UNIVERSIDADE FEDERAL DE LAVRAS

RAPHAEL HENRIQUE DA SILVA SIQUEIRA

CARACTERIZAÇÃO DO ENCROSTAMENTO SUPERFICIAL DO SOLO CULTIVADO COM CAFEEIROS SUBMETIDO AO CONTROLE DE PLANTAS DANINHAS COM HERBICIDA DE PRÉ-EMERGÊNCIA

LAVRAS - MG

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Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Ciência do Solo, área de concentração em Recursos Ambientais e Uso da Terra, para a obtenção do título de Doutor.

Orientador

Dr. Mozart Martins Ferreira

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nos seus atos, demonstram o quanto a simplicidade prevalece para o sucesso.
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quantas vezes for preciso.
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“A ciência nunca resolve um problema sem criar pelo menos outros dez.”

George Bernard Shaw

“O que sabemos é uma gota; o que ignoramos é um oceano.”

Isaac Newton

RESUMO

O solo desprovido de cobertura vegetal está sujeito ao impacto direto das gotas de chuva, acarretando a quebra dos agregados e dispersão da argila que, a partir da sua migração com a água infiltrante ocasiona o entupimento dos poros formando um selo superficial. No presente trabalho, objetivou-se caracterizar o encrostamento superficial e o comportamento físico-hídrico de um Latossolo Vermelho submetido ao controle químico de plantas daninhas em cultivo de café. Os tratamentos avaliados foram: herbicida de pré-emergência (solo encrostado), herbicida de pós-emergência e sem capina. O delineamento experimental adotado foi o de blocos casualizados, perfazendo um fatorial, 3x2, sendo três métodos de controle, duas camadas analisadas (0-5 e 5-15 cm) e nove repetições. Foram realizadas análises para caracterização física e química das camadas amostradas. A presença do encrostamento superficial do solo ficou caracterizada por baixos valores de infiltração acumulada e condutividade hidráulica, assim como pelos maiores valores de resistência à penetração e densidade do solo. A aplicação contínua de herbicida de pré-emergência no Latossolo Vermelho resulta em menor rugosidade superficial, parâmetro intrínseco de solos encrostados. Imagens por microscopia eletrônica de varredura (MEV) e mapeamento dos elementos, a partir da espectroscopia de energia dispersiva (EED), não somente permitiram visualizar a estrutura granular e presença de diversos minerais no Latossolo, mas também diferentes padrões de agregação e porosidade. A formação de crostas na superfície do solo influenciou o comportamento físico-hídrico do Latossolo Vermelho submetido a métodos químicos de controle de plantas daninhas na cultura do café. O manejo do solo com herbicida de pré-emergência, em decorrência da formação de encrostamento superficial, causou uma redução do volume de poros com diâmetro superior a 145 µM, afetando negativamente os processos na drenagem e arejamento do solo. Por outro lado, o aumento da capacidade de água disponível do solo com crosta superficial na camada subsuperficial denota um potencial de reter mais água do que os demais tratamentos avaliados.

Palavras-chave: Selamento. Agregação. Manejo do solo.

ABSTRACT

Soil devoid of vegetation cover are prone to the direct impact of raindrops, resulting in the breakdown of aggregates and clay dispersion that, combined with the infiltrating water, causes the clogging of pores and, consequently, a sealed surface. In this present study, we aimed at characterizing the surface crusting and physical-hydric behavior of a Red Latosol exposed to chemical weed control of coffee crop. The weed control methods evaluated were pre-emergence herbicide (crusted soil), post-emergence herbicide, and with no weeding (no crusted soil). The experimental design was of randomized block, using a 3x2 factorial scheme that represents three control methods and two layers (0-5 and 5-15 cm) with nine replicates. Physical and chemical analysis of the layers were performed. The presence of superficial crusting on the soil was characterized by smaller values of accumulated infiltration and hydraulic conductivity, as well as greater penetration resistance and bulk density. The continuous application of pre-emergence herbicide to Red Latosol resulted in lower surface roughness, an intrinsic pattern of crusted soils. The evaluation of Scanning Electron Microscopy (SEM) images and the mapping of elements from the Energy Dispersive Spectroscopy (EDS) were capable of demonstrating the presence of several minerals and the granular structure of a Latosol, as well as the different patterns of aggregation and porosity. Crust formation on the soil surface influenced the physical-hydric behavior of a Red Latosol exposed to chemical weed control methods in coffee crops. Soil management with pre-emergence herbicide caused a reduction in the amount of pores with diameter greater than 145 μm, due to the formation of surface crust, which negatively affected the processes of soil drainage and aeration. On the other hand, the increase of available water capacity for an encrusted soil in the subsurface layer denotes a potential to retain more water than the other evaluated treatments.

Keywords: **S**ealing. Aggregation. Soil management.

SUMÁRIO

PRIMEIRA PARTE

PRIMEIRA PARTE

1 INTRODUÇÃO

Na economia nacional, o café tem desempenhado função fundamental do desenvolvimento econômico, contribuindo para os setores de indústria e serviço. A exportação do café tem garantido divisas à economia brasileira que vem ocupando importante posição na economia mundial do setor cafeeiro, com 20% a 35% da produção mundial (YOSHIHIKO; TEIXEIRA FILHO; CONTINI, 2004).

A produtividade do cafeeiro é altamente dependente dos tratos culturais, além de fatores fisiológicos e ambientais. Entre as principais práticas que visam à produção sustentável do café, está o controle de plantas daninhas que, de um modo geral, tem sido realizado, desde os primórdios da agricultura, por meio de técnicas manuais, mecânicas e químicas, embora durante muito tempo, as preocupações com os resultados dessa prática estiveram mais relacionadas ao ponto de vista agrícola do que ambiental.

A aplicação de diferentes métodos de controle de plantas daninhas na cultura do cafeeiro influencia a qualidade física do solo, mais expressivamente na camada superficial. Alcântara e Ferreira (2000a) constataram que a utilização contínua de herbicida de pré-emergência, além de reduzir o teor de matéria orgânica, provoca o desenvolvimento de encrostamento superficial do solo. Esse último aspecto, embora bastante significativo do ponto de vista ambiental, tem recebido pouca ou nenhuma atenção por parte dos estudiosos do tema.

O encrostamento superficial favorece a degradação do solo, sendo, portanto, um dos principais efeitos negativos provocados pela atividade humana. Segundo Castilho, Cooper e Juhász (2011) o estudo e o monitoramento das crostas superficiais são importantes para o manejo e conservação do solo e da água, principalmente em regiões de clima tropical, nas quais os trabalhos realizados são insuficientes para entender como ocorrem os processos de formação e evolução das crostas.

Diversas propriedades do solo são influenciadas pela formação da crosta superficial. Dentre as principais modificações, estão: diminuição da condutividade hidráulica e infiltração de água no solo, diminuição da rugosidade superficial aumentando o escoamento superficial e a erosão laminar, além do adensamento das camadas superficiais do solo.

Contraditoriamente às considerações comuns de que o encrostamento superficial é responsável apenas por consequências negativas no funcionamento do solo, acredita-se que as crostas superficiais possam apresentar, ainda que limitadamente, algum benefício para as culturas. Como admitido anteriormente, as crostas formam uma barreira à evaporação da água no solo e, por consequência, acredita-se que mais água deve permanecer no sistema para utilização pelas plantas. Essa hipótese tem sido levantada quando se compara o vigor das plantas de cafeeiro presentes em áreas adjacentes com e sem a presença de encrostamento superficial do solo. Embora estudos específicos não tenham sido realizados, plantas desenvolvidas em áreas com a presença de crostas superficiais aparentam-se mais vigorosas. Alcântara e Ferreira (2000b) ao avaliarem os efeitos de diferentes métodos de controle de plantas daninhas sobre a produção de cafeeiros, verificaram que os diferentes métodos de controle mostraram pouca influência sobre a produção. Entretanto, os autores constataram que as parcelas onde não se fez o controle das plantas daninhas e onde o mesmo foi realizado com roçadeira, apresentaram as menores produtividades médias de café, enquanto as parcelas de controle com herbicida de pré-emergência estiveram entre aquelas com maior produtividade média.

O presente trabalho teve como objetivo caracterizar o encrostamento superficial de um Latossolo Vermelho distroférrico em lavoura perene de café submetida ao controle químico de plantas invasoras e as consequências que podem ocorrer a partir da sua consolidação na superfície do solo.

2 REFERENCIAL TEÓRICO

2.1 Encrostamento Superficial

O impacto das gotas de chuva na superfície do solo descoberto ocasiona uma série de efeitos: desintegração de agregados, destacamento, arrastamento e deposição de partículas, causando erosão e modificando a estrutura do solo de várias formas. Uma das alterações que ocorre é a formação de encrostamento superficial, característica comum em solos cultivados em várias regiões do mundo (HU et al., 2012; KINNEL, 2005).

A formação do encrostamento superficial é resultado de dois mecanismos complementares: (I) uma desintegração física dos agregados superficiais causada, principalmente, pela energia de impacto de gotas de chuva, levando à formação da fina camada superior; e (II) a dispersão físico-química das partículas de argila do solo, que migram no solo com a água infiltrante e obstruem os poros imediatamente abaixo da superfície (AGASSI; SHAINBERG; MORIN, 1981).

A crosta é uma fina camada na superfície do solo caracterizada por uma maior densidade, maior resistência ao cisalhamento e baixa condutividade hidráulica, cuja espessura pode variar de 0,1 mm até 50 mm, podendo apresentar rachaduras. O encrostamento pode ocasionar efeitos na erodibilidade do solo, aumentando o escoamento superficial, em razão da diminuição da sua permeabilidade (HYVÄLUOMA et al., 2012; VALENTIN; BRESSON, 1992).

Diversos estudos abordando selamento superficial e encrostamento do solo têm sido realizados, desde o início do século XX, e o interesse em ambos os fenômenos, não surpreendentemente, continua, em razão das suas importantes consequências, no meio ambiente, além de ocorrência do fenômeno em culturas com importância econômica (SOUZA et al., 2014).

O encrostamento superficial influencia na erosão do solo ao reduzir a rugosidade superficial, infiltração de água e erosão por salpicamento, ao mesmo tempo que aumenta o escoamento superficial (HU et al., 2012).

Associado ou não a fatores químicos e biológicos, o impacto das gotas de chuva sobre a superfície exposta do solo, quebrando os agregados e promovendo a subsequente dispersão da argila, é, provavelmente, a principal causa da formação de crostas no solo. Estudo nessa direção foi conduzido por Hu et al. (2012) que avaliaram o desenvolvimento de crostas superficiais no solo, em condições de chuva simulada. Segundo esse estudo, dois tipos de crostas são formadas, as estruturais e as deposicionais. Fato comum é que ambas são formadas a partir da quebra dos agregados e dispersão das partículas, com influência da textura do solo.

Uma série de mudanças nas propriedades do solo são ocasionadas pela formação de crostas superficiais, entre elas: alterações na textura, em razão do arrastamento de material mais fino, modificações na estabilidade estrutural provocadas durante o processo de formação das crostas, variação da rugosidade superficial ocasionando maiores perdas de solo, diminuição da permeabilidade do solo observada por alterações nos parâmetros de infiltração e condutividade hidráulica e o adensamento das camadas subsuperficiais do solo (BADORRECK; GERKE; HÜTTL, 2013; BREMENFELD; FIENER; GOVERS, 2013; DARBOUX; LE BISSONNAIS, 2007; SAJJADI; MAHMOODABADI, 2015; SOUZA et al., 2014).

Um requisito para o aparecimento de crostas superficiais é a dispersão das partículas. Seta e Karathanasis (1996), estudando a dispersibilidade de coloides do solo em água, relacionaram vários autores que apontaram diferentes fatores responsáveis pela dispersão da fase coloidal do solo. De acordo com esses estudos, o fenômeno de dispersão da fração argila é dependente da ação mecânica representada pelo impacto da gota de chuva sobre os agregados, mas é igualmente influenciado por fatores físico-químicos, tais como: a quantidade e tipo de cátion trocável presente, quantidade de agentes cimentantes, tais como a matéria orgânica, óxidos de Fe e Al, conteúdo de argila, composição mineralógica, força iônica da solução do solo e pH.

Reichert (1993), avaliando selamento superficial e erosão em solos com altos conteúdos de argila, demonstrou que a principal causa para erosão do solo pela água é a dificuldade do solo de infiltrar água em proporções iguais à precipitação ou irrigação. Ao aplicar sulfato de cálcio no solo, foi observado o aumento da concentração eletrolítica, aumento da infiltração de água e diminuição do escoamento superficial e erosão, em taxas que dependeram do tipo de solo, das condições de superfície e da intensidade e duração da chuva. No mesmo trabalho, o impacto das gotas de chuva na superfície do solo ocasionou encrostamento e subsequente redução da porosidade total, presença de poros menores, e menores poros planares (fissuras) do que a camada de solo subsuperficial.

A argila dispersa em água apresenta importante papel na formação do encrostamento, de acordo com Dexter e Czyz (2000). Alguns problemas associados com a argila dispersa em água e o encrostamento do solo incluem: redução da infiltração de água, aumento do escoamento superficial, restrição à emergência de plântulas, redução da aeração do solo, redução da evaporação de água e aumento da erosão hídrica. Estudos nessa direção foram realizados por Fuller, Goh e Oscarson (1995) e Robinson e Phillips (2001).

Nguetnkam e Dultz (2014), ao estudar a dispersão de argila em Latossolos no Norte de Camarões, concluíram que a adição de eletrólitos pode aumentar a força iônica por compressão da dupla camada difusa, tendo um papel decisivo na floculação.

Não obstante às considerações anteriores, Resende et al. (1997) destacam a participação da fração grosseira do solo na formação de selos superficiais. Segundo esses autores, a fração silte desempenha um papel muito importante no encrostamento do solo, sendo de se prever que solos mais ricos nessa fração tenham uma tendência mais acentuada em desenvolver crostas superficiais. Salientam ainda que é comum em muitos solos brasileiros, com bastante evidência nas áreas de cerrado, a formação de um pequeno encrostamento da camada superficial do solo. Considerando que, na região dos cerrados, predomina a classe de Latossolos, geralmente pobres em silte, supõe-se que sua fração argila, predominantemente com tendência a se manter floculada possa, funcionalmente, estar se comportando como silte e areia muito fina.

Estudos envolvendo dispersão da fração argila e estabilidade dos agregados do tamanho de silte em solos da região sudeste do Brasil foram realizados por Vitorino et al. (2003), que observaram efeito marcante das composições mineralógicas e químicas dos solos na dispersão de argila, com relexos na fração silte, sendo que quanto maiores os teores de gibbsita maiores foram as estabilidades dos agregados do tamanho de silte, enquanto que a caulinita proporcionou efeito inverso.

Lado e Ben-Hur (2004) também observaram que a mineralogia do solo apresenta substancial efeito na dispersão de argila e estabilidade de agregados e, portanto, na formação de encrostamento superficial, estando associada assim à taxa de infiltração, escoamento superficial e perda de solo. Esses autores constataram que solos esmectíticos são mais instáveis e propícios à formação de crostas superficiais, enquanto que os solos cauliníticos e ilíticos são mais estáveis e menos propícios à formação de selamento.

Farres (1978) demonstrou a relação entre formação do encrostamento e tamanho de agregados. Os agregados foram divididos em três classes: grandes, médios e pequenos (6,73; 3,36 e 1,68 mm, respectivamente), foi observado que quanto maior o volume de água aplicado maior foi a espessura da crosta formada, logo concluiu- se que quanto menores os agregados do solo, mais facilmente é formada a crosta superficial, além disso, para agregados maiores o limite de espessura da crosta também é maior.

Estudando a morfologia de crostas superficiais na Alemanha, Badorreck, Gerke e Hüttl (2013) sugerem que o tipo de crosta em combinação com a textura do solo influencia as propriedades hidráulicas de superfície, com menores valores de condutividade hidráulica não saturadas na presença de crostas.

Sajjadi e Mahmoodabadi (2015) avaliaram a quebra de agregados e formação de encrostamento superficial em solos do Irã, e verificaram que a taxa de infiltração de água diminuiu mesmo em solos que permaneceram saturados, durante o evento de chuva simulada, em vista disso concluíram que o encrostamento superficial formado foi o único fator responsável pela alteração na infiltração de água. Nos primeiros minutos de chuva, formou-se uma fina superfície vedada e com o passar do tempo desenvolveu-se uma camada encrostada mais robusta, junto a isso, também foi observada diminuição da rugosidade superficial do solo.

A rugosidade do solo descreve as microondulações na sua superfície, resultantes principalmente das práticas de manejo, sendo um dos principais fatores que influenciam fortemente a erosão (VÁZQUEZ; MIRANDA; GONZÁLES, 2005). Mais precisamente, a rugosidade compreende microelevações ou microdepressões observadas na superfície (KUIPERS, 1957). De acordo com Kidron (2007), a modificação do microrrelevo, em escala milimétrica, pode ocasionar um desenvolvimento significativo de escoamento superficial.

Alterações na rugosidade superficial do solo em cultivo de cafeeiros foi observada por (ALCÂNTARA; FERREIRA, 2000a), avaliando diversos métodos de controle de plantas daninhas, verificaram diminuição da rugosidade superficial do solo, em decorrência da aplicação contínua do tratamento com herbicida de pré-emergência que apresenta a desvantagem de deixar o solo descoberto e, portanto, exposto diretamente ao impacto das gotas de chuva na superfície.

Hu et al. (2012) afirmam que, como a estrutura de uma crosta de solo é instável, em razão do impacto das gotas de chuva e escoamento superficial, estudos estáticos e isolados não proporcionam um entendimento completo do desenvolvimento da crosta do solo.

Portanto, como foi observado, em área de cultivo de café implantado há 38 anos cujo controle das plantas daninhas foi realizado com herbicida de pré-emergência, consolidou-se o encrostamento superficial do solo na entrelinha, além disso, observou-se que os cafeeiros associados a essa prática se mostraram mais produtivos em relação aos cafeeiros onde foram aplicados outros métodos de controle de plantas daninhas. Com isso, almejou-se, neste trabalho, caracterizar o encrostamento superficial do solo, por meio de uma nova técnica de determinação da rugosidade superficial, além da avaliação das características físico-hídricas do solo e, com isso, buscar uma melhor compreensão das propriedades do solo que são afetadas pela formação da crosta.

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SEGUNDA PARTE - ARTIGOS

ARTIGO 1 *Superficial crusting characterization of a red latosol cultivated with coffee subjected to weed control with pre-emergence herbicide*

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ABSTRACT

Chemical weed control may result in changes on soil structure, mainly in the surface layer. The soil devoid of vegetation cover is submitted to the direct impact of raindrops, resulting in the breakdown of aggregates and clay dispersion to form a surface seal and from the clay migration and the infiltrating water causing the clogging of pores and consequently soil surface crusting. This present study aimed to characterize the superficial crusting of an Red Latosol subjected to chemical weed control in coffee crop. The weed control methods evaluated were: pre-emergence herbicide (crusted soil), post-emergence herbicide treatment, and without weeding. The experimental design was a randomized block, making a factorial 3x2, three control methods, two layers (0-5 and 5-15 cm) and nine repetitions. The following soil analysis were performed: cumulative infiltration (CI), hydraulic conductivity (HC), surface roughness (RS), penetration resistance (RP), bulk density (Bd), scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). The presence of soil superficial crusting was characterized by smaller values of accumulated infiltration and hydraulic conductivity as well as greater penetration resistance and bulk density. The continuous application of pre-emergence herbicide in Red Latossol resulted in a lower surface roughness, an intrinsic pattern of crusted soils. The evaluation of scanning electron microscopy (SEM) images and mapping of elements from the energy dispersive espectroscopy (EDS) techniques are able to demonstrate the granular structure of an Latossol as well as to infer the presence of several minerals.

Keywords: Sealing. Soil water. Soil management.

RESUMO

O manejo químico das plantas invasoras pode acarretar em modificações na estrutura do solo, principalmente na camada superficial. O solo desprovido de cobertura vegetal está sujeito ao impacto direto das gotas de chuva, acarretando na quebra dos agregados e na dispersão da argila, formando um selo superficial que, a partir da migração da argila com a água infiltrante, ocasiona o entupimento dos poros. No presente trabalho, objetivou-se caracterizar o encrostamento superficial do solo cultivado com cafeeiros submetido ao controle químico de plantas invasoras. Os métodos de controle de plantas invasoras avaliados foram: herbicida de pré-emergência (solo encrostado), herbicida de pós-emergência e tratamento sem capina. O delineamento experimental adotado foi o de blocos casualizados, perfazendo um fatorial, 3x2, sendo três métodos de controle, duas camadas analisadas (0-5 e 5-15 cm) e nove repetições. Foram realizadas as seguintes análises do solo: infiltração acumulada (IA), condutividade hidráulica do solo (CH), rugosidade superficial (RS), resistência do solo à penetração (RP), densidade do solo (Ds), microscopia eletrônica de varredura (MEV) e espectroscopia de energia dispersiva (EED). A presença do encrostamento superficial do solo caracterizou-se por menores valores de infiltração acumulada e condutividade hidráulica, assim como maior resistência à penetração e densidade do solo. A aplicação contínua do herbicida de pré-emergência no Latossolo Vermelho ocasionou menor rugosidade superficial, padrão intrínseco de solos encrostados. A avaliação das imagens por microscopia eletrônica de varredura (MEV) e o mapeamento dos elementos a partir da técnica de espectroscopia de energia dispersiva (EED) são artifícios capazes de demonstrar a estrutura granular do Latossolo, assim como inferir a presença de diversos minerais.

Palavras-chave: Selamento. Água do solo. Manejo do solo.

1 INTRODUCTION

Weed management and control in croplands can be performed through manual, mechanized or chemical techniques, with significant impacts on production costs. In addition, soil losses by water erosion can follow when weending in done without soil conservation practices or without critical evaluation of their effects on soil properties (MELONI et al., 2013). This is specially true when there is continued use of pre-emergence herbicides, which can decrease soil quality by reducing organic matter and aggregation, and promoting the formation of surface crusting (ALCÂNTARA; FERREIRA, 2000b).

The raindrop impact on bare soil surfaces exposed by continuous pre-emergence herbicides, for perennial tree crops promote erosion and change the soil structure in various ways. More specifically, raindrops promote aggregate disintegration, detachment, entrainment, and deposition of aggregate fragments. In consequence, surface sealing and subsequently the formation of crust can ensue. The crust is a thin layer on the ground surface characterized by increased density, greater resistance to penetration, and low hydraulic conductivity in the subsurface layer of soil, reducing the movement of water (SUN; KANG; JIANG, 2010). Surface crusting is a common feature of cultivated soils in many regions of the world (HU et al., 2012; KINNEL, 2005).

Many works highlight the influence of surface crusting on physical and hydraulic characteristics of the soil. Examples of these impacts are decreased water infiltration and consequent decrease in soil hydraulic conductivity, decreased surface roughness, and higher bulk density

(BADORRECK; GERKE; HÜTTL, 2013; DARBOUX; LE BISSONNAIS, 2007; SOUZA et al, 2014). It is also known that soil management influences the crust formation characteristics, as well as clay mineralogy (LADO; BEN-HUR, 2004).

Soil management influences directly the water infiltration. Stolte (2003) mentions that the hydraulic properties of the soil depend on the texture and structure, and although texture is a static property, soil structure can vary in space and time. Also, the usage of different weed control methods in coffee crop alter the soil structure influencing the stability of the aggregates, the water retention, and, consenquentely, the soil physical quality (ALCÂNTARA; FERREIRA, 2000a, 2000b; PAIS et al., 2011; SIQUEIRA et al., 2014).

Therefore, soil crusts are caused by the type of soil management. However, even with the superficial crust and its influences on the physic-hydric characteristics of the soil well established there is a necessity to characterize this fenomenom. That being said, the objective of this work was to characterize the surface crusting of a Red Latosol subjected to pre-emergence herbicide and other chemical weed control methods in coffee stands. The tested hypothesis was the one in which the superficial crust is distinctive in soils managed with pre-emergend herbicide to control weed.

2 MATERIAL AND METHODS

2.1 Study area

The study was conducted in the Experimental Station of Agricultural Research Corporation of Minas Gerais - EPAMIG, in São Sebastião do Paraíso county, Minas Gerais state, Brazil, approximately 47°07’10’’ W and 20º55’00’’ S, with an altitude of 890 m. Average annual rainfall is 1470 mm and mean annual temperature 20.8°C, with average maximum of 27.6°C and average minimum of 14.1°C.

According to the Brazilian Soil Classification System (EMBRAPA, 2013), the soil studied is as Latossolo Vermelho distroférrico típico, which corresponds to Rhodic Hapludox in Soil Taxonomy (UNITED STATES OF AMERICA, 2006). The native in a semideciduous forest, transitional to cerrado. The experimental area has an average slope of 8%. Selected physical and chemical properties are provided in Table 1.

Table 1 Physical and chemical caracterization of a Red Latossol (RL) at the study site

Layer (cm)	**Sand**	**Silt**	**Clay**	**pH**	**K**	**P**	**Ca**	**Mg**	**Al**	**SB**	**T**	**V**
	----g kg^{-1}----				---mg dm^{-3}---		--------------cmol$_c$ dm^{-3}-------------					(%)
0 – 5	280	220	500	6,41	99,33	26,28	5,51	0,93	0,08	5,70	6,80	68,31
5 – 15	270	230	500	6,34	99,11	15,50	4,51	0,95	0,07	6,72	5,78	66,36

2.2 Experimental design and layout

The *Coffee arabica* L. crop was planted in a 4 x 1 m spacing in 1974, with the Catuaí Vermelho LCH 2077-2-5-99 cultivar. In 2005, due to declining crop production, it was replaced by cultivar Paraíso MG1192 and the spacing was changed to 0.7 m between the coffee trees. The change operations of cultivars were performed keeping the effect of treatments over the years on between rows. The coffee rows, with 0.8 m wide at the crown projection, were kept clean by means of pre-emergence herbicides and post-emergence and manual weeding, to facilitate the application of fertilizers, management coffee and machinery moving.

The experimental design used was in randomized blocks, with three treatments and nine replications, in two depths (0-5 and 5-15 cm). The weed control methods tested were no weeding (spontaneous weed growter), pre and post emergence herbicides. There treatments were applied between tree rows, in a streak approximately 1.20 m wide. Each experimental plot consisted of three "streets", encompassing 108 coffee trees.

2.3 Weed management

The average number of operations required for satisfactory weed control during each year has varied according to the effectiveness of each method, to keep the weed infestation according to standards of a commercial coffee stands.

The Post-emergence herbicide (PstH) initially, comprised a mixture of Paraquat [1,1'-dimethyl - 4,4'-bipyridylium ion (dichloride)] and Diquat [1,1'-ethylene - 2.2 bipyridylium ion (dibromide)] at a 1:1 ratio. This changed later to glyphosate [N - (phosphonomethyl glycine)] at a dosage from 0.72 to 1.44 $L.ha^{-1}$, depending on the intensity of infestation, alternately with a mixture of glyphosate + D [2,4 dichlorophenoxyacetic acid], in proportion, respectively, 160 + 120 gL^{-1} and dosage 640g + 480g ha^{-1} a.i.(active ingredient); in a average of three applications per year. Pre-emergence herbicide (PreH) comprised a mixture of Ametryn (2-ethylamino-4isopropilamino-6-methylthio-s-triazine) + Simazine (2-chloro-4-6-bietilamino-s-triazine) at 1200g + 1200g ha^{-1} a.i as wettable poder, and later the same mixture (1125g + 1125g.ha^{-1} a.i.) in liquid formulation, with a spray volume 400L.ha^{-1}, after replacement of the cultivars the oxyfluorfen pre-emergence herbicide was used a base of 3 L ha^{-1} of commercial product, and No weeding (NW).

2.4 Analytical procedures

2.4.1 Water infiltration

Accumulated infiltration and hydraulic conductivity were measured with a mini disk infiltrometer, Macro.V.3 model of Decagon. Four tensions (0, 2, 4, 6 cm) were applied, and the readings were taken 7 times, running up to 180 seconds, with infiltration data was recorded every 30 seconds. The data were plotted in a graph of square root of time through cumulative infiltration, and hydraulic conductivity calculated from the formula: k = C / A, where A is the characteristic value for different textural classes of soils in function of the applied tension and C is the slope of the curve of accumulated infiltration.

2.4.2 Penetration Resistance

The penetration resistance was performed on undisturbed samples, at the pressures (6, 100 and 1500 kPa) in 5 replicates. We used a digital stand penetrograph Marconi MA 933, equipped with a circular cone tip of 45 ° and 3.84 mm diameter, with a constant speed of 100 mm. min^{-1} (TORMENA; SILVA; LIBARDI, 1998).

2.4.3 Surface Roughness

PVC pipes with 150 mm in diameter and 100 mm in height were used for the collection of undisturbed samples, of the soil surface, later the soil moistened and with the help of a knife, in six replicates per treatment. After the removal of the samples, they were sent to the Engineering Department of the Federal University of Lavras for illumination.

Figure 1A shows an example soil with surface crusting (pre-emergence herbicide) and in Figure 1B it is presented a sample without surface crusting (no weeding).

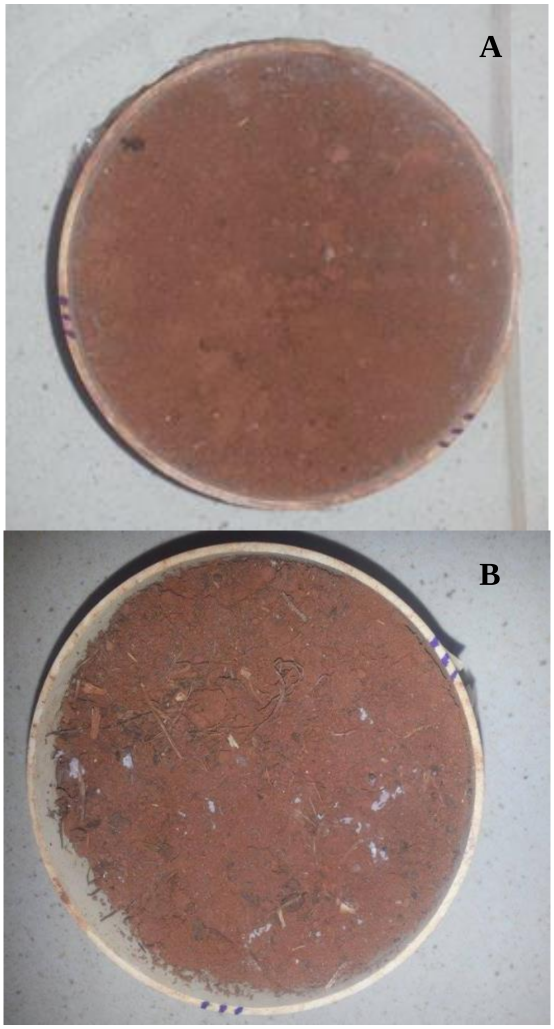

Figure 1 Soil with superficial crusting (A) and without superficial crusting (B).

2.4.4 Samples Illumination

The sample soil surfaces were illuminated with a Laserline LGE20/532/c at 20 mW, wave length of 532 nm (green). The laser was set at a rod 32 cm at a distance of 36 cm from the sample and an inclination angle of 42°22'.

The images were captured by Cannon EOS camera mounted on a tripod with 53 cm height, with a distance of 10 cm from the above the sample and the camera at an angle of 90 ° in relation to the tripod. The experimental arrangement is shown in Figure 2.

Figure 2 Surface roughness analysis set

Soil surface samples were illuminated and photographed at three different points distant 0.5 cm between them, generating eighteen images by treatment. Figure 3 shows images, and the area one of those cropped for image processing.

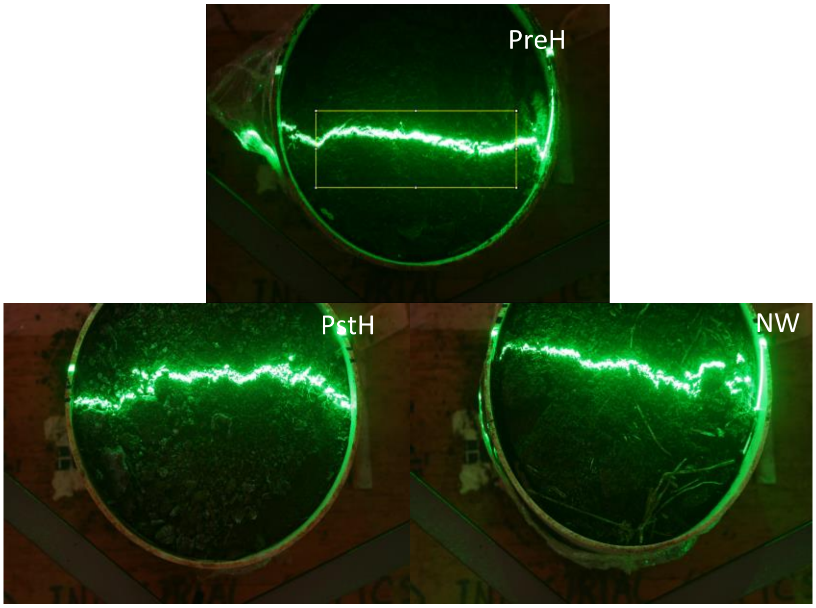

Figure 3 Samples illumination

2.4.5 Image processing

Images were preprocessed individually with the Image-J software, where they were cropped to 2304x708 pixels, transformed in 8 bits, smoothed Glaussian Blur with sigma of 5.0 and binarized image, whereby the white color is represented by the number "0 "and the color black by" 255 " (Figure 4).

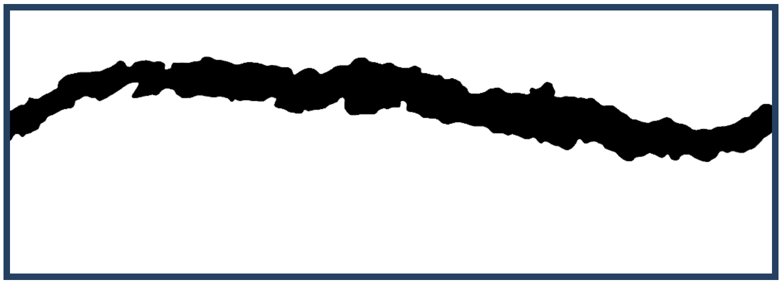

Figure 4 Preprocessed image by ImageJ

Then, all the images were imported to a Ri386 program 3.2.2 (R DEVELOPMENT CORE TEAM, 2008) and produced a variogram. In the program, a function for calculating the average number of the points of each column was adjusted by generating a set of points for each image.

Scanning Electron Microscopy (SEM) and Energy Dispersive Espectroscopy (EDS)

From the undsturbed samples collected, 2vs 1cm subsection of the vertical soil surface were examined by scanning electron microscopy (SEM) at magnifications of 60, 90, 530, 1000 and 2000 x, in the different treatments. Espectroscopy dispersive energy analysis were also performed to quantify the main elements presented in the surfaces. Multipoint analysis and mapping were made in three points closer to the sample surface and three points below the surface. To perform this analysis, a Scanning Electron Microscope (SEM) LEO Evo 40 XVP was used attached with microanalysis systems (Quantax EDS e Software Espirit) and cryotransmision and observation from Gatan (Alto 1000).

3 RESULTS AND DISCUSSION

Soil cumulative infiltration differed considerally among treatments (Figure 5).

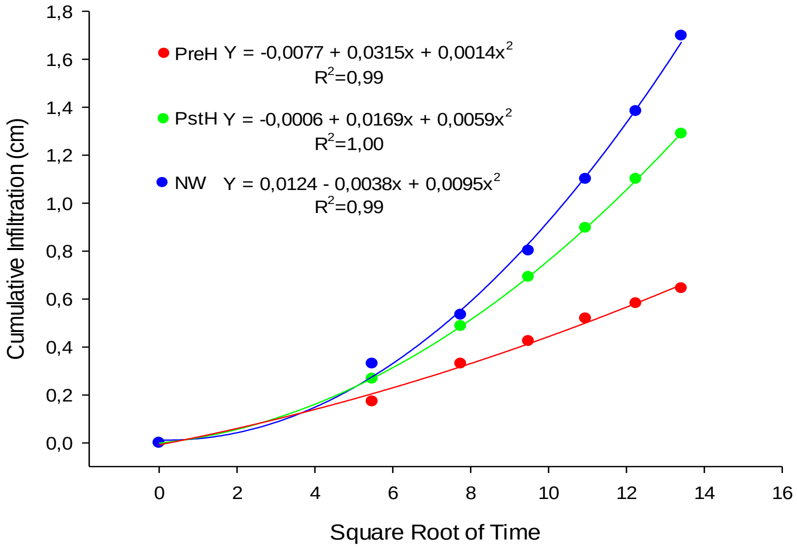

Figure 5 Cumulative Infiltration of an Red Latossol subjected to weed control methods in coffee stands

As expected, the no wedding treatment presented the highest cumulative infiltration, due to unrestricted weed growth and its positive effect on soil aggregation. Convenently, the soil with surface crusting (pre-emergence herbicide), due to the permanently bare surface, showed much lower infiltration. One of many characteristics of crusting surface soil are the decreased water infiltration followed by hydraulic conductivity. Badorreck, Gerke and Hüttl (2013) evaluated the morphology of soil physical crusts and infiltration patterns and concluded that under different matric potentials, the crust type in combination with the soil texture seems to strongly affect the surface hydraulic properties. They also observed lower unsaturated hydraulic conductivity values for soils with a structural crust. Similar results were observed for hydraulic conductivity for this experiment (Table 2).

Table 2 Hydraulic conductivity (HC), Penetration Resistance (PR) and bulk density (Bd) of an Red Latossol subjected to weed control methods in coffee stands

Treatments	**HC (cm h^{-1})**	**PR (MPa)**	**Bd (Mg dm^{-3})**
Pre-emergence herbicide	3,49 C	0,45 A	1,22 A
Post-emergence herbicide	8,21 B	0,35 B	1,14 B
No weeding	13,25 A	0,39 B	1,06 C

Means followed by the same letter, do not differ by the Scott Knott test at p<0,005.

Castilho et al. (2015) studied porosity changes the surface crusts of three soils in Piracicaba, São Paulo. The autors reported an effect of texture, since a clayey Rhodic Eutrudox showed significant changes in total porosity, pore number and morphology but not coarser-textured Typic Hapludox and Typic Hapladult. The pore modifications influence hydraulic conductivity and infiltration rates in soil with surface crusts (CARMI; BELINER, 2008).

In the crusted soil cultivated with pre-emergence herbicides, penetration resistance and bulk density were higher when compared to non-crusted soils. This mainly occurs due to detachment of surface soil particles and downward flow by infiltrating water, causing density to increase right below the surface (FOX, BRYANB; FOX, 2004).

Theoretically, soil resistance increases with depth, but this horizon (crusted soil) is an exception in wet condition since the resistance seems to be constant.

Soil surface roughness were always lower for the pre-emergence herbicide treatment soil showed the lowest roughness, whereas no weeding showed generally the highest values (Figure 6).

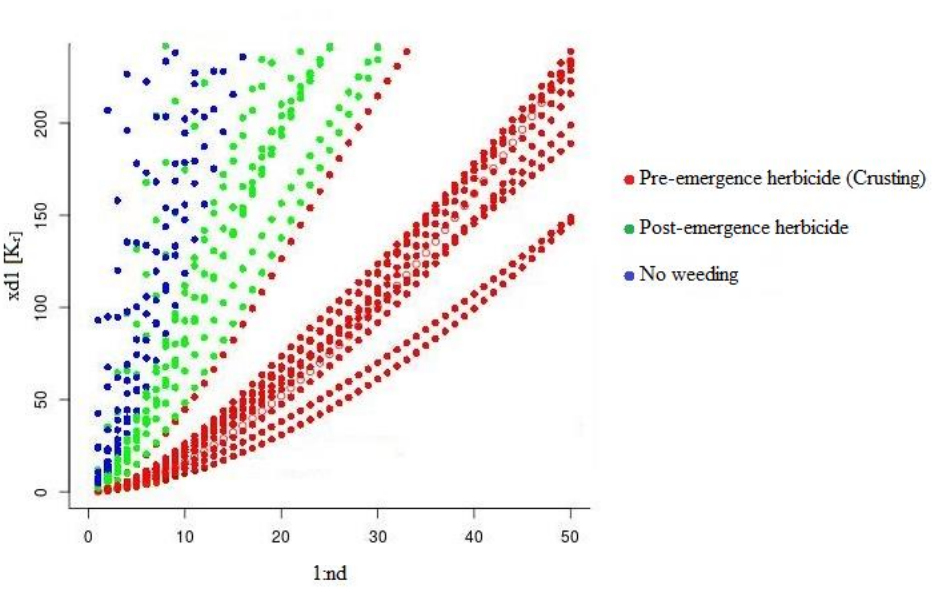

Figure 6 Surface roughness of an Red Latossol under different chemical weed control methods in coffee stands

Soil surface roughness is a critical parameter reflecting soil erosion and runoff processes, and is mainly influenced by soil characteristics (ZHENG; HE; WU, 2012) and management. The smaller the soil surface roughness, the greater the soil erosion and runoff, since water flow is higher. Therefore, the successive application of pre-emergence herbicides lead to soil losses, which is a enviromental concern, although coffee productivity in this treatment is higher than the other treatments (ALCANTARA; FERREIRA, 2000a). This is be due to the reduced competition with weeds, to wich coffee plants as high by sensitive (FIALHO et al., 2012). Alternatively, greater water retention in this treatment can also play a role. Sela, Svoray and Assouline (2015) report that the presence of crusting decreases stress caused by the lack of water in dry periods on the plants.

1. Image Analyses

The profile images from the treatments pre-emergence herbicide (PreH), post-emergence herbicide (PstH), and no-weed (NW) are presented in Figure 7.

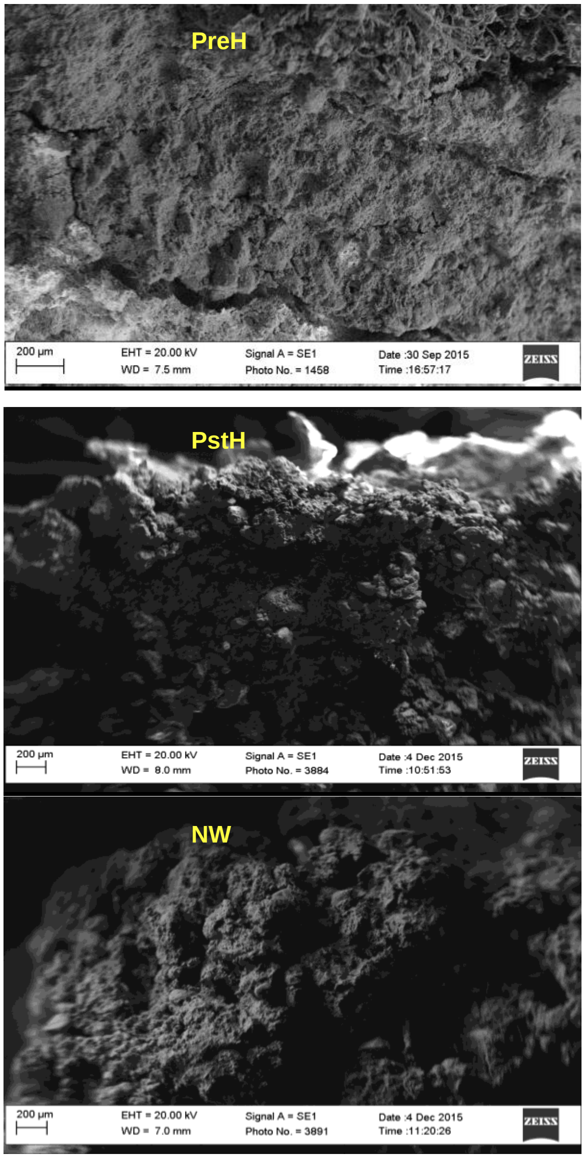

Figure 7 Perfil images of pre-emergence herbicide (PreH), post-emergence herbicide (PstH), and no weeding (NW) on SEM

It is observed the smaller size of the granules to the soil that was managed with the pre-emergence herbicide, which allow to infer the disruption e breakage of the aggregates in this profile, while the others present loose granules and consolidated structure.

The crust thickness ranged from 2.63 to 3.13 mm for the treatment with pre-emergence herbicide. According to Hyväluoma et al. (2012), the crust is a thin layer on the ground surface characterized by a higher density, greater shear resistance, and low hydraulic conductivity, whose thickness may vary from 0.1 mm to 50 mm and may be cracked.

The diferences in structure of the soil managed with different types of weed control can be observed in Figure 8.

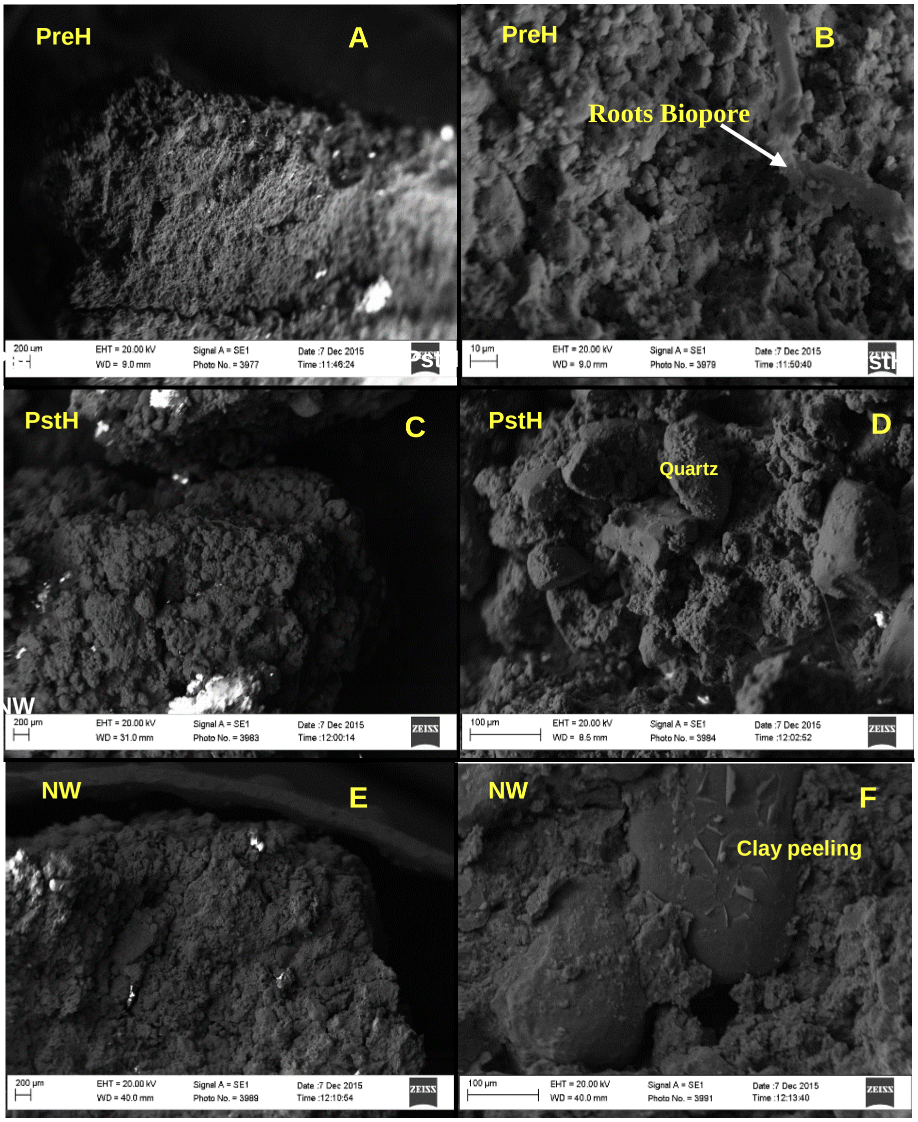

Figure 8 Structure of crusted soil of pre-emergence herbicide treatment (PreH), post-emergence herbicide (PstH) treatment, and no weeding (NW), increase 60 x (9A, 9C, 9E), 2000 x (PreH – 9B), 1000 x (PstH – 9D), and 530 x (NW – 9F) treatment on SEM

Figure 9 demontrates the physical crust formed by the breakage of the aggregates and obstruction of the pores, and also the biological crust formed in soil surface – characterized by the presence of fungal hyphae. According to Sela, Svoray and Assouline (2015), the formation of this biological crust reduces the water evaporation on the profile which causes a reduction on plant hydric stress in low water seasons.

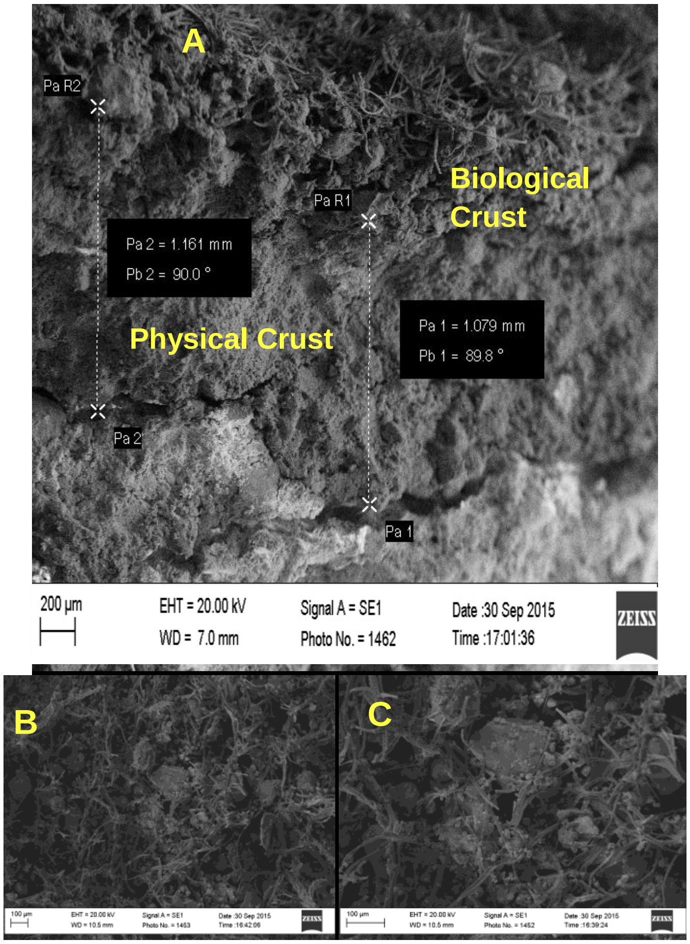

Figure 9 Pysical and Biological Crusts (A – profile image, magnified by 64 x) and biological crust (B and C – superficial image magnified by 173x e 373x, respectively) on soil managed with pre-emergence herbicide.

The evaluation of elements by EDS spectrum with multipoint allowed to observe the presence of four major elements: iron (Fe), aluminum (Al), silicon (Si), and titanium (Ti). These elements are typical of highly weathered, like gibbsitic Oxisols (Figures 10, 11).

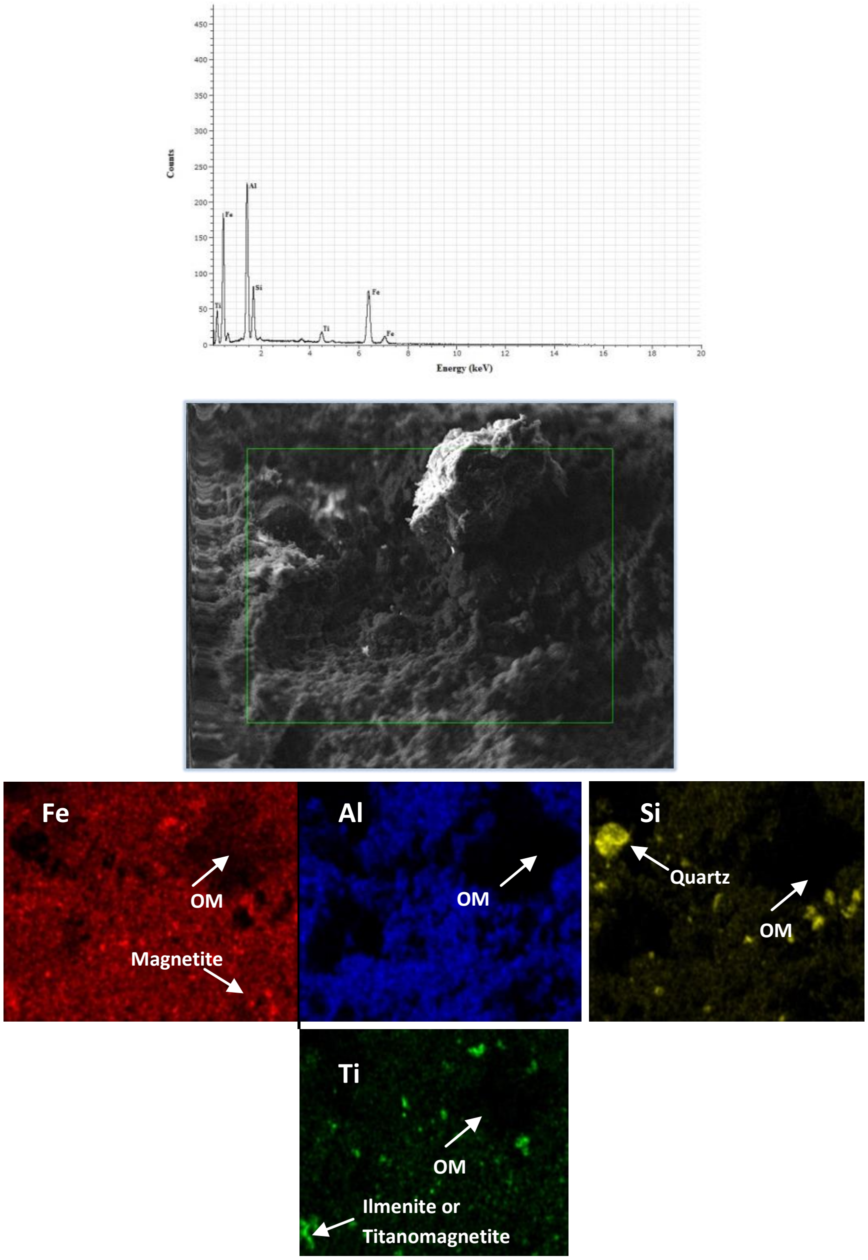

Figure 10 EDS mapping of soil surface crusting (pre-emergence herbicide) showing a Fe, Al, oxide composition,* OM= Organic Material

Predominance of Si as quartz and mutual occurence of Fe and Ti, suggesting the presence of Ilmenite ($FeTiO_3$) or titanomagnetite.

The considerable presence of titanium at several points, implier a high degree of weathering. When Fe and Ti occur in high amount at the same spot, this was explained by the presence of the Ilmenite ($FeTiO_3$) or Titanomagnetite. The presence of hematite, magnetite, and ilmenite are due to the decomposition of basaltic rocks. In addition, magnetite and ilmenite are concentrated in the sand fraction by its relative resistance to weathering (Cogo, 2012).

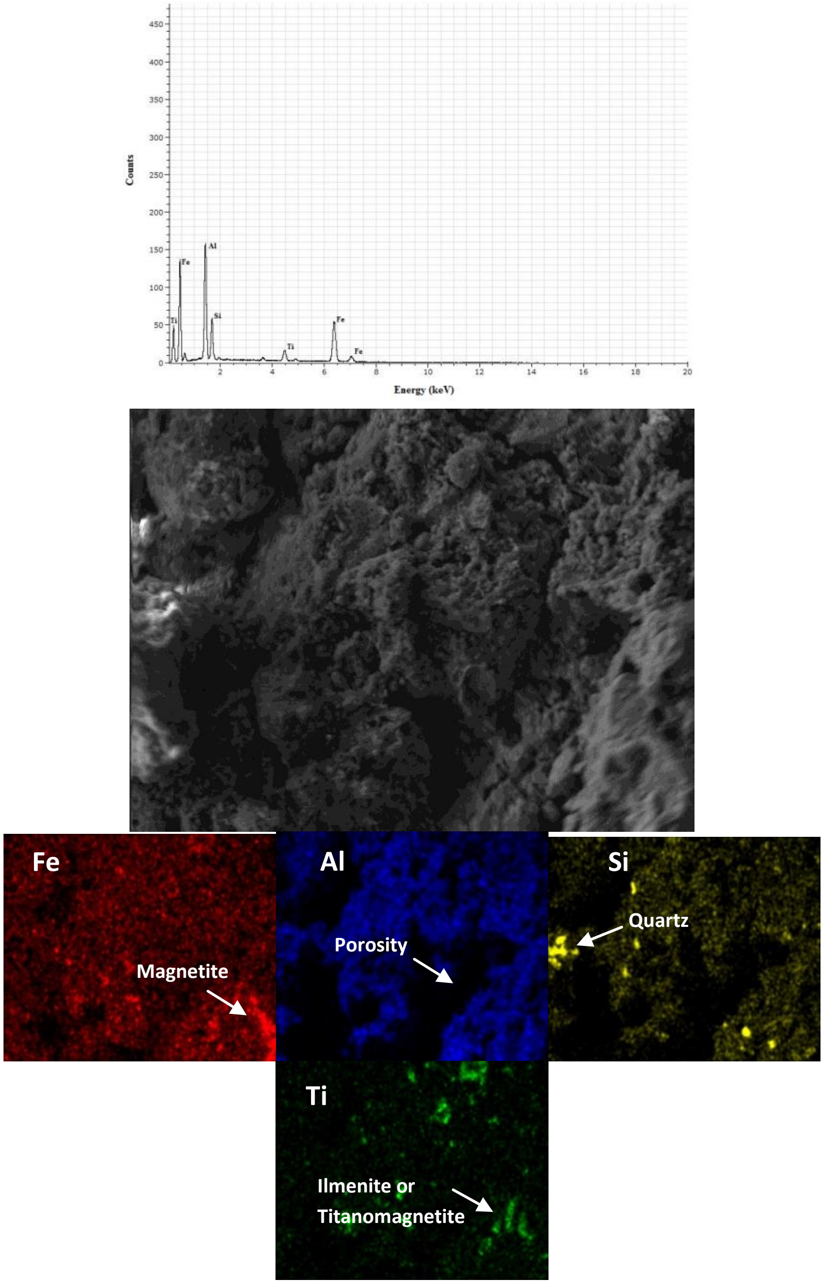

Figure 11 EDS spectrum and mapping of soil with no weeding treatment showing a Fe, Al, oxides composition. The large area in black are pores

The main difference between the pre-emergence herbicide and without weeding treatments is the greater volume of pores observed on the latter. The presence of higher amounts of roots can improve the porosity characteristics, due to their decomposition, resulting in the formation of biopores (LIMA et al, 2012).

4 CONCLUSIONS

- The presence of soil superficial crusting promoted lower accumulated infiltration and hydraulic conductivity, as well as greater penetration resistance and bulk density.

- The continuous application of pre-emergence herbicide in Red Latossol resulted in a lower surface roughness, an inherent pattern of crusted soils using an optical approach contactlessly.

- The evaluation of scanning electron microscopy (SEM) images and mapping of elements from the energy dispersive espectroscopy (EDS) technique are able to demonstrate the granular structure of an Latossol as well as to infer the presence of several minerals.

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ARTIGO 2 *Superficial crust in physic-hydric behavior of an red latosol cultivated with coffee subjected to weed control with pre-emergence herbicide*

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SUPERFICIAL CRUST IN PHYSIC-HYDRIC BEHAVIOR OF AN RED LATOSOL CULTIVATED WITH COFFEE SUBJECTED TO WEED CONTROL WITH PRE-EMERGENCE HERBICIDE

ABSTRACT

Rain causes changes in the surface structure of soil without vegetation causing the development of crusts. The aim of this work was evaluate the effect of superficial crusting in physic-hydric behavior of an Red Latosol cultivated with coffee subjected to weed control with pre-emergence herbicide. The weed control methods evaluated were: chemical control with post (PstH) and pre-emergence (PreH) herbicides and treatment without weeding (NW). The experimental design was randomized blocks, using a 3x2 factorial - referring to three treatments and two sampling depths (0-5 and 5-15 cm) with nine replicates. The following soil atributes were determined: mean geometric diameter of aggregates (MGD), eletric conductivity (EC), water dispersible clay (WDC), floculation index (FI), and soil organic matter content (OM). All these attributes were correlated. In addition, soil bulk density (Bd), total pores volume (TPV), macroporosity (Macro), microporosity (Micro), available water capacity (AWC) were also determined and water retention curves (WRC) were prepared. The soil surface crusting influenced the physic-hydric behavior the Red Latossol cultivated with coffee subjected to weed control with pre-emergence herbicide. The management of soil with pre-emergence herbicide, due to the formation of surface crusting, caused a reduction of the volume of pores of diameter greater than 145 µm class, negatively affecting processes in the drainage and aeration of the soil. The increase of avaiable water capacity for soil with crusting in subsurface layer denotes a potential to retain more water than the others treatments evaluated.

Keywords: cultivation, soil aggregation, soil water

RESUMO: *ENCROSTAMENTO SUPERFICIAL NO COMPORTAMENTO FÍSICO-HÍDRICO DE UM LATOSSOLO VERMELHO SUBMETIDO A MÉTODOS QUÍMICOS DE CONTROLE DE PLANTAS DANINHAS EM CULTIVO DE CAFÉ*

A chuva provoca modificações na estrutura da superfície do solo sem vegetação, causando o desenvolvimento de crostas. Objetivou-se, neste trabalho avaliar o efeito de encrostamento superficial no comportamento físico-hídrico de um Latossolo Vermelho cultivado com café submetido ao controle de plantas daninhas com herbicida de pré-emergência.. Foram avaliados os seguintes métodos de controle de plantas daninhas: controle químico com herbicidas de pós-emergência (PstH) e pré-emergência (PreH) e tratamento sem controle de plantas daninhas (NW). O delineamento experimental foi de blocos casualizados, perfazendo um fatorial 3x2, referindo-se aos três tratamentos, duas profundidades de amostragem (0-5 e 5-15 cm) com nove repetições. Foram determinados os seguintes atributos do solo: diâmetro médio geométrico de agregados (DMG), condutividade elétrica (CE), argila dispersa em água (ADA), índice de floculação (IF) e teor de matéria orgânica do solo (MO), todos esses atributos foram correlacionados. Além disso, também foram determinados a densidade do solo (Ds), volume total de poros (VTP), macroporosidade (Macro), microporosidade (Micro), capacidade de água disponível (CAD) e curvas de retenção de água foram confeccionadas. A formação de encrostamento superficial do solo influencia o comportamento físico-hídrico do Latossolo Vermelho cultivado com café submetido ao controle de plantas daninhas com herbicida de pré-emergência. O manejo do solo com herbicida de pré-emergência, em razão da formação de encrostamento superficial, causou uma redução do volume de poros com diâmetro superior a 145 uM, afetando, negativamente, os processos na drenagem e arejamento do solo. O aumento da capacidade de água disponível do solo com crosta superficial na camada subsuperficial denota um potencial de reter mais água do que os demais tratamentos avaliados.

Palavras-chave: tratos culturais, agregação do solo, água no solo

INTRODUCTION

Physical soil crusts are formed by the action of water and, to a lesser extent, wind on soil particles on the surface of bare areas (Fang et al., 2007). According to Castillo et al. (2011), the surface soil crusting is a major negative effect caused by human activity and promotes soil degradation. According to these authors, the study and monitoring of surface crusts are important for the management and conservation of soil and water, especially in tropical regions.

Associated or not with chemical and biological factors, the impact of raindrops on the exposed surface of the soil is probably the main cause of the formation of superficial crusts because it breaks down aggregated soil and promotes the subsequent dispersion of clay. Hu et al. (2012), evaluated the development of soil surface crusts in simulated rainfall and observed that two types of crusts are formed, structural and depositional. Common fact is that both are formed from the breakdown of aggregates and dispersion of the particles, with the influence of soil texture.

According to Alcântara and Ferreira (2000a), the continuous use of pre-emergence herbicide reduce the content of organic matter and also cause soil surface crusting formation. This last one, although it is very significant from an environmental point of view, has received little or no attention at all from researchers.

Some changes are observed in soil properties when the surface crust formation occur. Some of the most important are the following: textural (due to the drag of clay particles), soil structure changes (breakage of aggregates by the impact of raindrops), surface roughness and permeability decrease, and bulk density of the superficial layers increase (Darboux and Le Bissonnais, 2007; Bremenfeld et al., 2013; Badorreck et al., 2013; Souza et al., 2014; Sajjadi and Mahmoodabadi, 2015).

Calegari et al. (2006) studied the effect of management systems on soil improvement mainly on the aggregation rates. They observed that in conventional cultivation system - without vegetation cover - leads to higher dispersion of soil particles and also cause decay of the levels of soil organic matter when compared to other treatments, diminishing soil aggregation rates.

The water retention is also altered to formate the crusts. According to Sela et al. (2015), the soil cointains more water when the crusts are present. This fenomenon is linked to a decrease of evaporation due to a physical impediment.

Considering that the surface crusting can cause changes in different soil properties, this study aimed to evaluate the dispersive behavior of colloidal soil fraction and physic-hydric behavior of a Red Latossol cultivated with coffee subjected to weed control with pre-emergence herbicide.

MATERIAL AND METHODS

The study area

The study was conducted in Experimental Station of Agricultural Research Corporation of Minas Gerais - EPAMIG, in the county of São Sebastião do Paraíso-MG, Brazil, approximately 47°07’10’’ W and 20º55’00’’ S, with an altitude of 890 m, average annual rainfall of 1470 mm and a mean annual temperature of 20.8°C, average maximum of 27.6°C and average minimum of 14.1°C.

According to the Brazilian Soil Classification System (EMBRAPA, 2013), the soil studied is as Latossolo Vermelho distroférrico típico, which corresponds to Rhodic Hapludox in Soil Taxonomy (Soil Survey Staff, 2006). The native in a semideciduous forest, transitional to cerrado. The experimental area has an average slope of 8%. Selected physical and chemical properties are provided in Table 1.

Table 1. Physical and chemical caracterization of a Red Latossol at the study site.

Layer	**Sand**	**Silt**	**Clay**	**pH**	**K**	**P**	**Ca**	**Mg**	**Al**	**SB**	**T**	**V**
(cm)	----dag kg^{-1}----				---mg dm^{-3}---		--------------cmol$_c$ dm^{-3}-------------					(%)
0 – 5	28	22	50	6.41	99.33	26.28	5.51	0.93	0.08	5.70	6.80	68.31
5 – 15	27	23	50	6.34	99.11	15.50	4.51	0.95	0.07	6.72	5.78	66.36

Experimental design and layout

The crop was planted in 4 x 1 m spacing, in 1974, with cultivar Catuaí Vermelho LCH 2077-2-5-99. In 2005, due to the decline of the established crop production, it was replaced by Paraíso MG1192 coffee cultivar and changed spacing between coffee plants to 0.7 m. The change operations of cultivars were performed keeping the effect of treatments over the years on between rows. The coffee rows, with 0.8 m wide at the crown projection, were kept clean by means of pre-emergence herbicide, and post-emergence herbicide and manual weeding, to facilitate the application of fertilizers, management coffee and machinery moving. Therefore, the direct effect of the treatments between rows, regardless of Catuaí cultivation for 30 years and Paraíso for seven years, can be considered constant in the soil physic-hydrics characteristics.

The experimental design used in this study was a randomized blocks with three treatments and two layers in nine replications. The soil physic-hydric properties soil subjected to chemical weed control with pre- (PreH) and post-emergence (PstH) herbicides, are confronted with the area maintained no weeding (NW). This treatments were applied in the central part of the lines of each "rows" of the plot, in a range of approximately 1.20 m wide. Each experimental plot consisted of three "streets", encompassing 108 coffee pits.

Weed management

During the conduct of the experiment, all weed control operations have been performed where the growth of the same call. The average number of operations required for satisfactory weed control during each year has varied according to the effectiveness of each method, so keep the weed infestation in satisfactory and consistent way with the conduct of a commercial crop levels.

The number of operations for each details of the weed control methods and description of these methods are as follows: **Post-emergence herbicide** (PstH), initially, we used a mixture of Paraquat [1,1'-dimethyl - 4,4'-bipyridylium ion (dichloride)] and Diquat [1,1'-ethylene - 2.2 bipyridylium ion (dibromide)] at the ratio, respectively, . 200 + 200 gL^{-1} was used subsequently, the mixture was replaced by glyphosate [N - (phosphonomethyl glycine)] at a dosage from 0.72 to 1.44 L.ha^{-1}, depending on the intensity of infestation alternately with a mixture of 2.4 glyphosate + D [2,4 dichlorophenoxyacetic acid], in proportion, respectively, 160 + 120 gL^{-1} and dosage 640g + 480g ha $^{-1}$ a.i. (an average of three applications); **Pre-emergence herbicide** (PreH), was also at the beginning used a mixture of herbicides ametryn (2-ethylamino-4isopropilamino-6-methylthio-s-triazine) + Simazine (2-chloro-4-6-bietilamino-s-triazine), the base, respectively, 1200g + 1200g of active ingredient (ai) .ha^{-1} wettable powder and then makes up new application of this mixture (1125g + 1125g.ha^{-1} a.i.) in liquid formulation with a spray volume 400L.ha^{-1} (an average of two applications), after replacement of the cultiva the oxyfluorfen pre-emergence herbicide was used a base of 3 L ha^{-1} of commercial product, and **No weeding** (NW).

Sample collection, treatments, and data analysis

The soil physic-hydrics characterizations were performed by means of disturbed and undisturbed samples collected on depths of 0-5 and 5-15 cm in installments related to the control of weeds with pre-emergence herbicide and post-emergence herbicide, as well as the portion maintained without control (no weeding). Undisturbed soil samples were collected with a steel cylinder with dimensions of approximately 25 mm high and 50 mm in diameter. In each of the nine plots, the sampling points were randomly defined, forming a total of 18 samples per treatment when including the two depths.

The aggregate stability in water was performed according to Kemper and Rosenau (1986). The mean geometric diameter (DMG) of aggregates, as proposed by Mazurak (1950), was adopted as the aggregate index.

The particle size distribution and the dispersive behavior of colloidal soil fraction were determined through textural analysis, water dispersible clay, and flocculation index, according to Embrapa (1997). In addition to these attributes, the soil electrical conductivity was also measured according to Richards (1954).

The volumetric ring method (Blake and Hartge, 1986) was used to determine the soil bulk density (Bd) and the pycnometer method (Flint and Flint, 2002) to determine soil particle density (Pd). The total porosity (TP) was calculated using the formula $TP = (1-Bd/Pd) \times 100$. The microporosity (Micro) was determined as equivalent to the water content of the sample at a tension of 6 kPa (Oliveira, 1968) in a suction unit composed of Buchner funnels, which promoted the drainage of the sample at different suction heights, emptying the soil pores of a target diameter. The macroporosity (Macro) was calculated as the difference between TP and Micro. For the quantification of the pore size distribution was performed using the equation proposed by Bouma (1973), described in Oliveira et al. (2004): D = σ 4 Cosϴ / Ψm. Where D is the pore diameter (mM); σ is the surface tension of water (0.727 uM bar at 20 ° C); ϴ is the contact angle between the meniscus and the wall of the capillary tube (considered as zero); and Ψm is the matric potential (kPa). The available water capacity (AWC) was determined by the difference between field capacity obtained tension of -6 kPa and the permanent wilting point estimated to -1500 kPa. For the water retention evaluation, undisturbed soil samples were saturated and then subjected to tensions corresponding to -2, -4, -6, and -10 kPa, using the suction unit and to tensions of -33, -100, -500, and -1500 kPa, using the Richards extractor (Klute, 1986). The water retention curves (WRC) were obtained by nonlinear fitting of the volumetric water content values (θ) as a function of soil water tension (kPa) to the model proposed by van Genuchten (1980) with the Mualem constraint [$m = 1 - (1/n)$] using RTEC software (van Genuchten et al., 2009).

It was also determined the organic carbon using the analysis performed by Yeomans and Bremner (1988), with the wet oxidation method and ferrous ammonium sulfate as titrant.

Statistical Analysis

The results of physic-hidric characterization and water retention were subjected to analysis of variance and averages were compared by the Scott–Knott test at 5% probability. SISVAR statistical software (Ferreira, 2011) was used for both procedures. Correlations were performed using SigmaPlot software (SigmaPlot, 2011).

RESULTS AND DISCUSSION

The soil aggregation represented by the geometric mean diameter (GMD) was shown to be influenced by the treatments and layers, and interaction between these factors were also observed. When the control method was the pre-emergence herbicide (PreH) and it was observed the presence of surface crusting in the layer 0-5 cm, this method demonstrated less GMD compared to other treatments and, also, between the two layers evaluated. The treatments with post-emergence herbicide (PstH) and no weeding (NW) were not statistically different from each other (Table 2).

Table 2. Geometric mean diameter (GMD) of aggregates of a Red Latosol subjected to chemical weed control in coffee crop

Treatments	**Layer (cm)**	
	0-5	5-15
PreH	2.97 Bb	4.31 Aa
PstH	4.57 Aa	4.63 Aa
NW	4.64 Aa	4.82 Aa

Averages followed by the same letters, lowercase letters in the rows, and uppercase letters in the columns do not differ by the Scott–Knott test at 5% probability.

The lowest values of GMD for the treatment PreH indicate that the effect of surface crusting in soil aggregation is quite evident on damaging the soil structure, which may explain the decrease in aggregates size on the soil surface by the maintenance of the uncovered soil. This is due to a greater impact of rain drops on the surface of the soil, in which there is a greater breakage of the aggregates, and, moreover, it occurs a detachment of the surface particles and percolation of clay by infiltrating water, causing density increase just below the surface (Badorreck et al., 2013; Fox et al., 2004). A study conducted by Alcântara and Ferreira (2000b) mentions that the continuous use of pre-emergence herbicides adversely influence the quality of the soil, with direct effects on the structure, which can be noted from the lower aggregate stability and the formation of surface crust.

The variables electrical conductivity (EC), water dispersible clay (WDC), and flocculation index (FI) showed significant differences only between treatments and did not differ between layers. Soil organic matter (OM) showed no significant differences between treatments and layers. The EC showed differences between all treatments. Its highest value was the PstH treatment followed by NW, and the lower conductivity was with the application of PreH (Table 3).

Table 3. Eletric conductivity (EC), water dispersible clay (WDC), and floculation index (FI) and soil organic matter (OM) of a Red Latosol subjected to a chemical weed control in coffee crop

Treatments	**EC (µS)**	**WDC (%)**	**FI (%)**	**OM (%)**
PreH	95.12 C	19.93 B	59.92 A	3.04 A
PstH	249.57 A	24.21 A	52.08 B	3.47 A
NW	174.63 B	25.33 A	46.19 B	2.89 A

Averages followed by the same letters in the columns do not differ by the Scott–Knott test at 5% probability.

The PreH application on bare soil adversely influences the electrical conductivity of the soil, and according to experiment conducted by Kim and Miller (1996) it could be observed that increasing the EC the flocculation increases and soil erosion and runoff decrease.

Nguetnkam and Dultz (2014), studying clay dispersion in Oxisols and Utisols in the North of Cameroon concluded that the addition of electrolytes could increase the electrical conductivity (EC) by elevating the ionic strength by compression of the diffuse double layer which has a decisive role in flocculation. This has several practical implications, as for example the careful management of fertilizers through installment causes a considerable ionic strength reduction in the soil solution, and combining this with other practices such as the application of organic matter (OM), it can do much more to enhance the stability of aggregates. In a study by Fox et al. (2009) which correlated soil infiltration of superficial crusts and characteristics such as electric conductivity and clay, they observed that the greater the electrical conductivity of the soil is, the higher is the water infiltration into the soil.

In WDC and FI the use of PreH differed from the other treatments. The presence of a lower WDC can be explained by the physicochemical dispersion of soil clay particles, which migrate into the soil with the infiltrating water and clog the pores immediately beneath the surface (Agassi et al., 1981). According to Brandão et al. (2006), among the most effective variable in the description of the hydraulic resistance behavior of the crust in different soil layers are the water dispersible clay, the flocculation index, the macroporosity of topsoil, and the levels of total silt and sand. Hence, the presence of an higher FI than the other treatments could be lead to a higher hydraulic resistance on the crust layer.

The EC and WDC was only significant different on the PstH to the surface layer, presenting negative correlation. EC and FI showed positive correlation on the PreH and PstH in 0-5 cm, demonstrating the role of conductivity in particles flocculation. The correlation analysis also showed significant and negative correlations between EC and FI when all treatments were compared to this characteristics. It was observed that the treatment PreH showed significant correlation in the properties EC and GMD on the crusting layer (0-5 cm), and the treatment PstH demonstrated the same correlation but for the subsurface layer (Table 4).

Table 4. Pearson correlation between electric conductivity (EC), water dispersible clay (WDC), floculation index (FI), geometric mean diameter (GMD) and organic matter contente (OM) of a Red Latosol subjected to chemical weed control in coffee crop

	Soil Properties					
	WDC					
Layers	-------------0-5 cm------------			-------------5-15 cm------------		
Treatments	PreH	PstH	NW	PreH	PstH	NW
EC	-0.19^{NS}	-0.65*	-0.33^{NS}	-0.50^{NS}	-0.15^{NS}	0.06^{NS}
	FI					
EC	0.44*	0.78*	-0.14^{NS}	0.56^{NS}	0.24^{NS}	-0.31^{NS}
WDC	-0.93**	-0.95**	-0.85**	-0.74*	-0.95**	-0.82**
	GMD					
EC	0.74*	0.06^{NS}	0.07^{NS}	0.50^{NS}	0.71*	-
WDC	-0.06^{NS}	0.20^{NS}	-0.24^{NS}	-0.07^{NS}	-0.27^{NS}	-0.35^{NS}
FI	0.08^{NS}	-0.04^{NS}	0.24^{NS}	0.44^{NS}	0.29^{NS}	-0.03^{NS}
	OM					
EC	0.72*	0.32^{NS}	0.84**	0.08^{NS}	0.73*	0.55^{NS}
WDC	-0.11^{NS}	-0.85*	-0.27^{NS}	-0.10^{NS}	-0.39^{NS}	-0.41^{NS}
FI	0.18^{NS}	0.82**	-0.20^{NS}	0.17^{NS}	0.50^{NS}	-0.07^{NS}
GMD	0.72*	-0.17^{NS}	0.21^{NS}	0.47^{NS}	0.81**	0.37^{NS}

**· * $^{e\ NS}$, significative 1%, 5% and not significative, respectively. The corelation between MGD and EC in no weeding treatment was not observed.

When the OM was compared to the others properties, the EC showed positive correlation to PreH and NW for the surface layer and for PstH in the subsurface layer. Furthermore, this treatment revealed negative correlation with WDC and positive correlation with FI for the surface layer. As for the GMD variable, it presented a positive correlation for PreH and PstH on the surface and subsurface layers, respectively.

Amezketa et al. (2003) mention that even in soils with very similar mineralogy the dispersive behavior tends to be highly variable, which can be explained by other properties such as the organic matter content and fertilizers applied on the culture which changes the concentration of electrolytes. This effect was observed by Reichert (1993) when they evaluated the electric conductivity in the dispersive characteristics of the soil, demonstrating that the higher electrical conductivity and dispersion of the smaller soil particles causes an improvement in the soil aggregation state.

The properties linked to porosity of the soil was influenced by the treatment and layers (Table 5).

Table 5. Bulk density (Bd), total pore volume (TPV), microporosity (Micro) and macroporosity (Macro) of a Red Latosol subjected a chemical weed control in coffee crop

Treatments	**Bd**	**TPV**	**Micro**	**Macro**
	Mg dm^{-3}	------------------------ (%)		---------------------
		------------ Layer 0 – 5 cm --------------		
PreH	1.26 Aa	0.59 Ab	0.38 Aa	0.21 Aa
PstH	1.20 Aa	0.60 Ab	0.37 Aa	0.23 Ab
NW	1.17 Aa	0.62 Ab	0.37 Aa	0.25 Ab
		------------ Layer 5 – 15 cm --------------		
PreH	1.18 Ab	0.62 Ba	0.38 Aa	0.24 Ca
PstH	1.10 Bb	0.64 Ba	0.35 Bb	0.29 Ba
NW	0.96 Cb	0.66 Aa	0.32 Cb	0.34 Aa

Averages followed by the same letters, lowercase letters between layers and uppercase letters in each layer, both within the columns, do not differ by the Scott Knott test at 5% probability.

In all treatments, it was found that the depth of 0-5 cm compared to the 5-15 cm layer showed higher bulk density, lower total porosity, and decreasing macroporosity of soil. The surface layers were more affected by soil management, being more susceptible to surface crusting and compaction processes.

As pointed out by Alcantara and Ferreira (2000), the weed control is usually performed during the rainy season of the year when the soil has more moisture, favoring the process of soil compaction (Pais et al., 2011). The permanent control of weeds with pre-emergence herbicides let the soil surface uncovered and exposed to agents such as impact of raindrops and wetting and drying cycles, which contribute to the formation of the surface crusting (Araújo Junior et al. 2011; Pais et al, 2011).

In the depth of 5-15cm, the soil under pre-emergence herbicide application showed higher bulk density values, and correspondingly smaller values of macroporosity and higher microporosity in the soil. According to Araújo Junior et al. (2011), which evaluated the influence of adopting different management of invasive plants in the porous system and water holding capacity in a Red Latosol, concluded that the management of the soil can transform part of the macroporosity in microporosity. This can also be explained by the increase density that occurs once the clay is transported with the infiltrating water, causing clogging of the pores (Fox, 2004). The higher values of Bd and micropores for the subsurface layer were also observed by Jakab et al. (2013) in soils with sealing and crusting in Hungary. They found higher values for the crusted soil in relation to a soil with cover. This phenomenon can be considered beneficial to the availability of water for plants in these soils with lower distribution of interim pores and low water storage capacity (Oliveira et al., 2004).

Higher TPV was observed in the NW treatment and on the subsurface layer when compared to the surface. This increase can be explained by the presence of weed plants on area. Weed plants with aggressive radicular systems can assist in soil recuperation by increasing the macroporosity, total porosity, and hydraulic conductivity (Reinert et al., 2008). Macroporosity diminished remarkably on crusted soil. However, according to Usón and Pott (2000) the effects of tillage and management practices on the morphology of soil crust under a Mediterranean environment could not be observed in the decrease of the porosity, but the pores were less interconnected.

The pore size distribution identified the intensity of structural changes introduced by soil management (Table 6).

Table 6. Pore size distribution (μm) of a Red Latosol subjected a chemical weed control in coffee crop

Treatments	**>145**	**145-73**	**73.43-49**	**49-29**	**29-9.0**	**9.0-2.9**	**2.9-0.6**	**0.6-0.2**	**<0.2**
					---------m^3 m^{-3}---------				
PreH	0.13c	0.06a	0.03a	0.02b	0.06a	0.02a	0.02a	0.02a	0.22a
PstH	0.17b	0.05a	0.03a	0.03b	0.05a	0.02a	0.01b	0.01b	0.22a
NW	0.22a	0.06a	0.02a	0.05a	0.02b	0.01a	0.005c	0.007c	0.23a

Averages followed by the same letter in columns within each layer, do not differ by the Scott Knott test at 5% probability.

It was found that the management of the soil with pre-emergence herbicide caused a reduction of the quantity of pores of diameter greater than 145 μm (soil macropores) and the consequent increase of the smaller diameter classes, 2.9-0.6 and 0.6-0.2 μm.

The high pore volume of the larger class (145 μm) found in the management with NW may be related to the increased root mass provided by vegetation and possible channels (biopores), resulted from the decomposition and renewal of those roots (Lima et al, 2012;. Araújo Júnior et al 2011) combined with intense biological mesofauna activity, the organic carbon content, the accumulation of materials, and the good aggregation properties (Table 2). These results corroborate with Araujo Junior et al. (2008) and Pais et al. (2011), who demonstrated in their works with coffee crops that the preservation of the covered lines have beneficial effect on the root system of the weeds in the recovery of the soil structure as well as the protection of the soil from erosion, conserving soil moisture and contributing to system sustainability.

Moreover, considering that the water in macropores is easily drained, these pores play an important environmental role in contributing to groundwater recharge. Therefore, management practices that cause a reduction in the volume of these pores, as observed in the handling with pre-emergence herbicide (Table 6), may contribute to the reduction of water losses.

When the available water capacity was evaluated, no differences were observed on the treatment surface layers, but in the subsurface and between layers in each treatment some differences was shown (Table 7). The use of PreH caused the highest available water capacity values in the second layer in relation to the other treatments, while the use of PstH presented the intermediate and NW the lowest values.

Table 7. Available water capacity (AWC) of a Red Latosol subjected a chemical weed control in coffee crop

Treatments	**AWC (m^3 m^{-3})**	
	---0-5 cm---	---5-15 cm---
PreH	0.14Ab	0.16Aa
PstH	0.13Aa	0.13Ba
NW	0.13Aa	0.09Cb

Averages followed by the same letters, lowercase letters in the rows and uppercase letters in the columns, do not differ by the Scott–Knott test at 5% probability.

The AWC values were calculated to provide a better idea of the dynamics and availability of water for the crops (Klein e Libardi, 2000). It can be inferred from the results that the soil with the presence of crusting shows greater available water capacity.

Figure 1 shows the retention curves of the 0-5 cm layer adjusted according to Van Genuchten (1980).

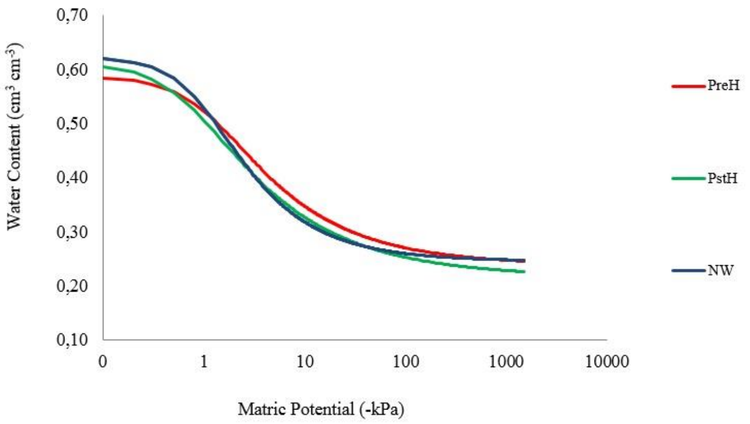

Figure 1. Water retention curves to the layer of 0-5 cm of a Red Latosol submitted to chemical weed control methods in the cultivation of coffee.

Similarly to what happened with the physical attributes, differences in water retention regarding different control methods in the 5-15 cm layer were almost exclusively observed. On the subsurface layer, a higher water content was found to the PreH treatment up to the tension of -10 kPa. This increased water content on PreH treatment reflects the higher micropore content found in that treatment (Table 5).

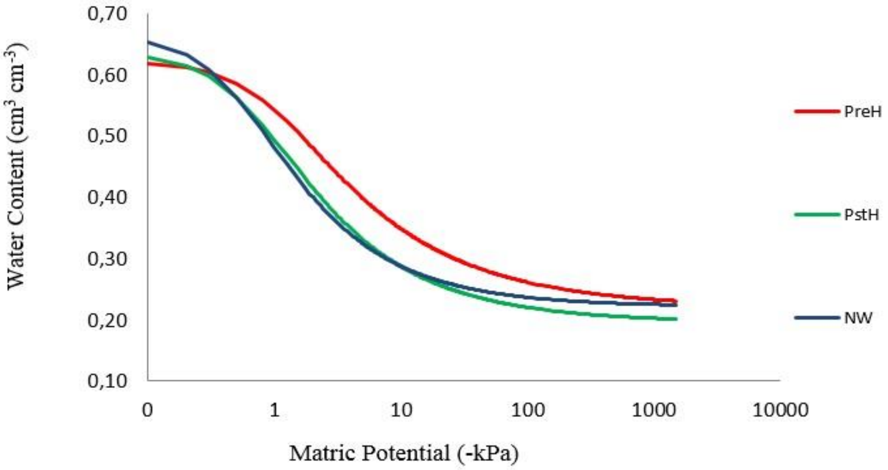

Figure 2. Water retention curves to the layer of 5-15 cm of an Red Latosol submitted to chemical weed control methods in the cultivation of coffee.

The different soil management systems affect the shape of the Red Latosol water retention curves (Figures 1 and 2). It was established a descending order of water retention to the Ψ -6 kPa with NW> post-emergence herbicide> pre-emergence herbicide, and these results are related to the soil physical quality in each of these environments (Tables 5 and 6), since this range is dominated by capillary phenomena that depend on soil structure (Ferreira and Dias Junior 2001). To the Ψ of -1500 kPa, the crust soil presents a higher water retention that can be explained by the higher volume of micropores in this layer which difficult the output of water from systems that have more negative pressures. Besides, the physical barrier formed by the crust avoid water losses by evaporation.

The importance of water content in soils with crusting is emphasized by Sela et al. (2015), which evaluated the effect of surface sealing in water absorption by plants in dry periods. They found out that the surface sealing can increase or decrease the absorption of water by plants, and this fact is dependent on the initial water content in the soil, rain intensity, and duration of dried intervals. In addition, there is a decrease of the plant hydric stress during the dry period of up to 31% on the soil with the presence of crusting compared to no crusting ones. Another factor that can influence the water retention is the presence of microbiotic crusts that act as physic crusts, retarding the evaporation and prolonging water retention in the soil (Liu et al., 2007).

These results alternate perspectives. On the one hand, there is a soil degradation and increased erosion to an equilibrium crust, and, on the other hand, one can obtain higher yields in coffee crop from a greater water holding capacity.

CONCLUSIONS

- The crust surface formation influence physic-hydric behavior on an Red Latossol subjected to chemical weed control methods in coffee crop.

- The management of soil pre emergence herbicide, due to the formation of surface crusting, caused a reduction of the volume of pores of diameter greater than 145 μm class, negatively affecting processes in the drainage and aeration of the soil.

- Most available water capacity for encrusted soil in subsurface layer denotes a potential to retain more water than the other evaluated treatments.

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