

Effects of soil temperature on some soil properties and plant growth

Abstract

Soil temperature varies seasonally and daily which may result from changes in radiant energy and energy changes taking place through the soil surface. It governs the soil physiochemical and biological processes and also influences the interspheric processes of gas exchange between the atmosphere and the soil. Environmental factors affect soil temperature by either controlling the amount of heat supplied to the soil surface and the amount of heat dissipated from the soil surface down the profile. Soil temperature alters the rate of organic matter decomposition and mineralization of different organic materials. It also affects soil water content, its conductivity and availability to plants. The paper introduced soil temperature as a major determinant of the processes that takes place in the soil which are necessary for plant growth.

Keywords: soil temperature, heat, organic matter decomposition, plant growth, radiant energy

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Introduction

Soil constitutes a major storage for heat, acting as a reservoir of energy during the day and source of heat to the surface at night. The soil stores energy during the warm season and releases it to air during the cold season Geiger et al.¹ The temperature of the soil depends on the ratio of the energy absorbed to that lost from the soil. It fluctuates annually and daily, affected mainly by variations in air temperature and solar radiation.² Soil temperature is one of the important factors that influence soil properties processes involved in plant growth. It governs the soil physical, chemical and biological processes (Buchan, 2001). It also influences the interspheric processes of gas exchange between the atmosphere and the soil Lehnert.³ The amount of radiation received by the soil affects soil temperature (Haskel et al. 2010), biological processes such as; seed germination, seedling emergence, plant root growth and the availability of nutrients Probert.⁴ The temperature of the soil alters the rate of organic matter decomposition and the mineralization of different organic materials in the soil (Davidson & Janssens, 2006). Soil temperature also affects soil water retention, transmission and availability to plants.

Soil temperature

Soil temperature is the function of heat flux in the soil as well as heat exchanges between the soil and atmosphere Elias et al.⁵ It is also defined as the function of the internal energy of the soil (Ghali 2003). The transfer of heat in the soil Zhao et al.⁶ and the latent heat exchanges at the surface Nwankwo et al.⁷ are the primary causes of variations in soil temperature. The main source of soil temperature is solar radiation. Soil temperature is measured with a thermometer. Soil temperature varies seasonally and daily which may result from changes in radiant energy and energy changes taking place through soil surface Chiemeka.⁸

Factors influencing soil temperature

Zhang (2003) divided these factors into two; the amount of heat made available to the soil surface and the amount of heat dissipated from soil surface down the profile.

A. The factors that affect the amount of heat supplied at the soil surface include; soil colour,⁹ mulching Matthias et al.,¹⁰ solar radiation Geiger et al.,¹ slope of land surface Elisbarashiviti et al.,¹¹ vegetative cover Decker et al.,¹² organic matter content¹³ and evaporation Lu et al.¹⁴

- i. **Soil colour:** Dark coloured soils absorb more radiant heat than light coloured soils.⁷ Thus dark coloured soils have a higher soil temperature than light coloured soils.
- ii. **Soil mulch:** Horton et al.,¹⁵ observed that mulch materials inhibit evaporation and increase soil moisture. Consequently, these materials reduce the temperature on the soil surface Shinnars et al.¹⁶ Therefore, mulching the surface of the soil serves to insulate heat thereby reducing soil temperature Dahiya et al.¹⁷ Generally less heat will flow into a mulched soil compared to bare soils.
- iii. **Slope of the land surface:** Solar radiation that reaches the land surface at an angle is scattered over a wider area than the same amount of solar radiation reaching the surface of the land at right angles. Therefore the amount of radiation per unit area of the land surface decreases as the slope of the land increases Elisabarashivilli et al.¹⁸ Thus soil temperature decreases as the slope of land increases.
- iv. **Vegetative cover:** A bare soil quickly absorbs heat, becomes hot during the hot season and becomes cold during the cold season. Vegetation acts as a thermal insulator and significantly affects the soil temperature.⁷ It does not allow the soil to become either too hot during the dry season or too cold during the rainy season Jimenez et al.¹⁹
- v. **Organic matter content:** Organic matter increases the water holding capacity of the soil. It also contributes to the dark colour of the soil. These two soil properties increase its absorption of heat, thereby increasing the soil temperature Fang et al.²⁰
- vi. **Evaporation:** The evaporation of water from the soil requires a large amount of energy. Soil water utilises the energy from solar radiation to evaporate thereby rendering it unavailable for heating

up of the soil.¹ Thus the greater the rate of evaporation, the more a soil is cooled and its temperature decreases.

vii. **Solar radiation:** This is the amount of heat from the sun that reaches the earth. The amount of radiation from the sun that a soil receives and absorbs affects the variability of soil temperature.²¹ As the solar radiation reaching the soil surface increases the soil temperature also increases Geiger et al.¹⁰

B. Some of the factors that affect the amount of heat dissipated from the soil down the profile include; moisture content²² and bulk density (Abu-Hamdeh, 2013).

i. **Soil moisture content:** Moisture influences soil heat dissipation down the profile. The flow of heat is higher in a wet soil than in a dry soil where the pores are filled with air. The rate of heat dissipation increases with moisture content Ochsner et al.²³

ii. **Bulk density:** High bulk density increases the soil surface by increases the amount of heat dissipated through the soil surface by increasing the rate at which heat energy passes through a unit cross-sectional area of the soil Abuel-Nagel et al. 2009.

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Effects on soil biological properties

Bioactivity: Soil temperature range of 10°C-28°C influence soil respiration by increasing the activity of extracellular enzymes that degrade polymeric organic matter in soils Conant et al.,²⁴ increase microbial retake of soluble substrates Allison et al.,²⁵ and increase microbial respiration rates Wallenstein et al.²⁶ Increase in soil temperature increases the soil nitrogen mineralization rates through the increase in microbial activity and increase in the decomposition of organic matter in the soil.²⁷ Soil temperature below freezing point decreases mineralization by inhibiting microbial activity and decreasing diffusion of soluble substrates in the soil Kaiser et al.²⁸

Soil micro-organisms: Most soil micro-organisms require temperatures between 10°C-35.6°C for their activities (Davidson & Janssens 2006). Soil microbial activities decrease with low soil temperatures and at freezing point, most activities cease Allison.²⁹

Soil macro-organisms: At a soil temperature range of 10°C-24°C, soil macro-organisms have increased rate of metabolism requiring them to either feed more or burn their own fat stores Conant et al.²⁴ At extreme high temperatures of 58°C, soil macro-organisms die because of the unfavourable temperature of the soil (Bristow, 1998). Soil macro-organisms do not survive in temperatures below freezing point.

Organic matter decomposition: At a temperature below 0°C the accumulation of soil matter increases due to the slow rate of decomposition Allison et al.²⁵ Organic matter decomposes slowly at lower temperatures as a result of decrease in microbial activities and biochemical processes.³⁰ Soil temperature between 2°C-38°C increases the organic matter decomposition³¹ by increasing the movement of soluble substrates in the soil Fierer et al.³² and stimulating microbial activities Fang et al.²⁰

Effects on chemical properties of the soil

Cation exchange capacity (CEC)

Increase in soil temperature decreases organic matter Ubeda et al.³³

through combustion. This decrease in organic matter and reduction in clay size clay fraction as a result of high temperature leads to a decrease in the cation exchange capacity of the soil Certini.³⁴ Increase in soil temperature leads to a decrease in the cation exchange capacity of the soil Rengasamy et al.³⁵

Available phosphorus

Yilvaiaio et al.,³⁶ observed that water-soluble phosphorus increased with soil temperature from 50c-250c due to the increase in the movement of phosphorus in the soil controlled by diffusion. Soils with low temperature have low availability of phosphorus because the release of phosphorus from organic material is hindered by low temperature Gahoonia et al.³⁷

Soil pH

At a soil temperature ranges of 25°C- 39°C the soil pH increases as a result of organic acid denaturation which increases at high temperature Menzies et al.³⁸

Effects on soil physical properties

Soil structure

Increase in soil temperature causes temperature induced dehydration of 2:1 clay minerals in the soil leading to strong interactions among the clay particles which in turn yield less clay and more silt-sized particles in the soil Arocena et al.³⁹ High soil temperature also leads to heat-induced cracks in the sand-sized particles that eventually lead to breakdown and consequently a reduced amount of sand-sized particles in the soil Pardini et al.⁴⁰ Increase in soil temperature lowers the clay sand contents and increases the silt content Assaf et al.⁴¹

Aggregate stability

At soil temperature above 30oc, the aggregate stability of the soil increases Fox et al.⁴² This is as a result of thermal transformation of iron and aluminium oxides, causing them to act as cementing agents for clay particles that then form strong silt-sized particles in the soil Terefe et al.⁴³

Soil moisture content

Reductions in soil moisture occur when increased soil temperatures decrease water viscosity, thus allowing more water to percolate through the soil profile Broadbent.³¹ In addition, reduced shade combined with increased soil temperatures also results in higher evaporation rates which in turn restrict the movement of water into the soil profile Rengasamy et al.³⁵

Soil aeration

Temperature influences the carbon dioxide content in the soil air. High temperature encourages micro-organism activity which results in higher production of carbon dioxide in the soil Allison.²⁹

Effects of soil temperature on plant growth

Soil temperature has a great effect on plant growth by influencing water and nutrient uptake Toselli et al.,⁴⁴ root and shoots growth Weih et al.⁴⁵

Water uptake

Water uptake decreases with low temperature. This is due to the

increased viscosity and decreased absorption rate of water at low temperature Toselli et al.⁴⁴ Decreased water uptake reduces the rate of photosynthesis.

Nutrient uptake

The metabolic activities of micro-organisms play an important role in the cycling of nutrients in the soil and ensuring the nutrients are in a form available to plants. Therefore increased metabolic activities of micro-organisms as a result of increase in soil temperature will stimulate the availability of nutrients for plants. Soil temperature also affects nutrient uptake by changing soil water viscosity and root nutrient transport Grossnickle,⁴⁶ Lahti et al.,⁴⁷ observed that at low soil temperature, nutrient uptake by plants reduce as a result of high soil water viscosity and low activity of root nutrient transport.

Root growth

Increase in soil temperature improves root growth because of the increase in metabolic activity of root cells and the development of lateral roots Repo et al.⁴⁸ Low soil temperature results in reduced tissue nutrient concentrations and as such decreases root growth Lahti et al.^{49–56}

Conclusion

The soil is indispensable for the maintenance of plant life, affording mechanical support, supplying nutrients and water. The soil constitutes a major storage for heat. The soil temperature is a catalyst for many biological processes. Soil temperature influences soil moisture, aeration and availability of plant nutrients which are necessary for plant growth.

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Conflict of interest

The author declares no conflict of interest.

References

- Geiger R Aron RN, Todhunter P. *The climate near the ground*. Lanham, USA: Rownaan and little field publishers, Inc; 2003. p. 42–50.
- Wu J, Nofziger DL. Incorporating temperature effects on pesticide dug radiation into a management model. *J environment Quali*. 1999;28:92–100.
- Lehnert M. The soil temperature regime in the urban and suburban landscapes of olomoric, Czech Republic. *Moravian geographical reports*. 2013;21(3):27–36.
- Probert RJ. The role of temperature in the regulation of seed dormancy and germination. In Fenner editor. *Seeds: the ecology of regeneration in plant communities*. England: CABI publishing; 2000. p. 261–292.
- Elias EA, Cichota R, Torraiani HH, et al. Analytical soil temperature model: correction for temporal variation of daily amplitude. *Soil science society of America Journal*. 2004;68(3):784–788.
- Zhao Y M, Xiao Mong MA, Wang L. Variations of soil temperature and soil moisture in Northern Tibet plateau. *Journal of Glaciology and Geocryology*. 2007;29(4):578–583.
- Nwankwo C, Ogunurue D. An investigation of temperature variation at soil depths in peats of Southern Nigeria. *American journal of environmental engineering*. 2012;2(5):142–147.
- Chiemeka IU. Soil temperature profile at Uturu, Nigeria. *Pacific Journal of Science and Tech*. 2010;11(1):478–482.
- Sándor R, Fodor N. Stimulation of soil temperature dynamics with models using different concepts. *The scientific world journal*. 2012;200:12–20.
- Martias AD, Musil S. Temperature and thermal diffusivity within a range land soil near Oracle, Arizona. *Journal of the Arizona–Nevada academy of science*. 2012;44(1):15–21.
- Elizaberashvili ES, Urashadze TF, Elizaberashvili ME, et al. Temperature regime of some soil types in Georgia. *Eurasian soil science*. 2010;43(4):427–435.
- Decker KT, Wang D, Waite C, et al. Snow removal and ambient air temperature effects on forest soil temperatures in Northern Vermont. *Soil science society of America Journal*. 2003;67(4):1234–1242.
- Abu–Hamdah NH, Reeder RC. Soil thermal conductivity affects of density, moisture, salt concentration and organic matter. *Soil science society of America Journal*. 2000;64(4):1285–1290.
- Lu S, Ren T, Gong Y, et al. An improved model for predicting soil thermal conductivity from water content at room temperature. *Soil science society of America Journal*. 2009;71(1):8–14.
- Horton R, Bristow RI, Rluitenber GJ, et al. Crop residue effects on surface radiation and energy–balance review. *Theoretical and applied climatology*. 1996;54(1–2):27–37.
- Shiners KJ, Nelson WS, Wang R. Effects of residue free band width on soil temperature and water content. *Transactions of the ASAE*. 1994;37(1):39–49.
- Daliya R, Ingwersen J, Streek T. The effect of mulching and tillage on the water and temperature regimes of a loess soil. Experimental findings and modeling. *Soil and tillage research*. 2007;96(1–2):52–63.
- Elizaberashvili ES, Elizaberashvili ME, Magalekelidze RV, et al. Specific features of soil temperature regime in Georgia. *Eurasian soil science*. 2007;40(7):761–765.
- Jamenez C, Tejedor M, Rodriguez M. Influence of land use changes on soil temperature regime of andosols on Tenerife, Canary Island, Spain. *European Journal of soil science*. 2007;58(2):445–449.
- Fang CM, Smith P, Monorieff JB, et al. similar response of cabile and resistant soil organic matter pools to changes in temperature. *Nature*. 2005;436:881–883.
- Abu–Hamdah NH. Thermal properties of soils as affected by density and water content. *Biosystems engineering*. 2003;86(1):97–102.
- Arkhanelskaya TA, Umarola AB. Thermal diffusivity and temperature regime of soils in large lysimeters of the experimental soil station of Moscow State University. *Eurasian Soil Science*. 2008;41(3):276–285.
- Ochsnor TE, Horton R, Ren T. A new perspective on soil thermal properties. *Soil science society of American journal*. 2001;65(6):1641–1647.
- Conant RT, Drijber RA, Haddix MC. Sensitivity of organic matter decomposition to warming varies with its quality. *Global change biology*. 2008;14(4):868–877.
- Allison D, Wallenstein MD, Bradford MA. Soil carbon response to warming dependent on microbial physiology. *Nature Geoscience*. 2010;3:336–340.
- Wallenstein MD, Allison S, Ernakovich J, et al. Controls on the temperature sensitivity of soil enzymes, a key driver of in-situ enzyme activity rates. *Soil Enzymology*. 2010;15:245–258.
- Yan L, Hangwen X. Effects of soil temperature, flooding and organic matter addition in N2O emissions from a soil of Hongze lake wetland, China. *J Appli Soil Ecol*. 2014;29:173–183.

28. Kaiser C, Meger A, Biasi C, et al. Conservation of soil organic matter through cryoturbation in arctic soils in Siberia. *J Appl Soil Ecol.* 2007;112(G2):173–183.
29. Allison SO. Cheaters, diffusion and nutrient content decomposition by microbial enzymes in spatially structured environments. *Ecology letters.* 2005;8(6):626–635.
30. Gilichinsky DA, Rivikina EM. Permafrost microbiology. In *encyclopaedia of Geo biology.* Ratner J, et al. editors. Netherlands: Springer; 2011. p. 726–732.
31. Broadbent FE. Soil organic matter. *Sustainable options in land management.* 2015;2:34–38.
32. Fierer N, Gruine JM, McLauchlan K, et al. Litter quality and the temperature sensitivity of decomposition. *Ecology.* 2005;86(2):320–326.
33. Ubeda X, Pereira P, Outeiro L, et al. Effects of fire temperature on the physical and chemical characteristics of the ash from two plot of cork oak (*Quercus suber*). *Land degradation development.* 2009;20(6):589–608.
34. Certini G. Effects of fire in properties of forest soils: A review. *Oecologia.* 2005;143(1):1–10.
35. Rengasmy P, Churchman GJ. Cation exchange capacity, exchangeable cations and solidity. In: Pevevilli KI, et al. editors. *Soil analysis.* Australia: an interpretation manual CSIRO publishing; 2009.
36. Yilvainio K, Pettovuori T. Phosphorus acquisition by barley (*Hordeum vulgare*) at suboptimal soil temperature. *Agricultural and food science.* 2012;21:453–461.
37. Gahoonia TS, Nielsen NE. Phosphorus uptake and growth of root hairless barley mutant (bald root barley) and wild type in low and high-p soils. *Plant, cell and environment.* 2003;26:1759–1766.
38. Mensies N, Gillman G. Plant growth limitation and nutrient loss following piled burning in slash and burn agriculture. *Nutr Cycl Agroecosyst.* 2003;65(1):23–33.
39. Arocena J, Opio C. Prescribed fire-induced changes in properties of sub-boreal forest soil. *Geoderma.* 2003;113(1–2):1–16.
40. Pardini G, Gispert M, Dunjo G. Relative influence of wildlife in properties and erosion processes in different Mediterranean environments in NE Spain. *Sci Total environment.* 2004;328(1–3):237–246.
41. Assaf I, Marcos L, Marcelo S, et al. Forest fire effects on soil chemical and physiochemical properties, infiltration, runoff and erosion in a semi-arid Mediterranean region. *Geoderma.* 2004;221(222):131–138.
42. Fox DM, Darboux F, Carrega P. Effects of fire induced water repellency on soil aggregate stability, splash erosion and saturated hydraulic conductivity for different size fractions. *Hydrol process.* 2007;21(17):2377–2384.
43. Terefe T, Mariscal Sancho I, Peregrina F, et al. Influence of heating on various properties of sic Mediterranean soils. A laboratory study. *Geoderma.* 2008;143(3–4):273–280.
44. Toselli M, Flore JA, Marogoni B, et al. Effects of root-zone temperature on nitrogen accumulation by non-breeding apple trees. *J hort Sci Biotech.* 1999;74:118–124.
45. Weih M, Karlson S. The nitrogen economy of mountain birch seedlings: implication for winter survival. *J Ecol.* 1999;87(2):211–219.
46. Grossnickle SC. *Ecophysiology of Northern spruce species in the performance of planted seedlings.* NRC–CNRC, NRC, Ottawa Ont, Canada: Research press; 2000. p. 325–407.
47. Lahti M, Aphalo PJ, Finer L, et al. Soil temperature, gas exchange and nitrogen status of 5-year old Norway spruce seedlings. *Tree physiol.* 2002;22(18):1311–1316.
48. Repo TI, Leinonen AR, Finer L. The effect of soil temperature on bud phenology, chlorophyll fluorescence, carbohydrate content and cold hardiness of Norway spruce seedlings. *Physio Plant.* 2004;121:93–100.
49. Balland V, Arp PA. Modeling soil thermal conductivities over a wide range of conditions. *Journal of environmental engineering and science.* 2005;4(6):549–558.
50. Bronick CJ, Lal R. Soil structure and management: A review. *Geoderma.* 2005;124(1–2):3–22.
51. Buchas GD. Soil temperature regime. In Smith KA, et al. editors. *Soil and environmental analysis: physical methods.* New York, USA: Marcel Dekker; 2001. p. 539–594.
52. Conyers M, Newton P, Condon J, et al. Long term trials end with a quasi-equilibrium between C, N, and pH and implication for C sequestration. *Soil research.* 2012;50:527–535.
53. Mc Michael BC, Burke JJ. Soil temperature and root growth. *Hort Science.* 1998;33(6):947–951.
54. Noborio K, McLanes KJ. Thermal conductivity of salt-affected soils. *Soil science society of America Journal.* 1993;57(2):329–334.
55. Pradel E, Pieri P. Influence of glass layer in vineyard soil temperature. *Australian journal of grape and wine research.* 2000;6(1):59–67.
56. Puhe J. Growth and development of the root system of Norway spruce (*Picea abies*) in forest stands—a review. *Ecol Manag.* 2003;175(1–3):253–273.