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Preplant Irrigation Effectiveness and Crop Yield and Water Productivity in the United States: A Review

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Abstract
Soil moisture content early growing season is determinant for crop season planning mainly a decision on planting date. In the region where off season or early season precipitation does not much the conditions for seed germination and plant growth/development, preplant irrigation is applied to meet these conditions. Also, under limited water availability or low system capacity to meet crop water requirement at peak evapotranspiration, preplant irrigation could be applied to store water within the crop root zone. However, its efficiency or effectiveness depends on the soil type and soil water storage efficiency. This review explored the advantages and disadvantages of the practice and its impact on crop yield and water productivity using summaries of different researches conducted mostly in the United States and other regions. The consideration of applying preplant irrigation should be examined regarding soil type, crop management practices, tillage and residue management, irrigation technique, actual precipitation pattern and forecast, crop choice to optimize the preplant irrigation practice for system sustainability.

Keywords: Preplant, Irrigation, Water, Productivity

Introduction
Preplant irrigation is a water management approach of applying irrigation water prior to planting or during the off season to increase soil water storage to be able to meet crop water requirement under low irrigation capacity. Preseason irrigation also referred to as preplant, off-season, or dormant season is an irrigation management technique that is practiced in the semi-arid and arid regions where the soil moisture is not optimum for planting or seeding and is not practiced in the humid and semi-humid regions. Figures 1 shows the long-term average soil moisture content estimated across the United States for the 1971-2000 period. The Western US suffers from adequate soil moisture in the month of April at the start of crop growing season. Particularly severe soil moisture deficit was noticed in April 2018 as shown in Figure 2. In the regions where soil moisture is not adequate at planting like the South Western US, producers must pre-irrigate their land before planting. Other producers with lower irrigation capacity might increase soil water storage by pre-irrigating their field to meet crop water requirement at the peak crop water use or evapotranspiration. The main purpose of preplant irrigation is to increase crop root zone soil water storage. It allows the germination of volunteer sorghum and weed seeds, particularly during a dry spring and permits soil preparation in areas where off season precipitation is unreliable. Preplant irrigation applied late spring provides seed zone moisture for germination and plant emergence [1]. Stone et al. indicated that preplant irrigation is more practiced across the US South and Central High Plains [2]. Early planting without relying on rainfall, improving soil conditions for soil seedbed preparation, and weed and volunteer crops control are the advantages while increase in production cost and decrease in water productivity constitute the disadvantages of the pre-irrigation practice [3]. Preplant irrigation may help to stabilize yield and reduce yield variability and uncertainties and economic risks. Soil temperature could be affected by preplant irrigation and delay some crops planting relative to their base temperature. The adoption of preplant irrigation under local soil and climate conditions should consider other water management strategies and techniques to reduce the water losses which might increase the total irrigation amounts [4-6]. Soil water management under crop production targets no water stress for yield maximization. Plant available water is kept above 50 -60% of the total available water in the crop root zone depending on the crop. However, when the available water for irrigation is less than the irrigation requirement of the crops, deficit irrigation strategies are adopted to optimize the available water source [6-14]. Whenever preplant irrigation has been practiced for long time across the Western and southern United States, limited technical review was reproduced and since 1990, studies on preplant irrigation have been done with opposed results. Therefore, the objective of this review was to summarize the findings and interpretations of different preplant irrigation studies mostly across the southwest United States to help growers with

necessary information, advantages, disadvantages and some criteria for decision making.

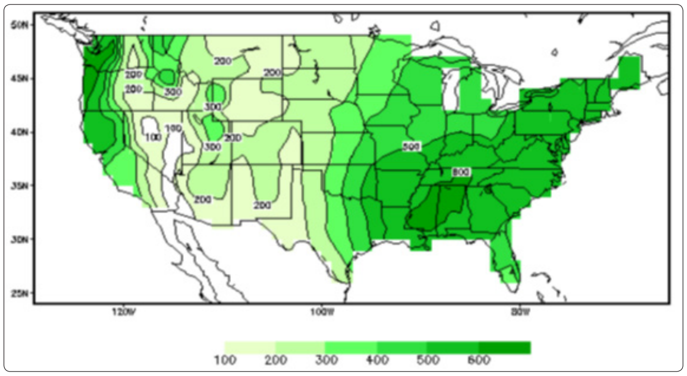

Figure 1: Long-term (1971-2000) average calculated soil moisture for the month of April cross the United States just before the start of the growing season (source: https://www.cpc.ncep.noaa.gov/products/Soilmst_Monitoring/US/Soilmst/Soilmst_clim.shtml#NOAA, accessed on January 26, 2019) [15]

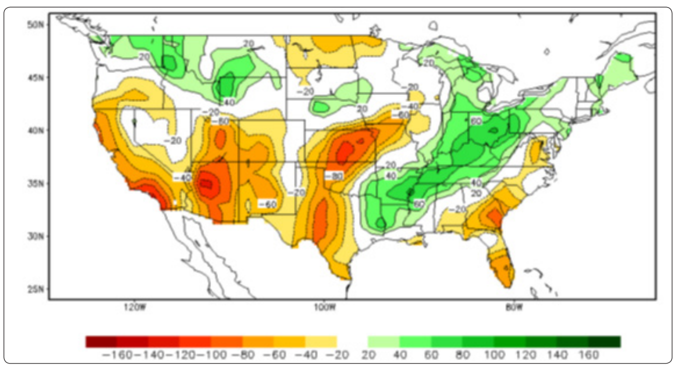

Figure 2: Calculated soil moisture anomaly across the United States just before the start of the growing season in April 2018 (source:https://www.cpc.ncep.noaa.gov/products/Soilmst_Monitoring/Figures/monthly/w.anom.201804.gif NOAA, accessed on January 26, 2019) [15]

Preplant Irrigation Timing and Effectiveness

Preplant irrigation timing is vital of the economics of the production system. Crop selection, soil texture, water demand and availability, planting date related to the thermal unit requirement of the crop species and hybrids. Rogers and Lamm reported that preplant irrigation of maize should not be a recommended practice for the northwest Kansas [16]. Musick and Lamm concluded from a review of preplant irrigation across the High Plains, that preplant irrigation practice is beneficial when the soil profile is dry before planting period and the practice is inefficient when soil profiles are moderately wet at planting time when irrigation may be applied [17]. Undersander and Regier investigated furrow irrigated sorghum at Etter, Texas on a silt clay loam soil from 1983 to 1985 in fall and Spring under five tillage practices [18]. They have used 237 mm for fall and 466 mm for spring preplant water requirements and found that fall preplant irrigation was considerably more efficient than spring preplant irrigation timing of preplant irrigation and soil storage efficiency averaged 26% for fall and 17% for spring preplant irrigation. Musick and Lamm from a review on the topic concluded that the greatest benefits of preplant irrigation are obtained when the soil profile is dry at the planting period, when adopting drought tolerant crops under no or reduced seasonal irrigation, early planting with precipitation at the desired planting date under high storage efficiency deep soil [17]. Hobbs and Krogman reported that preplant irrigation was relatively efficient when soil water was below 50% of maximum available soil water capacity [19]. Soil water evaporation and soil water drainage increase as soil water content increases and it regenerates increase in surface water runoff. Stone et al. found considerable soil profile water losses when dormant-season irrigation occurred under antecedent soil profile water content above 60% of maximum plant available soil water capacity in west-central Kansas [20]. Rogers and Lamm pointed out that additional irrigation above the amount required to bring the profile to 50% of maximum available water capacity has a high probability of being lost or wasted [16]. Preplant irrigation is sometimes requested to herbicide application for preemergence weed control. Hamilton et al. reported that incorporating 3-(3,4-dichlorophenyl)-1,1-dimethylurea (diuron) into furrow preplant irrigation controlled annual weeds until mid-season and treated cotton produced normal yields with no alteration of fibre properties and boll components [21]. Shem-Tov et al. also reported that herbicide pronamide at the rates of 0.67 or 1.34 kg ai/ha effectively controlled weed for lettuce (Lactuca sativa) production [22]. Early spring preplant irrigation was more effective compared to the fall off season irrigation [4]. For sustainable crop production under salt-affected soils, salt in the soil profile is managed and leached out using off season precipitation and preplant irrigation with good quality water during fallow periods [23-26]. Ayars reported the successful salt management by preplant irrigation in the San Joaquin Valley of California and other regions across the world [24].

Crop yield vs water amount and the crop yield vs crop water use evapotranspiration relationships could be used to reduce unproductive use of irrigation water mostly under preplant practice. Crop evapotranspiration threshold before grain production should be minimized to avoid unproductive water losses except under forage crop production where the evapotranspiration threshold is zero. From six-year field experiment in the southcentral Nebraska, Irmak found substantial interannual variability in sprinkler irrigated maize evapotranspiration threshold which varied from 209 to 418 mm and averaging 279 mm [10]. Subsurface drip irrigated maize evapotranspiration threshold averaged 309 mm at the same site in south-central Nebraska [13]. Threshold evapotranspiration was 277 mm for maize, 175 mm for grain sorghum, 137 mm for sunflower, 254 mm for winter wheat and 198 mm for soybean in western Kansas [27,28].

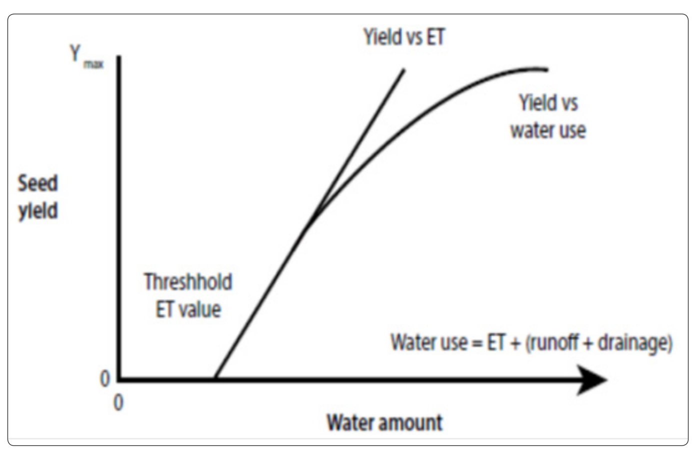

Figure 3: Generalized relationship between yield and water amount [evapotranspiration (ET) or water use] [29]

Effect of Preplant Irrigation on Crop Yields and Water use Efficiency

The major question to optimize preplant irrigation is when it should be applied to benefit the producer. Minimizing the nonproductive preplant irrigation is another concern as it could generate water losses through surface evaporation and or deep percolation. Therefore, preplant irrigation management should consider reducing soil water evaporation, improving snow and or rainwater harvesting and minimizing deep percolation out of the crop root zone. Preplant irrigation efficiency is a function of the actual soil available water when deciding of preplant irrigation [4]. Musick and Lamm reported the advantages and disadvantages of preplant irrigation practice and indicated that adopting the preplant irrigation strategy should not be based only on water storage in the soil and on-site precipitation patterns. Stone et al. pointed that early spring preplant irrigation was more effective than fall preplant irrigation [4,29]. Preplant irrigation is ensure good germination and better plant stand in the southwestern US and dry years in other areas [30]. However, crop evapotranspiration increases when the irrigation capacity is 2.5 mm/day and water productivity was not impacted by preplant irrigation depth at high and moderate irrigation system capacity [6]. High preplant irrigation frequency and depth increase water losses despite the irrigation capacity. Kisekka et al. indicated that under 2.5 mm/day irrigation capacity, minimum pre-irrigation amount of 75-100 mm was necessary to meet average seasonal crop evapotranspiration of 625 mm and found that water productivity was more impacted by the irrigation capacity than the preplant irrigation amounts in Kansas and no substantial variation was observed in maize plant transpiration under different preplant irrigation for system capacities of 3.4 and 6.4 mm/day [6]. Stewart and Peterson indicated that maximizing crop evapotranspiration should be the objective under water limited cropping systems as crop evapotranspiration is strongly related to crop yield and biomass accumulation [31]. Under very limited well capacity, preplant irrigation increased yield and was profitable [5]. Evaporation and or deep percolation were the main sources of the extra water applied. Under limited water conditions, the plant can develop deep rooting system to uptake water from the deeper soil layers [7,32]. Overall preplant irrigation should be considered under very limited irrigation capacity and should not be adopted when the irrigation system capacity is enough in most years [6]. The storage efficiency of the preplant irrigation might be influenced by the irrigation methods and techniques. Soil water evaporation losses are higher when preplant irrigation water is applied application through drip irrigation systems than when the preplant irrigation water is applied through a sprinkler and surface irrigation systems [12,33]. Lamm reported that pre-irrigation applied by subsurface irrigation system could increase seasonal capacity with a possibility to apply irrigation under near freezing temperature conditions while not possible under sprinkler irrigation systems [34]. Crop residue management reduces soil water evaporation and would be water saving strategy and improve the efficiency of preplant irrigation [33]. Bushong et al. reported the impact of preplant irrigation on phosphorus and potassium fertilizer management in winter wheat with grain yield and water productivity optimized under preplant irrigation condition [35]. Schlegel et al. found an increase in rainfed maize grain yield from 27 to 33 kg/ha/mm of pre-plant irrigation when in-season precipitation ranged from 196 to 215 mm and yield decrease from 9 to 25 kg/ha/mm when the in-season precipitation ranged from 288 to 354 mm under increasing preplant irrigation amounts (0, 38, 76, or 114 mm) at two locations in Kansas [36]. Rainfed grain sorghum yield also increased with increasing preplant irrigation amounts from 12 to 22 kg/ha/mm and from 0 to 6 kg/ha/mm under in-season precipitation ranges of 163 - 281 mm and 315 - 382 mm respectively [36]. Stone, et al. investigated the timing of off-season irrigation in maize in Kansas and found that off-season irrigation timing did not significantly impact maize yield and concluded that off-season irrigation of maize was not a water efficient practice [20]. Stone et al. indicated that storage efficiency of preplant irrigation was influenced by the irrigation amount and the precedent soil moisture content prior to irrigation event and concluded that preplant irrigation should be recommended only if it is necessary for crop establishment [2]. Excessive preplant irrigation might be required for seed germination and crop establishment when using surface irrigation with alternate furrow spacing in the areas where in-season precipitation is not reliable like West Texas and similar environment [37-41]. Luo, et al. found that drip preplant irrigation to bring soil water storage to 65-75% of field capacity could result in the highest cotton yield and water productivity and Chen, et al., coupling adequate pre-plant irrigation and basal fertilizer surface application produced a high-yield and high-efficiency cultivation technique in the arid areas of Xinjiang China [32,42]. Dhital investigated the effect of preplant in winter wheat (Triticum aestivum L) under different seeding rates of 45, 67 and 112 kg/ha and three nitrogen rates of 0, 67, 134 kg/ha near Stillwater, Oklahoma and found that preplant irrigation did not affect grain yield while the seeding rate and N rate were significant for number of heads [43]. Hemmati, et al. studied the effect of nitrogen application rates, pre-planting irrigation and maize planting patterns on weed seed bank population and found that preplant irrigation was an effective implement to reduce the weed seed bank that decreased by 57, 43, 34 and 9% at 200, 300, 400 and 500 kg N/ha however, the effect of preplant irrigation decreased with increasing applied nitrogen fertilizer [44].

Preplant irrigation practice was revealed non-efficient by most of the first studies [1,2,4,20,45]. Preplant irrigation depth and frequency should be related to soil texture as this could result in large water losses by drainage under coarse soils for clay soils with larges cracks during the off-season period [38,46]. Allen and Musick reported 70% increase in sorghum irrigation water amount by surface irrigation for only 10% grain yield increase indicating non-efficient practice of pre-irrigation as $10 increase in irrigation cost was not covered by the value of the increase in yield while the pre-irrigation permitted early seeding [3]. Schlegel et al. studies the effect of plant population (56,000, 68,000, and 80,000 plants ha-1) under different irrigation capacity (2.5, 3.8, and 5.0 mm d-1) preceded by 75 cm of preplant irrigation and without preplant irrigation near Tribune, Kansas and found that preplant irrigation did not significantly impact crop water productivity [5]. Preseason irrigation was profitable at all irrigation capacities, although only slightly profitable at the highest irrigation capacity while production profitability increased at higher seeding rate (80,000 seeds ha-1) when irrigation capacity was increased to 5.0 mm/day. Rasmussen and Berg indicated that planting pattern affects the efficiency of the preplant irrigation practice and applying 300 mm of furrow preplant irrigation water was the optimum preplant rate [47]. Planting beans in the bottom of pre-irrigated furrows without soaking completely between the furrows reduced preplant water application by 60% and the continuing within-row treatments reduced irrigation water use by 42% compared to conventional irrigation practices, however, total bean yields on the preplant, within-row treatments were not significantly different from the conventional treatments [47].

Table 1: Change in crop yield and water productivity as performance indicators of some key preplant irrigation studies in relation with soil types, irrigation systems, and preplant irrigation amounts

Authors	Study location	Soil type	Preplant irrigation depth	Irrigation system	Crop	Yield	Water productivity
Musick et al. (1971)	Texas, USA				grain sorghum	not increased	not increased
Hobbs and Krogman (1971)	Vauxhall, Alberta, Canada	Chin loan	25, 50, 75% soil holding capacity		Barley, clover, maize, beets	increase	relatively efficient
Rasmussen and Berg (1986)	southern Idaho, U.S.A	silt loam	300 mm	Furrow	dry beans	not significant	not increased
Stone et al. (1987)	west-central Kansas, USA		≤ 60% soil holding capacity		maize	beneficial	increase
Undersander and Regier (1988)	Etter, Texas , USA	silt clay loam	237 mm fall and 466 mm in spring		Sorghum	Increased	fall preplant ≥ spring preplant
Stone et al. (1994)	Western Kasas, USA	silt loam	152 mm	Basin	maize	not significant	not significant
Stone et al. (1994)	Bushland, Texas, USA	silt loam	106 mm	flood	sorghum	not significant	not significant
Rogers and Lamm (1994)			50% soil holding capacity			beneficial	increase
Stone et al. (2008)			<55% and <60% AW for fall and spring soil holding capacity				
Schlegel et al. (2012)	Tribune, Kansas, USA	silt loam	75 mm	flood	maize	profitable	not significant
Bushong et al. (2014)	Altus, Oklahoma, USA	silty clay loam	100 mm	Flood	winter wheat	Significatif	Significatif
Dhital (2016)	Stillwater, Oklahoma, USA		Mobile sprinkler		winter wheat	not significant	not significant
Chen et al. (2017)	Xinjiang, northwestern China	Clay loam	80% FC	n.m	Cotton	6.4 to 39.9 % increase	increased
Kisekka et al. (2017)	Tribune, Kansas, USA	Ulysses silt loam	75- 100 mm	Sprinkler	maize	10-17% increase	18% increase in PUE
Schlegel et al. (2017)	Cloby and Tribune, Kansas, USA	loessial Keith silt	38, 76, or 114 mm		maize, sorghum	Significatif	Significatif

Management Decision Tools for Preplant Irrigation

The decision to pre-irrigate a field before planting when the soil moisture is not adequate for seed planting depends strongly on the technical aspect the irrigation systems' capacities as reported by the above-mentioned studies. However, producers are guided by market crop prices and could even decide on the crop of the following season even before harvesting the actual crop [48]. There are different tools for online weather forecast (precipitation) with different precision used by crop consultants, crop growers and university researchers for planning purpose. Some tools are designed for the preplant irrigation management. Klocke et al. designed Crop Water Allocator (CWA) with focus on calculating the net return from different crops or crop combinations under split field conditions using irrigation and precipitation water [49,50]. Running CWA under different scenarios helps to choose the optimum crop or crops combination management for the highest economic return. Rogers and Alam conceived KanSched which is evapotranspiration-root zone soil water balance (evapotranspiration, rainfall, soil water storage, irrigation water) irrigation scheduling tool and water management under rainfed conditions [51]. Klocke et al. developed crop yield model called Crop Yield Predictor (CYP) used to predict crop yields under alternative irrigation management option [52]. Crop yield simulation under different irrigation management scenarios allows to determine the best management with the optimum net economic returns. Other crop yield simulating models have been developed and used successfully to simulate crop yield-water production function under different initial soil moisture condition. Different version of the Root Zone Water Quality Wodel (RZWQM), Decision Support System for Agrotechnology Transfer (DSSAT), Agricultural Production System Simulator (APSIM), Aqua Crop and other crop simulation models (CERES, CropSyst, WOFOST, etc.) have been successfully used across different agroecological zones under different soil water and water management strategies [53-56].

Conclusion

Preplant irrigation represents not only creation of better seed bed preparation and seeding condition with better seed germination and plant establishment, but also is water saving strategies within the crop root zone to meet crop water requirement at the peak demand under limited system capacity or reduced water availability environment. Kisekka, et al. indicated that preplant irrigation is mostly effective when the irrigation capacity is limited [6]. The effectiveness of the preplant irrigation depends on different factors such as soil texture, precedent soil moisture content prior to irrigation, irrigation technique, applied irrigation depth, etc. Water losses from the preplant irrigation by surface evaporation and deep percolation constitute the main disadvantage as it increases the production cost. Bordovsky and Porter found that, average irrigation water losses over spray, low energy precision application (LEPA), and subsurface drip irrigation (SDI) were 67%, 60%, and 47%, respectively [40]. In addition, crop yield is function of the preplant irrigation amount applied as applying a large amount of preplant irrigation could result in reduction in water productivity compared to the application of a sequence of smaller irrigation depths [5,57]. The fundamental guideline may concern the preplant irrigation application timing as the precedent soil moisture content tremendously affects the storage efficiency which decreases with the actual available plant water greater than 60% and early spring applications are more efficient than fall application [4]. As the operational costs and net income varied with inputs and across years while irrigation and nitrogen fertilizer applied rate shows an interacting effect on both gross and net income there is a need to optimize preplant irrigation to maximize the net income using the relationship between the relative net income and water use efficiency.

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