2064, 2000.

SORATTO, R. P.; CRUSCIOL, C. A. C. Atributos químicos do solo decorrentes da aplicação em superfície de calcário e gesso em SPD recém-implantado. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 32, n. 2, p. 675-688, 2008.

SOUZA, E. D.; COSTA, S. E. V. G. A; LIMA, C. V. S.; ANGHINONI, I.; MEURER, E. J.; CARVALHO, P. C. F. Carbono orgânico e fósforo microbiano em sistema de integração agricultura-pecuária submetido a diferentes intensidades de pastejo em plantio direto**. Revista Brasileira de Ciência do Solo**, Viçosa, v. 32, n. 3, p. 1273-1282, 2008.

SOUZA, Z. M.; ALVES, M. C. Propriedades químicas de umLatossolo Vermelho distroférrico de cerrado sob diferentes usos e manejos. **Revista Brasileira de Ciência do Solo,** Viçosa, v. 27, n. 1, p. 133-139, 2003.

TEIXEIRA, C. M.; CARVALHO, C. G.; ANDRADE, M. J. B.; SILVA, C. A. E PEREIRA, J. M. Decomposição e liberação de nutrientes das palhadas de milheto e milheto + crotalária no plantio direto do feijoeiro. **Acta Scientiarum Agronomy**, Maringá, v. 31, n. 4, p. 647-653, 2009.

THOMAS, G. A.; DALAL, R. C.; STANDLEY, J. No-till effects on organic matter, pH, cation exchange capacity and nutrient distribution in a Luvisol in the semi-arid subtropics. **Soil & Tillage Research**, Amsterdam, v. 94, n. 2, p. 295-304, 2007.