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The effects of tillage practices on water regime of soybean (*Glycine max* L.)

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Abstract: Continuous world population growth imposes the need to produce higher-quality food. Due to the high content of valuable protein and high concentration of carbohydrates, vitamins and minerals, soybean (*Glycine max* L.) is one of the most essential leguminous and oilseed crop that contributes to human alimentation and animal nutrition. This study assesses the possible impacts of soybean seedling development and seeds' quality indicators correlate to water supply aboveground and in the root zone. The level of water management is crucial in and out of the growing season; however, the increase in temperature may adversely affect climatic conditions. As a consequence of water contained in soil, leguminous crops can improve soil texture and the capacity of minerals if admissible water is available for the crop. Soil tillage is cardinal for agricultural water management; by practising proper tillage continuously, soil properties can increase, and exposedness can decrease in the long term.

Keywords: Glycine max L.; soybean; water regime; soil tillage; climate change

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Introduction

Due to the economic importance, soybean (*Glycine max* L.) is one of the most widely planted leguminous and oilseed crop that contributes to human alimentation and animal nutrition. The plant and its derivatives provide the raw material for the food industry, mainly in cereal and meat-based products as it contains numerous compounds that can act as antioxidants and are beneficial to human health, as they diminish the risk of many diseases (Kumar et al., 2014).

Among the main traits of soybean genotypes, two particularly important ones are the oil and protein content (Nascimento et al., 2010). In addition to this, soybean is considered as a kind of highly efficient nitrogen-fixing crop for improving acidic soil fertility (Yang et al., 2012). Nitrogen is the nutrient element that most limits plant growth and development. Plant available N in soils originates from mineral fertilizer and mineralization of organic matter and plant residues (Vinther et al., 2004). Inorganic N in the soil is subject to lose through processes like leaching, volatilization and denitrification. Accumulation of inorganic N, leaching of nitrates into ground water, or move through the soil could affect soil microorganisms (Lupwayi et al., 2010, 2012). Besides fixing the atmospheric nitrogen, this crop has the ability to grow in a range of environments, reduce soil erosion, suppress weeds and to suit inter as well as sequential cropping pattern (Jain et al., 2018).

To meet the increasing demand for soybean production, it is necessary to increase crop yield, even in low water availability conditions since there is a growing focus on growing water use efficiency in crops in recent years. Since rainfall occurs seasonal, water is an important limiting factor to subsequent growing crops especially soybean (Aliverdi et al., 2021). The aim of this review is to assess the relation of the effects of prevalent soil tillage practices and water regime induced by soybean and to summarize the latest scientific findings on the soil properties, especially in conventional soil tillage and minimum soil tillage systems. As known, tillage management can have positive and negative short-term effects on the agroecosystem. Therefore, searching for optimal tillage management is crucial for the maintenance and improvement of soil functions (Brezinščak & Bogunović, 2021).

Correlation between soybean production and water supply

Food legume crops play an important role in the farming system and contribute to food security in the developing world (Engels et al., 2017). However, in many regions, their production has been adversely affected by climate change which have impacted the water regime of the rains, causing severe drought in agricultural regions, and affecting the production of several crops (Mousavi-Derazmahalleh et al., 2019). This issue will cause many economic challenges and social impacts in agriculture (TerAvest et al., 2015; Werner & Vanneuville, 2012). Although water scarcity is a severe abiotic constraint of legume crops productivity, it remains unclear how the effects of drought covary with legume species, soil texture, agroclimatic region, and drought timing (Daryanto et al., 2015).

Water availability is one of the climate elements that most affect soybean development and productivity (Anda et al., 2020; Dong et al., 2019; Minosso et al., 2021) and to meet the growing demand for food, it is necessary to increase soybean yield, even in environments with low water availability. Soybean has a water requirement of 450–700 mm (Critchley, Siegert, & Chapman, 1991), which does not mean much water, however, water availability is needed in the early stage of growth, flower period, and filling of pods. Moreover, the most sensitive stage to possible yield loss under water shortage is the reproductive period. In general, short-term moderate soil water deficits during the vegetative stage do not impact soybean production (Comlekcioglu & Simsek, 2013; Karam et al., 2005; Oya et al., 2004). However, a more serious or persistent water deficit may result in decreased soybean production (Turan et al., 2019).

Narolia et al. (2021) reported a significant increase in yield, dry matter production, and growth rate by giving irrigation at the flowering and pod development stage. The proper arrangement of plants in appropriate plant density is one of the requirements to achieve high and stable yields during intensive production of soybean. Changing the shape of growing space and row spacing leads to change in microclimate growing conditions (light, relative humidity, aeration) where soybean is very sensitive (Kolaric et al., 2014).

Water regime system is needed to support the cultivation system on crops (Aminah et al., 2021) as soybean plants cultivated on different soil managements respond water stress differently (Jarvis & McNaughton, 1986; Jordan & Ritchie, 1971). The characteristics of plants, the supplied water, the irrigation methods, and the soil characteristics related to water are significant factors to provide sufficient water in crops. In addition, the local agro-ecological conditions, such as soil types, availability of water, and climate can also influence the water supply to the crops (da Silva et al., 2019).

The increase in rainfall is evidence of climate change, reduced water availability, and other unsuitable weather (Osman, 2018).

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However, increased rainfall as a part of climate change can provide some local benefits. There will also be several adverse effects, including reduced water availability and other extreme weather conditions (Arnell et al., 2011; Gosling & Arnell, 2013; Mancosu et al., 2015; Ummenhofer & Meehl, 2017).

Besides soil degradation and heat stress, drought is the abiotic factor that most adversely affects legume production. It turns, however, that the largest producers of pulses are located in regions that experience water shortage (India, China and many African countries) (Rockström et al., 2009). These countries thus rely heavily on variable rainfall to support agriculture production, which consequently is highly vulnerable to drought. It is also important to recognize that the impact of drought on crop yield can be variable, and therefore there is a need to consider legume crop and management factors such as species selection or planting date as these can determine crop response to water shortage and ultimately yield loss (Daryanto et al., 2015). When experiencing drought, soybean productivity can decrease by 40-65% (Engels et al., 2017). J. Omondi et al. (2017) reported that soybean, a crop whose production is being promoted in Sub-Saharan Africa is adversely affected by mid-season drought. This is due to the continuous erratic rainfall distribution and amount, which mostly occur at the important stages of soybean growth; flowering, pood filling and seed filling stages (J. O. Omondi et al., 2015).

Determination of water requirement for crops in resource limited areas in challenging yet worsened by the common assumption that all crop varieties within a species have similar water requirements (J. Omondi et al., 2017). Due to depleting water supplies and the cultivation of high water-demanding crops like soybean, water deficit in crop production has become a major concern. Soybean has been considered a possible substitution for high-water-demand crops with improved water productivity and nutrient quality. However, due to inefficient and injudicious water regime, the overall productivity and profitability of soybean is quite low (Rajanna et al., 2022). The optional soybean sowing date is an important factor affecting the plant growth and yield, and it changes depending on the climate conditions and the accompanying reactions of cultivars to the day length (Bastidas et al., 2008; Sincik et al., 2011). Next to cultivar earliness, the soybean yielding in Europe, similarly as in other countries, is much affected by water deficit, which essentially shortens both the vegetative and generative stage and thus lowers the yield (Borowska & Prusiński, 2021; Desclaux & Roumet, 1996).

Cover cropping, conservation tillage and mulching are some soil water regime techniques (Itabari et al., 2011; Wakindiki et al., 2007) practiced during mid-season drought. The objective of the study, which has been published by J. Omondi et al. (2017) was to indirectly determine crop evapotranspiration of soybean varieties, using reference evapotranspiration and shoot water content under tillage and no-tillage cultivation. Standard cores were used to collect soil samples at depths of 10, 20 and 30 cm, for soil water content measurement at 50% full bloom, pod filling and seed filling. These are the important stages of soybean growth in soil moisture studies (Doss et al., 1974). They reported that soil moisture content was not significantly different from tillage method and soybean variety interaction, neither was it significant for the interaction between tillage and soil depth. However, soil moisture content under interaction of soybean variety and soil depth was significant. Soil moisture content increased with depth under all varieties except for one at full bloom. According to another study conducted by Aminah et al. (2021) their result showed that the watering technique using the waterlogging method at the same time at the age of 15 days and full flowering had the potential to increase the yield production of soybean. Water use, economic benefits, and reduced environmental burdens can be obtained through innovative irrigation practices (Levidow et al., 2014). This study aimed to get the best irrigation method and determine the best time-effective provision of water to maintain optimum soil moisture for increased soybean crop production.

Coexistence of tillage and water balance in soils

Soil quality can be evaluated by the integration of chemical, physical and biological soil properties (Chen et al., 2003; Dominy & Haynes, 2002). Soil is a complex and dynamic biological system whose functions are mediated by a diversity of living organisms (Doran & Zeiss, 2000; Nannipieri et al., 2003). The structure and functioning of soil microbial communities reflect the interaction between a host of biotic and abiotic factors (Bending et al., 2002). Their number, diversity and activity is influenced by soil organic matter content, soil texture, pH, moisture, temperature aeration and other chemical, physical and biological factors such as water content (Chen et al., 2003).

The rhizosphere, defined as the layer of soil influenced by root metabolism (Berg et al., 2005), is greatly important to plant health and soil fertility (Yang et al., 2012). Root exudates are currently recognized to differ according to plant species (Rengel, 2002). Bacteria respond differently to the compounds released by roots, and thus the differences in root exudation are believed to explain the plant-specific bacterial communities in the rhizosphere (Berg et al., 2005; Jaeger et al., 1999).

Tillage and crop rotation are crucial factors influencing soil quality, crop production and the sustainability of cropping practices (Munkholm et al., 2013). Soybean plants are exposed to soil moisture stress at any age of their lifecycle will harm their development, yield, and yield components (Mahmoud et al., 2013; Rana et al., 2018). No-tillage is defined as the planting of crops in previously unprepared soil by opening a narrow slot, trench, or band only of sufficient width and depth to obtain proper seed coverage. No other soil preparation is performed (Phillips & Young, 1973). However, the elements of conventional soil tillage (basic working, preparation of the germinal layer, maintenance of the field, etc.) result in immediate positive effects. Some negative effects also manifest themselves. One of the main objectives for the soil tillage system is to create an optimal physicochemical condition of the soil and to preserve this condition over the whole vegetation period (Moraru & Rusu, 2010).

The book published by Phillips and Young (1973) shows that in the tests made on soybeans cultivated in the no-tillage (without ploughing) system by the USA experts from the University of Iowa, the soil humidity was a few percent higher compared to the soybeans cultivated in the conventional system (Sarpe, 2010). Influence of inter-row spacing on a productivity of soybean yield was studied by Kolaric et al. (2014) on the experimental field on a low carbonate chernozem soil. Amount and distribution of rainfall per year varied so that water regime in a year with less rainfall significantly affected the production of soybean. In the first year, when the weather was unfavourable for growing soybean, there was less rainfall in April, May and especially in June than during the previous years. In relation to a long-term average, rainfall deficit, combined with high temperatures especially in May and June, has caused a drastic reduction in grain yield of soybean.

According to another study conducted by Sarpe (2010), tests with genetically modified soybeans were made on an alluvial soil

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from the Danube Meadow. The soil moisture content was measured at 0–20; 20–40 and 40–60 cm depths, meaning in the soil layers where most of the soy roots start to grow. The soil moisture content was measured in three different periods of the year, respectively in June, August and before harvesting the soybeans. Almost the same moisture content values were registered for the no-tillage system, where the soil was neither ploughed nor prepared as in the classical system, the differences appeared to be part of the experimental errors. The result obtained in August is very important because this is the period in which the soybean reached the maximum development level as regards the vegetal mass and the roots. The explanation is the following: more water had evaporated from the soil when using the classical system because of the mechanical weeding/hoeing operation, while the 0–20 cm depth soil layer remained untouched when using the no-tillage system. Wang et al. (2009) has once proposed the triple intercropping system of wheat-maize-soybean as a new conservation tillage pattern which is highly efficient, ecological, and water saving.

Most studies investigate soil respiration in a single crop field. Few research cases deal with multiple cropping, crop rotation and relay intercropping (Zhang et al., 2016). Moraru and Rusu (2010) demonstrated that increased soil organic matter content, aggregation, and permeability are all promoted by minimum tillage systems. Krauss et al. (2020) reported a 15-year study on reduced tillage with organic manures revealed a that reduced tillage with organic farming practices enhances yield, soil organic carbon, and soil microbial biomass over conventional tillage. Soil moisture and crop yields have been shown to increase with improved land settings, tillage options, and residue retention as mulch (Mozafari et al., 2020; Parihar et al., 2017; Rajanna et al., 2022).

Statistical analysis of the results showed that the differences in accumulated soil water depended on the variants of soil tillage and type of soil. Soil texture and structure have a strong effect on the available water capacity. The results clearly demonstrate that minimum tillage systems promote increased humus content (0.85–22.1%) and increased water stable aggregate content (1.3–13.6%) at the 0-30 cm depth compared to conventional tillage. The implementation of such practices ensures a greater water reserve even across different soil types. The practice of reduced tillage is ideal for enhancing soil fertility, water holding capacity, and reducing erosion. The advantages of minimum soil tillage systems can be used to improve methods in low producing soils with reduced structural stability on sloped fields, as well as measures of water and soil conservation on the whole ecosystem. Careful planning and management are needed for the efficient use of water and nutrients in soybean-based cropping systems with suitable land modifications to enhance soil quality, production and profitability (Boutraa, 2010; Davies & Bennett, 2015; Evans & Sadler, 2008; Obalum et al., 2011). Thus, more effective irrigation techniques, growing tolerant genotypes, longer irrigation intervals, and deficit irrigation methods are all needed to reduce plant water consumption (Mahmoud et al. 2013). This irrigation management techniques would save a significant amount of irrigation water while providing comparable economic returns (Montoya et al., 2017).

Conclusion

The results of studies conducted in soil tillage and water regime entitle us to say that real soil conservation is represented by the complexity of soil, water regime and climate change. However, soybean adapts to non-extreme soil types effortlessly, which is demanding of soil water regime. Towards an increased food safety perspective, it is essential to ensure the environmental stability of crop production as in this scenario, soybean deserves to be highlighted due to its economic importance in the world market. Agricultural experts and farmers need to provide adequate knowledge of irrigation practices to adapt and implement appropriate solutions on the field since weather and soils properties can affect the variation of tillage operations, while future researches should investigate the effects of climate change measures and their potential to optimize the environmental benefits of conservational tillage. Altogether, the results suggest that conservation technologies can save soil and water, upgrade soil moisture content, and increase crop yield, all of which are important to long-term agricultural sustainability based on profitable plant production and environmental protection. These results indicate that conservation tillage can be a viable approach to increase production by significantly reducing the potential environmental risks.

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