EXPERIMENTS WITH FLOODING TOLERANCE OF ALFALFA FOR GROUNDWATER RECHARGE

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ABSTRACT

Winter groundwater recharge, where farmland is flooded during the winter using surface water to recharge the underlying groundwater, is a promising technology currently tested on alfalfa. In this study, we present results from intentional winter flooding experiments for groundwater recharge on alfalfa (*Medicago sativa L.*) with different fall dormancy ratings (3-8). Experiments were conducted at three different sites on soils promoting high percolation rates within the Central Valley and northern California (Siskiyou County) to test the effect of realistic water application amounts and different flooding durations and frequencies on alfalfa. Water application amounts ranged between 2.1 and 26 ft, application timings ranged between early January and mid-April and durations varied between short-lived, pulsed water applications (6 hours) and continuous flooding for 31 days. The statistical analysis of variance revealed, alfalfa yield of the first and second cutting of the growing season did not show significant differences between treatments (i.e. flood vs. control), even with semi-non-dormant varieties in warmer winter climates. Analysis of alfalfa forage quality of alfalfa variety Ameristand 835NT RR planted at the Kearney Research and Extension Center in Parlier, CA indicated a significant difference in crude protein (CP) content (p-value = 0.036), which varied between 20.17% and 21.56% and neutral detergent fiber (aNDF) content, which varied between 39.75% and 40.72% between the flood treatments and the control. Together these results indicate that while caution is appropriate to prevent crop injury, winter recharge in alfalfa fields with highly permeable soils appears to be a viable practice.

Key words: flooding tolerance, groundwater recharge, forage quality, alfalfa

INTRODUCTION

Many agricultural regions in the United States and across the world that use groundwater as irrigation supply have seen drastic declines in groundwater storage and groundwater levels (Wada et al. 2013). In California, U.S. the recent severe and extended drought (water years 2011–2012 through 2015–2016), caused groundwater level declines of 10–50 ft in 90% of the groundwater wells in the Central Valley, while some wells (8%) showed declines in groundwater level of more than 50 ft (DWR 2017). To curb these long-term trends the State of California passed the Sustainable Groundwater Management Act in California in 2014, which asks landowners overlying critically overdrafted groundwater basins to achieve groundwater sustainability by 2040. One approach to increase water supply reliability and to achieve

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groundwater sustainability in the coming decades that landowners, farmers and water managers increasingly consider is the intentional recharge of groundwater aquifers at times when excess surface water is available. Winter groundwater recharge, where farmland is flooded during the winter using surface water to recharge the underlying groundwater, could potentially provide a wide range of opportunities for long-term water security given the large irrigated acreage and water distribution infrastructure available in California.

Among the perennial crops, Alfalfa is considered a promising candidate for groundwater recharge for several reasons (Dahlke et al. 2018). It is widely grown in the western United States, with approximately 800,000 acres planted in California (USDA NASS 2017). Alfalfa is a nitrogen-fixing plant, hence, it seldom receives nitrogen fertilizer, which reduces the risk of leaching excess nitrate to groundwater, which is one of the main concerns when using farmland for groundwater recharge (Putnam and Lin 2016; Walley et al. 1996). However, challenges and concerns remain regarding the effect that winter groundwater recharge could have on alfalfa yield and crop health. One of the main concerns when flooding alfalfa is the risk of crop injury, yield reduction or stand loss under saturated conditions. Excessive anaerobic conditions could damage roots, increase the risk of root diseases, could cause excess aboveground humidity affecting insects or diseases, excessively high water tables, nutrient and herbicide leaching, and inability to perform field operations due to wet conditions. Past research has shown, alfalfa can be damaged by lack of oxygen in the root zone from prolonged saturation; however, the extent of crop damage is temperature dependent (Barta 1988; Barta and Sulc 2002; Drew and Lynch 1980). Alfalfa is less susceptible to injury when temperatures are cooler, even after prolonged saturation (Barta and Schmitthenner 1986; Cameron 1973; Finn et al. 1961; Heinrichs 1972). To evaluate the suitability of alfalfa fields for groundwater recharge, we conducted on-farm experiments on alfalfa stands with different fall dormancy ratings to measure the amount of groundwater recharge possible and to assess crop response to excess winter water applications in different climates. Three on-farm experiments were conducted, one at the Plant Science Research Farm at UC Davis (Yolo County) in 2015, one near Etna, CA in the Scott Valley (Siskiyou County; 2015-2016), and one at the Kearney Research and Extension Center in Parlier, CA. In all experiments, the effects of different water amounts, timings and durations of water application were evaluated.

SUITABILITY OF ALFALFA FOR WINTER GROUNDWATER RECHARGE IN COOL WINTER CLIMATES

Methods

Two on-farm experiments were conducted on a 5-year (variety WL 550.RR, fall dormancy rating 8) and 9-year old (BlazerXL, fall dormancy rating 3) alfalfa stand in northern California (Davis, Scott Valley) in a cool winter climate. The Davis experiment was conducted on a Yolo silty clay loam with an available water capacity of 11 inches. The experiment in Davis was a replicated study in which seven treatments with three replicates were tested in a randomized complete plot design (21 plots of 20 by 50 sq ft in size). The treatments consisted of three winter groundwater recharge timings (Jan/Feb/March) during which two different winter irrigation amounts (4 ft, 6 ft) were applied in addition to the control. In the Scott Valley 135 AF and 107 AF of water were applied on a 15-acre Stoner gravelly sandy loam field during the winter/spring season of 2015 and 2016, respectively. The field was divided into 4 treatment areas, each consisting of 3 checks (2 checks for the control) receiving different amounts of water during winter ranging from 2ft to

28ft depending on treatment and season. However, most notably, the continuous treatment plot received a total of 28 ft and 11 ft of water for 31 and 46 days in 2015 and 2016, respectively. Both sites were rated "Good" on the Soil Agricultural Groundwater Banking Index (O'Geen et al. 2015, https://casoilresource.lawr.ucdavis.edu/sagbi/) indicating that the soil supported high infiltration rates. Estimated infiltration rates averaged 0.9 ft of water per day on the Stoner gravelly sandy loam.

Results

Biomass data collected from each treatment and replication at the Davis site indicated that pulsed application of 4 - 6 ft of water onto dormant or semi-dormant alfalfa did not result in significant differences in yield. The winter water applications caused short-duration saturated conditions in the root-zone and high fractions (70-95%) of the applied water going to groundwater recharge with only 5-30% going to soil storage and evapotranspiration indicating that alfalfa is a promising crop for agricultural groundwater recharge if grown on suitable soils (e.g. soils with high water intake and deep percolation rates).

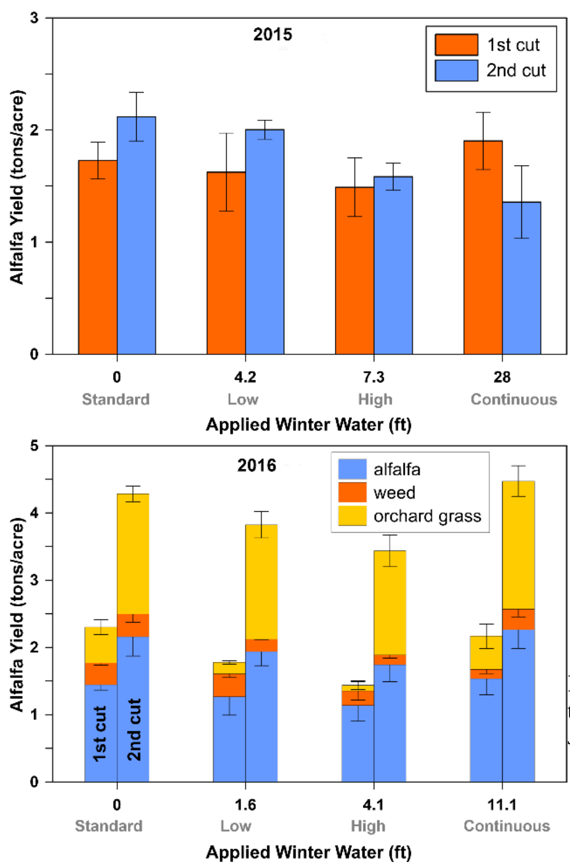

Fig. 1: Alfalfa yield for 1st (end of May) and 2nd cutting (mid-July) vs. average applied winter water (ft) for 2015 and 2016, Scott Valley, CA.

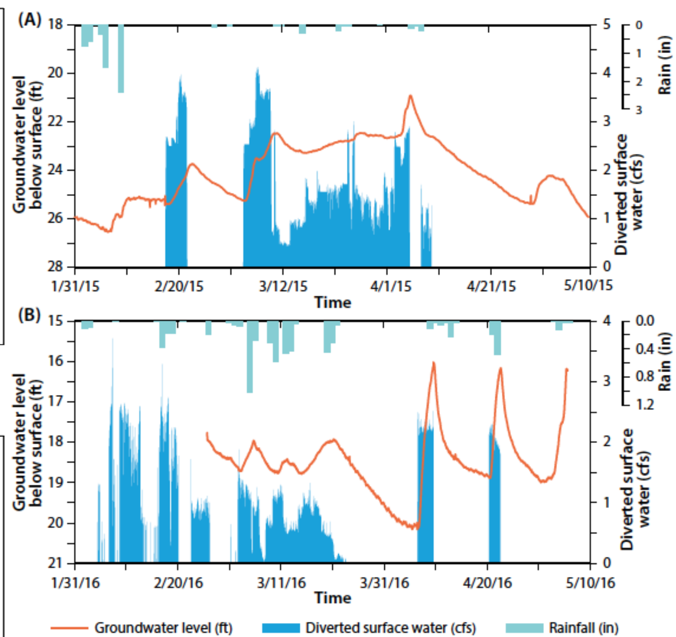

Fig. 2: Amount of winter water applied for recharge (cfs), change in depth to the groundwater table (ft) and rainfall (in per day) measured between January and May in 2015 (A) and 2016 (B) for the Scott Valley site.

At the Scott Valley site, the winter water application of up to 28 ft of water per treatment showed no discernible effect on alfalfa yield except for the 2nd cutting in 2015, which showed a decline in alfalfa yield with increasing amount of applied winter water (Fig. 1). However, despite the decline, the yield in the continuous treatment plot was only 0.5 tons/acre lower than the control, indicating that the economic loss for high water application amounts is modest. In 2016, checks receiving the largest amount of winter water (11.1 ft) showed a higher yield than the control plots during the 1st and 2nd cutting indicating that winter recharge might lead to increased crop water availability in the deep soil profile offsetting potential irrigation deficits during the growing season. During both years, the recharged surface water together with natural precipitation caused a rise in the groundwater table in a nearby well of about 6 feet in 2015 and 4.5 ft in 2016 (Fig. 2).

Results from these experiments indicate that 1) large fractions of the applied winter water is going to groundwater recharge (most events resulted in >90% of the applied water going to deep percolation), 2) that application of 2-28 ft did not conclusively result in a significant decline in yield, 3) that the risk of winter flooding is potentially small. However, the results also show high variability in alfalfa yields between treatments which complicated the statistical analysis of the winter water application effect. In fact, the results of a mixed-model analysis of covariance (ANCOVA) conducted with the Davis yield data indicated that water application timing and amount were not significant predictors of the observed yield, but instead that initial plant count and variability in soil properties across the field were better predictors. The high variability in yield observed across treatments and plots could also have been influenced by the fact that both experiments were conducted on older stands with relatively low plant density.

These two initial experiments were conducted under relatively cool, higher latitude conditions using alfalfa varieties with fall dormancy ratings of 8 (Davis) and 3/4 (Scott Valley). It is widely known that a primary determinant of crop injury under saturated conditions is anoxia in the root zone; with the rates of oxygen consumption by roots and microbes proportional to temperature (Drew and Lynch, 1980). At higher latitudes (e.g. Davis and especially in the Scott Valley), crop respiration occurs at a relatively low rate in winter due to the combination of dormant/semi-dormant varieties used, low temperature and shorter day length. However, questions remained as to whether alfalfa is a suitable cropping system for winter groundwater recharge in regions with warmer winter climates where semi-dormant alfalfa varieties, i.e. varieties with a fall dormancy rating of 8 or higher) prevail. To investigate this question a third experiment is currently under way at the Kearney Research and Extension Center in Parlier, CA.

SUITABILITY OF SEMI-DORMANT ALFALFA FOR WINTER GROUNDWATER RECHARGE IN WARM WINTER CLIMATES

In this third study, we evaluated the effect of two different flooding durations and frequencies for groundwater recharge on a 2-year alfalfa stand, variety Ameristand 835NT RR with a fall dormancy rating of 8 on a Hanford fine silty loam (SAGBI rating Good). We implemented three treatments: i) 4 days of flooding and 10 days off (low frequency), ii) 3 days of flooding and 4 days off (high frequency), and iii) control in a randomized complete plot design with three replicates on nine 20x44 sqft plots. Treatments were applied for a total of 6 weeks between Feb 11 and March 24, 2019. For the low frequency treatment, a total of 5.4 feet of water (106,059 gallons) were applied in addition to 2.32 inches of precipitation during the experiment. The high frequency treatment received a total of 11.9 ft (234,926 gallons) of water. The statistical analysis of variance revealed, alfalfa yield of the first and second cutting of the growing season did not show significant differences between treatments and varied between 3150 – 3284 lbs per acre for the first and 3393 -3762 lbs per acre (12% moisture content alfalfa) for the second cutting (Fig. 3).

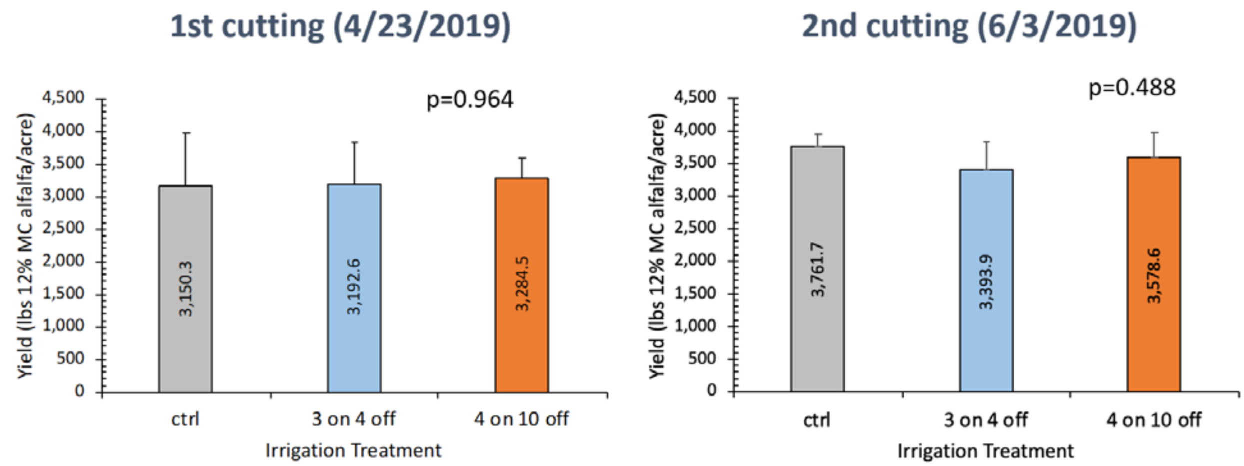

Fig. 3: Alfalfa yield for the first and second cutting for the three winter groundwater recharge treatments tested at the Kearney Center in Parlier, CA.

Subsamples of the collected biomass from both harvests were sent to Rock River Laboratory for feed quality analysis. The forage quality test results indicated a significant difference in crude protein (CP) content (p-value = 0.036), which varied between 20.17% and 21.56% and neutral detergent fiber (aNDF) content, which varied between 39.75% and 40.72% between the flood treatments and the control (Table 1). Although the neutral detergent fiber (aNDF) content of the alfalfa in the control plots was rated as “good” a closer look at the values reveals that the aNDF value was very close to the “Fair” category, which ranges from 40-44% aNDF. Due to the experimental setup (e.g. 9 plots in one check), the alfalfa in the control plots could have been impacted by the flood treatments in the neighboring plots. In order to rule this effect out, we will repeat the experiment this winter with a larger plot spacing at a later winter recharge timing (March/April). A Tukey test was also performed on the harvest dates. The results of this test revealed a significant difference in all parameters (CP, aNDF, ADF, Ash), which is to be expected, since the alfalfa increases the non-digestible fiber content over the growing season.

Table 1: Tukey's honestly significant difference test (Tukey's HSD) results on the effect of winter water recharge on feed quality.

	Treatment	Amylase-treated neutral detergent fiber (aNDF)			Acid Detergent Fiber (ADF)			Ash			Crude Protein (CP)		
Control	1	39.75	Good	b	31.54	Good	a	12.07		a	21.56	Premium	a
4 on 10 off	2	42.23	Fair	a	33.31	Fair	a	11.79	High	a	20.17	Premium	b
3 on 4 off	3	40.72	Fair	ab	32.02	Fair	a	11.96		a	20.76	Premium	ab
p-value		*0.047*			*0.078*			*0.69*			*0.036*		

CONCLUSIONS

Results from our experiments indicate that high-frequency and low-frequency flooding of dormant and semi-non-dormant alfalfa during late winter, early spring showed no significant effect on alfalfa yield. All three test sites have well-draining soil (SAGBI rating good-excellent) that supported the infiltration of variable amounts of water for winter groundwater recharge (2-28 acre-feet/acre), highlighting the role that soil drainage plays in reducing the risk of crop damage during winter recharge. High-frequency recharge (e.g. continuous flooding, large amounts) created short-lived anoxic conditions in the root zone during some of the recharge events, however, these effects can be avoided with the pulsed application of water. While conducting the experiments, we observed an increasing need for herbicide application either during or immediately following the experiment to reduce weed pressure. Lastly, winter groundwater recharge on alfalfa might have an effect on feed quality, particularly the digestible fiber content of the alfalfa. However, more research is needed to confirm these results.

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