Int. Agrophys., 2017, 31, 393-400
doi: 10.1515/intag-2016-0066

Least limiting water range of Udox soil under degraded pastures on different sun-exposed faces

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Received October 4, 2016; accepted June 19, 2017

Abstract. 7KH HI¿FLHQW XVH RI ZDWHU
WDQW DQG SURSHU VRLO PDQDJHPHQW
UHJLRQ RI WKH FRXQWU\ DOORZV
South and Caparaó regions of Espírito Santo, Brazil are charac-
WHUL]HG E\ UHOLHI RI µKLOO VHDV¶
pasture degradation due to sun exposure. The objective of this
VWXG\ ZDV WR HYDOXDWH WKH OHDVW OLPLWLQJ ZDWHU UDQJH LQ 8GR[VRLO
XQGHU GHJUDGHG SDVWXUHV ZLWK WZR IDFHV RI H[SRVXUH WR WKH VXQ
and three pedoenvironments. In each pedoenvironment - name-
O\ $OHJUH &HOLQD DQG &DIp WZR DUHDV ZHUH VHOHFWHG RQH ZLWK
exposure on the North/West face and the other on the South/
(DVW IDFH ,Q HDFK RI WKHVH DUHDV XQGLVWXUEHG VRLO VDPSOHV ZHUH
FROOHFWHG DW FP GHSWK WR GHWHUPLQH WKH OHDVW OLPLWLQJ ZDWHU
range. The exposed face of the pasture that received the highest
VRODU LQFLGHQFH 1RUWK :HVW SUHVHQWHG WKH ORZHVW YDOXHV LQ OHDVW
OLPLWLQJ ZDWHU UDQJH 7KH OHDVW OLPLWLQJ ZDWHU UDQJH SURYHG WR EH
a physical quality indicator for Udox soil under degraded pastures.

. H \ Z R U G V: soil quality, degraded soils, soil physics

INTRODUCTION

The current decade, eventually ZLOO EH PDUNHG E\ WKH ZDWHU FULVLV DQG WKH HI¿FLHQW XVH RI ZDWHU ZLOO EHFRPH increasingly important. In such scenario, the soil plays a major role, being a part of the hydrological cycle and constituting the sphere capable of management. In this sense, WKH HI¿FLHQW PDQDJHPHQW RI WKH VRLO JLYHQ WKH SDUWLFXODUL-ties of each region of the country, is fundamental for the sustainability of agriculture.

In the South and Caparaó regions of the State of Espírito QDQWR 6(\$ *WKH VSHFL¿F ZKHUH WKH ZDWHUFRXUVH RI WKH River is located, problems related to pasture degradation are critical due to natural factors and the anthropic performance. The region is also characterized by relief of hill seas - a geomorphological aspect described by Ab'saber (1970) - that generates another conditioning factor, exposure to the VXQ ZKLFK LQÀXHQFHV WKH EHKDYLRU RI WKH degradation state.

7KH YLVXDOO\ REVHUYHG GLVFUHSD of exposure are, amongst multiple factors, due to the indirect effects of the interception of the solar rays, effects ZKLFK DUH YDULDEOH GHSHQGLQJ RQ and the translation and rotation movements of the Earth. In the southern hemisphere, the north-facing slopes tend to receive higher incidence than those facing the South (Ferreira et al., 2005).

On a local scale, incident solar radiation is strongly LQÀXHQFHG E\ WRSRJUDSK\ PDLQO\ shape of the terrain, slope, and orientation of the face of exposure. Consequently, variations in soil temperature, HQHUJ\ EDODQFH DQG VRODU UDGLDWLRQ of soil physical factors (in addition to chemical and biological factors) and, as a result, play a role in conditioning SODQW GHYHORSPHQW /HWH\ Z atmosphere system. Thus, the interaction of these three components, among other factors, may have an impact on the soil structure.

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Changes in the soil structure lead to changes in the pore space architecture available for root development, aeration, DQG ZDWHU DYDLODELOLW\ WR WKH SODQWV LQ DGGLWLRQ WR LQGX ing changes in soil resistance to root penetration in regards to both space and time (Moreira et al., 2014; Tormena et al. 7KHUH LV WKHUHIRUH D FRPSOH[OLQN EHWZHHQ VRLO structure, daily and annual solar radiation regimes, and SODQW GHYHORSPHQW WKDW UHAHFW HIIHFWV RQ WKH SK\VLFDO TXD lity of cultivated soils.

Different determinations and indices have been used to evaluate the physical quality of cultivated soils, among ZKLFK WKH OHDVW OLPLWLQJ ZDWHU UDQJH //:5 LV KLJKOLJKW HG 7KH //:5 LQWHJUDWHV HIIHFWV RI ZDWHU SRWHQWLDO RQ VRLO mechanical resistance to root penetration, and soil porosity adequate to the diffusion of oxygen to the roots as a function of soil density for samples representing a given area (Silva et al. 7KLV LQGH[KDV DOVR VKRZQ VWURQJ sensitivity to soil structural indexes such as soil density and UHODWLYH GHQVLW\ DV ZHOO DV SHGRWUDQVIHU PRGHOV WR FKDUDFWHUL]H ZDWHU DYDLODELOLW\ et al., 2011).

The LLWR has been used as a tool to indicate the limitations and potentialities of soil physical conditions to plant development, including in pastures (Leão et al., 2004; Lima et al. DQG LQ FRPSDULVRQV EHWZHHQ SDVWXUHV and other land uses (Lima et al., 2009). It is also effective as an indicator of changes in the structure of latosols (Lima et al., 2012; Severiano et al. ZKLFK EHVW WUDQVODWHV physical edaphic quality to plants (Tormena et al., 2007).

7KXV WKH REMHFWLYH RI WKLV ZRUN ZDV WR HYDOXDWH WKH DOWHUDWLRQV RI WKH OHDVW OLPLWLQJ ZDWHU UDQJH RI ODWRVROV under degraded pastures in three pedoenvironment and WZR IDFHV RI H[SRVXUH WR WKH VXQ LQ WKH ZDWHUVKHG RI WKH Alegre river.

MATERIAL AND METHODS

7KH VWXG\ DUHD LV ORFDWHG LQ WKH DUHDV GH¿QHG LQ PEDEAG as South and Caparaó in the State of Espírito 6DQWR ± %UD]LO 6($* ,Q WKLV UHJLRQ VWXGLHV ZHUH carried out in the sub-basin of the Alegre River, located in WKH FLW\ RI $OHJUH (6 DQG LQVHUWHG LQ WKH ZDWHUVKHG RI WKH Itapemirim river. In this sub-basin, according to the predominance of the relief aspect, three pedoenvironment ZHUH VHSDUDWHG

– SHGRHQYLURQPHQW $OHJUH GHOLPLWHG EHWZHHQ DQG 400 m of altitude;
– SHGRHQYLURQPHQW &HOLQD GHOLPLWHG EHWZHHQ DQG 700 m altitude; and
– SHGRHQYLURQPHQW &DIp GHOLPLWHG EHWZHHQ DQG P DOWLWXGH ,Q HDFK SHGRHQYLURQPHQW DUHDV ZLWK GHJUDGHG EUDFKLDULD SDVWXUH ZHUH VHOHFWHG LQ DQG WZR GLVWLQFW IDFHV RI H[SRVXUH WR WKH VXQ and South/East.

In each pedoenvironment and face of exposure to the VXQ WKLUW\ XQGLVWXUEHG VRLO VDP lumetric ring at 0-10 cm depth using a Uhland type sampler ZLWK WKUHH UHSOLFDWHV

7KH YROXPHWULF θ ZDWHU FRQWHQW the -4, -6, -8, -10, -30, -50, -70, -100, -500, and 1500 kPa PDWUL[SRWHQWLDOV WR HVWDEOLVK (SWRC), using three undisturbed soil samples for each SRWHQWLDO ,PPHGLDWHO\ DIWHU UH the pressure plates extractor WKH VDPSOHV ZHUH and submitted to static laboratory penetrograph to establish a curve for resistance of soil to penentration (CRP). The penetrograph (Marconi MA 933) is composed of a linear HOHFWULF DFWXDWRU ZLWK VWHSSHU VSHHG DQG GLUHFWLRQ RI WUDYHO D nal capacity of 20 kg coupled to the end of the mechanical DUP RI WKH DFWXDWRU ,W DOVR KDV RI PP DQG WKH HQG KDV D FRQH WKD the soil resistance to penetration. The penetration velocity at 1 cm depth 7KH VDPSOHV ZHUH WKHQ GULHG L for 24 h to obtain soil moisture and soil density (Bd). 7KH WRWDO SRURVLW\ 7S ZDV FDOFX Tp = 1-Bd 3G ZKHUH WKH PHDQ YDOXH VLW\ 3G ZDV REWDLQHG E\ WKH YRO (EMBRAPA, 2011).

The physical characterization of the soil samples of the different pedoenvironments and faces of exposure to the sun consisted of granulometric analysis and determination of total porosity, macroporosity, and microporosity (EMBRAPA, 2011) (Table 1).

To obtain the LLWR, the results obtained from SWRC DQG &53 ZHUH FRQVLGHUHG 7KH 6:5& adjusting the values of θ as a function of soil matrix potential (Ψ), according to Silva et al. (1994) as described by Eq. (1):

$$\theta = a\Psi^{b} Bd^{c}, \quad (1)$$

ZKHUH θ LV WKH YROXPHWULF ZDWHU FRQ ($m^3\ m^{-3}$), Ψ is the soil matrix potential (kPa), Bd is the soil density (Mg m^{-3}); and a, b, and c ZHUH WKH PRGHO DGMXVWP (Table 2).

7KH &53 ZDV DGMXVWHG WR QRQOLQ tion of Bd (Busscher, 1990; Silva et al., 1994), according to Eq. (2):

$$PR = d\,\theta^{e} Bd^{f}, \quad (2)$$

ZKHUH PR is the resistance to penetration (kPa), θ the YROXPHWULF ZDWHU FRQWHQW ($m^3\ m^{-3}$), Bd the soil density (Mg m^{-3}); and d, e, and f are the adjustment parameters of the equation (Table 2).

7KH //:5 ZDV GHWHUPLQHG E\ DGRSW described by both Silva et al. (1994) and Tormena et al. (1998), modifying the limit of soil mechanical resistance to SHQHWUDWLRQ 7KH FULWLFDO ZDWHU FRQWHQWV WHG ZLWK WKH PDWULF SRWHQWLDO

T a b l e 1. Physical characterization of soil of pedoenvironments Alegre, Café and Celina, for the East/South (E/S) and North/West (N/W) sun exposure faces

Characteristic	Unit	Alegre		Café		Celina	
		E/S	N/W	E/S	N/W	E/S	N/W
Clay	(kg kg^{-1})	0.463	0.370	0.320	0.380	0.537	0.523
Silt	(kg kg^{-1})	0.103	0.153	0.107	0.070	0.117	0.117
Coarse sand	(kg kg^{-1})	0.317	0.347	0.470	0.377	0.253	0.250
Fine sand	(kg kg^{-1})	0.117	0.130	0.103	0.173	0.093	0.110
Total porosity	(m^3 m^{-3})	0.418	0.381	0.361	0.446	0.479	0.455
Macroporosity	(m^3 m^{-3})	0.060	0.012	0.022	0.087	0.034	0.043
Microporosity	(m^3 m^{-3})	0.358	0.369	0.339	0.359	0.445	0.412
Ground declivity	(%)	25	45	28	38	28	27

T a b l e 2. Linear regression parameters estimates for soil resistance to penetration (PR, 0 3 D D V D I X Q F W L R Q R I W K H Y content (θ, m^3 m^{-3}) and soil density (Bd, Mg m^{-3} D Q G I R U W K H V R O X P H W U L F Z D W H U F R Q W H Q W (θ, m^3 m^{-3}) as a function of soil density (Bd, Mg m^{-3}) and matric potential (Ψ, MPa)

Pedoenvironment		PR = d θ^e Bd^f			R^2	$\theta = a\ \Psi^b$ Bd^c			R^2
		d	e	f		a	b	c	
Alegre	E/S	0.107	-1.400	4.830	0.50	-1.884	0.369	-0.057	0.60
Alegre	N/W	0.343	-1.185	2.188	0.41	-1.011	-0.210	-0.070	0.71
Café	E/S	0.029	-1.756	5.693	0.56	-1.279	-0.180	-0.075	0.64
Café	N/W	0.005	-2.653	8.504	0.70	-2.927	0.975	-0.088	0.84
Celina	E/S	0.177	-2.46	1.170	0.49	-1.857	0.566	-0.065	0.91
Celina	N/W	0.112	-2.044	4.125	0.75	-1.740	0.305	-0.082	0.88

DQG DHUDWLRQ SRURVLW\ ZHUH ¿HOG FDSDFLW\ (θ_{FC}) ZDV HVWLPDWHG ZDWHU WLDO RI N3D WKH PRLVWXUH (θ_{PWP}) RU ZDWHU FRQWHQW DW 3 D WKH SHUPDQHQW limit of the mechanical resistance of soil penetration (θ_{PR}) RU WKH ZDWHU FRQWHQW ZKHUH WKH SHQHWUDWLRQ UHVLVWDQFH reaches a value of 3.0 MPa – value chosen based on the ZRUN RI /LSLHF DQG +DNDQVVRQ FRQWHQW LQ ZKLFK (θ_{AP}) is 0.10 m^3 m^{-3} DHUDWLRQ SRURVLW\ (AP), corresponding to 10% of the total porosity.

7KH XSSHU OLPLWV RI WKH //:5 ZHUH GH¿QHG DFFRUG- ing to the θ_{FC}, or θ_{AP} ZKHQ SHUWLQHQW DQG LV FRQVLGHUHG DGHTXDWH IRU WKH JURZWK DQG GHYHORSPHQW RI (0.10 m^3 m^{-3}) RU WKH ORZHU OLPLWV (θ_{PWP}, or for situations corresponding to the θ_{PR} LV OLPLWLQJ WKH ORSPHQW RI WKH SODQWV ZHUH the adopted critical level (3.0 MPa). The critical soil den-

sity (Bdc) LV SHFLILFDOO\ FRUUHVSRQGV WR WKH the LLWR is equal to zero and there is an intersection of the XSSHU DQG ORZHU OLPLWV 8/ DQG // et al. ZDV REWDLQHG E\ WKH ([FHO using the algorithm proposed by Leão and Silva (2004). Using excel, equations that relate the variables θ_{FC}, θ_{PWP}, θ_{AP}, and θ_{PR} ZLWK Bd ZHUH GHYHORSHG DV D WKH FHOO ZLWK Bd that is optimized to the value of Bdc $QRWKHU FHOO ZLWK WKH 8/ ± // needed to be created. Using the solver causes the target cell WR EHFRPH WKH FHOO ZLWK WKH YDO RSWLPL]DWLRQ LV FRQVLGHUHG DQG WKH µFH WKHQWV RI WKH FHOO Bd. The solver also adds a restriction relative to the cell resulting from UL – LL that prevents it from being less than zero and ensures that the Bdc ZLOO EH HTXDO WR WKH YDOXH RI Bd (Leão and Silva, 2004).

RESULTS AND DISCUSSION

$V WKH GHQVLW\ RI WKH 8GR[VRLO LQFUHDVHG WKHUH ZDV also an increase in the PR values and reduction of aera-WLRQ SRURVLW\ )LJ 6LPLODU EHKDYLRU ZDV REVHUYHG E\ both Silva et al. ZRUNLQJ ZLWK VLOW\ VRLO 86'$ VRLO WH[WXUH FODVVL¿FDWLRQ IURP &DQDGD DQG Tormena et al. (1998) in a Oxisoil under no-tillage. The soil solids approach to the same volume, a phenomenon that results in increased soil density, is caused by animal trampling (Tarrá et al., 2010), the passage of implements (Tormena et al., 1998), or even pedogenesis (Dantas et al., ZKLFK GLUHFWO\ LQÀXHQFHV WKH of soil pore volume and soil resistance to root penetration (Silva et al. 2006).

It is expected that as the soil density increases, the values of resistance to root penetration increase and the pore VSDFH ZLOO EH DOWHUHG HVSHFLDOO\ WKDW DUH UHVSRQVLEOH IRU WKH GU in the soil. Silva et al. (2006) also observed there is a nega-WLYH FRUUHODWLRQ EHWZHHQ PDFUR

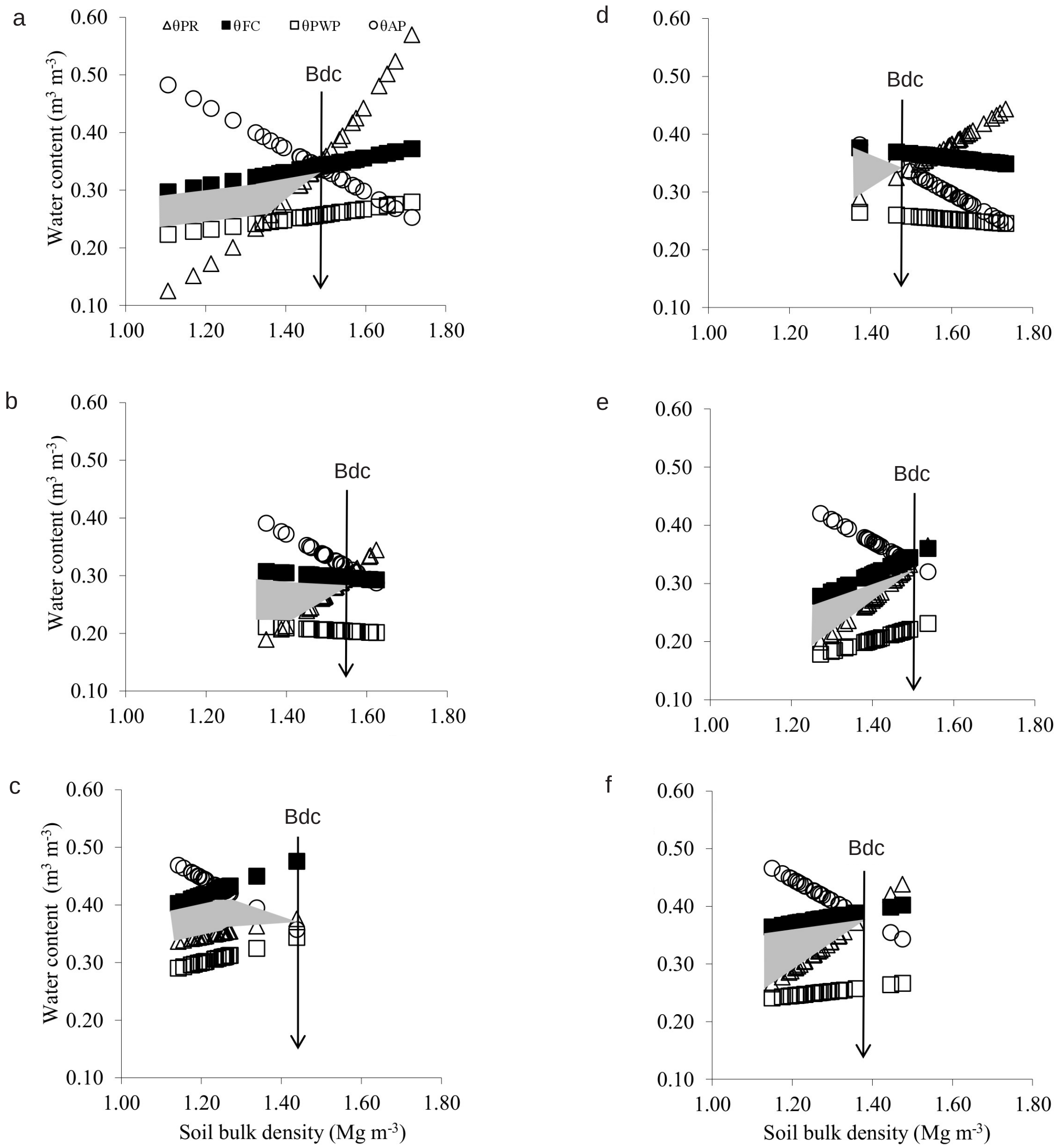

Fig. 1. :DWHU FRQWHQW YDULDWLRQ ZLWK VRLO GHQVLW\ DW FDSLOODU\ 0 3D FULWLFDO ZLOWLQJ SRLQW -1.5 MPa, aeration porosity (AP) of 10% and penetration resistance (PR) of 3.0 MPa for pedoenvironments: a – Alegre, South/East face; b – Café, South/East face; c – Celina, South/East face; d – Alegre, North/West face; e – Café, North/West face, and f – Celina, North/West face. Bdc – soil critical density. The grey areas represents the LLWR.

and soil penetration resistance. Given the proximity of the soil particles and aggregates and the reduction of available VSDFH IRU ERWK URRW JURZWK VROLGV DV D UHVSRQVH WR URRW WKH JURZWK RI XQGHUJURXQG S

The northern facing slopes in the southern hemisphere tend to receive higher irradiance than those facing the South. Thus, considering the same type of soil on the North IDFH LW LV H[SHFWHG WKDW WK more intense, and the soil cover, microbial activity, and RUJDQLF PDWWHU DFFXPXODWL WHQWV DUH ORZHU DQG VRLO V also discussed by Chagas et al. (2013). Consequently, slope soils facing the North/West tend to be less physically unfavorable for the development and productivity of plants than those of the South/East face, especially for the surface lay- HUV 7KH FXUUHQW VWXG\ UHDI LLWR for the 0-10 cm layer in all the pedoenvironments.

In the Alegre pedoenvironment, the left shift and nar- URZLQJ //:5 FOHDUO\ GHPRQVW physical conditions on the North/West face (Fig. 1). In the RWKHU SHGRHQYLURQPHQWV URZLQJ RI WKH //:5V LQ VXFK D Z of Bd on the North/West face suggest more restricted conditions for the development of plants. Above 1.52 Mg m^{-3} for Café and 1.38 Mg m^{-3} IRU &HOLQD UHJD content, soil physical conditions are not favorable to plants. Differently, on the South/East face of exposure, conditions are still favorable under values of Bd close to 1.55 Mg m^{-3} in the Café and 1.44 Mg m^{-3} in Celina. In the Celina pedoenvironment, this difference is even more pronounced. Physical FRQGLWLRQV DUH Bd varying from 1.38 to 1.44 Mg m^{-3} GHSHQGLQJ RQ VRLO ZD (DVW VLGH Bd values are already limiting to the development of plants on the North/West face. On the other hand, the soils on the South/East face may present slightly higher values of Bd, yet the physical conditions may be favorable to the plants.

In the Alegre pedoenvironment on the South/East face)LJ D WKH ORZHU OLPLW RI the moisture θ_{PWP} to the PR for the values of Bd > 1.32 Mg m^{-3} 7KLV PHDQV WK Bd values, PR becomes D SUREOHP RQO\ LQ YHU\ ORZ ZD OLPLWLQJ IDFWRU IRU SODQW available to the plants. In relation to the upper limit of the LLWR on the South/East face (Fig. 1a), θ_{AP} replaces the humidity θ_{FC} for values of Bd > critical soil density (Bdc), as in the case of values greater than 1.47 Mg m^{-3}. Thus, for values of Bd <1.47 Mg m^{-3} WKH SDVWXUH its development limited by the reduced diffusion of oxy- JHQ LQ WKH VRLO 7KLV ZLOO R TXLWH KLJK ¿OOLQJ PRUH WKDQ VRLO 2Q WKH 1RUWK :HVW IDFH Bd presented a value of 1.48 Mg m^{-3}, the θ_{AP} ZDV WKH XSSH LLWR for values of Bd > 1.35 Mg m^{-3}, demonstrating the LPSRUWDQFH RI ZDWHU UHWHQWLRQ D also be noted that in the Alegre pedoenvironment on this face, 93.3% of the samples presented the PR equal to zero.

When examining the soil of the Café pedoenvironment (DVW IDFH LW FDQ E limit of the LLWR is determined by the θ_{FC} for the entire range of Bd ZKHUH WKH //:5 KDV D YDOXH JU)LJ E ,W LV DOVR VKRZQ WKDW IRU Bd > 1.40 Mg m^{-3}, WKH ORZHU OLPLW θ_{PWP} and passes becomes the PR. During this time, the LLWR reduces drastically to the Bd of the soil. In the North/West face, the Bd Mg m^{-3} comparison to the South/East face.

In the Celina pedoenvironment on the South/East face, WKH ORZHU OLPLW RI WKH PR across the Bd range (Fig. 1c). At the upper limit, the θ_{AP} replaces the θ_{FC} for values of Bd > 1.25 Mg m^{-3}. On the North/West face (Fig. 1f), θ_{AP} constitutes the upper limit of the LLWR for values of Bd > 1.35 Mg m^{-3}. The critical soil density (Bdc) for the South/East face is 1.44 Mg m^{-3} (Fig. 1c), and for the North/West face, it is 1.38 Mg m^{-3} (Fig. 1f). West faces of exposure of all evaluated pedoenvironments ZDV GH¿QHG This demonstrates that for areas that receive higher solar incidence, the PR starts to assume an UROH LQ WKH ORZ SRWHQWLDOV ,W LV LPSRUWDQW UHGXFH ZLWK LQFUHDVHG VRLO PRLV HIIHFW RI WKH ZDWHU ZKLFK UHGXFH the particles in the soil matrix. On the other hand, the approximation of the solid particles of the soil, by means of compaction, raises the values of mass in a similar volume, (Vepraskas, 1984) and, thus, results in greater resistance of WKH VRLO WR WKH SHQHWUDWLRQ RI U determined by the PR on the South/East faces of the Alegre DQG &DIp SHGRHQYLURQPHQWV Bd. In the Celina pedoenvironment, the PR ZDV WKH ORZHU OL both faces, possibly due to the greater interference of the animal activity in pastures (bovine trampling). This due to its greater susceptibility to compaction because it has high clay contents compared to other areas (Table 1).

values of 1.35 and 1.25 Mg m^{-3} for the soils on the South/East face in the Alegre and Celina pedoenvironments, respectively (Fig. 2). Tormena et al. (1998) and Severiano et al. REVHUYHG VLPLODU- EHKDY LQJ ZLWK FOD\ WH[WXUHG 2[LVROV 7KLV EHKDYL by the occurrence of the granular structure for oxidic soils, increasing the porous aeration space (Severiano et al. by the approximation and rearrangement of the solid SDUWLFOHV ZKLFK DOORZV WKH GHY

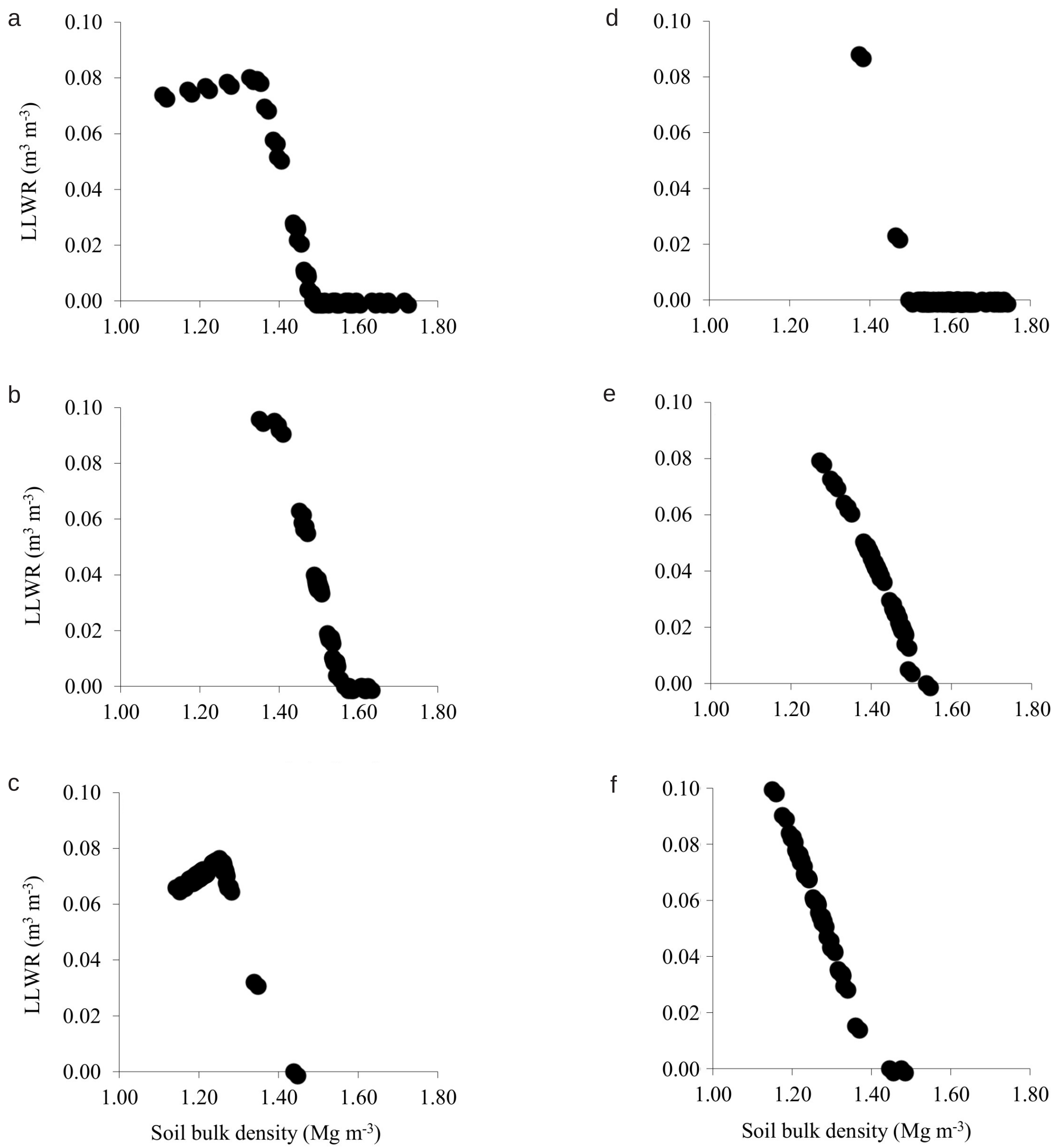

Fig. 2. 9DULDWLRQ RI OHDVW OLPLWLQJ ZDWHU UDQJH GHSHQGLQJ RQ VRLO GHQV South/East face; c – Celina, South/East face; d – Alegre, North/West face; e – Café, North/West face and f – Celina, North/West face.

pores to the detriment of larger diameter pores (such as porous aeration space). This increases θ retained at higher tensions, replacing pre-existing aeration porosity. It should be emphasized that if the proximity of the soil solid phase results in a minimum or limit of porous space, ZKLFK WHQGV WR RFFXU XQGHU VHTXHQFHV ZRXOG EH FRQWUDU\ SRUH YROXPH WKHUH ZRXOG EH RI ZDWHU D SURFHVV WKDW H[SODLQV to higher values of soil density at certain limits observed for this attribute.

The LLWR of the soil in the Café pedoenvironment for the South/East face did not vary until the Bd of 1.40 Mg m^{-3} $W WKLV YDOXH WKHUH ZDV LLWR, resulting in zero from values of Bd ≥ 0J P RQZDUG FRUUHVSRQGLQJ WR (Fig. 2b). The importance of LLWR in relation to the face of exposure of higher solar incidence (North/West) FDQ EH YHUL¿HG LQ)LJ G H DQG I LQ ZKLFK D UHGXFWLRQ RI WKH LV QRWHG RI ZDWHU LQ WKH VRLO LV UHGXFHG density of the soil increases, being 93.3% for the samples. In the case of the Alegre pedoenvironment, the LLWR presented equal to zero Bd ≥ 1.48 Mg m^{-3} (Fig. 2d).

)URP WKH FOLPDWLF SRLQW -R er solar incidence, promoted by the position of the slopes LQ WKH ODQGVFDSH JHQHUDWHV by evapotranspiration and reduces the development of JUDVVHV ,I ZDWHU UHTXLUHPHQWV be an increase in soil resistance to root penetration due to ORZHU VRLO PRL et al., 2011). Consequently, there is a reduction in both root and shoot development of grasses (Masle and Passioura, 1987). Without proper root development, the system loses the potential to produce biopores in the soil (Magalhães et al., 2009; Severiano et al., 2010; Calonego et al., 2011; Lima et al., 2012) and provide organic material (Fidalski et al. ZKLFK DUH important phenomena for the development and improvement of soil structure and physical quality (Andrade et al., 2009), including deep layers (Calonego et al., 2011). Works such as that of Leão et al. (2004), Lima et al. (2012), and Flávio Neto et al. (2015) emphasize the importance of adequate management of pastures and their effects under the conditions necessary for plant development in the LLWR available to the plants.

CONCLUSIONS

7KH OHDVW OLPLWLQJ ZDWHU UDQJH IRU WKH VRLO LV LQÀXHQFHG by the face of exposure to the sun. The face of exposure that receives the highest incident solar radiation (North/West) SUHVHQWHG ORZHU YDOXHV IRU WKH OHDVW OLPLWLQJ ZDWHU UDQJH /RZHU DOWLWXGH SHGRHQYLURQPHQWV OLNH WKH $OHJUH pedoenvironment, tend to suffer greater effects on the degradation of pastures, mainly due to the consequent effect of higher temperatures.

7KH OHDVW OLPLWLQJ ZDWHU UDQJH ZDV VKRZQ WR EH a sensitive indicator of physical quality of Oxisols under degraded pastures.

Conflict of interest: The Authors do not declare conÀLFW RI LQWHUHVW

REFERENCES

Ab'saber A.N., 1970. Geological provinces and morphoclimatic domains in Brazil (in Portuguese). Geomorfologia, 20, 1-26.

Andrade R.S., Stone L.F., and Silveira P.M., 2009. Cover crops and physical quality of an Oxisol under no-tillage (in Portuguese). Revista Brasileira de Engenharia Agrícola e Ambiental, 13, 411-418.

Asgarzadeh H., Mosaddeghi M.R., Mahboubi A.A., Nosrati A., Dexter A.R., 2011. Integral energy of conventional DYDLODEOH ZDWHU OHDVW OLPLWLQJ ZDWHU UDQJH DQG LQWHJUDO ZDWHU FDSDFLW\ IRU EHWWHU FKDUDFWHUL]DWLRQ RI ZDWHU DYDLODELO ity and soil physical quality. Geoderma 166, 34e4

Bengough A.G., McKenzie B.M., Hallett P.D., and Valentine T.A., 2011. 5RRW HORQJDWLRQ ZDWHU VWUHVV DQG PHFKDQLFDO LPSHGDQFH D UHYLHZ RI OLPLWLQJ VWUHVVHV DQG EHQH¿FLDO URRW tip traits. J. Experimental Botany, 62, 59-68.

Busscher W.J., 1990. $GMXVWPHQW RI ÀDW WLSSH UHVLVWDQFH GDWD WR D FRPPRQ ZDWHU can Society Agric. Eng., 33, 519-524.

Calonego J. C., Borghi E., and Crusciol C.A.C., 2011. Optimum ZDWHU LQWHUYDO DQG VRLO FRPSDFWLRQ and brachiaria (in Portuguese). Revista Brasileira de Ciência do Solo, 35, 2183-2190.

Chagas C. da S., Fontana A., Junior W. de C., Caires S.M. de, 2013. Topographical attributes in the differentiation of Argisols (in Portuguese). Revista Brasileira de Ciência do Solo, 37, 1441-1453.

Dantas J.S., Júnior J.M., Filho M.V.M., Resende J.M. do A., Camargo L.A., and Barbosa R.S., 2014. Genesis of cohesive soils of the East Maranhense: relation soil landscape (in Portuguese). Revista Brasileira de Ciência do Solo, 38, 1039-1050.

EMBRAPA, 2011. Brazilian Agricultural Research Corporation. Manual of methods of soil analysis (in Portuguese). Ministry of Agriculture and Supply, Rio de Janeiro, Brasil.

Ferreira F.P., Azevedo A.C. de, Wappler D., Kanieski A.J., Girelli D., and Pedrotti J., 2005. Solar exposition and soil properties in Santa Maria - RS (in Portuguese). Revista Brasileira de Agrociência, 11, 377-381.

Fidalski J., Tormena C.A., and Silva Á.P., 2010. Least limiting ZDWHU UDQJH DQG SK\VLFDO TXDOLW\ management systems in citrus. Scientia Agricola, 67, 448-453.

Flávio Neto J., Severiano E.C., Costa K.A.P., Guimarães Junior, W.S., Gonçalves W.G., and Andrade R., 2015. Biological soil loosening by grasses from genus Brachiaria in crop-livestock integration. Acta Scientiarum. Agronomy, 37, 375-383.

Leão T.P. and Silva A.P., 2004. $ VLPSOL¿HG ([FHOŠ DO IRU HVWLPDWLQJ WKH OHDVW OLPLWL Scientia Agricola, 61, 649-654.

Leão T.P., Silva A.P., Macedo M.C.M., Imhoff S., and Euclides V.P.B., 2004. 2SWLPXP ZDWHU LQWHUYDO LQ continuous and rotational grazing systems (in Portuguese). Revista Brasileira de Ciência do Solo, 28, 415-423.

Letey J., 1985. 5HODWLRQVKLS EHWZHHQ VRLO SK crop reduction. Advances in Soil Science, 1, 277-294.

Lima V.M.P., Oliveira G.C. de, Serafim M.E., Curi N., and Evangelista A.R., 2012. 2SWLPXP ZDWHU LQWHUYD tor of improvement of the structural quality of degraded latosol (in Portuguese). Revista Brasileira de Ciência do Solo, 36, 71-78.

Lima V.M.P., Oliveira G.C. de, Severiano E. da C., and Oliveira L.F.C. de, 2009. 2SWLPXP ZDWHU-UDQJH D ity of soils cultivated in an area of environmental protection in the south of Minas Gerais (in Portuguese). Revista Brasileira de Ciência do Solo, 33, 1087-1095.

Lipiec J. and Hakansson I., 2000. ,QÀXHQFHV RI -GHJUHH SDFWQHVV DQG PDWULF ZDWHU WHQVLR JURZWK ,QWHUSUHWDWLRQ RI ZDWHU DYDLODEL

Magalhães E.N., Oliveira G.C. de, Severiano E. da C., Costa K.A. de P., and Castro M.B. de, 2009. Structural recovery DQG VHOHFWHG RI PLFURRUJDQLVPV JUDVV LQ D F Argisol (in Portuguese). Ciência Animal Brasileira, 10, 68-76.

Masle J. and Passioura J.B., 1987. The effect of soil strength on WKH JURZWK RI \RXQJ ZKHDW SODQWV $XVWUDOLDQ -RXUQDO RI 3ODQW Physiology, 14, 643-656.

Moreira F.R., Dechen S.C.F., Silva Á.P. da, Figueiredo G.C., Maria I.C. de, and Terezinha P., 2014. 2SWLPXP ZDWHU interval in a red Latosol cultivated in a no-tillage system for 25 years (in Portuguese). Revista Brasileira de Ciência do Solo, 38, 119-127.

SEAG, 2008. State Secretariat for Agriculture, Supply, Aquaculture and Fisheries (in Portuguese). Strategic Plan IRU WKH 'HYHORSPHQW RI $JULFXOWXUH &DSL[DED QHZ PEDEAG 2007-2025 / State Secretariat for Agriculture, Supply, Aquaculture and Fisheries – Vitória, Brasil.

Severiano E.C., Oliveira G.C., Junior M.S.D., Costa K.A.P., Castro M.B., and Magalhães E.N., 2010. Potential of the decomposition of an Argisol promoted by tifton grass 85 (in Portuguese). Brazilian J. Agric. Environ. Eng., 14, 39-45.

Severiano E.C., Oliveira G.C. de, Júnior, M. de S. D., Costa K.A. de P., Silva F.G., and Filho S.M.F., 2011. Structural changes in Latosols representative of the Cerrado Region: , 5HODWLRQVKLSV EHWZHHQ VRLO SK\VLFDO DWWULEXWHV DQG OHDVW OLPLWLQJ ZDWHU UDQJH 5HYLVWD %UDVLOHLUD GH &LrQFLD GR 6ROR 35, 773-782.

Silva A.P., Kay B.D., and Perfect E., 1994. Characterization of WKH OHDVW OLPLWLQJ ZDWHU UDQJH 6RLO 6FL 6RF $P 1775-1781.

Silva S.R., Barros N.F., and Costa L.M., 2006. Atributos físicos de dois Latossolos afetados pela compactação do solo. Revista Brasileira de Engenharia Agrícola e Ambiental, 10, 842-847.

Tarrá I.L.C., Luizão F. de J., Wandelli E.V., Teixeira W.G., Morais W.J., and Castro J.G.D., 2010. Time of use in pastures and macropore volume of soil in Central Amazonia (in Portuguese). Revista Brasileira de Engenharia Agrícola e Ambiental, 14, 678-683.

Tormena C.A., Araújo M.A., Fidalski J., and Costa J.M. da, 2007. 7HPSRUDO YDULDWLRQ RI WKH RSW a dystroferric Red Latosol under no-till systems (in Portuguese). Revista Brasileira de Ciência do Solo, 31, 211-219.

Tormena C.A., Silva A.P., and Libardi P.L., 1998. Charac-WHUL]DWLRQ RI WKH RSWLPXP ZDWHU under no-tillage (in Portuguese). Revista Brasileira de Ciência do Solo, 22, 573-581.

USDA, 1993. Department of Agriculture, Soil Survey Division, Soil Conservation Service, Soil Survey Staff. Soil survey manual. Washington, (Agriculture Handbook, 18).

Vepraskas M.J., 1984. &RQH LQGH[RI ORDP\ VDQGV by pore size distribution and effective stress. Soil Sci. Society America J., 48, 1220-1225.