Cloud Publications
International Journal of Advanced Agricultural Sciences and Technology
2014, Volume 3, Issue 1, pp. 53-57, Article ID Sci-192
ISSN: 2320 – 026X

Cloud Publications

Research Article | Open Access

Effect of Bio-Fertilizers on Growth and Biomass of Coleus Vettiveroides

Nagappa Desai[1] and S. Thirumala[2]

[1]Department of Horticulture, Krishi Vigyana Kendra, Konehalli, Tiptur Taluk, Tumkur, Karnataka, India
[2]Department of Environmental Science, Govt. First Grade College & P.G. Centre, Davangere, Karnataka, India

Correspondence should be addressed to S. Thirumala, profthirumala@gmail.com

Publication Date: 18 June 2014

Article Link: http://scientific.cloud-journals.com/index.php/IJAAST/article/view/Sci-192

Abstract Coleus vettiveroides commonly known as Hrivera is a perennial herb belonging to family lamiaceae grown on sandy loams along river banks in plains. A pot experiment was conducted to optimize nutrient requirement through organic sources for optimum plant and root growth. The experiments were conducted at Hullikatte village of Tumkur district. Results found that the higher plant growth and biomass accumulation were found to be significant with the application of FYM along with bio fertilizer as compared with sole application of FYM or inorganic fertilizer.
Keywords *Bio-Fertilizers; Coleus Vettiveroides*

1. Introduction

Coleus vettiveroides best grown in sandy loam soil along river banks in plains. The pattern of root system differs when grown on light and heavy-textured soils. If grown on sandy soils, the tertiary roots are profuse with thin and long; and with less prominent primary and secondary roots. But if is grown on loamy soils, the primary and secondary roots will become prominent than tertiary roots [9].

Among various cultural practices conducive for enhancing root yield, nutrient management plays an important role in enhancing the yield per unit area. In the recent years, chemical fertilizers played significant role in providing nutrients for intensive crop production, but increased use of chemical fertilizer in an imbalanced manner has created problems of multiple nutrient deficiencies, diminishing soil fertility and unsustainable crop yields. Therefore, to minimize residue toxicity, etc. there is a need to practice organic farming. Therefore emphasis is now focused on growing the coleus using organic manures, such as Farm Yard Manure (FYM) and biofertilizers like Azatobacter, Azospirillum, Phosphorus Solubilizing Bacteria (PSB) and Arbuscular Mycorrhiza (AM fungi) are measures to produce roots of higher quality and safety.

Among agro techniques, integrated nutrient management plays an important role because of advantage of providing both organic sources of nutrients for improving biomass and preserving quality of plants products. Hence, integration of organic and inorganic sources of fertilizers is very essential in boosting the sustainable production of medicinal plants.

2. Materials and Methods

A pot experiment was conducted to optimize nutrient requirement through organic sources for optimum plant and root growth. The experiments were conducted at Farmers field of Hullikatte village of Tumkur district.

2.1. Details of the Experiments

The rooted stem cuttings of coleus vettiveroides were planted in pots with a capacity of 5 kg on March 12, 2008 in a growth media of 1:1:1 soil: Sand: FYM. The experiments were laid out in field with various levels of well decomposed FYM as indicated below:
Number of Treatments: 9
Number of Replications: 3

Biofertilizers: - Azotobacter chrococcum (5g) + Bacillus megaterium (5g) (phosphorus solubilizing bacteria) + Glomus mosseae (5g) (Arbuscular mycorrhiza fungi) in 1:1:1 to each pot.
Recommended N: 100 Kgha.

3. Results and Discussion

3.1. Growth Parameters

The data collected on growth parameters such as plant height, number of branches per plant, number of leaves per plant as influenced by micro flora and the treatment details are presented in Table 1.

The data revealed significant differences in plant height among the treatments. The maximum plant height (68.67 cm) was recorded in 25% of recommended N through FYM + biofertilizers and the minimum plant height (55 cm) were recorded in control. Significantly maximum numbers of branches (8.34) were recorded in 75% of recommended N through FYM and the minimum numbers of branches (5.67) were recorded in control. Significantly minimum numbers of leaves (41) were recorded in 100% of recommended N through FYM + Biofertilizers, as revealed in Table 1.

Growth parameters like plant height, number of branches were found to be more in plants applied with FYM along with Bio fertilizers. Further enhances the soil fertility status as biofertilizers like Azatobacter, Phosphorus solubilizing bacteria and Arbuscular Mychorriza fungi independently or in combination enhances the N and P status respectively, which assisted the host plant to promote growth [1] in Mentha spp, [7] in ginger, Earanna [3] in coleus barbatus, [4] in solanum nigrum, [8] in coleus parviflorus, [10] in viola pilosa.

Table 1: *Growth Parameters and Biomass (Per Plant) of Coleus Vettiveroides at Harvest as Influenced by Organic Sources and Bio Fertilizers*

Treatments	Plant Height (cm)	Number of Leaves	Number of Branches
T1: Control	55.00	29.34	5.67
T2: 25% of rec. N through FYM	60.67	37.67	7.34
T3: 25% of rec. N through FYM +Biofertilizers	68.67	39.00	7.67
T4: 50% of rec. N through FYM	59.00	33.67	6.34
T5: 50% of rec. N through FYM +Biofertilizers	59.34	34.34	7.34
T6: 75% of rec. N through FYM	59.67	36.34	8.34
T7: 75% of rec. N through FYM +Biofertilizers	63.34	34.67	6.67
T8: 100% of rec. N through FYM	56.00	37.00	7.67
T9: 100%of rec. N through FYM +Biofertilizers	56.67	41.00	8.00
S.Em +	0.98	1.12	0.41
CD @ 5%	2.91	3.33	1.23

3.2. Bio-Mass

Leaf Weight (g/ plant)

Comparing the leaf weight as influenced by organic sources and biofertilizers in unsterilized soil showed significant variations in influencing leaf weight. Significantly maximum leaf weight (130.34g) was noticed in 75% of recommended N through FYM + Biofertilizers, while the minimum leaf weight (81.18g) were noticed in control (Table 2).

Stem Weight (g/ plant)

Stem weight varied significantly among the treatments. The maximum stem weight per plant (139.69g) were recorded in 50% of recommended N through FYM + Bio fertilizer, however it was on par with 100% of recommended N through FYM + Bio fertilizer and the lowest root weight (12.83g) were recorded in control as given in Table 2.

Total Biomass (g/ plant)

Total biomass were found to be significantly higher (293.66g) in 75% of recommended N through FYM+ Bio fertilizer and the lowest total biomass (174.95g) were recorded in control, as given in Table 2.

Leaf weight, stem weight, root weight and total biomass of plant were found to increase in combination with organic with biofertilizers are compared to without biofertilizers. The positive influence on increased dry matter may be attributed to the higher level of organic manures, which are the rich sources of humus besides promoting higher N-fixation, P-solubilization and mobilization by the microbes, which consequently have increased the weight. Higher dry matter accumulation obtained in these treatments might be due to accelerated mobility of photosynthates from the source to the sink as influenced by the growth hormone release or synthesized due to the application of organic manures.

Table 2: *Biomass (Per Plant) of Coleus Vettiveroides at Harvest as Influenced by Organic Sources and Bio Fertilizers*

Treatments	Leaf weight(g)	Steam weight(g)	Root weight(g)	Total Biomass(g)
T1: Control	81.18	80.94	12.83	174.95
T2: 25% of rec. N through FYM	87.93	113.60	15.23	216.76
T3: 25% of rec. N through FYM + Biofertilizers	108.10	125.27	26.53	259.90
T4: 50% of rec N through FYM	83.88	110.23	16.28	210.40
T5: 50% of rec. N through FYM + Biofertilizers	115.06	139.69	28.05	282.80
T6: 75% of rec. N through FYM	85.43	116.60	18.19	220.22
T7: 75% of rec. N through FYM + Biofertilizers	130.34	136.52	26.65	293.66
T8: 100% of rec. N through FYM	90.65	121.68	23.18	235.52
T9: 100%of rec. N through FYM + Biofertilizers	121.16	138.35	31.34	290.85
S.Em +	1.61	1.98	0.80	2.83
CD @ 5%	4.80	5.88	2.39	8.42

The reason for the higher biomass with application of organic manures and Biofertilizers might have helped the plant metabolic activity through the supply of important micronutrient such as zinc, iron, copper, manganese, etc. These are involved in biochemical synthesis of many phytohormones. Besides, organic manures Azotobactor have a role in nitrogen fixation and are also involved in the production of phytohormones like IAA, GA and cytokinin like substances, phosphorous-solubilizing bacteria and Arbuscular mychorriza fungi help in solubilization and mobilization of phosphorous in soil. From the facts mentioned above, it is clear that higher dose of organic manures combined with bio fertilizers like Azatobacter chrococcum, Phosphorous- Solubilizing Bacteria (Bacillus megaterium) and Arbuscular Mycorriha fungi would have led to the higher yield of plants in these treatments. These results are in line with (Mukesh et al., 2006) in marigold, (Vikas et al., 2008) in viola pilosa and (Mohanchandra, 2003) in solanum nigrum.

4. Conclusion

The higher plant growth and biomass accumulation were found to be significant with the application of FYM along with biofertilizers as compared with sole application of FYM or inorganic fertilizer.

References

[1] Abdul Khaliq and Janardhana, K.K. *Influence of Vesicular Arbuscular Mycorrhizal Fungi on the Productivity of Cultivated Mints.* J. Med. Aroma. Pl. Sci. 1997. 19; 7-10.

[2] Bezdicek, S., Power, J.F., Keeney, D.R., and Wright, M.I. 1984: *Organic Farming: Current Technology and Its Role in a Sustainable Agriculture.* Proceedings of a Symposium Sponsored by Division S-3, S-4, S-6, S-8, and A-5 of the American Society of Agronomy, Wisconsin, USA.

[3] Earanna, N., Mallikarjuniah, R.R., Bagyaraj, D.J., and Suresh, C.K. *Response of Coleus Aromaticus to Glomus Fasciculatum and Other Beneficial Soil Microflora.* J. Spices and Aromatic Crops. 2001. 10 (2) 141-143.

[4] Mohanchandra, C.N., 2003: *Effect of Bio-fertilizers on Growth, Yield and Alkaloid Content in Makoi* (*Solanum Nigrum*). M.Sc. (Hort.) Thesis, University of Agricultural Sciences, Bangalore.

[5] Mukesh Kumar, Sharma, S.K., and Sultan Singh et al. Effect *of Farm Yard Manure and Different Biofertlizers on Yield and Nutrients Content of Marigold Cv. Pusa Narangi*. Haryana Journal of Horticultural Sciences. 2006. 35 (3/4) 256-257.

[6] Nageswari, K., 1991: *Studies on the Effect of Nitrogen, Potassium and Azospirillum on Growth, Yield and Quality of Coleus (Coleus parviflorus Benth) Cv. Co. 1".* M.Sc. (Hort.) Thesis, Tamil Nadu Agricultural University, Madurai.

[7] Nath, B., and Korla, B.N. *Studies on Effect of Bio-Fertilizers in Ginger.* Indian J. Hort. 2000. 57 (2) 160-171.

[8] Ramesh Babu, T.I., 1996: Nutritional Studies on Ashwagandha. M.Sc. (Hort.) Thesis Submitted to Horticultural College and Research Institute, Periyakulam.

[9] Shivananda, T.N, Mamatha, B., and Ganeshamurthy, A.N. *Problems and Prospects in Cultivation of Plecranthus vettiveroides (KC Jacob) NP Singh and BD Sharma I, Limitations in Identification, Nomenclature, Distribution and Cultivation: A Case Study.* Biomed. 2007. 2 (2) 146-154.

[10] Vikas Thakur, Meenu Sood, Rajneesh Mahajan and Som Dutt. *Effect of Organic Manure and Biofertilizers on Growth and Yield of Viola pilosa.* International Journal of Forest Usufructs Management. 2008. 9 (1) 96-99.

Cloud Publications
International Journal of Advanced Agricultural Sciences and Technology
2014, Volume 2, Issue 1, pp. 58-66, Article ID Sci-244
ISSN: 2320 – 026X

Research Article | Open Access

Chlorophyll a Fluorescence Imaging Analysis in Air-Drying Stressed Sorghum (*Sorghum bicolor* L.) Leaf

Sung Yung Yoo[1], Jong Yong Park[2], Doo Won Lee[2], Sun-Hee Woo[3], Tae Seok Ko[1] and Tae Wan Kim[1, 2]

[1]Institute of Ecological Phytochemistry, Hankyong National University, Jungang-ro 327, Anseong, Gyeonggi-do, 456-749, Republic of Korea
[2]Department of Plant Life and Environmental Science, Hankyong National University, Jungang-ro 327, Anseong, Gyeonggi-do, 456-749, Republic of Korea
[3]Department of Plant Resources Science, Chungbuk National University, Cheong-ju, 361-763, Republic of Korea

Correspondence should be addressed to Tae Wan Kim, taewkim@hknu.ac.kr

Publication Date: 7 November 2014

Article Link: http://scientific.cloud-journals.com/index.php/IJAAST/article/view/Sci-244

Abstract The objective of this study was to find a rapid determination of the air-drying stress of sorghum (*Sorghum bicolor* L.) leaves using portable chlorophyll fluorescence imaging instrument. To assess the photosynthetic activity of sorghum leaves, an imaging analysis of the photochemical responses of sorghum was performed with chlorophyll fluorescence camera. The observed chlorophyll imaging photos were numerically transformed to the photochemical parameters on the basis of chlorophyll a fluorescence. Chlorophyll a fluorescence imaging (CFI) method showed that the rapid decrease in F_m of leaf was occurred under air-drying stress. Although F_v/F_m ratios values in air-drying stressed sorghum leaves were not changed, all other photochemical parameters such as F_m, F_v, F_p and F_t were lowered after air-drying stress. In air-drying stressed sorghum leaves, it showed to increase in nonphotoquenching (NPQ) and decrease in ΦPSII. Thus, ΦPSII and NPQ were available to determine nondestructively the air-drying stress of sorghum leaves. In our study, it was clearly indicated that the air-drying could be a stress in sorghum leaves. The CFI analysis and its related parameters are applicable as a rapid indicating technique for the determination of air-drying stress.
Keywords *Sorghum; Air Drying Stress; Chlorophyll Fluorescence Imaging; Nonphotoquenching; ΦPSII*

1. Introduction

Sorghum is not only an important cereal crop but also a biofuel crop. In Korea, sorghum cultivation is front to abiotic stresses such as drought at early growth stage, wet in middle growth stage and chilling stress at heading stage. The drought and air-drying stresses are most damaging to biomass production which is most actively progressed before rainy period so called Monsoon. Therefore, a breeding endeavor for selection of air-drying tolerant sorghum mutants or lines was further needed. In

climate condition of Korea, sorghum is cultivated during dry season at least over 2 months during young vegetative stage. Therefore, the efficient selection of drought tolerant sorghum mutants or lines was important in Korean Peninsula. Biomass production and survival consequence are closely related to photosynthetic activity under dry condition. It was recently reported that the sorghum brown midrib mutant has reduced lignin content in the cell walls and vascular tissues [1]. They could potentially be advantageous for cellulosic biofuel production.

In the context of air-drying stress, chlorophyll a fluorescence transient analysis, so-called JIP-test, and chlorophyll fluorescence imaging (CFI) technique may be able to apply to investigate the energetic behaviour of photosynthetic sensory systems. The JIP-test is a tool to analyse the polyphasic rise of the chlorophyll *a* (Chl *a*) fluorescence transients (phases labelled “OJIP”). Although it corresponds to only a very small fraction of the dissipated energy from the photosynthetic apparatus of fruit surface, Chl *a* fluorescence is widely accepted to provide a means to a better understanding of the structure and function of the photosynthetic apparatus. At room temperature, the Chl *a* fluorescence of plants, algae, and cyanobacteria, in the 680–740 nm spectral regions, is emitted mainly by photosystem (PS) II, and thus it can serve as an intrinsic probe of the fate of its excitation energy. The spectra and the kinetics of Chl *a* fluorescence are powerful and non-invasive tools for such investigations. The primary use of fluorescence has included the estimation of chlorophyll concentration and pigment–protein interactions and studies of the stability of thylakoid membranes. However, the relationship between chlorophyll and *in vivo* fluorescence varies widely over time and space. These processes include species changes, nutrient concentrations, and incident radiation [2].

Most studies analysing the effects of heat or chilling stress on OJIP transients have been conducted on plant leaves [3, 4] but not precisely in sorghum leaves. Even these studies have been limited to apple [5-7]. Photosynthetic activities differ between leaves and fruits; for example, in the pericarp of cherry tomato, photosynthetic fixation of $^{14}CO_2$ has been shown to occur at higher rates than in the leaves [8].

The photosynthetic apparatus is the most sensitive component in evaluating the degree of temperature-related stress damage [9]. CFI technique has been mainly used as effective tools in order to study the damage and activity of the electron transport chain in the photosynthetic apparatus under various environmental stresses. CFI as a rapid and non-destructive technique has quickly progressed, and has been used successful in evaluating plant photosynthetic activity [10]. CFI incorporates advancements in the technology of light emission, imaging detectors, and rapid data handling [11]. This study was performed to evaluate the validity of CF technology to determine the degree of air-drying stress in sorghum leaves.

2. Materials and Methods

2.1. Growth Condition of Sorghum Seedling

Seeds of sorghum (*Sorghum bicolor* L.) mutants, M2P1064 bmr36, were obtained from USDA, Texas. Seeds were sown in pots mixed with basal fertilizer N-P-K (12-5-8 kg/10a). When the third leaves were occurred, the pots were transfer to growth chamber. The rapid air-drying was performed for 24 hours with 12 hours 2,500 μmol m^{-2} s^{-1} illumination. All of the treatments were prior to exposure to air-drying condition. Sorghum seedlings were placed in a chamber and kept at room temperature. The growth chamber was set to 50 % relative humidity. All treatments were performed and each treatment was carried out in triplicate.

2.2. Measurement of Chlorophyll Fluorescence Imaging

The sorghum seedlings were measured separately for each treatment at 7 days after treatment (DAH) of the air-drying stress. A CFI FluorCam (Handy FluorCam FC 1000-H, PS I, Czech Republic) was used to measure the fluorescence images of the leaves.

The source of actinic light was orange LED at an intensity of 200 $m^{-2}s^{-1}$. The source of saturating light was a halogen lamp with an intensity of 2,500 $m^{-2}s^{-1}$. The fluorescence parameters maximum quantum efficiency of PS II (F_v/F_m), PS II operating efficiency (ΦPS II = F'q/F'm), and non-photochemical quenching (NPQ) were monitored by quenching kinetics analysis [12-14]. The data were calculated according to the parameters of the CFI FluorCam, which measured quenching kinetic. Light conditions were: actinic light, red LED, 200 µmol m^{-2} s^{-1}; saturating light, moderate light, 1,250 µmol m^{-2} s^{-1}.

2.3. Chlorophyll Fluorescence Parameters

Chlorophyll fluorescence parameters were defined as follows [15];

F_0 : Minimal chlorophyll fluorescence intensity measured in the dark-adapted state, when all PS II RCs are open

F_m : Maximal chlorophyll fluorescence intensity measured in the dark-adapted state during the application of a saturating pulse of light

F_p : Maximum fluorescence value under saturating illumination when all reaction centers are closed or in reduced state

F_v : Variable chlorophyll fluorescence ($F_m - F_0$) measured in the dark-adapted state, when non photochemical processes are minimum

F_t : Fluorescence at time *t* after onset of actinic illumination

F_v/F_m : Maximum quantum yield

ΦPSII : Effective quantum yield of photochemical energy conversion in PS II (F'_q/F'_m)

NPQ : Non-photochemical quenching

Rfd : Fluorescence decrease ratio

2.4. Data Analysis

The measured data were analyzed with the CFI software (FluorCam Software 7.0, http://www.psi.cz/products/ fluorcams/). All statistical analyses were carried out in Microsoft Excel and SAS program (Version 9.02).

3. Results

3.1. Chlorophyll Fluorescence Imaging (CFI) Analysis

Sorghum seedlings were apparently similar. Thus, it was not ease to determine the damage on eyes before 18 hours after air-drying (Figure 1).

In air-drying stressed sorghum leaves, dark adapted fluorescence value (red color) at F_O was lower than in control at 24 hours after treatment (HAT). Fm value of 1,420 was about three fold lower in control than in air-drying stressed leaves of 560 (Figure 2).

3.2. Maximum Quantum Yield (F_v/F_m) and Other Parameters

The maximum quantum yield (F_v/F_m) was 0.82 before air-drying stress. It was not changed until 24 HAT. Although the F_v/F_m ratios in air-drying stress sorghum leaves were almost normal, F_m and F_v

values were far lower than in control seedling (Figure 3A, B). Also, maximum fluorescence value (F_p) under saturating illumination when all reaction centers are closed or in reduced state was extremely lowered by air-drying stress. F_t values were considerably reduced already at 6 HAT. In air-drying stressed leaves, all measured fluorescence parameters were declined to over halves comparing control seedling.

3.3. Effective Quantum Yield of Photochemical Energy Conversion (ΦPS II)

In air-drying stressed sorghum leaves, the ΦPS II has decreased from 0.52 to 0.36 at 24 HAT, indicating that the effective quantum yield of photochemical conversion in PSII was inactivated (Figure 3B).

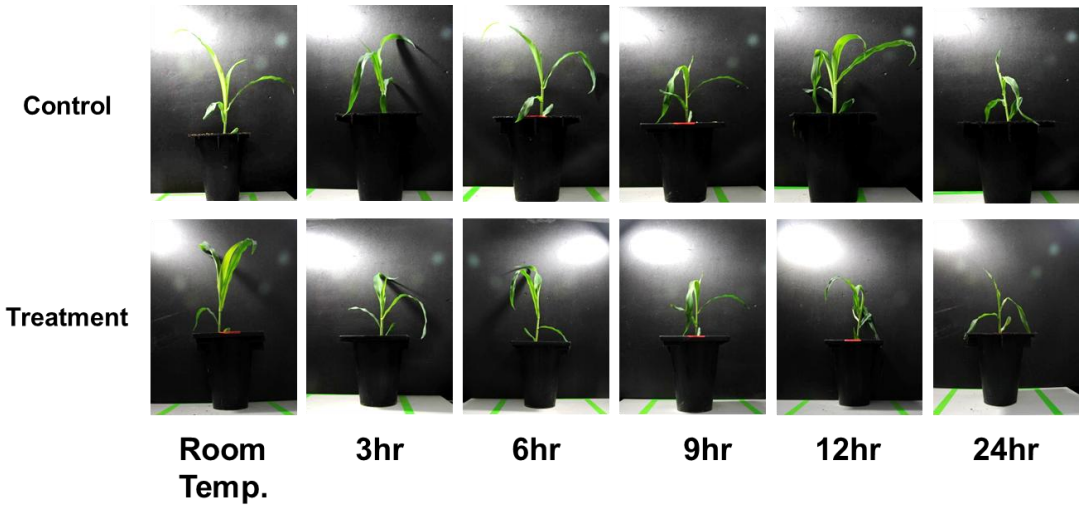

***Figure 1**: Sorghum Seedlings were grown in Growth Chamber Controlled with 23±2°C Temperature (Control) and 40% Relative Humidity (Air-Drying)*

3.4. Non-photochemical Quenching (NPQ)

In air-drying stressed leaves, the NPQ value has steeply increased from 0.33 to 0.70 at 6 HAT (Figure 3B). Finally, the value was enhanced up to 0.70 at 24 HAT.

3.5. Fluorescence Decrease Ratio (Rfd)

The Rfd value was considerably increased from 0.53 to 0.80 at 6 HAT, and then decreased to 0.48 at 12 HAT. At 24 HAT, the Rfd value was again increased to 0.73.

4. Discussion

4.1. CFI Technique

CFI was initiated to investigate whether it can be used as a reliable indicator to evaluate the air-drying stress of sorghum seedlings in order to study the light stress-specific difference that may be involved in the photosynthetic apparatus. CFI has been applied for different purposes in the postharvest life of fruits [6, 10], but the main focus has been on detecting factors that can increase or decrease product quality [10]. Moreover, the technique has been used for various objectives both in pre- and postharvest conditions for the detection of biotic or abiotic stresses in plants and plant products.

In comparison to the application of CFI for detection of abiotic stresses in different crops [6, 15], this study focused on the photochemical responses to air-drying stress condition. At least, CFI technique is applicable to determine the air-drying stress in numeric transformation of direct measured fluorescence values (Figure 2).

4.2. F_V/F_M Ratios

At 24 HAT, F_v/F_m value was not changed from 0.82 to 0.79 under air-drying stress. It may mean that the sorghum leaves are still photosynthetically active. Therefore, this photochemical parameter can be not good indicator for the determination of air-drying stress. In general, healthy plants have a very conservative F_v/F_m value of about 0.8 [16]. In air-drying stress condition, F_v/F_m has greatly retained compared to control. Björkman and Demmig [17] and Johnson et al. [18] also reported optimal values of F_v/F_m around 0.8 for most plant species, and values lower than this are observed in plants exposed to stress, indicating in particular the phenomenon of photoinhibition. However, it is still unclear whether air-drying stress is the case.

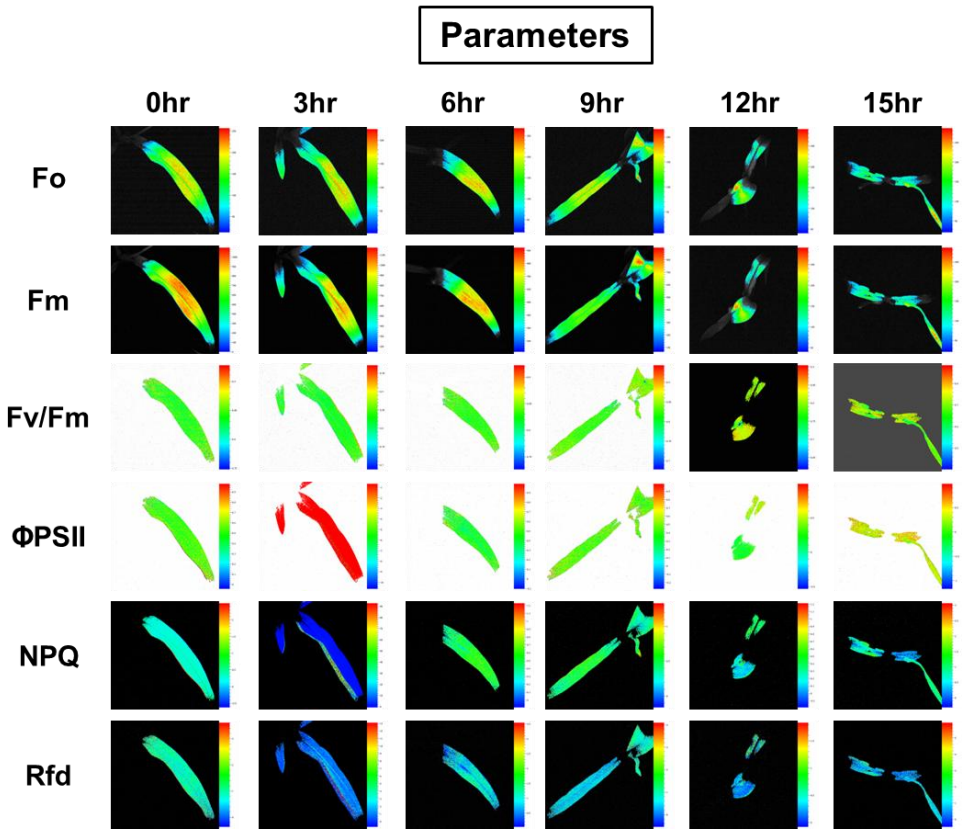

Figure 2: *Changes in Chlorophyll Fluorescence Imaging (F_o, F_m, F_v/F_m, ΦPSII, NPQ, and Rfd) of Sorghum Seedlings Grown in Growth Chamber Controlled with Temperature (23±2°C) and 40 Relative Humidity for 24 Hours*

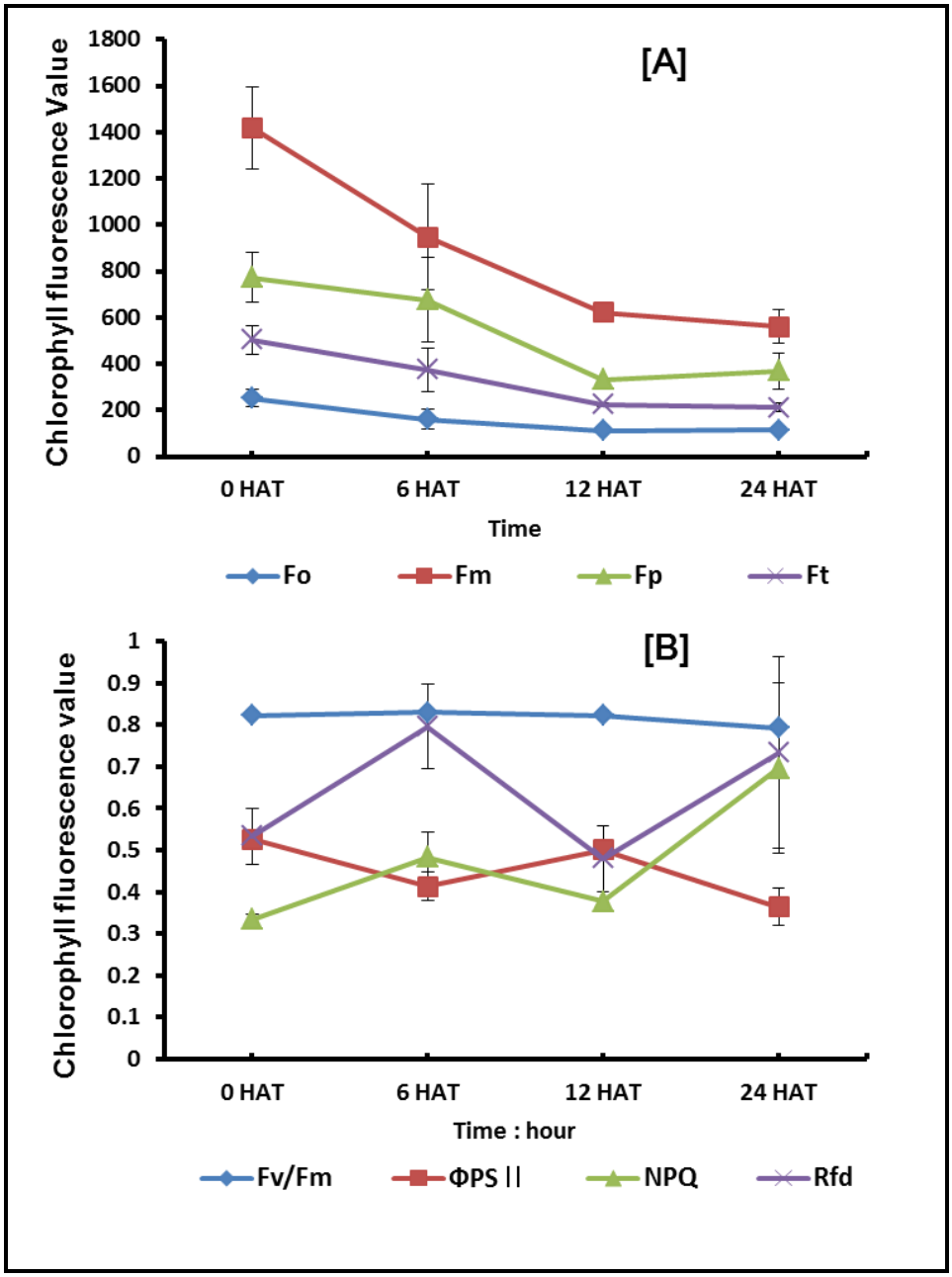

Figure 3: *Changes in Chlorophyll Fluorescence Imaging (F_o, F_m, F_v/F_m, ΦPSII, NPQ, and Rfd) of Sorghum Seedlings Grown in Growth Chamber Controlled with Temperature (23±2°C) and 40 Relative Humidity for 24 Hours*

4.3. ΦPSII

In air-drying stressed sorghum leaves, ΦPSII was gradually declined from 0.53 to 0.36 within 24 HAT (Figure 3). It has implied that they were photosynthetically inactive. The lower ΦPSII values in air-drying stressed sorghum leaves were assumed to be low chlorophyll a florescence in steady state, i.e. under continuous light pulse. In general, the chlorophyll fluorescence near at 25°C is most sensitive as the temperature in the growth chamber used in this study [16, 19, 20]. However, it was thought that this lower effective quantum yield of photochemical energy conversion in PS II was related to lower electron transport activity to Q^-_A resulting in severe stress on electron-transport from PSII to PSI.

4.4. NPQ

The NPQ values in air-drying stressed leaves have gradually increased from 0.33 to 0.70 at 24 HAT. In general, the increase in NPQ means inefficiency and energy dissipation in photosynthetic apparatus [14, 18, 21]. It may imply that the NPQ parameter is most sensitive to air-drying stress. Because the higher value of NPQ indicates low possibility of photosynthetic electron transport resulting in an increase in inactive chlorophyll of sorghum leaves [13, 21]. Thus, these NPQ values of sorghum leaves can be an available indicator parameter.

4.5. Rfd

In earlier report [22], the decrease of fluorescence decrease ratio (Rfd) in tomatoes under the sprinkler irrigation could be explained as photoinhibitory effect on the Calvin cycle by changes in the environmental conditions such as temperature, oxygen, light and physiological status of plants. There is no report until now on Rfd value under air-drying stress. Although the increase in Rfd seemed to be air-drying stress as shown in Figure 3B, the stressed sorghum leaves did not accompany with the increase of ΦPSII. Thus, it could be assumed that the stressed leaves were not recovered to normal status. When this parameter uses as a stress indicator, therefore, it should be carefully applied.

4.6. Comparison among Photochemical Parameters

The air-drying condition seemed to cause severe damage to the photosynthetic apparatus, resulting in changes in photosynthetic activity of sorghum leaves. The measurement of photochemical responses may be able to determine the photosynthetic stress of sorghum leaves under air-drying.

This study has shown that CFI can be used as a reliable tool to evaluate the healthy condition of sorghum leaves.

In sorghum leaves exposed to continuous air-drying stress condition for night, NPQ values increased gradually until 24 HAT. NPQ values in steady state have nonphotoquenching characteristics in dark-adapted state [16]. Although changes in NPQ are nonlinearly related to higher values than ΦPSII in leaves as earlier suggestion [16, 23], the ΦPSII seemed to be applicable to determine the stress under air-drying condition.

The air-drying stress causes severe damage to the photosynthetic apparatus, resulting in changes in appearing viability of leaves. This study has clearly shown that CFI can be used as a reliable tool to evaluate the air-drying stress of sorghum leaves.

5. Conclusion

The fluorescence imaging and the numeric data of F_v/F_m, ΦPSII, and NPQ showed that different responses occurred under air-drying stress condition. This practical study of the CFI technique has shown that the numeric values in F_v/F_m, ΦPSII, and NPQ could be applied to determine the light stress. Especially, F_m and ΦPSII values were declined under air-drying condition. F_v/F_m values retained almost 0.8. On the basis of the results of this study, the photochemical numeric parameters obtained from CFI were useful for an evaluation of air-drying stressed sorghum leaves. The numeric data derived from CFI analysis can be a rapid method for lair-drying stress determination

Acknowledgements

This work was supported by a grant from the Next-Generation BioGreen 21 program (No. PJ009101), Rural Development Administration, Republic of Korea.

References

[1] Li, Q., Xie, Q., Yu, S., and Gao, Q. New Approach to Study Starch Gelatinization Applying a Combination of Hot-Stage Light Microscopy and Differential Scanning Calorimetry. J Agric. Food Chem. 2013. 61; 1212-1218.

[2] Falkowski, P.G. and Raven, J.A., 2013: *Aquatic Photosynthesis*. Princeton, New Jersey, USA: Princeton University Press.

[3] Ogweno, J.-O., Song, X.-S., Hu, W.-H., Shi, K., Zhou, Y.-H., and Yu, J.-Q., 2009: *Detached Leaves Of Tomato Differ in their Photosynthetic Physiological Response to Moderate High and Low Temperature Stress*. Scientia Horticulturae. 2009. 123; 17-22.

[4] Wahid, A., Gelani, S., Ashraf M., and Foolad, M.R. *Heat Tolerance in Plants: An Overview*. Environmental and Experimental Botany. 2007. 61; 199-223.

[5] Chen, L.-S. and Cheng, L. *Photosystem 2 is More Tolerant to High Temperature in Apple (Malus domestica Borkh.) Leaves than in Fruit Peel*. Photosynthetica. 2009. 47; 112-120.

[6] Chen, L.-S., Li, P., and Cheng, L. *Comparison of Thermotolerance of Sun-Exposed Peel and Shaded Peel of 'Fuji' apple*. Environmental and Experimental Botany. 2009. 66; 110-116.

[7] Chen, L.-S., Li, P., and Cheng, L. *Effects of High Temperature Coupled with High Light on the Balance between Photooxidation and Photoprotection in the Sun-Exposed Peel of Apple*. Planta. 2008. 228; 745-756.

[8] Laval-Martin, D., Farineau, J., and Diamond, J. *Light versus Dark Carbon Metabolism in Cherry Tomato Fruits I: Occurrence of Photosynthesis. Study of the Intermediates*. Plant Physiology. 1977. 60; 872-876.

[9] Rachmilevitch, S., DaCosta, M., and Huang, B., 2006: Physiological and Biochemical Indicators for Stress Tolerance. Plant–Environment Interactions. 3rd Ed. Boca Raton, FL: CRC Press. 321-356.

[10] Nedbal, L. and Whitmarsh, J., 2004: *Chlorophyll Fluorescence Imaging of Leaves and Fruits*. In: Chlorophyll Fluorescence*;* George C. Papageorgiou and Govindjee (eds). Springer Netherlands. 389-407.

[11] Barbagallo, R.P., Oxborough, K., Pallett, K.E., and Baker, N.R. *Rapid, Noninvasive Screening for Perturbations of Metabolism and Plant Growth Using Chlorophyll Fluorescence Imaging*. Plant Physiology. 2003. 132; 485-493.

[12] Genty, B., Briantais, J.-M., and Baker, N.R. *The Relationship between the Quantum Yield of Photosynthetic Electron Transport and Quenching of Chlorophyll Fluorescence*. Biochimica et Biophysica Acta (BBA)-General Subjects. 1989. 990; 87-92.

[13] Genty, B., Wonders, J., and Baker, N.R. *Non-photochemical Quenching of Fo in leaves is Emission Wavelength Dependent: Consequences for Quenching Analysis and Its Interpretation*. Photosynthesis Research. 1990. 26; 133-139.

[14] Gorbe, E. and Calatayud, A. *Applications of Chlorophyll Fluorescence Imaging Technique in Horticultural Research: A Review.* Scientia Horticulturae. 2012. 138; 24-35.

[15] Yoo, S.Y., Ferrah, S., and Kim, T.W. *Chlorophyll Fluorescence Imaging Analysis for Fresh Quality Assessment of Apple and Kiwi Fruits Preserved Under Different Storage Conditions.* International Journal of Advanced Information Science and Technology. 2014. 29; 60-68.

[16] Baker, N.R. *Chlorophyll Fluorescence: A Probe of Photosynthesis in vivo*. Annu. Rev. Plant Biol. 2008. 59; 89-113.

[17] Björkman, O. and Demmig, B. *Photon Yield of O_2 Evolution and Chlorophyll Fluorescence Characteristics at 77 K among Vascular Plants of Diverse Origins*. Planta. 1987. 170; 489-504.

[18] Johnson, G., Young, A., Scholes, J., and Horton, P. *The Dissipation of Excess Excitation Energy in British Plant Species.* Plant, Cell & Environment. 1993. 16; 673-679.

[19] Fracheboud, Y., Haldimann, P. Leipner, J., and Stamp, P. Chlorophyll Fluorescence as a Selection Tool for Cold Tolerance of Photosynthesis in Maize (*Zea mays* L.). Journal of Experimental Botany. 1999. 50; 1533-1540.

[20] Baker, N.R. and Rosenqvist, E. *Applications of Chlorophyll Fluorescence Can Improve Crop Production Strategies: An Examination of Future Possibilities*. Journal of Experimental Botany. 2004. 55; 1607-1621.

[21] Havaux, M., Strasser, R.J., and Greppin, H. *A Theoretical and Experimental Analysis of the qP and qN Coefficients of Chlorophyll Fluorescence Quenching and their Relation to Photochemical and Nonphotochemical Events*. Photosynthesis Research. 1991. 27; 41-55.

[22] Krupa, Z., Siedlecka, A., Maksymiec, W., and Baszynski, T. *In vivo Response of Photosynthetic Apparatus of Phaseolus vulgaris L. to Nickel Toxicity*. Journal of Plant Physiology. 1993. 142; 664-668.

[23] Baker, N.R. *A Possible Role for Photosystem II in Environmental Perturbations of Photosynthesis.* Physiologia Plantarum. 1991. 81; 563-570.