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Wheat residue mulch and anti-transpirants improve productivity and quality of rainfed soybean in semi-arid north-Indian plains

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ABSTRACT

Soybean (*Glycine max* L. Merr.) is largely grown in moisture-stressed conditions resulting in low yield. A 3-year field experiment was conducted during rainy seasons of 2012–2014 to determine: (i) the effects of straw mulches and anti-transpirants on soil moisture retention, rainwater-use efficiency (RWUE), photosynthesis, growth, yield, and quality of soybean (cv. PS 1347), and (ii) the influence of climate (year) on responses of soybean to straw-mulch and anti-transpirant application. The treatments included two mulching treatments, no-mulch and wheat residue mulch (at 5 Mg ha^{-1}), and the use of anti-transpirants, $MgCO_3$ (5%), glycerol (5%), Na_2CO_3 (2%), KNO_3 (1%) and no-anti-transpirant (control) sprayed 15 days after flower initiation. Wheat straw mulching enhanced surface soil (0–30 cm) moisture content by 20% over plots under no-mulch, improved leaf SPAD (soil plant analysis development) values, net-photosynthetic rates and boosted soybean grain yield by ~16% over no-mulching. Plots with wheat straw mulching also had ~18, 18 and 17% higher protein yield, oil yield and RWUE compared with no-mulch plots. Spraying $MgCO_3$ and KNO_3 along with wheat residue mulching (5 Mg ha^{-1}) caused significant enhancement in grain-and protein-yield, and RWUE over control. However, Na_2CO_3 was not a suitable anti-transpirant as it reduced soybean growth, yield and quality. These results suggest that wheat residue mulch and anti-transpirants, $MgCO_3$ and KNO_3, can significantly improve the yield and quality of soybean in moisture-stressed rainfed environments.

1. Introduction

Soybean (*Glycine max* L. Merr.) is the vital oilseed crop of India and the world that shows a wide range of geographical adaptation and offers many nutritional, health benefits. Moreover, it enriches soil fertility by fixing 50–300 kg ha^{-1} atmospheric nitrogen (N) depending upon agro-climatic conditions, variety, strains, etc. (Keyser and Li, 1992) and by adding 1.0–1.5 Mg leaf-litter ha^{-1}. In the last two decades, soybean has attained unprecedented growth in the world, both in terms of area and production. In 2014–15, soybean was cultivated on 118.2 million hectares (Mha) globally, producing 318.95 million tonnes (Mt) grain, with 2.7 Mg ha^{-1}average productivity (USDA, 2016). It contributes 48.2 and 60% to the world-oilseed acreage and production, respectively. In India, it contributes ~25% to the edible oil pool and also earns sizeable amount of foreign exchange (US $1553.4 million through soy-meal export). Soybean is, in-fact, viewed as a potential replacer of high water demanding rice crop from Indo-Gangetic Plains. But, a low average soybean productivity (~1.0 Mg ha^{-1}) is a serious concern in India. High yields (2.5–3.5 Mg ha^{-1}) from the farmers' fields in some districts of Maharashtra state of India (Tiwari, 2014) indicate the possibility of achieving high and profitable soybean productions.

Water stress imposes serious limitations on growth and yield of a crop. Yield reduction due to the impact of water stress in crop plants can be 50% in various regions of the world (Lisar et al., 2012). Yet, two-thirds of world food production through cultivation occurs under water stress (Gerten and Rost, 2010). In this context, and because of the prospect of global climate change, most crops will be exposed to negative impacts caused by drought. Most soybean regions of India are located in dry climate, and 98% soybean crop is cultivated rainfed. Due to drought occurrence, the crop suffers from heat and moisture stresses during critical growth stages. This problem is encountered not only in India, but also in other tropical, semi-arid and arid regions of the world (Yousef et al., 2013). Water deficits are the consequences of low and erratic rainfall, poor soil with low water holding capacity, and transpiration exceeding water uptake (Yousef et al., 2013). Water stress

Abbreviations: RWUE, rainwater use efficiency; PAR, photosynthetically active radiation; NPR, net photosynthetic rate; DMA, dry matter accumulation; SPAD, soil plant analysis development; RLWC, relative leaf water content; PAR, photosynthetically active radiation

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alters patterns of plant growth and development. Depressed water potential suppresses cell division, organ growth, net photosynthesis, protein synthesis and perturbs the hormonal balances of major plant tissues (Gusta and Chen, 1987). The cellular water deficit results in concentration of solutes, turgor loss, cell volume change, disruption of water potential gradients, membrane integrity change, protein denaturation and several physiological and molecular components (Hossein et al., 2009). Plants through various mechanisms, such as stomatal closure, reduced transpiration, greater root weight and length, higher photosynthesis, respiration and osmo-regulation can increase the resistance to drought (Levitt, 1980).

In soybean, net photosynthesis decreased by 40 and 70% under mild and severe water stress, respectively (Ribas-Carbo et al., 2005). Decreasing leaf water potential to −0.80 MPa reduced leaf elongation rate by 40% relative to greater values of water potential which caused 60 and 65% reduction in leaf area and plant dry matter in soybean, respectively (Bunce, 1977). Catuchi et al. (2011) observed a 40% reduction of leaf area per plant and 50% reduction in shoot dry mass in soybean due water stress imposed at vegetative stage compared to control. A drastic reduction in leaf area and root elongation occurred due to water stress but the effect on leaf area was more severe, as carbon partition shifts towards root under water deficit conditions (Akýnci and Lösel, 2012). The symbiotic N-fixation, an important process in soybean nutrition, is significantly impaired by the soil moisture deficit (Purcell et al., 2004). When stress occurred during grain filling, the number of grains per pod and the grain weight were most affected traits (Desclaux et al., 2000). The reduction of the other biomass parameters under conditions of water deficits is related to decreased photosynthetic rates and biomass accumulation. Thus translocation to grain is consequently impaired (Neumaier et al., 2000) finally resulting in yield reduction.

Like any other abiotic or biotic stresses, moisture stress can be managed employing genetic and agronomic approaches of crop improvement. However, with relatively narrow genetic base of soybean, it is not always possible to identify genotypes with high yield potential and with high average stability under adverse environment. This necessitates devising agronomic approaches that enhance stress tolerance and stabilize soybean productivity, when cultivated under unfavourable soil water regimes.

Crop residues or by-products, if spread on soil surface as mulch, improve soil moisture conditions by facilitating greater infiltration of rainwater into the soil and reducing evaporation losses of soil water, minimizes runoff, soil and nutrient losses, and ameliorates environmental stress to plants (Chaudhary et al., 2003; Macilwain, 2004; Dass et al., 2006; Sudhishri et al., 2007; Dass et al., 2013). Mulch also improves soil thermal regimes. In India, wheat is cultivated during winter season in 31 Mha and mostly combine harvested, leaving 30–40% of crop biomass in the field. A large proportion of these residues are burnt to prepare the fields for the next (rainy) season. Residue burning causes increased air pollution and greenhouse gases production. The excess wheat residues can be used purposefully as a mulching material in succeeding rainy season crops, including soybean.

Although mulches considerably reduce the evaporative loss of water from soils, transpiration losses of water still continue. To curtail the water losses through transpiration and maintaining water potential in crop plants under deficit soil moisture condition, use of anti-transpirants can be beneficial. The use of anti-transpirants enables crop plants to maintain their water balance by reducing the transpiration losses and fight water deficits.

Application of anti-transpirants reduced the effect of water stress on soybean as evinced by significant increase in growth parameters, yield components, yield and harvest index of soybean grown under limited moisture conditions (Javan et al., 2013; Devi et al., 2014). Magnesium carbonate ($MgCO_3$) and sodium carbonate (Na_2CO_3) are the stomata closing type anti-transpirants that affect metabolic process of live tissue. Magnesium carbonate at 5% improved plant growth and yield of *taro* (*Colocasia esculenta)* (El-Zohiri and Abdelal, 2014), barley (El-Kholy et al., 2005) and wheat (El-Kholy and Gaballah, 2005). Glycerol is a film-forming anti-transpirant permeable to gases like O_2 and CO_2, but is impermeable to water vapour. Potassium nitrate (KNO_3) can improve water and salt balance in the plant and improves the plant's metabolic activities under moisture stress conditions. Earlier, the role of anti-transpirants in conjunction with mulches has not been investigated adequately in soybean. Moreover, the responses are climate and location specific. Hence, present investigation was carried out (i) to determine the effect of mulches and anti-transpirants on photosynthesis, growth, yield, water productivity and quality of soybean and (ii) to study the influence of climate (year) on response of soybean to mulch and anti-transpirant applications.

2. Materials and methods

2.1. Study area, meteorological parameters and years of study

A 3-year field experiment was conducted during rainy seasons (July–November) of 2012–2014 at the ICAR-Indian Agricultural Research Institute, New Delhi (28°40′ N 77°12′ E and 229 m above mean sea level). The climate of New Delhi is of sub-tropical and semi-arid type with hot and dry summer and cold winter, and falls under the agro-climatic zone 'Trans-Gangetic Plains'. During the crop growth period, mean maximum temperature was 33.8, 32.5 and 33.4 °C, while the mean minimum temperatures were 22.9, 22.1 and 22.3 °C in 2012, 2013 and 2014, respectively (Fig. 1). Crop seasons in 2012, 2013 and 2014 received 423, 854 and 391 mm rainfall, respectively. The study site soils are alluvial type with sandy loam texture and low to medium fertility. Ground water table is deep and has no direct influence on the root zone soil moisture. The important physical and chemical properties of the experimental field surface soil are given in Table 1.

2.2. Treatments, experimental design and crop management

The experiment was designed with ten treatments consisting of two levels of mulching, no-mulch and straw mulch (5 Mg ha^{-1}), and five anti-transpirants, $MgCO_3$ (5%), Glycerol (5%), Na_2CO_3 (5%, 2%), KNO_3 (1%) and water spray (control). Volume of water used for spraying anti-transprants and in control (no anti-transpirant) was 1,000 L ha^{-1}. Straw mulching was imposed immediately after pre-emergence herbicide application on 2nd day after sowing and the anti-transpirants were applied 15 days after flower initiation. The treatments were set in a three-time replicated factorial RBD. In all, there were 30 experimental plots of 3.6 × 6 m size each.

The soybean cultivar, PS 1347 with medium maturity (123 days), determinate plant type, good vigor, broad adaptation, resistance to yellow mosaic virus, *Rhizoctonia* aerial blight, bacterial pustule, soybean mosaic virus and charcoal rot diseases, and high yield potential (> 3 Mg ha^{-1}), was planted on 14 July in 2012, 23 July in 2013 and 19 July in 2014 after the onset of the monsoons, at a planting interval of 45 cm × 5 cm. Before sowing, the seeds were treated sequentially with imidachlropid solution (1 mL L^{-1} water), thiram (2.5 g kg^{-1} seed + bavistin 1 g kg^{-1}) and *Rhizobium* 4 g kg^{-1}. The crop was fertilized with 5 Mg farmyard manure (FYM) 30 kg N, 32.3 kg P and 33.2 kg K ha^{-1} and 56 kg S ha^{-1} (through single super phosphate). The crop was kept free of weeds by pre-emergence application of pendimethalin at 0.75 kg ha^{-1} followed by one hand weeding. The crop was protected from white fly infestation by application of imidachloprid at 1 mL/L of water, from termites by soil application of fipronil 0.3 G at 25 kg ha^{-1}.

2.3. Data collection and analyses

Photosynthetically active radiation (PAR) was determined using a canopy analyser LP-80 AccuPAR and net intercepted PAR was deter-