Originalarbeit

Reinhard W. Neugschwandtner[1], Helmut Wagentristl[2], Hans-Peter Kaul[1]

Concentrations and uptake of macro and micronutrients by chickpea compared to pea, barley and oat in Central Europe

Konzentrationen und Aufnahme von Makro- und Mikronährstoffen durch Kichererbse im Vergleich zu Erbse, Gerste und Hafer in Zentraleuropa

Abstract

Chickpea (*Cicer arietinum*) could be a promising new crop in Central Europe for contributing to agro-system diversification and reducing the substantial deficit of vegetable protein sources in the European Union. A two-year field experiment was conducted in eastern Austria to assess concentrations and uptake of macro (Ca, K, Mg, P) and micronutrients (Cu, Mn, Zn) of chickpea as compared to pea, barley and oat to gain information for a possible introduction of chickpea to Central European agro-system with regard to its contribution to human and livestock nutrition and its nutrient demand. Chickpea grain had higher concentrations of all analysed nutrients (except of Mn) than cereal grains. In year with average climatic conditions, chickpea had a lower grain nutrient uptake of Mg and P than pea, barley and oat but a similar one to barley and oat for K, Cu and Zn as higher grain concentrations of chickpea could compensate its lower grain yield. Whereas, chickpea could outperform the other crops in a year with drought conditions regarding the uptake of macronutrients Ca, K, Mg and P and micronutrient Cu due to both a similar grain yield with the other crops and higher grain concentrations of these elements as compared to barley and oat.

Key words: Chickpea, *Cicer arietinum*, macronutrients, micronutrients, nutrient uptake

Zusammenfassung

Ein zweijähriger Feldversuch wurde im Osten Österreichs durchgeführt, um die Konzentrationen und die Aufnahme von Makro- (Ca, K, Mg, P) und Mikronährstoffen (Cu, Mn, Zn) durch Kichererbse (*Cicer arietinum*) im Vergleich zu Erbse, Gerste und Hafer zu erheben, um so Informationen für die mögliche Einführung von Kichererbse in zentraleuropäische Agrarsysteme zu gewinnen. Die Körner von Kichererbse wiesen höhere Nährstoffkonzentrationen (mit Ausnahme von Mn) auf als jene der beiden Getreidearten. In einem Jahr mit durchschnittlichen klimatischen Verhältnissen konnte die Kichererbse eine geringe Aufnahme von Mg und P ins Korn pro Fläche erreichen, während der K-, Cu- und Zn-Kornertrag ähnlich jenem von Gerste und Hafer war, da die Kichererbse den geringeren Kornertrag durch höhere Nährstoffkonzentrationen kompensieren konnte. Indessen konnte die Kichererbse in einem Jahr mit starker Trockenheit die anderen Kulturpflanzen im Kornertrag der Makronährstoffe Ca, K, Mg und P und des Mikronährstoffes Cu übertreffen, und zwar aufgrund des mit den weiteren Kulturpflanzen ähnlichen Kornertrages und den höheren Kornkonzentrationen dieser Elemente im Vergleich zu Gerste und Hafer.

Stichwörter: Kichererbse, *Cicer arietinum*, Makronährstoffe, Mikronährstoffe, Nährstoffaufnahme

Institute
BOKU – University of Natural Resources and Life Sciences, Vienna, Department of Crop Sciences, Division of Agronomy, Tulln, Austria[1]
BOKU – University of Natural Resources and Life Sciences, Vienna, Department of Crop Sciences, Experimental Farm Groß-Enzersdorf, Austria[2]

Correspondence
Dr. Reinhard W. Neugschwandtner, BOKU – University of Natural Resources and Life Sciences, Vienna, Department of Crop Sciences, Division of Agronomy, Konrad Lorenz-Str. 24, 3430 Tulln, Austria, E-Mail: reinhard.neugschwandtner@boku.ac.at

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Introduction

Chickpea is providing high-quality protein in cereal-dominated diets of Asia and North Africa. Additionally, it is used as feed for livestock and contributes to the sustainability in farming systems through fixing of atmospheric nitrogen (SINGH, 1997). Chickpea was planted in 2012 worldwide on 11.3 million hectares with a total production amounting to 11.6 million tonnes. It is ranking among pulses second in area and production following beans (with 15.6% of total area and 16.3% of total production among pulses) (FAOSTAT, 2014). Production focuses mainly in arid or semiarid environments (CANCI and TOKER, 2009) where it can effectively cope with drought conditions due to several morphological and physiological advantages (SERRAJ et al., 2004; CUTFORTH et al., 2009; ZAMAN-ALLAH et al., 2011). Main producer countries are India (with two-third of the production area worldwide) followed by Pakistan, Iran, Australia and Turkey. In Europe, chickpea is mainly produced in Spain (FAOSTAT, 2014). Recently, the crop has been tested in the Northern Great Plains in North America (MILLER et al., 2002) and in western Canada (ANBESSA et al., 2007). Field trials comparing chickpea with pea, barley and oat in eastern Austria have shown that chickpea could maintain a higher crop growth rate and a higher relative growth rate under conditions of drought resulting in reasonable grain and N yields in dry environments of Central Europe (NEUGSCHWANDTNER et al., 2013, 2014, 2015).

Introducing a new grain legume to Central European agricultural systems would be beneficial for reducing the substantial deficit of vegetable protein sources in the European Union (HENSELER et al., 2013) and would contribute to diversification. Currently just about 1.6 percent of the arable land in Austria is planted with legumes (BMLFUW, 2013). A new drought-resistant crop can help for addressing the challenges of climate change which are expected in Central Europe to go along with a higher risk of drought during summer (TRNKA et al., 2011).

For introducing a new crop in an agricultural system, knowledge of the mineral composition of the harvest products and residues of the crop is important. Firstly, the possible contribution of the crop to human and livestock nutrition can be estimated. Regarding human nutrition, chickpea is a good source of carbohydrates and high quality vegetable protein, vitamins and minerals (JUKANTI et al., 2012). Chickpea is providing several essential minerals for humans. It is a rich source of macronutrients phosphorus and magnesium and micronutrients copper, iron, manganese, selenium and zinc (WOOD and GRUSAK, 2007). Nutrient uptake of chickpea was shown to be affected by harvest timing (ADAK et al., 2007), water availability (TALEBI et al., 2013), fertilization (TOGAY et al., 2008) and rhizobium inoculation (ROKHZADI and TOASHIH, 2011). Secondly, values for nutrient removal are an important component in the management of agricultural systems as nutrients removed by harvest or other losses must be replaced annually or at least within the crop rotation cycle to maintain soil fertility (HECKMAN et al., 2003). As nutrient requirements of crops depend on species, cultivar, soil and climatic conditions, soil biology and management practices (FAGERIA, 2009), these requirements have to be adapted to the agricultural production system.

Currently, little information exists on the agronomy and the performance of chickpea grown in northern latitudes (GAN et al., 2009). Therefore, the objective of the presented work was to evaluate nutrient concentrations and nutrient uptake in grain and residues of chickpea as compared to pea, barley and oat under Central European growing conditions to gain information for a possible introduction of this crop to Central Europe.

Material and methods

Experimental site and weather conditions

The experiment was carried out in Raasdorf (48° 14’ N, 16° 33’ E) on the experimental farm of BOKU University. Raasdorf is located close to the east of Vienna, Austria, on the edge of the Marchfeld plain, an important crop production region in the north-western part of the Pannonian Basin. The soil is classified as a chernosem of alluvial origin and rich in calcareous sediments (pH_{CaCl2} = 7.6). The texture is silty loam; soil organic carbon content is at 2.2–2.3%. At sowing in 2006 and 2007, soil mineral nitrate (NO_3-N) was at 5.6 and 10.7 mg kg^{-1}, CAL-extractable P was at 106 and 138 mg kg^{-1}, CAL-extractable K was at 191 and 248 mg kg^{-1} and $CaCl_2$-extractable Mg was at 94 and 115 mg kg^{-1}, respectively. Thus, according to the Austrian fertilization guidelines (BMLFUW, 2006), the humus content was medium and the nutrient availability was high for P in both years, sufficient in 2006 and high in 2007 for K and sufficient for Mg in both years. The mean annual temperature is 10.6°C, the mean annual precipitation is 538 mm (1980–2009). Tab. 1 shows the long-term average monthly temperatures and precipitation from February to July and the deviations during two experimental 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 whereas the growing season 2007 was characterized by a severe spring drought without rainfall from end of March to beginning of May.

Experimental factor

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 was obtained by the seed company Károly R. Fôisk (Kompolt, Hungary) and commercial seeds of a chickpea genotype of unknown origin were obtained from the trade company Hirschhofer (Pöttelsdorf, Austria) (both were Kabuli type genotypes). The seeds had been multiplied on-farm. Certified seeds of pea (cv. Attika and Rosalie), barley (cv. Xanadu) and oat (cv. Jumbo) were obtained by the seed trading company RWA (Vienna, Austria) and used as standards of comparison.

Crop management

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) according to product specifications before sowing. Inoculation was performed as eastern Austrian soils may not contain the specific rhizobia for chickpea to ensure an effective plant-microbe association for nitrogen fixation. Inoculation of chickpea seeds has been shown to increase yield and protein content of seeds (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. Plant shoots were harvested at full ripeness on 0.96 m^2 per plot, separated into grain and residues and 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.

Nutrient determination and nutrient uptake

For determination of macro and micronutrients, samples were ground, dried (105°C for 4 h) and digested in a tri-acid mixture (HNO_3:H_2SO_4:$HClO_4$ = 20:2:1, v/v/v) on a hot plate (JACKSON, 1958); concentrations of Ca, K, Mg, Cu, Mn and Zn in the digests were measured using atomic absorption spectrometry (Varian SpektrAA-300, Vienna, Austria) (BEATY and KERBER, 1993); P was analyzed by a spectrophotometer (Varian DMS 200) (CAVELL, 1955). Grain or residue nutrient uptake was calculated by multiplying nutrient concentration of grain or residue by the respective yield.

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 SAS software 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

Yields and harvest index

A significant interaction of crop×year was observed for grain yield with chickpea (CP) having by far the lowest grain yield in 2006 but just a slightly lower grain yield than barley (BY) and a higher one than pea (PE) and oat (OT) in 2007. Furthermore, chickpea was the only crop with a higher yield in 2007 than in 2006 (n.s.) (Fig. 1a). The residue yield was higher in 2006 than in 2007 and ranked for crops as follows pea ≥ barley, oat ≥ chickpea (Fig. 1b). The harvest index (HI) was lowest for chickpea in 2006 followed by pea; in 2007, HI of chickpea was on a similar level with oat, lower than that of barley and higher than that of pea (n.s.) (Fig. 1c).

Concentrations, uptake and harvest index of macronutrients

Ca concentrations in grain of CP were higher than in other crops (especially in 2006) and in residues higher than in BY and OT but lower than in PE. Ca uptake in grain was ranked as follows CP, OT, PE > BY (with highest values in CP) and in residues as follows PE > CP, BY, OT. Both grain and residues uptake were higher in 2006 than in 2007. Ca HI was generally higher in cereals than in pea (with CP showing intermediate values) (Fig. 2a-e).

K concentrations in grain were higher in legumes than in cereals, concentrations in residues were lowest in CP in 2006 with no differences between crops in 2007. K uptake in grain was higher in PE than in CP, BY and OT in 2006 but higher in CP in 2007 followed by PE. K uptake in residues was clearly lowest in CP in 2006 but on a similar level for all crops in 2007. K HI was highest in both years in CP (Fig. 2f-j).

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

	Temperature (°C)			Precipitation (mm)		
	Mean (1980–2009)	2006 (±)	2007 (±)	Mean (1980–2009)	2006 (±)	2007 (±)
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

Mg concentrations were ranked in grain as follows CP > PE > BY, OT (with higher values in 2007 than in 2006) and in residues as follows PE > CP, BY, OT. Mg uptake in grain was lowest for CP in 2006 but higher in CP than in OT (with slightly higher values for CP than for PE and BY); uptake in residues was highest in PE. Mg HI was lowest for PE (Fig. 2k-o).

P concentrations in grain were ranked as follows PE > CP > OT, BY; no differences were observed in residue P concentrations between crops. In 2006, P uptake in grain was lowest in CP whereas it was slightly higher in CP than in other crops in 2007. P uptake in residues was higher in PE than in cereals (with CP showing intermediate values). P HI did not differ between crops with a higher HI in 2006 than in 2007 (Fig. 2p-t).

Concentrations, uptake and harvest index of micronutrients

Cu concentrations in grain and residues were higher in legumes than in cereals with higher values in grain in 2006 and in residues in 2007. Cu uptake in grain of PE and OT was impaired in 2007 with highest value for CP in 2007; uptake in residues was ranked as follows PE > CP, BY, OT and it was lower in 2007 than in 2006 for all crops for but CP. Cu HI did not differ between crops and years (Fig. 3a-e).

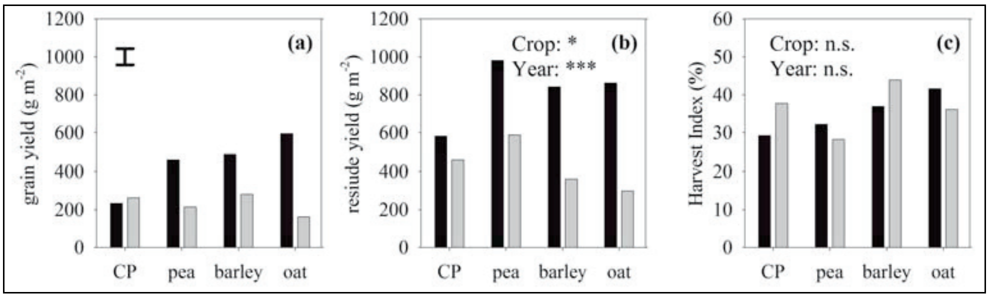

Fig. 1. (a) Grain yield, (b) residue yield and (c) harvest index depending on crop and year. Error bars are LSD ($p < 0.05$). Significant effect at $p < 0.05$ (*) and $p < 0.001$ (***).

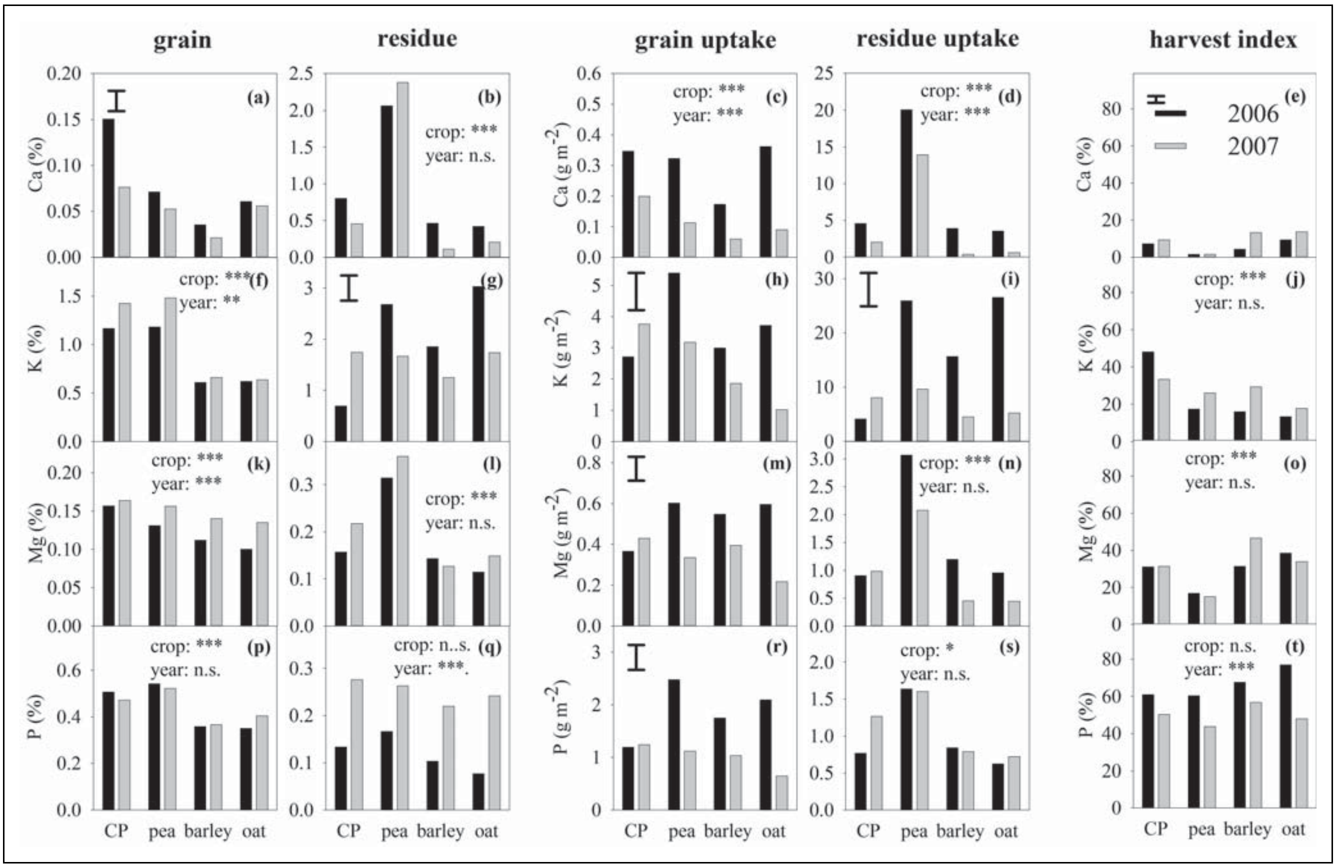

Fig. 2. Macronutrient concentrations of grain (a, f, k, p) and residues (b, g, l, q), macro-nutrient uptake of grain (c, h, m, r) and residues (c, i, n, s) and macro-nutrient harvest index (e, j, o, t) depending on crop and year. Error bars are LSD ($p < 0.05$). Significant effect at $p < 0.05$ (*), $p < 0.01$ (**) and $p < 0.001$ (***). CP = chickpea.

Mn concentrations were ranked in grain as follows OT > CP > BY, PE and in residues as follows OT > PE > BY, CP. Mn uptake in grain was similar in CP, PE and BY with highest uptake by OT in 2006; in 2007, grain uptake was highest in OT and CP. Mn uptake in residues was in both years on a low level in CP. Mn HI was ranked as follows CP > OT, BY > PE (Fig. 3f-j).

Zn concentrations in grain were higher in legumes than in cereals and in residues ranked as follows PE ≥ CP, BY ≥ OT (with higher values in 2007 than in 2006). Zn uptake was impaired in grain for PE and OT in 2007 with similar values for CP and BY in both years; uptake in residues was ranked as follows PE > CP, BY, OT with a higher uptake in 2007 than in 2006. Zn HI was higher in 2006 than in 2007 with no differences between crops (Fig. 3k-o).

Discussion

Mineral element analysis showed that CP grains are rich in macronutrients Ca, K, Mg and P (as already described by Nobile et al., 2013). The higher concentrations of Ca, K, Mg, P, Cu and Zn in grains of legumes than in cereals highlight their importance in human nutrition (cf. Fageria, 2009); just Mn concentrations were higher in the grain of OT than in those of the legumes (with higher values for CP than for PE). Thus, including CP in human diets is valuable for addressing micronutrient deficiencies which are a widespread challenge (Welch and Graham, 2004).

Under conditions in eastern Austria, macronutrient concentrations of CP grain were higher than those of both cereals. Compared to PE, concentrations of K were on a similar level, those of Mg higher and those of P lower. The uptake of macronutrients by CP was clearly below the other crops in 2006 (except for Ca), which was due to the comparatively low biomass production in that year, whereas CP had a higher uptake of Ca, K, Mg and P in 2007. CP had the highest HI for K and a higher one for Ca and Mg than PE, though with lower values compared to cereals. Contrary to our findings, Fageria (2009) reported a higher HI for Ca and Mg for legumes than for cereals.

Regarding micronutrient concentrations, Cu and Zn were higher in grain of legumes than in cereals; Mn concentrations was higher in CP than in PE and BY but lower than in OT. Considerably higher Mn concentrations in grain of oat than in barley are in accordance with Redshaw et al. (1978). Higher grain yields of other crops in 2006 resulted in higher micronutrient uptake, whereas CP had in 2007 the highest uptake of Cu among tested crops and a high uptake of Mn and Zn. No differences were observed between harvest indices of Cu and Zn whereas the Mn HI was highest in CP.

CP can obtain reasonable macro and micronutrient yields under drought conditions in Central Europe compared to PE, BY and OT. Nutrient concentrations and nutrient uptake in crops are reported to be reduced by

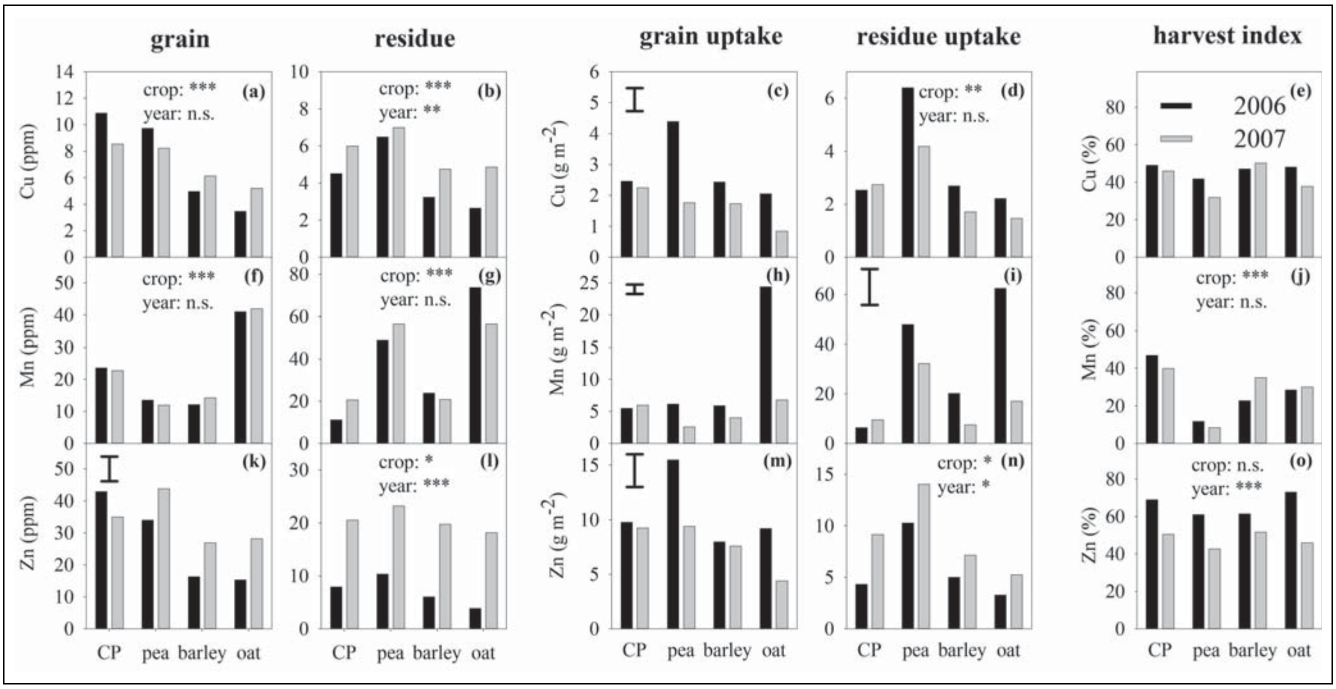

Fig. 3. Micronutrient concentrations of grain (a, f, k) and residues (b, g, l), micro-nutrient uptake of grain (c, h, m) and residues (d, i, n) and micro-nutrient harvest index (e, j, o) depending on crop and year. Error bars are LSD ($p < 0.05$). Significant effect at $p < 0.05$ (*), $p < 0.01$ (**) and $p < 0.001$ (***). CP = chickpea.

drought (Fageria et al., 2002; Gunes et al., 2006). Regarding CP, grain concentrations of K (and also slightly of Mg) were higher in the dry year of 2007 with no differences between years for P, Cu, Mn and Zn. Higher K concentrations were also observed in CP residues in 2007. Talebi et al. (2013) have already shown that chickpea increases K uptake during drought stress. Uptake of K is contributing to osmotic adjustment in drought stressed chickpea (Moinuddin and Imas, 2014).

Conclusion

Chickpea achieved reasonable grain and macro and micronutrients yields in a dry growing season in Central Europe. Thus, under conditions of climate change with expected more summer drought in Central Europe, it could be a promising new legume crop for that growing area.

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