Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga

ISSN 0100-316X (impresso)
ISSN 1983-2125 (online)
http://dx.doi.org/10.1590/1983-21252021v34n416rc

SURFACE RESIDUES: EFFECTS ON SOIL MOISTURE AND TEMPERATURE[1]

GUSTAVO HADDAD SOUZA VIEIRA[2]*, ARILDO SEBASTIÃO SILVA[3], ARUN DILIPKUMAR JANI[4], LUSINERIO PREZOTTI[2], PAOLA ALFONSA VIEIRA LO MONACO[2]

ABSTRACT - This study aimed to determine how crop residue placement and composition would affect soil water content and temperature during the dry season in the central region of Espírito Santo state, Brazil. A 19-week field study was conducted from April to August 2017. A 2 x 4 factorial study with four replications was implemented using a randomized complete block design. Factors were soil management [conventional tillage (CT) and no soil disturbance (ND)] and residue amendment [maize (*Zea mays* L.), sunn hemp (*Crotalaria juncea* L.), a maize-sunn hemp mixture, and a no amendment control]. Soil water content and temperature were measured weekly at predetermined soil depth intervals. Soil water content was higher in ND plots amended with surface residues than under all other treatments in the 0 to 0.05 m depth range. All residue amendments in this range were equally effective in conserving soil water. Surface residues reduced soil temperature by up to 8.4 °C relative to the control in ND plots. Incorporating residue amendments by CT cancelled all temperature-moderating benefits provided by surface residues. These results indicate that surface residues from cereals, legumes, or cereal/legume mixtures are equally effective in conserving soil water and moderating soil temperature during the dry season. Additional research is needed to determine how improved soil environmental conditions, generated by surface residues, would affect nutrient acquisition and crop performance.

Keywords: *Crotalaria juncea* L. *Zea mays* L. Organic mulches. Tillage.

RESÍDUOS DE SUPERFÍCIE: EFEITOS SOBRE A TEMPERATURA E A UMIDADE DO SOLO

RESUMO - Este estudo teve como objetivo determinar como a disposição e composição dos resíduos culturais afetam o teor de água do solo e a temperatura durante a estação seca na região central do estado do Espírito Santo, Brasil. Um estudo de campo de 19 semanas foi conduzido de abril a agosto de 2017, no esquema fatorial 2 x 4 com quatro repetições, em blocos casualizados. Os fatores foram: preparo do solo [preparo convencional (CT) e sem preparo (ND)] e tipos de cobertura [milho (*Zea mays* L.), crotalária (*Crotalaria juncea* L.), mistura de crotalária com milho e sem cobertura morta (controle)]. O teor de água e a temperatura do solo foram medidos semanalmente em intervalos de profundidade pré-determinados. A umidade do solo foi maior no NT do que nos demais tratamentos na profundidade de 0-0.05 m. Todas as coberturas mortas nessa profundidade foram igualmente eficazes na conservação da umidade do solo. Os resíduos da superfície reduziram a temperatura do solo em até 8,4 °C em relação ao controle nas parcelas NT. A Incorporação dos resíduos eliminou todos os benefícios de redução de temperatura fornecidos pela manutenção dos resíduos na superfície. Estes resultados indicam que os resíduos superficiais de cereais, leguminosas ou misturas desses são igualmente eficazes na conservação da água do solo e na moderação da temperatura do solo durante a estação seca. Pesquisas adicionais são necessárias para determinar como as melhores condições ambientais do solo, geradas por resíduos de superfície, afetariam a aquisição de nutrientes e o desempenho da cultura.

Palavras-chave: *Crotalaria juncea* L. *Zea mays* L. Cobertura morta orgânica. Preparo do solo.

*Corresponding author
[1]Received for publication in 09/25/2020; accepted in 08/23/2021.
Paper extracted from the Master's thesis of the second author.
[2]Department of Agronomy, Instituto Federal do Espírito Santo, Santa Teresa, ES, Brazil; ghsvieira@gmail.com - ORCID: 0000-0001-9963-1571, lusineriop@ifes.edu.br – ORCID: 0000-0002-2073-0532, paolalomonaco2004@yahoo.com.br - ORCID: 0000-0001-5498-7451.
[3]Postgraduate program in agroecology, Instituto Federal do Espírito Santo, Alegre, ES, Brazil; arildos.silva@gmail.com - ORCID: 0000-0002-5801-4064.
[4]Ecological Sciences Division, Departamento de Agricultura dos Estados Unidos da América, Natural Resources Conservation Service, Portland, OR, USA; arun.jani@usda.gov - ORCID: 0000-0001-8665-8636.

INTRODUCTION

Reduced tillage practices that minimize soil disturbance can enhance crop productivity by improving soil structure, which facilitates root development and nutrient acquisition by crops (PRIMAVESI, 2002; RAI et al., 2017). Conversely, conventional tillage (CT) often reduces soil biological activity, destroys soil aggregate stability, and depletes soil organic carbon stocks relative to reduced tillage practices (CARVALHO et al., 2012; CHAUDHARY et al., 2018; NARESH at al., 2018; SÁ et al. 2014). The negative impact that CT has on soil water retention is also important, especially in regions where precipitation and irrigation supplies are limited. De Vita et al. (2007) found that soil subjected to CT and planted to wheat (*Triticum aestivum* L.) dried more rapidly and produced lower grain yields than soil managed without tillage. Considering the importance of soil water as a determinant of nutrient availability and crop productivity (OLIVEIRA; ROQUE, 2016), growers should consider soil and crop management practices that enhance soil water retention.

High soil temperature reduces seed germination rates (REDDY et al., 2017) and hinders root development, resulting in lower nutrient and water uptake by roots (BERGAMASCHI; GUADAGNIN, 1993; GIRI et al., 2017; JHA et al., 2017). However, leaving crop residues on the soil surface moderates soil temperature and can be used by farmers to improve soil temperature conditions for crop growth, especially during warm months (AWAL et al., 2019; STEFANOSKI et al., 2013). In addition to moderating soil temperature, surface residues also mitigate soil erosion rates, enhance soil organic carbon and nutrient concentrations, and increase infiltration rate and volumetric water content at field capacity (ESSER, 2017; HUBBARD; STRICKLAND; PHATAK, 2013; RYKEN et al., 2018; SOUZA et al., 2018).

Crop residue persistence on the soil surface largely depends on residue carbon-to-nitrogen (C/N) ratio. Compared to cereals, leguminous residues have a low C/N ratio and structural carbohydrate composition (SIEVERS; COOK, 2018), both of which favor rapid decomposition and explain why leguminous residues usually decompose faster than cereal residues (MULVANEY et al., 2010). Previous research in temperate regions has also shown that decomposition rates of cereal-legume residue mixtures fall in between rates observed for their individual components (POFFENBARGER et al., 2015). However, additional research is needed to better understand how species composition of surface residues with different C/N ratios affects soil water and temperature conditions in tropical regions.

In this study, we aimed to identify soil and residue management practices that growers in the central region of Espírito Santo state, Brazil could use to improve soil environmental conditions for crop production during the dry season.

MATERIAL AND METHODS

A 19-week field experiment was conducted from April to August 2017 at the Federal Institute of Espírito Santo (IFES) Campus Santa Teresa, Brazil (19°48'36"S, 40°41'16"W, 134 m elevation). The soil at the field site is classified as a Dystrophic Red-Yellow Latosol, with medium texture, according to the criteria of the Brazilian Soil Classification System (EMBRAPA, 2009). Before the experiment began, soil samples were randomly collected to 0.20 m depth and assessed for soil physical and chemical properties presented in Table 1.

Table 1. Initial soil properties at the study site in Espírito Santo, Brazil.

Soil properties	Units	Red-Yellow Latosol
P	mg dm^3	127.0
K	mg dm^3	160.0
Mg	$cmol_c$ dm^3	1.0
Ca	$cmol_c$ dm^3	4.0
Al + H	$cmol_c$ dm^3	1.7
CEC	$cmol_c$ dm^3	5.7
pH	-	6.3
Organic matter	%	2.0
Base saturation	%	77.0
Bulk density (0-0.05 m)	g cm^3	1.21
Bulk density (0.10-0.15 m)	g cm^3	1.25
Water content -10 kPa (0-0.05 m)	%	25.96
Water content -1,500 kPa (0-0.05 m)	%	15.85
Water content -10 kPa (0.10-0.20 m)	%	18.46
Water content -1,500 kPa (0.10-0.20 m)	%	13.12

P and K: extracted by Mehlich-1; Mg and Ca: extracted by KCl; H+Al: extracted by calcium acetate; CEC: cation exchange capacity at pH 7.0; pH in H_2O 1:2.5; Organic matter, Walkley-Black method.

The region is characterized by a tropical climate, with average annual temperature and rainfall of 28 °C and 1,078 mm, respectively, classified as Aw (ALVARES et al. 2013). Most rainfall occurs between October and April. Air temperature and rainfall data were collected during the study using an onsite weather station (Figure 1).

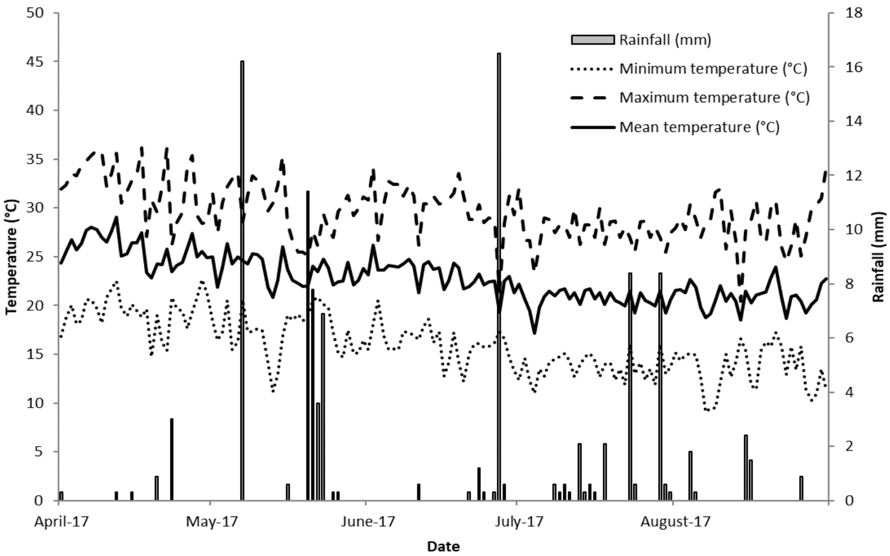

Figure 1. Daily maximum (dashed lines), minimum (dotted lines), and mean (solid lines) air temperatures (°C) at 2 m above the soil surface and precipitation (mm). Data were collected from on-site weather stations.

A 2 x 4 factorial experiment with four replications was implemented using a randomized complete block design. Two soil management practices (CT – conventional tillage and ND – no soil disturbance) and four residue amendment options (maize, sunn hemp, maize/sunn hemp mixture, and unamended control without residues) were evaluated in 2 x 2 m plots (Figure 2). Maize residues were collected following harvest from organic farms in Santa Maria de Jetibá, Espírito Santo, Brazil. Sunn hemp residues were obtained from the horticultural experimental area at IFES-Santa Teresa Campus. At the time of residue collection, the sunn hemp stand was approximately 90 days old and had just begun pod formation.

Figure 2. Experimental layout at the Federal Institute of Espírito Santo (IFES) - Santa Teresa *campus*, Brazil (19°48'36"S, 40°41'16"W, 134 m elevation).

The experimental area was cultivated with vegetables for over ten years and, before the experimental period, it was kept fallow with spontaneous vegetation (weeds) dominated by colonião (*Panicum maximum*), for one year. The area was weeded to remove all plant residues immediately before implementing the experiment.

The four residue amendments were added to plots on a fresh weight basis, except in the control, in the following proportions for maize, sunn hemp, and the maize/sunn hemp mixture, respectively: 60, 45, and 53 kg per plot (150, 112.5 and 132.5 t ha^{-1}). Residues were distributed manually to cover soil. For CT treatments, residues were incorporated using a rotating hoe coupled to a microtractor, while in ND treatments, residues remained on the soil surface as mulch. Although crops were not grown in the experimental area, plots were irrigated three times per week to raise soil water to field capacity and simulate a typical irrigation schedule for dry season vegetable production in the region. Irrigation scheduling was supported by a spreadsheet developed by the irrigation research group at the IFES Santa Teresa Campus.

Soil water content was determined on a gravimetric basis. Samples were collected from plots at 0 to 0.05 and 0.10 to 0.15 m depths approximately 72 hours after the last irrigation event. Upon collection, samples were placed in aluminum containers, covered, and transported to IFES Campus Santa Teresa Soil Laboratory. Fresh samples were weighed on a precision scale and then, oven-dried at 105 °C for 48 hours. Soil water content was determined using Equation 1 (MANTOVANI; BERNARDO; PALARETTI, 2009).

$$SM = \frac{M1 - M2}{M2 - M3} x100 \qquad (1)$$

where *SM* is soil water, *M1* refers to the mass of fresh soil plus the container (g), *M2* represents the mass of the dry soil plus the container (g), and *M3* is the mass of the container.

Based on soil water results from plots, total available water content was calculated using Equation 2 as described by Mantovani, Bernardo and Palaretti (2009):

$$TAW = \frac{(FC - PWP)}{10} \rho_b Z \qquad (2)$$

where TAW represents total available water (mm), *FC* is field capacity (percent by weight), *PWP* refers to permanent wilting point (percent by weight), ρ_b is bulk density (g cm^{-3}), and Z is effective root depth (m). A value of 0.05 m was used for *Z*, which referred to the 0.05 m depth used for sample collection. Based on TAW, the volume of water stored (mm) and water savings (L ha^{-1}) were determined.

Soil temperature was measured weekly using a Soloterm 1200 type k soil thermometer (Solotest®, Bela Vista, São Paulo, Brazil), with a resolution of 0.1 °C for a temperature range from -40 to 200 °C. Readings began each week at 12:00 PM. In each plot, a reading was taken on the soil surface and at depths of 0.03 and 0.13 m.

Analysis of variance was conducted manually using methods described by Banzato and Kronka (2009) to assess soil water and temperature data. Soil tillage and residue amendments were treated as fixed effects, while replication and any replication by main effect interactions were treated as random effects. Pairwise comparisons between treatment means were made using Tukey's honest significant difference (HSD; α = 0.05) on least squared means.

RESULTS AND DISCUSSION

Soil water at both depth intervals was affected by the soil tillage × residue amendment interaction. At the 0 to 0.05 m soil depth interval, soil water was higher under ND amended with surface residues than under all other treatments (Table 2). All residue amendments in ND plots were also equally effective in retaining soil water at this depth interval. Therefore, our hypothesis that residue composition and placement would determine soil water content was only partially supported.

There was an expectation that maize surface residues would persist longer than surface residues of sunn hemp or the maize/sunn hemp mixture due to the higher C/N ratio of maize relative to sunn hemp residues (STALLINGS et al. 2017) and would decompose at a slower rate (LYNCH et al. 2016). Visual observations during the study indicated our expectation was met as maize residues persisted longer than other residue amendments, making it difficult to explain the lack of residue composition effect on soil water retention. It is conceivable that irrigation frequency supplied sufficient water to overcome soil water limitations that would have been caused by lower residue persistence in sunn hemp and maize/sunn hemp mixture plots relative to maize plots under drier conditions.

Soil water in control plots under both CT and ND was similar at the 0 to 0.05 m depth interval, suggesting that mulch rather than tillage was the primary factor affecting soil water retention. In addition to conserving soil water near the soil surface, mulching in ND plots resulted in 15% higher soil water content at 0.10 to 0.15 m soil depth compared to soil water in control plots (Table 2). While soil water under CT increased with depth regardless of residue amendment, we only observed higher soil water with depth in ND plots that were amended with maize or in the control. When soil water did increase with depth, the magnitude of increase was greater under CT. Moving from 0 to 0.05 to 0.10 to 0.15 m depth intervals, soil water increased up to 39 and 21% under CT and ND, respectively.

Table 2. Soil water at 0-0.05 and 0.10-0.15 m depth intervals in plots amended with residues of maize, sunn hemp, or a maize/sunn hemp mixture either incorporated into soil by conventional tillage (CT) or left on the soil surface with no soil disturbance (ND). Control plots were not amended with residues but were subjected to CT or ND. Data were averaged over the 19-week study period.

		Soil moisture (%)	
		-----------Soil depth (m)--------	
Tillage	Residues amendment	0-0.05	0.10-0.15
CT	Maize	11.03 Bb	15.51 Ab
	Sunn hemp	11.68 Bb	15.60 Ab
	Maize + sunn hemp	11.88 Bb	16.00 Ab
	Control	11.13 Bb	14.71 Abc
ND	Maize	16.07 Ba	17.25 Aa
	Sunn hemp	15.88 Aa	15.99 Aab
	Maize + sunn hemp	16.05 Aa	16.08 Aab
	Control	11.88 Bb	13.93 Ac

Means followed by the same uppercase letter in a row or the same lowercase letter in a column are not significantly different at α = 0.05 according to Tukey's HSD.

Mulching blocks the movement of water vapor from soil to the atmosphere (ALLEN et al. 1998), enabling soil water conservation and, thus, promoting greater water use efficiency by crops (EL-MAGEED et al., 2018; GAO et al., 2019; LI et al. 2018). As in this study, Oliveira Neto et al. (2011) reported both legume and cereal mulches were highly effective in conserving soil water compared to soils without mulch in sugar beet (*Beta vulgaris* var. saccharifera) production in Rio de Janeiro State, Brazil. Similarly, Ribeiro et al. (2016) also found that the use of cereal mulch in onion (*Allium cepa* L.) production in Rio de Janeiro State, Brazil conserved soil water and enhanced bulb yields compared to when mulch was not used.

Residue amendments used as mulch under NT in this study could substantially reduce water use for irrigation. For example, there was a soil water difference of 2.54 mm in ND plots amended with maize residues compared to the ND control, on a weekly basis, representing a water savings of 25.4 m^3 ha^{-1}. Assuming an irrigation frequency of three times per week, which is typical of dry season vegetable production in the region, weekly savings would amount to 76.2 m^3 ha^{-1} in ND plots with maize surface residues. Comparing ND and CT plots amended with maize residues indicated an even larger water savings, which amounted to 3.05 mm per ha, or 91.5 m^3 ha^{-1} in weekly savings by leaving maize residues on the soil surface instead of incorporating them.

Soil temperature was also affected by the soil tillage × residue amendment interaction. All surface residues in ND plots reduced soil temperatures relative to the control, with the largest impact detected on the soil surface where the temperature was approximately 8.4 °C lower in mulched compared to control plots (Table 3). Soil temperature depends on the extent of surface coverage by residues, soil water content, and solar radiation intensity and duration (AMADO; MATOS; TORRES, 1990; OBIA et al., 2020; ONWUKA, 2016). These large differences in temperature between mulched and control ND soils can be explained by surface residues in mulched plots reflecting solar radiation and acting as a thermal wave attenuator, thereby, producing lower soil temperatures compared to when residues were absent (BONACHELA et al. 2020). Among mulches, maize and sunn hemp produced similar soil temperatures from the soil surface to 0.03 m in depth, while the maize/sunn hemp residue mixture reduced soil temperature by 2.2 °C at this depth interval.

Table 3. Soil temperature at the soil surface, 0.03 m depth, and 0.13 m depth in plots amended with residues of maize, sunn hemp, or a maize/sunn hemp mixture either incorporated into soil by conventional tillage (CT) or left on the soil surface with no soil disturbance (ND). Control plots were not amended with residues but were subjected to CT or ND. Data were averaged over the 19-week study period.

		Soil temperature (°C)		
		------------------Soil depth (m)---------------		
Tillage	Residues amendment	Surface	0.03	0.13
CT	Maize	38.09 Aa	33.48 Ba	27.36 Ca
	Sunn hemp	37.58 Aa	33.58 Ba	27.86 Ca
	Maize + sunn hemp	37.57 Aa	33.33 Ba	27.72 Ca
	Control	37.89 Aa	34.13 Ba	28.32 Ca
ND	Maize	28.37 Ab	27.00 Ab	25.66 Bb
	Sunn hemp	28.37 Ab	27.26 Ab	25.46 Bb
	Maize + sunn hemp	29.05 Ab	26.89 Bb	25.54 Bb
	Control	36.97 Aa	32.95 Ba	28.12 Ca

Means followed by the same uppercase letter in a row or the same lowercase letter in a column are not significantly different at $\alpha = 0.05$ according to Tukey's HSD.

Incorporating residue amendments by CT negated all temperature-moderating benefits provided by mulch. Soil temperature under CT was only affected by depth and decreased by approximately 10 °C from the soil surface to 0.13 m in depth. For ND plots amended with any residue amendment, soil temperature only decreased by 3 °C at this same interval. Primavesi (2002) reported that high soil temperatures, like those found under CT in our study, contribute to the mortality of meso- and macrofaunal soil components. An increase in microbial activity under ND in the 0 to 0.05 m depth range was observed in studies evaluating microbial residues under different forms of soil management (CARLOS et al, 2021; LEÓN et al., 2017). While ND has a positive impact on soil biology, structure and fertility, results from our study clearly show that ND alone does not moderate soil temperature and water conditions relative to CT and should be used in conjunction with residue retention as a best management practice for potential vegetable production during the dry season in Espírito Santo, Brazil.

CONCLUSION

Results from this study indicate that surface mulches comprised of residues from cereals, legumes, or cereal/legume mixtures are equally effective at conserving soil water and maintaining favorable soil temperatures during the dry season in Espírito Santo, Brazil. Incorporating residues with CT cancels the soil water and temperature-moderating benefits provided by surface mulch. Our results suggest that the absence of soil disturbance alone is not an effective strategy for conserving soil water and maintaining favorable soil temperatures, but rather undisturbed soil should be accompanied by residues retention on the soil surface. Moving forward, additional research is needed to determine how the improved soil environmental conditions generated by mulching practices used in this study would affect nutrient uptake dynamics and crop performance during the dry season in Espírito Santo, Brazil.

ACKNOWLEDGEMENTS

The authors thank the Espírito Santo Research Support Foundation (FAPES) for granting funds to develop this research. Thanks to PRODIF-IFES for the financial contribution to the publication of this paper.

REFERENCES

ALLEN, R. G. et al. Crop evapotranspiration: guidelines for computing crop water requirements. **Rome: FAO – Irrigation and drainage**. 1998.

ALVARES, C. A. et al. Köppen’s climate classification map for Brazil. **Meteorologische Zeitschrift**, 22: 711–728, 2013.

AMADO, T. J. C.; MATOS, A. T.; TORRES, L. Flutuação de temperatura e umidade do solo sob preparo convencional e em faixas na cultura da cebola. **Pesquisa Agropecuária Brasileira**, 24: 625-631, 1990.

AWAL, R. et al. Soil Physical Properties Spatial Variability under Long-Term No-Tillage Corn. **Agronomy**, 9: 750-767, 2019.

BANZATO, D. A.; KRONKA, S. N.

Experimentação Agrícola. 4 ed. Jaboticabal, SP: FUNEP, 2009. 237 p.

BERGAMASCHI, H.; GUADAGNIN, M. R. Modelos de ajuste para médias de temperatura do solo, em diferentes profundidades. **Revista Brasileira de Agrometeorologia**, 1: 98-99, 1993.

BONACHELA, S. et al. How mulching and canopy architecture interact in trapping solar radiation inside a Mediterranean greenhouse. **Agricultural and Forest Meteorology**, 294: 108132, 2020.

CARLOS, F. S. et al. A long-term no-tillage system can increase enzymatic activity and maintain bacterial richness in paddy fields. **Land Degradation & Development**, 32: 2257-2268, 2021.

CARVALHO, L. A. et al. Spatial variability of soil physical properties in two management systems in sugarcane crop. **Engenharia Agrícola**, 32: 60-68, 2012.

CHAUDHARY, M. et al. Soil Organic Carbon Fractions, Soil Microbial Biomass Carbon, and Enzyme Activities Impacted by Crop Rotational Diversity and Conservation Tillage in North West IGP: A Review. **International Journal of Current Microbiology and Applied Sciences**, 7: 3573-3600, 2018.

DE VITA, P. et al. No-tillage and conventional tillage effects on durum wheat yield, grain quality and soil water content in southern Italy. **Soil and Tillage Research**, 92: 69-78, 2007.

EL-MAGEED, T. A. A. Compost and mulching modulates morphological, physiological responses and water use efficiency in sorghum (bicolor L. Moench) under low moisture regime. **Agricultural Water Management**, 208: 431-439, 2018.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. Centro Nacional de Pesquisa de Solo. **Sistema brasileiro de classificação de solos**. 2. ed. Rio de Janeiro, RJ: EMBRAPA-SPI, 2009. 412 p.

ESSER, K. B. Water infiltration and moisture in soils under conservation and conventional agriculture in agro-ecological Zone IIa, Zambia. **Agronomy**, 7: 40-54, 2017.

GAO, H. et al. Exploring optimal soil mulching to enhance yield and water use efficiency in maize cropping in China: A meta-analysis. **Agricultural Water Management**, 225: 105741, 2019.

GIRI, A. et al. Heat stress decreases levels of nutrient-uptake and assimilation proteins in tomato roots. **Plants**, 6: 6-21, 2017.

HUBBARD, R.K.; STRICKLAND, T.C.; PHATAK, S. Effects of cover crop systems on soil physical properties and carbon/nitrogen relationships in the coastal plain of southeastern USA. **Soil and Tillage Research**, 126: 276-283, 2013.

JHA, S. K. et al. Root development and water uptake in winter wheat under different irrigation methods and scheduling for North China. **Agricultural Water Management**, 182: 139-150, 2017.

LEÓN, P. et al. No tillage and sugar beet foam amendment enhanced microbial activity of degraded acidic soils in South West Spain. **Applied Soil Ecology**, 109: 69-74, 2017.

LI, Q. et al. Mulching improves yield and water-use efficiency of potato cropping in China: A meta-analysis. **Field Crops Research**, 221: 50-60, 2018.

LYNCH, M. J. et al. Decomposition, nitrogen and carbon mineralization from food and cover crop residues in the central plateau of Haiti. **Springer Plus**, 5: 973, 2016.

MANTOVANI, E. C.; BERNARDO, S.; PALARETTI, L. F. **Irrigação: princípios e métodos**. 2. ed. Viçosa, MG: UFV, 2009. 355 p.

MULVANEY, M. J. et al. Carbon and nitrogen mineralization and persistence of organic residues under conservation and conventional tillage. **Agronomy Journal**, 102: 1425-1433, 2010.

NARESH, R. K. et al. Carbon and nitrogen dynamics, carbon sequestration and energy saving in soils under different tillage, stubble mulching and fertilizer management in rice–wheat cropping system. **Journal of Pharmacognosy and Phytochemistry**, 7: 723-740, 2018.

OBIA, A. et al. Conservation tillage and biochar improve soil water content and moderate soil temperature in a tropical Acrisol. **Soil & Tillage Research**, 197: 104521, 2020.

OLIVEIRA, L. F. C.; ROQUE, C. G. Determinação da umidade do solo por micro-ondas e estufa em três texturas de um Latossolo Vermelho-Amarelo do Cerrado. **Journal of Neotropical Agriculture**, 3: 60 -64, 2016.

OLIVEIRA NETO, D. H. et al. Evapotranspiração e coeficientes de cultivo da beterraba orgânica sob cobertura morta de leguminosa e gramínea. **Horticultura Brasileira**, 29: 330-334, 2011.

ONWUKA, B. M. Effects of soil temperature on

Some Soil properties and plant growth. **Scholarly Journal of Agricultural Science**, 6: 89-93, 2016.

PRIMAVESI, A. M. **Manejo ecológico do solo: a agricultura em regiões tropicais**. NBL Editora, 2002.

POFFENBARGER, H. J. et al. Legume Proportion, Poultry Litter, and Tillage Effects on Cover Crop Decomposition. **Agronomy Journal**, 107: 2083-2096, 2015.

RAI, R. K. et al. Soil Analysis. In: RAI, R. K.; SINGH, V. P.; UPADHYAY, A. (Eds.). **Planning and Evaluation of Irrigation Projects**. London: Academic Press, 2017. cap. 17, p. 505-524.

REDDY, K. R. et al. Temperature Effects on Cotton Seedling Emergence, Growth, and Development. **Agronomy Journal**, 109: 1379-1387, 2017.

RIBEIRO, E. C. et al. Onion yield under agroecological farming system using distinct irrigation depths and soil covers. **Ciência Rural**, 46: 783-789, 2016.

RYKEN, N. et al. Soil erosion rates under different tillage practices in central Belgium: New perspectives from a combined approach of rainfall simulations and ^{7}Be measurements. **Soil and Tillage Research**, 179: 29-37, 2018.

SÁ, J. C. M. et al. Long-term tillage systems impacts on soil C dynamics, soil resilience and agronomic productivity of a Brazilian Oxisol. **Soil and Tillage Research**, 136: 38-50, 2014.

SIEVERS, T.; COOK, R. L. Aboveground and Root Decomposition of Cereal Rye and Hairy Vetch Cover Crops. **Soil Science Society of America Journal**, 82: 147-155, 2018.

SOUZA, T. E. M. D. S. et al. Reducing erosion in sorghum crops with mulching. **Revista Caatinga**, 31: 730-736, 2018.

STALLINGS, A. M. Nitrogen mineralization from ‘AU Golden’ sunn hemp residue. **Journal of Plant Nutrition**, 40: 50-62, 2017.

STEFANOSKI, D. C. et al. Uso e manejo do solo e seus impactos sobre a qualidade física. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 17: 1301-1309, 2013.