Deficit irrigation did not reduce yield in alfalfa.

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testing 0.2 mg kg⁻¹ B. Alfalfa was planted in 2016. Levels of B Kc, crop coefficient; NDF, neutral detergent fiber; RFV, relative feed value; TDN, total digestible nutrients.

Core Ideas

• Application of B or irrigation increase petiole B concentration of alfalfa.
• Increases of petiole B due to B fertilization did not increase alfalfa yield and crude protein.
• Deficit irrigation did not reduce yield in alfalfa.
• Regardless of water regime, application of B on B-deficient soil did not improve yield and crude protein content of alfalfa, regardless of soil moisture availability.

ABSTRACT

Boron (B) fertilization based on soil B status may prevent negative effects on alfalfa (Medicago sativa L.) yield and quality. Our objective was to determine the effects of foliar-applied B and water regimes on alfalfa yield and quality. A 2-yr (2016–2017) study was done at Creston, MT in a fine sandy loam soil that tested 0.2 mg kg⁻¹ B. Alfalfa was planted in 2016. Levels of B ranging from 0 to 2.24 kg B ha⁻¹ were applied in association with three water regimes including rainfed, 50%, and 100% evapotranspiration (ET). There was no effect of B on yield or crude protein (P > 0.05) in either year. Both B fertilization and irrigation application increased petiole B concentration. In 2017, the water regime x B level interaction was significant specifically for the yield of the second cutting (P = 0.02), as well as for the relative feed value, neutral detergent fiber, and petiole B concentration in the third cutting (P < 0.05). Irrigation decreased (P < 0.01) forage quality only in the second cutting of 2016. Irrigation increased alfalfa yield by 45% in the establishment year (2016), but only by 12% in the following year. However, there was no yield difference observed (P > 0.05) between the 100ET and 50ET treatments each year, and irrigation water productivity decreased in the second year of alfalfa growth. The foliar application of B on a B-deficient soil did not increase yield or crude protein content of alfalfa, regardless of soil moisture availability.

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Abbreviations: ADF, acid detergent fiber; B, boron; CP, crude protein; ET, evapotranspiration; ETc, crop evapotranspiration; ETo, reference evapotranspiration; IWP, irrigation water productivity; Kc, crop coefficient; NDF, neutral detergent fiber; RFV, relative feed value; TDN, total digestible nutrients.
leaf structure, dense top canopy (Herrera-Rodriguez et al., 2010; Undersander et al., 2000), necrosis of terminal buds, and wilting of leaves (Willis and Piland, 1937). These known B deficiency symptoms could lead producers to apply B, especially when an initial soil test result for B is low.

Nutrient deficiency is influenced by the low availability of moisture. Uptake of nutrients can be reduced with drought, and it is evident in the literature where plant nutrient studies are mostly conducted under drought conditions (Berger, 1962). Fine-tuning fertilizer amendments, such as B, may be dependent on the availability of moisture. Historically, studies of B uptake have been conducted under either rainfed (Berger, 1962; Chandler et al., 1946; Razmjoo and Henderlong, 1997) and lately, irrigated (Dordas, 2006; Grant and Miller, 1998; Radeke, 1986; Kheirkhah et al., 2016; Sapkota et al., 2017, 2018) conditions exclusively, but the synergistic effect between levels of B applications on a B-deficient soil and levels of water regime in alfalfa has not been well studied. Except for the irrigated alfalfa B report by Sapkota et al. (2018), no other B performance study of alfalfa in Montana is available in the literature.

We hypothesized that B uptake from the soil is influenced by soil moisture availability. The objectives of this study were to evaluate the effect of different rates of B, water regimes, and their synergistic effect on alfalfa yield and quality on soil tested for very low soil B guidelines; Kelling, 1999. The rate of B fertilizer, in this recent study, was based on the local fertilizer guidelines (Jacobsen et al., 2005).

**MATERIALS AND METHODS**

**Site Description**

This study was conducted in 2016 (establishment year) and continued into the next growing season (2017) on the same plots at the Northwestern Agricultural Research Center in Creston, MT (48°11’10” N, 114°8’39” W, elevation of 894 m). The research site had a fine sandy loam soil (coarse loam, mixed, Pachic Haploxeroll; USDA-SCS and MAES, 1959). The field was fall-plowed at 20-cm depth after the previous crop of winter wheat (Triticum aestivum L.) was harvested, and then disked the following spring. Composite soil samples were collected in 2016 from 0- to 15-, 15- to 60-, and 60- to 90-cm using a soil probe (Giddings, Windsor, CO) for soil nutrient analysis. The site had soil pH 6.7 (1:1 soil/water; Peters et al., 2015), 18 g kg⁻¹ organic matter (loss on ignition; Combs and Nathan, 2015), 125 kg ha⁻¹ NO₃-N (cadmium reduction; Gelderman and Beegle, 2015), 18 mg kg⁻¹ P ( Olsen sodium bicarbonate; Frank et al., 2015), and 88 mg kg⁻¹ K (1.0 M NH₄OAc [pH 7] extraction on dry soil; Warnacke and Brown, 2015).

Fertilizers (48 N, 114 P₂O₅, and 264 K₂O kg ha⁻¹), were applied based on the alfalfa fertilizer guideline for Montana crops (Jacobsen et al., 2005) only in 2016. Fertilizers were incorporated and seedbed packed before planting in 2016 (establishment year). The preseeding spring soil analysis for B (DTPA-sorbitol method; Miller et al., 2000) in 2016 indicated that B content of the experimental site was very low (0.2 mg kg⁻¹; Kelling, 1999) and 2.24 kg B ha⁻¹ is recommended when soil B content is within 0 to 0.5 mg kg⁻¹ when planting any crops (Jacobsen et al., 2005). This research investigated the response of alfalfa to varied levels of B and moisture regimes.

Monthly, seasonal, and 29-yr (1989–2017) rainfall and mean temperature during the growing season are shown in Table 1.

The year 2016 had near-average seasonal rainfall and temperature, as well as the month-to-month comparisons with the 29-yr data. However, year 2017 had low seasonal precipitation and high air temperature compared with the 29-yr data. The year 2017 was classified as a severe drought occurrence by the United States Drought Monitor (2017). Rainfall for 2017 was 42% below the 29-yr average from May to September, with minimal rainfall after June 15, the first cutting (Fig. 1b). The mean air temperature from May to September was consistently higher in 2017 than the 29-yr average.

**Treatments and Experimental Design**

Alfalfa variety ‘Hybriforce-3400’ (fall dormancy 4, Dairyland Seed, West Bend, WI) was broadcast seeded at the rate of 22.4 kg ha⁻¹ on 24 May 2016. Weeds were controlled with a postemergence application of herbicides only on 5 July 2016: bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) at the rate of 1.2 L ha⁻¹ and imazethapyr ([±]-2-[4,5-dihydro-4-methyl-4-[1-methylethyl]-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid) at the rate of 0.4 L ha⁻¹.

The experiment was established as a split-plot design with three water regimes as the whole-plot and five B treatments as the subplot factors (Table 2), replicated four times. The water regime treatments are described in Table 2. Treatments of 100% evapotranspiration (100ET) and 50% evapotranspiration (50ET) were included to evaluate alfalfa response to B under nonwater-stressed (100ET) and simulated water-stressed treatments, respectively. The B treatments (amount and time of application; Table 2) were adapted from Sapkota et al. (2018). Each of the experimental units dimension was 3.1 by 4.6 m, with a 1.5-m alley between replications and around the experimental plots to allow easy access for plot maintenance and harvest. Treatment randomization and the amount of B for each experimental unit (based on the B treatments in Table 2) were generated using Agriculture Research Manager (Gylling Data Management, 2016).

The daily crop ET (ETc) and soil water balance approaches were used to schedule irrigation. The grass-based reference ET (ETₐ) was retrieved from the Creston Weather Station (USBR, 2017a) located 30 m from the experimental site. The crop coefficient (Kc) values used for the specific growth stages of alfalfa were: 0.2 (beginning of the spring growth), 0.4 to 0.7 as alfalfa growth increases, and 0.9 after the full canopy cover. These Kc values are based on the curve developed on lysimeter plots, Kimberly, ID 1969–75 (USBR, 2017b). Daily ETc was calculated by multiplying ET₀ and the alfalfa Kc (Allen et al., 1998).
Daily soil water depletion was determined by subtracting daily $ET_c$ of the current day soil water content. The rooting depth to calculate depletion during the 2016 seedling year was 0 to 60 cm which was adjusted to 0 to 90 cm as soon as alfalfa plants were near full canopy, as well as throughout the second year (2017). During rainfall events, the water in excess of field capacity was considered lost by deep drainage, as there was no evidence of surface run-off in the field. Hence soil water depletion can be adjusted to zero or a full soil profile (Andales et al., 2015). No temporary water was assumed withheld above field capacity due to the coarse soil texture of the study site. The B content of the irrigated water was below the detection limit of 0.1 mg kg$^{-1}$.

To irrigate, seven drip tapes were laid in each irrigated plot at equal distances (30 cm apart) leaving 60 cm on each side of the plot to avoid lateral movement of water to adjacent plots. The 100ET treatment was irrigated whenever 35% plant available water (based on soil water balance approach; Allen et al., 1998) was depleted from the field capacity. The 50ET irrigation events were applied on the same day as the 100ET plots received irrigation, but at only half the applied amount of the 100ET.
Agrisolutions, St. Paul, MN) was foliar-applied with a CO2–pressurized backpack sprayer equipped with a 3.1-m wide hand-held boom with flat fan nozzles. When spraying the solution, the boom was maintained at 0.6 m above the ground level. The single application of 2.24 kg ha–1 occurred at 8-cm spring growth. The same amount of B was only re-applied to treatments B1 to B4, (Table 2), respectively. For both years, the initial application of B fertilizer was made in spring to all treatments B1 to B4 (Table 2), respectively. For both years, the initial application of B fertilizer was made in spring to all treatments B1 to B4 when the crop reached 8-cm height. The same amount of B was only re-applied to treatments B1 to B4 after the first-cutting regrowth reached 8-cm height.

Treatment. For each irrigation event, 2.54 and 1.27 cm of water was applied in 100ET and 50ET treatments, respectively (Table 2). Due to the adequate soil moisture in spring (initial soil field capacity and the amount of rainfall received), alfalfa was not irrigated for the first cutting of 2017, but irrigation began soon after the first cutting. Irrigation and rainfall events in 2016 and 2017 are shown in Fig. 1. Irrigation water productivity (IWP), defined as the amount of yield produced (in reference to the rainfall) per unit of irrigation water use (Molden, 1997), was also calculated.

A liquid B fertilizer formulation (10% B [100 mL L–1], Agrisolutions, St. Paul, MN) was foliar-applied with a CO2–pressurized backpack sprayer equipped with a 3.1-m wide hand-held boom with flat fan nozzles. When spraying the solution, the boom was maintained at 0.6 m above the ground level. The spray volume was 187 L ha–1. The volume of solution (water and B) for each experimental unit was 318 mL with liquid B amounts of: 4.8, 9.5, 19, and 38.1 mL B corresponding to treatments B1, B2, B3, and B4 (Table 2), respectively. For both years, the initial application of B fertilizer was made in spring to all the B treatments (B1 to B4) when the crop reached 8-cm height. The same amount of B was only re-applied to treatments B1 to B4 after the first-cutting regrowth reached 8-cm height.

Data Collection
Alfalfa was harvested at 10% bloom for all cuttings in both years (27 July and 17 Sept. 2016; 15 June, 21 July, and 9 Sept. 2017). Plant height and number of trifoliate leaves on the main stem were recorded before each cutting. A forage harvester was used to harvest a 1.5- by 4.6-m strip in the middle of the 3.1- by 4.6-m plot leaving 5-cm stubble height. Collected strips were weighed for fresh weight production.

Fresh biomass subsamples were collected from the harvested strip, immediately weighed, and then oven-dried (forced-air, 60°C) for at least 72 h or until a stable weight was reached, to determine the dry matter percentage for plot yield determination. The top 15-cm petioles of 20 plants were randomly collected from each plot during the harvest for petiole B analysis. Another 20 whole plant subsamples also were collected from each plot for forage quality analysis. The petiole subsamples were dried, ground, and analyzed for petiole B concentration by digestion and inductive coupled plasma determination method (Jones, 2001). Whole plant samples were also dried and ground for quality determinations: crude protein (CP; method 990.03; AOAC International, 2016), acid detergent fiber (ADF; modified AOAC International, 2016), neutral detergent fiber (NDF; Van Soest et al., 1991), total digestible nutrients (TDN), and relative feed value (RFV). Values of ADF and NDF were used to estimate TDN and RFV values.

Statistical Analysis
Data were analyzed using PROC GLIMMIX in SAS version 9.4 (SAS Institute, 2014, Cary, NC) separately for each year and each cutting, with B rate and water regime as fixed effects. Block and its interaction with water regime were set as random effects. An additional analysis testing the effect of cutting events across years was also analyzed as a fixed effect as the 2017 experiment was conducted in the same plots as in 2016. The LINES option was used for pairwise least square mean comparisons. Treatment effects were considered significant at α = 0.05.

RESULTS
Effect of B fertilization on plant height, yield, CP, and trifoliate node number was nonsignificant for all cuttings of the study. Petiole B increased (P < 0.001) with B rates in both cuttings of 2016. The highest rate of the applied B (2.24 kg B ha–1, Fig. 2a) for both cuttings had no difference in petiole B content between the split and the one-time application. Within each cutting during 2017, petiole B concentration increased (P ≤ 0.024) with increasing B rates, yet mostly remained below the sufficiency range, except, the highest B rates during the first and second cuttings (Fig. 2b). For all cuttings, the highest petiole B was consistently observed with the highest B rates, whether B fertilizer was split-applied or applied at one time (Fig. 2).

The increases in petiole B concentration with B rates were also evaluated for their effects on hay quality. Boron rates influenced (P < 0.05) ADF, NDF, TDN, and RFV in 2016 (Fig. 3) when the data from all cuttings within each year were averaged. The CP was not influenced by the application of B in either year; however, fiber quality indicators in alfalfa were affected by B rate. In 2016, the increase in NDF and ADF and the decrease in RFV and TDN (Fig. 3) occurred at the split-applied highest B rate (2.24 kg B ha–1). In contrast, in 2017, the split-applied
highest B rate had lower NDF \((P = 0.037; \text{Fig. } 3b)\) and the highest RFV \((P = 0.028; \text{Fig. } 3d)\) compared to the other treatments. This effect was only observed when the data for each year were combined, and was not observed for each cutting of 2017.

While B did not increase yield and had an inconsistent effect on forage quality, irrigation application increased \((P < 0.05)\) yield, plant height, petiole B concentration, and mean trifoliate node count number. Petiole B at the first cutting in 2016 and the plant height in 2017 second cutting were not influenced by irrigation treatment. Seasonal total dry matter yield of alfalfa increased \((P < 0.01)\) with irrigation application in either year (Table 3). Irrigation increased alfalfa total dry matter yield by 45\% \((P < 0.001)\) in 2016 and only 12\% \((P = 0.012)\) in 2017 compared with the rainfed treatment (Table 3). Of all cuttings, only the second cutting of 2017 (data not shown) showed no difference \((P = 0.372)\) in yields between the irrigated treatments. Overall, yield tripled between 2016 (establishment year) and 2017 (second year). Also, there was no significant difference between the 50ET and 100ET water regime treatments on total yield in any cuttings. As a result, the IWP of 50ET was consistently greater by two-fold each year compared with 100ET. Lastly, the overall IWP in 2016 was at least twice the 2017 IWP (Table 3).

While there was a consistent yearly effect of irrigation on yield and its components, irrigation’s influence on forage quality parameters varied. Effects of irrigation on forage quality parameters (CP, ADF, NDF, TDN, and RFV) were influenced \((P < 0.05)\) by water regimes only in the second cutting of 2016 (Fig. 4). Forage quality parameters did not differ between 50ET and 100ET for any of the cutting events. None of the forage-quality parameters were different \((P > 0.9)\) in 2017 and thus, are not shown. Both CP and TDN decreased (Fig. 4a, 4d), whereas NDF and ADF increased (Fig. 4b, 4c) with irrigation application in the 2016 second cutting.

The interaction of B rates and water regimes was nonsignificant for all response variables during the year of establishment (2016; \(P \geq 0.074\)). However, interactions were observed for four response variables in 2017. These included the second cutting yield \((P = 0.020; \text{Fig. } 5a)\), along with NDF \((P = 0.040; \text{Fig. } 5b)\), RFV \((P = 0.017; \text{Fig. } 5c)\), and petiole B \((P = 0.049; \text{Fig. } 5d)\) from the third cutting of 2017.

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Fig. 3. Effects of boron (B) application in 2016 (left panels) and 2017 (right panels) on alfalfa neutral detergent fiber (NDF; a and b), relative feed value (RFV; c and d), acid detergent fiber (ADF; e and f), and total digestible nutrients (TDN; g and h). Underlined B rates were split-applied: half at 8-cm spring growth and half at 8-cm regrowth following first cutting. The single application of 2.24 kg ha\(^{-1}\) occurred at 8-cm spring growth. Data were averaged within years. Error bars are the standard error of the means. Same letter assignment denotes the lack of significance at \(\alpha = 0.05\) within each year.
The interaction rate response of B and water regimes was inconsistent in the second year. Yield in the second cutting of 2017 increased with increasing B rates up to the split-applied 1.12 kg ha\(^{-1}\) B in rainfed plots. Under split-applied 0.56 kg ha\(^{-1}\) B, all water regime treatments resulted in statistically similar yields (4741 ± 137 kg ha\(^{-1}\); Fig. 5a). At the B rate of 2.24 kg ha\(^{-1}\), whether a split or single application, RFV increased (Fig. 5c) and NDF decreased (Fig. 5b) in the rainfed plots in 2017 third cutting. At any given B application rate, 100 and 50 ET increased petiole B compared with the rainfed treatment (Fig. 5d).

The B uptake was found to be 0.06 kg Mg\(^{-1}\) of alfalfa production for the control B treatment in 2016 and increased by 27% in the second year of establishment. Increasing B rates showed linear increases in alfalfa B uptake for both years (Fig. 6).

**DISCUSSION**

Boron fertilization did not improve alfalfa yield in either year of this study regardless of water regime, despite a soil test B in the very low range. The yield interaction between water regime and B was significant only for the second cutting of 2017. It was only under 50ET treatment where yield was compromised when B was applied twice at this cutting (Fig. 5a). Boron is documented to aid stimulation of root growth when moisture is limited in plants (Hodecker et al., 2014). With the lack of supporting data in this study, it is unclear whether the limited irrigation (50ET) and excessive B supplies increased carbon sink to stimulate root growth rather than the aboveground biomass. The biological interpretation for the reduced irrigation (50ET) with increased B availability is complex and future investigation is warranted.

Overall, the effect of B on total yield was nonsignificant in northwestern Montana, similar to reported findings in literature (Grant and Miller, 1998; Pecinovsky and Lang, 2012; Razmjoo and Henderlong, 1997; Sapkota et al., 2017, 2018). Razmjoo and Henderlong (1997) found that application of B up to 2 kg ha\(^{-1}\) did not affect alfalfa yield in Columbus, Ohio on a Crosby silty clay loam soil. Similary, Grant and Miller (1998) and Sapkota et al. (2018) reported no increases in alfalfa yield with increased B rate applications. Our recent study...

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**Table 3.** Alfalfa plant height and petiole boron (B) concentration at each cutting event and the yearly mean trifoliate node count, total yield, and irrigation water productivity (IWP) with water regimes in 2016 and 2017. The fully irrigated treatment is designated as 100ET and the deficit irrigated treatment (50% water applied in reference with 100ET) is designated as 50ET. Two and three cuttings were made in 2016 and 2017, respectively. Data on the first cutting of 2017 was not shown as irrigation commenced after the first cutting that year. Same letter assignment indicates the lack of significance between treatments at \(\alpha = 0.05\) within each cutting event (plant height and petiole B) or year (yield).

<table>
<thead>
<tr>
<th>Year</th>
<th>Water regimes</th>
<th>Plant height</th>
<th>Petiole B</th>
<th>Mean trifoliate node no.</th>
<th>Total dry matter yield</th>
<th>IWP</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>First</td>
<td>Second</td>
<td>Third</td>
<td>First</td>
<td>Second</td>
</tr>
<tr>
<td>2016</td>
<td>Rainfed</td>
<td>47.4c</td>
<td>49.8c</td>
<td>33a</td>
<td>28c</td>
<td>12.4b</td>
</tr>
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<td></td>
<td>050ET</td>
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<td>68.1b</td>
<td>n/a†</td>
<td>36a</td>
<td>44b</td>
</tr>
<tr>
<td></td>
<td>100ET</td>
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<td>73.3a</td>
<td>38a</td>
<td>50a</td>
<td>13.4a</td>
</tr>
<tr>
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<td>63.7</td>
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<td>41</td>
<td>13.0</td>
</tr>
<tr>
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<td>77.1b</td>
<td>18c</td>
<td>11c</td>
<td>12.7b</td>
</tr>
<tr>
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</tr>
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<td>95.2a</td>
<td>34a</td>
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<td>88.2</td>
<td>27</td>
<td>58</td>
<td>13.3</td>
</tr>
</tbody>
</table>

† n/a: not applicable.
documented that the B uptake of alfalfa (i.e., 0.06–0.08 kg B Mg⁻¹ production in reference to the control treatment, Fig. 6) was of close resemblance to the 0.05 kg B Mg⁻¹ production in Shorrocks (1997). The higher B uptake with the control treatment in 2017 than 2016 also indicates greater root proliferation (as expected) down the soil profile for nutrient uptake. The linearity of the B uptake showed the availability of B to the plants as the rate of the applied B increased (Fig. 6). Though it is outside the scope of this study, B sorption which affects B availability in the soil, is mostly reported in calcareous soil (pH > 7.0; Majidi et al., 2010). The soil pH in this present study was 6.7 and it was evident in our result that there were corresponding increases of tissue B with increased concentration of applied B (Fig. 2, 6). Still, B application on the B-deficient soil of this study, did not increase yield regardless of water regime.

Boron fertilization increased the fiber content of alfalfa (ADF and NDF) only in the establishment year. This outcome is in agreement with Rouquette et al. (2001), who found that with an application of 2.24 and 4.48 kg B ha⁻¹, fiber content increased. Crude protein was not affected by B in this study, nor in the research performed by Rouquette et al. (2001). Another study in Pennsylvania showed no effect of foliar-applied B products on alfalfa yield and quality (Hall et al., 2002). Sapkota et al. (2018) also reported no effect of B on the forage quality of alfalfa in a study conducted in Montana.

While B application had limited effect on forage quality with no evidence of increased yield across water regimes, the application of irrigation increased alfalfa yield but with no yield difference observed between 50ET and 100ET. Other researchers have evaluated deficit irrigation in alfalfa with varied outcomes. Deficit irrigation from 100ET down to 70ET did not affect alfalfa yield in Kansas (Harmoney et al., 2013), but a study in China found that the use of 60ET reduced alfalfa yield relative to 100ET (Li et al., 2016) of which yields can be influenced by timing of rainfall events or even possibly the resiliency of the crop. In our study, irrigating alfalfa at 50ET did not reduce yield which corresponds to Harmoney et al. (2013). The 50ET approach increases the opportunity to capture and fully utilize rainfall, increasing the chance for efficient storage. In the second year (2017) of the planting, rainfall events were almost nonexistent from 80 d after regrowth through the final cutting (Fig. 1b), yet the alfalfa yield at 50ET remained similar to 100ET that year. It is possible that water stress due to 50ET approach was minimized by facilitating root growth beyond the 90-cm soil depth. The yield effect of 50ET resulted in a three- and two-fold increases in IW/P in 2016 and 2017, respectively, compared with the well-watered 100ET treatment (Table 3).

The important components of alfalfa yield are leaves and stems (Sheaffer et al., 2000) and increased moisture is known to facilitate stem elongation (Saeed and El-Nadi, 1997). This is similar to our present study, where stem elongation followed.
with the levels of moisture regimes in the establishment year (2016; Table 3). This was not the case in 2017 (Table 3) where each of the water regime treatments, except the rainfed at the third cutting, had similar plant heights. This demonstrates the decreased severity of water stress of the 50ET and the rainfed check during the second year, resulting in only a 12% increase in yield over the rainfed check, compared to a 45% increase in yield in 2016. It can only be assumed that the imposed water stress at the establishment year (2016) facilitated root growth leading plants in the rainfed check and 50ET plots to develop resilience to the low water supply and enabling them to utilize available soil water deeper in the soil profile.

A reduced number of trifoliate nodes is also indicative of water stress in alfalfa (Boutraa and Sanders, 2001) and may be used to evaluate the aforementioned resiliency resulting from deficit irrigation (other than yield). In this study, water regime did affect trifoliate counts with rainfed treatments having lower counts than the irrigated treatments. Budding stage, the start of reproductive development, involves a high demand for photosynthate (i.e., sink) and is known to occur earlier when plants experience drought stress (Chaves et al., 2002). Thus, the trifoliate appearance slows down at the reproductive stage (Boutraa and Sanders, 2001) as also documented in other crops (Bastidas et al., 2008; Torrion et al., 2012). The reduced trifoliate appearance could negatively affect yield after the bud stage (Perry and Larson, 1974). In our study, the irrigated treatments had similar trifoliate counts in both years (Table 3) which indicate the lack of yield-reducing stress within the 50ET in relation to 100ET.

The effect of irrigation on yield in the second year (2017) was only 12% (Table 3). It may be that providing less water (deficit irrigation) than required for full replenishment (100ET) may be advantageous in terms of irrigation management for the second year. This study does not include data on alfalfa performance for the third year and beyond, but future longer-duration data collection is warranted. Our data showed minimal response to irrigation despite the reported severe drought (United States Drought Monitor, 2017) indicative of the resiliency of alfalfa to drought during its second year of growth by the assumed root growth facilitation of imposed stress during the establishment year.

Though forage quality was not affected by irrigation in 2017, the forage quality parameters such as CP and TDN were decreased with irrigation later in the season of the prior year (2016; Fig. 4a, 4b). Similar results were reported by Holman et al. (2016) and Li and Su (2017). Decreased CP and increased NDF and ADF in 2016 (Fig. 4) were similar to the findings of Undersander et al. (1987), where CP content of alfalfa was greater under water-stressed conditions, and that ADF and NDF content increased as water-stress decreased. With irrigation, plant height significantly increased (Table 3), resulting in a decreased leaf-to-stem ratio and increased fiber content. The leaf-to-stem ratio affects forage quality (Elliott et al., 1972) as leaves are of higher nutritional value than stem tissue (Fick et al., 1994).

Based on this 2-yr data, applying B based on low initial soil B test did not correspond to increased alfalfa yield across water regimes. Alfalfa yield increased with irrigation; however, the 50ET and 100ET treatments had similar yield. By applying only 50% of required irrigation amounts, it may be possible to produce a similar yield to full irrigation under the semiarid conditions of northwestern Montana or similar. Irrigation significantly decreased forage quality in the establishment year, but not in the second year of the study. The effect of B application on forage quality parameters was inconsistent between years. Foliar application of B, based on a B-deficient soil to determine when to apply B, was ineffective. In-season field observation for B deficiency with confirmatory tissue test is recommended when managing B in alfalfa. Results from the current study and Sapkota et al. (2018) conducted in Montana indicate that the local soil test B recommendation should be reevaluated with additional confirmatory studies.

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REFERENCES


