Effect of cultivar and soil characteristics on nutritional value in organic and conventional wheat

Murphy, K.[1], Hoagland, L.[2], Reeves, P.[3] & Jones, S.[4]

Key words: micronutrients, soil organic matter, quality, organic wheat cultivars, soil pH

Abstract

Evidence of greater nutritional value in organic crops is currently a subject of intense debate. Our objectives in this study were to test for grain mineral concentration in 35 winter wheat cultivars in paired organic and conventional systems, and to determine the influence of cultivar, soil characteristics and farming system on mineral concentration. Here we report preliminary results that show that the grain mineral concentration in organic wheat was higher for copper (Cu), magnesium (Mg), manganese (Mn), phosphorus (P) and zinc (Zn) and lower in calcium (Ca), than the grain mineral concentration in conventional wheat. No difference was found between systems for iron (Fe) concentration. Cultivar was significant in determining mineral concentration for Ca, Cu, Mg, Mn and P. Soil mineral concentration was not responsible for grain mineral concentration, with the exception of P. The organic wheat farming systems had higher grain mineral concentrations of Cu, Mg, Mn, P and Zn than the conventional systems, possibly due in part to increased soil organic matter and pH in the organic systems. Growing specific cultivars capable of exploiting particular soil conditions may be necessary in order to optimize the nutritional value in organic farming systems.

Introduction

While global cereal grain yields have increased dramatically since the Green Revolution (Borlaug 1983), global food systems are not providing sufficient micronutrients to consumers (Welch 2002). Over 40% of the world's population is currently micronutrient deficient, resulting in numerous health problems, inflated economic costs borne by society, and learning disabilities for children (Sanchez and Swaminathan 2005). Though a diversification of diet to include micronutrient rich traditional foods is a preferred solution to these challenges, staple cereal grains are the primary dietary source of micronutrients for much of the world's population without access to varied food crops (Bouis 2003).

Genetic variation among wheat cultivars have been shown to be responsible for considerable differences in both mineral content and grain yield (Garvin et al. 2006, Murphy et al. in review). Cropping system can also have an impact on grain mineral

[1] Department of Crop and Soil Sciences, Washington State University, 201 Johnson Hall, Pullman, WA 99164-6420, USA, E-mail kmurphy2[a]wsu.edu

[2] Department of Crop and Soil Sciences, Washington State University, 201 Johnson Hall, Pullman, WA 99164-6420, USA, E-mail lori_hoagland[a]wsu.edu

[3] USDA-ARS, Grand Forks Human Nutrition Research Center, 2420 Second Avenue North, Grand Forks, ND 58202, USA, E-mail preeves[a]gfhnrc.ars.usda.gov

[4] Department of Crop and Soil Sciences, Washington State University, 387 Johnson Hall, Pullman, WA 99164-6420, USA, E-mail joness[a]wsu.edu

concentration and yield among wheat cultivars (L-Baeckström et al. 2006; Murphy et al. 2007). We are conducting a study that compares the mineral nutrient concentration of calcium (Ca), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), phosphorus, (P), and zinc (Zn) among 35 wheat cultivars grown in both organic and conventional systems. The objectives of this study are to compare the mineral concentration of wheat in organic and conventional systems and to estimate the variation in mineral content due to cultivar, soil characteristics and cropping system.

Materials and methods

Thirty-five soft white winter wheat cultivars were grown in side-by-side organic and conventional fields in Pullman, Washington (latitude 46º73'N, longitude 117º18'W) in the 2004-2005 and 2005-2006 growing seasons on a Palouse silt loam soil. Annual precipitation is approximately 500 mm/year. The organic and conventional fields were separated by buffer strips (7m minimum), though otherwise located in similar microclimatic conditions with comparable soil properties. Cultivars were grown in a randomized complete block design with four replicates. Samples were analyzed simultaneously for Ca, Cu, Fe, Mg, Mn, P, and Zn using Inductively Coupled Argon Plasma techniques. Four NIST (National Institute of Standards and Technology, Gaithersburg, MD, USA) durum wheat standards and four acid blanks were run with each batch of samples. Twenty soil samples from each field in each system were randomly collected to a depth of 18-cm and pooled for analysis. Soil organic matter, pH, and available Cu, Fe, Mg, P and Zn were determined by the University of Idaho soil lab (additional replicates of soil samples are currently being analyzed). This study was expanded to two locations in 2006-2007 and 2007-2008 (results not yet available) to strengthen the statistical power of the data and increase the geographical scope of the results to include a larger area of the wheat growing region of the Pacific Northwest (PNW) in the US.

The organic fields in Pullman have been certified organic since 2002. The two-year rotation in the organic systems was winter wheat/winter pea plowdown. The organic fields were fertilized with ~40 kg/ha of N from the winter pea plowdown and supplemented with certified organic PerfectBlend® fertilizer at the rate of 6 kg/ha each of N, P, and K, drilled with the seed at planting. This management practice was intended to reflect low-input, organic soft white winter wheat production in the PNW. The conventional fields were fertilized with 100, 23 and 17 kg/ha of nitrogen, phosphate and sulphur, respectively, and managed as a 2-year winter wheat/fallow rotation. Seed was treated with fungicide and insecticide before planting and weed control was accomplished with herbicide and hand weeding throughout the growing season in the conventional systems. All plots were harvested with a Hege plot combine with stainless steel sieves and cleaned with a Hege seed cleaner with stainless steel sieves.

Results

Grain grown in the organic system had significantly higher levels of Cu, Mg, Mn, P and Zn than grain grown in the conventional system. In an analysis of variance for each mineral, only P had a significant cultivar x system interaction. Grain Ca concentration was significantly higher in the conventional system than in the organic systems; no significant difference between systems was found for grain Fe concentration (Tab. 1). Cultivar was a highly significant source of variation for Ca and Mg ($P<0.001$) and Cu, Mn and P ($P<0.01$). There were no significant genotypic differences for Fe or Zn.

Tab. 1: Mean mineral concentration (mg/kg) between organic and conventional systems

System	*Ca*	*Cu*	*Fe*	*Mg*	*Mn*	*P*	*Zn*
Organic	339	2.78*	28.6	971*	45.1*	2845*	17.1*
Conventional	349*	2.40	29.2	929	43.6	2650	15.8

* significantly higher value (P<0.05)

Soil organic matter, pH, and available soil P and N (nitrate + nitrite) were greater in the organic systems. Available N (ammonia) Cu, Fe, Mn and Zn were greater in the conventional system (Tab. 2). Cation exchange capacity was similar in both systems.

Tab. 2: Soil characteristics between organic and conventional systems

System	Organic Matter	Cation Exchange Capacity	pH	N (Ammonia)	N (Nitrate + Nitrite)	Cu	Fe	Mn	P	Zn
	(%)	cmol(+)/kg					(ug/g)			
Organic	3.4	24	6.1	14	12	2	54	61	11	0.8
Conventional	2.4	23	5.2	32	9	2.4	81	81	6	1.7

Discussion

The organic grain had slight, though statistically significant, increases in the levels of Cu, Mn and Zn over the conventional grain, despite lower concentration of these minerals in the organic soil. Only P had greater concentration in both the grain and the soil. Concentrations of available Cu, Mn, Zn, and Fe in the soil were greater in the conventional system. Micronutrient availability in the soil has been shown to increase in more acidic soils (Fageria et al. 2002). The lower soil pH in the conventional fields may be due to the higher applications of inorganic N fertilizer and higher levels of available soil N in the form of ammonia.

How then does the lower soil micronutrient availability in organic soils translate into higher micronutrient concentration in organic grain? Organic matter has been shown to positively influence available soil micronutrients (Fageria et al. 2002; Wei et al. 2006) and the organic matter was 1.0% higher in the organic systems. Additionally, root colonization by mycorrhizal fungi can improve acquisition of Cu, Zn, Mn, and Fe (Marshner and Dell 1994), and has been found to be greater in organic as compared to conventional wheat cropping systems (Ryan et al. 2004). Both the increased organic matter and the potential for greater root colonization by mycorrhizal fungi may have played a role in the greater nutrient concentrations in grain from the organic system.

All cultivars used in this study were in the soft white market class. Soft white wheat represents the most important market class in the PNW and is typically used for products where high protein content is unnecessary, including steamed bread, cookies and sponge cakes. Within each system, cultivar was important in determining Ca, Cu, Mg, Mn and P concentrations. This suggests that certain cultivars may be optimally adapted to organic farming systems in a way that allows for higher grain mineral concentration. These cultivars are likely capable of exploiting the higher organic matter in the organic systems to achieve higher nutritional value.

Our previous results have shown that a biological trade-off between yield and mineral concentration likely does not exist (Murphy et al. in review). Our preliminary results from this study show several cultivars with both high yields and high concentrations of minerals, which suggests the potential for simultaneous selection of both grain yield and nutritional value.

Conclusions

Grain mineral concentration was higher in organic systems than conventional systems for Cu, Mg, Mn, P and Zn. Only Ca had a higher grain concentration in conventional systems than in organic systems. It is plausible that increased root colonization by the mycorrhizal fungi present in organic fields with higher percent organic matter may have resulted in enhanced uptake of soil nutrients and higher grain nutrient concentration. This hypothesis is currently being tested. Of further interest is the apparent ability of certain cultivars to achieve both high yields and increased nutritional value specifically within organic fields. Mechanisms for this evident adaptation to organic systems will be explored in greater detain in an expanded, multi-location, multi-year continuation of this trial.

Acknowledgments

We thank the Center for Sustaining Agriculture and Natural Resources at Washington State University, the Organic Farming Research Foundation and the United States Department of Agriculture's Integrated Organic Program (USDA-CSREES) for their generous support of this research. We especially thank Meg Gollnick, Kerry Balow and Steve Lyon for their invaluable assistance in this project.

References

Borlaug NE (1983) Contributions of conventional plant breeding to food production. Science 219:689-693

Bouis HE (2003) Micronutrient fortification of plants through plant breeding: can it improve nutrition in man at low cost? Proceedings of the Nutrition Society 62:403-411

Fageria NK, Baligar VC, Clark RB (2002) Micronutrients in crop production. Advances in Agronomy, Vol 77,

Garvin DF, Welch RM, Finley JW (2006) Historical shifts in the seed mineral micronutrient concentration of US hard red winter wheat germplasm. J Sci Food & Agric 86:2213-2220

L-Baeckstrom G, Lundegardh B, Hanell U (2006) The interactions between nitrogen dose, year and stage of ripeness on nitrogen and trace element concentrations and seed-borne pathogens in organic and conventional wheat. J Sci Food Agric 86:2560-2578.

Marschner H, Dell B (1994) Nutrient uptake in mycorrhizal symbiosis. Plant Soil 159:89-102.

Murphy, K, Reeves, PR, Jones SS (in review) Relationship between yield and mineral nutrient concentration in historical and modern spring wheat cultivars. Euphytica.

Murphy, K., Campbell, KG, Lyon, S, Jones SS (2007) Evidence for varietal adaptation to organic farming systems. Field Crops Research 102: 172-177.

Ryan MH, Derrick JW, Dann PH (2004) Grain mineral concentration and yield of wheat grown under organic and conventional management. J Sci Food Agric 84:207-216.

Sanchez PA, Swaminathan MS (2005) Cutting world hunger in half. Science 307:357-359

Welch RM (2002) The impact of mineral nutrients in food crops on global human health. Plant and Soil 247:83-90