ABSTRACT

The fructification period of pinto bean cultivar BillZ was evaluated in three commercial fields, in relation to the effect of drip irrigation with the temperature regime within the crop, in the Yaqui Valley, Sonora, Mexico, during the spring season 2020. Five warm periods with a maximum temperature range from 36 to 40°C were recorded from the flowering stage to completely filled grain. Maturity to harvest was reduced between 6 to 10 days with respect to the normal of 100 days. All fields recorded between 10.4 and 27% of pods without grain, and those with grains showed variable weight. The bean field with the highest grain yield had an average thermic level of 32 to 33°C; as the temperature rose above this level with continuous 8 hour periods (10:00 am-18:00 pm), the highest detachment of flowers and pods shorter than 2 cm were recorded. With respect to the theoretical water use by evapotranspiration, the sheets of water applied by the farmer were sufficient with the exception of the field with a theoretical irrigation deficit between 27 and 33%. The interaction of temperature with irrigation water sheets was highly significant for all variables; the highest grain yield was attributable to the well programed irrigation and to a minor differential average temperature of 1.9°C during the flowering period to harvest.

Keywords: Common bean, Phaseolus vulgaris, temperature, drip irrigation.

1. INTRODUCTION

Common bean (Phaseolus vulgaris L.) is an important crop in many countries since it is a primary component in human consumption. In the first decade of the present century, Brazil was the leader in productivity with 16%, followed by India (15.9%), Myanmar (10.5%), China (8.9%), and Mexico (5.8%) (Lépiz et al., 2015). Although Mexico has been one of the leaders in bean production generating 5.8% of the world production, during 2003-2016 an accumulated reduction was observed in area sown with bean (20.01%) as well as in productivity (23.05%) (SAGARPA, 2017). Bean is a key crop in the mexican diet with 9.9 kg per capita consumption; the national production covers almost the total domestic requirement. During the year 2016, 1.08 million t produced covered 89.24% of the domestic consumption, the rest was supplied by importations from the United States (84.07%), Canada (13.47%), and China (2.05%). The production bean systems in Mexico are based on: 1) sowing season (spring, spring-summer, and fall-winter), 2) humidity conditions (rainfed and irrigated), and 3) socioeconomic level (subsistence farming and business agriculture) (Acosta et al., 2000). Aproximately, 76.07% of the crop is established under rainfed conditions. The main bean types sown and consumed are: national and american pinto, regional azufrado and peruvian azufrado, flor de mayo, flor de...
junio, negro and bayo. Consumption habits vary with the region, so in the northwest the preference is the azufrado types, and pintos and bayos in the north and northeast. Although in central Mexico all types of beans are consumed, there is a marked tendency for flor de mayo and in the south black beans are preferred (Castellanos et al., 1997). During the spring-summer season 2020, under irrigation and rainfed conditions, common bean production in Mexico was 729,337.97 t from an area of 1,314,933.40 ha in 29 states with an average yield of 0.55 t/ha; the state of Zacatecas had the largest area sown with bean (639,850.50 ha) (SIAP, 2021). In the state of Sonora, under rainfed conditions there were 94 ha harvested with a production of 64.25 t with an average yield of 0.68 t/ha, while under irrigation there were 2,431.5 ha harvested with a production of 5,494.18 t with an average yield of 2.26 t/ha (SIAP, 2021).

In the Yaqui Valley which is part of the southern region of the state, farmers use several ways for irrigation: flooding, furrow, drip, center pivot, frontal move, and spray irrigation (SAGARHPA, 2011). The most common is furrow irrigation. In the case of beans which has increased in area in the last few years (INIFAP, 2020), farmers use primarily furrow irrigation and secondly drip irrigation. Some of the main constraints for bean production in Sonora are Bean common mosaic virus, Bean southern mosaic virus, Bean chlorotic mosaic virus, Bean golden yellow mosaic virus, Pumpkin leaf curly (Padilla et al., 2000), and rust caused by the fungus Uromyces appendiculatus var. appendiculatus (Valenzuela and Armenta, 1990; Ramírez, 1991). Analysis of the temperature during the last 10 years in southern Sonora, Mexico, indicates that the spring season (February-May) of beans has maintained a 0.2°C increase tendency per season, mainly during the months of April and May (REMAS, 2021). The events of extreme minimum temperature have a tendency to increase and the relative humidity has been unstable. Generally, the southern region of the state of Sonora, is characterized by extreme minimum temperatures of -1.8°C mainly in January, and extreme maximum temperatures of 32.5 to 44.2°C during June, July, and August; although in certain years like 2020, temperatures above 32°C during the day might occur in May and September (REMAS, 2021). The wide environmental adaptability reported in some edible bean types, indicates that some cultivars may stand extreme temperatures between 5 and 40°C (White and Singh, 1991). Sowing bean during the spring is a feasible option for farmers who cultivate a fall-winter crop and take advantage of the residual fertilization, the water assignment, and the minimum till, with a short season crop like bean; therefore, it is important to determine the risk level that bean might have, if sowing is carried out outside the established technical dates recommended for the region (Padilla-Valenzuela et al., 2009). The objective of this work was to evaluate bean fructification-production period during the spring 2020, under the thermic impact caused by sowing outside the recommended dates and under drip irrigation.

2. MATERIALS AND METHODS

The productive phase of bean cultivar Pinto Bill Z was analyzed in three commercial fields located in Blocks 1502 (100 ha), 2110 (100 ha), and 2228 (290 ha) (Fig. 1), in the Yaqui Valley, Sonora, Mexico, during the spring 2020, under drip irrigation and the temperatures that prevailed during the season. The irrigation tape was Stream line 8000 with a capacity of 0.89 liter of water per hour by each dropper, which were separated by 30 cm. Digital sensors Omega (OM-EL-WIN-USB data Logger software v7.2.1) were placed in each field to record temperature and relative humidity within the crop; as a reference, climatic data but primarily Eto (evapotranspiration), were also obtained from weather stations of the automated weather station...
network in the state of Sonora (REMAS), which were located in: 1) Block 1703, 7 km south of the sensor in Block 1502, 2) Block 2010, 4 km north of sensor in Block 2110, and 3) Block 2328, 4 km south of sensor in Block 2228.

Figure 1. Blocks where the productive phase of bean cultivar Pinto Bill Z was evaluated in the Yaqui Valley, Sonora, Mexico, during the spring 2020.

The Eto of a crop is an indicator of water demand by the crop (Penman-Monteith cited by Allen et al., 1998), and indirectly estimates the water sheet needed. The climatic date based was generated in hourly format from February to June, 2020. Due to the shortage of water, fields in Blocks 1502 and 2228 were divided into two sections, one with higher irrigation sheet (H) and the other with a low irrigation sheet. Sowing dates for field B-1502H was March 26, for B-1502 March 31, B-2110 March 25, B-2228H February 20, and for B-2228 March 09. Irrigation sheets were calculated based on the number of hours, use of water by the irrigation hose, and irrigation frequency. Three 1 m² plant samples were collected from each field to quantify pod production, pods with grain, a thousand grain weight, and grain yield. The sources of variation were the irrigation sheets and temperature. The analysis of variance was performed with the program InfoStat of Balzarini (2008).

3. RESULTS AND DISCUSSION

Periods of temperature with a threshold greater than 30°C were recorded between March 10 and 11, 24 and 25, April 7 and 8, 14 and 18, and from April 20 onward the temperature increased up to the time of harvest and had oscillations greater than 40°C; this last heat wave was detected in 90% of the weather stations. Temperature records within fields (Fig. 2) showed that plants staded average thermic levels of 32.5°C, with periods of 8 continuous hours (10:00am-18:00 pm) with constant irrigation, according to the best yield recorded in the field located in Block 2110.
When the temperature rose above this level, there was greater flower and pod (less than 2 cm in length) fall off, and its effect increased in the second and third portion of the plant. Monterroso and Wien (1990) reported that a 10 hour period at 35°C for two days during the flowering stage, caused 82% abscission of pods (shorter than 2 cm) and pollen dehydration.

Similar to the weather stations, sensors within the crop recorded in certain days during the period of study, temperatures greater than 36°C, reaching 40.5°C (Fig. 2). The highest average temperature was recorded in fields located in Blocks 2228 and 1502. The thermic differences between fields could be related to the frequency of irrigation and closeness to the ocean. The maturity to harvest period was related to the irrigation sheet and temperature, and so the field in Block 2228 accelerated the maturity, followed by 1502. Field observations indicated a reduction in pod size (Fig. 3A), and grain size and weight (Fig. 3B), as a compensatory effect by temperature excess and lack of water. Previous studies carried out by Turner (1990), Efetha et al. (2011), and Bárzaga (2010), indicate that water stress will cause a reduction in the size and number of grains per pod, consequently a reduction in grain yield per area (Efetha et al., 2011; Elmetwali and Ibrahim, 2016; Rai et al., 2020). Table 1 describes the theoretical amount of water used by the crop that was recorded by the weather station closest to the field. For bean fields B-2110, B-1502-H, and B-1502, sown on March 25, 26, and 31, respectively, it was 49, 41, and 39 cm; and the irrigation sheets applied were 48, 42, and 38 cm which indicates sufficiency of irrigation with respect to the period from sowing to harvest. For bean fields in B-2228-H and B-2228 sown on February 20 and March 9, respectively, the weather station recorded a theoretical water use of 49 and 43 cm; irrigation sheets of 36 and 29 cm were applied, respectively, which renders a theoretical deficit between 27 and 33%. Counting total pods and those without grain, showed that in the three fields there were pods without grain (Fig. 3C), so that damage to pods accounted for between 10.4 a 27%, (Table 1). Pods that were threshed had one, two, three, and exceptionally four grains per pod. Grain development was variable in size.
and weight in the three fields, as well as the number of pods with grain. The significant differences in higher grain yield were influenced by greater irrigation sheet with a lower temperature (Tables 2 and 3).

Figure 3. Pods from commercial bean cultivar Pinto Bill Z sown in the Yaqui Valley, Sonora, Mexico, during the spring 2020.

Table 1. Water use calculated based on the evapotranspiration, days to harvest, and percentage of pods without grain, in three commercial fields in the Yaqui Valley, Sonora, Mexico, during the spring 2020.

| Fields  | Sowing dates | Evapotranspiration (cm)* | Days to harvest | Pods without grain(%) |
|---------|--------------|--------------------------|-----------------|-----------------------|
| B-2110  | Mar-25       | 49                       | 86              | 15.2                  |
| B-1502-H| Mar-26       | 41                       | 84              | 10.4                  |
| B-1502  | Mar-31       | 39                       | 80              | 15.5                  |
| B-2228-H| Feb-20       | 49                       | 89              | 13.3                  |
| B-2228  | Mar-09       | 43                       | 80              | 27.0                  |

*Calculated based on the sowing date to harvest, using the weather station closest to the field.

Studies carried out by Padilla-Valenzuela (1992) with Pinto Bill Z cultivar, indicated that the normal bean spring season lasts 100 days from sowing to harvest, and that if the season is shortened by 8 days, grain yield will be reduced by 16%. In this evaluation, the season was shortened to harvest by 6 to 10 days; this season reduction is closely related to an increase in temperature and to the frequency irrigation differential, according to field observations, which derived in highly significant difference in grain yield (Tables 2, 3, and 4). A nonquantified statistical effect was the irrigation frequency, which was prolonged by insufficiency in water supply to fields located in Block 2228 and 1502.
Table 2. Analysis of variance of the response variables of bean cultivar Pinto Bill Z with irrigation sheets and average temperature of the period, in three commercial fields in the Yaqui Valley, Sonora, Mexico, during the spring 2020.

| Response variable                  | Temperature Vs. | Irrigation sheet Vs. |
|-----------------------------------|-----------------|----------------------|
|                                  | R²   | CV % | p>0.01 | R²   | CV % | p>0.01 |
| Total pods                        | 0.64 | 5.3  | 0.0023**| 0.79 | 17.0 | 0.0019**|
| Pods with grain                   | 0.56 | 5.7  | 0.0076**| 0.73 | 22.4 | 0.0068**|
| Weight of 1000 grains (g)         | 0.72 | 1.5  | 0.0004**| 0.78 | 7.4  | 0.0023**|
| Grain yield (kg/ha)               | 0.69 | 49.7 | 0.0009**| 0.72 | 31.4 | 0.0081**|

Table 3. Response variables of bean cultivar Pinto Bill Z with different irrigation sheets, in three commercial fields in the Yaqui Valley, Sonora, Mexico, during the spring 2020.

| Block-field | Irrigation sheet (cm) | Total pods | Pods with grain | Weight of 1000 grains (g) | Grain yield (kg/ha) |
|-------------|-----------------------|------------|-----------------|--------------------------|---------------------|
| B-2110      | 48                    | 406 a      | 344 a           | 270 a                    | 3430 a              |
| B-1502-H    | 42                    | 328 ab     | 294 a           | 239 ab                   | 2096 b              |
| B-1502      | 38                    | 366 ab     | 309 a           | 236 b                    | 1824 b              |
| B-2228-H    | 36                    | 275 b      | 239 a           | 191 c                    | 1489 b              |
| B-2228      | 29                    | 165 c      | 120 b           | 214 bc                   | 1033 b              |

Numbers with the same letter in a column are not statistically different (Tukey’s test, 0.05).

Table 4. Response variables of bean cultivar Pinto Bill Z under different average temperature regimes, in three commercial fields in the Yaqui Valley, Sonora, Mexico, during the spring 2020.

| Block-field | Average temperature (°C) | Total pods | Pods with grain | Weight of 1000 grains (g) | Grain yield (kg/ha) |
|-------------|--------------------------|------------|-----------------|--------------------------|---------------------|
| B-2110      | 32.5                     | 406 a      | 344 a           | 270 a                    | 3430 a              |
| B-1502*     | 34.2                     | 347 a      | 301 a           | 237 b                    | 1960 b              |
| B-2228*     | 34.6                     | 220 b      | 180 b           | 203 c                    | 1261 b              |

*Average of the two sections of the field.
Numbers with the same letter in a column are not statistically different (Tukey’s test, 0.05).

4. CONCLUSIONS
Temperature oscillation greater than 32.5°C caused a reduction in pod number with grains in all the fields. The interaction temperature by irrigation sheet significantly affected the number and grain weight. The irrigation programmed and sufficient, congruent with the evapotranspiration, provided a significant beneficial grain yield to the field located in Block 2110 during this warm
season. Spring sowing in southern Sonora has a high risk in warm seasons, but it is an economic feasible option, as long as the irrigation is well programmed and sufficient.

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