Kansas Agricultural Experiment Station Research Reports

Volume 9
Issue 6 *Western Kansas Agricultural Research*

Article 8

2023

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Recommended Citation

Aguilar, Jonathan; Moghbel, Farzam; and Fazel, Forough (2023) "Evaluation of Novel Deficit Irrigation Techniques in Western Kansas," *Kansas Agricultural Experiment Station Research Reports*: Vol. 9: Iss. 6. https://doi.org/10.4148/2378-5977.8492

Evaluation of Novel Deficit Irrigation Techniques in Western Kansas

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Summary
In search of techniques to reduce irrigation water use in the Ogallala Aquifer region, several deficit irrigation techniques were evaluated in corn and cotton production. Several iterations of deficit irrigation (based on ET), including partial root-zone deficit (PRD) and regulated deficit irrigation (RDI) treatments, were implemented in the 2021 and 2022 summer season. Corn and cotton did respond to the different deficit irrigation treatments. Significant yield advantages were observed in fixed PRD on both crops while RDI also showed some yield advantage for corn.

Introduction
One of the most crucial elements of the economy in Kansas is irrigated agriculture. However, the sustainability of the western Kansas irrigation district is threatened by declining water supplies from the Ogallala aquifer (Klocke et al., 2011; Lamm et al., 2007). Therefore, exploring agricultural water management methods to increase water productivity of current cultivations in the region, and testing alternative crops which are less water demanding are ongoing. Deficit irrigation is one of the convenient techniques that could be advantageous in water scarce regions such as western Kansas. Novel deficit irrigation management methods include partial root-zone drying (PRD) (Cheng et al., 2021; Giuliani et al., 2017) and regulated deficit irrigation (RDI) (Greaves and Wang, 2017; Wang et al., 2023). These methods have received increased attention due to their effectiveness in maintaining yields of crops and reducing water application. However, few studies have tested the implementation of PRD and RDI concepts for sprinkler irrigation systems. This study's main objectives were to explore the effects of PRD and RDI methods on corn and cotton cultivation under a linear move irrigation system at Kansas State University's Southwest Research-Extension Center.

Experimental Procedures
Two-year field experiments were conducted in 2021 and 2022 based on randomized complete block designs with three replications. For the cotton crop, in 2021, irrigation treatments were based on 100% (full), 50%, and 0% (dryland) of the crop's full water requirements. In 2022, regulated deficit irrigation (RDI) treatments were applied at 100% (full), 80%, 70%, 50%, 30%, and 0% (dryland). Two fixed PRD treatments were started 35 (FPRD 1-COT) and 45 (FPRD 2-COT) days before the approximate date of a crop growth regulator. For the corn crops, two fixed PRD treatments were started 25 (FPRD 2) and 45 (FPRD 1) days before the approximate date of crop maturity, and two alternative PRD treatments were applied weekly (APRD1) and bi-weekly

(APRD2). Four RDI treatments were started early in the season, and at mid-season, that provided treatments of: 30% of crop water demand, (RDI30-1, RDI30-2); 70% of crop water demand (RDI70-1, RDI70-2); full irrigation; and dryland. The experimental treatments are summarized in Table 1.

The experiment was conducted at the Southwest Research-Extension Center irrigation research field near Garden City, KS (38°01'16.5"N, 100°49'16.0"W, 887 m altitude). Soil type in the field is well-drained Ulysses silt loam (fine-silty, mixed, mesic Aridic Haplustoll). The plot sizes were 45 ft × 45 ft. The treatments were applied using a four-span linear move irrigation system (model 8000, Valmont Corp, Valley, NE). Irrigation scheduling followed 50% maximum allowable depletion (MAD) of soil water content under full irrigation treatment. Irrigation events were triggered when the values of volumetric soil water content reached 50% of soil available water content. The irrigation depth for full irrigation treatment was 25.4 mm at each irrigation event. Manual ball valves were used to implement PRD treatments and a variable irrigation rate (VRI) device was used to implement RDIs and regular deficit irrigation treatments. Every other nozzle was closed for PRD treatments, and irrigation management prescriptions were prepared for other deficit irrigation treatments in each irrigation event.

The weather data for the calculation of evapotranspiration and rainfall effects were obtained from the K-State Mesonet tower close to the experimental station. The calculated daily reference evapotranspiration was based on the FAO-56 Penman Monteith equation (Allen et al., 1998) and precipitation values for the 2021 and 2022 growing seasons are presented in Figure 1. The volumetric soil water contents were measured using neutron attenuation techniques to 8 ft soil depth with 1-ft increments, and soil moisture sensors to 3 ft soil depth with 2-in increments during the growing season. The neutron probe readings were used to calculate the actual seasonal evapotranspiration based on the soil water balance approach.

The Phytogen 205 cotton variety seeds were planted on May 27, 2021, and May 16, 2022. The planting density was 75,000 and 60,000 seeds/a in 2021 and 2022, respectively. The crop growth stages were recorded during the growing season accordingly. Harvest dates for the first and second growing seasons were October 26, 2021, and November 1, 2022, respectively.

Conventional corn variety (P0339CYFR) seeds were planted on May 28, 2021, and May 13, 2022. The planting density was 32,000 seeds/a for both growing seasons. The corn was harvested on October 21, 2021, and October 4, 2022. The weed management and fertilizer application were applied uniformly following related recommendations in the region. The crop's above-ground biomass and yield have been measured based on 3 m rows located in the middle of plots.

Statistical analysis regarding ANOVA and comparisons of means were done in R environment software.

Results and Discussion

Cotton Deficit Irrigation

The effects of deficit irrigation treatments on cotton yield (lint + seed) and irrigation water use efficiency (IWUE) are presented in this section (Figure 2). Results of statistical analysis showed no significant difference between effects of fixed PRD treatments (FPRD 1 and FPRD 2) on cotton yield compared with full irrigation treatment for both growing seasons ($P < 0.05$). To a great extent, the fixed PRD treatments, more specifically FPRD 2, increased cotton yield for two consecutive years of study while it reduced the water application by approximately 30%. The 50% deficit irrigation significantly increased IWUE compared with full irrigation treatment. Moreover, this study demonstrated that using dryland conditions for cotton production could be an option for water scarce region of western Kansas.

Corn Deficit Irrigation

Total aboveground biomass, grain yield, and IWUE of the corn under experimental treatments are presented for both growing seasons (Figure 3). Results indicated that the fixed PRD treatments were successful in maintaining corn total biomass as no significant difference was observed between total biomass values obtained under FPRD 1, FPRD 2, and full irrigation treatments. The RDI70-2 treatment had highest total biomass values comparing to other deficit irrigation treatments and the corresponding total biomass values was not significantly different from full irrigation treatments. Results of the corn grain yield under experimental treatments also revealed that the most convenient deficit irrigation treatments that did not significantly reduce crop yield compared to full irrigation condition were FPRD 1, FPRD 2, and RDI70-2. The effectiveness of fixed PRD treatments and 70% regulated deficit irrigation started at mid-season (V12 growth stage of corn). The conservation of water resources and maintenance of crop yield has been validated by IWUE results.

Acknowledgments

This work is supported in part by the U.S. Department of Agriculture Ogallala Aquifer Program.

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Table 1. Summary of the experimental treatments in 2021 and 2022 for cotton and corn

Cotton		Corn	
Irrigation treatments	**Label**	**Irrigation treatments**	**Label**
Full irrigation (100%)	Full	Full irrigation (100%)	Full
30% deficit irrigation	30% DI	Regulated deficit irrigation compensated 30% crop water requirement starting early season	RDI30-1
50% deficit irrigation	50% DI	Regulated deficit irrigation compensated 30% crop water requirement starting late season	RDI30-2
70% deficit irrigation	70% DI	Regulated deficit irrigation compensated 30% crop water requirement starting at early season	RDI70-1
80% deficit irrigation	80% DI	Regulated deficit irrigation compensated 70% crop water requirement starting at late season	RDI70-2
0% irrigation	Dryland	Alternative partial root-zone deficit treatments applied weekly	APRD1
Fixed PRD treatment started 35 days before cotton growth regulator	FPRD 1-COT	Alternative partial root-zone deficit treatments applied biweekly	APRD2
Fixed PRD treatment started 45 before cotton growth regulator	FPRD 2-COT	Fixed PRD started at 25 days before crop maturation	FPRD 1
		Fixed PRD started at 45 days before crop maturation	FPRD 2

The 30, 50, 70, and 80% DI compensated respective percentages of crop full seasonal irrigation water depth requirements.

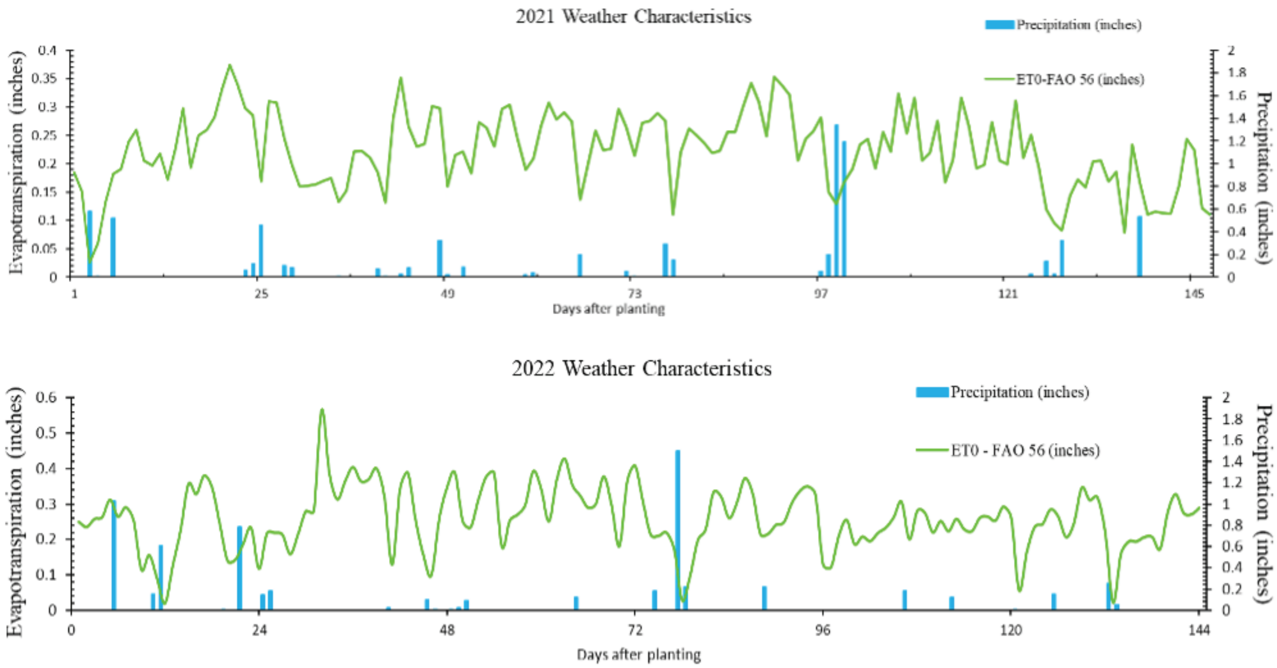


Figure 1. Weather characteristics for 2021 and 2022 growing seasons. ETO – FAO 56 is the computed daily crop water demand for those growing seasons.

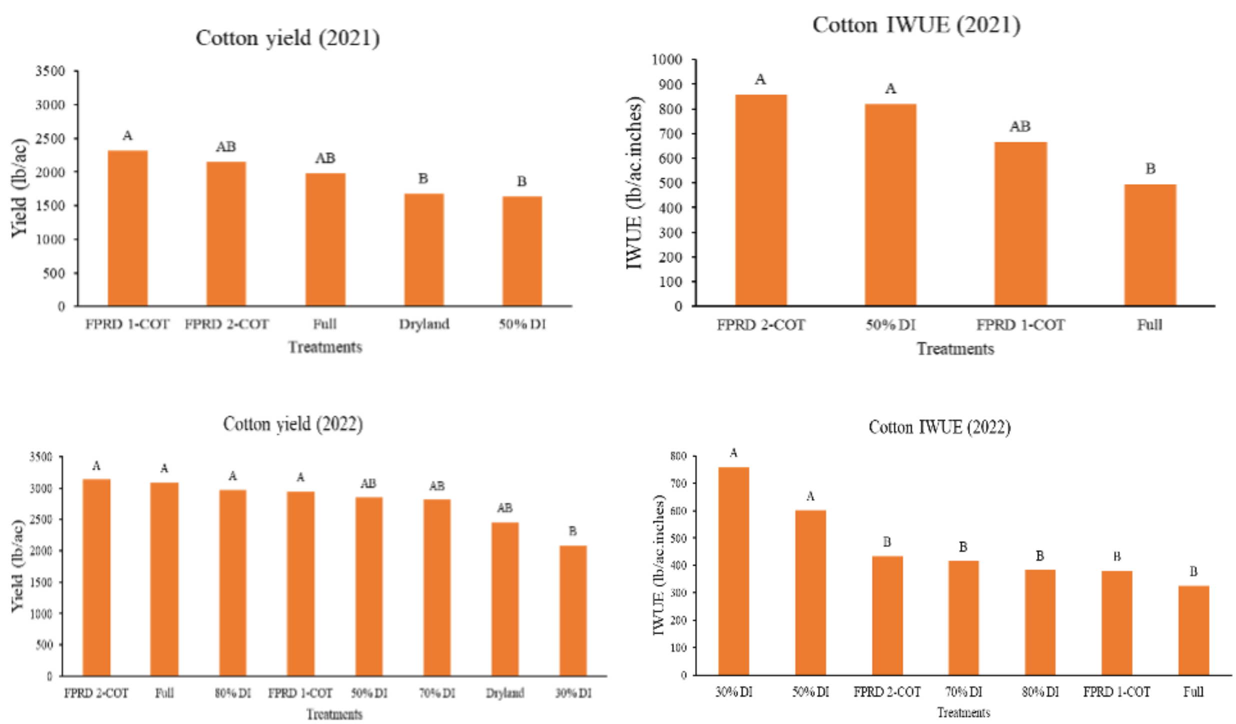
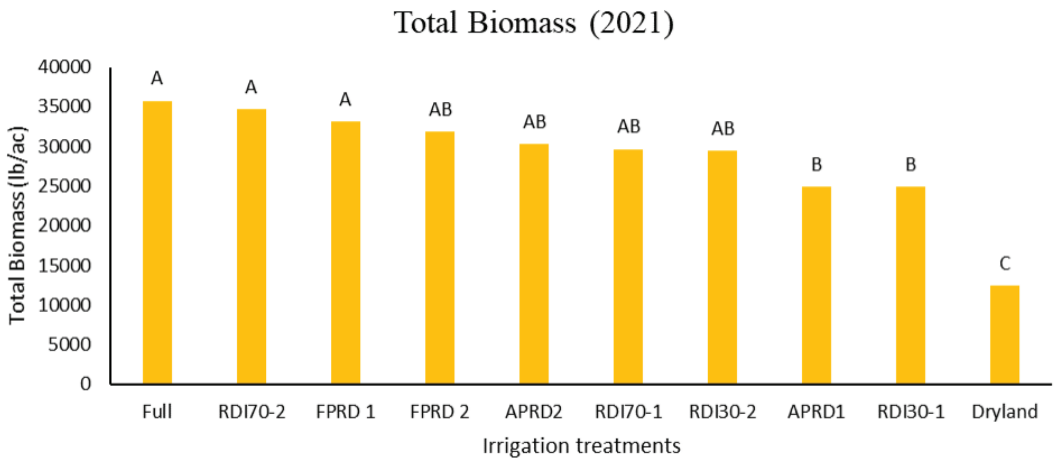
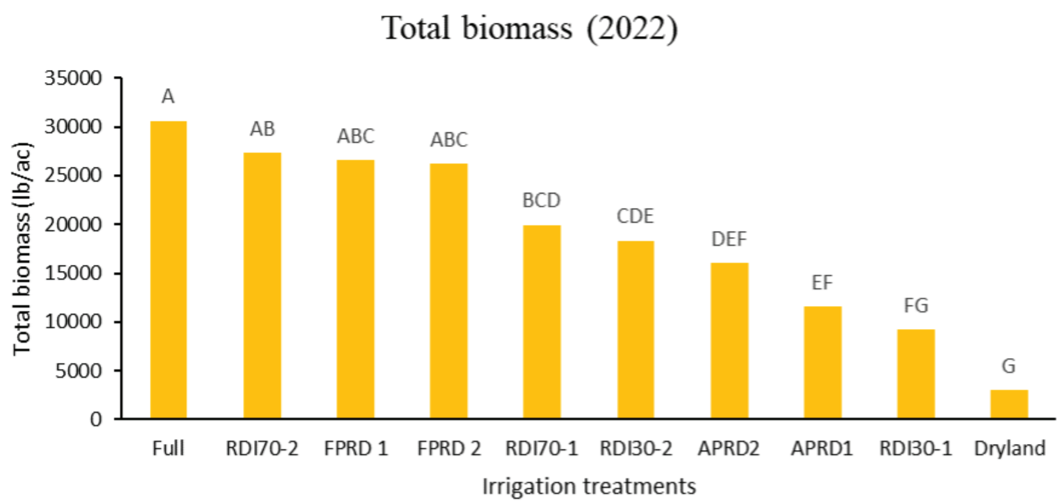
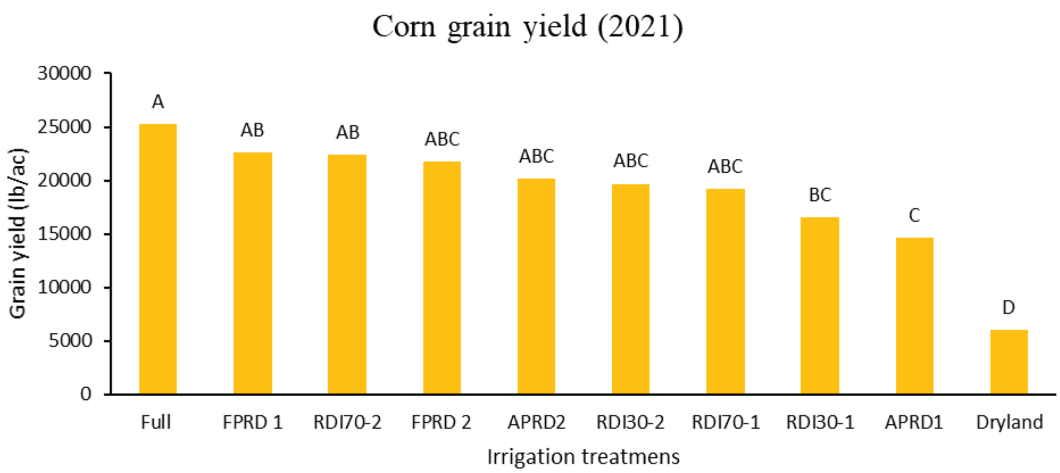
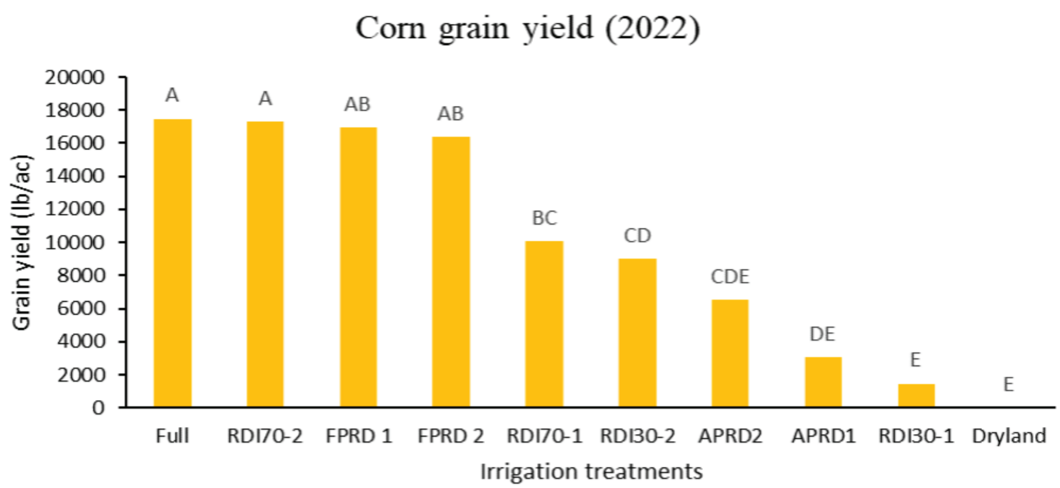


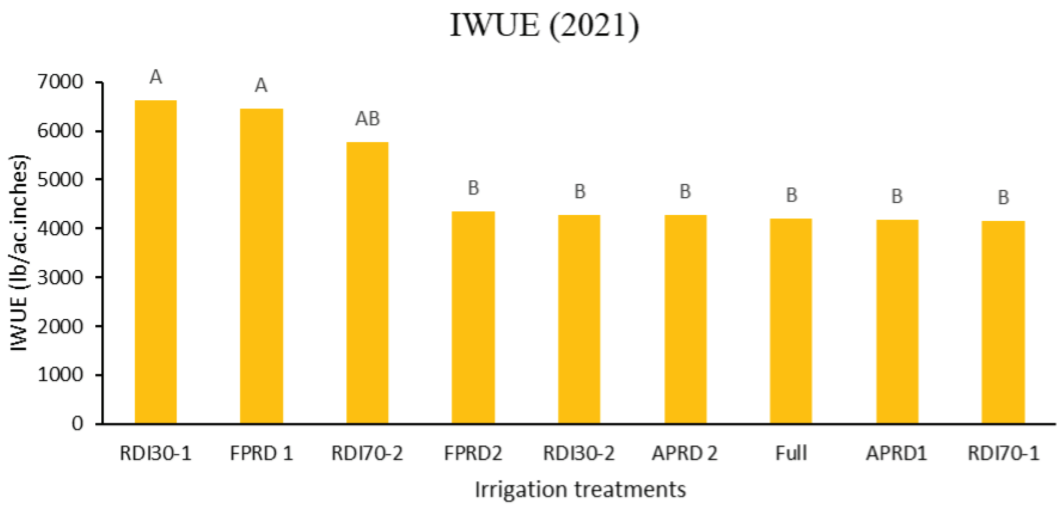
Figure 2. Cotton yield and irrigation water use efficiency (IWUE) as affected by experimental treatments outlined in Table 1. Same letters in the bars indicate that it is not statistically different.


Total Biomass (2021)
Total Biomass (lb/ac)
40000
35000
30000
25000
20000
15000
10000
5000
0
A
A
A
AB
AB
AB
AB
B
B
C
Full
RDI70-2
FPRD 1
FPRD 2
APRD2
RDI70-1
RDI30-2
APRD1
RDI30-1
Dryland
Irrigation treatments


Total biomass (2022)
Total biomass (lb/ac)
35000
30000
25000
20000
15000
10000
5000
0
A
AB
ABC
ABC
BCD
CDE
DEF
EF
FG
G
Full
RDI70-2
FPRD 1
FPRD 2
RDI70-1
RDI30-2
APRD2
APRD1
RDI30-1
Dryland
Irrigation treatments


Corn grain yield (2021)
Grain yield (lb/ac)
30000
25000
20000
15000
10000
5000
0
A
AB
AB
ABC
ABC
ABC
ABC
BC
C
D
Full
FPRD 1
RDI70-2
FPRD 2
APRD2
RDI30-2
RDI70-1
RDI30-1
APRD1
Dryland
Irrigation treatmens


Corn grain yield (2022)
Grain yield (lb/ac)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
A
A
AB
AB
BC
CD
CDE
DE
E
E
Full
RDI70-2
FPRD 1
FPRD 2
RDI70-1
RDI30-2
APRD2
APRD1
RDI30-1
Dryland
Irrigation treatments



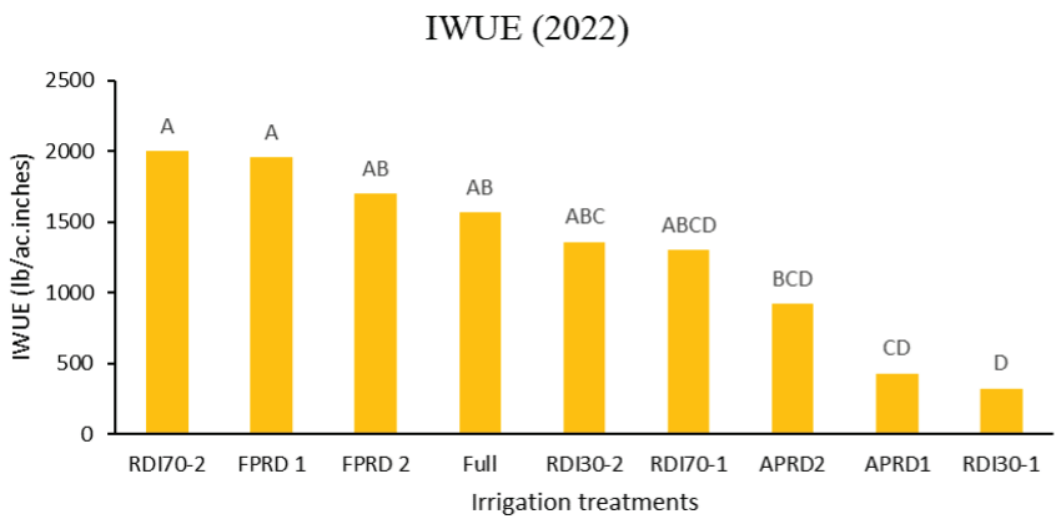


Figure 3. Corn total biomass, grain yield, and irrigation water use efficiency (IWUE) affected by experimental treatments outlined in Table 1. Same letters in the bars indicate that the result is not statistically different.