Adaptation of Chickpea to High Latitude Areas with Short Growing Seasons: Biomass and Seed Yield Responses

Y. Gan[a], T. Warkentin[b], R.P. Zentner[a], C.L. McDonald[a], and A. Vandenberg[b]

[a]Agriculture and Agri-Food Canada, SPARC, Swift Current, SK, S9H 3X2
[b]Crop Development Centre, University of Saskatchewan, Saskatoon, SK, S7N 5A8

Abstract

This study was conducted to determine plant establishment, biomass and seed yield of chickpea under diverse environmental and crop management conditions. Four cultivars were grown on three types of seedbed using N fertilizer rates of 0, 28, 64, 84, and 112 kg N ha^{-1} with and without *Rhizobium* inoculant (GR), at six sites in Saskatchewan, Canada. On average, chickpea grown on fallow seedbed produced the highest straw biomass, 5.8 t ha^{-1}, or 28% greater than chickpea grown on barley stubble and 13% greater than being grown on wheat stubble. Similarly, chickpea grown on fallow produced seed yield of 2.5 t ha^{-1}, 22 and 14% greater than chickpea grown on barley and wheat stubble, respectively. The cultivar CDC-Frontier produced biomass of 7.6 t ha^{-1}, 13% greater than CDC-Xena and 7% greater than Amit and CDC-Anna. Increasing N rates from 0 to 112 kg ha^{-1} without GR increased biomass production and seed yield in a linear relationship with the slopes being 0.556, 0.475, and 0.089 (t ha^{-1} per kg of N fertilizer) for biomass produced on barley-, wheat-, and fallow-seedbeds, respectively, and the slopes for seed yield being 0.231, 0.226, and 0.055, respectively. CDC-Frontier produced the greatest biomass and seed yield and was the most stable cultivar across the diverse growing environments, whereas CDC-Xena had the lowest productivity with highest variability. This study showed that there was large variability in primary production of chickpea biomass and seed yield in these high latitude areas, but the variability can be minimized by adopting best management practices such as optimizing seedbed conditions, selecting cultivars with high yield potentials, and use of effective N-fixing inoculants.

Introduction

Being a legume, chickpea can form symbiotic associations with an effective *Rhizobium* strain. Under favorable conditions, symbiotic N_2 fixation can produce up to 170 kg N ha^{-1}, and provide up to 85% of the N requirements by chickpea plants. Inoculation with an effective *Rhizobium* strain is an economical way of enhancing primary production and seed quality. However, rhizosphere colonization and nodule formation can be influenced by climate and growing conditions. Likewise, the proportion of N derived from symbiotic N_2 fixation is also affected by environmental conditions. In situations when the N_2 fixation activity is limited by environmental stress, chickpea crops may benefit from the use of low rates of fertilizer N where some synergistic effects can be derived from the combination of N sources. However, little is known about how these management practices affect chickpea productivity and their interactions with environmental conditions under high latitude areas.

The objective of this study was to determine the adaptability of chickpea under various environmental and management conditions in high latitude areas with short growing seasons; the focus was to assess their effects on plant establishment, biomass production, and seed yield and yield stability across varying environmental conditions. A previous report discussed the effects of environmental and management conditions on chickpea maturity in these same high latitude areas.

Materials and Methods

The study was conducted at Swift Current and Shaunavon, Saskatchewan during 2004-2006 seasons. At each of the six environments ('*environment*' refers to location by year combinations and is used throughout the paper), the following three market classes of chickpea were tested: (i) large-seeded kabuli chickpea (c.v., 'CDC-Xena' with seed size of 465 mg seed^{-1}, and 'CDC-Frontier' with 365 mg seed^{-1}), (ii) small-sized kabuli chickpea (c.v., 'Amit' with 260 mg seed^{-1}), and (iii) desi chickpea (c.v., 'CDC-Anna' with 210 mg seed^{-1}). The cultivar in each class was selected based on its popularity in the local areas. Each cultivar was grown on standing wheat- and barley-stubble and on conventional summerfallow. The following fertility/inoculation treatments were applied to each cultivar x seedbed combination:

1) N=0, no-inoculant (control);
2) N=0, with granular inoculant (GR);
3) N=28 kg ha^{-1}, no-inoc.;
4) N=56 kg ha^{-1}, no-inoc.;
5) N=84 kg ha^{-1}, no-inoc.;
6) N=112 kg ha^{-1}, no-inoc.;
7) N=28 kg ha^{-1} with GR;
8) N=84 kg ha^{-1} with GR.

Treatments were arranged in a split-plot design with four replicates. Seedbed conditions were main plots and cultivar by fertility/inoculation combinations were sub-plots (2 x 10 m). At each environment, there were 384 experimental units.

Plant establishment was determined by counting plants in 4 rows of ½ meter length 3 weeks after seedling emergence. At maturity, two 1-m^2 samples (back and front) in each plot was hand harvested and was used for determinations of straw biomass, seed mass, and harvest index. In addition, 10 individual plants were hand harvested from each plot, bulk-bagged and used for determination of the following variables: total number of pods, pods with 0, 1, 2, or 3 seeds per pod, total number of seeds, and weight per seed. When seed moisture reached about 160 g kg^{-1}, the central 6 rows in each plot were harvested using a plot combine, and seed yields were determined and reported on a dry matter basis.

The data were analyzed using the PROC MIXED procedure of SAS with applied treatments as fixed effects, and environments and replicates as random effects. A combination of variance estimates and P values were used to determine the relative importance of the effects due to environment and the applied treatments. Least significant differences (LSD) were determined using LSMEANS with the PDIFF option of the MIXED model. Mean seed yields were used as the reference to determine the relative sensitivity of each cultivar against overall environmental strengths including precipitation and growing degree-days. In addition, an extension of the statistical model was implemented to further categorize the relative yield stability (variability) of cultivar x N rate combinations under diverse environmental conditions. For all analyses, effects were declared significant at $P < 0.05$.

Results and discussion

Plant establishment

Large differences in the rate of seedling emergence were observed among years. Seedling emergence occurred 23, 16, and 12 days after seeding (DAS) in 2004, 2005, and 2006, respectively. Slow seedling emergence in 2004 was largely due to lower than normal temperatures during the period of seed germination. Overall, plant establishment was excellent on all six environmental sites, ranging from 36 to 47 plants m^{-2}, which was in the optimal range of plant density for the production of chickpea in the northern Great Plains. The optimum plant density was achieved partly because a 75% field emergence rate was taken into account in the seeding rate calculation. The effect of seedbed conditions on plant density was not statistically significant, although the plant density was higher on fallow (42.3 plants m^{-2}) than on barley and wheat stubble (40.8 plants m^{-2}), likely due to better seed-soil contact on fallow plots.

A significant linear association was detected between rates of N fertilizer and plant density. Increasing rates of N fertilizer decreased plant density on all three seedbeds and for all four cultivars. Cultivar x N rate interaction was significant for plant density, largely due to the cultivar CDC-Anna having a mild decline in plant density with increased N rates, while other cultivars displayed much sharp declines. CDC-Anna is a desi-type chickpea cultivar, and as such has a thick, pigmented seed coat, whereas the three other cultivars were kabuli-types with thin seed coats. The thicker seed coat of the desi chickpea may have provided protection to germinating seeds from potential chemical fertilizer damage. Whether or not the pigment of the seed coat interacted with N fertilizer in affecting seed germination is not known. Our results suggest that chickpea is very sensitive to N fertilizer, even though the N fertilizer was applied as a side-band with no direct contact with the seeds. Nevertheless, mean plant density was near the optimum so that the potential effect of plant density on biomass or other yield-related variables is expected to be minimal.

Biomass

ANOVA revealed significant effects of seedbed, cultivar, soil fertility, seedbed x cultivar, and seedbed x soil fertility interactions for chickpea biomass. On average, chickpea grown on fallow seedbed produced the highest straw (5.8 t ha^{-1}) and seed (2.5 t ha^{-1}) biomass, which averaged 28% and 22% greater, respectively, than those grown on barley stubble, and were 13% and 14% greater than those grown on wheat stubble. Greater soil moisture coupled with more available soil N on the fallow fields provided advantages for the biomass production. Among the four cultivars, CDC-Frontier consistently produced the highest total (straw + seed) biomass at 7.6 t ha^{-1}, which was 13% greater than CDC-Xena and 7% greater than Amit and CDC-Anna. Seed mass of CDC-Frontier was also 23% greater than CDC-Xena on barley-stubble, 35% greater on wheat-stubble, and 35% greater on fallow. Consequently, CDC-Frontier had a significantly greater harvest index (HI) than CDC-Xena on all seedbeds. CDC-Frontier also produced greater straw and seed biomass than Amit and CDC-Anna with an equal value of HI.

In the present study, granular inoculant (GR) was used alone or combined with N fertilizer at varying rates. The results showed that N fertilizer plus GR did not increase biomass compared to GR alone. These results suggest that the N requirements of chickpea for biomass production are provided by N_2-fixation when an effective *Rhizobium* inoculant is applied, and that additional N fertilizer is required to optimize biomass in the absence of inoculant or when the inoculant fails. Similar observations have been reported previously. These results also indicate that use of GR at the recommended rate (5 kg ha^{-1} of inoculant with 100 million viable cells of *Rhizobium* per gram) allows biomass production to the same extent as when the crop is fertilized at 80 kg N ha^{-1}.

Seed yield

Significant effects of cultivars, seedbed, N rates, and seedbed x N interaction were detected for seed yield. On average, CDC-Frontier produced the highest seed yield at 2030 kg ha^{-1}, which was 4% greater than CDC-Anna, 7% greater than Amit, and 30% greater than CDC-Xena. Seed yields of all four cultivars responded similarly to the rates of N fertilizer. Increasing N rates with no GR increased seed yields significantly. Under the condition of zero-N fertilizer with no GR (as control), the seed yield was 1550 kg ha^{-1} for Amit and CDC-Anna, 1630 for CDC-Frontier, and 1328 for CDC-Xena. Compared to the control, use of GR without N fertilizer increased seed yield by 27% for Amit, 32% for CDC-Anna, 28% for CDC-Frontier, and 22% for CDC-Xena. With the *Rhizobium* inoculation and zero-N fertilizer, all cultivars produced seed yields similar to the treatments in which 84 to 112 kg N ha^{-1} was applied without inoculant. These results clearly show that use of an effective *Rhizobium* GR at recommended rates can result in a saving of approximately 100 kg N ha^{-1} of fertilizer in producing an equivalent seed yield. Chickpea receiving a combination of *Rhizobium* GR and N fertilizer at 28 and 84 kg ha^{-1} produced seed yield similar to those produced by chickpea receiving *Rhizobium* GR alone, suggesting that there is no need to apply N fertilizer when an effective strain of *Rhizobium* is applied.

The response of seed yield to N fertilization was interactively affected by seedbed conditions. The interaction was largely due to the fact that linear association between seed yield and N rates was significant for chickpea grown on barley- and wheat-seedbeds, but the association was not significant when grown on fallow-seedbed, as shown by the regression equations:

on barley	$y = 1190 + 169x$	$r^2 = 0.98^{**}$
on wheat	$y = 1278 + 161x$	$r^2 = 0.94^{**}$
on fallow	$y = 1870 + 23x$	$r^2 = 0.35$ NS

where, y is the seed yield, x is the rates of N fertilizer in the range of 0 to 112 kg N ha^{-1}, and **, NS indicate the linear regression significant at $P<0.01$ and insignificant, respectively.

Yield stability

Yield stability (or variability) was assessed using two approaches: (i) the responses of each cultivar to 18 diverse growing conditions (i.e., 3 seedbed conditions x 6 site-years) where the growing conditions had been sorted from worst to best based on the overall yielding ability, and (ii) the biplot method that determined relative variability of the crops on different seedbeds where cultivar x N rates combination was considered as the main responding factor.

Based on the values of slopes and regression coefficients, the responses of four cultivars to 18 diverse growing conditions showed that CDC-Frontier was the most sensitive to environmental conditions. Amit and CDC-Anna had nearly identical responses; both being more sensitive than CDC-Xena to changes in growing conditions. The cultivar CDC-Xena was the least sensitive to changing environments and also had the highest variability as indicated by lowest regression coefficient (r^2 = 76) among the four cultivars. In situations where the foliar fungal disease Ascochyta blight occurred, this cultivar appeared to be more sensitive to infestation than other cultivars under the same disease-control program.

Conclusions

Even though chickpea has a strong indeterminate growth habit, it can be adapted successfully to high latitude areas with short growing seasons. Global warming is expected to continue in a consistent manner and the changing climate could provide more promising opportunity to improve primary productivity of the ‘warm-season’ chickpea in the cool and high latitude areas of the world. This study showed large variability in biomass and seed yield when examined across diverse environmental conditions, but the variability can be minimized by adopting best management practices such as optimizing seedbed conditions, selecting cultivars with high yield potentials, and use of effective N-fixing inoculants. For example, chickpea grown on fallow-seedbeds produced higher seed yields with lower variability compared to barley- and wheat-seedbeds; this was largely due to chickpea on the cereal-seedbeds yielding about half that obtained on fallow-seedbed under dry conditions, while they were similar under wet conditions. The yield variability was also cultivar specific, with the cultivar CDC-Xena having the highest variability and CDC-Anna the lowest. The yield variability was reduced substantially by use of moderate rates (28-84 kg ha^{-1}) of N fertilizer or the application of an effective *Rhizobium* strain. Biomass and seed yield increased linearly with N fertilizer in the range of 0 to 112 kg ha^{-1} without *Rhizobium* inoculant.

Acknowledgements

We acknowledge the excellent technical assistance of Greg Ford, Lee Poppy, and Ray Leshures, and the financial support of the Saskatchewan Pulse Growers, Alberta Pulse Growers, Agricultural Development Fund of Saskatchewan Agriculture, and the Matching Investment Initiate of Agriculture and Agri-Food Canada.

References

Beck DP, Wery J, Saxena WC, Ayadi A (1991) Dinitrogen fixation and nitrogen balance in cool-season food legumes. *Agronomy Journal*, 83, 334–341.

Clayton GW, Rice WA, Lupwayi NZ, Johnston AM, Lafond GP, Grant CA, Walley F (2004) Inoculant formulation and fertilizer nitrogen effects on field pea: Crop yield and seed quality. *Canadian Journal of Plant Science*, 84, 89–96.

Funakawa S (2007) Dynamics of water and soil organic matter under grain farming in Northern Kazakhstan - toward sustainable land use both from the agronomic and environmental viewpoints. *In*: Lal R, Suleimenov M, Stewart DA, Hansen LO, Doraiswamy P (eds) Climate change and terrestrial carbon sequestration in Central Asia. Pp. 279-333. Taylor & Francis, London, UK.

Gan Y, Goddard T (2008) Roles of annual legumes in no-till farming systems. In: *No-till Farming Systems* (eds, Goddard T, Zoebisch MA, Gan Y, Ellis W, Watson A, Sombatpanit S). Pp. 279-289. World Association of Soil and Water Conservation, Funny Publ., Bangkok. 2008. ISBN: 978-974-8391-60-1.

Gan YT, Jayakumar P, Symons S, McDonald CL (2008a) Synergic effect of N and moisture on biochemical property of nodules and seed yield in chickpea. *Australian Journal of Crop Sciences*, 1, 11-22.

Knights EI, Acikgoz A, Warkentin T, Bejiga G, Yadav SS, Sandhul IS (2007) Area and production distribution. In: *Chickpea breeding and management* (eds, Yadav SS, Redden RJ, Chen W, Sharma S). Pp. 167-179. CABI International, Cambridge, MA, ISBN-13:9781845932138.

Kyei-Boahen S, Slinkard AE, Walley FL (2002) Evaluation of rhizobial inoculation methods for chickpea. *Agronomy Journal*, 94, 851–859.

Littel RC, Stroup WW, Freund RJ (2002) SAS for Linear Models (4th ed.). SAS Institute, Cary, NC. 466 pp.

Menzel A, Fabian P (1999) Growing season extended in Europe. *Nature*, 397, 659-663.

Menzel A, Sparks TH, Estrella N et al. (2006) European phenological response to climate change matches the warming pattern. *Global Change Biology*, 12, 1969–1976.

McConnell JT, Miller PR, Lawrence RL, Engel R, Nielsen GA (2002) Managing inoculation failure of field pea and chickpea based on spectral responses. Canadian Journal of Plant Science, 82, 273–282.

Siddique KHM, Loss SP, Regan KR, Pritchard DL (1998) Adaptation of lentil *(Lens culinaris* Medik) to short season Mediterranean-type environments: response to sowing rates. *Australian Journal of Experimental Agriculture*, 49, 613-626.

Walley FL, Kyei-Boahen S, Hnatowich G, Stevenson C (2005) Nitrogen and phosphorus fertilizer management for desi and kabuli chickpea. Canadian Journal of Plant Science, 85, 73–79.

Zentner RP, Wall DD, Nagy CN, Smith EG *et al* (2002) Economic crop diversification and soil tillage opportunities in the Canadian prairies. *Agronomy Journal*, 94, 216-230.