Dry Beans

Dry Bean Yield Response to Different Irrigation Rates in Southwestern Colorado

Mahdi M. Al-Kaisi, Abdel F. Berrada, Mark W. Stack

Research Question

Concerns about irrigation efficiency, water quality, and yield have prompted this study. Over-irrigation is a key factor that contributes to deep percolation and nutrient leaching to the groundwater. The objective of this study was to determine the effect of five different irrigation rates on dry bean yield response and water use efficiency.

Literature Summary

The dry bean is very sensitive to irrigation management. Studies indicate that dry bean yields can vary significantly as irrigation rates go from dryland to optimal rates. However, the increase in yield may not be significant with the increase of the irrigation rate beyond optimum water need. It was reported that dry bean can extract water from the soil profile much deeper under dry and limited-irrigation conditions than over-irrigated conditions.

Study Description

The field study was conducted to investigate the impact of five irrigation rates on dry bean growth response. The irrigation rates used in this study were 0.00, 0.33, 0.67, 1.00, and 1.33 of estimated evapotranspiration (ET). The soil on the site is Wetherill silty clay loam. The experiment was a randomized block design with four replications. A surface drip irrigation system was used to achieve the complete designed irrigation rates. An irrigation scheduling program was used to manage irrigation. Weather data from a local weather station on the site was used to estimate ET by using the Penman Equation. The water balance approach was used to determine the 1.00ET irrigation rate based on estimated ET, precipitation (total seasonal precipitation was 7.6 and 5.0 in. from June to September of 1992 and 1994, respectively), change in soil moisture, runoff, and drainage terms in the 1992 and 1994 seasons.

Applied Questions

How does dry bean respond to different irrigation rates?

Seed yield and dry matter increased significantly as the irrigation rates were increased up to the optimal water use (1.00ET) in 1994. However, maximum seed yield was obtained at 0.67ET in the cooler year (1992), while 1.00ET or greater was required to achieve maximum biomass yield in both years. Improvement in the yield was related to the water and irrigation use efficiencies, where yield production (seed or dry matter) per 1 in. of applied or used water was greater when the irrigation rate was kept at or below 1.00ET. Therefore, exceeding plant water requirements not only leads to waste of water, but also can affect plant performance and soil environment.

What is the impact of the irrigation rate on soil water use or root moisture extraction pattern?

Over-irrigation encouraged a shallow root system. The effective root depth under an irrigation rate greater than 1.00ET was 12 in. Conversely, limited irrig-
RecommeDation

tation treatments encouraged the development of a deeper root system and water uptake down to 3-ft. Also, the soil moisture profile under over-irrigated and 1.00ET was close to field capacity during the growing season, which may lead to potential deep percolation and nutrient loss to the groundwater.

Dry bean production in semi-arid climate areas like southwestern Colorado can be improved significantly by using proper irrigation scheduling. Irrigation scheduling can improve irrigation and water use efficiencies, especially in areas such as southwestern Colorado, where water management is critical to crop yield and water quality. The dry bean root system can use soil moisture more efficiently from lower depths (24 in. or deeper) when optimum irrigation was applied (equal to or less than 1.00ET). However, the irrigation scheduling program (SCHED) may have overestimated water requirements in the cooler year to achieve maximum seed yield, while predicting the water requirements needed for maximum biomass yield at 1.00ET or greater in both years.
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The dry bean (Phaseolus vulgaris L.) crop is sensitive to irrigation management. Irrigation efficiency, water quality, and yield production are concerns in southwestern Colorado. This field study was conducted in 1992 and 1994 at the Southwestern Colorado Research Center to study the effects of five irrigation rates on dry bean seed yield and dry matter. The soil on the site is Wetherill silty clay loam (fine-silty, mixed, superactive, mesic, aridic haplustalf). A surface drip irrigation system was used to achieve the irrigation rates of 0.00, 0.33, 0.67, 1.00, and 1.33 of the estimated evapotranspiration (ET).

The experiment was set up using a randomized complete block design with four replications. Optimum conditions during the 1992 season led to higher dry matter and seed yields than in 1994. Irrigation rates had a significant effect on total above-ground dry matter (TDM) and seed yield in both years. There was no significant increase in seed yield and TDM beyond 0.67E and 1.00ET, respectively, in 1992. However, maximum seed yield was obtained at a 0.67ET irrigation rate in the cooler year (1992), while 1.00ET or greater was required to achieve maximum biomass yield in both years. Total DM and seed yield continued to increase up to 1.33ET in 1994, reaching a similar level as in 1992. Irrigation use efficiency declined as the irrigation rate increased in both years. The pattern of biomass accumulation was similar in 1992 and 1994, as more growth occurred with the greater irrigation rates. Visual observations revealed a shallower root system under the higher irrigation rates than under the nonirrigated (0.00ET) and the limited-irrigation (0.33ET) treatments. This was confirmed by the soil moisture profile at harvest in 1992 and 1994.

Dry bean can extract soil water from the 0 to 24 in. soil profile under dryland conditions, and from the 0 to 12 in. soil profile under well-irrigated conditions (1.00ET). Soil moisture content below 12 in. was at or near field capacity under the over-irrigation treatment (1.33ET), which suggests the potential for deep percolation and leaching of nitrates and other soluble salts. Over-irrigation appears to encourage a shallow root system, less than 2 ft (field plant root inspection), which may reduce the use of soil moisture at lower depths and encourage deep percolation to the groundwater.

IRRIGATION PROVIDES the means to optimize plant water use and to increase crop production in many areas.

Abbreviations:

ET, evapotranspiration; ETWUE, water use efficiency; HI, harvest index; IWUE, irrigation water use efficiency; SYdr, nonirrigated dry bean seed yield; SYir, irrigated dry bean seed yield; TDM, total above-ground dry matter; TOM, nonirrigated total dry matter; TDMir, irrigated total dry matter.
under their yield response. In studies by Miller and Burke (1983), it was found that yield increased with water applied up to approximately 17 in. of water per season in southwestern Colorado. Therefore, increasing the acreage in dry bean and cowpea [Vigna unguiculata] would help avoid water shortages associated with over-irrigation combines with a saline geologic formation (Mancos Shale), which contributes heavily to deep-water percolation and improving water quality downstream.

Another consideration is the efficiency of the water delivery system of the Dolores River Project, which was estimated at 97%, due to water losses as seepage and evaporation. Also, the very large area of the Dolores River Basin (135,000 acres) is under irrigation, with total production of 800 lb/acre (Colorado Department of Agriculture, 1998). However, this does not imply endorsement or preferential treatment by the authors or any other interested party to the reader and does not imply any recommendation of the product by the authors or any other interested party.

Many researchers have investigated the relationship between yield and estimated water use. There have been reports of increased yield with increased water application rates. Also, Stegman and Howe and Rhoades (1961) reported that black bean seed yield and seed weight, and advanced the maturity of the dry bean. Irrigation efficiency is an issue in southwestern Colorado, which includes several counties including Montrose and Dolores Counties, the Yuma, Weld, Kit Carson, Montrose, and Dolores counties are harvested under irrigation, with total production of 2,120,000 lb/acre (Colorado Department of Agriculture, 1998). Irrigation was applied using the manageable application rates, which were replicated four times in a randomized complete block design. The treatments were separated by a buffer zone 10-ft. wide and diked to contain the irrigation water and eliminate water runoff.

Several studies have examined the impact of soil moisture on crop yields. In a study conducted by Hanks et al. (1976) to study the yield response of crops such as dry bean and cowpea [Vigna unguiculata subsp. unguiculata], it was found that different grain legumes respond differently to irrigation variability. Also, it was found that dry bean yield increased linearly with the increase in water application rates. Also, Stegman and Howe and Rhoades (1961), yields of dry bean varied by approximately 17 in. of water per season in southwestern Colorado. Therefore, increasing the acreage in dry bean and cowpea [Vigna unguiculata] would help avoid water shortages associated with over-irrigation.

Implementing sound irrigation water management practices are Yuma, Weld, Kit Carson, Montrose, and Dolores. In southwest Colorado, which includes several counties including Montrose and Dolores Counties, the Yuma, Weld, Kit Carson, Montrose, and Dolores counties are harvested under irrigation, with total production of 800 lb/acre (Colorado Department of Agriculture, 1998). Irrigation was applied using the manageable application rates, which were replicated four times in a randomized complete block design. The treatments were separated by a buffer zone 10-ft. wide and diked to contain the irrigation water and eliminate water runoff.

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Soil moisture affects nutrient availability to crops and plant height and leaf area were most sensitive to water stress during the reproductive growth stage. Irrigation efficiency is an issue in southwestern Colorado, which includes several counties including Montrose and Dolores Counties, the Yuma, Weld, Kit Carson, Montrose, and Dolores counties are harvested under irrigation, with total production of 800 lb/acre (Colorado Department of Agriculture, 1998). Yields of dry bean varied by approximately 17 in. of water per season in southwestern Colorado. Therefore, increasing the acreage in dry bean and cowpea [Vigna unguiculata] would help avoid water shortages associated with over-irrigation.
In 1994. This may be attributed to the weather differences between the 2 yr (temperature and precipitation). The significant difference in yield between the 1992 and 1994 seasons, compared with 2356 lb/acre and 3970 lb/acre, respectively, was due to the weather conditions and management practices.

The dry bean (cv. Bill Z) was planted at 84 000 seeds/acre at a depth of 1 in. Soil was prepared by tilling 1 month before planting. Rows were 12 in. wide and were 4 ft apart. Plant samples for dry matter were taken at different growth stages for the 1.00ET treatment by using ground level (two rows by 5 ft). In 1994, Treflan (trifluralin) was applied in 3 lb ai/acre to control weeds. The irrigation schedule was applied in 1994 based on soil test results. Three pounds of 4 to 5 lb N/acre was applied in 1994 plus precipitation at 0.67ET. There was no significant response when the irrigation rate exceeded 1.00ET (or 1.33ET). The seed yield was significantly increased as the irrigation rate increased up to 1.00ET. There was no significant response when the irrigation rate increased from 0.00ET to 0.33ET. The results show that the 1.33ET treatment produced a significant increase in seed yield.

The relationships used to describe these functions are:

\[ I_{\text{TDM}} + P - SW = 0 \]

where the terms on the left-hand side of the above equation represent the net addition of water to the soil profile over a time period of interest. On the right hand side of the equation are water flows or storages or terms in the equation are positive except for D and SW, which may be either positive or negative depending on the terms in the equation.

The following water balance relationship was used in determining the irrigation amount:

\[ I_{\text{TDM}} = \text{irrigation amount} \]

The water balance approach, which includes estimated ET, soil moisture change, precipitation, and drainage to determine the irrigation amount. The following water balance relationship was used in determining the irrigation amount:

\[ I_{\text{TDM}} = \text{irrigation amount} \]

where the irrigation rate was equal to 0.67ET, while maximum biomass yield in both years. In 1992, TDM, which included seed yield results from the 1994 season showed significant differences in yield response among all treatments and high evaporative demands during the growing season contributed to higher yields compared with 1994 under limited irrigation.

The results of the combined analysis of variance of total dry matter and seed yield of the 1992 and 1994 dry bean growing seasons are shown in Table 1. The dry bean dry matter and seed yield as influenced by irrigation are shown in Table 2. The relationships used to describe these functions are:

\[ I_{\text{TDM}} + P - SW = 0 \]

where the terms on the left-hand side of the above equation represent the net addition of water to the soil profile over a time period of interest. On the right hand side of the equation are water flows or storages or terms in the equation are positive except for D and SW, which may be either positive or negative depending on the terms in the equation.
Table 3. Dry bean water use efficiency and harvest index as influenced by irrigation amount in the 1992 and 1994 growing seasons.

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>TDM Seed</th>
<th>Seed Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>0.00 ET</td>
<td>0.33 ET</td>
<td>0.67 ET</td>
</tr>
<tr>
<td></td>
<td>1.00 ET</td>
<td>1.33 ET</td>
<td>1.00 ET</td>
</tr>
<tr>
<td>1994</td>
<td>0.00 ET</td>
<td>0.33 ET</td>
<td>0.67 ET</td>
</tr>
<tr>
<td></td>
<td>1.00 ET</td>
<td>1.33 ET</td>
<td>1.00 ET</td>
</tr>
</tbody>
</table>

IWUE = \( \frac{SY - SYd}{ET} \)

ETWUE = \( \frac{SY - SYd}{Irrig} \)

IWUE = \( \frac{TDM - TDMd}{Irrig} \)

Where:
- SYi = irrigated seed yield
- TDMi = total irrigated above-ground dry matter
- SYd = nonirrigated seed yield
- TDMd = total nonirrigated above-ground dry matter

Irrigation water use efficiency for TDM declined as the irrigation rate increased in 1992, whereas seed yield showed an increase in ETWUE up to 1.00ET. On the other hand, both TDM and seed yield water use efficiencies declined as the irrigation rate increased in 1994 (Table 3). Irrigation use efficiency for TDM was greater than that for seeds at all irrigation rates. In contrast, crop ETWUE decreased considerably for TDM and seeds during both years beyond the 1.00ET irrigation rate. This may be related to the small yield increase at 1.33ET, compared with lower application rates, and the possibility of deep-water percolation below the root zone. The impact of different irrigation treatments can be expressed in terms of HI. The ratio of seed yield to TDM did not show any significant difference between all treatments for either year, except for the 0.67ET treatment in 1992.

![Fig. 1. Dry bean dry matter during 1992 and 1994 growing seasons under different irrigation rates.](J. Prod. Agric., Vol. 12, no. 3, 1999 425)
the 0.00ET treatment in 1994. In general, the HI reflects that seed production was higher in 1992 than in 1994. Also, the HI shows that the irrigation treatment has significant impact on the seed: matter ratio compared with the nonirrigated treatment.

Effect of Irrigation Treatments on Growth Response

In general, irrigation treatments had a significant impact on seed yield and total dry matter in both 1992 and 1994 (Table 2). Plants under limited irrigation (0.33ET), even below the water requirement (16-19 in.; Schwartz et al., 1996), showed a significant increase in dry matter and seed yield, when compared with the nonirrigated treatment (0.00ET) (Table 2). In general, seed yield and dry matter increased as the irrigation rate increased. However, an irrigation rate over 0.67ET did not contribute significantly to the increase of seed yield, where it did for TDM in 1992. The increase in TDM under higher rates of irrigation was consistent during 1992 and 1994 compared with seed yield, where a significant increase was observed only in the 1994 season (Table 2). Treatments 0.00ET, 0.33ET, and 0.67ET were harvested 7 d earlier than 1.00ET, and 10 d earlier than 1.33ET. Therefore, greater irrigation rates may contribute to late maturity and considerable delay in harvest, and hence is a concern, where the possibility of early frost and rainfall exist.

Dry matter response during the growing season as a function of time for different irrigation treatments showed a non-linear relationship (Fig. 1). Total dry matter significantly increased with increasing irrigation amounts (40-90 d after emergence). The impact of the 1.33ET irrigation rate on dry matter production during different times of the growing season showed a slight improvement in dry matter over 1.00ET, especially in the 1994 season. However, dry matter for all treatments showed no significant difference until 40 d after emergence. Furthermore, field observations and plant inspections, where plant root samples from different irrigation treatments were dug out and inspected, revealed a shallower root system under greater irrigation rates, compared with limited or no irrigation.

Effect of Irrigation Rates on Soil Moisture Extraction

The depth of soil moisture extraction by the plant root system is directly related to the water availability in the soil profile. The soil moisture profile showed considerable differences among the irrigation treatments in both years (Fig. 2). Dryland and limited irrigation treatments (0.00ET and 0.33ET) showed deeper soil moisture depletion at harvest than the other treatments down to 24 in., compared with the high rates of irrigation. This may be attributed to a deeper root system that developed under dryland and limited irrigation treatments. Figure 2 shows no soil moisture change below 12 in. for the soil profile under the 1.00ET and 1.33ET treatments compared with lower irrigation rates. In contrast, soil moisture content showed little change below 24 in. for the 0.33ET and 0.67ET treatments. Therefore, under dryland conditions, dry bean has the potential to extract moisture from the soil profile as deep as 24 in. as indicated by Schwartz et al. (1996), that the active rooting depth for the dry bean is between 24 to 36 in., where the majority of moisture is extracted from the top 18 in. It was also reported that roots developed to 30 to 36 in. extract water late in the season when the bean plant is nearly mature (Schwartz et al., 1996). Nielsen and Nelson (1998) found...
much deeper water extraction with black bean (6 ft) when evaporative demand was high and water supply was limited. The soil moisture profile under the over-irrigation treatment was almost at field capacity (4.5 in./ft) for 24 to 48 in. soil depths. This means any extra water, such as irrigation or precipitation, after the crop season, will have the potential for deep percolation, and consequently, could lead to nitrate and other soluble salts leaching to the groundwater.

CONCLUSION

Water use by dry bean under variable irrigation rates was affected by the water application rate. Optimum irrigation rates and weather conditions during 1992 led to higher seed yield and dry matter. Irrigation rates in both years had a significant impact on seed yield and TDM. Maximum seed yield was achieved at an irrigation rate equal to 0.67ET in the cooler year, while 1.00ET or greater rate was required to obtain maximum biomass yield in both years. Crop ETWUE and IWUE decreased considerably for TDM and seed yield during both years beyond the 1.00ET irrigation rate. However, both IWUE and ETWUE for dry matter was greater than those for seed yield for all irrigation rates. Variable irrigation rates showed a significant effect on the HI (seed:dry matter ratio) compared with dryland treatments. Observations of the plant roots confirmed that a shallow root system was developed under high irrigation rates, compared with dry and limited irrigation treatments. The soil moisture extraction by the roots appeared to primarily at the top 12 in. of the soil profile for high irrigation rate treatments, compared with 24 in. under dry and limited irrigation treatments, especially in 1992. The soil moisture profile was at or near field capacity under the over-irrigated treatments (1.33ET) after harvest, which could lead to the potential of deep water percolation and leaching of nitrate and other soluble salts.

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