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Estimating on-farm wheat yield response to potassium and potassium uptake requirement in China

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ABSTRACT

Understanding grain yield response to potassium fertilizer supply and potassium uptake requirements is essential for devising optimized potassium fertilizer management policies in China. Currently, potassium fertilization is often ignored due to high natural levels of potassium in the soil. We conducted 836 on-farm experiments at 209 sites in China to quantify wheat (*Triticum aestivum* L.) grain yield response to potassium application rates, and evaluate potassium uptake requirements with increasing grain yield. Across all 209 sites, wheat grain yield increased by 70% from 3.3 Mg ha^{-1} at a control level to 5.6 Mg ha^{-1} for recommended potassium treatments (RKR, 102 kg K_2O ha^{-1}). With 150% RKR treatments, no yield gains were achieved, while there was a notable decrease in potassium use efficiency. The potassium uptake requirements per Mg of grain (K_{req}) increased from 21.1 kg with RKR treatments to 21.9 kg with 150% RKR treatment, which indicated that a luxury potassium uptake occurred under excessive potassium application. Under RKR treatments, K_{req} decreased from 23.8 kg with <4.5 Mg ha^{-1} to 20.2 kg with >7.5 Mg ha^{-1}, which was attributed to the increase of the harvest index (from 45.5% to 48.6%) and decline in grain potassium concentrations (from 4.7 g kg^{-1} to 4.0 g kg^{-1}). When the grain yield was <7.5 Mg ha^{-1}, potassium accumulation during post-anthesis was lower than that at pre-anthesis, by −78.5 kg ha^{-1} and −30.8 kg ha^{-1} with <6 Mg ha^{-1} and 6–7.5 Mg ha^{-1} yield ranges, respectively, but higher than that at pre-anthesis when the grain yield was >7.5 Mg ha^{-1} and by 18.2 kg ha^{-1}. In summary, potassium fertilization can increase wheat grain yield in China and total potassium uptake requirements were shown to decrease with increasing grain yield. This suggests that potassium optimization must be taken into account in management decisions for high-yielding wheat production in China.

1. Introduction

Potassium (K) is a mineral element essential for plant growth, development, and fecundity (Marschner, 1995; White and Karley, 2010). Current intensive agricultural systems are commonly associated with unbalanced and insufficient K fertilization (Römheld and Kirkby, 2010). For example, a survey conducted from 2005 to 2008 in northern China found that 32% and 58% of farmers did not apply K fertilizer on wheat and maize fields, respectively (Peng, 2012). In contrast, high K fertilizer (as high as 200 kg ha^{-1}) has often been supplied in high-yield studies in China in order to achieve high wheat grain yield (>9 t ha^{-1}) (Li et al., 2014). The different practices among farmers suggest that there is a complicated relationship between grain yield and K supply, and further study is needed in order to optimize K management for high-yielding wheat production in China.

Many studies have focused on wheat grain yield response to K fertilization as affected by soil properties, application methods, and available soil K content (Vyn and Janovicek, 2001; Schneider et al., 2003; Huang et al., 2009; Roshani and Narayanasamy, 2010; Zhang et al., 2011). In the wheat production industry in China, there has been general agreement that there would be no grain yield response to K fertilization due to the relatively high soil K content (National Extension Center of Agricultural Technique in China, 2004). For example, studies conducted in northern China with high soil K content (as high as 288 mg kg^{-1}) found that wheat grain yield under K supply treatment showed no large difference compared with that

Abbreviations: K_{req}, potassium requirement per Mg grain yield; HI, harvest index; KHI, potassium harvest index; PFP_K, partial factor productivity of applied K; RE_K, apparent recovery efficiency; AE_K, agronomic efficiency.

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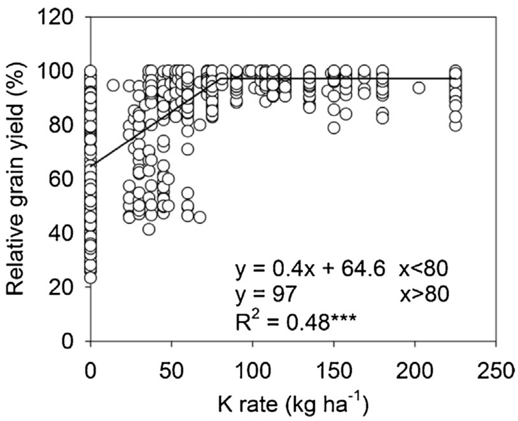

Fig. 1. Wheat relative grain yield as a function of K fertilizer rate. *** Significant at the 0.001.

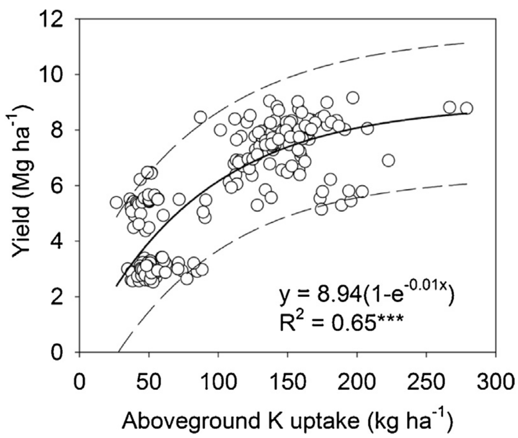

Fig. 2. Relationship between aboveground K uptake and grain yield (at 13% moisture) under RKR treatments from 2005 to 2009. The solid line represents the relationship. The dashed lines represent the prediction band (P = 0.95). *** Significant at the 0.001.

under no K supply treatment (Zhang et al., 2011). Recently, other studies from northern China have reported increasing crop yield responses to K fertilization (Huang et al., 2009; Jin, 1994), but lack information on a larger regional scale.

High-yielding wheat with high biological yield absorbs large amounts of nutrients to satisfy healthy plant growth (Osaki et al., 1991). Understanding K uptake requirements with increased grain yield is therefore essential to optimize K management for high-yielding wheat production to meet increasing food demand in future. Wheat K uptake requirements per Mg of grain yield have been studied across varieties, crop management practices, and soil K content. However, many uncertainties still remain as to how K requirement responds to increasing grain yield. Niu et al. (2013) found that wheat K_{req} decreased with increasing grain yield under the same K application rate. While Cao (2014) reported that wheat K_{req} increased with increasing wheat grain yield.

It is not yet clear whether increasing yields must be improve K uptake requirement as a proportion. Generally, low or no K is accumulated during post-anthesis stage for wheat production. For example, some studies of wheat growth reported that no more K accumulated during the post-anthesis stage (Li, 2012). However, studies in high-yielding wheat production systems often recommend top dressing K fertilizer at the post-anthesis stage to increase K accumulation (Wu and Cui, 2000; Yu et al., 2007; Wu et al., 2008). These observations make the traditional K management more complicated and challenging.

Previous studies estimating the requirements of wheat have generally involved site-specific field experiments, mostly conducted at research stations. Very few attempts have been made to investigate the physiological uptake-yield relationship across different farming environments (Liu et al., 2006; Chuan et al., 2014). Therefore, such a study could provide valuable information for developing optimal management strategies, as well as introducing these benefits to a wide range of farmers and policymakers who implement such recommendations. The objectives of this study, therefore, were to: (1) investigate the response of grain yield to K application in China; (2) quantify wheat grain yields in relation to K requirements; and (3) evaluate dry matter accumulation and K uptake at pre- and post-anthesis stages with increasing grain yield.

2. Materials and methods

2.1. On-farm experiments

836 on-farm experiments were conducted at 209 sites in China to analyze the winter wheat yield (with moisture of 13%) and K parameters at physiological maturity. These included the total dry matter measurements of the grain and straw, as well as the K concentrations of the grain and straw. The 209 sites were located in the Hebei (n = 46), Shandong (n = 47), Shaanxi (n = 24), and Jiangsu (n = 92) provinces conducted by the authors in collaboration with other partners from 2005 to 2009.

Winter wheat was cultivated with one harvest per year and was followed with maize or rice. At all of the sites, local commercially available winter wheat adapted to the specific environment with high yield potential was grown. Winter wheat was planted from early to mid-October and harvested in mid-June. Surface soil (0–20 cm) properties at the beginning of the experiment at all 209 sites from 2005 to 2009 were measured: average organic matter 15.9 g kg^{-1} (and ranged from 6.7 to 23.6 g kg^{-1}); average total N 0.9 g kg^{-1} (and ranged from 0.1 to 1.3 g kg^{-1}); average Olsen-P 16.2 mg kg^{-1} (and ranged from 2.4 to 34.4 mg kg^{-1}); average released K 17.3 mg kg^{-1} (and ranged from 2.6 to 32.4 mg kg^{-1}); average exchangeable K 96.6 mg kg^{-1} (and ranged from 40.0 to 137.0 mg kg^{-1}).

All experimental fields received the following treatments: K control (K_0, 0 kg K_2O ha^{-1}); recommended K rate (RKR, ranged from 48 to 150 kg K_2O ha^{-1}, averaged 102 kg K_2O ha^{-1}); 50% RKR (ranged from 14 to 75 kg K_2O ha^{-1}, averaged 51 kg K_2O ha^{-1}); and 150% RKR (ranged from 72 to 225 kg K_2O ha^{-1}, averaged 154 kg K_2O ha^{-1}). The RKR was derived from agronomist recommendations and soil tests, which varied from field to field. K was broadcast and incorporated by plowing before sowing. Based on the recommendation of local agronomists and soil test, all plots received appropriate amounts of N as urea (135–375 kg N ha^{-1}, an average of 237 kg N ha^{-1}) and phosphorus as triple superphosphate (45–180 kg P_2O_5 ha^{-1}, average of 105 kg P_2O_5 ha^{-1}). No obvious water, weeds, diseases, or insect pests were observed at any of the sites over the growing season.

To better understanding the relationship between yield and dry matter and K accumulation at the pre- and post-anthesis stages, 50 measurements of winter wheat dry matter and K parameters were performed at anthesis and maturity and were collected from the RKR treatments.

2.2. Sampling and laboratory procedures

Measurement at the anthesis stage was done by sampling the aboveground parts of two rows of wheat (with a length of 0.5 m) and drying to a constant weight at 75 °C. At maturity, the entire plot was harvested to measure biomass and grain yield, and dried to a con-