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# Forage production of cool season pasture grasses as related to irrigation

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**Abstract**

A significant portion of the irrigated acreage in the intermountain western U.S. is comprised of cool season grass pastures. Droughts, coupled with increasing demands for limited water supplies in the region, have decreased the water volumes available for irrigating these pastures and other crops. Consequently, relationship between crop yield and irrigation (water production functions) should be defined for various species and cultivars to help growers and water managers make appropriate selections based on water availability.

During a 3-year study on the Colorado Plateau, a line-source irrigation system was used to evaluate the relationship between applied water and dry forage production of orchardgrass (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* Schreb.), meadow brome (*Bromus riparius* Rehmann), smooth brome (*Bromus inermis* Leyss.), two cultivars of intermediate wheatgrass (*Elytrigia intermedium* [Host] Nevski), crested wheatgrass (*Agropyron cristatum* L. Gaertn. X *desertorum* [Fisch. ex Link] J.A. Schultes) and perennial ryegrass (*Lolium perenne* L.). Irrigation treatments, including precipitation, ranged from 457 to 970 mm in 1996, 427 to 754 mm in 1997 and 490 to 998 mm in 1998. There was a positive linear relationship between yield and irrigation for all cultivars when averaged over all years but the relationships varied between cultivars and years. Orchardgrass, meadow brome and tall fescue produced more dry forage than the other grasses at the highest irrigation levels in all years. These grasses also produced the greatest rates of yield increase per unit of irrigation (average of 0.0129 Mg $ha^{-1}$ $mm^{-1}$) and exhibited greater yield stability from year to year than the other grasses at irrigation levels above 700 mm. The intermediate wheatgrasses produced more forage than the other grasses under limited irrigation (less than 600 mm) but the average production rate with irrigation (0.0066 Mg $ha^{-1}$ $mm^{-1}$) was only about half that of the aforementioned

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grasses. The average rate of forage produced per mm of irrigation was intermediate in the smooth brome (0.0096 Mg $ha^{-1}$) and lowest in the crested wheatgrass and perennial ryegrass (0.0048 and 0.0034 Mg $ha^{-1}$, respectively). These results suggest that orchardgrass and meadow brome be included in irrigated pastures receiving more than 700 mm of water annually while the intermediate wheatgrasses be selected for pastures receiving an annual water application of less than 700 mm.


*Keywords:* Pasture grass; Irrigation; Water production functions

## 1. Introduction

Population growth along with increased urban, industrial and agricultural development in the semi-arid, intermountain region of western U.S. has placed ever increasing demands on the limited water supplies of the region. To ensure an adequate supply to sustain all entities in the future, water re-allocations, based upon beneficial use and economic value, may decrease the amount of water available for crop and landscape irrigation in the region (Engelbert and Scheuring, 1984; Clevenger et al., 1989; Lansford et al., 1989; Postel, 1999). By improving water-use efficiencies through careful irrigation management and selecting drought-tolerant species for planting, potential deleterious affects of these reduced water supplies on crop production and economic returns can be mitigated (Howell, 2001; Lansford et al., 1989). To assist in the species selection effort, the relationship between crop production and water-use or irrigation (water production function) must be defined for various species and cultivars (Hexem and Heady, 1978).

Pastureland and grass hay fields comprise a significant proportion of the total irrigated acreage in the mountain states of the western U.S. (U.S. Department of Agriculture, 1997). While generally not as economically valuable as cash crops harvested for fruit or grain (Glover and Baker, 1997; Byerley et al., 1999), irrigated grasslands are an important source of forage and/or cover for livestock and wildlife and they are commonly used to help reclaim disturbed sites and stabilize soils and watersheds (Wasser, 1982). Introduced cool season grasses have replaced much of the native, warm season grass ranges of the intermountain region because of their superior nutritional quality, longer growing season, higher forage production and better tolerance to grazing (Ball et al., 1996). Grasses commonly recommended for the area include orchardgrass (*Dactylis glomerata* L.), bromegrasses (*Bromus* sp.), wheatgrasses (*Elytrigia* or *Agropyron* sp.) and fescues (*Festuca* sp.) (Glover and Baker, 1997; Nichols, 1981). While these grasses produce acceptable forage yield and quality under conditions of adequate irrigation, limited information is available pertaining to their performance on the Colorado Plateau under deficit irrigation conditions (Alderson and Sharp, 1993; Ball et al., 1996).

In a long term dryland study conducted in North Dakota between 1970 and 1978 (Power, 1985), intermediate wheatgrass (*Elytrigia intermedium* [Host] Nevski) produced overall greater forage yields and exhibited higher water-use efficiencies (over a range of N fertility and precipitation levels) than six other cool-season grasses, including smooth brome

(*Bromus inermis* Leyss.) and crested wheatgrass (*Agropyron cristatum* L. Gaertn. X *desertorum* [Fisch. ex Link] J.A. Schultes). Similar results were reported by Berdahl et al. (2001) from a study conducted at the same site between 1994 and 1998. In another non-irrigated evaluation conducted in England by Garwood et al. (1979), tall fescue (*Festuca arundinacea* Schreb.) produced significantly more forage during extended droughts than five other grasses, including perennial ryegrass (*Lolium perenne* L.). In a similar study conducted in Minnesota by Sheaffer et al. (1992), Reed canarygrass (*Phalaris arundinaceus* L.) and orchard grass produced more forage than smooth bromegrass during droughts. However, smooth bromegrass had greater persistency and compensatory growth than the other species after droughts. Hill et al. (2000) studied the response of several grass varieties to irrigation at a high altitude site in northern Utah and found that the forage production of all the grasses increased with increasing irrigation depths. Forage production of meadow brome (*Bromus riparius* Rehmann) was greater than that of orchardgrass at low irrigation levels (less than 380 mm) but was about equal to that of orchardgrass at irrigation levels ranging from 380 to 810 mm. In more recent northern Utah studies, Jensen et al. (2001) and Waldron et al. (2002) compared the forage yields of several pasture grasses at five levels of seasonal irrigation imposed by a sprinkler line-source. In the Waldron et al. (2002) study, all the grasses exhibited a positive yield response to increasing irrigation levels between 360 and 730 mm but insignificant yield increases at irrigation levels above 730 mm. In this study and the Jensen et al. (2001) study, tall fescue produced more forage than the other grasses at all irrigation levels, while perennial ryegrass produced lower yields than meadow brome, orchardgrass and smooth brome at irrigation levels less than 850 mm. In southern Utah, the seasonal water requirement for maximum production of mixed, cool season pastures has been reported to range between 737 and 1110 mm (Criddle et al., 1964; Hill, 1994; Hill and Heaton, 2001). No information relating to the water requirements or the effects of water deficits on the growth and yield of grass cultivars grown for pasture on the Colorado Plateau in northern New Mexico has been published.

The objectives of this study were to (1) evaluate the effects of irrigation depth on the growth and forage yield of eight cool season grasses commonly recommended for pastures on the Colorado Plateau and (2) formulate crop production functions for each grass to help growers select appropriate grasses based on crop water availability.

## 2. Materials and methods

This study was conducted at New Mexico State University's Agricultural Science Center at Farmington, NM, during 1996, 1997 and 1998. The site is located on the Colorado Plateau at an elevation of 1720 m above mean sea level. The location is semi-arid, receiving an average (30 year) annual precipitation of 208 mm (Smeal et al., 2001). The frost-free period averages 162 days from May 4 to October 14 and average daily temperatures range from −2 °C in January to 24 °C in July. The soil type at the study site was a Wall sandy loam (Typic Camborthid, coarse, loamy, mixed calcareous, mesic family) having an available water holding capacity of about 155 mm in the top 1.2 m of the profile (Anderson, 1970).

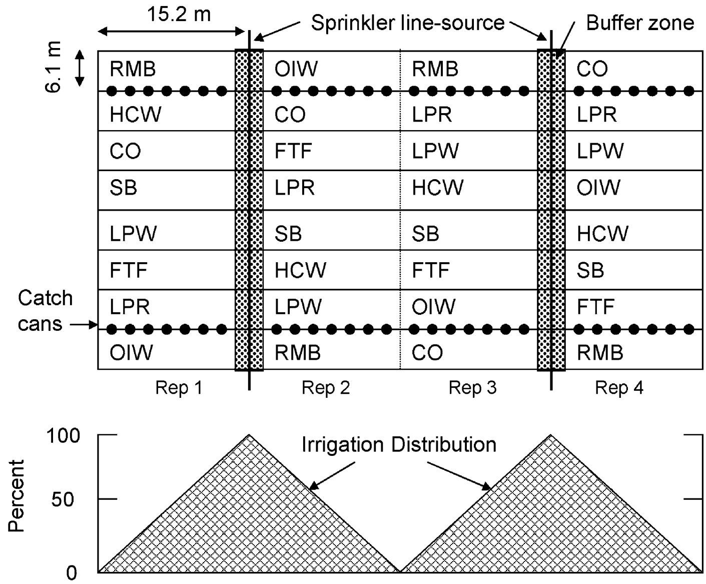


Fig. 1. Diagram (top) and water distribution (bottom) of the duplicated sprinkler line-source design used to evaluate forage production of eight cool season pasture grasses at seven levels of irrigation (abbreviations indicate cultivars; refer to text for definitions).

Eight cool season pasture grasses: ‘Crown’ orchardgrass (CO), ‘Hycrest’ crested wheatgrass (HCW), smooth brome (SB), ‘Fawn’ tall fescue (FTF), ‘Linn’ perennial ryegrass (LPR), ‘Regar’ meadow brome (RMB) and two intermediate wheatgrasses; ‘Oahe’ (OIW) and ‘Luna’ (LPW) were planted into a clean-tilled field in 250 mm wide rows at respective seeding rates of 4.5, 11.2, 14.6, 9.0, 9.0, 19.0, 16.8 and 15.7 kg ha$^{-1}$ on September 6, 1995 using a small-plot cone seeder equipped with disk openers. Each grass was planted into 6.1 m × 15.2 m subplots in four replications (Fig. 1) and the entire plot area (61 m × 49 m) was irrigated uniformly in the fall of 1995 for seed germination and plant establishment using five equally spaced sprinkler lines. On April 11, 1996, irrigation treatments were initiated in the grasses using two separate sprinkler line-sources (Hanks et al., 1976) (Fig. 1). By operating the sprinkler lines during low wind conditions at a water pressure of 310–345 kPa, continuously decreasing gradients of water application were provided on each side of both lines (Fig. 1, bottom). Subplots were oriented perpendicular to the sprinkler lines and divided into seven, six-row (1.5 m) wide irrigation levels on each side of the two lines. Subplots were 6.1 m long but were shortened to 5.5 m by cutting alleyways on each end to clearly delineate cultivars prior to harvest. Catch cans were set on the risers above crop canopy in the center of each irrigation treatment near both ends of the plot to measure applied water after irrigations (Fig. 1). Due to unmeasurable water drainage at the sprinkler line joints on fill and shutdown, data were not collected from six-row buffer zones immediately adjacent to the sprinkler lines (Fig. 1). The design mimicked a modified split-plot with eight cultivars as whole plots and seven irrigation levels as subplots replicated four times (Fig. 1).

Irrigations were scheduled in 1996 so that about 90% of the estimated reference evapotranspiration (ETo), as calculated by the New Mexico Climate Center (http://weather.nmsu.edu), was replaced each week at the irrigation treatment level closest to the buffer zone (2.3 m away from the line-source). In 1997 and 1998, this treatment received a depth of water sufficient to replace about 70% of ETo each week. Between green-up in spring (about April 1) and final harvest of each year (August 7, 1996; August 19, 1997 and September 15, 1998), the pasture plots were irrigated 33, 21 and 31 times, respectively, at an irrigation frequency of between 3 and 6 days. A total of 29, 168 and 124 mm of precipitation occurred during these respective time periods. Total applied water (irrigation plus precipitation) from the lowest to highest irrigation treatment ranged from 457 to 970 mm in 1996, 427 to 754 mm in 1997 and 490 to 998 mm in 1998 (Table 1). Additional irrigations (not included in Table 1) were applied after the final harvest of each season to maintain the grass stand until the end of the irrigation season (mid-October) but due to limited growth, residual forage was not harvested.

### 2.1. Fertilization

Prior to planting in 1995, ammonium-nitrate fertilizer (34-0-0) was broadcast and disked into the top 100 mm of soil in the entire plot area at a rate of 112 kg N $ha^{-1}$. In 1996, liquid urea–ammonium-nitrate (UAN) was applied uniformly to the entire plot area at a rate of 75 kg N $ha^{-1}$ through fertigation. The UAN (32-0-0) was injected into the line-source sprinklers and three additional lines on May 3, May 21, June 6, June 25 and July 15 at a rate of 15 kg N $ha^{-1}$ per fertigation. In 1997, ammonium sulfate (20-0-0) was broadcast uniformly to the plot at the rates of 103 and 58 kg N $ha^{-1}$ on April 17 and August 12, respectively. An additional 15 kg N $ha^{-1}$ as UAN was applied uniformly through fertigation on June 19, 1997. In 1998, 20-0-0 was broadcast to the plot area at rates of 45 and 67 kg N $ha^{-1}$ on February 13 and June 17. Monoammonium phosphate was also broadcast to the plot on February 13, 1998 at a rate of 43 kg N $ha^{-1}$ and 198 kg $P_2O_5$ $ha^{-1}$.

### 2.2. Pest control

For broadleaf weed control, the entire plot area was sprayed with dicamba (3, 6-dichloro-*o*-anisic acid) and 2-4-D-(2,4-dichlorophenoxyacetic acid, butoxyethyl ester) at rates of 0.15 kg active ingredient (ai) $ha^{-1}$ and 0.43 kg ai $ha^{-1}$, respectively, on both February 12 and June 17, 1996. On June 20, 1997, the same two herbicides were applied at the rates of 0.15 and 0.60 kg ai $ha^{-1}$, respectively. On June 22, 1998, the respective rates were 0.15 and 0.21 kg ai $ha^{-1}$. Additionally, a combination herbicide was broadcast to the plot area at a rate of 2.2 kg ai $ha^{-1}$ benefin (*N*-butyl-*N*-ethyl-α,α,α,-trifluoro-2, 6-dinitro-*p*-toludine) and 2.2 kg ai $ha^{-1}$ oryzalin (3,5-dinitro-$N^4$,$N^4$-dipropylsulfanilamide) on February 13, 1998 to control germination of annual grass seeds. On June 22, 1998, carbaryl (1-naphthyl *N*-methylcarbamate) was sprayed on the plot at a rate of 0.56 kg ai $ha^{-1}$ to control grasshoppers.

Table 1
Dry forage yield[a] of eight cool season pasture grasses at seven irrigation levels, 1996–1998

| Water applied (mm) | Crown orchard (Mg ha$^{-1}$) | Hycrest crested wheat (Mg ha$^{-1}$) | Smooth brome (Mg ha$^{-1}$) | Fawn tall fescue (Mg ha$^{-1}$) | Linn perennial ryegrass (Mg ha$^{-1}$) | Regor meadow brome (Mg ha$^{-1}$) | Oahe intermed. wheat (Mg ha$^{-1}$) | Luna pubescent wheat (Mg ha$^{-1}$) | Mean (Mg ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 1996 | | | | | | | | | |
| 970 | 8.03ab[b] | 6.15bc | 8.07ab | 9.56a | 5.89c | 8.93a | 8.30a | 8.71a | 7.96 |
| 894 | 8.55ab | 5.81c | 7.29b | 8.93a | 4.91c | 8.47ab | 8.24ab | 7.93ab | 7.52 |
| 780 | 7.46a | 4.44c | 5.89b | 6.75ab | 3.32c | 6.35ab | 6.98ab | 5.88b | 5.88 |
| 660 | 4.93ab | 3.53c | 3.58c | 4.51abc | 1.91d | 4.27abc | 5.37a | 4.06bc | 4.02 |
| 566 | 3.04ab | 2.40b | 2.35b | 2.71ab | 0.86c | 2.44b | 4.05a | 3.04ab | 2.61 |
| 495 | 1.53ab | 1.80a | 1.54ab | 1.61ab | 0.23b | 1.66ab | 2.84a | 2.36a | 1.70 |
| 457 | 0.90ab | 1.25ab | 0.95ab | 0.81ab | 0.10b | 1.09ab | 1.96a | 1.78a | 1.11 |
| 1997 | | | | | | | | | |
| 754 | 6.12ab | 3.83d | 4.30cd | 6.69a | 3.67d | 6.72a | 4.94c | 5.81b | 5.26 |
| 709 | 6.70a | 3.89c | 4.23c | 6.17ab | 4.25c | 6.77a | 4.89bc | 5.68ab | 5.32 |
| 648 | 6.17a | 3.21c | 3.17c | 4.43b | 3.18c | 5.45ab | 4.74b | 4.42b | 4.35 |
| 566 | 5.12a | 3.03cd | 2.86d | 3.87bc | 2.24d | 4.02b | 4.95a | 3.94b | 3.75 |
| 508 | 3.79a | 2.98b | 2.69b | 2.98b | 1.85c | 3.87a | 4.36a | 3.75a | 3.28 |
| 465 | 2.75cd | 3.13bc | 2.29de | 2.18e | 1.54f | 2.90bc | 3.89a | 3.28b | 2.75 |
| 427 | 2.16bc | 2.39bc | 2.23bc | 2.29bc | 1.54c | 2.75ab | 3.64a | 3.08ab | 2.51 |
| 1998 | | | | | | | | | |
| 998 | 6.99ab | 3.83e | 4.49de | 6.37abc | 2.26f | 7.35a | 5.10cde | 5.72bcd | 5.26 |
| 917 | 7.43ab | 4.61c | 4.84c | 6.03bc | 2.59d | 8.34a | 5.37c | 5.29c | 5.56 |
| 820 | 6.15a | 3.68c | 3.80c | 4.45bc | 1.80d | 5.57ab | 4.67abc | 4.22bc | 4.29 |
| 706 | 3.36ab | 2.44b | 2.61b | 2.46b | 1.48c | 3.08ab | 3.61a | 3.33ab | 2.80 |
| 627 | 1.92abc | 2.03ab | 1.52bcd | 1.28cd | 0.99d | 1.48bcd | 2.46a | 2.57a | 1.78 |
| 544 | 0.67abc | 0.87ab | 0.51bc | 0.45c | 0.70abc | 0.81abc | 0.95a | 0.96a | 0.74 |
| 490 | 0.49a | 0.45a | 0.39a | 0.28a | 0.17a | 0.58a | 0.52a | 0.53a | 0.43 |

[a] Values represent the mean of four replications and total from four cuts in 1996 and 1998 and three cuts in 1997.
[b] Means in a row followed by the same letters (a–e) are not significantly different from each other at the 5% level based on the Student–Newman–Keuls comparison of means test.

### 2.3. Harvest

A small-plot forage harvester equipped with a 1.5-m wide sickle bar and conveyor belt for carrying material to a weighing bucket was used to cut and weigh grass forage when about 10% of the individual plants were in boot stage in at least half of the cultivars. Grasses were cut to a height of about 50 mm above the soil surface in plots that were 1.5 m (six rows) wide × 5.5 m long. Immediately after weighing, sub-samples were taken from each plot for forage moisture determination. These fresh sub-samples were weighed and placed in a forced-air drying oven at a temperature of 80 °C for at least 48 h before being re-weighed. Yield values are presented as oven dry weights and represent the mean of four replications. The grasses were cut four times in 1996 (May 14, June 11, July 5 and August 7), three times in 1997 (May 20, June 17 and August 19) and four times in 1998 (May 14, June 15, July 20 and September 15). Statistical analysis of variance (ANOVA) procedures (CoHort, 2001) were used to compare the mean yields between cultivars and years and interactions between all the variables. Due to the non-randomization of irrigation treatments imposed by the line-source design, a valid error term was not available in the ANOVA for testing the main effect of irrigation (Hanks et al., 1980). Statistical regression and correlation analyses (CoHort, 2001) were used to identify significant linear and non-linear regression coefficients relating total seasonal forage yield, the dependent variable, to total seasonal irrigation, the independent variable, and to formulate crop production functions for each grass.

## 3. Results and discussion

There was a highly significant positive linear relationship between total season dry forage yield and water applied (IR) in each of the grasses when data from all three years were combined (Fig. 2A–H). Averaged over all three years, the orchardgrass, tall fescue and meadow brome, produced greater yields at high IR and exhibited higher rates of yield increase with IR (average of 0.0129 Mg $ha^{-1}$ $mm^{-1}$) than the other grasses (Figs. 2 and 3). The negative *Y*-intercept of the production functions for these grasses, average of −4.29 Mg $ha^{-1}$, indicated little to no forage production at seasonal IR less than 350 mm if the water is dispersed evenly over the entire season (Fig. 2). Forage yields of smooth brome and the intermediate wheatgrasses at the highest IR (970 mm) were not significantly different from those of the aforementioned grasses in 1996 (all producing more than 8 Mg $ha^{-1}$) but were significantly less than these grasses at the highest IR in 1997 and 1998 (Table 1). The intermediate wheatgrasses exhibited lower rates of yield increase with IR (average of 0.0066 Mg $ha^{-1}$ $mm^{-1}$) than the tall fescue, meadow brome or orchardgrass but produced more forage than the other grasses at IR less than 600 mm (Table 1; Fig. 3). The overall yield response of smooth brome to IR (0.0096 Mg $ha^{-1}$ $mm^{-1}$) was intermediate between the meadow brome–orchardgrass–tall fescue response and the wheatgrass response while the crested wheatgrass and perennial ryegrass exhibited the lowest rates of yield increase with IR (0.0048 and 0.0034 Mg $ha^{-1}$ $mm^{-1}$, respectively) (Figs. 2 and 3).

In addition to variability in the 3-year average production functions among the grasses, the functions varied considerably for each grass between years (Table 2). This variability is evidenced by comparing the coefficients of determination ($r^2$) between the combined functions (Fig. 2) and the individual year functions (Table 2). At any given IR, forage production of all the grasses was typically less in the third year of growth (1998) than in 1996 and 1997 (Fig. 2). The total yields of most cultivars from only three cuts at the highest IR in 1997 (754 mm) were equal to the total yields from four cuts in 1998 at a greater IR (917 mm). This interseasonal variability in the production functions may have been the result of lower production potential due to the age of stand (Berdahl et al., 2001), soil micronutrient deficits, rodent and insect damage, low soil moisture reserves at the beginning of the 1998 season due to low winter precipitation or other factors. Nitrogen fertilization has been shown to have a significant effect on pasture forage production and water-use efficiency (Power, 1985) and can thus contribute to interseasonal production function variability. In our study, the N source and application methods varied between

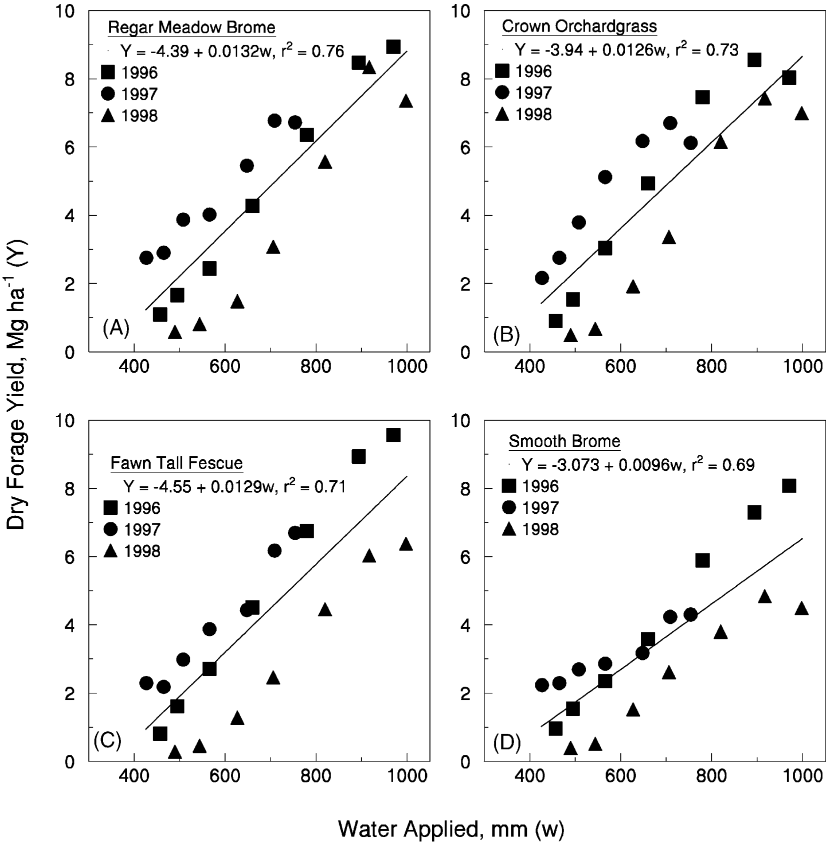


Fig. 2. Combined 3-year (1996–1998) water production functions for: (A) meadow brome; (B) orchardgrass; (C) tall fescue; (D) smooth brome; (E and F) intermediate wheatgrasses; (G) crested wheatgrass; and (H) perennial ryegrass.

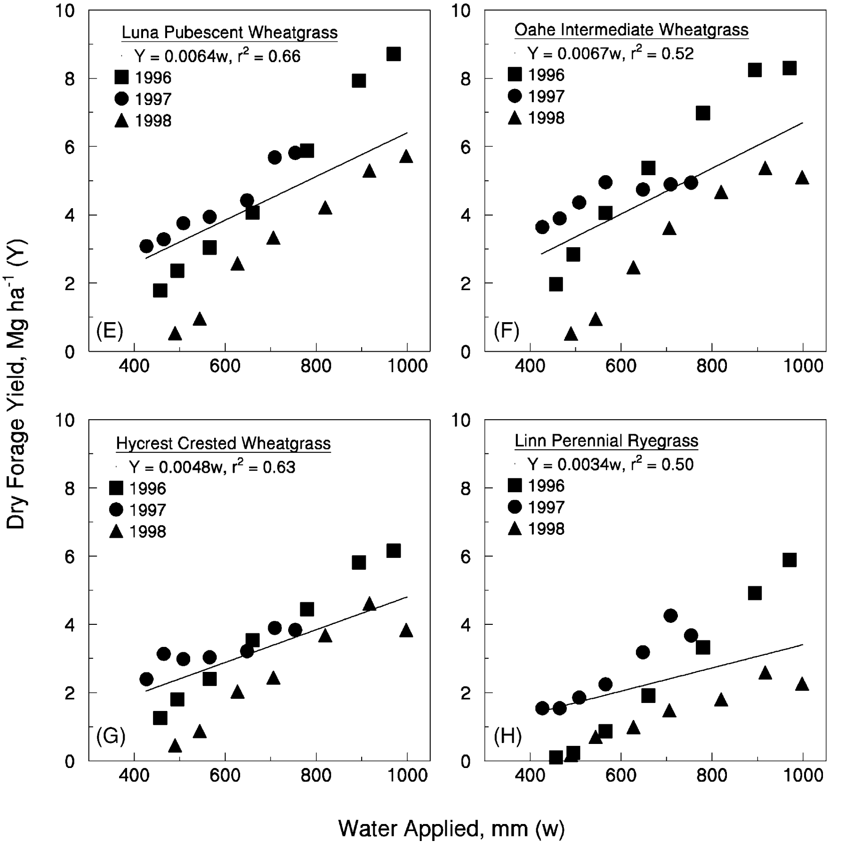


Fig. 2. (*Continued*).

years but total N applied was similar among seasons (187, 176 and 155 kg N $ha^{-1}$ in late 1995/1996, 1997 and 1998, respectively) and was not surmised to be a limiting factor to yield in any year.

Maximum yield of most grasses in most years was produced at the highest IR (Table 1). In the orchardgrass, however, maximum yields of 8.55, 6.7 and 7.43 Mg $ha^{-1}$ in 1996, 1997 and 1998, respectively, occurred at a seasonal IR averaging 7% less than the maximum IR in each year (Table 1). This resulted in a significant curvilinear relationship between yield and IR for this grass in all the three years (Table 2). A significant quadratic coefficient was also observed in all years for the Oahe intermediate wheatgrass and for the perennial ryegrass in 1996 and Luna wheatgrass in 1998 (Table 2). Waldron et al. (2002), who found a similar quadratic relationship between yield and irrigation for tall fescue and orchardgrass, suggested an irrigation threshold (irrigation level beyond which yields increase significantly) of 730 mm for these grasses in northern Utah. Based on the results of our study, the irrigation threshold for these same grasses in northwestern New Mexico appears to be greater than 800 mm (Fig. 2B and C).

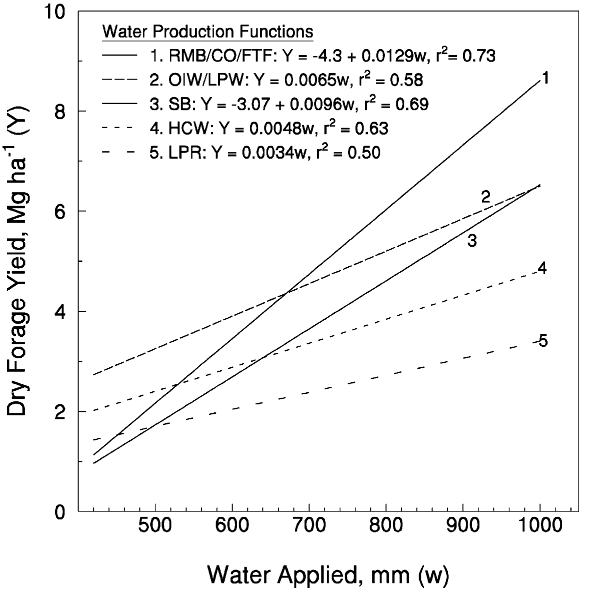


Fig. 3. Water production functions combined over three years (1996–1998) and over homogenous cultivars for eight pasture grasses: meadow brome (RMB), orchardgrass (CO), tall fescue (FTF), intermediate wheatgrasses (OIW and LPW), smooth brome (SB), crested wheatgrass (HCW) and perennial ryegrass (LPR).

### 3.1. Yield stability

If only the linear components are considered in the relationships between seasonal yield and IR, the meadow brome and orchardgrass had homogenous slopes ($p > 0.05$) when compared between years. In 1996, the tall fescue produced more dry forage (9.56 and 8.93 Mg $ha^{-1}$) than all other cultivars at the two highest IR (970 and 894 mm, respectively) but at similar IR in 1998, tall fescue yields as well as those of all cultivars except the orchardgrass and meadow brome decreased by more than 25%. The lower difference in yield (less than 10%) between 1996 and 1998 by the orchardgrass and meadow brome, coupled with the relatively higher $r^2$ values of the 3-year average production functions (Fig. 2A and B), indicate a greater persistency and yield stability in these grasses than the others when fully irrigated. This greater yield stability over time for meadow brome and orchardgrass, as compared to the other grasses, was also noted by Waldron et al. (2002). Tall fescue, while also providing high yields and yield stability in the Waldron study, had lower yields than meadow brome and orchardgrass at comparable irrigation levels in 1998 in our study due to pocket gopher (*Geomys* sp.) damage (Table 2; Fig. 2). A statistical test for homogeneity of linear regression slopes and correlation coefficients ($r$) indicated no significant difference ($p > 0.05$) between the 3-year combined production functions for meadow brome, orchardgrass and tall fescue and they were combined (Fig. 3). The same tests indicated a similar homogeneity between the production functions for the two intermediate wheatgrasses and these functions were combined (Fig. 3).

Table 2
Significant regression coefficients ($P \leq 0.05$) describing the production functions ($Y = A + B_1x + B_2x^2 + B_3x^3$) relating total seasonal dry forage yield in Mg ha$^{-1}$ ($Y$) to total seasonal applied water in mm ($x$)

| Grass[a] | $A$ ($Y$-intercept) | $B_1$ (linear) | $B_2$ (quadratic) | $B_3$ (cubic) | $r^2$ |
|---|---|---|---|---|---|
| 1996 | | | | | |
| CO | 15.88 | −0.1007 | $1.964 \times 10^{-4}$ | $-1.040 \times 10^{-7}$ | 0.999 |
| HCW | −3.04 | 0.0097 | ns | ns | 0.994 |
| SB | −5.63 | 0.0143 | ns | ns | 0.995 |
| FTF | −7.16 | 0.0176 | ns | ns | 0.996 |
| LPR | −2.08 | 0.0012 | $7.301 \times 10^{-6}$ | ns | 0.999 |
| RMB | −6.40 | 0.0162 | ns | ns | 0.993 |
| OIW | −10.55 | 0.0345 | $-1.533 \times 10^{-5}$ | ns | 0.997 |
| LPW | −4.64 | 0.0137 | ns | ns | 0.993 |
| 1997 | | | | | |
| CO | 19.92 | 0.0723 | $-4.959 \times 10^{-5}$ | ns | 0.983 |
| HCW | 1.03 | 0.0037 | ns | ns | 0.810 |
| SB | −0.74 | 0.0066 | ns | ns | 0.938 |
| FTF | −4.15 | 0.0141 | ns | ns | 0.965 |
| LPR | −2.26 | 0.0084 | ns | ns | 0.914 |
| RMB | −3.12 | 0.0133 | ns | ns | 0.970 |
| OIW | −4.82 | 0.0289 | $-2.127 \times 10^{-5}$ | ns | 0.925 |
| LPW | −0.69 | 0.0085 | ns | ns | 0.951 |
| 1998 | | | | | |
| CO | 51.37 | −0.2446 | $3.711 \times 10^{-4}$ | $-1.709 \times 10^{-7}$ | 0.999 |
| HCW | −3.13 | 0.0078 | ns | ns | 0.905 |
| SB | −4.30 | 0.0095 | ns | ns | 0.954 |
| FTF | −6.70 | 0.0134 | ns | ns | 0.981 |
| LPR | −1.76 | 0.0044 | ns | ns | 0.931 |
| RMB | −7.95 | 0.0162 | ns | ns | 0.936 |
| OIW | −13.85 | 0.0380 | $-1.890 \times 10^{-5}$ | ns | 0.989 |
| LPW | −9.25 | 0.0244 | $-9.376 \times 10^{-6}$ | ns | 0.992 |

[a] CO, crown orchardgrass; HCW, hycrest crested wheatgrass; SB, smooth brome; FTF, fawn tall fescue; LPR, linn perennial ryegrass; RMB, regar meadow brome; OIW, oahe intermediate wheatgrass; LPW, luna pubescent wheatgrass.

## 4. Conclusion

This study has shown that water production functions for cool season pasture grasses vary among cultivars and, thus, should be considered when deciding which grass to plant on the Colorado Plateau where availability of water for irrigation may vary considerably between locations and seasons. If ample irrigation and precipitation are available to provide 750 mm or more to a pasture each year, then cultivars such as Crown orchardgrass and Regar meadow brome may provide the greatest forage production and persistency. Tall fescue, while also providing high forage yields at high irrigation levels in our study and others (Garwood et al., 1979; Jensen et al., 2001; Waldron et al., 2002), may be less preferable than the orchardgrass and meadow brome due to toxicity concerns (Ball et al., 1996; Lauriault et al., 2003) and potential preference by pocket gophers. If water availability is expected to be less than 750 mm, the intermediate wheatgrasses may provide more forage than the other grasses and should be considered.

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