

GROWTH, BIOMASS PARTITIONING AND CHLOROPHYLL FLUORESCENCE RESPONSE TO DROUGHT STRESS: A COMPARATIVE STUDY OF *COMMELINA COMMUNIS* L. BIOTYPES

MUHAMMAD HAROON^{1,4}, FAZLI WAHID¹, MUHAMMAD ILYAS², MUKHTAR ALAM¹,
HIDAYAT ULLAH¹, RAFI ULLAH¹, BEENA SAEED¹, MIAN AHMAD RAZA¹, MASAUD KHAN³ AND LI XIANGJU⁴

¹Department of Agriculture, University of Swabi, Pakistan

²Department of Botany, Kohsar University Murree, Punjab, Pakistan

³Department of Water Resources Management, The University of Agriculture Peshawar, Pakistan

⁴Institute of Plant Protection, Chinese Academy of Agricultural Sciences, 100193 Beijing China

*Corresponding author's email: xjli@ippcaas.cn

Abstract

Plants continuously adjust to their surroundings to organize the growth and photosynthesis activity in response to environmental fluctuations. The growth and photosynthesis response is mostly achieved by linking multiple environmental signals. Drought stress is one of the environmental setbacks which negatively affects growth and physiological processes of plants. In this study drought stress was applied to *C. communis* biotypes to provide the basic information and to detect the efficiency of photosystem II. Three different biotypes of *C. communis* (JL-1-1, LN-8 and HB-9-1) were used and compared each other in this study. These biotypes were treated with 100% field capacity (control) and 60% field capacity followed by 10 days drought stress condition. Under drought stress, plant growth, biomass partitioning and chlorophyll fluorescence were significantly decreased in all three biotypes as compared to control. In conclusion *C. communis* biotypes JL-1-1 under drought stress showed a healthy status having a superior photosynthetic capacity than LN-8 and HB-9-1. This study revealed the survival and competitiveness mechanism of *C. communis* biotypes under drought stress conditions and may serve as a theoretical basis to protect *C. communis* populations.

Key words: *C. communis*, Biomass partitioning, Chlorophyll fluorescence, Drought stress.

Introduction

Plant growing in ecosystem faces various types of ecological stress such as drought, minerals, temperature, heavy metal etc. (Ravanbakhsh *et al.*, 2018; Aysin *et al.*, 2020; Chernyshuk *et al.*, 2020). Among stressors drought is the main factor which adversely affect plant outturn by imposing certain changes at growth stages (Abid *et al.*, 2017). The water changes effect on growth and distribution of plant is more and more prominent. Previous studies focused on various plant species and their response to soil moisture changes (Wu *et al.*, 2007; Dahiya & Chaudhry, 2020). Castillo *et al.*, (2006) found *Lantana camera* a successful plant, maintain most of the functions of photosynthetic system II and also maintain high photosynthetic rate under drought conditions. However, some studies have shown that some weed species such as *Wedelia trilobata* (L.) Hitchc. *C. communis* L. and *Chenopodium album* L. are highly dependent on the water and susceptible to water environment (Song *et al.*, 2009; Haroon *et al.*, 2019; Dahiya & Chaudhry, 2020).

In order to determine the photosynthetic damage affected by drought stress, chlorophyll fluorescence is one of the promising and important powerful technique for screening of plant photosynthetic activities (Sajbidorova *et al.*, 2015). There are different changes occurring in chlorophyll fluorescence during environmental stress. The absorbed light energy is directed in three ways; used to drive photosynthesis, dissipated as heat or remission as fluorescence (Müller *et al.*, 2001). The results revealed that drought stress causes a reduction in maximal fluorescence (Fm), photochemical efficiency of photosynthesis II (ΦPSII), photochemical quenching (qP)

and increase in non-photochemical quenching (qN) (Guo *et al.*, 2015). Similar outcomes have also been described in *Coronilla varia* (Yang *et al.*, 2013) indicating that drought stress significantly affect chlorophyll fluorescence parameters. Drought stress is a different dimensional stress severely affect plant growth, biomass and photosynthesis activities (Bolat *et al.*, 2014; Zarafshar *et al.*, 2014). In general, plants under drought stress illustrated a negative effect on photosystem II quantum yield, photochemical quenching, electron transport rate and more heat dissipation (Xiang *et al.*, 2013).

C. communis is a fast-growing annual herb, native to East Asia and northern part of Southeast Asia (Santiago & Micheal, 2009). Additionally, *C. communis* has a broad ecological plasticity that allow it to survive better and maintain its dominance in some harsh environments (Kutbay & Uckan, 1998). *C. communis* is known for its excessive growth habit having adventitious root system (Huang *et al.*, 2000; Li *et al.*, 2008; Pyšek, 2001; Santiago & Micheal, 2009). At present it is the most common weed of China. Wherever it goes, it extrudes the crop and form a dense community. It is of great significance to control the harm and the trend of *C. communis*. Therefore, this study was carried out to determine the drought stress effect on *C. communis* for predicting their future spreading trend and effectively controlling their harm.

Materials and Methods

A greenhouse-based experiment was carried out in Institute of Plant Protection, Graduate School of Chinese Academy of Agricultural Sciences, Beijing-China. Seed of *C. communis* biotypes were collected from three different provinces of China i.e., JL-1-1 (Minzhu Village,

Xiwei Town, Yitong Manchu Autonomous County, Siping City, Jilin Province Corn field), LN-8 (Zhalan Village, Dasijiazzi Town, Zhangwu County, Fuxin City, Liaoning Province Corn field) and HB-9-1 (Experimental base of Hebei North University, Zhangjiakou City, Hebei Province Road sides). The seed of *C. communis* were grown in big pots (Height 29 cm and width 37 cm) May, 2018. After seeds emergence, the seedlings (4 cm) were transplanted into a free draining pot (Height 12.5 cm and width 14 cm) having 2:1(v/v) mixed with surface soil and nutritional soil (organic content $\geq 15\%$) and were allowed one *C. communis* seedling per pot. All the seedlings were well water until well established.

Drought stress treatment: The experiment layout consists of three biotypes (JL-1-1, LN-8 and HB-9-1) and treatment layout included control and drought stress. All the experimental pots were well water until all the seedling well established. The control plants were grown under 100% field capacity (FC) and drought stress treated plant were grown under 60% FC for 30 days then the *C. communis* plants were exposed to drought stress for 10 days and not watered for succeeding days. All the experimental pots were under a mobile rain shelter to avoid rainfall during drought stress.

Growth and biomass parameters: At 40 days of the experiment, the plant height (cm), number of leaves, leaves biomass (g), stem biomass (g), root biomass (g) and total plant biomass (g) were determined. The shoot mass ratio (S:M) was calculated by shoot mass and total biomass and root shoot (R:S) ratio was calculated by root biomass and shoot biomass.

Chlorophyll fluorescence: Determination of Chlorophyll Fluorescence Parameters: Chlorophyll fluorescence parameters were assessed using imaging-PAM Mini-Series (IMAG-K5, WalZ Germany) for plant determination under drought stress. Before the measurement, the living plants were placed in a dark for 30 minutes to adapt to the test. Six circular test target regions (AOI, area of interest) were selected from the fully unfolded leaf. The dynamic curves of chlorophyll fluorescence parameters were detected in the kinetics window of the software. The corresponding data could be directly derived from the report window. The related chlorophyll fluorescence parameters are expressed as follows: maximum fluorescence (F_m'), quantum yield of PSII (Φ_{PSII}), photochemical quenching (qP) and non-photochemical quenching coefficient (NPQ). The non-cyclic photosynthetic electron transport rate (ETR) of PSII was calculated by a systematic formula: $ETR = Yield \times PAR \times 0.5 \times Abs.$ in which PAR (photosynthetically active radiation) refers to the intensity of photochemical light; Abs., the absorption coefficient of the leaf, which can be calculated by the function of measuring the absorption of light from the leaf of the instrument itself; 0.5, the absorption value of each AOI assigned to PSII.

Statistical analysis of experimental data using 3 repeated mean using SPSS.11.5 for two-way ANOVA analysis and significant differences between the indicators using LSD method for multiple comparisons.

Results and Discussion

Plant height (cm) and number of leaves: The analyzed data exhibited that drought stress greatly influenced growth and biomass partitioning of *C. communis* biotypes (Table 1). The growth and biomass trend of three *C. communis* biotypes was found normal under normal supply of water (control) and a significant decreased was observed in mild stress followed by 10 days of drought stress ($p < 0.05$). By comparison among biotypes, the JL-1-1 plant height was maximum (38.67 cm) than the other *C. communis* biotypes. Similarly, the plant height under normal supply of water (control) was found normal as the plant height was decreased during drought stress (30.44 cm). As interaction of drought stress and biotypes was found non-significant (Fig. 1). The interaction of biotypes and treatment showed that JL-1-1 x control resulted maximum plant height (43.33 cm) as HB-9-1 x drought recorded minimum plant height (28 cm). In addition, data regarding number of leaves showed that among biotypes maximum number of leaves (54.17) was observed for LN-8 under normal water supply (control). As a decreased trend was observed in drought stress and recorded minimum number of leaves (20.44). Moreover, the interaction of biotypes and treatment showed an increase in number of leaves (64.00) for LN-8 x control as minimum values (30.66) was observed in JL-1-1 x drought stress. Under the consideration of above results, *C. communis* biotypes plant height and number of leaves were greater in control. As their plant height and number of leaves was greatly affected and a decline trend was observed under drought stress. This experiment was designed to quantify the *C. communis* biotypes ability to tolerate drought stress damage. Drought is one of the important limiting factors which negatively affect plant growth and productivity (Tatrai *et al.*, 2016; Nawaz *et al.*, 2020). It stimulates several biochemical and phenological changes (Maraghni *et al.*, 2014) resulted in plant growth reduction (Benjamin *et al.*, 2014). Some studies observed a reduction in plant height, number of leaves per plant, shoot biomass and root biomass under drought stress condition (Riaz *et al.*, 2013; Guo *et al.*, 2016). Likewise, Bravo *et al.*, (2017) observed that maximum plant height and plant biomass of *A. palmeri* ecotypes collected from corn field as compared with biotypes collected from short canopy crops i.e., vegetables. Some studies have reported reduction of growth and production with increasing soil water stress i.e., *Amaranthus palmeri* (Chauhan, 2013; Sarangi *et al.*, 2015). Likewise, some studies have shown that some weed species such as *Wedelia trilobata* (L.) Hitchc. are highly dependent on the water and susceptible to drought environment (Song *et al.*, 2009).

Table 1. Growth and biomass parameters of different *C. communis* biotypes as affected by drought stress.

Parameter	Population mean			Treatment mean	
	JL-1-1	LN-8	HB-9-1	Control	Drought
Plant height	38.67 a	35.33 b	34.67 b	42.00 a	30.44 b
No. of leaves	44.17 b	54.17 a	44.50 b	57.33 a	37.88 b
Leaves biomass (g)	06.78 a	07.22 a	06.41 a	08.01 a	05.61 b
Stem biomass (g)	16.75 a	19.82 a	12.81 b	21.07 a	11.84 b
Root biomass (g)	04.14 a	02.12 b	1.57 b	03.05 a	02.16 b
Total plant biomass	22.16 b	28.13 a	17.11 c	27.89 a	17.03 b
Shoot: mass ratio	0.70 a	0.73 a	0.66 b	0.72 a	0.67 b
Root: shoot ratio	0.26 a	0.11 b	0.13 b	0.189 a	0.144 b

Means of the same category followed by different letters are significantly different at $p \leq 0.05$ level using LSD test

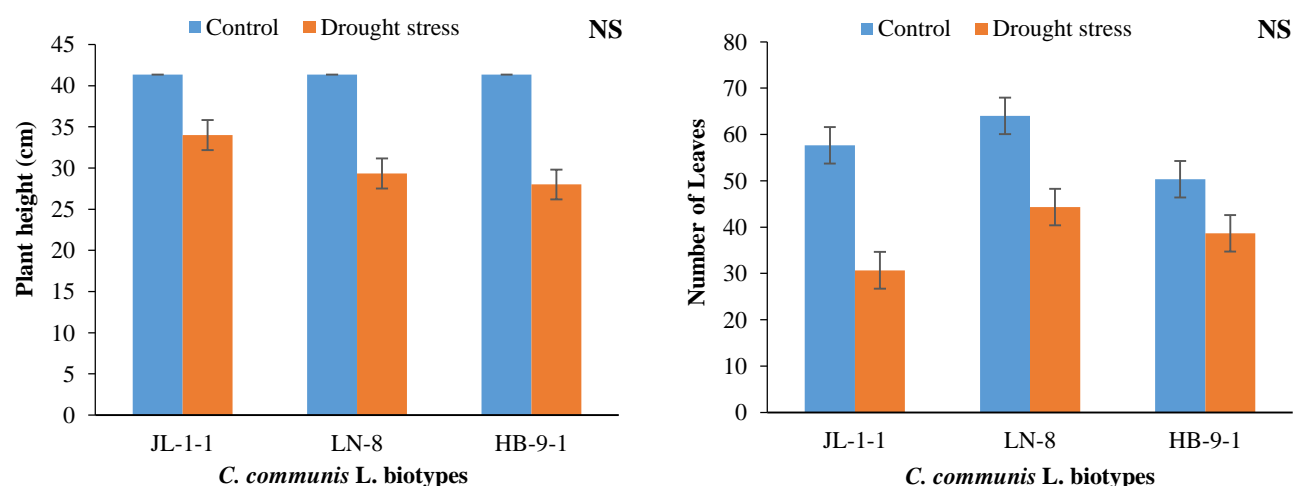


Fig. 1. Interactive effect of *C. communis* biotypes and drought stress on plant height (cm) and number of leaves.

Biomass (g): Likewise, growth parameter it also affects the plant leaves, stem, root and total plant biomass and a decrease trend were recorded in drought stress treatment (Table 1, Fig. 2). By comparison among biotypes, the maximum leaves biomass was recorded for LN-8 (6.78 g) and followed by JL-1-1 and HB-9-1, respectively. As a significant lowest leaves' biomass was observed in drought stress (5.61 g). However, the interaction was also found non-significant, as maximum leaves biomass (8.16 g) was recorded for JL-1-1 x control while minimum leaves biomass (5.31 g) was recorded for HB-9-1 x drought stress. The data regarding stem biomass showed a significant effect of drought stress on three *C. communis* biotypes. Among the biotypes, the obvious maximum stem biomass (19.82 g) was observed for LN-8 statistically which followed by JL-1-1. As the biomass was rapidly decreases during drought stress and recorded the minimum stem biomass (11.84 g), the general trend is opposite to control. Likewise leaves and stem biomass, drought stress also arrested the root and total plant biomass. During the experimental duration, among biotypes maximum root biomass (4.14 g) was recorded for JL-1-1 while a significant marginal difference was observed in treatment and minimum root biomass (2.16 g) was under drought stress. The interaction was also found significant and recorded maximum root biomass (4.71 g) for JL-1-1 x control as minimum root biomass (1.34 g) were observed under

HB-9-1 x drought stress. In this experiment, the total plant biomass of *C. communis* biotypes significantly affected by drought stress. However, interaction was found non-significant (NS). By comparison, among biotypes the total plant biomass increased in LN-8 (28.13 g) followed by JL-1-1 and HB-9-1. Over all the trend was decreased in drought stress. Moreover, among biotypes a significant increase was found in shoot: mass (0.73) for LN-8 as decrease trend were found in drought stress with minimum shoot: mass ratio (0.67). However, the interaction of biotypes and treatment was found non-significant. The root: shoot was observed to be significantly higher in JL-1-1 (0.26), as a decrease trend was observed in drought stress (0.14). The interaction of biotypes and treatment was also found non-significant. *C. communis* biotypes produce more leaves, stem and root biomass due to its higher growth in control than drought stress treatment. Likewise, different study reported the effect of water availability and limitation on plant growth, biomass, biochemical and physiological process (Bortolheiro & Silva, 2017; Zulfikar *et al.*, 2020). Water is one the most important constituents for plant growth and for longtime survival (Kebbas *et al.*, 2018). Similarly, Chahal *et al.*, (2018) reported the highest growth and biomass production of *A. palmeri* for 100% FC as compared to treated plants. Most of plant species manage the variability in water supply by changing the biomass pattern.

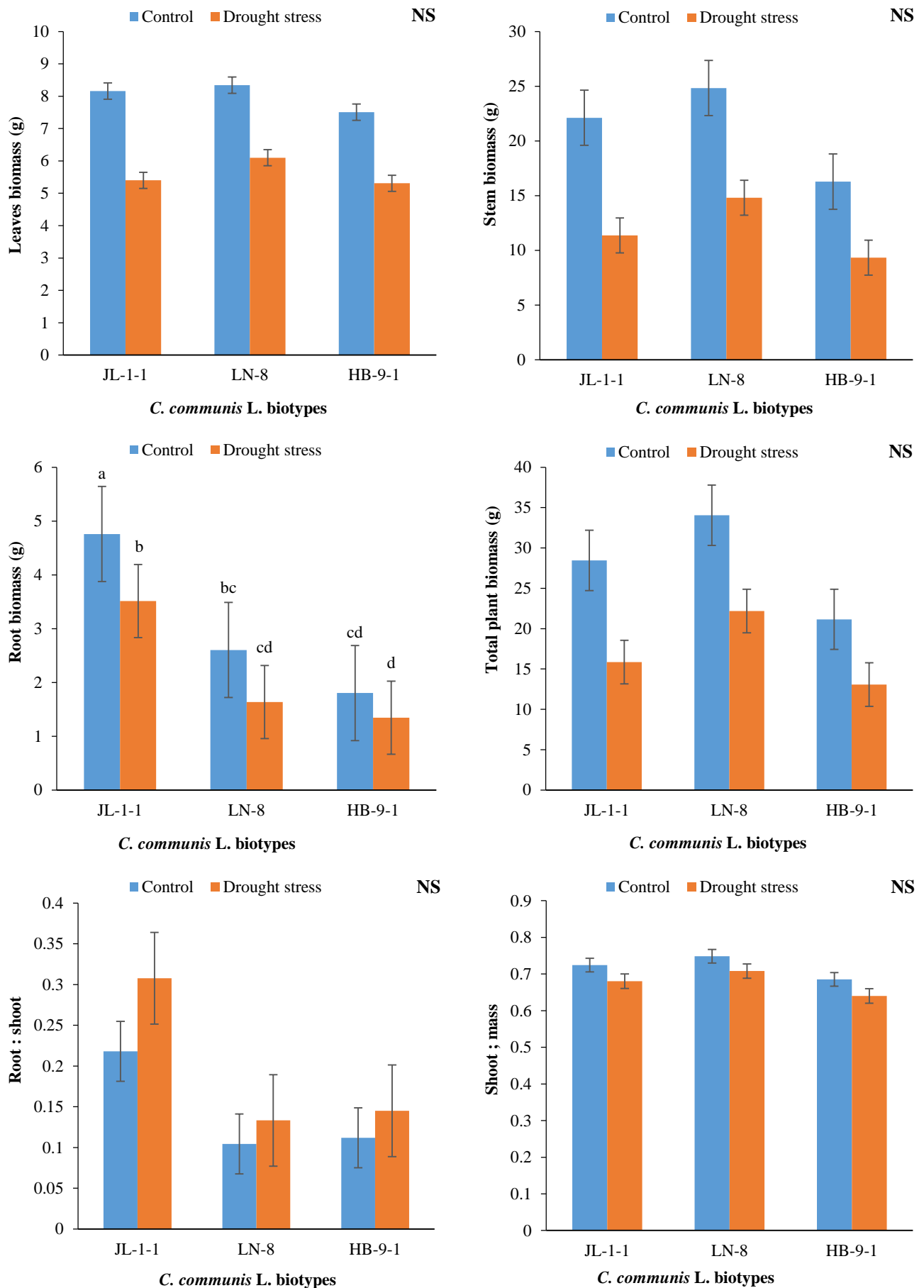


Fig. 2. Interactive effect of *C. communis* biotypes and drought stress on leaves biomass (g), stem biomass (g), root biomass (g), total plant biomass (g), root: shoot and shoot: mass.

Plant photochemistry: The results showed that drought stress greatly affects the photochemistry of *C. communis* biotypes (Table 2). The results showed that drought stress significantly affect the maximal fluorescence (F_m') of three *C. communis* biotypes i.e. a decline trend was observed during drought stress. Among biotypes the maximum F_m' value were recorded for JL-1-1 (0.1779) as among treatment minimum F_m' value was observed under drought stress. The interaction of treatment and biotypes was also found significant, as the maximum F_m' value was observed for JL-1-1 x control (0.2456) while minimum F_m' value was recorded for JL-1-1 x drought stress (0.0962). In addition, the drought stress significantly affects the quantum yield of PSII (Φ PSII) while the interaction was also found significant. As among biotypes the maximum value were recorded for JL-1-1 (0.3526) whilst the minimum quantum yield of PSII were observed when the plant subjected to drought stress (0.2242). As for interaction of biotypes and treatment, the maximum quantum yield of PSII were recorded in JL-1-1 x control (0.4495) as the decline trend was observed in HB-9-1 x drought stress (0.1998). The non-photochemical quenching (NPQ) shows the energy proportion, that is absorbed by the PSII pigments, as dissipated in the form of heat. The data regarding non-photochemical quenching showed a significant affect among biotypes and treatment as interaction of biotypes and treatment was found significant. Among biotypes the maximum NPQ were recorded in LN-8 (0.7212) as a decrease trend was observed in control recorded minimum value (0.4979). Moreover, the variation trend of photochemical quenching among biotypes were affected by drought stress while their interaction was found non-significant. Photochemical quenching of *C. communis* biotypes increase in control and the maximum value were recorded for JL-1-1 (0.6281) as a decline trend was observed in drought stress having minimum qP value (0.4904). As for interaction of biotypes and treatment, the maximum qP value were recorded for JL-1-1 x control as minimum value were recorded for HB-9-1 (0.4354). Electron transport rate (ETR) shows the transport of electron in the PSII reaction center under light conditions. *C. communis* biotypes were significantly affected by drought stress as the interaction was found non-significant. Among biotypes highest ETR

were recorded in JL-1-1 (23.561). However, ETR is greatly affect by drought stress with a decline trend and recorded minimum ETR value under drought stress (14.559). As for interaction of biotypes and treatment it was found significant, the maximum ETR value were recorded for JL-1-1 c control (30.36) as minimum values were found for HB-9-1 x drought stress (12.837).

The results showed a significant difference in *C. communis* photochemistry due to drought stress treatments (Fig. 3). The maximal fluorescence (F_m'), quantum yield of PSII electron transport (Φ PSII), non-photochemical quenching (NPQ), photochemical quenching (qP) and electron transport rate (ETR) are the important parameters for chlorophyll fluorescence which are used to study plant under drought stress (Fu *et al.*, 2012; Murchie and Lawson, 2013). At drought stress, the parameters of chlorophyll fluorescence of different biotypes was considerably reduced. Drought stress stimulates various inhibitory effect on photosynthesis via destruction of photosynthetic pigments and components (Massacci *et al.*, 2008), photosynthetic apparatus (Takahashi & Murata, 2008; Zlatev, 2009; Kumari and Sharma, 2010). In our study F_m' , Φ PSII, qP and ETR significantly decrease under drought stress while an increase trend was observed in NPQ values under drought stress. Similar results have been reported by (Li *et al.*, 2008; Guo *et al.*, 2015) maximal fluorescence (F_m'), maximum photochemical quenching (qP), electron transport (ETR) declines while nonphotochemical quenching (NPQ) increases under drought stress in cucumber seedlings. Similarly, many studies reported that drought stress reduce the efficiency of chlorophyll fluorescence parameter of many species i.e. *Coronilla varia*, and *L. ruthenicum* (Yang *et al.*, 2013; Guo *et al.*, 2016). Besides, stress on plant photosynthesis in the study of photosynthetic efficiency can make effective evaluation on plant photosynthesis, although different ecotypes have different mechanism and functions of stress resistance. Therefore, in the study of *C. communis* stress tolerance using Y(II) to evaluate the overall stress or stress early warning is superior to other parameters. In addition, *C. communis* biotypes JL-1-1 under drought stress showed a healthy status having a superior photosynthetic capacity than LN-8 and HB-9-1.

Table 2. Chlorophyll fluorescence parameters of different *C. communis* biotypes as affected by drought stress.

Parameter	Population mean			Treatment mean	
	JL-1-1	LN-8	HB-9-1	Control	Drought
F_m	0.1709 a	0.1666 a	0.1365 b	0.1971 a	0.1189 b
Φ PS II	0.3526 a	0.2589 b	0.2516 b	0.3511 a	0.2242 b
NPQ	0.4813 b	0.7212 a	0.6638 a	0.4979 b	0.7463 a
qP	0.6281 a	0.5357 b	0.5137 b	0.6279 a	0.4904 b
ETR	23.561 a	16.774 b	16.453 b	23.300 a	14.559 b

Means of the same category followed by different letters are significantly different at $p \leq 0.05$ level using LSD test

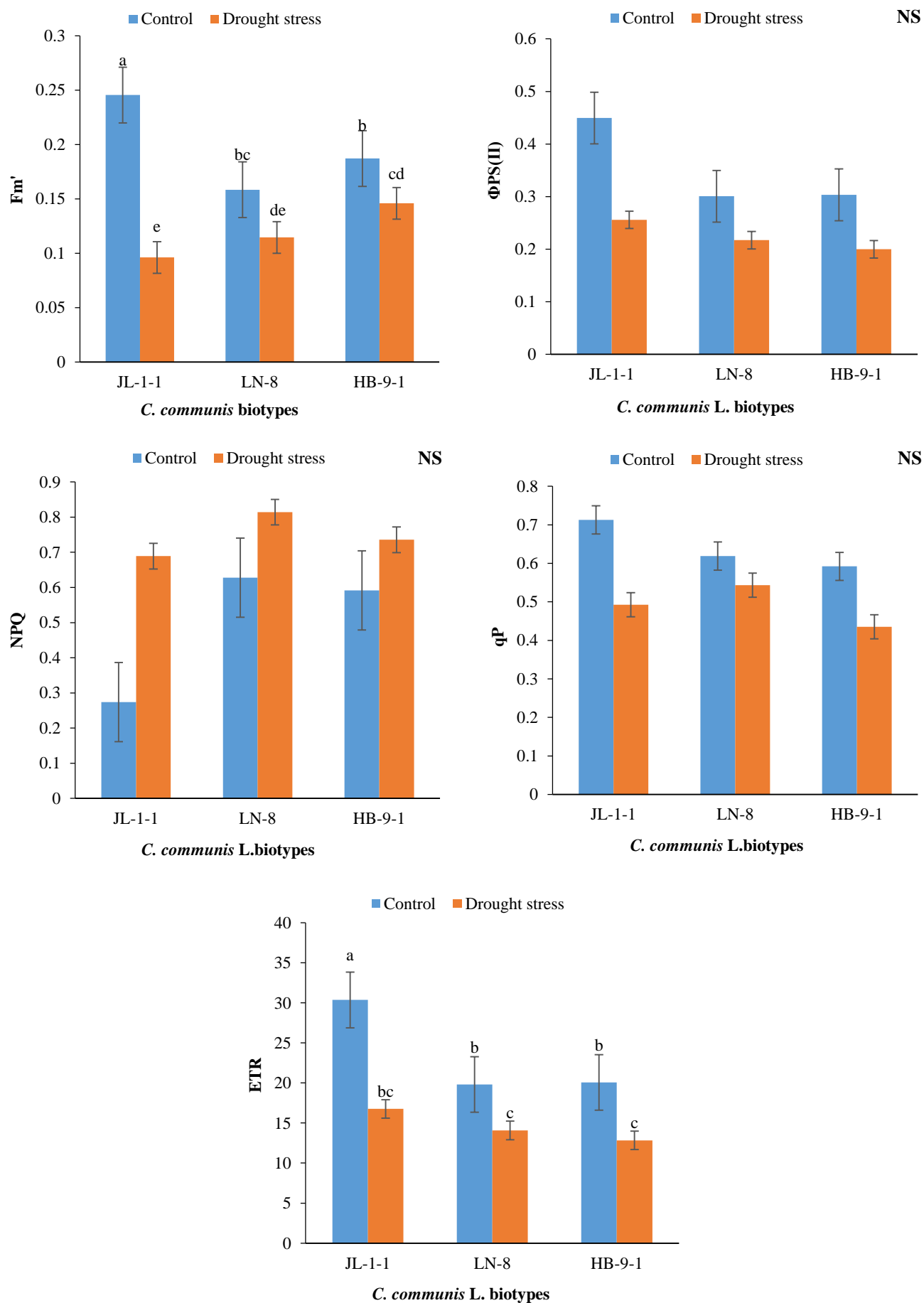


Fig. 3. Interactive effect of *C. communis* biotypes and drought stress on Fm', ΦPS (II), NPQ, qP and ETR.

Conclusion

This study showed that *C. communis* biotypes showed different response to tolerate drought stress. In conclusion, growth, biomass partitioning and chlorophyll fluorescence of *C. communis* biotypes have been observed under drought stress. It is evident that growth, biomass partitioning and chlorophyll fluorescence of *C. communis* biotypes were severely affected by drought stress. In case of biomass of *C. communis* biotypes was limited may be due to reduction in photosynthesis efficiency in order to reduce the damage caused by drought stress to photosynthetic apparatus. By analyzing chlorophyll fluorescence parameters JL-1-1 biotypes is drought resistant as compare to LN-8 while HB-9-1 is a drought sensitive biotype. Therefore, in the study of *C. communis* stress tolerance using ΦPSII to evaluate the overall stress or stress early warning is superior to other parameters. This research showed the survival strategies of *C. communis* biotypes under drought stress and may serve as a theoretic base to protect *C. communis* populations.

Acknowledgements

This study was funded by the National Key Research and Development Program of China (2016YFD0300701) and the earmarked fund for China Agriculture Research System (CARS-25).

References

- Abid, G., K. Hessini, M. Aouida, I. Aroua, J.P. Baudoin, Y. Muhovski, G. Mergeai, K. Sassi, M. Machraoui, F. Souissi and M. Jebara. 2017. Agro-physiological and biochemical responses of faba bean (*Vicia faba* L. var. 'minor') genotypes to water deficit stress. *Biotechnol. Agron. Soc. Environ.*, 21(2): 146-159.
- Aysin, F., A. Karaman., A. Yilmaz., O. Aksakal., E. Gezgincioglu and S.M. Kohnehsahri. 2020. Exogenous cysteine alleviates mercury stress by promoting antioxidant defense in maize (*Zea mays* L.) seedlings. *Turk. J. Agric. For.*, 44: 506-516.
- Benjamin, J.G., D.C. Nielsen, H.F. Vigil, M.M. Mikha and F. Calderon. 2014. Water deficit stress effects on corn (*Zea mays* L.) root:shoot ratio. *O.J.S.S.*, 4: 151-160.
- Bolat, I., M. Dikilitas., S. Ercisli., A. Ikinci and T. Tonkaz. 2014. The effect of water stress on some morphological, physiological, and biochemical characteristics and bud success on apple and quince rootstocks. *Sci. World J.*, 2014: 769732.
- Bravo, W., R.G. Leon, J.A. Ferrell, M.J. Mulavaney and C.W. Wood. 2017. Differentiation of life history traits among Palmer amaranth populations (*Amaranthus palmeri*) and its relation to cropping systems and glyphosate sensitivity. *Weed Sci.*, 65: 339-349.
- Castillo, J.M., P. Leira-Doce, J.C. Tacuri, E.M. Guacho, A.A. Solis, G. Curado, D. Doblas, A.E.R. Casal, A.A.A. Lopez, S.R.Gomez, R. Berjano, G. Guerrero, A.D. Cires, E. Figueroa and A. Tye. 2006. Contrasting strategies to cope with drought by invasive and endemic species of Lantana in Galapagos. *Biodiv. Conserv.*, 16(7): 2123-2136.
- Chahal, P.S., S. Irmak, M. Jugulam and A.J. Jhala. 2018. Evaluating effect of degree of water stress on growth and fecundity of Palmer amaranth (*Amaranthus palmeri*) Using Soil Moisture Sensors. *Weed Sci.*, 66(6): 738-745.
- Chauhan, B.S. 2013. Growth response of itchgrass (*Rottboellia cochinchinensis*) to water stress. *Weed Sci.*, 61: 98-103
- Chernyshuk, D.K., L.Y. Ivachenko., H. Doğan., G. Raza., M.A. Ali., K.S. Golokhvast and M.A. Nawaz. 2020. Dihydroquercetin increases the adaptive potential of wild soybean against copper sulfate and cadmium sulfate toxicity. *Turk. J. Agric. For.*, 44: 492-499.
- Dahiya, B. and S. Chaudhry. 2020. Response of *Chenopodium album* L. to varying levels of water stress: effects on physiological and biochemical parameters. *Plant Arch.*, 20(1): 2081-2086.
- Fu, W., P. Li and Y. Wu. 2012. Effects of different light intensities on chlorophyll fluorescence characteristics and yield in lettuce. *Sci. Hort.*, 135: 45e51.
- Guo, Y., H. Yu, D. Kong, F. Yan, D. Liu and Y. Zhang. 2015. Effects of gradual soil drought stress on the growth, biomass partitioning, and chlorophyll fluorescence of *Prunus mongolica* seedlings. *Turk. J. Biol.*, 39: 532-539.
- Guo, Y.Y., H.Y. Yu, D.S. Kong, F. Yan and Y.J. Zhang. 2016. Effects of drought stress on growth and chlorophyll fluorescence of *Lycium ruthenicum* Murr. Seedling. *Photosynthetica*, 54(4): 524-531.
- Haroon, M.Y. Haiyan, C. Hailan and L. Xiang-ju. 2019. Growth and seed production response of *Commelina communis* L. to drought stress. *Gesunde Pflanzen*, 71: 281-288.
- Huang, C.Y., T.B. Chen, Y. Wang and B.H. Sun. 2000. Weed survey of soybean field in north region of Heilongjiang province. *Soybean Sci.*, 19: 341-345. (in Chinese)
- Ke Abbas, S., T. Benseddik, H. Makhloufi and F. Aid. 2018. Physiological and biochemical behaviour of *Gleditsia triacanthos* L. young seedlings under drought stress conditions. *Not. Bot. Horti. Agrobot.*, 46(2): 585-592.
- Kumari, N. and V. Sharma. 2010. Stress-mediated alteration in V-ATPase and V-PPase of *Butea monosperma*. *Protoplasm*, 245: 125-132.
- Kutbay, H.G. and F. Uckan. 1998. Phenotypic plasticity in Turkish *Commelina communis* L. (Comelinaceae) populations. *Turk. J. Bot.*, 22: 199-204.
- Li, Q.M., B.B. Liu, Y. Wu and Z.R. Zou. 2008. Interactive effects of drought stresses and elevated CO₂ concentration on photochemistry efficiency of cucumber seedlings. *J. Integr. Plant Biol.*, 50(10): 1307-1317.
- Li, X.Y., B. Tao, Y.H. Li and L.J. Qiu. 2008. Genetic diversity in dayflower at six locations of Heilongjiang Province by using RAPD markers. *Crops*, (2): 21-25. (in Chinese)
- Marghani, M., M. Gorai, M. Neffati and M.C. Van-Labeke. 2014. Differential responses to drought stress in leaves and roots of wild jujube, *Ziziphus lotus*. *Acta Physiol. plant*, 36: 945-953.
- Massacci, A.S.M., L. Nabiev, S.K. Pietrosanti, T.N. Nematopv, K. Chernikova, J. Thor, M. Maraghni, M. Gorai, M. Neffati and M.C. Van Labeke. 2014. Differential responses to drought stress in leaves and roots of wild jujube, *Ziziphus lotus*. *Acta Physiol. Plant.*, 36: 945-953.
- Müller, P., X.P. Li and K.K. Niyogi. 2001. Non-photochemical quenching. A response to excess light energy. *Plant Physiol.*, 125: 1558e1566.
- Murchie, E.H. and T. Lawson. 2013. Chlorophyll fluorescence analysis: a guide to good practice and understanding some new applications. *J. Exp. Bot.*, 64: 3983e3998.
- Nawaz, H., N. Hussain., M. Jamil., A. Yasmeen., A. Bukhari., M. Auringzaib and M. Usman. 2020. Seed biopriming mitigates terminal drought stress at reproductive stage of maize by enhancing gas exchange attributes and nutrient uptake. *Turk. J. Agric. For.*, 44: 250-261.
- Pyšek, P. 2001. Past and future of predictions in plant invasions: A field test by time. *Diversity & Distributions*, 7: 145-151.

- Rolf F J. 1998. Numerical Taxonomy and Multivariate Analysis System. Version 2.0. Exeter Publishing, Setauket, New York, America.
- Ravanbakhsh, M., R. Sasidharan, L.A.C.J. Voeselek and G.A. Kowalchuk. 2018. Microbial modulation of plant ethylene signaling: ecological and evolutionary consequences. *Microbiome*, 6: 52.
- Riaz, A., A. Younis, A.R. Taj, A. Karim, U. Tariq, S. Munir and S. Riaz. 2013. Effect of drought stress on growth and flowering of Marigold (*Tagetes erecta* L.). *Pak. J. Bot.*, 45(S1): 123-131.
- Sajbidorova, V., H. Lichtnerova and V. Paganova. 2015. The impact of different water regime on chlorophyll fluorescence of *Pyrus pyraeaster* L. and *Sorbus domestica* L. *Acta Uni. Agric. et Silv. Mendelianae Brun.*, 63(5): 1575-1579.
- Santiago, M.U. and D.K. Micheal. 2009. Response of Asiatic dayflower (*Commelina communis*) to glyphosate and alternatives in soybean. *Weed Sci.*, 57: 74-80.
- Sarangi, D., S. Irmak, J.L. Lindquist, S.Z. Knezevic and A.J. Jhala. 2015. Effect of water stress on the growth and fecundity of common Waterhemp (*Amaranthus rudis*). *Weed Sci.*, 64: 42-52.
- Song, L., S. Lan-lan, S. Zhan, Z. Wei, L. Wei-Hua and P. Chang-Lian. 2009. Effect of drought stress and rehydration on chlorophyll fluorescence characteristics in leaves of invasive *Wedelia trilobata*. *Acta Ecol. Sin.*, 29(7): 3714-3721.
- Takahashi, S. and N. Murata. 2008. How do environmental stresses accelerate photoinhibition? *Trends Plant Sci.* 13: 178-182.
- Tatrai, Z.A., R. Sanoubar, Z. Pluhár, S. Mancarella, F. Orsini and G. Gianquinto. 2016. Morphological and physiological plant responses to drought stress in *Thymus Citriodorus*. *Int. J. Agron.*, ID 4165750.
- Wu, J., Z. Houben, L. Hongfang and P. Shaolin. 2007. Effects of soil water regimes on the growth of the exotic invasive plant: *Chromolaena Odorata*. *Ecol. & Environ.*, 16(3): 935-938.
- Xiang, D.B., L.X. Peng, J.L. Zhao, L. Zou, G. Zhao and C. Song. 2013. Effect of drought stress on yield, chlorophyll contents and photosynthesis in tartary buckwheat (*Fagopyrum tataricum*). *J. Food Agric. Environ.*, 11: 1358-1363.
- Yang, W.Q., M.Y. Gu and J.C. Kou. 2013. Effect of drought and rewatering on the photosynthesis and chlorophyll fluorescence of *Coronilla varia*. *Acta. Agrestia. Sin.*, 21: 1130-1135.
- Zarafshar, M., M. Akbarinia, H. Askari, S.M. Hosseini, M. Rahaie, D. Struve and G.G. Striker. 2014. Morphological, physiological and biochemical responses to soil water deficit in seedlings of three populations of wild pear tree (*Pyrus boissieriana*). *Biotechnol. Agron. Soc. Environ.*, 18: 353-366.
- Zlatev, Z. 2009. Drought-induced changes in chlorophyll fluorescence of young wheat plant. *Biotechnol.*, 23: 437-441.
- Zulfiqar, F., A. Younis, A. Riaz, F. Mansoor, M. Hameed, N.A. Akram and Z. Abideen. 2020. Morpho-Anatomical adaptations of two *Tagetes erecta* L. cultivars with contrasting response to drought stress. *Pak. J. Bot.*, 52(3): 801-810.

(Received for publication 12 August 2021)