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Effect of regulated deficit irrigation scheduling on water use of corn in southern Taiwan tropical environment

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ABSTRACT

The enhancement of common irrigation practices can substantially contribute to sustainable water development. This study was conducted to determine an effective water application depth for improving agricultural water use (irrigation water use efficiency (IWUE) and water use efficiency (WUE)) in surface irrigated corn production, and to determine an effective rooting depth for irrigation planning in a tropical region. The effect of five irrigation treatments on corn growth, yield and root extraction patterns were investigated and assessed. The treatments included a full irrigation treatment with a water application depth of 6 cm (T_5), and four deficit irrigation (DI) treatments with depths of: 5 cm (T_4), 4 cm (T_3), 3 cm (T_2) and 2 cm (T_1). Irrigation water was applied to all treatments when soil moisture for T_5 was depleted by 40%. Seasonal water applied varied from 235 to 555 mm while the seasonal crop evapotranspiration ranged from 331 to 605 mm. Results revealed all treatments sustained varying levels of water stress except for T_5. Corn grain yield ranged from 567.13 g m^{-2} in T_1 to 911.26 g m^{-2} in T_5, a significant increase ($P < 0.05$) of 37.7%. Similarly, there were significant differences in biomass ranging from 1012.64 to 1774.05 g m^{-2} and leaf area index ranging from 3.99 to 5.83 m^2 m^{-2}. The highest WUE of 1.79 kg m^{-3} and IWUE of 2.41 kg m^{-3} were observed for T_3 and T_5, respectively, whereas the lowest was found in T_5 with respective values of 1.52 and 1.63 kg m^{-3}. Results indicate that it is possible to implement DI strategies for reducing agricultural water use without significant impact on grain yield. Treatments T_3 and T_4 offer water savings of 29% and 14% respectively in irrigation application with a 10.5% and 8.6% insignificant reduction in grain yield relative to T_5. Further, agricultural water productivity can be enhanced by employing a rooting depth of 60 cm when planning irrigation application amount.

1. Introduction

The global challenges of food security and food self-sufficiency are intrinsically linked to the increasing pressure on natural resources, particularly on land and water. Decreasing water availability, increased competition for water from non-agricultural sectors, demographic pressure and erratic climate conditions places immense strain on agricultural production and development. These constraints, further exacerbated by unsustainable water withdrawal from the Earth's ecosystem, have highlighted the importance of optimizing irrigation for increasing food production which must be in sync with increasing agricultural water productivity (AWP) (Wang et al., 2009a), especially for major crops like corn (*Zea mays* L.). The production of corn plays a major role in the economic and socio-economic development of many countries owing to the diversification of its uses: food commodity, feed commodity and a significant bioethanol source. However, it's optimum production have high irrigation demands (Karam et al., 2003; Stone et al., 1996) as corn is among the largest plant user of water (WMO, 2012).

During the interim of more efficient technology adoption, reducing water wasted in surface irrigation is essential for improving water availability (Wang et al., 2009b). Deficit irrigation (DI) is an advocated strategy to improve water use in surface irrigated corn production (Farré and Faci, 2009; Klocke et al., 2004). DI is the intentional under irrigation of crops below full crop water requirements (crop evapotranspiration, ET_c) (Fereres and Soriano, 2007). However, this technique is limited by the fact that water deficits may induce crop water stress which can affect crop growth and development. Soil water stress directly affects plants ability to capture

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resources needed for photosynthesis and the efficiency with which they convert these physical resources into biological materials, i.e., biomass and grain yield (Yi et al., 2010). For instance, water deficits have been shown to reduce corn dry biomass (Igbadun et al., 2008), plant height (Çakir, 2004), leaf area index (Mansouri-Far et al., 2010), and grain yield (Djaman et al., 2013; Lamm et al., 1995; Payero et al., 2009).

Although yield reduction is generally expected when crops are subjected to DI (Lamm et al., 1995), a well-designed DI regime can minimize the impact on yield and still lead to growers' profitability (Fereres and Soriano, 2007; Rodrigues et al., 2013), thereby contributing to sustainable agricultural water development. Corn yields variability on account of soil water deficit is a function of severity and timing of water deficits, available soil water at planting, and effective rainfall and irrigation (Payero et al., 2009). Many studies reported that corn yield is most affected by water stress when it occurs during the reproductive growth stage (Klocke et al., 2004; Pandey et al., 2000). Choosing the most suitable irrigation regime under the condition of water deficits involves: identifying water-yield relationship, knowledge of irrigation scheduling and climatic influence, and understanding of spatial soil-water availability and uptake by plant roots. Several studies have developed mathematical models to quantify some of the relations (Doorenbos and Kassam, 1979).

Irrigation management can be classified as soil-plant or climate based or combinations (Martin et al., 1990). Generally, soil based methods consider root zone management of water and perhaps have a wider applicability than the latter two methods, as it is more easily achievable (financially and technically), especially for non-commercial farms. This method relies on the monitoring of soil water status and usually irrigates based on predefined levels of soil moisture depletion. Literature account demonstrates that it can be effectively used for irrigation management (Panda et al., 2004; Steele et al., 2000). Often times, in the literature, irrigation water application depth caters to a rooting depth ranging from about 90 cm to a high 120 cm when planning application amounts or timing (Kuscu et al., 2013; Steele et al., 2000). In this study, it was hypothesized that this leads to overwatering and thus a potential for water savings.

In Taiwan, there is a growing need to revive the corn industry owing to over production of rice, high world corn prices, and increasing demands – particularly as a food source for the growing swine and poultry industry (Perng, 2013). Imported feed corn delivers more than 60% of the demand (Perng, 2013). The average cultivated area of corn in Taiwan is about 18, 000 ha/year (2005–2009 estimate), a substantial decrease from about 90,000 ha/year in 1980–1990 (COA, 2011). With increasing severity of water supply deficit, extreme temporal and spatial variability of rain, increasing non-agricultural sectorial demand, and high evaporative demands associated with Taiwan's warm climate, potential expansion will depend on effective and efficient use of water resources amid a water intensive rice industry, and the dire need to improve Taiwan's AWP. Taiwan agriculture sector claims about 71% of water withdrwals (Cheng and Liao, 2011), where surface irrigation is still the dominant irrigation system utilized.

Mitigating water wasted in level basin surface irrigated corn through root zone water management is highly dependent on optimizing water application depth and or timing. Varying water application depths will impose different levels of water stress as the different soil profile depths fall short of their theoretical total and readily available water. Unlike other DI studies, this research focuses only on varying water application depth, irrespective of growth stage. The rationale for this was to design an irrigation schedule/application amount that could be consistent throughout the growing season without the need to make inter-seasonal adjustments to water application.

The objectives of this study were to: (1) examine the effects of predefined water application depths on corn production – growth characteristics and yield- and the impact on irrigation and water use efficiency, to determine an effective water depth for improving water productivity in surface irrigated corn production, and (2) to determine an effective rooting depth for irrigation planning in a tropical region. Understanding and evaluating plants ability to cope with water stress in specific/localized environments will lead to better-informed decisions of best (/suitability of) irrigation management practices. Farré and Faci (2009) and Payero et al. (2006) observed that DI as a water management strategy may not be suitable under all climatic environments.

2. Materials and methods

2.1. Study area

This research was conducted at the irrigation experimental site of National Pingtung University of Science and Technology in Pingtung County, southern Taiwan (22.65°N: 34.95°E: 71 m above sea level). The experimental period was from November 2014 to March 2015. The climate for southern Taiwan is classified as tropical wet and dry, with annual average temperature exceeding 25°C, and extreme spatial and temporal rainfall distribution. More than 80% of the rainfall occurs in the wet period from May to October and most of the rain is concentrated in typhoon events. In fact, Taiwan has been described as "a country with rich rains but short of water" (Cheng and Liao, 2011).

The soil at the experimental site is classified as loamy with bulk density 1.4 g cm^{-3}, and average volumetric water contents at saturation, field capacity and permanent wilting point of 42.9%, 30.5% and 15%, respectively. The water table at this site was well below the 1 m root zone depth. Extractable plant water for a 1 m root zone is estimated at 155 mm.

2.2. Experimental design and crop agronomy

The field experiment consisted of 5 irrigation treatments arranged in a completely randomized block design, with 3 replicates per treatment. The experimental area was divided into 15 equal plot size of 10 m^2 (width –2.5 m x length–4 m). Soil levees, 0.30 m high and 1 m wide, were used to create a buffer zone between plots. Each plot consisted of 5 rows of corn plants spaced at 0.40 m between rows and at 0.30 m within rows, thus accommodating a plant density of 8.3 plants m^{-2}. Treated corn seeds were planted in holes at 0.05 m deep.

Corn was planted on November 22nd 2014, on well-leveled basins and harvested on March 20th 2015. Fertilizer (275, 125, and 125 kg ha^{-1} of N, P_2O_5 and K_2O) was applied over the entire field in three applications: one pre-planting, one at the 4th leaf stage and one at tasseling. Weeds, insects and diseases were rigorously controlled during the cropping season. Crop phenology was constantly monitored during the growing season and the different phenological stages categorized according to Ritchie et al. (1992) were subsequently recorded (Table 1).

2.3. Irrigation treatments

Five irrigation treatments were differentiated by the amount of irrigation water applied (one fully irrigated treatment, FIT, and four deficit irrigation treatments). Irrigation depth and time were determined based on the maximum allowable depletion (MAD) of total available soil water (TAW) in the soil profile (Panda et al., 2004). The TAW is the difference between field capacity (FC, $m^3\ m^{-3}$) and permanent wilting point (PWP, $m^3\ m^{-3}$) of the soil. The FC and PWP inherently captures basic soil physical properties such as particle