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Chlorophyll fluorescence induction kinetics and yield responses in rainfed crops with variable potassium nutrition in K deficient semi-arid alfisols

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ABSTRACT

Optimum potassium (K) nutrition in semi-arid regions may help crop plants to overcome constraints in their growth and development such as moisture stress, leading to higher productivity of rainfed crops, thus judicious K management is essential. A study was conducted to evaluate the importance of K nutrition on physiological processes like photosynthesis through chlorophyll a fluorescence and chlorophyll fluorescence induction kinetics (OJIP) of rainfed crops viz., maize (*Zea mays* L.), pearl millet (*Pennisetum glaucum*), groundnut (*Arachis hypogaea*), sunflower (*Helianthus annuus*), castor (*Ricinus communis* L.) and cotton (*Gossypium hirsutum*) under water stress conditions by studying their growth attributes, water relations, yield, K uptake and use efficiency under varied K levels. Highest chlorophyll content was observed under K60 in maize and pearl millet. Narrow and wide Chl a:b ratio was observed in castor and groundnut respectively. The fluorescence yield decreased in the crops as K dosage increased, evidenced by increasing of all points (O, J, I and P) of the OJIP curves. The fluorescence transient curve for K60 was lower than K0 and K40 for all the crops. Potassium levels altered the fluorescence induction and impaired photosynthetic systems in all the crops studied. There was no distinct trend observed in leaf water potential of crops under study. Uptake of K was high in sunflower with increased rate of K application. Quantitatively, K uptake by castor crop was lesser compared to all other crops. Our results indicate that the yield reduction under low K was due to the low capacity of the crops to translocate K from non-photosynthetic organs such as stems and petioles to upper leaves and harvested organs and this in turn influenced the capacity of the crops to produce a high economic yield per unit of K taken up thus reducing utilization efficiency of K.

1. Introduction

Potassium (K) is the third most essential macronutrient needed by plants to complete their life cycle successfully, after nitrogen and phosphorus. Essentiality of K in plant life cycle is evidenced by its role in activating about 80 enzymes which are involved in various physiological processes such as energy metabolism, starch synthesis, nitrate reduction, photosynthesis and sugar degradation. As a component of plant cytoplasmic solution, K reduces loss of water from leaf surfaces by regulating stomatal closure and increases water uptake efficiency of roots from soil mainly due to the role of K in regulating cellular osmotic potentials [1]. Thus, K has a positive impact on improved drought tolerance of plants growing under water shortage conditions [2] in rainfed regions. Agriculture in rainfed regions suffers from constraints like poor soil fertility particularly K, low soil moisture availability/retention, and reduced nutrient use efficiency which directly affect the performance of crop plants resulting in reduced productivity. The general practice in these regions is to only use NP rich fertilizers excluding K fertilization in major rainfed crops such as maize (*Zea mays* L.), pearl millet (*Pennisetum glaucum*), cotton (*Gossypium hirsutum*), groundnut (*Arachis hypogaea*), sunflower (*Helianthus annuus*) and castor (*Ricinus communis* L.) which are also known to be K exhaustive crops. Thus, continuous cropping in absence of optimum K nutrition resulted in depletion of soil K reserve such as non-exchangeable K fraction [3,4]. Many studies across Indian soils and elsewhere in the world are becoming K deficit in different soil types [5]; this resulted in K deficiency in soils and sub-optimal K nutrition is an important productivity constraint particularly in rainfed dryland regions, highly vulnerable weather conditions mainly elevated temperature and untimely rainfall.

Semi-arid alfisol regions in general experience droughts in quick succession mainly due to monsoon failures which have a serious impact on crop yields. Deficit rainfall due to delayed onset or breaks in south west monsoon is of major concern in rainfed agriculture that reduced productivity of major crops [6]. Effective K management is one of the key approaches that will help the plant to overcome these situations resulting in normal yields rather than critical loss of crop.

During the photosynthetic process, light is absorbed by the antenna molecules within the photosynthetic membrane and the absorbed

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energy is transferred as excitation energy. There are two ways that determine the fate of this energy one is that the energy is trapped at a reaction center and used in photochemistry, and the other is that it is dissipated mainly in the form of heat and fluorescence. This fluorescence emission offers interesting opportunities in studying the plants' response to environmental conditions. The properties of this emitted fluorescence are basically determined by the pigments that absorb them, the transfer of energy by the excitation process, and the nature and orientation of the fluorescing pigments. Chlorophyll (Chl) fluorescence is a non-invasive method to monitor the alterations of photosynthetic processes [7] by measuring the emitted radiation from the crop. It is a useful indicator as it gives important information about the state of health of a photosynthetic apparatus and it is a valuable tool for plant studies from leaf to ecosystem levels [8,9]. Chl fluorescence can be characterized by different phases: Chlorophyll Fluorescence Induction Kinetics (OJIP) is fluorescence transient corresponding to the redox states of photosystem PSII and PSI, and to the efficiencies of electron transfer through the intersystem chain to the end electron acceptors at the PSI acceptor side [10,11]. It is known that K impacts photosynthesis of the crop canopy via solar radiation interception, and we thus hypothesize that increasing doses of K will have an impact on the growth and development and yield of crops, there is a dearth of literature on the relationship between of Chl fluorescence and K levels in rainfed crops. Hence, current study was planned to evaluate the importance of K nutrition on crops and with the objective to study the effects of applied K on Chl a fluorescence in addition to exploring the possibilities to surmount the effects of early, mid-season and terminal droughts that become common occurrences in rainfed regions affecting performance of rainfed crops like maize, pearl millet, cotton, groundnut, sunflower and castor.

2. Material and Methods

2.1. Details of Experiment Site

A series of field experiments were carried out on different rainfed crops at Gunegal Research Farm of ICAR-Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad (India) during summer season of 2012 and 2013. Location coordinates are 17° 05′ 01.19″ N 78° 40′ 06.32″ E and the average annual rainfall is 690.0 mm, mean annual temperature was 25.7 °C. Mean monthly rainfall and temperature during experiment period are presented in Fig. 1. Soils are sandy loam in texture, slightly acidic in reaction (pH 5.1), EC was in normal range (0.08–0.1 dS m^{-1}), low in organic carbon (3.4 g kg^{-1}), available N (141–153 kg ha^{-1}), medium in available P (16–19 kg ha^{-1}) and available K (154–188 kg ha^{-1}). Among micronutrients Zn was deficient (0.48 mg kg^{-1}).

2.2. Crops and Treatment Details

Popular varieties of major rainfed crops viz., maize (DHM-117), pearl millet (Shanti), cotton (MRC-7347 BG-1, MRC-7351 BG-1 and NCS-207 Mallika Bt-2) groundnut (JL-24), sunflower (KBSH-1) and castor (DCS-9) of the region were selected for the experiment. There were three treatments comprising of 0, 40 and 60 kg ha^{-1} K respectively denoted as K0, K40 and K60. Three K levels respectively depict nil, medium and maximum K recommendations for a crop. The levels of K were finalized with reference to package of practices suggested for different crops of the region by State Agricultural University. Details of the spacing, sowing and harvesting of each crop is given in Table 1 and monthly mean rainfall and temperature during experiment period is given in Fig. 1. Except differential dose of K application all other nutrients were supplied uniformly as per recommendation considering soil test values.

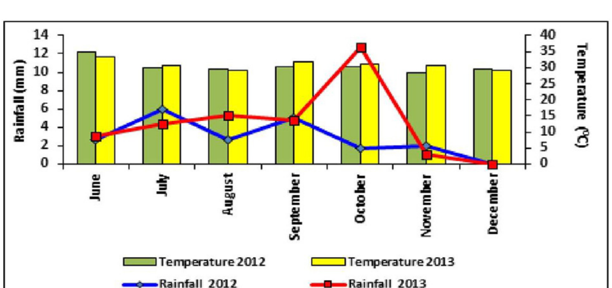

Fig. 1. Mean monthly rainfall and temperature during experiment period.

2.3. Carotenoids and Chlorophyll Content of Leaf Tissue

Carotenoids and chlorophyll content in plant leaf were measured (mgg^{-1} of fresh weight) following the procedure outlined by Wellburn [12] and equations developed by Arnon [13] were used to calculate Chla, Chlb and Total Chl are as follows,

$$\text{Chla}\left(\text{mg g}^{-1}\right) = 0.0127\ \text{A663}–0.00269\ \text{A645}$$

$$\text{Chlb}\left(\text{mg g}^{-1}\right) = 0.0029\ \text{A663}–0.00468\ \text{A645}$$

$$\text{Total Chl}\left(\text{mg g}^{-1}\right) = 0.0202\ \text{A663} + 0.00802\ \text{A645}$$

2.4. Chlorophyll Fluorescence Measurements

The OJIP fluorescence transient was measured using a portable fluorometer (FluorPen FP 100; Photon Systems Instruments; Drasov, Czech Republic). Fully developed youngest leaves were selected for the measurements. The leaves were dark-adapted for 30 min before starting the measurements using leaf clips provided by the manufacturer. Measurements were done three times on the adaxial leaf surface. For each measurement, two places per leaf were selected in one plant. Data were analyzed from 10 measurements (five plants with two places per leaf, and one leaf per plant) for each treatment and control. The method followed was according to Thwe and Kasemsap [8]. The OJIP fluorescence parameters were calculated based on the formulas shown in Table 2. Minimum fluorescence (F0) was measured at 50 μs when all PSII reaction centers are open and it is defined as the O step, followed by the J step (at 2 ms), the I step (at 60 ms) and at maximum fluorescence (FM) when all PSII reaction centers are closed, known as the P step [10]. The OJIP test represents a translation of the original data to biophysical parameters that quantify the energy flow through PS II [14]. From each OJIP fluorescence induction, specific energy fluxes per reaction center were analyzed and compared.

2.5. Leaf Water Potential

Measurement of leaf water potential is a better indicator for plant physiological response under water shortage conditions. For all crops leaf water potential was measured timely within field using Psypro™ Wescor water potential system.

2.6. Soil Sampling and Analysis

Soil samples from three depths i.e., 0–0.2, 0.2–0.4 and 0.4–0.6 m were collected with the help of tube augar before and after every crop. Soil samples were air dried, gently ground and passed through a 2-mm sieve. Further these processed samples were analyzed for basic physico-chemical properties viz., pH and EC, respectively indicating acidity–alkalinity and salt concentration of the soil. A known quantity of soil (20 g) was vigorously shaken after adding distilled water (1:2.5 soil:water ratio) [15]. After a time period pH of soil was determined