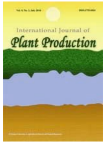

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Nitrogen yield and nitrogen use of chickpea compared to pea, barley and oat in Central Europe

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Abstract

European agriculture suffers from a substantial deficit of protein sources for livestock and the projected changes in agro-climatic conditions in Central Europe include a higher risk of drought. To address these challenges, the drought resistant legume crop chickpea was compared with pea, barley and oat regarding its nitrogen (N) yield, protein yield and N use and utilization efficiency under Central European growing conditions. The two year trial was conducted in eastern Austria with calcium ammonium nitrate or the depot fertilizer Basacote® Plus 6M at two levels of N rate each besides an unfertilized control. In 2006, chickpea had the lowest grain yield and grain N yield among the four crops while under drought conditions in 2007 chickpea attained a higher grain protein yield that surpassed those of barley and oat. Under both, the more humid conditions in 2006 and the drier weather in 2007, chickpea maintained a constant partial factor N use efficiency (PFNUE: grain yield per unit fertilizer N) and a consistently high N utilization efficiency (NUtE: grain yield per unit N in the above-ground dry matter) for grain production whereas these parameters were severely decreased by drought with pea, barley and oat. Results indicate that chickpea could be an alternative in a future more dry climate for achieving a reasonable protein yield in Central Europe through its ability to maintain high PFNUE and NUtE under conditions of drought.

Keywords: Chickpea; Nitrogen use; Calcium ammonium nitrate; Basacote® Plus 6M; Protein yield; Central Europe.

Introduction

Among others, European agriculture is facing two important challenges: (i) the expected changes in agro-climatic conditions and (ii) the substantial deficit of protein sources for livestock. The projected changes in agro-climatic conditions in Central Europe are expected to become manifest in an increase in air temperature, changes in the amount and distribution of precipitation and prolonged growing seasons. These conditions may cause a lower productivity of rainfed spring crops due to a higher risk of drought (Trnka et al., 2011). The high deficit of vegetal protein for livestock feed in the European Union requires large imports (around two-thirds of consumption) of soybean meal and soybeans (*Glycine max* (L.) Merr.) which come mainly from Argentina, Brazil and the United States (Henseler et al., 2013). Under the expected changes in agro-climatic conditions, the adoption of crops with a pronounced warm-season growth habit such as chickpea (*Cicer arietinum* L.) in northern latitude areas may be promising (Gan et al., 2009). Furthermore, the introduction of a new grain legume to Central European agricultural systems could be beneficial for reducing the substantial deficit of protein sources. Chickpea as a legume would additionally contribute to the nitrogen (N) supply of crops in the rotation if an effective symbiosis with suitable soil bacteria (*Mesorhizobium* sp.) can be established.

Chickpea is mainly produced in arid or semiarid environments (Canci and Toker, 2009) where the crop can cope effectively with drought conditions due to several morphological and physiological advantages (Serraj et al., 2004; Cutforth et al., 2009; Zaman-Allah et al., 2011). Chickpea is an important food legume in Asia and Africa providing protein, minerals, dietary fiber and vitamins. Additionally it is used as feed (Sarmah et al., 2012). Although chickpea is not a common crop in Central Europe, it could provide an alternative for food and feed protein production in the face of climate change. Recently, the plant has been adopted in Australia (Siddique and Sykes, 1997), New Zealand (McKenzie and Hill, 1995), in the Northern Great Plains in North America (Miller et al., 2002) and in western Canada (Anbessa et al., 2007). A previous study has already shown that chickpea can have higher grain and biomass yield than spring sown barley and oat under conditions of severe drought (Neugschwandtner et al., 2013). Furthermore, the adoption of chickpea in Central Europe could improve crop diversification and improved productivity of sustainable agricultural systems, which can satisfy a bulk of their N demand from symbiotic nitrogen fixation by bacteria, thus minimizing the demand for N fertilizer inputs within crop rotations (van Kessel and Hartley, 2000). Positive yield effects on subsequent non-legume crops result from the soil-N sparing effect of the legumes and the transfer of biologically fixed N via crop residue (Chalk, 1998; Kaul, 2004).

Information is required on the agronomy and performance of chickpea in Central European agricultural systems for introducing this crop. Currently, little information exists on the performance of chickpea grown in northern latitudes (Gan et al., 2009). To partly close this gap, the objectives of the presented work were to evaluate (i) concentration and yield of N in grain and residue and (ii) N use and utilization efficiencies of chickpea under Central European growing conditions as compared to pea (*Pisum sativum* L.), barley (*Hordeum vulgare* L.) and oat (*Avena sativa* L.) as standard spring crops with a similar growing pattern.

Materials and Methods

Experimental site and weather conditions

The experiment was carried out in Raasdorf (48° 14' N, 16° 33' E) in eastern Austria on fields of the experimental farm Gross-Enzersdorf of BOKU University. The soil is classified as a chernosem of alluvial origin and rich in calcareous sediments ($pH_{CaCl2=}7.6$) (ÖNORM L 1083). The texture is silty loam (silt: 56%, clay: 24%); the content of organic matter is 2.2-2.3% (ÖNORM L 1080).

The mean annual temperature and precipitation are 10.6 °C and 538 mm (1980-2009). Table 1 shows the long-term average monthly temperatures and precipitation from February to July and the deviations during the 2006 and 2007 growing seasons. The temperature was considerably higher in 2007 than in 2006 (except for July). Monthly precipitation was well above average in April and May in 2006. Contrary to that, the growing season 2007 was characterized by a severe spring drought without rainfall from the end of March to beginning of May.

Table 1. Long-term average monthly temperature and precipitation (1980-2009) and deviations during the 2006 and 2007 growing seasons.

	Temperature (°C)			Precipitation (mm)		
	Mean	2006	2007	Mean	2006	2007
	(1980-2009)	(±)	(±)	(1980-2009)	(±)	(±)
February	1.7	-1.9	+3.8	26.4	-7.7	+17.7
March	5.8	-2.1	+2.3	38.5	7.7	+28.0
April	10.7	+1.3	+2.1	35.3	+30.3	-34.4
May	15.6	-0.5	+1.6	56.1	+16.7	-9.8
June	18.5	+0.6	+2.8	72.3	-9.9	-3.9
July	20.8	+2.8	+1.9	59.1	-52.3	-6.2

Experimental factors

Two chickpea genotypes were tested in comparison to common regional varieties of pea and the non-legume crops barley and oat with similar vegetation periods. The chickpea variety Kompolti and commercial seeds of a chickpea genotype of unknown origin obtained from a trade company were planted (both are Kabuli type genotypes). The seeds had been multiplied on-farm. Pea cv. Attika and Rosalie, barley cv. Xanadu and oat cv. Jumbo were used as standards of comparison. Nitrogen fertilizer was given in two types as calcium ammonium nitrate (27% N, 10% Ca) (CAN) and the depot fertilizer Basacote® Plus 6M (16% N, 3.5% P, 10% K, 1.2% Mg, 5% S and micronutrients) (DF) were applied manually right after sowing at two N rates (10 and 20 g N m^{-2} (equivalent to 100 and 200 kg ha^{-1})). In addition, an unfertilized control was included.

Crop management and measurements

Seeds were sown with an Oyjard plot drill (row distance: 12 cm; plots size: 30 m^2). Chickpea seeds were inoculated with *Mesorhizobium ciceri* (Jost GmbH), seeds of pea with *Rhizobium leguminosarum* (Radicin No4, Jost GmbH) before sowing according to product specifications. Inoculation was performed as eastern Austrian soils may not contain the specific rhizobia for chickpea to ensure an effective plant-microbe association for N fixation. Inoculation of chickpea seeds has been shown to increase yield and grain protein content (El Hadi and Elsheikh, 1999). Sowing was performed on 14 April 2006 and on 11 April 2007, respectively, with a sowing rate of 90 seeds m^{-2} for chickpea and pea and 300 seed m^{-2} for barley and oat. Weeds were controlled mechanically. Above-ground plant biomass was harvested manually at full ripeness on 0.96 m^2 per plot; biomass was further divided into grain and residue. The materials were dried at 100 °C for 24 h. Harvest dates were: chickpea: 1 August 2006 and 23 July 2007; pea: 20 July 2006 and 9 July 2007; barley: 18 July 2006 and 23 July 2007; oat: 24 July 2006 and 23 July 2007.

Nitrogen and protein determination

For N determination sub-samples of grain and residue were ground to pass through a 1 mm sieve. The nitrogen concentration was determined as an average of duplicate samples per plot of about 500 mg each with a combustion technique using a LECO-2000CN auto analyzer (LECO, 1994). Nitrogen yield was calculated from N concentration and dry matter yield for each fraction and the total above-ground dry matter. The protein yield was obtained by multiplying the grain N yield × 6.25.

Partial factor N use efficiency (PFNUE) and nitrogen utilization efficiency (NUtE) were computed according to Sinebo et al. (2004) as follows:

$$(1)\ \text{PFNUE (g g}^{-1}\text{ m}^{-2}) = \frac{YLD}{N_{fert}}$$

$$(2)\ \text{NUtE (g g}^{-1}\text{ N)} = \frac{YLD}{NY_{AGDM}}$$

where YLD is the grain yield, N_{fert} the fertilizer amount per unit area; NY_{AGDM} is the N yield in the above-ground dry matter.

Statistics

The experiment was set up in a randomized complete block design with two replications. As genotype differences within chickpea and pea, respectively, were not significant, data were pooled for analysis. Statistical analyses were conducted using software SAS version 9.2. Analyses of variance (PROC GLM) with subsequent multiple comparisons of means were performed. Means were separated by least significant differences (LSD), when the F-test indicated factorial effects on the significance level of $P<0.05$.

Results and Discussion

Analysis of variance results are summarized in Table 2. Based on these results, data of grain and residue yield, harvest index, N concentration, N yield and nitrogen harvest index are presented for N fertilization (main effect) and interactions of crop × year; PFNUE and NUtE are presented for crop × fertilization, crop × year and fertilization × year. All yield and N concentration data are given on a dry matter basis.

Table 2. Analysis of variance results for grain and residue yield, harvest index (HI), N concentration (%), N yield, nitrogen harvest index (NHI), partial factor N use efficiency (PFNUE) and nitrogen utilization efficiency (NUtE).

	Yield		HI	N (%)		N yield		NHI	PFNUE	NUtE
	G	R		G	R	G	R	(%)		
Crop	***	***	***	***	***	***	***	***	***	***
Fertilization		**	**	***	***		***	***	***	***
Year		***	***	***	***	***		***	***	***
C × F									**	**
C × Y	***	***	***		*	***	*	***	***	***
F × Y		**							***	***
C × N × Y									*	***

Significant effects at P<0.05 (*), P<0.01 (**) and P<0.001 (***). Blank values indicate no significant effect (P>0.05). G=grain, R=residue.

Grain and residue yield, N concentration, N yield and protein yield

Chickpea had the lowest grain and residue yield among the four crops in 2006. In the dry year of 2007, chickpea had a higher grain yield than pea and oat and a higher residue yield than barley and oat (Figures 1a, d). The lower yield of chickpea in 2006 compared to pea, barley and oat may be due to the lower yield potential. Miller et al. (2001) have shown for the semiarid Canadian prairie that chickpea had a considerable lower yield potential than pea and wheat. Limited precipitation in 2007 strongly impaired the grain yield of pea, barley and oat but did not affect chickpea grain yield due to the crop's adaptability to drought stress (Serraj et al., 2004; Cutforth et al., 2009; Zaman-Allah et al., 2011). The grain yield of all crops was not affected by N fertilization in both years (Table 3), whereas the residue yield of all crops was significantly increased by N fertilization in 2006 but not in 2007 (data not shown). The very fertile soil on the experimental site with a high supply of mineralized N even in the unfertilized control plots presumably is the reason why grain yield did not differ between N fertilization treatments. We found similar results with chickpea and barley in pot experiments (Farzaneh et al., 2009).

The N concentration in grain and residue was higher in all crops in the dry year of 2007 than in 2006 (Figures 1b, e). The grain N concentration of chickpea and pea was higher than those of barley and oat. Highest residue N concentration was observed for pea in both years. The chickpea N residue concentration was in a similar range with that of barley and oat in 2007 and slightly higher than that of the two cereals in 2006. The higher N concentration in the grain of the dry year is in contrast to findings from Abreu et al. (1993) who reported for wheat (*Triticum aestivum*) that drought stress significantly reduced grain N uptake and concentration. Contrary to that, Sinebo et al. (2004) reported that warmer temperatures limit the time for carbon assimilation and partitioning to the grain; thereby N dilution is reduced and the grain N concentration remain high. The N fertilizer application decreased the N concentration of grain in the following order: 20 CAN > 20 DF > 10 CAN > 10 DF > control (Table 3). The N concentration of residue was significantly higher in the 20 CAN treatment than in the other N fertilization regimes.

The grain N yield of pea, barley and oat was significantly lower in the dry year of 2007 than in 2006. Contrary to that, the grain N yield of chickpea was on a similar level in both years. While in 2006 chickpea had the lowest grain and residue N yield, in 2007 the grain N yield of chickpea was slightly higher than that of barley and significantly higher than that of oat and the straw N yield was slightly higher than that of barley and oat (not significant) (Figures 1c, f). Fertilization did not affect the grain N yield of the crops (Table 3). Reaching a high protein yield is crucial for introducing new crops as alternative protein sources (Gresta et al., 2010). Only the protein yield of chickpea tended to be higher in the dry year of 2007 than in 2006 (Table 4). Yet, in 2006 the protein yield of chickpea was lowest among all tested crops.

The residue N yield was highest with 20 CAN fertilization and lowest in the control (Table 3). Soltani et al. (2006) and Koutroubas et al. (2009) reported that variations of N yield of chickpea were mainly linked to corresponding above-ground dry matter (AGDM) variations. Our results show that variations of both AGDM and N concentration affected the grain and residue N yield of the crops. Although slightly a higher grain protein yield was observed in the fertilized treatments, differences between the treatments were not significant, indicating that plenty of plant available N was supplied from soil resources even in the unfertilized control (cf. Farzaneh et al., 2009).

The harvest index (HI) was significantly reduced by 20 CAN and slightly decreased by 10 CAN and 20 DF compared to the control (Table 5). Chickpea and barley had a higher HI in 2007 whereas the HI of pea was lower in 2007 than in 2006. The nitrogen harvest index (NHI) was highest in the control and 10 DF and lowest with both doses of CAN (with 20 DF showing intermediate values) (Table 5). The NHI of chickpea and barley was on a similar level in both years whereas in 2007 the NHI of pea and oat was strongly impaired. A decrease of NHI with increasing N fertilization has already been reported by Bulman and Smith (1993).

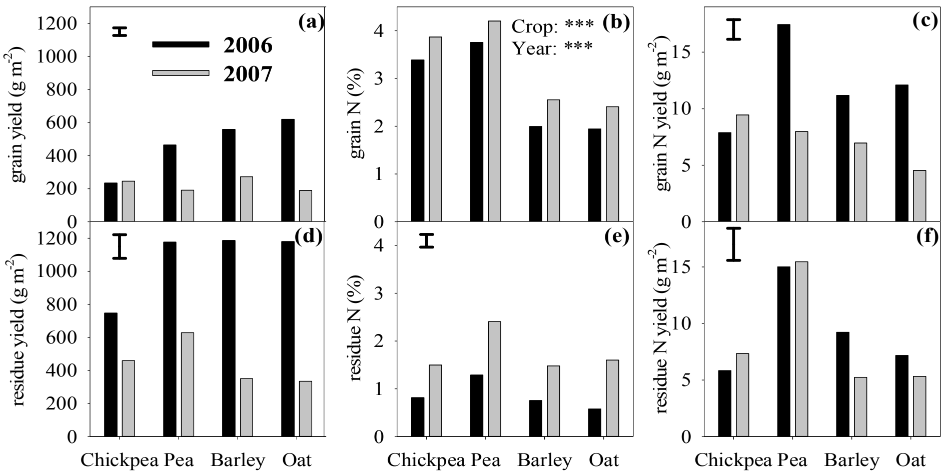

Figure 1. (a) Grain and (d) residue yield, (b) grain and (e) residue N concentration and (c) grain and (f) residue N yield at harvest as affected by crop and year. Bars give the LSD (P<0.05).

Table 3. Grain and residue yield, N concentration and N yield at harvest as affected by fertilization (means across crops and years).

g N m^{-2}	Yield (g m^{-2})		N concentration (%)		N yield (g m^{-2})	
	grain	residue	grain	residue	grain	residue
0	322^{a}	632^{b}	3.06^{d}	1.23^{b}	9.42^{a}	7.48^{b}
10 CAN	331^{a}	783^{a}	3.30^{bc}	1.40^{b}	10.07^{a}	9.84^{b}
10 DF	337^{a}	722^{ab}	3.19^{cd}	1.25^{b}	10.12^{a}	8.38^{b}
20 CAN	300^{a}	855^{a}	3.49^{a}	1.65^{a}	9.75^{a}	12.79^{a}
20 DF	341^{a}	789^{a}	3.36^{ab}	1.32^{b}	10.75^{a}	9.12^{b}

CAN: calcium ammonium nitrate; DF: depot fertilizer Basacote® Plus 6M. Different letters indicate significant differences between means within columns (P<0.05).

Table 4. Protein yield of the grain as affected by fertilization (means across crops and years) and by interaction crop × year (means across fertilizer levels).

Protein yield (g m^{-2})				
Fertilizer (g m^{-2})	Mean (across crops and years)	Crop	Year	
			2006	2007
0	58.9^{a}	Chickpea	49.3	59.1
10 CAN	62.9^{a}	Pea	109.0	49.8
10 DF	63.3^{a}	Barley	69.9	43.5
20 CAN	60.9^{a}	Oat	75.6	29.4
20 DF	67.2^{a}	LSD	10.8	

CAN: calcium ammonium nitrate; DF: depot fertilizer Basacote® Plus 6M. Different letters indicate significant differences between means (P<0.05); LSD: least significant difference for interaction effect.

Table 5. Harvest index and nitrogen harvest index as affected by fertilization (means across crops and years) and by interaction crop × year (means across fertilizer levels).

Fertilizer (g m^{-2})	Mean (across crops and years)	Crop	Year 2006	Year 2007
Harvest index (%)				
0	34.4^{a}	Chickpea	24.2	35.7
10 CAN	30.5^{a}	Pea	29.0	23.5
10 DF	33.4^{a}	Barley	32.4	44.9
20 CAN	25.7^{b}	Oat	35.0	36.8
20 DF	31.8^{a}	LSD	5.3	
Nitrogen harvest index (%)				
0	58.4^{a}	Chickpea	57.1	58.3
10 CAN	51.3^{b}	Pea	54.3	35.3
10 DF	57.7^{a}	Barley	56.3	58.2
20 CAN	43.6^{b}	Oat	65.7	46.5
20 DF	54.5^{ab}	LSD	8.0	

CAN: calcium ammonium nitrate; DF: depot fertilizer Basacote® Plus 6M. Different letters indicate significant differences between means (P<0.05); LSD: least significant difference for interaction effect.

Partial factor N use efficiency (PFNUE) and nitrogen utilization efficiency (NUtE)

Higher doses of N decreased PFNUE of all four crops with no differences due to fertilizer type (with CAN impairing PFNUE of chickpea slightly more than DF) (Figure 2a). Across all fertilizer treatments, the PFNUE of chickpea was lower than that of the cereals (with pea showing intermediate values). In 2006, PFNUE of chickpea was lower than those of the cereals with pea showing intermediate values (Figure 2b); in 2007, however, PFNUE of all crops were at a similar level. Drought in 2007 impaired the PFNUE on average by 48% compared to 2006; the PFNUE was by 50% lower with 20 g N m^{-2} than with 10 g N m^{-2} in 2006 and by 55% in 2007 (means across fertilizer types) (Figure 2c).

The NUtE of chickpea was reduced by CAN whereas DF had no effect (as compared to the control) (Figure 2d). While NUtE was just slightly decreased by fertilization in pea, for cereals a decrease with higher N doses was observed (with CAN causing a higher decreased than DF at both N rates). The NUtE was significantly lower in 2007 than in 2006 for pea, barley and oat, whereas NUtE of chickpea was just slightly decreased in 2007 (Figure 2e). CAN fertilization treatments reduced NUtE in both years compared to the control (with 20 CAN showing the highest decrease). Drought in 2007 decreased NUtE on average by 30% compared to 2006 (means across crops and fertilization treatments). The NUtE was decreased with increasing N rates in 2006 as compared to the control (with CAN causing a higher decreased than DF at both N rates) whereas in 2007 just CAN reduced the NUtE (Figure 2f). NUtE decreased with higher N doses as grain yield did not differ between fertilization treatments; thus N fertilization could not effectively been utilized for grain production. Further one, harvest indices tended to be lower with fertilization further impairing NUtE as observed for fertilized buckwheat by Schulte auf'm Erley et al. (2005). Results support the observations by Kirda et al. (2005) that NUtE is highly impacted by water availability.

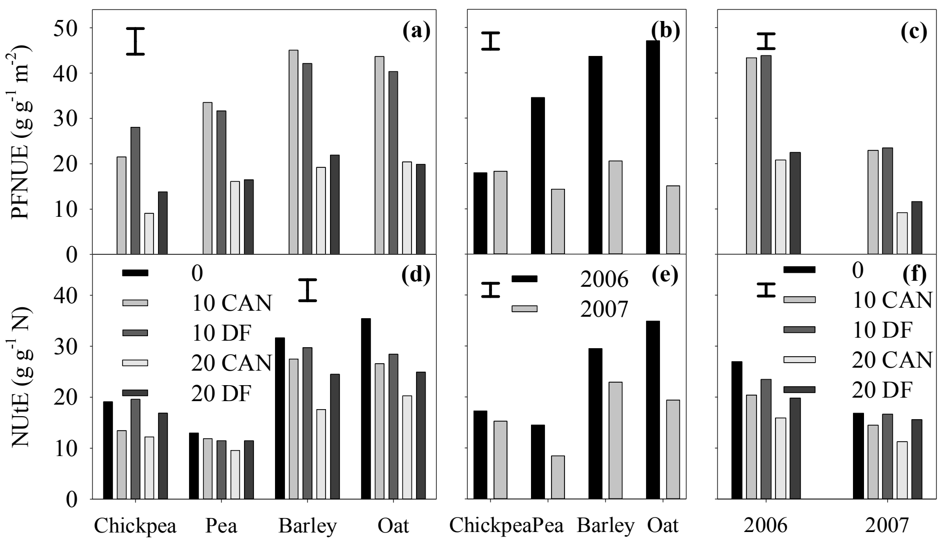

Figure 2. (a, b, c) Partial factor N use efficiency (PFNUE) and (d, e, f) nitrogen utilization efficiency (NUtE) as affected by the interactions of crop × fertilization, crop × year and fertilization × year. Bars give the LSD (P<0.05).

Conclusion

Chickpea had under optimum precipitation conditions in eastern Austria a lower grain and protein yield than pea, barley and chickpea due to the lower yield potential of chickpea compared to the other crops. Under conditions of drought, chickpea had among the four tested crops a consistently high grain and protein yield even under conditions of drought, because chickpea crops maintain high partial factor N use and N utilization efficiency. Thus, chickpea could be an alternative in a future more dry climate for achieving a reasonable grain protein yield in Central Europe especially in years with high drought intensity.

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