Interaction of planting and harvest dates, and irrigation on fenugreek in the semi-arid High Plains of the USA

Pavlista, Alexander D. and Dipak K. Santra

University of Nebraska, Panhandle Research & Extension Ctr., 4502 Avenue I, Scottsbluff, NE 69361,
USA

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Abstract

Fenugreek can be grown for medicinal purposes, as a spice or as an annual hay. Most fenugreek production is in India; none is grown in the USA. Practices suitable for growing fenugreek in the U.S. High Plains is unknown. The objectives were to identify the irrigation need, and planting and harvest dates in western Nebraska. Fenugreek was planted from early May to early June and harvested from late Aug to early Oct. Irrigation consisted of none, 15 and 30 cm. Height, flowering and fruiting, and seed and straw yields were measured. Later planting did not affect final height but delayed flowering and fruiting (late June to early Aug). Years differed due to weather variations. Seed and straw yields were greatest with later planting and with earlier harvest in 2013 and 2014. Irrigation affected yields primarily in 2013. The lowest yields were in 2015 when the agronomic parameters had the least effect probably due to the very wet spring conditions. For 2013 and 2014, maximum seed yields ranged from 1724 to 1886 kg · ha⁻¹, and maximum straw yields ranged from 4352 to 4981 kg · ha⁻¹ when planted late, irrigated and harvested in late Aug or early Sep. Recommendations are that when May is very dry, plant near 1 June,

irrigate and harvest in late Aug or early Sep, when May is slightly wet, plant in late May, do not irrigate and harvest early Sep, and when May is very wet, do not plant for seed and do not irrigate.

1. Introduction

Fenugreek (*Trigonella foenum-graecum* L.), an annual legume, has been known for millennia for its medicinal properties (Al-Habori and Raman, 2002; Zandi et al., 2015), e.g., treating Type 2 diabetes (Eidi et al., 2007). Currently, 75% of the world supply is produced in India, primarily in Rajasthan, and there is no production in the USA. Fenugreek would do well in light soil (sandy, sandy loam) and alkaline soil (pH 8-8.5) (Acharya et al., 2008; Petropoulos, 2002). Both these conditions characterize western Nebraska soils as well as that of Rajasthan. Furthermore, fenugreek requires less N than many crops ($30\text{--}50\text{ kg} \cdot \text{ha}^{-1}$) and does well under low rainfall (30-40 cm). It is considered drought resistant (Duke, 1986), and its relatively low precipitation requirement suggests suitability for the semi-arid conditions of the Great Plains as in Alberta, Canada (Acharya et al., 2008), Kansas (Obour et al., 2015), and western Nebraska. Fenugreek is a new crop for the western Hemisphere (Acharya et al., 2006) and two North American fenugreek cultivars developed were AC Amber and Tristar, targeted as annual forages for Alberta and Manitoba (Acharya et al., 2007; Thomas et al., 2011). The Canadian cultivars are shorter season, 120 day, as opposed to those used in India and therefore better suited for the shorter growing season of northern US and Canada. Fenugreek grows well where alfalfa (*Medicago sativa* L.) is grown (Petropoulos, 2002). It has a high dry matter yield (straw yield) suitable for silage with a nutritive value for cattle similar to that of alfalfa (Mir et al., 1998). Fenugreek would not be difficult to incorporate in a crop rotation with winter crops (Acharya et al., 2008). Under dryland conditions in Alberta, Tristar and AC Amber yields were not significantly different, but under irrigation at Lethbridge, Alberta, Tristar seed and straw yields were higher than AC Amber (Acharya et al., 2007). However, the suitability of either cultivar is unknown for seed and straw production in the High Plains of the USA, an area within the Great Plains of North America.

The objectives of this study were to identify planting dates, harvest dates and irrigation level for growing fenugreek in western Nebraska for highest seed and straw yields of the two Canadian cultivars. The interactions between planting, harvest and irrigation were determined. Besides yields, the effect of these parameters on plant height, flowering and fruiting dates, and seed size were measured.

2. Materials and Methods

2.1 Field Conditions

In 2013, 2014 and 2015, fenugreek (*Trigonella foenum-graecum* L.) cultivars AC Amber and Tristar (Acharya et al., 2007) were conducted at the University of Nebraska's Panhandle Research and Extension Center, Scottsbluff, NE (lat. 41.9 N, long. 103.7 W, elevation 1126 m). A Tripp fine sandy loam soil at pH 8.0, considered in optimal range (Petropoulos, 2012). The organic matter content of the soil was 1%. Pre-plant soil N levels in the top 40 cm were 62, 45 and 19 kg · ha⁻¹ for each year respectively (Table 1). No fertilizer was added. Seeds were inoculated with a mixture of *Rhizobium leguminosarum biovar trifolii* and *Sinorhizobium metilii* (N-Dure at 170 g/ 22.7 kg seed) just prior to planting (Petropoulos, 2002). Previous crops were sunflower (*Helianthus annuus* L.), winter wheat (*Triticum aestivum* L.), and corn (*Zea mays* L.) for 2013, 2014 and 2015 respectively.

Soil water content in the top 40 cm prior to the start of irrigation was 16.6, 14.6 and 18.0% for each year respectively (Table 1) corresponding to 75, 66 and 82% of soil saturation. Rainfall and temperature were monitored by the High Plains Regional Climate Center (Changnon et al. 1990) and presented for each year by month with comparison to the 30-year mean in Table 1. Each year represented very different weather conditions. In May of 2013, rainfall was in extreme deficit with only 43 mm (Table 1). The year 2013 was considered a drought year with less than 50% average rainfall for the growing season, June,

July and August. Temperature was above normal in May and during the growing season (Table 1). In 2014, May had slightly above normal rain but was dry during the summer and temperature was below normal for May and the summer (Table 1). May of 2015 experienced 173 mm of rain, more than double the normal amount (Table 1). Although June and August were dry, July rain was also much above normal, and as a result, the rainfall from June to August was near normal. The overall temperature for 2015 was near normal (Table 1). In 2015, the trial was exposed to a severe hail storm on July 27 that caused 30-40% defoliation.

Weed control was accomplished by application of trifluralin [1.4 l Trust (43% AI) /ha] one day after planting (pre-emergence) followed by a post-emergence application, 2 to 3 weeks after planting or 1 to 2 weeks after emergence, of imazamox [292 ml Raptor (12.1% AI) /ha] (Moyer et al., 2003). Fenugreek is insect tolerant (Acharya et al., 2008) and no insecticide was applied or needed. Nor was any fungicide applied or needed.

Plots consisted of four rows of which the center two rows were harvested. Rows were spaced 30 cm apart. Seeding rate was $22 \text{ kg} \cdot \text{ha}^{-1}$ which in separate trials was determined to be within the optimal range (unpublished data). Planting was performed using a grass drill. In 2013, to promote germination, 6 mm of irrigation was applied a few days after each planting (Duke, 1986). Plots were 15.25 m long of which 4.6 m was harvested at each harvest date. Harvesting was performed by manually undercutting the plants with a shovel after which they were bagged. Bags were stored in a hoop tunnel until dry. Plants were then weighed to determine straw yield and mechanically threshed using a combine, mimicking windrow harvesting. The seed was cleaned and weighed to determine seed yield.

2.2 Experimental Conditions

This study contained three variables, planting date, harvest date and irrigation level. Planting dates were 7

May, 17 May and 28 May in 2013, 6 May, 20 May and 2 Jun in 2014, and, due to high rainfall, 15 May, 1 June and 8 June in 2015. Harvest dates were 20 Aug, 10 Sep and 2 Oct in 2013, 19 Aug, 10 Sep and 2 Oct in 2014, and 26 Aug, 9 Sep, and 25 Sep in 2015. Three irrigation levels were tested, no irrigation (rain-fed), half-irrigated (deficit irrigation) when 152 mm of water was irrigated, and fully-irrigated when 304 mm of water was added (Bhati, 1993). The target was to separate the irrigation levels by 152 mm of irrigation water during the growing season, June, July and August. Actual exposure, rain plus irrigation water are presented in Table 1. May rainfall is reported in Table 1 as well as it may have impacted the results. In 2013, May was very dry; in 2014, it was slightly above normal, and in 2015, May was very wet. Irrigation regimes commenced on 3 Jun 2013 due to the dry May conditions, and due to wetter conditions, on 3 Jul 2014 and on 2 Jul 2015. The aim was to separate the three irrigation levels by 152 mm of irrigation for the growing seasons.

2.3 Data Collection

Plant height, flowering and fruiting data were taken weekly in June, July and August. Plant height was measured with a meter stick at two places in each of the two center rows in each plot. The percent flowering was visually estimated based on the number of open flowers versus total buds, open and closed, on plants. The percent fruiting was visually estimated based on the number of pods versus total flowers plus pods. Peak flowering or bloom, and peak fruiting or podding, were the dates at which the percent flowering and fruiting were the highest. Seed and straw yields were measured at each of the three harvest dates. Tristar seed harvested in Aug and Sep were measured for their weight and volume. Seed weight was determined by counting out 100 seeds and weighed. To determine seed volume, seed were poured into a 10-ml graduated cylinder to the 10 ml mark and weighed. Seed number in 1 cc was calculated by the weight of seed in 1 cc by the weight of a seed.

The two cultivars, AC Amber and Tristar, were planted side-by-side in a paired plot design within each

planting date section. Within each replicate, planting date sections were placed in a 3 by 3 Latin Square. Irrigation level were the main plots and consisted of three replications placed in a 3 by 3 Latin Square. Data, comparing years, cultivars, planting dates, harvest dates, and irrigation levels, were analyzed using Proc ANOVA in SAS with means separated using least significant differences and inferences based on a 5 % significance level (SAS Institute 2003) when $p < 0.05$. Possible interactions were determined as well. Years were significantly different with respect to plant height, flowering and fruiting peaks, and seed and straw yields.

3. Results

3.1 Growth and development

The final plant height for none and half irrigated plants in 2013 was significantly less than that in 2014 and 2015 (Table 2). This may be due to the drought in 2013 especially in May prior to irrigation (Table 1). Fully irrigated plants achieved the similar height regardless of year. There was no significant difference between the two cultivars nor between planting dates in any of the three years (Table 2). Irrigation level only affected height in 2013 when none irrigated plants were significantly shorter than fully irrigated plants (Table 2).

Peak flowering and fruiting dates were the same for both cultivars, AC Amber and Tristar. In 2013, comparing similar planting dates, flowering and fruiting peaked earlier than in 2014 and 2015 (Table 3). This may be attributable to the drought stress in 2013 (Table 1). Fruiting tended to peak one to two weeks after the flowering peak in all cases regardless of planting date or irrigation level (Table 3). Flowering and fruiting peaks were delayed with later planting dates. In 2013, irrigation did not affect peak flowering and fruiting dates, but in 2014 and 2015, there seemed to be a delay in reaching these peaks when plots were planted on 1 and 2 June and irrigated (Table 3). Note that in 2015, there was a severe hail event on 27

July and the month experienced high rainfall; these factors may have had contributed to the delay that year.

3.2 *Seed yield*

The fenugreek cultivars AC Amber and Tristar were not significantly different for seed yield (Table 4) and therefore their data were averaged. In 2013, seed yield was significantly affected by planting date, harvest date and irrigation, in 2014; irrigation had no significant effect, and in 2015, harvest date had no significant effect (Table 4). Note the weather differences between years (Table 1) which may explain the seed yield variation between years. Years were significantly different; the overall seed yield, combining all treatments, showed the year 2014 with a mean seed yield of $1265 \text{ kg} \cdot \text{ha}^{-1}$ to be significantly greater than the years 2013 and 2015, by 48% and 70% respectively. There was an interaction between irrigation with planting date and with harvest date in 2013. Seed yield for years, irrigation level, planting date, and harvest date were presented separately in Table 5 for comparison.

In 2013 and 2014, planting later with irrigation increased yield at both the Aug and Sep harvest (Table 5). In both years, yields harvested on 2 Oct had significantly poorer yields than the two earlier harvest but the pattern of higher yields with later planting remained similar. In 2013, irrigating significantly increased yield in 2013 for all planting dates at all harvest dates (Table 5). The greatest seed yields, 1772 to $1813 \text{ kg} \cdot \text{ha}^{-1}$, were attained that year by planting on 17 and 28 May with full irrigation and harvesting on 21 Aug, and by planting on 28 May with half and full irrigation and harvesting on 10 Sep (Table 5). In 2014, irrigation did not have a significant effect on seed yield (Table 5). The greatest seed yields, 1724 to $1886 \text{ kg} \cdot \text{ha}^{-1}$, were attained in 2014 by planting on 2 Jun and harvesting on 10 Sep regardless of irrigation (Table 5). In 2015, seed yields were very low, $<950 \text{ kg} \cdot \text{ha}^{-1}$, and there were few significant differences detected (Table 5).

3.3 *Seed size*

Years 2013 and 2014 did not differ with respect to seed size, i.e., weight of seed, volume of seed, number of seed in a given volume (Table 6). In 2015, seed were significantly lighter than the other two years and more seed was needed to reach a given volume indicating smaller seed. Due to 2015 being a very wet year, there was significant interaction between year and irrigation on seed weight and size (Table 6). In all three years, harvesting in early Sep resulted in lighter and slightly smaller seed (Table 6). Irrigation increased the weight and size of seed (Table 6).

3.4 *Straw yield*

The overall straw yield, combining all treatments, in 2014 gave the highest yield of $4360 \text{ kg} \cdot \text{ha}^{-1}$, significantly greater than 2013 ($2842 \text{ kg} \cdot \text{ha}^{-1}$) and 2015 ($2781 \text{ kg} \cdot \text{ha}^{-1}$) by 53% and 57% respectively (Table 7). Cultivars showed no significant difference in 2013 and 2015 (Table 4), but in 2014, AC Amber straw yield was $4787 \text{ kg} \cdot \text{ha}^{-1}$, significantly greater than Tristar with $3931 \text{ kg} \cdot \text{ha}^{-1}$ by 22%. For simplicity, however, data from the two cultivars were averaged as they showed the same pattern in 2014. In both 2013 and 2015, straw yield was affected by planting date, harvest date and irrigation level (Table 4). In 2014, only harvest date affected straw yield; that year's weather was nearest to normal (Table 1). There were no interaction for straw yield in any year (Table 4). Straw yield for years, irrigation level, planting date, and harvest date were presented separately in Table 7 for comparison.

In 2013 at the Aug harvest, straw yield was increased with later planting when irrigated (Table 7). The Sep harvest showed a similar trend, but the Oct harvest did not (Table 7). At all three harvest, irrigation increased straw yield of all three planting dates. Straw yield harvested on 2 Oct was significantly below, by a third, that from the two earlier harvest (Table 7). The highest straw yield (4352 to $4843 \text{ kg} \cdot \text{ha}^{-1}$), as with seed yield, was attained that year by planting on 17 and 28 May with full irrigation and harvesting

21 Aug, and by planting 28 May under irrigation and harvesting 10 Sep (Table 7). Note that this year also had very low rainfall in May before the start of irrigation and was considered a drought year (Table 1). The year 2014 had the highest straw yield of the three year. However, there was no significant effect on straw yield by planting date or irrigation level; however, yield was significantly less when harvested in Oct ($3652 \text{ kg} \cdot \text{ha}^{-1}$) compared to the two earlier harvests, 4445 and $4981 \text{ kg} \cdot \text{ha}^{-1}$, respectively (Table 7). In 2015, straw yield was greatest with the first harvest compared to the two later ones (Table 7). For the first harvest on 26 Aug, straw yield was not affected by planting date, but for the 15 May and 1 Jun planting dates, there may have been a yield promotion by irrigation (Table 7). For the second and third harvests, straw yield was greatest when planting was on 8 Jun (Table 7). In the second harvest, greater irrigation increased straw yield when planting was 15 May and 1 Jun, but not at 8 Jun, but in the third harvest, irrigation only affected the 8 Jun planting (Table 7).

4. Discussion

4.1 Field conditions

In a separate trial (2014), seeding rate of fenugreek was determined to be optimal at $21 \text{ kg} \cdot \text{ha}^{-1}$ (unpublished data) which agreed with the literature (Petropoulos, 2002). Row spacing was 30 cm which also conformed with the literature (Petropoulos, 2002). In a preliminary trial in 2012 under full irrigation, nitrogen was added pre-plant and had no effect on yield. It was determined that the residual N in the top 40 cm was over $50 \text{ kg} \cdot \text{ha}^{-1}$ (unpublished data) which was more than sufficient for fenugreek production. Therefore, no fertilizer was added in 2013, 2014 and 2015. In 2015, however, soil N measured prior to irrigation was low ($19 \text{ kg} \cdot \text{ha}^{-1}$) probably due to leaching caused by the unusual rain of May.

4.2 Plant height and development

Plant height was not affected by planting date. With the exception of 2013 non-irrigated plots, fenugreek height ranged from 33 to 41 cm for the two cultivars within the range reported for fenugreek in Turkey, 36 to 44 cm (Tuncturk et al., 2011) and for fenugreek in India, 25 to 54 cm depending on genotype with a mean of 38 cm (Chandra et al., 2000). In Canada, the height of Tristar at flowering was about 40 cm (Acharya et al., 2007). Irrigation had no effect on plant height in 2014 and 2015 when May rainfall was above normal, but height was increased when 15 or 30 cm of irrigation was applied in 2013 when rainfall was very low in May. A similar height response to irrigation was reported with winter-grown fenugreek in India with seasonal water application of 33-34 cm, rain plus irrigation (Bhati, 1993) and with potted plants in Poland (Zuk-Golaszewska et al, 2015).

In the review by Petropoulos (2002), he indicated that flowering of fenugreek occurred between 30 and 40 days after planting (DAP) in Europe. Chandra et al. (2000) observed flowering of fenugreek between 48 and 58 DAP depending on genotype with a mean of 52 DAP in India. In 2013, this study showed flowering to occur from 50 DAP for the 6 May planting to 43 DAP for the 28 May planting. In 2014, flowering was at 57 DAP for the 6 May planting and 44 DAP for the 2 Jun planting (Table 3). Flowering in 2014 may have been later than in 2013 due to the wetter May and Jun in 2014. Based on calendar day, later flowering occurred with later planting as was reported by Petropoulos (2002) with planting from mid Mar to mid Apr. In 2015, flowering was later than the previous years occurring 52 to 59 DAP (Table 3) and was not affected by planting date, possibly due to the very wet May and July (Table 1). Fruit (pod) appearance was observed one to two weeks after flowering. Irrigation did not affect flowering or fruiting peak dates (Table 3). In all years, flowering and fruiting peaks took fewer days to reach when seeds were planted later.

4.3 Seed yield

In 2013 and 2014, seed yield harvested in late Aug and early Sep with applied irrigation increased with later planting. In 2012, a preliminary trial (unpublished data) on AC Amber and Tristar was conducted with two planting dates in April under full irrigation and harvest in early Sep. These planting dates were chosen because of practices in the U.K., mid-Mar to mid Apr and in Germany, April, for seed production (Petropoulos, 2002). Petropoulos (2002) also reported that planting later in the spring resulted in a decrease in seed yield. The 2012 trial results suggested that April may be too early to plant in western Nebraska and therefore, later planting dates were chosen for subsequent trials. When the seed yield data from AC Amber and Tristar were averaged, and the seed yield for the three years under full irrigation and with early Sep harvested were graphed against planting date, seed yields increased as planting was delayed (Fig. 1). The highest yield was attained when planting was on 28 May 2013 and 2 June 2014. The regression line indicated a $26 \text{ kg} \cdot \text{ha}^{-1}$ gain for each day planting was delayed with an R^2 of 0.97. Note that data from 2015 were not included due to the unusually low yields possibly resulting from the very wet weather in May. These results are in contrast to that reported in Alberta for forage / hay production where planting from mid-April to mid-May was recommended (Acharya et al., 2008). In Kansas, Obour et al. (2015) reported no effect of planting between 1 Apr to 22 May on forage yield. In Poland, Bienowski et al. (2016) reported the highest seed yield per plant was attained with the earliest planting in spring; however the maximum seed yield reported was $840 \text{ kg} \cdot \text{ha}^{-1}$.

Irrigation increased seed yield for all planting dates and harvest dates in 2013, a drought year with very low rainfall, 43 mm, in May. There was no irrigation effect in 2014, a more normal year with slightly above normal rainfall, 173 mm, in May. In Iran, Dadrasan et al. (2015) reported that deficit irrigation, three-quarters that required by plant based on evapotranspiration measurements, decreased seed yield by 27% and forage yield by 40% when pre-planting rainfall was less than 89 mm (2012) and 45 mm (2013), and seasonal rain was less than 27 mm. In India, with winter-grown fenugreek, under low rainfall, irrigation increased seed yield to a maximum of $1300 \text{ kg} \cdot \text{ha}^{-1}$ (Kumar et al., 2000). Bhati (1993)

reported that 30 cm seasonal irrigation was needed to achieve maximum yield in India. Seed yields from irrigated fenugreek in Alberta were 1020 and 1290 kg · ha⁻¹ for AC Amber and Tristar, respectively (Acharya et al., 2007). In potted plants, soil water deficit decreased seed yield (Zuk-Golaszewska et al., 2015).

Harvesting of fenugreek achieved the highest yield when it was conducted in late Aug to early Sep. Yields decreased significantly and substantially when harvest was around 1 Oct. This may be explained by the high risk of shatter and seed loss (Petropoulos, 2002). With Aug harvest, fenugreek can easily be incorporated as a legume into a crop rotation with a winter crop such as wheat (Acharya et al., 2008).

Tuncturk et al. (2011) reported a seed weight of 1.8 g /100 seeds in Turkey which is heavier than observed in western Nebraska. In Poland, a seed weight range of 1.4 to 1.5 g/100 seeds, similar to that reported here, was reported (Bienkowski et al., 2016). Variation in seed weight is probably due to germplasm as different germplasms differ in seed weight even when grown next to each other in the same year (Santra, unpublished data).

4.4 *Straw yield*

The highest straw yield, plant dry weight at harvest, a.k.a. forage, silage, occurred in 2013 and 2014. Straw yield, in 2013 when May was very dry, was primarily increased by irrigation, but in 2014 when May was slightly wet, it was not affected by irrigation. Later planting dates may show a yield increase but the effect varied by year, irrigation and harvest date. Straw yield was observed as high as 5200 kg · ha⁻¹ which was considerably above that reported for AC Amber (852 kg · ha⁻¹) and Tristar (753 kg · ha⁻¹) in Kansas (Obour et al., 2015). However, the western Nebraska yields were near the range (5700 kg · ha⁻¹) reported for Alberta (Acharya et al., 2007; 2008).

5. Conclusion

Fenugreek can be grown for both seed and straw successfully in western Nebraska. It is best to plant in late May and harvest from late Aug to early Sep. If rain in May is below normal, 43 mm in 2013, and the season is dry, irrigation will be needed. If irrigation is 15 cm, then it is best to harvest in early Sep but with 30 cm, harvest in late Aug is acceptable. If rain in May is sufficient but not excessive, 89 mm in 2014, and even when the seasonal rain is below normal, 102 mm in 2014, irrigation may not be required. If rain in May is excessive, 173 mm in 2015, then it may be best not to plant fenugreek in western Nebraska. Note that since, the two cultivars studied here were bred in Alberta as a forage crop, locally adapted cultivars are needed to be bred and identified for optimal yields (Zandi et al., 2015). Such a program is currently in progress (Santra, personal communications).

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References

- Acharya, S.N., Blade, S., Mir, Z., Moyer, J.R. 2007. Tristar fenugreek. *Can. J. Plant Sci.* 87:901-903.
- Acharya, S.N., Thomas, J.E., Basu, S.K. 2006. Fenugreek: an “old world” crop for the “new world.” *Biodiversity* 7:27-30.
- Acharya, S.N., Thomas, J.E., Basu, S.K. 2008. Fenugreek, an alternative crop for semiarid regions of

North America. Crop Sci. 48:841-852.

Al-Habori, M., Raman, A. 2002. Pharmacological properties. In: Petropoulos, G.A. (Ed.), Fenugreek The genus *Trigonella*. CRC Press, Boca Raton, FL, USA. pp. 162-182.

Bienkowski, T., Zuk-Golaszewska, K., Kurowski, T., Golaszewski, J. 2016. Agrochemical indicators for *Trigonella foenum-gracum* L. Production in the environmental conditions of northeastern Europe. Turkish J. Field Crops 21:16-28.

Bhati, D.S. 1993. Effect of irrigation and phosphorus on seed yield and its attributes of fenugreek (*Trigonella foenum-graecum*). Indian J. Agron. 38:449-452.

Changnon, S.A., Lamb, P., Hubbard, K.G. 1990. Regional climate centers: new institutions for climate services and climate-impact research. *Bulletin of the American Meteorological Society* 71:527-537.

Chandra, K., Sastry, E.V.D., Singh, D. 2000. Genetic variation and character association os seed yield and its component characters in fenugreek. Agric. Sci. Digest 20:93-95.

Dadrasan, M., Chaichi, M.R., Pourbabaee, A.A., Yazdani, D., Keshavarz-Afshar, R. 2015. Deficit irrigation and biological fertilizer influence on yield and trigonelline production of fenugreek. Ind. Crops Prod. 77:156-162.

Duke, A.J. 1986. Handbook of Legumes of Word Economic Importance. Plemus Press, N.Y.

Eidi, A., Eidi, M., Sokhteh, M. 2007. Effect of fenugreek (*Trigonella foenum-graecum* L.) seeds on serum

parameters in normal and streptozotoci-induced diabetic rats. Sci. Digest 27:728-733.

Kumar, V., Yadav, J.S., Singh, J., Yadav, B.D. 2000. Irrigation and phosphorus requirement of fenugreek (*Trigonella foenum-graecum*) on light soil. Indian J. Agric. Sci. 70:515-517.

Mir, Z., Mir, P.S., Acharya, S.N., Zaman, M.S., Taylor, W.G., Mears, G.J., McAllister, T.A., Goonewardene, L.A. 1998. Comparison of alfalfa and fenugreek (*Trigonella foenum-graecum*) silages supplemented with barley grain on performance of growing steers. Can. J. Anim. Sci. 78:343-349.

Moyer, J.R., Acharya, S.N., Mir, Z., Doram, R.C. 2003. Weed management in irrigated fenugreek grown for forage in rotation with other annual crops. Can. J. Plant Sci. 83:181-188.

Obour, A., Obeng, E., Holman, J.D. 2015. Influence of different seeding dates on fenugreek (*Trigonella foenum-graecum* L.) forage yield and nutritive value. Kansas Agric. Exp. Sta. Res. Report: vol. 1, iss. 2.

Petropoulos, G.A. 2002. Cultivation. In: Petropoulos, G.A. (Ed.), Fenugreek The genus *Trigonella*. CRC Press, Boca Raton, FL, USA. pp. 26-72.

Thomas, J.E., Bandara, M., Driedger, D., Lee, E.L. 2011. Fenugreek in western Canada. Amer. J. Plant Sci. Biotech. 5:32-44.

Tuncturk, R., Celen, A.E., Tuncturk, M. 2011. The effects of nitrogen and sulphur fertilizers on the yield and quality of fenugreek (*Trigonella foenum-graecum* L.). Turkish J. Field Crops 16:69-75.

Zandi, P., Basu, S.K., Khatibani, L.B., Balogun, M.O., Aremu, M.O., Sharma, M., Kumar, A., Sengupta, R., Li, X., Li, Y., Tashi, S., Hedi, A., Cetzal-Ix, W. 2015. Fenugreek (*Trigonella foenum-graecum* L.) seed: a review of physiological and biochemical properties and their genetic improvement. *Acta Physiol. Plant.* 37:1714, p.14. DOI 10.1007/s11738-014-1714-6.

Zuk-Golaszewska, K., Wierzbowska, J., Bienkowski, T. 2015. Effects of potassium, *rhizobium* inoculation and water deficit on the yield and quality of fenugreek seed. *J. Elementology* 20:513-524.

Figure Legend

Figure 1. Seed yield obtained from different planting dates. Data points were the average of yield from fenugreek cv. AC Amber and Tristar grown under full irrigation, targeted for 406 mm rain plus irrigation during the growing season, and harvested in early Sep. Linear regression equation indicated that for each day that planting was delayed after mid-April, there was a $26 \text{ kg} \cdot \text{ha}^{-1}$ increase in seed yield with a $R^2 = 0.97$.

Table 1

Table 1. Soil water and nitrogen at planting and after harvest, and monthly rainfall and temperature at the Panhandle Research & Extension Center, Scottsbluff, NE.

		Year		
		2013	2014	2015
Soil Water ¹	pre-irrigated ²	16.6%	14.6%	18.0%
Rainfall	May	43 mm (60% ³)	89 mm (120%)	173 mm (220%)
	June	41 mm (52%)	38 mm (49%)	51 mm (66%)
	July	24 mm (38%)	50 mm (82%)	85 mm (138%)
	August	15 mm (32%)	13 mm (29%)	27 mm (59%)
	June to August	79 mm (42%)	102 mm (55%)	164 mm (88%)
Irrigation (June to 2 nd harvest)	no irrigation	0	0	0
	half irrigation	150 mm	150 mm	114 mm
	full irrigation	292 mm	304 mm	254 mm
Rain + Irrigation	no irrigation	79 mm	102 mm	164 mm
	half irrigation	229 mm	252 mm	278 mm
	full irrigation	371 mm	406 mm	418 mm
Temperature	May	14.3°C (+0.3 ⁴)	13.8°C (-0.2)	11.4°C (-2.6)
	June	20.9°C (+1.5)	18.8°C (-0.7)	21.3°C (+1.9)
	July	22.8°C (-0.3)	22.4°C (-0.7)	21.8°C (-1.3)
	August	22.8°C (+1.0)	21.3°C (-0.5)	21.3°C (-0.5)
	June to August	22.2°C (+0.7)	20.8°C (-0.6)	21.5°C (+0.1)
Nitrogen ⁵	May	62 kg/ha	45 kg/ha	19 kg/ha
	October	64 kg/ha	49 kg/ha	35 kg/ha

¹ Soil water contents as amount in the top 40 cm of soil were measured using gravimetric procedure.

² Measurements were taken on 28 May 2013, 2 July 2014, and 1 July 2015; irrigation treatments began on 3 June 2013, 3 July 2014, and 2 July 2015.

³ Percentages in parenthesis are the % of the 30-year average for site.

⁴ Numbers in parenthesis are the +/- temperature deviation from the 30-year average for site.

⁵ Soil nitrate-N content in the top 40 cm of soil were measured by Ward Lab., Kearney, NE.

Table 2

Table 2. Fenugreek height in the last week of August¹ as affected by planting date and irrigation level for cultivars AC Amber and Tristar in 2013, 2014, and 2015.

Planted Date	Amber			Tristar		
	no irrigation ²	half irrigation	fully irrigation	no irrigation	half irrigation	fully irrigation
cm						
2013						
7 May	23	29	34	25	33	36
17 May	24	32	41	26	34	37
28 May	23	32	40	24	34	35
mean	23 B ³ ,Z ⁴	33 A,Z	38 A	25 B,Z	34 A,Z	36 A
2014						
6 May	40	39	43	37	39	38
20 May	38	43	43	37	39	43
2 Jun	42	39	42	40	40	39
mean	40 Y	40 Y	43	38 Y	39 Y	40
2015						
15 May	36	38	38	36	38	39
1 Jun	40	41	40	41	40	41
8 Jun	39	41	43	42	41	43
mean	38 Y	40 Y	40	40 Y	40 Y	41

¹ Heights were measured on 28 Aug 2013, 27 Aug 2014, and 26 Aug 2015.

² For the growing season of June, July and Aug, non-irrigated = rain-fed; half-irrigated targeted at 152 mm irrigation, and fully-irrigated targeted at 304 mm irrigation.

³ Numbers in rows (irrigation level) followed by different letters (A and B) for each cultivar differed significantly at $p < 0.05$ using least square separation of the means.

⁴ Means in columns (year) followed by different letters (Y and Z) differed significantly at $p < 0.05$ using least square separation of the means.

Table 3

Table 3. Dates when fenugreek flowering and fruiting peaked as affected by planting date and irrigation level for cultivars AC Amber and Tristar in 2013, 2014, and 2015.

Planted Date	Peak Flowering Date(s)			Peak Fruiting Date(s)		
	no irrigation ¹	half irrigation	fully irrigation	no irrigation	half irrigation	fully irrigation
2013						
7 May	26 Jun	26 Jun	26 Jun	3-10 Jul	3-10 Jul	3-10 Jul
17 May	3 Jul	3 Jul	3 Jul	10 Jul	10 Jul	10 Jul
28 May	10-17 Jul	10-17 Jul	10-17 Jul	24 Jul	17-31 Jul	24 Jul
2014						
6 May	2 Jul	2 Jul	2 Jul	9 Jul	9 Jul	9 Jul
20 May	2-16 Jul	2-16 Jul	16 Jul	23 Jul	16-23 Jul	23 Jul
2 Jun	16 Jul	16-23 Jul	30 Jul	30 Jul	30 Jul	6 Aug
2015						
15 May	1-8 Jul	8 Jul	8 Jul	23 Jul	23 Jul	23 Jul
1 Jun	15 Jul	15-23 Jul	23 Jul	23 Jul	6 Aug	6 Aug
8 Jun	6 Aug	6 Aug	6 Aug	6-12 Aug	6-12 Aug	6-12 Aug

¹ For the growing season of June, July and Aug, non-irrigated = rain-fed; half-irrigated targeted at 152 mm irrigation, and fully-irrigated targeted at 304 mm irrigation.

Table 4

Table 4. Statistical analyses of seed and straw yield of fenugreek by year.

	seed yield			straw yield		
	2013	2014	2015	2013	2014	2015
	p-value					
cultivar (C)	NS ¹	NS	NS	NS	<0.01	NS
planting date (P)	<0.01	<0.01	0.02	0.01	NS	<0.01
harvest date (H)	<0.01	<0.01	NS	<0.01	<0.01	<0.01
Irrigation (I)	<0.01	NS	0.05	<0.01	NS	<0.01
C*P	NS	NS	0.03	NS	NS	NS
C*H	NS	NS	NS	NS	NS	NS
C*I	NS	NS	NS	NS	NS	NS
P*H	NS	NS	<0.01	NS	NS	NS
P*I	0.01	NS	NS	NS	NS	NS
H*I	<0.01	NS	NS	NS	NS	NS
P*H*I	NS	NS	NS	NS	NS	NS

¹ NS indicates $p > 0.05$.

Table 5

Table 5. Seed yields of fenugreek as affected by planting date and irrigation level for cultivars AC Amber and Tristar, averaged, in 2013, 2014, and 2015.

Planted Date	non-irrigated ¹	half-irrigated	fully-irrigated	non-irrigated	half-irrigated	fully-irrigated	non-irrigated	half-irrigated	fully-irrigated
kg/ha									
2013	harvested on 21 Aug			harvested on 10 Sep			harvested on 2 Oct		
7 May	681 Y ²	878 B,Y	1419 B,X	590 Z	912 B,Y	1187 B,X	113 B,Z	216 B,Y	371 X
17 May	645 Z	1076 B,Y	1800 A,X	613 Y	1123 B,X	1335 AB,X	200 A,Y	290 B,XY	378 X
28 May	650 Z	1315 A,Y	1813 A,X	639 Y	1772 A,X	1785 A,X	239 A,Y	466 A,XY	563 X
	harvest mean = 1142 (1) ³			harvest mean = 1106 (1)			harvest mean = 315 (2)		
2014	harvested on 19 Aug			harvested on 10 Sep			harvested on 2 Oct		
6 May	1060 B	974 B	1254 B	1281 B	1194 B	1198 B	709 B	752 B	939 B
20 May	1144 AB	1048 AB	1339 AB	1626 B	1421 AB	1582 AB	913 AB	1064 A	1078 AB
2 Jun	1375 A	1330 A	1560 A	1886 A	1724 A	1864 A	1274 A	1221 A	1348 A
	harvest mean = 1232 (2)			harvest mean = 1531 (1)			harvest mean = 1033 (3)		
2015	harvested on 26 Aug			harvested on 9 Sep			harvested on 25 Sep		
15 May	783	694 A	790	683	655	734	653	663	678
1 Jun	756	728 A	698	744	745	873	768	725	773
8 Jun	701	575 B	685	810	786	807	760 Y	869 X	922 X
	harvest mean = 712			harvest mean = 760			harvest mean = 757		

¹ For the growing season of June, July and Aug, non-irrigated = rain-fed; half-irrigated targeted at 152 mm irrigation, and fully-irrigated

targeted at 304 mm irrigation

² Within each year, under each harvest date, numbers in rows followed by different letters (X, Y, Z) differed significantly at $p < 0.05$ using least square separation of the means and numbers in columns followed by different letters (A, B) were likewise significantly different.

³ Harvest means, averaging planting dates and irrigation levels, for each year followed by different parenthetic numbers (1, 2, 3) differed significantly at $p < 0.05$ using least square separation.

Table 6

Table 6. Seed size of fenugreek harvested in late Aug and early Sep for each year as affected by harvest date and irrigation level in the Nebraska Panhandle.

	g of 100 seed ¹	g seed in 10 cc ²	seed number in 1 cc ³
year (Y)			
2013	1.31 A ⁴	7.21	55 B
2014	1.34 A	7.17	54 B
2015	0.94 B	7.16	76 A
harvest (H)			
late August	1.25 A	7.23 A	58 B
early September	1.20 B	7.15 B	60 A
irrigation level (I)			
0 (none)	1.17 C	7.24 A	62 A
15 cm (half)	1.23 B	7.19 AB	58 B
30 cm (full)	1.28 A	7.13 B	56 C
Y	<0.01	NS ⁵	<0.01
H	<0.01	<0.01	0.01
I	<0.01	<0.01	<0.01
Y*H	<0.01	<0.01	<0.01
Y*I	<0.01	<0.01	<0.01
H*I	NS ⁵	NS	NS
Y*H*I	NS	NS	NS

¹ Seed weight was determined on 100 seeds² Seed volume was estimated by the weight of seed that fills a 10-ml graduated cylinder.³ Seeds per cc was calculated by dividing the weight of seed in 1 cc by the weight of 1 seed.⁴ Numbers in each column in each section followed by different letters differed significantly at $p < 0.05$ using least square separation of the means.⁵ NS indicates $p > 0.05$.

Table 7

Table 7. Straw yields of fenugreek as affected by planting date and irrigation level for cultivars AC Amber and Tristar averaged, in 2013, 2014, and 2015.

Planted Date	non-irrigated ¹	half-irrigated	fully-irrigated	non-irrigated	half-irrigated	fully-irrigated	non-irrigated	half-irrigated	fully-irrigated
kg/ha									
2013	harvested on 21 Aug			harvested on 10 Sep			harvested on 2 Oct		
7 May	2407 Y ²	2916 b,Y	3879 B,X	1760 Y	2550 B,Y	3771 X	1311 Y	1784 Y	2957 X
17 May	2125 Z	3502 ab,Y	4843 A,X	1754 Y	3053 B,X	3735 X	1299 Z	2125 Y	2927 X
28 May	2179 Y	3825 a,Y	4585 A,X	1838 Y	4352 A,X	4783 X	1449 Y	2215 X	2820 X
	harvest mean = 3362 (1) ³			harvest mean = 3066 (1)			harvest mean = 2099 (2)		
2014	harvested on 19 Aug			harvested on 10 Sep			harvested on 2 Oct		
6 May	4077	3562	4346	4657	4968	4298	3328	3143	3723
20 May	4358	4562	5220	5094	5358	4795	3634	3855	3765
2 Jun	4615	4568	4693	5573	4969	5118	3766	3675	3975
	harvest mean = 4445 (1)			harvest mean = 4981 (1)			harvest mean = 3652 (2)		
2015	harvested on 26 Aug			harvested on 9 Sep			harvested on 24 Sep		
15 May	2694 y	2981 xy	3098 x	2152 B,Y	2332 B,XY	2664 B,X	2176 B	2415 B	2442 B
1 Jun	2831 y	3200 xy	3292 x	2544 AB,Y	2712 AB,XY	3134 A,X	2601 A	2445 B	2628 B
8 Jun	2873	3149	3433	2745 A	2924 A	3017 A	2554 A,Y	2993 A,X	3053 A,X
	harvest mean = 3061 (1)			harvest mean = 2691 (2)			harvest mean = 2579 (2)		

¹ For the growing season of June, July and Aug, non-irrigated = rain-fed; half-irrigated targeted at 152 mm irrigation, and fully-irrigated

targeted at 304 mm irrigation.

² Within each year, under each harvest date, numbers in rows followed by different letters (X, Y, Z) differed significantly at $p < 0.05$ using least square separation of the means and numbers in columns followed by different letters (A, B) likewise differ significantly. Similarly, numbers followed by different ordinal letters (a,b and x,y) were different at $p < 0.10$.

³ Harvest means, averaging planting dates and irrigation levels, for each year followed by the same parenthetic number (1, 2) are not significantly different at $p < 0.05$ using least square separation.

Figure 1