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Original Article

Impact of Water Deficit on Epicuticular Wax, Proline and Free Amino Acid Content and Yield of Banana Cultivars and Hybrids

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ABSTRACT

The field experiment was conducted at national research centre for banana to screen the banana cultivars and hybrids for water deficit tolerance and to elucidate information on epicuticular wax, proline, free amino acid and yield mechanism 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 per cent 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 per cent 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 per cent with the soil water potential of -14 bars. In stressed plots, 50 per cent 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 epicuticular wax, proline, free amino acid and yield were significantly increased during water deficit conditions. Among the twelve cultivars and hybrids, Karpuravalli, Karpuravalli x Pisang Jajee, Saba, and Sannachenkathali was identified as tolerant to water stress with highly accelerated by water stress treatment in the range of 18, 24 and 27 per cent over control in epicuticular wax content, proline and free amino acid leads to maintains the higher osmotic potential and water potential during stress conditions and get higher yield; whereas, Matti, Pisang Jajee x Matti, Matti x Anaikomban and Anaikomban x Pisang Jajee were notified as sensitive cultivars and hybrids with lesser increase in epicuticular wax content, proline and free amino acid of 13 per cent than control which is leads to get very low yield.

***Key words**: banana, water stress, epicuticular wax, proline, free amino acid and yield*

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INTRODUCTION

Banana is the 'queen of tropical fruits' and is one of the oldest fruits known to mankind from pre-historic times. Today, it is the leading tropical fruit in the world market with a highly organized and developed industry. It is the fourth largest fruit crop in the world after grapes, citrus fruits and apples. Drought is an insidious hazard of nature. Although it has scores of definitions, it originates from a deficiency of precipitation over an extended period of time, usually a season or more. This deficiency results in a water shortage for some activity, group, or environmental sector. Water deficit occurs when water potentials in the rhizosphere are sufficiently negative to reduce water availability to sub-optimal levels for plant growth and development. On a global basis, it is a major cause limiting productivity of agricultural systems and food production [5]. Banana plant productivity is greatly affected by environmental stresses such as drought, water and cold. Plants respond and adopt to these stresses to survive under stress condition at the molecular and cellular levels as well as at the physiological and biochemical levels. Physiological responses to soil water deficit are the feature that is most likely to

determine the response of the crop to irrigation. The banana plants are sensitivity to soil moisture stress is reflected in changes in reduced growth through reduced stomatal conductance and leaf size[11] increased leaf senescence[27]. Bananas (*Musa* spp.) rarely attain their full genetic potential for yield due to limitations imposed by water ultimately limiting the plants photosynthesis [29]. The banana is sensitive to soil water deficits, expanding tissues such as emerging leaves and growing fruit are among the first to be affected. As soil begins to dry, stomata close and leaves remain highly hydrated, probably through root pressure. Productivity is affected because of the early closure of stomata. Measurements of leaf water potential using either the exuding xylem or relative leaf water content could not be reliably linked to plant functions such as stomatal movement, net photosynthesis or leaf folding [29]. Water potential measured by the exuding latex method appeared the best for determining leaf water status, but even this shows a small change in plants experiencing soil water deficit [29] supporting the hydrated status of banana leaves although the soil is dry. Understanding banana plant response to soil moisture deficit and higher expression of epicuticular wax content, proline and free amino acid content with lesser reduction in yield 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.

MATERIALS AND METHODS

The experiment was carried out at at national research centre for banana, Thiruchirapalli, during 2011-2012. The experiment consists of two treatments as considered as main plot and twelve cultivars and hybrids as taken as sub plots were laid out in split plot design with three replications. The main plots are, M_1 (control) with the soil pressure maintained from -0.69 to -6.00 bar, M_2 (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 (Fig 1) .The sub plots are, $\mathbf{S_1}$: Karpuravalli (ABB), $\mathbf{S_2}$: Karpuravalli x Pisang Jajee, $\mathbf{S_3}$: Saba (ABB), $\mathbf{S_4}$: Sanna Chenkathali (AA), $\mathbf{S_5}$: Poovan (AAB), $\mathbf{S_6}$: Ney poovan (AB), $\mathbf{S_7}$: Anaikomban (AA), $\mathbf{S_8}$**:** Matti x Cultivar Rose, $\mathbf{S_9}$: Matti (AA), $\mathbf{S_{10}}$: Pisang Jajee x Matti, $\mathbf{S_{11}}$: Matti x Anaikomban and $\mathbf{S_{12}}$: Anaikomban x Pisang Jajee. The epicuticular wax content, proline and free amino acid content were recorded during 3rd, 5th, 7th, 9th month after planting and at harvest stages of the crop. The yield were assessed at the time of harvesting. Epicuticular wax (ECW) content by the method of Ebercon *et al.* (1977)[7] and expressed as mg g^{-1} dry weight, Proline content were estimated in physiologically active leaves as per the procedure of Bates *et al.* [3] and expressed as µg g^{-1} of fresh weight and Free amino acid content were recorded by using the procedure of Mishra and Dhillon [15] and expressed as µg g^{-1} during 3rd, 5th, 7th, 9th month after planting and at harvest stages of the crop.

RESULT AND DISCUSSION

Epi Cuticular Wax (ECW)

The time trend of ECW revealed an increasing trend from 3rd to 7th MAP declining towards harvest (Table 1). The main and sub-plot treatments differed significantly at all the growth stages. Between the main plots, M_2 recorded higher wax content of 6.91 µg cm^2 over M_1 (5.34 µg cm^2) at 7th MAP stage. Among the sub plot treatments, S_1 (9.87 µg cm^2) was found to contain the highest ECW, followed by S_2 (9.55 µg cm^2) and S_3 (9.44 µg cm^2). The lesser wax content was observed in the treatment of S_{12} with the value of 3.46 µg cm^2. All the interaction treatments of M at S and S at M differed significantly. The treatment M_1S_1 registered higher wax content of 8.43 µg cm^2 followed by M_1S_2 (8.11 µg cm^2). However, a considerable increase in ECW could also be observed due to M_2 and subplot treatments. M_2S_1, M_2S_2, M_2S_3 and M_2S_4 registered about 35 to 44 per cent increase, whereas all the other treatments recorded about 17 to 24 per cent increase over the interaction between M_1 and subplot treatments.

The plant cuticle and waxes have many important functions. They reduce the loss of water, reflect or attenuate radiation, form the basis of phyllosphere, protect plant tissues against penetration by fungi, bacteria and insects, as well as from mechanical damage (by wind, rain, soil particles etc.) reduce water retention on the plant surface, and provide a self-cleaning surface. The **Epicuticular waxes (ECW)** are composed of a mixture of chemical compounds such as hydrocarbons, primary alcohols and aldehydes

[9]. Compositionally, the cuticle is characterized by two specific groups of lipid substances, insoluble polymeric cutins which constitute the backbone of the membrane called as cutin matrix and soluble waxes deposited on the outer surface as ECW and embedded within the cutin matrix as intracuticular wax [2]. The cuticle plays a fundamental protective role against water loss, particularly when stomata are closed during water stress [9]. The level of ECW was higher in stress condition [24]. In this research study, the ECW content increased under stress conditions of about 40 per cent in tolerant cultivars like Karpuravalli, Karpuravalli x Pisang jajee, Saba and Sannachenkathali over control. The susceptible cultivars of Matti, Matti x Anaikomban, Matti x cultivar rose and Pisang jajee x Matti, registered only 15 to 20 per cent increase in ECW over control. It was also established that, when drought progressed, stomata got closed with higher deposition of ECW leading to decreased cuticular permeability of water loss and increasing the crop albedo [4]. The increase in cell membrane stability and ECW under water deficit conditions has been associated with drought tolerance [18]. The cuticle plays a fundamental protective role against water loss, particularly when stomata are closed during water stress [9].

Proline

The proline content showed an increasing trend as the growth stage advanced upto 7th MAP and declined towards harvest (Table 2). Between the treatments, M_2 had higher proline content of 98.3 µg g^{-1} than M_2 (79.4 µg g^{-1}) at 7th MAP. Analyzing the effect of sub-plot treatments, S_1 recorded an increased proline accumulation of 98.4 µg g^{-1}. This treatment was followed by S_2 (97.8 µg g^{-1}) and S_3 (94.9 µg g^{-1}). The treatment, S_{12} showed an lesser proline accumulation (87.5 µg g^{-1}) at 7th MAP. The interaction effects of M at S and S at M revealed significant differences at all the stages of growth. The treatment M_2S_1 recorded the highest value of 116.5 µg g^{-1} followed by M_2S_2 (112.1 µg g^{-1}), M_2S_3 (109.2 µg g^{-1}) and M_2S_4 (108.7 µg g^{-1}) at 7th MAP. The treatment M_2S_{10}, M_2S_{10}, M_2S_{11} and M_2S_{12} found to accumulate the proline at significantly lower level than the other treatments.

Proline accumulation is an universal response of plants to various stresses. Proline acts as an osmolyte and helps the plants to maintain tissue water potential under all kinds of stresses. Proline, as an osmoprotectant, is largely confined to the cytoplasm and is mostly absent from the vacuole [14]. It plays a key role in the cytoplasm as a scavenger of free radicals as well as a mediator in osmotic adjustment and also increases the solubility of sparingly soluble proteins [6,22]. Water stress enhanced the accumulation of proline in many plant species and it might function as a source of solute for intercellular osmotic adjustment under water stress [23]. Proline might severe as a storage compounds for reduced carbon and nitrogen during stress [25]. Proline might regulate the osmotic balance of the cell thus relieving the negative effect of stress [21]. In the present study also, cultivars like Karpuravalli, Karpuravalli x Pisang jajee, Saba and Sannachenkathali had higher amount of proline accumulation particularly at 7th MAP followed by Poovan, Ney Poovan, Anaikomban and Anaikomban x Pisang jajee than cultivars of Matti, Matti x Anaikomban, Matti x cultivar rose and Pisang jajee x Matti. These findings are further supported by the results of [16] in banana, which explained that the enhancement in free proline content could occur either due to *'de novo'* synthesis of proline or breakdown of proline-rich protein or shift in metabolism. There are three main reasons for the accumulation of proline in stressed leaves. The first and main component for this accumulation is the stimulation of proline synthesis from glutamic acid. The second is an inhibition of proline oxidation to other soluble compounds, and the third an inhibition of protein synthesis. The metabolic conversion of glutamic acid to proline and thereafter to other products via oxidation occurs readily in turgid leaves of barley and is stimulated by higher levels of proline [12].

Free Amino Acid (FAA)

Free amino acid (FAA) content of the leaf increased upto 7th MAP with a decline towards harvest (Table 3). Main plot treatments of M_1 and M_2 differed significantly at all the growth stages, with significantly higher contents maintained by M_2 (12.3, 14.7, 16.2, 14.0 and 11.2 mg g^{-1}) throughout the growth periods than M_1 (9.4, 11.9, 12.5, 10.7 and 7.9 mg g^{-1}). All the sub-plot treatments also differed significantly. Among the sub plot treatments, S_1 recorded highest content of 19.2 mg g^{-1}, followed by S_2 (17.4 mg g^{-1}) and S_3 (17.3 mg g^{-1}) at 7th MAP. Treatment S_{12} (12.8 mg g^{-1}) followed by S_{11} (13.1 mg g^{-1}) exhibited lesser content of FAA at same stage of growth. The interaction effects of M at S and S at M revealed significant differences at all the stages of growth. Among them, the treatment M_2S_1, M_2S_2, M_2S_3, and M_2S_4 registered the highest

content of FAA (21.0, 19.0, 18.9 and 14.4 mg g^{-1}) over the M_1 and subplot treatments. However, a considerable increase in FAA activity could also be observed due to interaction with M_2 and subplot treatments. M_2S_1, M_2S_2, M_2S_3, and M_2S_4 registered about 40 to 45 per cent increase. Other interactive treatments such as M_2S_5, M_2S_6, M_2S_7, and M_2S_8 showed about 25 to 30 per cent increase, whereas, M_2S_9, M_2S_{10}, M_2S_{11} and M_2S_{12} exhibited lesser content of FAA (18 to 20 per cent) than M_1 and subplot treatments.

Accumulation of **free amino acids** is also significant under water stress and may be due to induced hydrolysis of proteins as reported in crops like *Arachis hypogeae* and *Vicia faba* [19,8]. The contribution of solutes in the osmotic adjustment during moderate stress levels than severe stress level [10]. As observed in the present studies, cultivars of Karpuravalli, Karpuravalli x Pisang jajee, Saba and Sannachenkathali registered 22 per cent increase in FAA content than the control. These findings are in accordance with [25] found an accumulation of free amino acids in the presence of water deficit leading to a dynamic adjustment of nitrogen metabolism. The increase in free amino acids could contribute to the tolerance of the plant to water deficit through an increase in osmotic potential or as a reserve of nitrogen principally for the synthesis of specific enzymes[17]. Increased accumulation of FAA during stress conditions could be an indicator of the adaptive nature of the coconut palms to cope up with the adverse conditions during summer months [13]. Once water deficit is established, the level of free amino acids in plants increased under moderate stress and severe stress conditions [10]. The increase in aspatate, glutamate, proline, alanine and valine compound due to increase in free amino acids content in stressed leaves could help maintain energy fluxes of the chloroplast [1].

Bunch weight (kg $bunch^{-1}$)

Bunch weight varied significantly among main as well as sub plot treatments. Comparing the two main plot treatments, M_1 recorded significantly higher mean bunch weight of 11.9 kg $bunch^{-1}$ whereas M_2 recorded a mean value of 10.0 kg $bunch^{-1}$. All the sub plot treatments significantly influenced the bunch weight. Among them, S_1 registered the highest bunch weight of 22.0 kg $bunch^{-1}$, followed by S_3 (18.3 kg $bunch^{-1}$), S_5 (17.1 kg $bunch^{-1}$) and S_4 (13.5 kg $bunch^{-1}$). The lowest bunch weight was recorded by S_{12} (3.4 kg $bunch^{-1}$), followed by S_{11} (3.5 kg $bunch^{-1}$). The interaction effects of M at S and S at M were also significant. Among the interaction treatments, M_1S_1 outperformed all the others by recording the highest bunch weight of 23.0 kg $bunch^{-1}$, however, as the result of interaction with M_2 the bunch weight was reduced to 21.0 kg $bunch^{-1}$ with per cent reduction of 8.7. This treatment was followed by M_1S_3 (19.5 kg $bunch^{-1}$) with the reduction of 11.5 per cent when interacted with M_2 (17.0 kg $bunch^{-1}$). Similarly, M_1S_9, M_1S_{10}, M_1S_{11} and M_1S_{12} recorded the bunch weight of 12.0, 4.5, 4.0 and 4.0 kg $bunch^{-1}$ with the reduction per cent of 24.6, 38.8, 26.2 and 31.2 when interacted with M_2. Bunch yield of banana is considered as the major contributing factor for the final plant yield, generally expressed in kg per bunch. In the present study, comparing bunch weight of all the twelve cultivars of banana as affected by water deficit, significant variations could be observed. The cultivars of Karpuravalli, Karpuravalli x Pisang jajee, Saba and Sannachenkathali produced the mean bunch weight of 17.5, 15.5, 14.5 and 14.5 kg $bunch^{-1}$ followed by Poovan, Ney Poovan, Anaikomban and Anaikomban x Pisang jajee recording 14.0, 9.5, 6.0 and 5.5 kg $bunch^{-1}$, whereas Matti, Matti x Anaikomban, Matti x cultivar rose and Pisang jajee x Matti produced lower bunch yield of 4 to 4.5 kg $bunch^{-1}$ due to water deficit. Besides these cultivar variations due to water deficit exhibited their significant inhibitory effect on bunch yield. The tolerant cultivars had lesser effect on bunch weight with the mean reduction of 25 per cent respectively over control. The susceptible cultivars were highly vulnerable to water deficit showing bunch weight reduction of 68 to 75 per cent over control. Similar to this study, Turner and Rosales (2005) noticed a reduction in bunch yield due to water deficit.

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Table 1. Effect of water stress on leaf Epicuticular wax (µg cm^2) at different growth stages of banana cultivars in main crop

Treatments	3rd MAP	5th MAP	7th MAP	9th MAP	Harvest	Mean
Main plot						
M_1	298.2	454.6	534.2	347.6	360.6	**399.0**
M_2	499.0	592.0	735.0	485.0	458.0	**553.8**
Mean	**398.6**	**523.3**	**634.6**	**416.3**	**409.3**	**476.4**
SEd	**1.54**	**1.12**	**1.54**	**1.12**	**0.76**	
CD (P= 0.05)	**6.65**	**4.84**	**6.65**	**4.82**	**3.30**	
Sub plot						
S_1	666.3	759.3	902.3	652.3	650.3	**726.1**
S_2	634.3	727.3	870.3	620.3	618.3	**694.1**
S_3	623.3	716.3	859.3	609.3	607.3	**683.1**
S_4	467.3	560.3	703.3	453.3	451.3	**527.1**
S_5	371.3	514.3	607.3	407.3	395.3	**459.1**
S_6	355.3	498.3	591.3	391.3	379.3	**443.1**
S_7	352.3	495.3	588.3	388.3	376.3	**440.1**
S_8	344.3	487.3	580.3	380.3	368.3	**432.1**
S_9	285.3	423.3	521.3	316.3	309.3	**371.1**
S_{10}	255.3	393.3	491.3	286.3	279.3	**341.1**
S_{11}	221.3	359.3	457.3	252.3	245.3	**307.1**
S_{12}	207.3	345.3	443.3	238.3	231.3	**293.1**
Mean	**398.6**	**523.3**	**634.6**	**416.3**	**409.3**	**476.4**
SEd	**14.3**	**17.6**	**21.4**	**14.4**	**14.1**	
CD (P= 0.05)	**28.8**	**35.5**	**43.1**	**29.0**	**28.4**	

Interaction effect

Treatments	3rd MAP	5th MAP	7th MAP	9th MAP	Harvest	Mean
M_1S_1	606.5	699.5	842.5	592.5	615.5	**671.3**
M_1S_2	574.5	667.5	810.5	560.5	583.5	**639.3**
M_1S_3	563.5	656.5	799.5	549.5	572.5	**628.3**
M_1S_4	407.5	500.5	643.5	393.5	416.5	**472.3**
M_1S_5	255.6	448.6	491.6	341.6	344.6	**376.4**
M_1S_6	239.6	432.6	475.6	325.6	328.6	**360.4**
M_1S_7	236.6	429.6	472.6	322.6	325.6	**357.4**
M_1S_8	228.6	421.6	464.6	314.6	317.6	**349.4**
M_1S_9	159.6	342.6	395.6	235.6	248.6	**276.4**
M_1S_{10}	129.6	312.6	365.6	205.6	218.6	**246.4**
M_1S_{11}	95.6	278.6	331.6	171.6	184.6	**212.4**
M_1S_{12}	81.6	264.6	317.6	157.6	170.6	**198.4**
M_2S_1	726.0	819.0	962.0	712.0	685.0	**780.8**
M_2S_2	694.0	787.0	930.0	680.0	653.0	**748.8**
M_2S_3	683.0	776.0	919.0	669.0	642.0	**737.8**
M_2S_4	527.0	620.0	763.0	513.0	486.0	**581.8**
M_2S_5	487.0	580.0	723.0	473.0	446.0	**541.8**
M_2S_6	471.0	564.0	707.0	457.0	430.0	**525.8**
M_2S_7	468.0	561.0	704.0	454.0	427.0	**522.8**
M_2S_8	460.0	553.0	696.0	446.0	419.0	**514.8**
M_2S_9	411.0	504.0	647.0	397.0	370.0	**465.8**
M_2S_{10}	381.0	474.0	617.0	367.0	340.0	**435.8**
M_2S_{11}	347.0	440.0	583.0	333.0	306.0	**401.8**
M_2S_{12}	333.0	426.0	569.0	319.0	292.0	**387.8**
Mean	**398.6**	**523.3**	**634.6**	**416.3**	**409.3**	**476.4**
SEd						
M at S	**19.4**	**23.9**	**29.0**	**19.5**	**19.1**	
S at M	**20.2**	**24.9**	**30.2**	**20.3**	**19.9**	
CD (P= 0.05)						
M at S	**39.5**	**48.3**	**58.7**	**39.5**	**38.6**	
S at M	**40.8**	**50.3**	**61.0**	**41.0**	**40.3**	

Table 2. Effect of water stress on proline (µg g^{-1}) at different growth stages of banana cultivars in main crop

Treatments	3rd MAP	5th MAP	7th MAP	9th MAP	Harvest	Mean
Main plot						
M_1	73.6	75.3	79.4	71.3	71.1	**74.15**
M_2	91.9	93.4	98.3	89.6	89.4	**92.52**
Mean	**82.76**	**84.33**	**88.86**	**80.46**	**80.26**	**83.33**
SEd	**2.00**	**2.01**	**2.01**	**1.98**	**1.98**	
CD (P= 0.05)	**8.60**	**8.64**	**8.67**	**8.55**	**8.54**	
Sub plot						
S_1	95.8	96.7	98.4	93.5	93.3	**95.55**
S_2	95.1	96.1	97.8	92.8	92.6	**94.90**
S_3	92.2	93.9	94.9	89.9	89.7	**92.14**
S_4	91.7	93.4	94.4	89.4	89.2	**91.64**
S_5	84.9	86.6	87.6	82.6	82.4	**84.83**
S_6	84.2	85.9	86.9	81.9	81.7	**84.13**
S_7	80.5	82.2	83.2	78.2	78.0	**80.43**
S_8	78.8	80.5	83.4	76.5	76.3	**79.11**
S_9	74.2	75.9	82.1	71.9	71.7	**75.18**
S_{10}	72.1	73.8	84.6	69.8	69.6	**74.00**
S_{11}	71.8	73.5	85.3	69.5	69.3	**73.90**
S_{12}	71.6	73.3	87.5	69.3	69.1	**74.18**
Mean	**82.76**	**84.33**	**88.86**	**80.46**	**80.26**	**83.33**
SEd	**0.88**	**0.90**	**0.91**	**0.85**	**0.85**	
CD (P= 0.05)	**1.78**	**1.82**	**1.84**	**1.73**	**1.72**	

Interaction effect

Treatments	3rd MAP	5th MAP	7th MAP	9th MAP	Harvest	Mean
M_1S_1	81.5	83.2	80.3	79.2	79.0	**80.64**
M_1S_2	80.8	82.5	83.5	78.5	78.3	**80.72**
M_1S_3	77.9	79.6	80.6	75.6	75.4	**77.82**
M_1S_4	77.4	79.1	80.1	75.1	74.9	**77.32**
M_1S_5	77.1	78.8	79.8	74.8	74.6	**77.02**
M_1S_6	76.4	78.1	79.1	74.1	73.9	**76.32**
M_1S_7	72.7	74.4	75.4	70.4	70.2	**72.62**
M_1S_8	71.0	72.7	75.6	68.7	68.5	**71.30**
M_1S_9	68.9	70.6	76.8	66.6	66.4	**69.86**
M_1S_{10}	66.8	68.5	79.3	64.5	64.3	**68.68**
M_1S_{11}	66.5	68.2	80.0	64.2	64.0	**68.58**
M_1S_{12}	66.3	68.0	82.2	64.0	63.8	**68.86**
M_2S_1	110.1	110.2	116.5	107.8	107.6	**110.47**
M_2S_2	109.4	109.7	112.1	107.1	106.9	**109.08**
M_2S_3	106.5	108.2	109.2	104.2	104.0	**106.47**
M_2S_4	106.0	107.7	108.7	103.7	103.5	**105.97**
M_2S_5	92.7	94.4	95.4	90.4	90.2	**92.63**
M_2S_6	92.0	93.7	94.7	89.7	89.5	**91.93**
M_2S_7	88.3	90.0	91.0	86.0	85.8	**88.23**
M_2S_8	86.6	88.3	91.2	84.3	84.1	**86.91**
M_2S_9	79.5	81.2	87.4	77.2	77.0	**80.51**
M_2S_{10}	77.4	79.1	89.9	75.1	74.9	**79.33**
M_2S_{11}	77.1	78.8	90.6	74.8	74.6	**79.23**
M_2S_{12}	76.9	78.6	92.8	74.6	74.4	**79.51**
Mean	**82.76**	**84.33**	**88.86**	**80.46**	**80.26**	**83.33**
SEd						
M at S	**2.33**	**2.35**	**2.36**	**2.30**	**2.30**	
S at M	**1.25**	**1.27**	**1.29**	**1.21**	**1.21**	
CD (P= 0.05)						
M at S	**8.62**	**8.67**	**8.69**	**8.57**	**8.55**	
S at M	**2.51**	**2.57**	**2.60**	**2.44**	**2.44**	

Table 3. Effect of water stress on free amino acid (mg g^{-1}) at different growth stages of banana cultivars in main crop

Treatments	3rd MAP	5th MAP	7th MAP	9th MAP	Harvest	Mean
Main plot						
M_1	9.45	11.86	12.49	10.70	7.88	**10.47**
M_2	12.31	14.72	16.16	14.04	11.22	**13.69**
Mean	**10.88**	**13.29**	**14.32**	**12.37**	**9.55**	**12.08**
SEd	**0.159**	**0.173**	**0.177**	**0.168**	**0.150**	
CD (P= 0.05)	**0.686**	**0.746**	**0.764**	**0.723**	**0.648**	
Sub plot						
S_1	15.78	18.19	19.21	17.42	14.60	**17.04**
S_2	14.13	16.54	17.41	15.62	12.80	**15.30**
S_3	14.05	16.46	17.28	15.49	12.67	**15.19**
S_4	10.30	12.71	13.17	11.38	8.56	**11.22**
S_5	10.25	12.66	13.68	11.89	9.07	**11.51**
S_6	10.14	12.55	13.42	11.63	8.81	**11.31**
S_7	9.86	12.27	13.09	11.30	8.48	**11.00**
S_8	9.53	11.94	12.40	10.61	7.79	**10.45**
S_9	9.30	11.71	13.23	10.94	8.12	**10.66**
S_{10}	9.19	11.60	13.12	10.83	8.01	**10.55**
S_{11}	9.15	11.56	13.08	10.79	7.97	**10.51**
S_{12}	8.83	11.24	12.76	10.47	7.65	**10.19**
Mean	**10.88**	**13.29**	**14.32**	**12.37**	**9.55**	**12.08**
SEd	**0.143**	**0.168**	**0.174**	**0.155**	**0.126**	
CD (P= 0.05)	**0.288**	**0.339**	**0.351**	**0.313**	**0.255**	

Interaction effect

Treatments	3rd MAP	5th MAP	7th MAP	9th MAP	Harvest	Mean
M_1S_1	14.35	16.76	17.39	15.60	12.78	**15.38**
M_1S_2	12.70	15.11	15.74	13.95	11.13	**13.73**
M_1S_3	12.62	15.03	15.66	13.87	11.05	**13.65**
M_1S_4	8.87	11.28	11.91	10.12	7.30	**9.90**
M_1S_5	8.82	11.23	11.86	10.07	7.25	**9.85**
M_1S_6	8.71	11.12	11.75	9.96	7.14	**9.74**
M_1S_7	8.43	10.84	11.47	9.68	6.86	**9.46**
M_1S_8	8.10	10.51	11.14	9.35	6.53	**9.13**
M_1S_9	7.87	10.28	10.91	9.12	6.30	**8.90**
M_1S_{10}	7.76	10.17	10.80	9.01	6.19	**8.79**
M_1S_{11}	7.72	10.13	10.76	8.97	6.15	**8.75**
M_1S_{12}	7.40	9.81	10.44	8.65	5.83	**8.43**
M_2S_1	17.21	19.62	21.04	19.25	16.43	**18.71**
M_2S_2	15.56	17.97	19.09	17.30	14.48	**16.88**
M_2S_3	15.48	17.89	18.91	17.12	14.30	**16.74**
M_2S_4	11.73	14.14	14.42	12.63	9.81	**12.55**
M_2S_5	11.68	14.09	15.51	13.72	10.90	**13.18**
M_2S_6	11.57	13.98	15.10	13.31	10.49	**12.89**
M_2S_7	11.29	13.70	14.72	12.93	10.11	**12.55**
M_2S_8	10.96	13.37	13.65	11.86	9.04	**11.78**
M_2S_9	10.73	13.14	15.56	12.77	9.95	**12.43**
M_2S_{10}	10.62	13.03	15.45	12.66	9.84	**12.32**
M_2S_{11}	10.58	12.99	15.41	12.62	9.80	**12.28**
M_2S_{12}	10.26	12.67	15.09	12.30	9.48	**11.96**
Mean	**10.88**	**13.29**	**14.32**	**12.37**	**9.55**	**12.08**
SEd						
M at S	**0.251**	**0.286**	**0.295**	**0.269**	**0.228**	
S at M	**0.202**	**0.237**	**0.246**	**0.219**	**0.179**	
CD (P= 0.05)						
M at S	**0.737**	**0.817**	**0.839**	**0.783**	**0.688**	
S at M	**0.408**	**0.478**	**0.497**	**0.442**	**0.361**	

Fig 1. Soil moisture measurement by using Pressure Plate Membrane Apparatus

Pressure plate with sample ring

Saturated soil sample filled inside the ring

Completely filled saturated soil sample

Setting the pressure

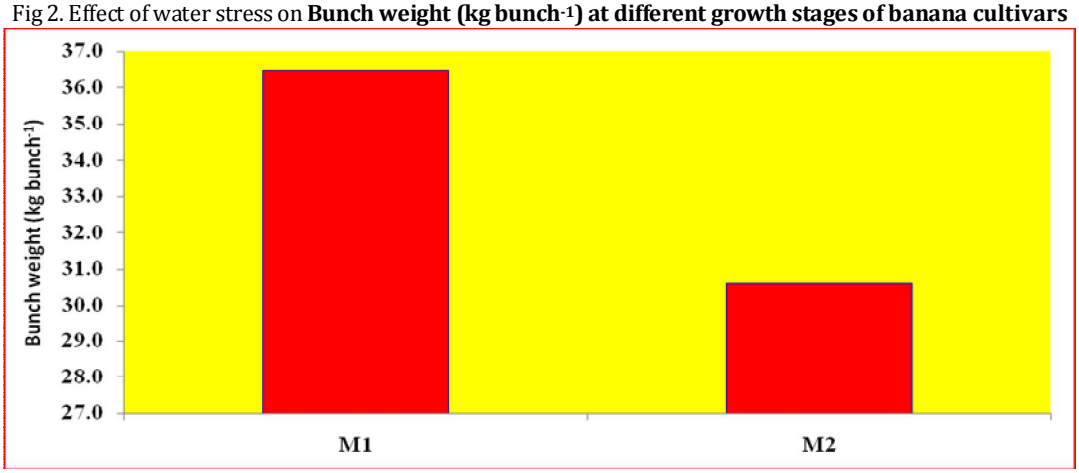
Running the instrument

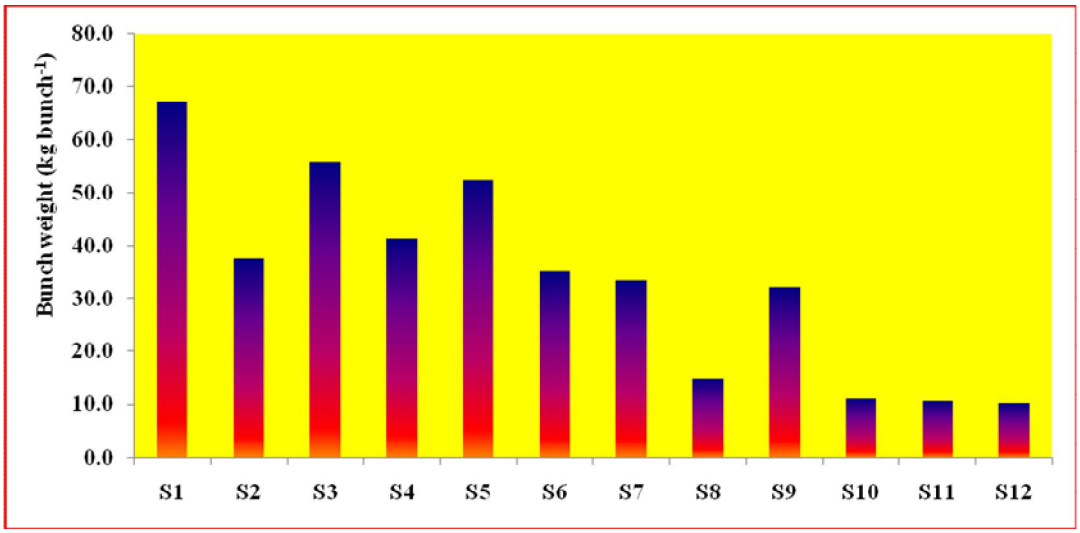
Ring removed from the plate

Collection of the soil sample from the plate

Soil sample in the hot air oven for drying

Fig 2. Effect of water stress on **Bunch weight (kg bunch^{-1}) at different growth stages of banana cultivars**





S_1- Karpuravalli
S_2- Karpuravalli x Pisang Jajee
S_3 - Saba
S_4 - Sannachenkathali
S_5 – Poovan
S_6 – Neypoovan
S_7 – Anaikomban
S_8 - Matti x Cultivar Rose
S_9 - Matti
S_{10} - Pisang Jajee x Matti
S_{11} - Matti x Anaikomban
S_{12}-Anaikomban x Pisang Jajee

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