DOI: https://doi.org/10.17921/1415-6938.2022v26n4p445-450

Irrigation Depths Adjustment Methods on Yield Components, Grain Yield and Water Use Efficiency of Dry Beans Crop

Métodos de Ajuste da Lâmina de Irrigação Sobre os Componentes de Redimento, Produtividade e Eficiência de Uso de Água da Cultura do Feijão

Patricia Mara de Almeida*[a]; Nataly Katia De Marco[a]; Luan Junior Kuhn[b]; Renan Marré Biazatti[a]; Franciele Fátima Fernandes[c]; Eduarda Posser Pazzini[a]; Hugo von Linsingen Piazzetta[a]

[a]Universidade Tecnológica Federal do Paraná, Postgraduate Program in Agronomy. PR, Brazil.
[b]Agronomist Self-Employed Engineer. RS, Brazil.
[c]Universidade Estadual de Santa Catarina, Postgraduate Program in Plant Production. SC, Brazil.
*E-mail: patimara97@hotmail.com

Abstract

Dry beans are one of the most important crops for Brazilians people diet, features a low national yield, which can be explained by the occurrence of water deficit events. Thus, this study aimed to evaluate the yield components, the grain yield and the water use efficiency of dry beans submitted to different ways to adjust the irrigation depth, and validate the Lâmina spreadsheet to recommend irrigation to the culture crop. The experimental design was a randomized block with four replications. Four treatments: non-use of irrigation; soil moisture equivalent to actual capacity of water in the soil at 45% of the total capacity of the ground water; soil moisture equivalent to 100% of the field capacity; and irrigation depth adjustment provided by Lâmina spreadsheet. The Lâmina treatment showed the best results for grain yield and water use efficiency, however the yield components were not significant, except for pods thickness. Thus, the Lâmina spreadsheet showed great potential, with high yield and contributing to the rational water use in dry beans crop.

Keywords: *Phaeseolus vulgaris* L. Water Deficit. Rainfall.

Resumo

O feijão é uma das principais culturas na dieta humana brasileira, apresentando baixa produtividade nacional, o que pode ser explicado pela ocorrência de períodos de deficiência hídrica para a cultura. Desta maneira, objetivou-se avaliar os componentes de rendimento da cultura, a produtividade de grãos e a eficiência do uso da água, em diferentes manejos da lâmina de irrigação e validar a planilha Lâmina para recomendação de irrigação da cultura. O delineamento experimental foi de blocos casualizados com quatro repetições. Os tratamentos foram: não utilização da irrigação; manutenção da umidade do solo na capacidade real de água no solo em 45% da capacidade total de água do solo; manutenção da umidade do solo equivalente em 100% da umidade da capacidade de campo; e ajuste da lâmina de irrigação utilizando a planilha "Lâmina". Determinou-se a quantidade total de água recebida pela cultura, a produtividade de grãos, a relação litros por quilograma de grãos, o ciclo e os componentes do rendimento. O tratamento Lâmina apresentou os melhores resultados para a produtividade, e maior eficiência no uso da água, no entanto não se obteve diferenças significativas para as componentes do rendimento exceto para a componente espessura das vagens. Assim, a planilha Lâmina apresentou grande potencial, tendo alta produtividade e colaborando para a racionalização do uso de água na cultura do feijão.

Palavras-chave: *Phaeseolus vulgaris L. Déficit de Água. Precipitação.*

1 Introduction

Dry beans grain represents an important protein source for human diet in developing countries, especially in tropical and subtropical regions. For Abreu (2005), besides the relevant role in the Brazilian diet, the dry beans are one of the agricultural products of higher socio-economic importance with approximately 65% of production from family farming.

Brazil, the world's third largest dry beans producer, obtained in the 2015/2016 agricultural season a production of 3.18 million tons in a planted area of 3.04 million hectares (CONAB, 2016). The Brazilian production is mainly concentrated in the South (28.13%) and Midwest (24.64%) regions, being the Paraná state the main producer with 666400 tons, followed by Minas Gerais and Mato Grosso states, both with an output of 548900 and 426600 tons, respectively (CONAB, 2016).

The national dry beans yield average is relatively low, reaching only 1050.00 $kg \cdot ha^{-1}$ leaving a low profitability to the farmer (CONAB, 2016). Many are the reasons to the low average yield, highlighting the weather instability. It is important to note that the dry beans are grown in almost all the national territory and at many seasons of the year, adapting to a wide range of climatic conditions, which contributes to a low national grain yield (GUIMARÃES *et al*., 2003).

Being the water deficit one of the main causes to yield loss in this crop, the use of an irrigation system is necessary, to decrease the losses and to optimize the crop profitability. However, in Brazil, irrigation in many cases is still developed with little technology and without concern for the rational water use (GOMIDE, 1998). Currently, there are few tools available to the farmers to assist in making decisions regarding when to irrigate and how much water to apply (SILVEIRA; STONE, 2001).

Therefore, it was necessary to study the crop water relations, aiming to know the real water needs and to determine the amount of water to be applied in the different stages, as well as to identify the correct time, to improve the water use efficiency. Following these needs, the present study aimed to evaluate the amount of water received by the dry bean crop, as well as to evaluate the yield components, grain yield and water use efficiency, in order to validate the “Lâmina” spreadsheet to recommend irrigation depth in this crop.

2 Material and Methods

The study was conducted in Erechim city, Rio Grande do Sul state, during the 2015/16 agricultural season. The soil in the study area is classified as red latosol aluminum-ferric humic according to Embrapa (2006). According to the Köppen (1931), the climate is classified as Cfa, where the temperature in the hottest month is above 22 °C and below 18 °C in the coldest month. The rainfall presents to be well distributed throughout the year.

To reach the goals, the following methods of irrigation depth adjustment were compared: non-irrigation (control), irrigation depth determined by the “Lâmina” spreadsheet (Lâmina); soil moisture maintenance to actual capacity of water in the soil at 45% of the total capacity of the ground water (45% RWC); and maintenance of the soil moisture at 100% of field capacity (100% FC). The irrigation was realized manually, using a digital hygrometer to measure the water amount applied in the crop rows, with a 2-days interval. A randomized block experimental design with four replications was used. Each experimental unit was constituted of a plot 3 m wide and 3 m long (9 m²).

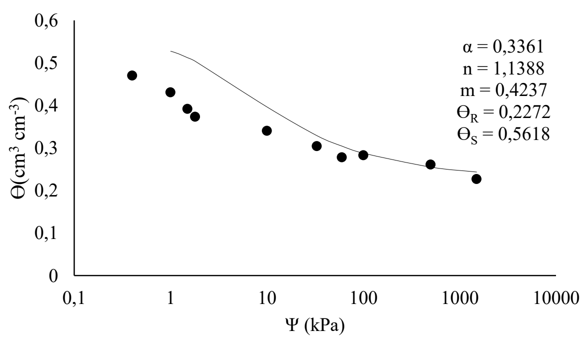
The soil acidity correction was carried out using limestone filler, applied in soil surface. The limestone dose was determined by raising bases saturation to 70%, hence, 5500 kg.ha^{-1} of limestone (100% RPTN) was used. The crop was sown in a no-till system on November 3rd, 2015, using the BRS Campeiro cultivar. The row planter was regulated to obtain a population of 250000 ha^{-1} with 0.5 m between rows and 3 cm depth. The seed was previously treated with insecticide (Tiametoxan) and fungicide (Carboxin + Thiram), in the doses of 300 ml each product by 100 kg of seeds. The fertilizer used was 160 kg.ha^{-1} of NPK (10-20-20), plus 13 kg.ha^{-1} of Potassium Chloride (60% K_2O) at sowing and 24 kg.ha^{-1} of urea (45% N), in V4 vegetative stage, characterized by the third trifoliate leave, fully open present in 50% of the plants (FERNANDEZ *et al*., 1985). All the fertilizer doses were calculated according to SBCS (2004), based in the nutrients available in the soil, determined by soil chemical analysis.

The weed plants were controlled applying a post-emergent herbicide, (Glyphosate) with 3 L.ha^{-1} dose in pre-seeding. After crop emergence, Fomesafem + Fluazifop-p-butílico (1.5 L.ha^{-1}) herbicide was applied when the first weeds emerged. Pests and diseases were controlled using insecticides and fungicides registered for the crop, always when the economic thresholds were reached, so the crop was constantly monitored.

In order to determine the soil hydraulic properties, the soil retention curve was constructed, using the Richards chambers methodology (RICHARDS *et al*., 1943; EMBRAPA, 1997). To do so, four undisturbed soil samples were collected with cylindrical rings of known volume, in 0 - 10 cm depth, using a manual auger type “Uhland”. To construct the retention curve, the following pressures were applied: 0.4, 1.0, 1.5, 1.8, 10, 33, 60, 100, 500, and 1500 kPa.

In the end of all pressures applied, the samples were dried in an oven with forced air circulation, at 105±2 °C for 72 hours. Thus, the samples volumetric moisture was calculated to each pressure. Then, the water retention curve was constructed, adjusting the moisture values by Van Genuchten (1980) model, which it is showed in Figure 1.

Figure 1 - Soil water retention curve of this study



Source: Research data.

Following the methodology described, the field capacity (θ_{FC}) was obtained at 33 kPa pressure (32.92%), and the wilting point (θ_{WP}) at 1500 kPa presure (24.00%). Other soil physical properties calculated were macropores (13.10%), micropores (18.74%) and cryptopores (24.36%) totalizing 56.20% of solids present in the soil.

The different treatments were applied from the crop sowing to the harvest. In the non-irrigation treatment (control), water available to plants were provided by the natural rainfall, and monitored with automatic weather station (Agrosystem brand, Vantage Pro 2 model), installed near the study area. For the treatment soil moisture equivalent to 100% of the field capacity (100% FC), the soil moisture was determined using a TDR probe (Time Domain Reflectometry - Soil Moisture Equipment brand, Mini-Trase Kit model). The amount of water needed to recover field capacity moisture was applied according to the irrigation level, obtained through Equation 01 proposed by (BERNARDO, 2005).

$$IL = \frac{(\theta_{FC} - \theta_f)}{10} \times z \qquad \text{Eq. 01}$$

Where, IL is the irrigation level (mm); is the volumetric soil moisture at field capacity (%); is the volumetric soil moisture read (%); and z is the actual root depth (0.6 m for been).

For the treatment soil moisture maintained at actual capacity of water in the soil at 45% of the soil water total capacity (45% RWC), according to the soil depletion factor to the crop, established by Allen and Pereira (1998), the soil water total capacity (WTC) was calculated according to Equation 1 and the real soil water capacity (RWC) Equation 2, both proposed by Bernardo (2005).

$$IL = \frac{(\theta_{FC} - \theta_f)}{10} \times z \times p \qquad \text{Eq. 01}$$

Where, IL is the irrigation level (mm); is the volumetric soil moisture at field capacity (%); is the volumetric soil moisture read (%); z is the actual root depth (0.6 m for been); and p is the soil depletion factor to the crop (0.45 for been).

In the "Lâmina" treatment, the irrigation level was obtained using a spreadsheet designed by the authors, according to FAO document 56, drafted by Allen *et al*. (1998). The spreadsheet uses location data, soil, irrigation system, crop, and weather conditions to calculate the soil water balance in relation to the grown crop and provide an irrigation depth to meet the crop needs.

In this way, global solar radiation ($MJ.m^{-2}.day^{-1}$), average air temperature (°C), average and minimum air relative humidity (%), wind speed ($m \cdot s^{-1}$) and precipitation ($mm \cdot day^{-1}$) data were collected every day. These data were collected with an automatic weather station installed near the study area. Putting into the spreadsheet the weather data, plus the location (latitude, longitude and altitude), the soil physical properties (θ_{FC} and θ_{WP}) and crop (specie and stage), the irrigation level was obtained, using two days' interval.

In all the treatments the total water applied to the crop was determined, allowing to relate the water amount and the crop yield. The crop harvest was done manually in a 4 m^2 area each plot. The grain moisture was around 10 to 16%. The crop was harvested by cutting the plants close to the ground, when about two-thirds of the pods had completely matured. The yields components analyzed were: pods per plant; grains per pod, pod length, pod thickness and thousand grain weight.

In ten plants randomly selected in the plot the variables were measured: pods per plant, pod length, pod thickness and grains per pod, according to the methodology described by IPGRI (2001). Then, the pods were separated and dried in an oven with forced air circulation for two days at 60 °C, to allow the manual threshing process. After, the manually threshing process, the grains moisture was determined, allowing grain moisture correction at 13% and estimate the grain yield in $kg.ha^{-1}$, by weighting the grains harvested in each plot in an analytical scale. The thousand grains weight was determined taking a weight of 8 samples of 100 grains each in an analytical scale, and also adjusting to 13% moisture. The water use efficiency was calculated dividing the amount of water provided to the plants by the kilograms of grain produced ($L.kg^{-1}$).

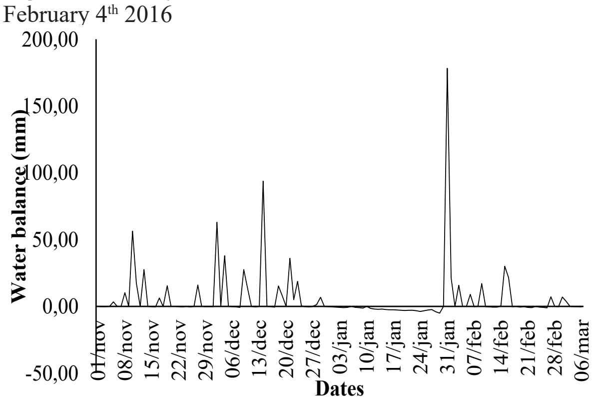
The data were submitted to analysis of variance and treatment averages were compared by Duncan's Multiple Range test ($p \leq 0.05$). For these procedures, the SPSS software v.22.0 was used.

3 Results and Discussion

During the study time, the average daily temperatures ranged from 16.1 °C to 28.6 °C with an average of 21.6 °C, which are in an adequate range to dry beans crop, according to Dourado Neto and Fancelli (2000) that suggest the optimal temperature to the crop around 21 °C, ranging from 15 to 29.5 °C. The total rainfall in the period was 1049.8 mm, being above the historical averages. According to Matzenauer *et al*. (2011), the normal rainfall to this period is 615.40 mm, demonstrating an excessive rainfall during the study. This high amount of rainfall occured can be explained by the El Niño-Southern Oscillation phenomenon (ENSO) positive phase or just El Niño, that influenced the weather in the 2015/16 season. According to Berlato *et al*. (2005) the ENOS phenomenon positive phase causes rainfall above the averages while the negative phase (La Niña) causes drought at the beginning of the summer, in the Rio Grande do Sul state.

However, analyzing the daily water balance (Figure 2), despite the large amounts of rainfall, there were periods of water deficit during the crop growth season, especially in the period of January 10th to 30th. During this time, the maize was in initial grain filling stage.

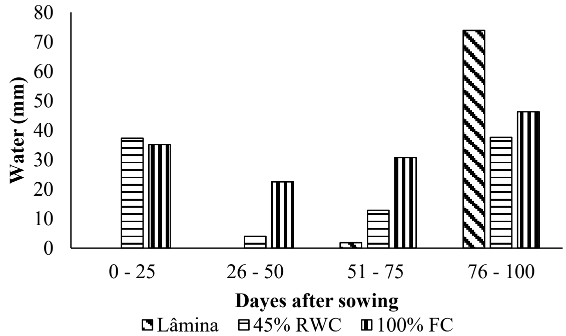
Figure 2 - Daily water balance, from November 1st 2015 to February 4th 2016



Source: Research data.

Following the methodology proposed, the irrigation depth and timing in different treatments varied according to the available water to the plants. Thus, to better understand the irrigations applied, the irrigations distribution are shown in Figure 3 through time, during the crop growth, being the irrigation averages of the four replications, in 25 days period combined.

Figure 3 - Irrigation averages (mm) distribution combined in a 25-day period, during the crop growth



Source: Research data.

For the 100% FC treatment, an uniform distribution is made of water applied along the crop growth, which is also observed to the 45% RWC treatment. In Lâmina treatment the irrigations were concentrated in the period between 76 and 100 days after sowing, when the longer deficit water period occurred. Table 1 presents the total amount of water (mm – rainfall + irrigation) provided to the crop by different treatments. Analyzing the water provided to the crop, it is observed that control treatment received the least amount of water, which was only the rainfall that occurred during crop growth. Thus, the Lâmina used the least amount of water, among the irrigated treatments, not showing significant differences from 45% RWC treatment, which showed similar results to 100% FC treatment.

Table 1 - Water supplied for dry bean crop in different irrigation level adjustment methods

Treatment	Water (mm)
Control	673.00^{c}
Lâmina	1032.18^{b}
45% RWC	1069.25^{ab}
100 % FC	1148.22^{a}
CV (%)	5.23

Averages followed by the same letter in the column do not differ according to the Duncan's Multiple Range test ($p \leq 0.05$).
Source: Research data.

Table 2 presents the crop yield components, where it can be observed that for all the treatments there were not significant differences, except for the component pod thickness. Arf *et al.* (2004) found similar results to the irrigation depth effect on dry beans, where, applying three different irrigations depths, in two different agricultural seasons (2001 and 2002), only found significant differences to the thousand-grain weight, and the intermediary irrigation depths obtained the best results. According to the author, the increasing in the soil water by increasing the irrigation depth might have caused conditions of lower soil aeration, interfering in the production of photoassimilates for the grains filling .

According to Dourado Neto and Fancelli (2000), the thousand-grain weight and the pod thickness are correlated variables that are defined during the grain filling stage, final phase of reproductive growth. Even if the thousand-grain weight showed no significant difference, it was observed a higher weigh to the Lâmina followed by the 45% RWC and 100% FC treatment, fact which can explain the significant differences to the pod thickness component. The least pod thickness and thousand grain weight to the control treatment can be explained by the water deficit in the final grain filling stage (Figure 2).

Table 2 - Dry bean yield components in different irrigation level adjustment methods

Treatment	Pods/plant	Grains/pod	Pod length (mm)	Pod thickness (mm)	Thousand grain weight (g)
Control	8.02^{ns}	5.36^{ns}	87.43^{ns}	8.21^{b}	173.60^{ns}
Lâmina	9.57	5.29	86.76	8.71^{a}	181.60
45% RWC	8.12	5.08	86.82	8.57^{ab}	178.97
100 % FC	8.30	5.31	88.60	8.80^{a}	176.04
CV (%)	13.25	5.51	3.62	3.34	4.28

Averages followed by the same letter in the column do not differ according to the Duncan's Multiple Range test ($p \leq 0.05$). ^{Ns} - No significant difference.
Source: Research data.

In this way, Table 3 presents the grain yield ($kg.ha^{-1}$), water use efficiency ($L.kg^{-1}$) and crop growth length (days), for the treatments. The average grain yield of the study was 1646.40 $kg.ha^{-1}$ showing to be above the national average, for the same year, that was 1050 $kg.ha^{-1}$ (CONAB, 2016).

The Lâmina treatment had the highest grain yield, but it was not significant different from 45% RWC and 100% FC treatments, showing significant difference only for control treatment, difference which was of 520.53 $kg.ha^{-1}$. The 45% RWC and 100% FC treatments did not show significant differences from the control. The differences found for grain yield proved that even with a great amount of rainfall, the occurrence of water deficits during the crop growth had a negative effect on grain yield, especially on grain filling stage. These results are in agreement with those found by Arf *et al*. (2004), which did not find significant differences for dry beans grain yield under irrigated treatments. Similar results were also found by Santana *et al*. (2009), which increased the dry beans grain yield, applying water reaching a peak at 100% reposition of the water consumed by the crop, and decreasing the grain yield above this amount.

Table 3 - Grain yield, water use efficiency and crop growth length, for dry bean in different irrigation level adjustment methods

Treatment	Grain yield (kg.ha^{-1})	Water use efficiency (L.kg^{-1})	Crop growth length (days)
Control	1362.56^{b}	5154.04^{b}	83.00^{c}
Lâmina	1883.09^{a}	5644.60^{ab}	94.00^{b}
45% RWC	1718.63^{ab}	6483.44^{ab}	96.00^{ab}
100 % FC	1621.34^{ab}	7141.18^{a}	100.00^{a}
CV (%)	15.91	17.18	3.24

*Averages followed by the same letter in the column do not differ according to the Duncan's Multiple Range test ($p \leq 0.05$).
Source: Research data.

The present study obtained a grain yield gain of 38.20%, 26.13% and 18.99% for treatments 45% RWC, Lâmina and 100% FC, respectively, comparing to the control treatment. Silva *et al*. (2007) studying sunflower crop response to irrigation, found a grain yield gain of 9.17%, 33.26% and 48.79% applying an irrigation depth of 50.84 mm (75% Etc), 428.70 mm (100% Etc) and 522.14 mm (130% Etc), respectively comparing to an irrigation depth of 117.20 mm (non-irrigated). Lima *et al*. (2008) applying different irrigation depths on coffee crop found significant results on crop yield, which between 2000/2001 and 2004/2005 agricultural season, the yield gain in response to irrigation reached 119% in the 60% Evaporation Pan irrigation depth, compared to non-irrigated. For soybean, Sartori *et al*. (2015) observed an increase in crop yield in the use of supplemental irrigation on soil moisture conditions below 60% of field capacity.

According to Gomes *et al*. (2000) the dry beans water needs are varied, being influenced by factors such as sowing time and region, cultivar, soil and weather conditions and growth stage. Dourado Neto and Fancelli (2000) highlight that dry beans crop needs between 250 and 500 mm of water along the crop growth, thus, observing the rainfall occurred during the crop growth period,a greater availability occurred of water from rainfall than crop needs. However, Figure 2 shows the occurrence of water deficits, being the highest greater between January 10th and 20th, period that the crop was around 65 and 85 days after sowing, final grain filing stage. Mac Kay and Eanes (1962) emphasize that the pre-flowering is the most critical for the dry beans crop; on the other hand, Kattan and Fleming (1956) point flowering, and Doorenbos and Pruitt (1976) and Bergamaschi et al. (1988) indicate the flowering and pods appearance as the most critical periods. However, Doorenbos and Kassam (1979), indicate that the dry bean water needs ranges from 300 to 500 mm to obtain high yields. In this way, the highest yield for Lâmina treatment can be associated mainly to the irrigations, since it was concentrated at the greatest water deficit period.

To the water use efficiency, control, Lâmina and 45% RWC did not show significant differences between each other, obtaining a greater efficiency compared to the 100% FC treatment. Significant differences were only found between treatment control and 100% FC which was 1987.14 L.kg. According to Balardin *et al*. (2000) irrigations have positive outputs on dry bean grain yield, when compared to non-irrigated. However, greater efficiency is obtained when the water is applied at water deficit in the soil, especially when it is associated with the crop critical period for water deficit. This happened because when the water deficit occurs on the vegetative growth stages, the crop can be recovered by irrigations or rainfall, resulting only in a reduction of the plants height. On the other hand, if water deficit happens on reproductive growth stages, the yield losses can be unrecovered (SILVEIRA; STONE, 1998). This fact explains the less water use efficiency obtained on 100% FC treatments, in addition, the harvest delay can be another cause of the yield loss.

The total crop growth length had a difference of 17 days, comparing the control treatment to the 100 % FC treatment. In the control, the harvest forwardness happened because of the accelerated leaves senescence, resulted from water deficit in the final grain filling stage (FLOSS, 2011). The Lâmina treatment showed significant differences to the control and 100% FC treatments. Carneiro *et al*. (2015) state that in the maturation stage, the water excess can extend the crop growth length, delaying the harvest, resulting in damaged and diseases on grains, and the pods can stay in contact with the ground. Due to the harvest delay on 100% FC treatment and the occurrence of great amounts of water near the harvest of this treatment, a strong incidence was observed of diseases in the dry bean pods. Even the diseases being not analyzed in this study, it probably had a negative impact in the crop yield for the 100% FC treatment.

4 Conclusion

By using the "Lâmina" spreadsheet it was possible to improve the yield components, crop yield and water use efficiency of dry beans. In this way, the Lâmina" spreadsheet can be used to recommend irrigation depth for this crop. However, more studies are needed to test the spreadsheet in different agricultural seasons.

References

ABREU, Â.F.B. *et al*. Spring and second crop bean cultivation in the southern region of Minas Gerais. *Embrapa*, 2005. Available in: <https://sistemasdeproducao.cnptia.embrapa.br/FontesHTML/Feijao/FeijaoPrimSegSafraSulMG/> Acess in: Jun 02 2016.

ALLEN, R.G.; PEREIRA, L. S. Crop evapotranspiration: guidelines for computing crop water requirements. *FAO Irrigation and Drainage Paper*, v.56, n.9, p. 300, 1998.

ARF, O. *et al*. Soil, water and nitrogen management in bean cultivation. *Pesq. Agropec. Bras.*, v.39, n.2, p.131-138, 2004. doi: 10.1590/S0100-204X2004000200005

BALARDIN, R.S. Beans: Technical Recommendations for Cultivation in Rio Grande do Sul. *Comissão Estadual de Pesquisa de Feijão (CEPEF)*, 80p., 2000.

BERGAMASCHI, H. *et al*. Water deficiency in common bean. *Pesquisa Agropecuária Brasileira*, v.23, n.7, p.733-743, 1988.

BERLATO, M.A.; FARENZENA, H.; FONTANA, D.C. Association between El Niño Southern Oscillation and corn yield in the state of Rio Grande do Sul. *Pesq. Agropec. Bras.*, v.40, n.50, p.423-432, 2005. doi: 10.1590/S0100-204X2005000500001

BERNARDO, S. Irrigation manual. Viçosa: UFV, 2005.

SBCS - Brazilian Society of Soil Sciences. Fertilization and liming manual for the states of Rio Grande do Sul and Santa Catarina. Porto Alegre, 2004.

CARNEIRO, J.S.; PAULA JUNIOR, T.; BOREM, A. Beans: from planting to harvesting. *UFV*, 2015.

DOORENBOS, J.; KASSAM, A.H. Yield response to water**.** *FAO (Irrigation and Drainage Paper)*, v.33, 1979.

DOORENBOS, J.; PRUITT, W.O. Crop water needs. *FAO (Estúdio FAO Riego y Drenage)*, v.22, 194p., 1976.

DOURADO NETO, D. D.; FANCELLI, A. L. Bean production. Guaíba: Agropecuária Ltda, 2000.

EMBRAPA. Soil analysis methods manual. National Soil Research Center, v.2, 212p., 1997.

EMBRAPA. National Soil Research Center. Brazilian system of soil classification. Rio de Janeiro: Serviço de Produção de Informação, 2006.

FERNÁNDEZ, F.; GEPTS, P.; LÓPEZ, M. Stages of development of the bean plant (*Phaseolus vulgaris* L.). Cali: International Center for Tropical Agriculture, 1986.

FLOSS, E. L. Physiology of cultivated plants. Passo Fundo: UPF, 2011.

FREITAS , F. D. O. Genetic-archaeological evidence on the origin of the common bean in Brazil. *Braz. Agricul. Res.*, v.41, n7, p.1199-1203, 2006. doi: 10.1590/S0100-204X2006000700018

GOMIDE, R.L. Monitoring for irrigation management: instrumentation, automation and methods. *UFLA*, v.2, p.133-238, 1998.

GOMES, A.A. *et al*. Biomass accumulation, physiological characteristics and grain yield in irrigated and rainfed common bean cultivars. *Braz. Agricultural Res.*, v.35, n.10, p.1927-1937, 2000.

GUIMARÃES, C.M.; STONE, L. F.; BRUNINI, O. Adaptation of the common bean to drought (*Phaseolus vulgaris* L.). *Braz. J. Agricul. Environ. Eng.*, v.10, n.1, p.70-75, 2003.

IPGRI. Descriptors for *Phaseolus vulgaris* L. Rome: International plant genetic resources institute, 2001.

KATTAN, A.A.; FLEMING, J.W. Effect of irrigation at specific stages of development on yield, quality growth and composition of snap beans. *Proc. Am. Soc. Horticultural Scie.*, v.68, p.329-342, 1956.

KÖPPEN, W. Grundriss der Klimakunde. Berlin: Walter de Gruyter & Co, 1931.

LIMA, L.A.; CUSTODIO, A.A.P.; GOMES, N.M. Coffee productivity and yield in the first five crops irrigated by center pivot in Lavras, MG. *Scie. Agrotechnol.*, n.32, v.6, p.1832-1842, 2008.

MAC KAY, D.C.; EANES, C.A. Influence of irrigation treatments on yields and on fertilization by sweet corn and snap beans. *J. Plant Scie.*, v.42, p.219-228, 1962. doi: 10.4141/cjps62-032

MATZENAUER, R.; RADIN, B.; ALMEIDA , R.D. Climatic Atlas: Rio Grande do Sul. Porto Alegre: FEPAGRO, 2011.

NATIONAL SUPPLY COMPANY (CONAB). Harvest Survey, 2016. Available in: <http://www.conab.gov.br/OlalaCMS/uploads/arquivos/16_05_27_09_24_04_boletim_graos_maio__2016_-_final.pdf>. Acess im: May 14 2016.

RICHARDS, L.A.; FIREMAN, M. Pressure plate apparatus for measuring moisture sorting and transmission by soils. *Soil Science*, v.56, p.395-404, 1943.

SARTORI, G. M. S. *et al.* Soybean yield as a function of surface planting and irrigation systems in Planosols. *Brazilian Agricultural Research***,** v.50, n.12, p.1139-1149, 2015.

SANTANA, M.J. et al. Viabilidade técnica e econômica da aplicação de água na cultura do feijoeiro comum (*Phaseolus vulgaris* L.). *Scie. Agrotechnol.*, v.33, n.2, p.532-538, 2009. doi: 10.1590/S1413-70542009000200027

SILVA, M.L. O. *et al.* Technical and economic viability of irrigated sunflower off-season cultivation in the region of Lavras, MG. *Scie. Agrotechnol.*, v.31, n.1, p.200-205, 2007.

SILVEIRA, P.M.; STONE, L.F. Bean irrigation. Santo Antônio de Goiás: Embrapa Rice and Beans, 2001.

SILVEIRA, P.M.; STONE, L.F. Irrigation. In: VIEIRA, C.; PAULA JÚNIOR, T.J.; BORÉM, A. Beans: general aspects and culture in the State of Minas. Viçosa: UFV, 1998.

SOUTH BRAZILIAN BEANS TECHNICAL COMMISSION (CTSBF). Technical information for bean cultivation in southern Brazil. Florianópolis: Epagri, 2012.

VAN GENUCHTEN, M.T. A closed form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Scie. Soc. Am. J.*, v.44, n.5, p.892-898, 1980. doi: 10.2136/sssaj1980.03615995004400050002x

YOKOYAMA, L.P. Cultivo de feijão comum. Embrapa, 2003. Available in: <https://sistemasdeproducao.cnptia.embrapa.br/FontesHTML/Feijao/CultivodoFeijoeiro/importancia.htm/. Acess in: Jun 02 2022.