Effect of Supplemental Irrigation Interval and Mulching on Hydrothermal Properties of an Alfisol Cropped with Cucumis sativus

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Abstract. Irrigation and mulching are important soil management practices for sustainable food productions. Different irrigation and mulching treatments could however affect soil hydrothermal properties and hence the soil productivity. This study evaluated the effect of drip irrigation interval and mulching type on selected hydrothermal properties of an Alfisol cropped with Cucumber (Cucumis sativus). A field experiment, laid out in a randomized complete block design (RCBD) with three replications, was conducted with split-plot arrangement having irrigation interval as the main-plot and mulching material as the sub-plot. Three irrigation intervals: two days per week (D²), four days per week (D⁴) and six days per week (D⁶); and two mulching materials: plastic (M₁) and spear grass (Imperata cylindrica) (M₂) were applied. There were nine (9) treatment combinations which gave a total of 27 plots. Soil physical properties of soil water content (SWC), bulk density (BD) and saturated hydraulic conductivity (Ksat) were monitored during the growing cycle. Thermal conductivity, resistivity, diffusivity and volumetric specific heat of the soil were measured. There was no significant difference in thermal conductivity, thermal resistivity, thermal diffusivity and volumetric specific heat, under the irrigation intervals. The cucumber yield under the mulch treatment was in the order of M₁ > M₂ > M₃. The Cucumis sativus yield was highest under M₁ and D₄ (11629.63 kg/ha) and lowest in M₃ and D₂ (3362.22 kg/ha). The mulching treatment had significant effect on the soil temperature, SWC, BD and yield while the irrigation treatment had no significant effect on the soil properties considered.

1 Introduction

The importance of vegetables in human diets cannot be overemphasised. In recent times, particularly in Nigeria, a larger percentage of the population has become educated and conscious of their health. To this end, many individuals are shifting their diet to vegetable-based one. Cucumber, one of the most popular vegetables, because of its many health benefits has become a household name in many Nigerian homes.
However, the production of the vegetable, particularly in the South is far less than the demand [1]. Cucumber, a popular member of the Cucurbitaceae family comprises 90 genera and 750 species [2].

In modern agriculture, sustaining the production of food at higher degrees to meet the growing demand for the world population from the limited land and water resources as well as a smaller rural labour force, has become an issue of real concern [3,4]. As a result of the pressure on the limited freshwater and land resources, sustaining productivity at higher levels will require the efficient use of these resources. Irrigation and mulching have become very important agricultural practices in managing the limited soil and water resources. In many areas of the world, the quantity and timing of rainfall are not adequate to meet the water requirements of crops, which could result in reduced crop productivity. This has made irrigation essential. Irrigation intervals and mulching materials by modifying the soil hydrothermal properties may affect plant growth, development, and crop production [5,6]. Irrigation and mulching will create thermal variations in the soil, and this has the potential of creating changes in physical, chemical and biological properties of the soil with a likely consequence of poor crop performances. Increase in soil temperature may reduce microbial activities in the soil which will consequently affect nutrient conversion. Other thermal properties of the soil such as thermal conductivity, thermal resistivity, volumetric specific heat and thermal diffusivity may affect water movement as well as availability in the soil for plant use. There is dearth of information on the combined effects of irrigation interval and type of mulching on some hydraulics and physical properties of soil. The work therefore was designed to investigate the effect of irrigation interval and mulching type on the properties of an Alfisol cropped with cucumber in Ogbomoso, Nigeria.

2 Materials and Methods

2.1 Description of the experimental site

The field experiment was conducted at the Teaching and Research Farm of the Department of Agricultural Engineering, Ladoke Akintola University of Technology, Ogbomoso (8°10'06" N and 4°16'12" E), in Southwest Nigeria. The experiment was conducted between August and October 2016. The area receives an average annual rainfall of about 1200 mm [7]. The mean maximum and minimum temperatures are 33 and 28 °C, respectively. The relative humidity of the area is relatively high (approximately 74%) throughout the year except in January when the dry monsoon wind blows from the North [8].

2.2 Experimental design and treatments

The experiment was laid out in a randomised complete block design (RCBD), in a split-plot arrangement, with two sets of experimental treatments. Three drip irrigation intervals were allotted in the main plots and two mulching materials were arranged as sub-plots. The irrigation treatments that were used are intervals of every two days (D2), every four days (D4) and every six days (D6). The mulching treatments were plastic mulch (M1), grass mulch (M2) and no mulch (M3), which served as control. The application density of spear grass (*Imperata cylindrica*) used was 7.4 kg/m². The experiment was set up in three replicates, thus making a total number of 27 sub-plots. Each sub-plot was randomly treated with the mulching materials. Irrigation treatments D2, D4 and D6 were applied for 15, 30 and 45 minutes, respectively at each application schedule. This ensured that the same quantity of water was applied to each experimental plot. The drip irrigation set pre-fitted with pressure compensating emitters, delivered water to the field at a rate of 1.1 L h⁻¹. The layout of the experiment is shown in Fig. 1.
Figure 1. The Field Layout

Legend
M1 = Plastic mulch
M2 = Grass mulch
M3 = No mulch
D2 = Interval of every two days
D4 = Interval of every four days
D6 = Interval of every six days
2.3 Field and crop management
The cucumber seeds ("Marketer" variety) were sown manually to the depth of 2 – 3 cm with two seeds per stand and at a seed spacing of 30 cm and row spacing of 90 cm. This translated to a population of 37,037 plants/ha and a plant nutrient area (PNA) of 2700 cm²/plant. The field was adequately and uniformly irrigated for crop emergence and establishment. After crop establishment, the irrigation treatments were applied. Weeding was done manually as required. Staking and training of vines were carried out at the appropriate time.

2.4 Soil sampling and evaluation
Prior to irrigation treatments, both disturbed and undisturbed soil samples were collected to evaluate the initial status of the soil. Disturbed soil samples were collected with the aid of shovel and hand trowel. Undisturbed samples were collected at 0 – 10, 10 – 20, 20 – 30 and 30 – 40 cm soil layer using core samplers of diameter 57 mm and height 40 mm from two representative profiles that were dug within the experimental field. Samples were kept in sealed plastic containers and transported to the laboratory for analysis. The soil samples were analysed to evaluate soil texture, soil bulk density and saturated hydraulic conductivity. The granulometric composition was determined using hydrometer method (ASTM 152N) following the procedure described by [9]. The textural class was obtained from the USDA textural triangle.

2.5 Field measurements
Field measurements were made and recorded on a weekly basis, starting from 2 weeks after sowing (WAS). The field measurements carried out were saturated hydraulic conductivity (Ksat), bulk density, soil water content (measured by the gravimetric method) and soil thermal properties using KD2 pro thermal analyser (Decagon Devices). Soil thermal properties measured include thermal conductivity, thermal resistivity, volumetric specific heat and thermal. HYELEC MS6501 K−Type Digital Thermometer was used for the measurement of soil temperature. Three plants were randomly selected in each treatment. The selected plants were monitored for fruit yield. The yield was measured using a digital weighing balance (model MP 10001, Gallenhamp).

2.6 Statistical data analysis
SPSS (v.17) software was used for the statistical analysis of the data collected. The data collected were statistically analysed using analysis of variance (ANOVA) techniques. Duncan Multiple Range Test (DMRT) was used to compare the means at $\alpha_{0.05}$.

3 Results and Discussion

3.1 Soil physical properties
Some soil physical properties of the site before the experiment were presented in Table 1. The result indicated that there was no significant difference in the physical characteristics of the soil considered at the different layers except for saturated hydraulic conductivity (Ksat), which has a lower value of 7.06 cm/hr at the surface layer. The low value of Ksat at the surface may be attributed to the soil surface conduction such as the presence of dried organic matter which will initially absorb moisture and swell up before allowing the passage of water through it. The presence of organic matter may also block the soil pore spaces. The texture of all the four layers evaluated was sandy loam. Bulk density ranged between 1.49 and 1.60 g cm⁻³, which was not significantly different.
Table 1. Some Soil Properties of the Site before the Experiment

| Soil depth, cm | Bulk density, g/cm³ | Ksat, cm/hr | Soil Texture |
|---------------|---------------------|-------------|--------------|
| 0 – 10        | 1.52a               | 7.06a       | Sandy Loam   |
| 10 – 20       | 1.53a               | 18.87b      | Sandy Loam   |
| 20 – 30       | 1.49a               | 12.11b      | Sandy Loam   |
| 30 – 40       | 1.60a               | 17.86b      | Sandy Loam   |

Means followed by the same letter are not significantly different (DMRT, p<0.05)

3.2 Effect of mulch and irrigation interval on soil properties.

3.2.1 Soil temperature. The soil temperature in the plastic mulch treatments were significantly higher than the grass mulch and no-mulch treatment. Grass mulch values were not significantly different from the no-mulch values (Table 2). No significant differences were found under the irrigation intervals though there was a mean increase in soil temperature in the order D₆ > D₄ > D₂.

Mulching materials served as a buffer media between the atmosphere and the soil surface and hence influenced soil temperature. The plastic mulch was able to increase average soil temperature more than the grass mulch due to the property of the plastic to absorb solar energy more effectively than the grass mulch. Plastic mulch is able to radiate much of this energy as sensible heat to the air above and the soil below.

Table 2. Effect of Mulch and Irrigation Interval on Average Soil Temperature (°C)

| Irrigation Interval | Grass Mulch | Plastic Mulch | No mulch | Mean |
|---------------------|-------------|---------------|----------|------|
| D₂                  | 25.14ₐ       | 25.96ₐ        | 25.12ₐ   | 25.41|
| D₄                  | 25.45ₐ       | 25.99ₐ        | 25.45ₐ   | 25.63|
| D₆                  | 25.55ₐ       | 26.20ₐ        | 25.44ₐ   | 25.73|
| Mean                | 25.38       | 26.05         | 25.34    |

Letters in superscript and subscript indicate horizontal and vertical comparisons, respectively. Means followed by the same letter are not significantly different (DMRT, p<0.05)

3.2.2 Soil water content. Average SWC was significantly lower under the plastic mulch treatment compared to the grass and no-mulch treatment for irrigation intervals D₂ and D₄ (Table 3). The effect of the mulching treatments was not significant for irrigation interval D₆. These results were in disparity with the results of some other researchers. For example experiments conducted by [6] and [10] reported that more relative moisture conservation under plastic mulch. This disparity could be due to the shedding of excessive water by the plastic mulch away from the crop root zone during periods of rainfall since this experiment was under supplemental irrigation. The slight increase in average SWC values under the grass mulch (0.135 cm³ cm⁻³) could be as a result of the reduction in the evaporation rate influenced by the mulch material as compared to the open bare soil (0.128 cm³ cm⁻³). No significant differences was observed under the irrigation intervals. This could be attributed to the even distribution of moisture brought about by rainfall.

Table 3: Effect of Mulch and Irrigation Interval on Average Soil Water Content (cm³ cm⁻³)
### Table 4. Effect of Mulch and Irrigation Interval on Average Bulk Density (g cm⁻³)

| Irrigation Interval | Mulch Treatments  | Mean |
|---------------------|-------------------|------|
|                     | Grass             | Plastic | No mulch |
| D₂                  | 1.56cy            | 1.48aₓ  | 1.52bₓ   | 1.52 |
| D₄                  | 1.52bₓ            | 1.44aₓ  | 1.51bₓ   | 1.49 |
| D₆                  | 1.53bₓy           | 1.46aₓ  | 1.50bₓ   | 1.49 |
| Mean                | 1.53              | 1.46    | 1.51     |

Letters in superscript and subscript indicate horizontal and vertical comparisons, respectively. Means followed by the same letter are not significantly different (DMRT, p<0.05)

### Table 5. Effect of Mulch and Irrigation Interval on Average Saturated Hydraulic Conductivity (cm/hr)

| Irrigation Interval | Mulch Treatments  | Mean |
|---------------------|-------------------|------|
|                     | Grass             | Plastic | No mulch |
| D₂                  | 53.64aₓ           | 68.84aₓ | 68.14aₓ  | 63.54 |
| D₄                  | 82.61aᵧ           | 60.26aₓ | 81.69aₓ  | 74.85 |
| D₆                  | 69.78aₓy          | 59.44aₓ | 62.32aₓ  | 63.85 |

Letters in superscript and subscript indicate horizontal and vertical comparisons, respectively. Means followed by the same letter are not significantly different (DMRT, p<0.05)

3.2.3 **Bulk density.** Plastic mulch significantly caused a reduction in bulk across the irrigation intervals. Values under grass and no-mulch were not significantly different except for D₂ where grass mulch was significantly the highest (Table 4). Compared to the control, plastic reduced average bulk density by 0.04 g cm⁻³ while grass increased average bulk density by 0.03 g cm⁻³. The reduction in bulk density could be attributed to the higher temperature under plastic mulch which made the soil loose and well aerated. Thus, roots have easy access to adequate oxygen which promotes high microbial activity and hence reduces bulk density. Low soil bulk density enhances access to soil moisture and increases nutrient uptake resulting in higher crop yield.

Irrigation interval D₂ had the highest average bulk density. This could be attributed to more alternate wetting and drying cycles, indicating that slaking and dispersion phenomenon was not necessarily at play [11].

3.2.4 **Saturated hydraulic conductivity (Ksat).** Saturated hydraulic conductivity (Ksat) values showed no significant differences under the mulching treatments (Table 5). The irrigation intervals showed no significant differences for Ksat values under plastic and no-mulch. Under grass mulch, D₂ and D₄ gave significantly different values. This could be attributed to the corresponding significant difference and improvement of bulk density under the same intervals of consideration (Table 4). Saturated hydraulic conductivity is largely associated with porosity and pore size distribution; the larger the pores, the more water is transmitted through the soils.
### 3.3 Effect of mulch and irrigation interval on soil thermal properties

The average thermal conductivity values showed no significant differences under the mulch treatments except under D4 where M1D4 was significantly lower (Table 6). This could be as a result of a relative reduction in bulk density and soil water content in M1D4. Since the thermal conductivity of the soil is closely related to the amounts of the solid, liquid and gas phases that make up the soil, as the bulk density of a soil decreases, its thermal conductivity decreases. Because as the bulk density increases, the soil void ratio and hence air amount decreases thereby causing the solid particles to contact more tightly. The filling of these voids with water instead of air increases thermal conductivity. The thermal conductivity of water is 25 times better than that of the air. Hence, as the water content of the soil increases, thermal conductivity also increases.

#### Table 6. Effect of Mulch and Irrigation Interval on Average Thermal Conductivity (W/(mK))

| Irrigation Interval | Mulch Treatments | Mean |
|---------------------|------------------|------|
|                     | Grass            | Plastic | No mulch |      |
| D2                  | 1.42a           | 1.33a  | 1.56a  | 1.43 |
| D4                  | 1.49b           | 1.21a  | 1.49a  | 1.40 |
| D6                  | 1.41b           | 1.28a  | 1.54a  | 1.41 |
| Mean                | 1.44            | 1.27   | 1.53   |      |

Letters in superscript and subscript indicate horizontal and vertical comparisons, respectively. Means followed by the same letter are not significantly different (DMRT, p<0.05)

Thermal resistivity and conductivity are inversely related. This is proven by the significant increase in M1D4 (Table 7). The thermal resistivity, like the conductivity, is also a function of SWC and BD. The lower the BD and SWC, the higher the thermal resistivity as the medium for thermal movement are not readily available. There were no significant differences in the values of volumetric specific heat from the mulching treatments as well as the irrigation intervals, though grass mulch had the highest average value of 1.712 mJ/(m³K) followed by no mulch and plastic mulch with values of 1.697 and 1.665 mJ/(m³K), respectively (Table 8). This differences could be as a result of the water content as these values also follow the trend of the average soil water content from the respective mulch treatments (Table 3). Water has a higher specific heat capacity than air. Therefore soils with higher moisture content will have higher volumetric heat because of replacement of air in the soil void spaces with water. This result agrees with the findings of Abu-Hamdeh [12] who proved that specific heat increased with increasing water content. Thermal diffusivity values were not significantly different under the mulching treatments. Average values were highest in no-mulch (0.920 mm²/s), lowest in plastic mulch (0.760 mm²/s) while grass mulch had a value of 0.844 mm²/s (Table 9). The differences in the values also followed the trend of the soil water content under the respective mulch treatment, which is also indicative of the fact that soil water content played a role in influencing the thermal diffusivity property of the soil. Since thermal diffusivity is the ratio of thermal conductivity and volumetric heat capacity. It showed that the increase in thermal conductivity with increase in moisture content was relatively greater than in volumetric heat capacity.

There was no significant difference in thermal conductivity, thermal diffusivity, volumetric specific heat and thermal resistivity under the irrigation intervals. This could be as a result of the ambient condition of the climate. Rainfall causes thermal equilibration. The soil moisture dynamics tend to be more uniform than when irrigation is applied.
Table 7. Effect of Mulch and Irrigation Interval on Average Thermal Resistivity ((°C·cm)/W)

| Irrigation Interval | Mulch Treatments | Mean |
|---------------------|------------------|------|
|                     | Grass            | Plastic | No mulch |      |
| D₂                  | 72.59ₐₓ          | 78.55ₐₓ | 65.85ₐₓ | 72.33 |
| D₄                  | 68.24ₐₓ          | 87.17ₐₓ | 67.61ₐₓ | 74.34 |
| D₆                  | 73.46ₐₓ          | 102.41ₐₓ | 66.49ₐₓ | 80.79 |
| Mean                | 71.43            | 89.38   | 66.65    |      |

Letters in superscript and subscript indicate horizontal and vertical comparisons, respectively. Means followed by the same letter are not significantly different (DMRT, p<0.05)

Table 8. Effect of Mulch and Irrigation Interval on Average Volumetric Specific Heat ((MJ/(m³·K))

| Irrigation Interval | Mulch Treatments | Mean |
|---------------------|------------------|------|
|                     | Grass            | Plastic | No mulch |      |
| D₂                  | 1.64ₐₓ           | 1.70ₐₓ | 1.69ₐₓ | 1.68 |
| D₄                  | 1.80ₐₓ           | 1.61ₐₓ | 1.74ₐₓ | 1.72 |
| D₆                  | 1.70ₐₓ           | 1.69ₐₓ | 1.66ₐₓ | 1.68 |
| Mean                | 1.71             | 1.67   | 1.70    |      |

Letters in superscript and subscript indicate horizontal and vertical comparisons, respectively. Means followed by the same letter are not significantly different (DMRT, p<0.05)

Table 9. Effect of Mulch and Irrigation Interval on Average Thermal Diffusivity (mm²/s)

| Irrigation Interval | Mulch Treatments | Mean |
|---------------------|------------------|------|
|                     | Grass            | Plastic | No mulch |      |
| D₂                  | 0.867ₐₓ          | 0.787ₐₓ | 0.931ₐₓ | 0.862 |
| D₄                  | 0.835ₐₓ          | 0.750ₐₓ | 0.869ₐₓ | 0.818 |
| D₆                  | 0.831ₐₓ          | 0.742ₐₓ | 0.958ₐₓ | 0.844 |
| Mean                | 0.844            | 0.760 | 0.920    |      |

Letters in superscript and subscript indicate horizontal and vertical comparisons, respectively. Means followed by the same letter are not significantly different (DMRT, p<0.05)

3.4 Cucumber yield

The average cucumber yield under the mulch treatment was in the order of M₁>M₂>M₃ (Table 10), though yield under grass and no mulch was not significantly different. Relative to the M₁ as control, yield increased by 211.9, 79 and 73.9% under plastic mulch in D₂, D₄, and D₆, respectively. Fruit yield under the different irrigation intervals showed no significant difference except under D₂ where fruit yield under no mulch was significantly lower than D₄ and D₆. The highest and lowest fruit yield was 11629.63 and 3362.22 kg/ha under M₁D₄ and M₁D₂, respectively. The increase in fruit yield by mulches is in agreement with findings of several researchers. For example, Yaghi et al. [6] reported that non-mulched treatments had lower yield amounts of cucumber compared to treatments with transparent and black plastic mulching. These results also support findings of Sahin et al. [13], El-Shaikh and Fouda [14], Spiżewski et al. [15], Mikkelsen et al. [16], and Choudhary et al. [17]. The significant increase in fruit yield under plastic mulch could be due to the increase in soil temperature brought about by the plastic mulch which provides a more suitable
environment for plant growth and fruit development as cucumber is known to thrive better under slightly increased soil temperature [18]. The comparative reduction in yield under grass mulch could also be attributed to the allelopathic effect of the grass mulch (*Imperata cylindrica*) on the growth and development of the cucumber plants [19].

**Table 10. Effect of Mulch and Irrigation Interval on Average Fruit Yield (kg/ha)**

| Irrigation Interval | Mulch Treatments | Mean       |
|---------------------|-----------------|------------|
|                     | Grass           | Plastic    | No mulch   | Mean   |
| D2                  | 5373.09<sup>a</sup> | 10487.16<sup>b</sup> | 3362.22<sup>a</sup> | 6407.49 |
| D4                  | 6278.27<sup>a</sup> | 11629.63<sup>b</sup> | 6496.79<sup>ab</sup> | 8134.90 |
| D6                  | 7350.62<sup>a</sup> | 10810.37<sup>b</sup> | 6215.80<sup>a</sup> | 8125.60 |
| Mean                | 6333.99         | 10975.72   | 5358.27    |         |

Letters in superscript and subscript indicate horizontal and vertical comparisons, respectively. Means followed by the same letter are not significantly different (DMRT, p<0.05)

### 4 Conclusion

The effect of supplemental irrigation interval and mulching material on some soil hydrothermal properties and yield of cucumber were investigated. From the study, plastic mulch increased soil temperature, and decreased soil water content, bulk density and saturated hydraulic conductivity. Grass mulch increased soil water content and bulk density. Both the grass and plastic mulch increased the fruit yield. However, plastic mulch gave the higher yield. The irrigation intervals generally had little or no effect on the measured hydrothermal parameters. Based on the findings of this work, it is recommended that cucumber should be grown with plastic mulch and a drip irrigation interval of four days. Further studies is also recommended for investigation under total irrigation and other varieties of cucumber. The effects of plastic mulch of different colour as well as other types of organic mulching materials (grasses) on the soil properties and yield of cucumber should be investigated.

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