Plant Gene and Trait, 2013, Vol.4, No.4, 17−24
http://pgt.sophiapublisher.com

Research Report **Open Access**

Impact of Water Deficit on Photosynthetic Pigments and Yield of Banana Cultivars and Hybrids

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Plant Gene and Trait, 2013, Vol.4, No.4 doi: 10.5376/pgt.2013.04.0004
Received: 21 Mar., 2013
Accepted: 11 Apr., 2013
Published: 24 May, 2013

Preferred citation for this article:
Surendar et al., 2013, Impact of Water Deficit on Photosynthetic Pigments and Yield of Banana Cultivars and Hybrids, Plant Gene and Trait, Vol.4, No.4 17-24 (doi: 10.5376/pgt.2013.04.0004)

Abstract A field experiment was carried out to investigate the effect of water deficit on total chlorophyll content, soluble protein content 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 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. The total chlorophyll content, soluble protein content and yield were decreased during water deficit conditions. Among the twelve cultivars and hybrids, Karpuravalli, Karpuravalli × Pisang Jajee, Saba, and Sannachenkathali was identified as tolerant to water deficit with least reduction in total chlorophyll content, soluble protein content and yield in the range of 8, 9 and 11 per cent over control.; whereas, Matti, Pisang Jajee × Matti, Matti × Anaikomban and Anaikomban × Pisang Jajee were notified as sensitive cultivars and hybrids with highest reduction per cent of 22, 26 and 19 total chlorophyll content, soluble protein content and yield than control which is leads to get very low yield.

Keywords Banana; Water deficit; Total chlorophyll; Soluble protein and yield

1 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. 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 leads to reduction in photosynthetic pigments (Kallarackal et al., 1990) with increased leaf senescence (Turner, 1998). Bananas (*Musa* spp.) rarely attain their full genetic potential for yield due to limitations imposed by water ultimately limiting the plants photosynthesis. Turner and Thomas (1998) reported that, 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. Turner and Thomas (1998) who showed 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. Understanding banana plant response to soil moisture deficit and least reduction in total chlorophyll content, soluble protein 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.

2 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, M1 (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.The sub plots are, S_1: Karpuravalli (ABB), S_2: Karpuravalli × Pisang Jajee, S_3: Saba (ABB), S_4: Sanna Chenkathali (AA), S_5: Poovan (AAB), S_6: Ney poovan (AB), S_7: Anaikomban (AA), S8: Matti × Cultivar Rose, S_9: Matti (AA), S_{10}: Pisang Jajee × Matti, S_{11}: Matti × Anaikomban and S_{12}: Anaikomban × Pisang Jajee. The total chlorophyll content, soluble protein content were recorded during 3^{rd}, 5^{th}, 7^{th}, 9^{th} month after planting and at harvest stages of the crop. The yield was assessed at the time of harvesting. Total chlorophyll content were estimated by the method of Hixcox and Israelstam (1979) and expressed as mg/g dry weight, soluble protein content were estimated in physiologically active leaves as per the procedure of Bradford (1974) and expressed as mg/g fresh weight.

3 Result and discussion

3.1 Total chlorophyll content (mg/g)

The data on total chlorophyll content reflected similar time trend of chlorophyll 'a', chlorophyll 'b' (Table 1). Main plot treatments differed significantly at all growth stages. Among the main plot treatments, M1 out performed with higher total chlorophyll content of 1.03 mg/g than M_2 (0.90 mg/g) showing a 13 per cent reduction over M1 at 7^{th} MAP stage. With regard to the sub-plot treatment S_1 recorded higher total chlorophyll content of 1.31 mg/g closely followed by S_2 (1.17 mg/g) and S_3 (1.08 mg/g). S_{12} however, recorded the lowest content of 0.72 mg/g among the subplot treatments at 7^{th} MAP stage. Significant differences among the interaction treatments also revealed the differential responses of M_1 and M_2 treatments over sub-plot treatments. Among them M_1S_1 registered higher total chlorophyll content of 1.35 mg/g over M_2. Treatments such as M_1S_2 and M_1S_3 also performed better than other treatments with 7 to 13 per cent increase over M_2 treatment interaction. A considerable reduction in total chlorophyll content could also be observed due to interaction with M_2, the percentage however, varies with different sub plots. Among the sub plot treatments, M_2S_1, M_2S_2, M_2S_3 and M_2S_4 exhibited 6 to 12 per cent reduction in total chlorophyll content, whereas, all the other treatments showed 13 to 17 per cent reduction over M_1 and subplot interaction.

The chloroplast in green plants constitutes the photosynthetic apparatus. Chlorophylls and other photosynthetic pigments are found in the form of protein pigment complexes mainly in thylakoid membranes of grana. Photosynthetic pigments play major role in

Table 1Effect of water stress on total chlorophyll (mg/g) at different growth stages of banana cultivars and hybrids

Treatments	3^{rd} MAP	5^{th} MAP	7^{th} MAP	9^{th} MAP	Harvest	Mean
Main plot						
M_1	0.64	1.01	1.03	0.62	0.44	0.75
M_2	0.52	0.92	0.90	0.54	0.38	0.65
Mean	0.58	0.96	0.97	0.58	0.41	0.70
SEd	0.031	0.052	0.060	0.034	0.026	
CD (P= 0.05)	0.134	0.226	0.260	0.146	0.113	
Sub plot						
S_1	0.72	1.29	1.29	0.75	0.58	0.93
S_2	0.69	1.19	1.18	0.72	0.58	0.87
S_3	0.69	1.09	1.08	0.71	0.53	0.82
S_4	0.68	1.05	1.05	0.68	0.50	0.79
S_5	0.61	0.98	0.98	0.62	0.46	0.73
S_6	0.60	0.94	0.95	0.61	0.46	0.71
S_7	0.57	0.91	0.91	0.57	0.40	0.67
S_8	0.56	0.90	0.90	0.54	0.39	0.66
S_9	0.51	0.89	0.89	0.52	0.35	0.63
S_{10}	0.48	0.86	0.85	0.48	0.26	0.59
S_{11}	0.43	0.77	0.77	0.41	0.22	0.52
S_{12}	0.41	0.72	0.72	0.37	0.18	0.48
Mean	0.58	0.96	0.97	0.58	0.41	0.70
SEd	0.078	0.133	0.134	0.086	0.066	
CD (P= 0.05)	0.157	0.268	0.270	0.174	0.134	
Interaction effect						
M_1S_1	0.78	1.31	1.35	0.77	0.60	0.96
M_1S_2	0.75	1.21	1.24	0.74	0.60	0.91
M_1S_3	0.74	1.11	1.13	0.73	0.55	0.85
M_1S_4	0.71	1.07	1.08	0.70	0.52	0.82
M_1S_5	0.68	1.03	1.05	0.67	0.50	0.79
M_1S_6	0.67	1.00	1.02	0.66	0.50	0.77
M_1S_7	0.64	0.97	0.98	0.62	0.44	0.73
M_1S_8	0.63	0.95	0.97	0.59	0.43	0.71
M_1S_9	0.58	0.95	0.96	0.57	0.39	0.69
M_1S_{10}	0.55	0.91	0.92	0.53	0.30	0.64
M_1S_{11}	0.50	0.83	0.84	0.46	0.26	0.58
M_1S_{12}	0.48	0.77	0.79	0.42	0.22	0.54
M_2S_1	0.66	1.27	1.23	0.73	0.56	0.89
M_2S_2	0.63	1.17	1.12	0.70	0.56	0.84
M_2S_3	0.65	1.07	1.04	0.69	0.51	0.79
M_2S_4	0.65	1.03	1.02	0.66	0.48	0.77
M_2S_5	0.54	0.92	0.91	0.57	0.42	0.68
M_2S_6	0.53	0.88	0.88	0.56	0.42	0.66
M_2S_7	0.50	0.85	0.84	0.52	0.36	0.62
M_2S_8	0.49	0.84	0.83	0.49	0.35	0.60
M_2S_9	0.44	0.83	0.82	0.47	0.31	0.58
M_2S_{10}	0.41	0.80	0.78	0.43	0.22	0.53
M_2S_{11}	0.36	0.71	0.70	0.36	0.18	0.47
M_2S_{12}	0.34	0.67	0.65	0.32	0.14	0.43
Mean	0.58	0.96	0.97	0.58	0.41	0.70
SEd						
M at S	0.110	0.188	0.191	0.122	0.094	
S at M	0.110	0.187	0.189	0.121	0.094	
CD (P= 0.05)						
M at S	0.242	0.412	0.429	0.267	0.207	
S at M	0.222	0.380	0.382	0.246	0.190	

plant productivity, as they are responsible for capturing light energy and using it as a driving force for producing the assimilates. Water deficit induces disintegration of thylakoid membranes and causes degradation of chlorophyll pigments. This could substantially contribute to the overall inhibition of photosynthesis in leaves of water deficit plants (Farquhart et al., 1982). As observed in the present study, the water deficit caused considerable reduction in chlorophyll content during shooting stage (7^{th} MAP) of about 5 to 18 per cent in Matti, Matti ×Anaikomban, Matti × cultivar rose and Pisang jajee × Matti over control. The mechanism of reduction in chlorophyll content due to the enhancement of chlorophyllase activity in water stressed plants could be the cause for chlorophyll degradation. Ghavami (1973) noticed a drastic reduction in the total chlorophyll content under water deficit condition due to the disruption of fine structure of chloroplast and instability of pigment and enhanced chlorophyllase activity. Thomas and Turner (2001) also observed a decrease in chlorophyll content in banana cultivars leading to decrease in photosynthesis. Besides these results, Alberte et al. (1977) reported that water deficit also caused similar inhibitory effect on chlorophyll content in Jack bean. Water stressed plants suffered reduction in chlorophyll level probably due to the action of reactive oxygen species, mainly by hydrogen peroxide that is accumulated under water deficiency, because its provokes the inactivation/ oxidation of the pigments pre-existing in chloroplast (Patonnier et al., 1999). Similar to this finding, Havaux et al. (1991) noticed a decreased in chlorophyll content leads to the reduction of oxidized quinon-A portion, thus representing a fraction of PS-Ⅱ centers prone to suffer photoinhibitory damages by chronic over excitation and subsequent changes in D_1 protein. Besides these results, Robinson and Bower (1988) reported that resistant banana cultivars maintained higher amount of total chlorophyll content at the active growth stage. In the present study also, the cultivars of Karpuravalli, Karpuravalli × Pisang jajee, Saba and Sannachenkathali recorded lesser reduction in total chlorophyll content with only 5 to 8 per cent loss due to water deficit and thereby maintained higher level of total chlorophyll content than the other cultivars. It was also exhibited that higher leaf relative water content induced increase in total chlorophyll content due to higher amount of chlorophyll ‘a’ under water stress conditions (Turner et al., 2007). Graan and Boyer (1990) found that accumulating higher photosynthetic pigments in leaves under water stressed conditions could help capture more light energy per unit leaf area thus improve photosynthetic capacity per unit leaf area in water stressed plants.

3.2 Soluble protein (mg/g)

Progressive increasing trend of soluble protein content was observed from 3^{rd} to 7^{th} MAP stage with a remarkable decline towards harvest (Table 2). The two main plot treatments differed significantly, with the higher value of 11.2 mg/g being recorded by M1 at 7^{th} MAP stage. Treatment M_2 (9.9 mg/g), however, recorded around 13 per cent lesser soluble protein content than M1 at the same stage of growth. Among the sub-plot treatments, S_1 registered higher soluble protein content of 12.7 mg/g. Other treatments viz., S_3, S_4, S_7, S_8 and S_{10} were on par with each other, and their performance were significantly lesser than S_1 (12.7 mg/g). Interaction effects of M at S and S at M revealed significant differences at all the stages of growth. The treatment M_1S_1 recorded higher soluble protein content of 13.3 mg/g followed by M_1S_5 (12.1 mg/g). However, a considerable reduction per cent trend could also be noticed in soluble protein content due to interaction of M_2 and subplot treatments. M_2S_1, M_2S_2, M_2S_3 and M_2S_4 was found better than the other treatments in recording about 9 to 11 per cent reduction, whereas, M_2S_5 to M_2S_{12} was found to show reduction with 13 to 18 per cent in soluble protein content over the M1 and sub plot treatments.

Table 2 Effect of water stress on foliage soluble protein (mg/g) at different growth stages of banana cultivars and hybrids

Treatments	3rd MAP	5th MAP	7th MAP	9th MAP	Harvest	Mean
Main plot						
M_1	10.7	10.8	11.2	9.6	5.5	9.58
M_2	8.7	8.8	9.9	8.2	4.6	8.03
Mean	9.67	9.81	10.54	8.93	5.06	8.80
SEd	0.049	0.049	0.053	0.048	0.024	
CD (P= 0.05)	0.211	0.214	0.229	0.208	0.106	
Sub plot						
S_1	11.8	11.9	12.7	11.8	6.1	10.85
S_2	10.9	9.4	10.6	10.9	5.0	9.36
S_3	10.3	9.1	9.9	9.4	4.9	8.71
S_4	8.8	9.4	9.9	7.3	5.7	8.23
S_5	9.7	10.5	11.5	6.9	5.0	8.69
S_6	8.4	10.9	11.3	7.7	5.8	8.82
S_7	9.4	9.8	9.8	7.8	4.6	8.25
S_8	9.4	8.9	10.4	8.9	4.8	8.47
S_9	10.2	8.2	10.0	9.5	4.8	8.55
S_{10}	10.1	9.5	9.3	9.6	4.6	8.61
S_{11}	9.0	10.5	10.5	9.0	4.8	8.75
S_{12}	8.2	9.6	10.7	8.5	4.7	8.35
Mean	9.67	9.81	10.54	8.93	5.06	8.80
SEd	0.129	0.132	0.134	0.123	0.067	
CD (P= 0.05)	0.261	0.267	0.270	0.249	0.136	
Interaction effect						
M_1S_1	12.4	12.5	13.3	12.4	6.5	11.40
M_1S_2	11.5	10.0	11.2	11.5	5.4	9.91
M_1S_3	10.9	9.7	10.5	10.0	5.2	9.26
M_1S_4	9.4	10.0	10.5	7.9	6.0	8.77
M_1S_5	10.8	11.6	12.1	7.6	5.5	9.52
M_1S_6	9.6	12.1	11.9	8.4	6.3	9.64
M_1S_7	10.5	11.0	10.4	8.4	5.1	9.08
M_1S_8	10.6	10.0	11.1	9.5	5.3	9.29
M_1S_9	11.5	9.4	10.8	10.3	5.4	9.49
M_1S_{10}	11.4	10.7	10.1	10.4	5.2	9.56
M_1S_{11}	10.2	11.8	11.3	9.8	5.4	9.69
M_1S_{12}	9.5	10.9	11.5	9.4	5.3	9.29
M_2S_1	11.2	11.3	12.1	11.2	5.8	10.31
M_2S_2	10.3	8.8	10.0	10.3	4.7	8.82
M_2S_3	9.7	8.5	9.3	8.8	4.5	8.17
M_2S_4	8.2	8.8	9.3	6.7	5.3	7.68
M_2S_5	8.5	9.3	10.8	6.3	4.5	7.86
M_2S_6	7.2	9.7	10.6	7.1	5.3	7.99
M_2S_7	8.2	8.7	9.1	7.1	4.1	7.42
M_2S_8	8.3	7.7	9.8	8.2	4.3	7.64
M_2S_9	9.0	6.9	9.2	8.7	4.2	7.60
M_2S_{10}	8.8	8.2	8.5	8.8	4.0	7.66
M_2S_{11}	7.7	9.3	9.6	8.2	4.2	7.80
M_2S_{12}	7.0	8.3	9.9	7.7	4.1	7.40
Mean	9.67	9.81	10.54	8.93	5.06	8.80
SEd						
M at S	0.183	0.186	0.188	0.174	0.094	
S at M	0.183	0.187	0.189	0.174	0.095	
CD (P= 0.05)						
M at S	0.405	0.405	0.409	0.382	0.205	
S at M	0.369	0.378	0.382	0.352	0.192	

The soluble protein content of the leaf, being a measure of RuBP carboxylase activity was considered as an index for photosynthetic efficiency. There were reports that RuBP-case enzyme forms nearly 80 per cent of the soluble proteins in leaves of many plants (Joseph et al., 1981). Diethelm and Shibles (1989) opined that the RUBISCO content per unit leaf area was positively correlated with that of souble protein content of the leaf. Soluble protein content was estimated in order to find out the photosynthetic capacity of banana cultivars under water deficit situations. In the present study, water deficit caused a significant reduction in soluble protein content of leaves of all the banana cultivars. Among the cultivars studied, Karpuravalli, Karpuravalli × Pisang jajee, Saba and Sannachenkathali maintained higher soluble protein content with 9 per cent reduction over control, followed by cultivars of Poovan, Ney Poovan, Anaikomban and Anaikomban × Pisang jajee with 15 per cent reduction. However, the cultivars of Matti, Matti × Anaikomban, Matti × cultivar rose and Pisang jajee × Matti recorded the lowest soluble protein content with higher reduction of 19 per cent than control. The mechanism of reduction in soluble protein content due to water deficit by reduction in RUBISCO enzyme activity leads to lower CO_2 assimilation. These findings were in accordance with the results of Wahad et al. (2000) who observed a significant reduction in soluble protein content of banana plants grown under drought stress conditions. Besides these results, Martignone et al. (1987) observed that in soybean soluble protein content was the first nitrogenous compound affected under stress conditions, which at severity got denatured and lost the activity. It was further explained that soluble protein, world's most abundant protein containing the enzyme RUBISCO, is involved in CO_2 assimilation; therefore, the reduction in soluble protein might have a direct adverse effect on photosynthesis. Hsio (1974) reported that the decrease in the protein level in water stressed plants could be attributed to decrease in protein synthesis, the decreased availability of amino acids and denaturation of the enzymes involved in amino acid and protein synthesis, perhaps at the ribosomal level.

3.3 Bunch yield (kg/bunch)

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 × Pisang jajee, Saba and Sannachenkathali produced the mean bunch weight of 17.5 kg/bunch, 15.5 kg/bunch, 14.5 kg/bunch and 14.5 kg/bunch followed by Poovan, Ney Poovan, Anaikomban and Anaikomban × Pisang jajee recording 14.0 kg/bunch, 9.5 kg/bunch, 6.0 kg/bunch and 5.5 kg/bunch, whereas Matti, Matti × Anaikomban, Matti × cultivar rose and Pisang jajee × Matti produced lower bunch yield of 4 to 4.5 kg/bunch due to water deficit (Figure 1). Besides these cultivar variations due to water deficit exhibited their significant inhibitory effect on bunch yield. The tolerant cultivars had lesser effect on bunch

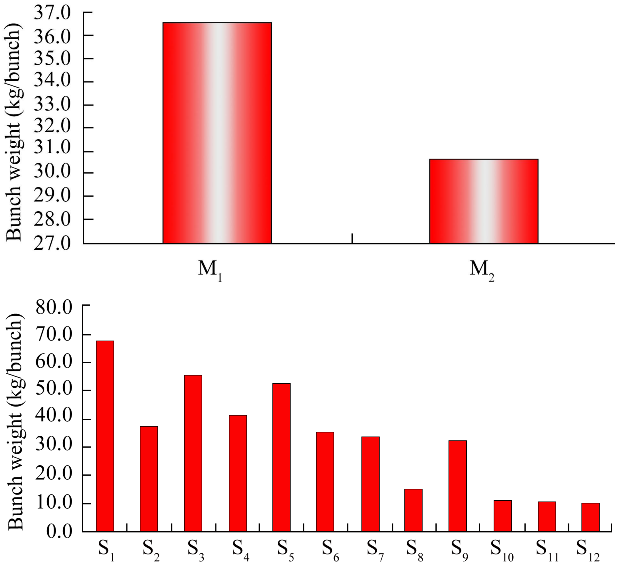

Figure 1 Effect of water stress on bunch weight (kg/bunch) of banana cultivars and hybrids at different growth stages

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.

Acknowledgment

The research have been supported and facilitated by National Research Centre for Banana (ICAR), Trichy. Tamil Nadu. India. I extend my sincere thanks to Dr. M. M. Mustaffa (Director) NRC for banana, Dr. D. Durga Devi (Professor) TNAU and Dr. I. Ravi (Sr. Scientist) NRC for banana for given proper guidance during research.

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