Evaluating Winter Small Grain Crops for Water Productivity and Soil Health Dynamics Under Deficit Irrigation Regime in Desert Agricultural Systems of Arizona: Final Report

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Abstract

Deficit irrigation strategies are often considered as an effective irrigation technology to conserve water and have been tested in different crop production systems, and under different environments. We investigated deficit irrigation strategies in the desert Southwest, specifically in central Arizona, for durum wheat and grain barley production under flood irrigation. The experiment was carried out at the Maricopa Agricultural Center, University of Arizona. We tested 10% and 20% irrigation deficits and found that only 10% deficit irrigation declined 30% and 45% grain yield in durum wheat and barley, respectively. Additionally, we did not record any changes in soil chemical properties or soil health. Our study concluded that under flood-irrigated durum wheat and barley grain production, deficit irrigation may not be an economically viable strategy for water conservation in desert agroecosystems. However, this study also indicated the need for similar research with drip or sprinkler-irrigated small grain production systems.

Introduction

Desert agricultural systems are facing continuous challenges from the megadrought (Williams et al., 2022) and diminishing water availability in the irrigated agricultural production systems, forcing us to explore new technologies. Deficit irrigation has been tested successfully in grain production systems (Memon et al., 2021); however, there is a knowledge gap in understanding the effect of deficit irrigation on major small grain crops in desert environments. Therefore, this study will provide the knowledge necessary for the adoption of irrigation regimes to reduce freshwater consumption. Additionally, small grain crops have been reported to improve soil health (Jernigan et al., 2020), but little information is available in desert environments. We designed this study to investigate two major winter small grain crops in Arizona, durum wheat and barley, for their growth and impact on soil health following deficit irrigation regimes. Additionally, this study is based on the hypothesis that soil health improvement might facilitate freshwater savings. Our research outcomes will help the industry fine tune agronomic management practices to become more climate resilient under water-limited scenarios.

Methods

Experimental Layout

The experiment was laid out at the Maricopa Agricultural Center (MAC), University of Arizona, over a 2-acre plot following a randomized complete block design during the spring of 2023. Due to the wet winter season in 2022-2023, the crops were planted late on February 14, 2023, which may have impacted the crop performance. We conducted a randomized replicated research trial to understand the effects of deficit flood irrigation regimes, 15% and 30% deficit irrigations, on (i) grain yields and protein content of barley and durum wheat, (ii) soil chemical properties, and (iii) soil health indicators. We grew two popular varieties, BARETTA barley, and TIBURON desert durum wheat for this trial. For barley and durum wheat, the seeding rates were 150 lbs./acre and 170 lbs./acre, respectively. Herbicides and pesticides were sprayed as needed.

Irrigation and Fertilization

Figure 1. Wheat and Barley plots are getting irrigated at Maricopa Agricultural Center

A total of 8 irrigations were applied to the control plots, whereas for the deficit regimes, 7 and 6 irrigations were applied. The deficit was applied by skipping a flood irrigation event/The skipped irrigations were applied on April 19 and May 10, 2023. However, due to the delayed planting and harsh summer, **we could only apply a 10% and 20% deficit irrigation**, while we targeted a 15% and 30% irrigation deficit originally; control plots received 3.6 acre-feet of water during the growing season. We also irrigated both crops similarly.

A total of 200 lbs. of N was applied as Urea Ammonium Nitrate (32-0-0), split into four applications (initial soil test nitrate level was 28 lbs. N/a): 75 lbs. at planting, 50 lbs. on April 4, and April 26, and a final dose of 25 lbs. N/a was applied on May 19 to boost grain protein contents and minimize the adverse effects of delayed planting and a shorter growing season. Fertilizers were applied through irrigation, only on days when all plots were scheduled to be irrigated to ensure all plots received similar amounts of nutrients. Nutrients other than nitrogen were applied at a rate that is used by the growers in central Arizona.

Soil and Plant Tissue Sampling

Soil samples were collected from the top 0-6" soil profile and then processed at Sanyal Lab. We measured the following parameters to monitor soil health and crop growth: Potentially mineralizable nitrogen (PMN), soil organic matter (SOM), permanganate oxidizable carbon (POXC), soil respiration, soil protein, pH (1:1) and electrical conductivity, soil nitrate-ammonium, nutrients, and plant tissue nutrient composition. Potentially mineralizable nitrogen (PMN) is an indicator of the capacity of the soil microbial communities to mineralize nitrogen (N) tied up in complex organic residues into the plant-available forms of N. Microbially active carbon or POX-C is an indicator of the small fraction of SOM that can serve as a readily available food and energy source for the soil microbial community, thus helping to maintain a healthy soil food web to support optimum microbial activity. Soil respiration is a measure of the metabolic activity of the soil microbial community. As the microbes respire or decompose SOM, CO_2 is evolved, and this test measures CO_2 evolved during microbial metabolism as an indicator for soil microbial activity. Soil protein is an indicator of the amount of protein-like substances in the soil. Soil protein is a large pool of organically bound N in the SOM

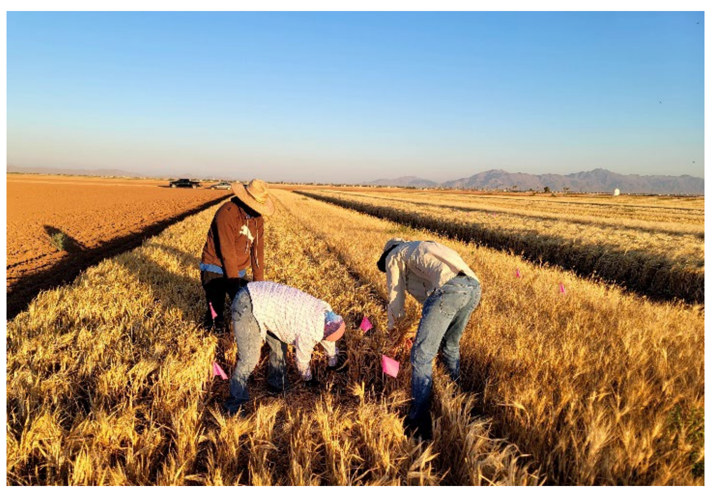

Figure 2. Mr. Stackpole and the farm crew harvesting microplots for grain yield and quality analyses

which soil microbes can mineralize. Therefore, protein content is well associated with overall soil health status, especially the N and carbon in the soil. Soil health parameters were measured at the Sanyal Lab using protocols described in Sanyal et al. (2023), and soil samples were sent to a commercial lab for soil chemical analyses. Plant samples were collected at the physiological maturity stage and sent to a commercial lab for nutritional analyses, especially protein.

Harvest and Yield

The crops were harvested on June 22, 2023. For the calculation of grain yields, 5 random microplots were harvested inside each treatment plot. The dimension of each microplot was 3.28 ft. x 3.28 ft. (1 m x 1 m). The samples with grains were then threshed at the MAC facility, and the grains were weighed and sent out to a commercial lab for nutrient analyses.

Result and Discussion

Chemical Soil Properties

Data from initial soil properties are given in Table 1. The soil was medium textured and alkaline, but soluble salt concentration was low. We did not see any changes in soil chemical properties during the experimentation; however, we expected salt build-up in experimental plots where we applied deficit irrigation regimes. Notably, we had low plant-available phosphorus levels before the experiment, and the levels were exhausted by the crop further. Very low plant available phosphorus levels at the reproductive stage may also suggest that the crops could have utilized an additional application of phosphorus fertilizers (Table 1). Similarly, plant available K was taken up by the crops. We also concluded that our nitrogen fertilizer application strategy was correct as the crop assimilated most of the N applied to the soil as evident from the residual soil nitrate-nitrogen levels after the harvest. No change in soil organic matter levels was observed. From these results, we can conclude that deficit irrigation did not change soil chemical properties or soil fertility levels in manners that were detrimental to crop growth.

Table 1. *Soil chemical properties before the experimentation, at the reproductive growth stage, and after the small grain crop harvest*

Soil Parameters	Initial	Reproductive Stage			Post-harvest		
		Control	*10% Deficit*	*20% Deficit*	*Control*	*10% Deficit*	*20% Deficit*
Soil pH (1:1)	8.4	8.3	8.3	8.3	8.4	8.4	8.4
Soluble Salts (dS/m)	0.20	0.25	0.24	0.21	0.18	0.20	0.21
Organic Matter (%)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Nitrate-nitrogen (lbs./a)	28	5.7	5.9	2.6	2.8	2.6	2.9
Olsen P (ppm)	4.5	0.2	1.0	0.8	0.9	0.8	1.3
Potassium (ppm)	313	223	206	210	205	195	204
Sulfate-S (ppm)	21.7	20	21	17	19	17	21
Zinc (ppm)	0.55	0.5	0.5	0.5	0.4	0.4	0.5
Sum of Cations (meq/100g)	28.8	23	22	23	24	24	24

Grain Yield and Quality of Durum wheat and Barley

Durum wheat and barley grain yields were significantly reduced with just a 10% irrigation deficit under flood irrigation systems; increasing the deficit did not decline the yields further. We have seen a 30% decline in grain yield for durum wheat and a 45% decline for barley (Figure 3) when a 10% deficit was applied. We did not find any significant difference in grain protein content. The grain protein content was 15, 17, 16% for barley, and 18, 19, 19% for durum wheat, under control, 10%, and 20% irrigation deficit treatments, respectively. These outcomes make it evident that deficit flood irrigation may not be a sustainable nor economically viable practice for growers as potential yield reductions may offset the cost of growing durum wheat and barley. Our finding is similar to many previous reports that indicated wheat grain yield loss following deficit irrigation (Ali et al., 2007; Tari, 2016). However, our findings were more drastic because of the extreme arid environment of Arizona.

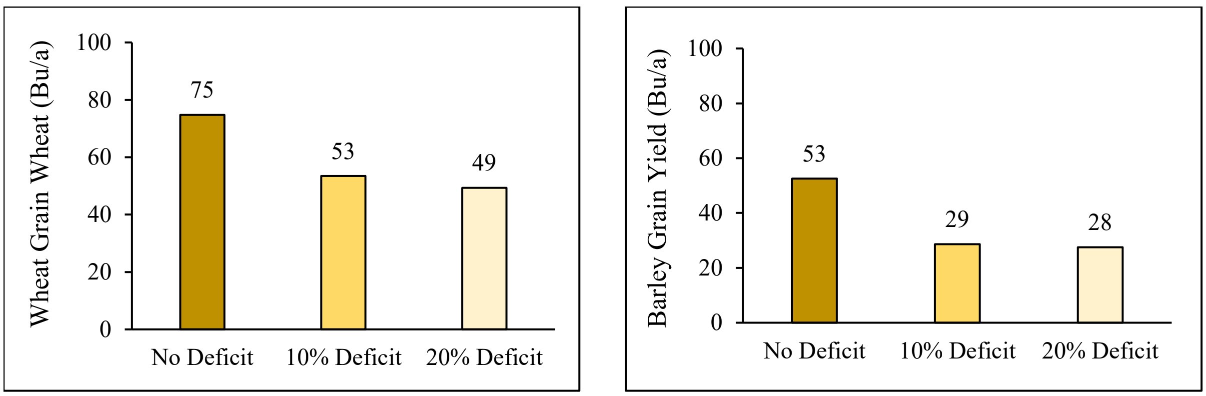

Figure 3: Grain yields (Bu/acre) of durum wheat and wheat under deficit flood irrigation regimes

The average durum grain yield in the state of Arizona was 103 Bu/a (https://www.nass.usda.gov/), but our average durum grain yields were significantly lower, possibly due to the wet winter/spring that delayed our planting and shortened the growing season; the highest durum grain yield in our experimental plots was 85 Bu/a. Barley grain yield was reduced by a comparatively larger amount due to the late planting. The average barley grain yield in Arizona was 132 Bu/a in 2023, whereas our average yield was only 53 Bu/a, and the highest barley grain yield we recorded in our experimental plots was 64 Bu/a. These outcomes may suggest that a late planting of small grain crops grown for grain yield may not be economically viable as suggested in many studies previously (Shah et al., 1994; Shah et al., 2020).

Soil Health Assessments

We did not find a particular trend for soil health changes in our study under different irrigation regimes and for different small grain crops, durum wheat, and barley. However, we found that POXC levels declined during the reproductive stage and increased afterward (Table 2). It can be speculated that during the reproductive growth stage, higher soil microbial activity to cycle nutrients (Table 1) exhausted the POXC source for energy. Then, after physiological maturity, the crop did not need more nutrients, and soil microbes in the rhizosphere were therefore signaled by the crops to not provide nutrients, and soil microbes decomposed other carbon forms in leftover carbonaceous plant tissues, which added to the POXC levels post-harvest. A similar trend was found for soil protein levels for the deficit treatments, and a contrasting trend was found in control plots; however, soil protein levels declined as the crop grew, possibly due to microbial utilization of soil nitrogen reserve that helped plants avail nitrogen as needed

(Geisseler et al., 2019). Several scientific reports can support these theories (Robertson et al., 1997; Sainju et al., 2022; Liu et al., 2023), but, we do not have any scientific evidence from this study as we did not measure soil microbes or their activities.

Table 2. *Mean values of potentially mineralizable nitrogen (PMN), permanganate oxidizable carbon (POXC), soil respiration, and soil protein before the experimentation, at the reproductive growth stage, and after the small grain crop harvest*

Soil Parameters	**Initial**	**Reproductive Stage**			**Post-harvest**		
		Control	*10% Deficit*	*20% Deficit*	*Control*	*10% Deficit*	*20% Deficit*
PMN (µg NH_4 /g soil)	3.60	2.2	1.8	1.3	1.3	0.9	2.4
POXC (mg C/kg)	251	211	219	174	230	309	368
Soil Respiration (mg CO_2/g/4d)	1.23	1.01	1.01	1.38	1.06	1.07	1.00
Soil Protein (g/kg soil)	0.45	0.29	0.24	0.15	0.16	0.27	0.37

Conclusion

Overall, our study concludes that deficit irrigation strategies may not be sustainable or economically viable for durum wheat and barley grain production systems, especially when flood irrigation is practiced. We reported significant yield loss even with 10% deficit irrigation. We also did not find any grain quality benefits from reduced yield. Deficit irrigation did not affect soil chemical properties or soil health. However, further studies should investigate soil biology, especially the soil microbial communities and their functions. The outcomes of this study indicated that future research should investigate other irrigation methods such as sprinkler or drip irrigation methods for more effective deficit irrigation regimes.

Recommendation and Future Direction

1. It is not recommended to use deficit irrigation if durum wheat and barley are grown for grain yield, especially under delayed planting.
2. The deficit irrigation strategy under the flood irrigation method is not sustainable for commercial agriculture.
3. If it is necessary to use deficit irrigation, a different irrigation method should be applied such as drip irrigation.
4. Future deficit irrigation studies on durum wheat and barley for grain production should be conducted using different irrigation methods like sprinkler or drip systems.

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