Effect of Water Stress on Leaf Temperature, Transpiration Rate, Stomatal Diffusive Resistance and Yield of Banana

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Abstract The present investigation was undertaken under field condition to study the effect of water deficit on leaf temperature, transpiration rate, stomatal diffusive resistance and yield of banana cultivars and hybrids. Stress was imposed at different critical stages viz., 3rd, 5th, 7th and 9th month after planting. The stress was given by scheduling irrigation at the 50% available soil moisture (ASM) characteristic during critical stages. The soil moisture content was analyzed by using pressure plate membrane apparatus. In control plots, the irrigation was given at the ASM of 80% with the soil water potential of around -6 bars and in the case of stressed plots; the irrigation was given when an ASM reached 50% with the soil water potential of -14 bars. In stressed plots, 50% ASM was reached around 30 days. In this present study conducted with twelve cultivars and hybrids with three replications. The data were analyzed by using split plot design. The research revealed that, leaf temperature was usually negatively correlation with transpiration rate. Transpiration rate revealed a decreasing trend throughout the growth period of the crop with increasing in leaf temperature and stomatal diffusive resistance. The cultivars and hybrids of Karpuravalli, Karpuravalli×Pisang Jajee, Saba, and Sannachenkathali was identified as tolerant to water stress with highly accelerated in transpiration rate by water stress treatment with slight increase in leaf temperature over control.

Keywords Banana; Water deficit; Leaf temperature; Transpiration rate; Stomatal diffusive; Resistance and yield

Introduction Water is one of the most essential components for plant organisms. It serves as a solvent of different solutes and transporter of solutes between cells and organs. The greater part of water uptake from the soil is consumed by transpiration preventing temperature increases. The rate of transpiration is directly related to the gradient of water vapour concentration in the intercellular spaces of the leaf and the ambient air. Rapid changes in the transpiration rate from a leaf or leafy shoot as a result of excision of the leaf or shoot have been observed in many plants including banana plants (Anderson et al., 1994). Rufelt (1963) stated that the increased water supply to the leaf is presumably responsible for increased stomatal opening and increased transpiration in banana, which is called “Rufelt’s hypothesis”. Allerup (1960) reported that increased stomatal opening as a result of excision of young barley leaves considers this as for Rufelt’s hypothesis. High rate of transpiration was recorded even when the stomata were apparently partially closed in banana (Shmueli, 1953). A positive correlation between relative water content and gas exchange activities was reported by David (2002) and the reduction of RWC strongly reduced photosynthesis and transpiration. Therefore, plant growth and development severely depends on water availability (Turner, 1990) and it is the primary limiting factor for banana plant growth in terrestrial ecosystems. Wilting of mesophyll cells and withdrawal of water from the epidermal and subsidiary cells permitted the guard cells to bulge outward causing opening of the stomatal pores. Decreased water supply caused the mesophyll cells to wilt. A strong stomatal opening response was observed under conditions of low transpiration. Under such conditions there would have been very little tension to relieve. Increased stomatal opening also occurred as a
result of freezing rather than cutting the vascular supply to the leaf (Rufelt, 1963). Shmueli (1953) dealing with the concept of stomata and transpiration stated that stomatal closure was a major cause for decline in transpiration rate during water stress. Understanding banana plant response to soil moisture deficit and expression of leaf temperature, transpiration rate and stomatal diffusive resistance traits are of basic scientific interest and have potential application bananas (Musa spp). With a view to elicit information on these aspects, field and laboratory investigations were undertaken. M1 maintained the temperature around 30°C to 33°C, whereas M2 recorded an elevated temperature of 30 to 36°C during the growth period. Among the subplot treatments, S11 and S12 recorded the highest temperature of about 35.3°C, whereas S1 recorded the lowest temperature of 32.6°C. All the other subplot treatments maintained the temperature of around 34°C. Interaction effects of M at S and S at M revealed significant difference at all the stages of growth. Leaf temperature had positive correlation with yield were noticed in this present research study.

**Result**

**Leaf temperature**

Leaf temperature was significantly influenced by both main plot and subplot treatments over the entire period of growth (Table 1; Figure 1). The main plot treatment M1 maintained the temperature around 30°C to 33°C, whereas M2 recorded an elevated temperature of 30 to 36°C during the growth period. Among the subplot treatments, S11 and S12 recorded the highest temperature of about 35.3°C, whereas S1 recorded the lowest temperature of 32.6°C. All the other subplot treatments maintained the temperature of around 34°C. Interaction effects of M at S and S at M revealed supporting evidence significant difference at all the stages of growth. Leaf temperature had positive correlation with yield were noticed in this present research study.

![Figure 1 Correlation of leaf temperature and yield in banana cultivars and hybrids](image)

**Stomatal Diffusive Resistance**

Stomatal Diffusive Resistance (SDR) showed an progressive increasing trend from 3rd to 7th MAP stage with a sharp decline thereafter. There existed significant differences in main and sub plot treatments at all stages (Table 3). Comparison of two treatment at main plot level revealed that, M2 had higher SDR of 0.078 s cm^{-1} than M1 (0.071 s cm^{-1}) at 7th MAP stage. Among the sub-plot treatments, S12 recorded the highest SDR of 0.099, 0.101, 0.109, 0.103 and 0.084 s cm^{-1} at 3rd, 5th, 7th, 9th MAP and at harvest stages, followed by S11 and S10. The treatment S1 showed a lowest stomatal diffusive resistance of 0.056, 0.052, 0.065, 0.059 and 0.039 s cm^{-1} at all the growth stages. Interaction effects of M at S and S at M revealed significant difference at all the stages of growth.

![Figure 2 Correlation of transpiration rate and yield in banana cultivars and hybrids](image)

**Transpiration rate**

The time trend of transpiration rate revealed a decreasing trend throughout the growth period of the crop (Table 2; Figure 2). Between the two main plot treatments, M1 (86.3, 82.4, 77.7, 74.7 and 72.5 µg H2O cm^{-2} s^{-1}) registered significantly high rate of transpiration over M2 (80.5, 76.6, 71.9, 69.0 and 67.0 µg H2O cm^{-2} s^{-1}) at 3rd, 5th, 7th, 9th and at harvest stages. Among the sub-plot treatments, S1 registered higher rate of transpiration (94.5, 88.5, 84.6, 80.9 and 76.0 µg H2O cm^{-2} s^{-1}) at all the growth stages, which was followed by S2, S3 and S4. The significantly lower transpiration rate was, however registered by S11 and S12 (62.4 and 63.6 µg H2O cm^{-2} s^{-1}) at 7th MAP. Interaction effects of M at S and S at M were significant at all growth stages. In this present research study, transpiration rate had positive correlation with yield.
### Table 1 Effect of water stress on leaf temperature (˚C) at different growth stages of banana cultivars and hybrids

| Treatments | 3rd MAP | 5th MAP | 7th MAP | 9th MAP | Harvest | Mean |
|------------|---------|---------|---------|---------|---------|------|
| **Main plot** |         |         |         |         |         |      |
| M1         | 33.08   | 31.19   | 33.19   | 31.70   | 29.22   | 31.68|
| M2         | 34.65   | 32.76   | 36.30   | 33.27   | 30.79   | 33.55|
| Mean       | 33.87   | 31.97   | 34.74   | 32.49   | 30.01   | 32.62|
| SEd        | 0.22    | 0.24    | 0.24    | 0.23    | 0.21    |      |
| CD (P=0.05) | 0.98    | 1.03    | 1.05    | 1.00    | 0.92    |      |
| **Sub plot** |         |         |         |         |         |      |
| S1         | 32.95   | 30.86   | 32.60   | 31.65   | 28.68   | 31.34|
| S2         | 33.03   | 32.20   | 33.59   | 32.73   | 31.97   | 33.10|
| S3         | 33.71   | 31.62   | 33.69   | 32.72   | 29.44   | 32.23|
| S4         | 33.90   | 31.98   | 33.96   | 32.34   | 31.00   | 32.83|
| S5         | 33.91   | 31.81   | 34.04   | 32.70   | 29.63   | 32.57|
| S6         | 33.91   | 31.81   | 34.02   | 32.69   | 29.60   | 32.58|
| S7         | 33.94   | 31.87   | 34.26   | 32.72   | 29.65   | 32.62|
| S8         | 33.95   | 31.85   | 34.28   | 32.73   | 29.59   | 32.62|
| S9         | 33.95   | 32.63   | 34.92   | 31.48   | 29.61   | 32.51|
| S10        | 33.96   | 32.83   | 34.97   | 32.72   | 29.64   | 32.82|
| S11        | 33.99   | 32.16   | 35.26   | 32.75   | 30.53   | 32.93|
| S12        | 35.27   | 32.08   | 35.24   | 32.70   | 30.79   | 33.21|
| Mean       | 33.87   | 31.97   | 34.74   | 32.49   | 30.01   | 32.62|
| SEd        | 0.34    | 0.37    | 0.37    | 0.35    | 0.32    |      |
| CD (P=0.05) | 1.70    | 0.75    | 0.75    | 0.72    | 0.65    |      |
| Interaction SEd | ** ** ** ** | ** ** ** | ** ** ** | ** ** ** | ** ** ** | ** ** ** |

### Table 2 Effect of water stress on transpiration rate (µg H2O cm⁻² s⁻¹) at different growth stages of banana cultivars and hybrids

| Treatments | 3rd MAP | 5th MAP | 7th MAP | 9th MAP | Harvest | Mean |
|------------|---------|---------|---------|---------|---------|------|
| **Main plot** |         |         |         |         |         |      |
| M1         | 86.3    | 82.4    | 77.7    | 74.7    | 72.5    | 78.7 |
| M2         | 80.5    | 76.6    | 71.9    | 69.0    | 67.0    | 73.0 |
| Mean       | 83.4    | 79.5    | 74.8    | 71.8    | 69.7    |      |
| SEd        | 0.56    | 0.54    | 0.53    | 0.55    | 0.54    |      |
| CD (P=0.05) | 2.43    | 2.35    | 2.29    | 2.40    | 2.35    |      |
| **Sub plot** |         |         |         |         |         |      |
| S1         | 94.5    | 88.5    | 84.6    | 80.9    | 76.0    | 84.9 |
| S2         | 90.1    | 87.2    | 82.4    | 78.0    | 75.3    | 82.6 |
| S3         | 89.8    | 87.0    | 82.0    | 77.3    | 74.6    | 82.2 |
| S4         | 89.1    | 86.0    | 81.1    | 77.1    | 74.5    | 81.6 |
| S5         | 85.9    | 82.0    | 77.1    | 73.1    | 71.2    | 77.9 |
| S6         | 84.9    | 79.7    | 76.2    | 72.3    | 70.9    | 76.8 |
| S7         | 82.6    | 79.4    | 75.1    | 72.1    | 70.9    | 76.0 |
| S8         | 80.7    | 77.8    | 73.7    | 70.5    | 68.9    | 74.3 |
| S9         | 78.7    | 75.8    | 71.4    | 68.5    | 65.9    | 72.1 |
| S10        | 75.7    | 72.8    | 67.6    | 65.8    | 64.4    | 69.3 |
| S11        | 74.6    | 71.7    | 63.6    | 64.8    | 63.2    | 67.6 |
| S12        | 73.9    | 66.0    | 62.4    | 61.5    | 60.9    | 64.9 |
| Mean       | 83.4    | 79.5    | 74.8    | 71.8    | 69.7    |      |
| SEd        | 0.87    | 0.84    | 0.79    | 0.79    | 0.77    |      |
| CD (P=0.05) | 1.77    | 1.69    | 1.60    | 1.59    | 1.55    |      |
| Interaction SEd | ** ** ** ** | ** ** ** | ** ** ** | ** ** ** | ** ** ** | ** ** ** |

M at S: ** ** ** **
S at M: * ** ** **
CD (P=0.05): ** ** ** **
M at S: ** ** ** **
S at M: ** ** ** **

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Table 3 Effect of water stress on stomatal diffusive resistance (sec/cm) at different growth stages of banana cultivars and hybrids

| Treatments     | 3rd MAP | 5th MAP | 7th MAP | 9th MAP | Harvest | Mean   |
|----------------|---------|---------|---------|---------|---------|--------|
| **Main plot**  |         |         |         |         |         |        |
| M1             | 0.060   | 0.067   | 0.071   | 0.064   | 0.054   | 0.063  |
| M2             | 0.067   | 0.074   | 0.078   | 0.071   | 0.061   | 0.070  |
| Mean           | 0.064   | 0.071   | 0.075   | 0.067   | 0.057   |        |
| SEd            | 0.0006  | 0.0006  | 0.0007  | 0.0007  | 0.0005  |        |
| **CD (P=0.05)**| 0.0027  | 0.0028  | 0.0032  | 0.0032  | 0.0021  |        |
| **Sub plot**   |         |         |         |         |         |        |
| S1             | 0.056   | 0.052   | 0.065   | 0.059   | 0.039   | 0.054  |
| S2             | 0.071   | 0.081   | 0.067   | 0.088   | 0.076   | 0.077  |
| S3             | 0.060   | 0.063   | 0.070   | 0.073   | 0.057   | 0.063  |
| S4             | 0.057   | 0.065   | 0.070   | 0.067   | 0.057   | 0.063  |
| S5             | 0.038   | 0.060   | 0.070   | 0.042   | 0.050   | 0.052  |
| S6             | 0.062   | 0.066   | 0.071   | 0.064   | 0.045   | 0.061  |
| S7             | 0.058   | 0.061   | 0.072   | 0.047   | 0.052   | 0.058  |
| S8             | 0.052   | 0.064   | 0.072   | 0.062   | 0.041   | 0.058  |
| S9             | 0.061   | 0.063   | 0.073   | 0.049   | 0.056   | 0.060  |
| S10            | 0.074   | 0.081   | 0.078   | 0.089   | 0.079   | 0.080  |
| S11            | 0.083   | 0.096   | 0.081   | 0.065   | 0.051   | 0.075  |
| S12            | 0.094   | 0.101   | 0.109   | 0.103   | 0.084   | 0.098  |
| Mean           | 0.064   | 0.071   | 0.075   | 0.067   | 0.057   |        |
| SEd            | 0.0009  | 0.0010  | 0.0010  | 0.0010  | 0.0008  |        |
| **CD (P=0.05)**| 0.0019  | 0.0020  | 0.0021  | 0.0021  | 0.0017  |        |

**Interaction SEd**

| M at S | ** | ** | * | ** | * | * |
| S at M | * | * | ** | ** | ** | ** |
| **CD (P=0.05)** | ** | ** | ** | ** | ** | ** |

Discussion

The transpiration rate and stomatal conductance tended to decrease in the banana plants subjected to water deficit (Sen Gupta and Berkowitz, 1987). Reduction in transpiration rate under water deficit conditions leads to reduce the photosynthetic rate by inhibition of CO2 entry into the chloroplast through the stomata. The effect of water deficit in minimizing the transpiration rate could be observed from the present study in all the banana cultivars (Figure 1). Differential banana cultivar responses were also noticed in terms of reduction in transpiration rate. The cultivars of Matti, Matti×Anaikomban, Matti×cultivar rose and Pisang jajee×Matti had higher reduction in transpiration rate due to water deficit with 12 to 14 per cent, while cultivars of Karpuravalli, Karpuravalli×Pisang jajee, Saba and Sannachenkathali with 3% to 5% reduction over control. Robinson and Bower (1988) suggested that reduction in transpiration under water deficit might perhaps the premise of a mechanism of resistance to drought. According to Robinson (1984) transpiration and stomatal conductance values were higher, when relative humidity was low and decreased gradually when it increases. More than 18% increase in stomatal diffusive resistance caused about 5% reduction in transpiration rate as noticed in the cultivars of Karpuravalli, Karpuravalli×Pisang jajee, Saba and Sannachenkathali than the control. It was also exhibited that the increase in stomatal diffusive resistance in response to water stress is a behavior which causes a significant reduction in water loss (Pallar et al., 1979). Besides these results, Robinson (1984) reported that a higher stomatal diffusive resistance was associated with minimizing the water loss during water stress conditions.

Leaf temperature is an important factor in controlling leaf water status under water deficit conditions as reported by Leopold et al (1994). As observed in the present study, cultivars of Karpuravalli, Karpuravalli×Pisang jajee, Saba, Sannachenkathali and also cultivars of Poovan, Ney Poovan, Anaikomban and Anaikomban×Pisang jajee were found to increase the leaf temperature of 2°C and 3°C due to water deficit.
over control. Whereas, the cultivars of Matti, Matti×Anaikomban, Matti×cultivar rose and Pisang jajee×Matti showed an increase in leaf temperature of 4°C subjected to water stress conditions. These results are strongly supported by Siddique et al (2000) who reported that the exposure of plants to water stress substantially decreased the leaf water potential, relative water content and transpiration rate with a concomitant increase in leaf temperature.

### Conclusion

Plants respond to drought stress through alteration in physiological and biochemical processes. Our results showed that the activities of antioxidant enzymes increased under the water deficit condition. The banana cultivars and hybrids of Karpuravalli, Karpuravalli×Pisang Jajee, Saba and Sannachenkathali with decreasing trend of transpiration rate throughout the growth period of the crop with increasing in leaf temperature and stomatal diffusive resistance due to water deficit. The findings of this research also showed that the leaf temperature, transpiration rate and stomatal diffusive resistance can be used as a drought tolerance index to selection tolerant genotypes under water deficit conditions in banana cultivars and hybrids.

### Materials and Methods

The experimental design was a split plot design with three replications. The main plots are, M₁ (control) with the soil pressure maintained from −0.69 to −6.00 bar, M₂ (water deficit) with the Soil pressure maintained from −0.69 to −14.00 bar. Soil pressure of −14.00 bar was reached at 30 days and measured by using soil moisture release curve and measured the soil moisture by using the pressure plate membrane apparatus. The sub plots considered as twelve banana cultivars and hybrids (S₁: Karpuravalli (ABB), S₂: Karpuravalli×Pisang Jajee, S₃: Saba (ABB), S₄: Sanna Chenkathali (AA), S₅: Poovan (AAB), S₆: Ney poovan (AB), S₇: Anaikomban (AA), S₈: Matti×Cultivar Rose, S₉: Matti (AA), S₁₀: Pisang Jajee×Matti, S₁₁: Matti×Anaikomban and S₁₂: Anaikomban×Pisang Jajee.) were randomly distributed within the sub-plots in each of the drought stress treatments (main plots). The leaf temperature, transpiration rate and stomatal diffusive resistance were estimated during 3rd, 5th, 7th, 9th month after planting and at harvest stages of the crop with measuring procedure was given below:

#### Transp

The transpiration rate was measured in a fully expanded third leaf from the top with the help of Li−1600 Steady State Porometer and expressed as µg cm⁻² s⁻¹.

#### Stomatal diffusive resistance

Stomatal diffusive resistance was measured with a pre-calibrated Li−1600 Steady State Porometer having a lithium chloride sensor. This was measured in a fully expanded third leaf from the top and expressed as s cm⁻¹.

#### Leaf temperature

The leaf temperature was measured in fully expanded third leaf from the top by using Li–1600 Steady State Porometer and was expressed as ºC. The above measurements connected with Steady State Porometer were recorded at 13~14 hours.

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