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ROLE OF OSMOPROTECTANTS AND SOIL AMENDMENTS FOR SUSTAINABLE SOYBEAN (*Glycine max* L.) PRODUCTION UNDER DROUGHT CONDITION: A REVIEW

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Tolerance

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ABSTRACT

Water stress has a significant effect on yield and quality of soybean through negatively influencing seedling establishment, growth, phenology and finally yield of soybean. The enhancement of soybean productivity and quality against water stress, application of proline, glycine betaine and soil application of compost play a vital role for improving the physiological processes. The current review highlights the physiological responses of soybean during various growth stages under water stress. Additionally, the review evaluates the mitigation mechanism of the adverse of water deficit stress on soybean through exogenous application of osmoprotectants as well as soil application of organic amendments. The study also tried to summarize the current understandings of exogenous application of osmoprotectants such asproline and glycine betaine, and soil amendments that could be used to minimize the harmful effect of water stress on seed yield and quality of soybean.

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1 Introduction

Soybean (*Glycine max*) belongs to a leguminous family that grown for obtaining edible oil and forage. Seeds of soybean have a high content of proteins (40%), lipids (20%) and carbohydrates (Popović et al., 2015). It has been a good source of protein for human and animals feeding (Liu, 1997). Further, soybean seed oil is rich in essential fatty acids. Currently, it is considered as a potential plant to produce of biodiesel (Hill et al., 2006).

Growth, development, yield and end-product quality of a plant are highly influenced by environmental conditions, especially temperature and precipitation. (Meena et al., 2017; Islam et al., 2011; EL Sabagh et al., 2015h; Abdelaal et al., 2018). Among the environmental stress, Among the abiotic stresses, the drought has been identified as one of the principal global problems in future and will face a great challenge to crop production in worldwide especially in arid and semi-arid region (Barutcular et al., 2017). Similar to other susceptible crop, water stress is one of the major problems to limit the yield of soybean. Whereas water stress is one of the major problems to limit the yield of soybeanby changing different physiological and biochemical process of the plants during different growth stages (Farooq et al., 2009). Flowering and seed development stages of soybean are most sensitive to soil moisture stress (Popović et al., 2015). This can lead to a reduction in soybean grain yield up to 40% (Pathan et al., 2007; Popović et al., 2015). Some of the molecules like glycine, betaine and proline act as osmoprotectants (maintain osmotic pressure in plants) can be used to alleviate the unfavorable impacts of water stress under field condition (Hadiarto & Tran, 2011; Thapa et al., 2011; Dadhich, et al., 2014).

Osmoprotectants can adding to plants in various ways i.e., through the rooting medium, foliar spray and pre-sowing seed treatment. Whereas, Ashraf &Foolad, (2007) reported that foliar application of proline is more effective to alleviate the adverse effects of abiotic stresses than other application methods. Therefore, plant growth and development can be maintained with exogenous application of osmoprotectants under water deficit stress (drought) condition (Ashraf & Foolad, 2007; Hadiarto & Tran, 2011). Glycine betaine (GB), is pre-dominant in higher plants that synthesized in chloroplast from serine via ethanolamine, choline, and betaine aldehyde (Genard et al., 1991; Rhodes & Hanson, 1993). It is a member of quaternary ammonium compound that plays a vital role for osmotic adjustment and protection of thylakoid membrane, thereby maintaining photosynthetic efficiency osmolytes under drought condition (Genard et al., 1991; Chaitanya et al., 2009). However, GB implementation has been taken as an approach to enhance the tolerance in plants under stress environments (Meena et al., 2016).

Incorporation of organic matter in soil has also a positive effect on growth, productivity, and yield of soybean (Ibrahim et al., 2008). Application of compost derived from agricultural wastes can improve soil physical properties that maintain a supply of water and nutrients to plants for a longer period (Tejada et al., 2009). Compost is called as a soil conditioner that improves soil physicochemical properties such as water holding capacity and soil aeration (Patel et al., 1993), and serves as a source of plant nutrients (Campbell et al., 1986). Considering the above information, the current review aimed to clarify the physiological responses of soybean during various growth stages under drought conditions. Further more, the present review attempt to evalute the exogenous application of osmoprotectants and soil application of compost for the alleviation of adverse effects of water deficit stress on soybean and also for maximizing the yield of soybean.

2 General perspectives of drought stress to soybean plant

Water deficiency during plant growth and development is commonly known as a drought. It is one of the major environmental factors that is considered as a one of the limiting factor that limits the global crop production (Larcher, 2003; Centritto et al., 2008). According to Al-Barrak (2006), water stress has a significant effect on plant growth characters as well as seed and oil yields, however, seed oil content remains unaffected. Gaballah et al. (2008) and Ouda et al. (2008) reported the highest soybean yield and its components under irrigation using pan evaporation coefficient equal to 1.2. However, reduction in seed yield (3.3-3.4%) was recorded when irrigation scheduled at pan evaporation coefficient of 1.0 and further reduction in seed yield (47.5-58.4%) was recorded under pan evaporation coefficient of 0.8. Tawfik (2008) also found a significant reduction in soybean yield under water stress treatments. Al-Suhaibani (2009) reported that soybean yield attributes, seed crude protein and carbohydrate content in the seed are highly correlated with soil water availability to plants. Photosynthetic pigment contents in relation to seed yield and yield contributing parameters of plants are fully depend on water and, macro and micronutrient nutrients uptake use efficiency (Alderfasi & Alghamdi, 2010). Khalil & Ismae (2010) reported significantly higher plant growth and relative leaf water content (RLWC) under sufficient soil moisture supply; however, water stress had a negative effect on these parameters. They also reported that the decreasing trend of soil moisture levels caused a significant increase in proline and alkaloids contents. Abdel & Al-Rawi (2011) found that irrigation at every 8 days interval decreased growth and yield attributes, which ultimately reduced the soybean yield and seed yield per plant by 91.3 and 83.7%. Irrigation scheduling at 10 and 20 days interval and water stress treatments revealed that reproductive stage is the most sensitive than vegetative stage causing a reduction in water-use efficiency and seed yield by at least 50% (Ahmed & Suliman, 2010). Allahmoradi et al. (2011) found that both vegetative and reproductive stage respond similarly to water stress. However, the decrease in oil content was more when stress was imposed at flowering stage to stem elongation stage (Hosseini & Hassibi, 2011).

3 Effect of water stress on soybean plants

3.1 Effect on Germination and seedling establishment

Perfect, rapid and uniform germination is essential for having a good green area and crop growth rate for better radiation utilization and higher yield (Ashraf & Mehmood, 1990). Germination period is more sensitive to water stress. At sowing time seeds generally, absorb water (50 percent of its weight) to begin germination. However, decrease in germination percentage and increase in germination time is observed under limited water supply or water stress (Willenborb et al., 2004). The percentage of germination and other traits related to germination are severely influenced by abiotic stress (Rasaei et al., 2013; EL Sabagh et al., 2015a.).The initiation of cell elongation during seed germination (McDonough, 1975) and seed vogour (Bayoumi et al., 2008) is very sensitive to water stress. Other researchers noticed that water deficit also induced osmotic stress and negatively influenced the growth of seedling (Djibril et al., 2005), although the exact potential inhibiting germination varied considerably under water stress conditions due to a smaller negative osmotic potential (Taylor et al., 1982). Comparative studies on the effect of different plant parts have showed that water stress reduced the linear growth of shoots while compared to those of unstressed plants (Kumar & Sharma, 2009). The negative effect of water stress on plant growth/morphological parameters such as leaf area, number of leaves and tillers, and stem girth diameter have been well-documented by Abdalla & El-Khoshiban, (2007).

3.2 Effect on Plant growth and development

The adverse effect of soil water stress was observed in RLWC, MSI, HI and DTI (Shinde et al., 2010). A significant decrease in chlorophyll *a*, chlorophyll *b* and total chlorophyll contents were also recorded when water stress was imposed during vegetative or anthesis stage (Mafakher et al., 2010). They also observed the negative effect of water stress (drought) on photosynthesis, transpiration, stomatal conductance that ultimately reduced the yield of affected crop. Other researchers found significant reduction in dry matter accumulation, crop growth rate and relative growth rate as well as yield contributing characters i.e., grains per plant, grain filling duration and grain weight under water stress (Ghassemi-Golezani et al., 2009). During water stress root length of the sunflower genotypes was increased, while stem length, total leaf area, fresh and dry weights were decreased significantly that ultimately lead to reduce the total chlorophyll and carotenoid content, finally decreased the yield of sunflower(Manivannan et al., 2008). The decline in leaf area under water stress conditions is mainly attributed to declining in turgor pressure (Prasad et al., 2008). EL Sabagh et al. (2016a) observed that chlorophyll content of soybean plant decreased significantly under different level of water deficit conditions (Figure 1). Further, the previous results showed a negative impact on the growth parameters (EL Sabagh et al, 2015f). Yokas et al. (2008) observed that the reduction in leaf chlorophyll under drought stress condition is due to the destruction of chlorophyll pigments and instability of the pigment-protein complex. Similarly, water stress caused a reduction in Chl a, Chl b and carotenoid contents as well as the Chl a/b and carotenoid/Chl a+b ratios in the leaves that ultimately lead to decrease the final yield (EL-Tayeb 2006). The alteration of chlorophyll might be an indicator in plants to understand the severity of environmental stresses (Barutçular et al. 2016a). They also found that water stress resulted in a decrease in RLWC and MSI and increase in lipid peroxidation level, catalase (CAT) and peroxidase (POX) activity. These led to decrease in photosynthesis rate and protein synthesis materials under water stress; therefore protein synthesis decreased drastically or even stops (Smiciklas et al., 1992). Under water deficit environments lipid peroxidation as malondialdehyde (MDA) significantly increased while decreasing catalyze and peroxidase activities (Abdelaal et al., 2017).

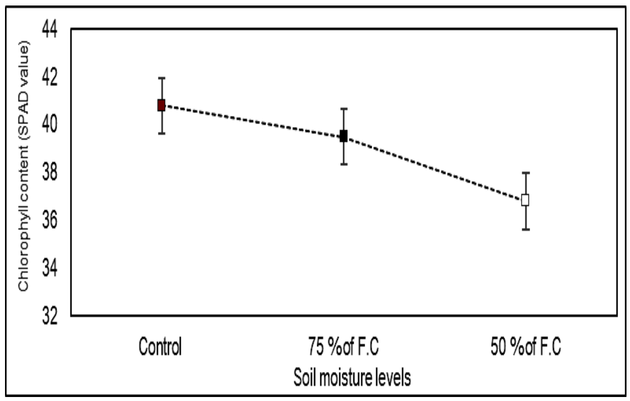

Figure 1 Water deficit condition influenced the chlorophyll content of soybean (F.C; field capacity). (Source: EL Sabagh et al., 2016a)

Inadequate water supply to plant, limits the productive potential due to a decrease in plant vegetative growth and reproductive period (Sibel & Birol, 2007). Studies have indicated that leaf area growth decreased in response to water stress in many species of soybean (Zhang et al., 2004; Abdalla & El-Khoshiban, 2007). EL Sabagh et al. (2016a) found that under different Water deficit condition (different field capacity level), chlorophyll content of soybean influenced significantly that lead to decrease the final seed yield of soybean (Figure 1 & 2).

3.3 Effect on Biomass production

The biomass production reduced with an increase in water deficit stress; nonetheless, in major cases, the tolerant genotypes had less reduction in biomass than susceptible ones (Salem, 2003). Water stress also inhibits partitioning of photo-assimilates within the plants (Bota et al., 2004). Environmental stresses led to significant reduction in growth parameters causing diminished crop productivity (Barutçular et al., 2016b; EL Sabagh et al., 2017; Rahman et al., 2017). Water stress during early grain development stage reduces the final grain dry matter (Khanna et al., 1994). Similarly, Sinaki et al. (2007) noticed that water stress during seed development stage reduces seed yield via reduction of seed weight. The yield and yield attributed traits have been significantly reduced by environmental stresses (Hossain et al., 2012a; Hossain et al., 2012b; Hossain et al., 2013; Hossain &Teixeira da Silva, 2013; EL Sabagh et al., 2015a; EL Sabagh et al., 2015h; Hasan et al., 2017). Further, it is observed that water stress for short period during grain development stage decreases grain size and grain weight which ultimately affect the final grain yield. Water stress during early flowering stage increases death of floret and loss of seed size which resulted in reduction of harvest index (Seghatoleslami et al., 2008). Actually, water stress initiates a series of biochemical and physiological processes in plants which results in the reduction of crop yield (Shahbaz et al., 2011). The seed yield reduction of soybean due to water deficit stress was recently reported (EL Sabagh et al., 2016a & Figure 2). Further, reduction of growth, yield and attributed traits of various crops have been well-documented (Abd el-wahed et al., 2015a; Abd el-wahed et al., 2015b; EL-Sabagh et al., 2015a: Barutçular et al. 2016c, EL Sabagh et al., 2017; Rashwan et al.,2016).

Hence, there are many defense mechanisms in plants such as osmoregulation, ion homeostasis, antioxidant and hormonal systems which induce the water stress tolerance in plants (Mahajan & Tuteja, 2005). Many plants in dry habitats are known to accumulate organic solutes such as proline and glycine betaine (GB) (Khan & Gul, 2006). Proline is a plant osmoregulator, whose accumulation is considered as an early response to water deficit stress (Ramanjulu & Sudhakar, 2000). Proline accumulation plays an adaptive role in the plant to survive under stress condition (Verbruggen & Hermans, 2008). Several investigators reported that proline plays a regulatory role in activity and function of the enzymes in plant cells and in their participation in the development of metabolic responses to environmental factors (Ozturk & Demir, 2002). Similarly, these mechanisms are promoting photosynthesis, maintaining enzymatic activity and scavenging reactive oxygen species. Earlier studies noticed that the exogenous application of proline regulates uptake of mineral nutrients in plants subjected to water deficit conditions (Jaleel et al., 2007) and it is one of the osmotic protection mechanisms in the plant under water stress (Yamada et al., 2005).

Proline and GB are known to serve as compatible osmolytes, macromolecules protections and also as scavengers of ROS under stressful environments (Ashraf & Foolad, 2007). Enhancement of proline concentration in whole plant organs is considered to be

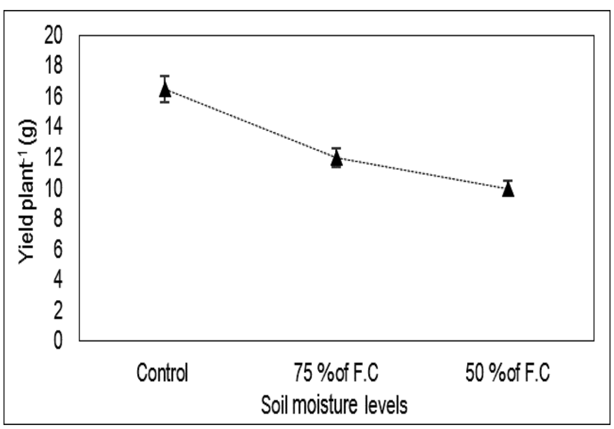

Figure 2 Influence of water deficit on yield plant^{-1} of soybean (Source: EL Sabagh et al., 2016a).

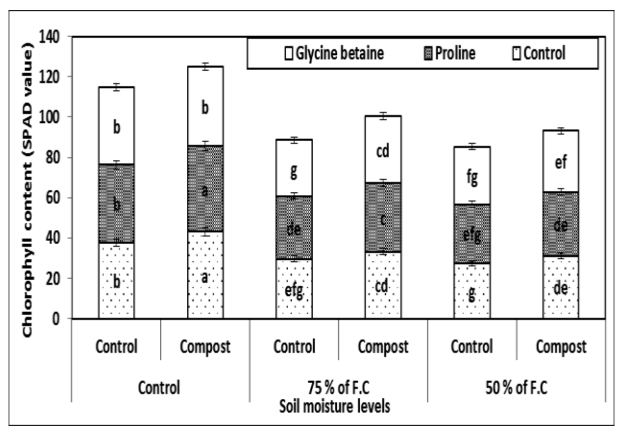

Figure 3 Effects of proline, glycine betaine and compost application on chlorophyll content in soybean under water stress (Source: EL Sabagh et al., 2015c).

4 Strategies for managing environments stresses through bioregulatore and compost application

4.1 Proline

The enhancing of tolerance to stress environment of the plant is a viable strategies to find an answer to the problem induced by climate change, so, implementation of phytochemicals plays a vital role in improving stress tolerance in plants (Kazemi, 2014).

correlated with water stress tolerance (Heikal & Shaddad, 1982). However, the proposed functions of accumulated proline are osmoregulation, maintenance of membrane and protein stability under water stress condition (Taiz & Zeiger, 2006; Wahba et al., 2007). It has been also observed that proline may protect chlorophyll damage (Figure 3) under water stress (EL Sabagh et al., 2015c). Much attention has been paid to define the role of proline in water stress tolerance as a compatible osmolyte (Samaras et al., 1995), which contributes in an osmotic adjustment in plant tissues (Bajji et al., 2000). However, little attention has been given to its role in affecting the uptake and accumulation of inorganic nutrients in plants (Khedr et al., 2003).

4.2 Glycine betaine (GB)

In a stressful environment, plants store multiple groups of compatible solutes such as sugars, free amino acids like glycine betaine (GB), proline and polyols to survive (Hoque et al., 2007). Chaitanya et al. (2009), GB is a member of quaternary ammonium compounds that are pre-dominant in higher plants subjected to water stress condition. It is one of the compatible solutes that play a significant role under drought condition for enhancing the productivity of soybean (EL Sabagh et al., 2015b; EL Sabagh et al., 2015d; EL Sabagh et al., 2015g; Figure 4).

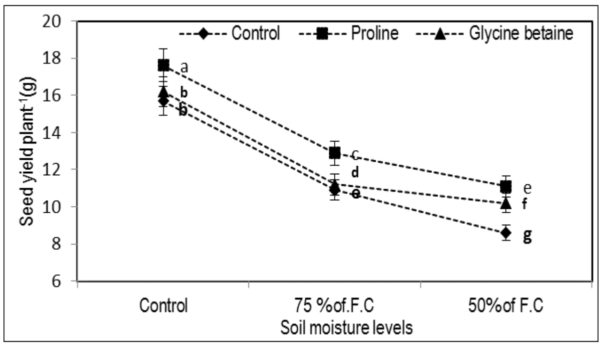

Figure 4 Effects of proline and glycine betaine application on seed yield/plant in soybean under water stress (Source: EL Sabagh et al., 2015b).

Further, Ibrahim & Aldesuquy (2003) observed the protective role of GB in the growth and development of plant through osmotic adjustment where it acts as a non-toxic cytoplasmic osmolyte. Ashraf & Foolad (2007) reported positive effects of exogenous application of GB on plant growth and final crop yield of soybean under water. Similarly, Mahmood et al. (2009), reported that application of GB at 50mM showed the maximum amelioration effect on growth under water stress by increasing shoot fresh biomass as well as leaf area per plant. While, GB did not influence the net CO_2 assimilation rate, stomatal conductance, shoot and root N, K^+, Ca^{++} and P and water use efficiency (Mahmood et al. 2009). Wang et al. (2010) reported that application of GB increased the osmotic adjustment in plants for water stress tolerance by improving antioxidative defense system including antioxidative enzymes in wheat crop. GB possesses anti-transparent properties which improve water stress tolerance in plants by reducing irrigation water requirements without sacrificing various quantitative indices (Agboma et al., 1997). Ali & Ashraf (2011) found that exogenous application of GB ameliorate the negative effects of seed oil physicochemical attributes under water deficit conditions.

4.3 Stress Management through compost application

Balanced fertilization is an important factor to increase the productivity of agriculture. Addition of compost is essential to provide necessary nutrients for crops and improving soil physicochemical properties (Meena et al., 2015). The combined application of organic and inorganic fertilizers (INM) may reduce the demand for mineral fertilizer and soil degradation as well as save production cost. In addition, global environmental pollution can be also managed considerably by the reduction in the use of mineral fertilizer (Khaim et al., 2013). Compost application is one of the important practical measures to enhance seed yield under water stress condition as reported by EL Sabagh et al. (2015b; Figure 5). Further, it also improves soil microbial activities such as dehydrogenase and soil microbial biomass carbon (Sun et al., 2003).

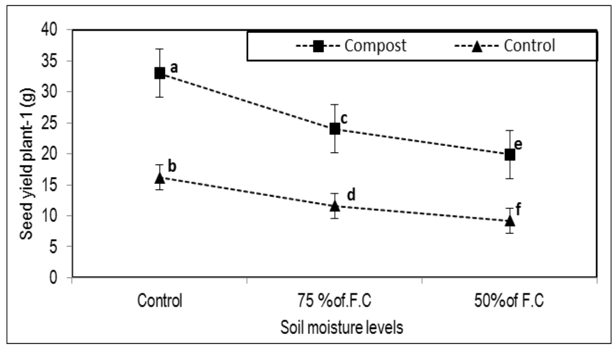

Figure 5 Effects of compost application on seed yield /plant in soybean under water stress (Source: EL Sabagh et al., 2015b).

An organic fertilizer like compost is considered as a soil conditioner and has potential to maintain higher soil moisture content for a longer period which in turn led to enhancement in crop growth and yield (Zhang et al., 2009). In addition**,** application of compost improves soil water-holding capacity and increases water and nutrients availability to plants (Wesseling et al., 2009). Enhancement in vegetative growth of sunflower under irrigation with different concentration of sea salt was recorded due to the application of vermicompost and biogas slurry (Ahmad & Jabeen, 2009). However, the combined application of vermicompost and biogas slurry showed maximum benefits. Sayed et al. (2010) found the highest leaf relative water content (RLWC) of soybean by using 100% super absorbent polymer (200 kg/ha) under water stress. They also reported cell membrane stability (CMS) increased with increasing drought stress and decreased by using animal manure and super absorbent polymer. Further, the combined application of compost (FYM+NB) and proline exhibited the best results for enhancement in vegetative growth parameters, yield components and yield of wheat (El-Sadek, 2005; Raafat et al., 2011). Bio-fertilizers also have a significant role in good yield and better utilization of water under stress condition (Rahimizadeh et al., 2007). The increase in plant growth parameters is positively associated with a quantity of compost applied to the soil (Sun et al., 2003; Chaturvedi et al., 2010). The potential influence of compost and organic matter on growth, productivity and quality of different crops under various environmental extremists was well understood (EL Sabagh et al., 2015b; EL Sabagh et al., 2015c; EL Sabagh et al., 2015e; EL Sabagh et al., 2016b; EL Sabagh et al., 2016c; EL Sabagh et al., 2016d; EL Sabagh et al., 2016e).

Concluding Remarks

In conclusion, this review demonstrated different responses of soybean plants to water stress. Water stress has an adverse effect on growth, physiology, yield, and quality of soybean. However, application of osmoprotectants and compost soil application of in soybean crop could be an alternative to improve the productivity of soybean under water stress condition. The study also confirms that the research related to water stress can solve the seasonal water stress problem to a greater extent and also provide the technical knowledge for sustainable agriculture development.

Disclosure Statement

Authors declare that no conflict of interest could arise

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