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Winter wheat grain yield in response to different production practices and soil fertility in northern China

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ABSTRACT

Scientific production management in the field is the main measure to increase crop yield. Different production practices and soil fertility has profound effects on the yield of wheat (*Triticum aestivum* L.) in northern China. A meta analysis of 6470 observations from 175 research papers for studies done across 77 locations in northern China was undertaken with respect to grain yield (GY) of winter wheat as influenced by soil organic matter (SOM), total nitrogen (TN), available phosphorous (AP), and available potassium (AK) under common production practices. The results were as follows: (1) Mulching and tillage increased GY by 13.2 and 7.8% relative to that from conventional tillage, respectively. (2) GY, spike number (SN), and grain number per ear (GNE) were markedly affected by mineral nitrogen (N) application rate at 200–285 kg ha^{-1}. (3) Application of N affected GY nearly three times more than mulching combined with tillage did, and the effect of N being evident mainly in SN and GNE. (4) SOM at 10–14.9 g kg^{-1}, TN at 1–1.5 g kg^{-1}, AP at 10–19.8 mg kg^{-1}, and AK at 100–200 mg kg^{-1} were the most effective soil fertility levels to improve wheat GY among all the research levels.

1. Introduction

Wheat (*Triticum aestivum*) is one of the world's most important crops and by 2050 the world will need to increase food production to feed a projected figure of nine billion people (Beddington, 2010). Northern China is a vast semi-arid region with an average annual precipitation of 300–600 mm and is a major contributor to the country's winter wheat production. Winter wheat–summer maize double-cropping system is one of the main cropping systems in the plains (Li et al., 2010). Water scarcity and large variations in both inter- and intra-annual rainfall are the main constraints to rain-fed crop production, resulting in low and unstable yields (Liu et al., 2014). Because grain yield (GY) is the main indicator of best crop management practices, the importance of soil quality and production practices for sustainable agricultural development have received much attention in recent years (Dumanski and Pieri, 2000).

China has only 9% of the world's arable land but feeds nearly 22% of the world population and therefore depends heavily on mineral fertilizers to increase grain production (Cui et al., 2010). Of all the nutrients required by crops, mineral nitrogen (N) remains the most essential and accounts for 30%–50% of the increase in crop yield due to fertilizers (Tilman et al., 2002). Many studies have shown that a large dose of N prior to stem elongation generally leads to greater number of grains per ear (GNE) (Lu et al., 2015). Because N influences GY of arable crops decisively and contributes to the maintenance of soil organic matter (SOM), selecting the most appropriate rate of N is one of the most important decisions in practical farming. Different crop production models have been developed and tested in Europe to calculate the relationship between crop GY and the rate of N application (Makowski et al., 1999; Backman et al., 1997). In China, Zhou and Klaus (2014) showed that crop GY does not respond linearly to inputs of N fertilizer. In response to changes in the structure of agriculture, sustainable crop management using conservation tillage is now of increasing interest to Chinese research and policy communities (Li et al., 2007). Mulching and tillage can ameliorate soil physical properties (Ronald, 1997), increase SOM and fertility, and promote better retention of nutrients (Dinnes et al., 2002). Chen et al. (2009) reported that in northern China, compared to conventional tillage (CT), no tillage coupled with returning crop residue to the soil increased soil organic carbon by 13.7% in the upper 15 cm layer of soil after 11 years. Ridge furrow mulching and rotational tillage increased wheat GY by 18% and 15%, respectively, on the Loess Plateau (Wang and Shangguan, 2015).

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Mulching with plastic film has been used for harvesting rainwater and is now a well-established technique for agriculture in arid, semi-arid, and sub humid areas (Zhang et al., 2005).

Monitoring the increase or decrease in a single parameter, such as SOM, total nitrogen (TN), total phosphorus (TP), and available nutrients can be used to measure the efficiency of farm management practices (Zhou et al., 2012). SOM has been considered an indicator of soil quality because it improves soil physical and chemical properties, protects soil against erosion, and promotes the activity of soil microorganisms (Jimenez et al., 2002). Particularly, the presence of SOM is regarded as being critical for the supply of nutrients (Jimenez et al., 2002). Soil fertility influences GY significantly; in meadow soils, it can account for as much as 34%–53% of the total GY (Xu et al., 2006). Therefore, when applying fertilizers, we should also consider the inherent capacity of soil to supply nutrients. Soil–plant systems have been increasingly used to analyse the growth of crop biomass and GY and to evaluate the impact of possible environmental changes and the effectiveness of management practices (Abalos et al., 2014; Strickland et al., 2015). The greater capacity of soil to supply nutrients, the less its dependence on chemical fertilizers to produce higher GY. The present study builds on this principle to suggest new approaches to determining fertilizer doses based on soil testing and to guide farmers in northern China on optimizing fertilizer doses for winter wheat while maintaining high yields.

Soil fertility is one of the important material bases for GY in winter wheat. However, studies on the relationship between soil fertility and wheat GY have been widely dispersed so far. Meta analysis offers a formal statistical method to compare and integrate the results of such multiple studies to elicit general patterns on regional and global scales (Gurevitch and Hedges, 1999). The present study is a meta analysis that seeks answers to four main questions: (1) To what extent is wheat GY altered by production practices (application of nitrogenous fertilizers, mulching, and tillage)? Our hypothesis is that such practices will result in GY higher than those following CT. (2) What is the most appropriate dose of N for winter wheat GY in northern China? Our hypothesis is that wheat GY may increase with the dose up to a point but will decrease beyond that point. (3) What are the optimum levels of SOM, TN, available phosphorus (AP), and available potassium (AK) for GY? Our hypothesis is that higher levels will result in higher GY. (4) Is there a strong linkage between GY and soil fertility under both CT and tillage combined with mulching?

2. Materials and methods

2.1. Data search and collection

Relevant literatures covering the period 2000–2015 were searched for studies in northern China on changes in GY, spike number (SN), GNE and thousand-kernel weight (TKW) as influenced by the application of mineral N, mulching, tillage practices and different soil fertility levels, details of them were given in Tables 1 and 2. Peer-reviewed journal articles were searched in the Web of Science and in the online database of the Chinese Academy of Sciences for the purpose. After scrutinizing the results, 6470 observations from 175 studies conducted at 77 sites (Fig. 1 and Supporting information 1) that fitted our selection criteria for the meta analysis were selected. Data expressed in the form of figures or charts were transformed into numerical values from their digital versions using GetData Graph Digitizer (ver. 2.24, Russian Federation).

To avoid distortions caused in publication selection, the data chosen for transformation had to satisfy the following criteria: (1) the field studies must involve application of N, mulching, or tillage, including a local control treatment, namely CT; (2) the values of soil fertility must be derived from surface soil (0–20 cm depth); and (3) the means, standard deviations (or standard errors), and sample sizes of the variables concerned must be directly available or amenable to being calculated from the data. The collected data for GY (kg ha^{-1}), SN (10^4 ha^{-1}), GNE, and TKW (g) for sampling locations in Anhui, Beijing, Gansu, Hebei, Henan, Ningxia, Shaanxi, Shandong and Shanxi (all in northern China) are shown in Fig. 1.

Table 1
The levels of response variables included in the meta analysis.

Parameter	Levels
Soil organic matter (SOM) (g kg^{-1})	below 10 10–14.9 15–20 above 20
Total nitrogen (TN) (g kg^{-1})	below 1 1–1.5
Available phosphorus (AP) (mg kg^{-1})	below 10 10–19.8 20–30 above 30
Available potassium (AK) (mg kg^{-1})	below 100 100–200 above 200
Mineral nitrogen (N) (kg ha^{-1})	60–94 100–195 200–285 300–350 360–450

2.2. Data processing

The data were analysed using the methods of meta analysis described by Hedges and Olkin (1985). The magnitude of the effects of production practices for each individual observation of GY, SN, GNE, and TKW under different soil nutrients were estimated by the SMD (standardized mean difference, *g*) which is the relative value to measure the superposition between two groups that also reflects the differences and relationships between them.

$$g = \frac{(\overline{X}_E - \overline{X}_C)}{S_{within}}J \tag{1}$$

$$S_{within} = \sqrt{\frac{(N_E - 1)^2(S_E)^2(N_C - 1)(S_C)^2}{N_E+N_C - 2}} \tag{2}$$

$$J = 1 - \frac{3}{4(N_C+N_E - 2) - 1} \tag{3}$$

$$V_g = (\frac{N_C+N_E}{N_C N_E}+\frac{d^2}{2(N_C+N_E)})J^2 \tag{4}$$

where $\overline{X}_E$ and $\overline{X}_C$ are the means of the treatment and control groups, respectively; N_E and N_C are the sample sizes for the treatment and control groups, respectively; V_g is the variance of independent research; S_E and S_C are the standard deviations for all comparisons in the treatment and control groups, respectively; and S_{within} is the comprehensive standard deviation within groups for every study. Standard deviation was calculated using the following formula which is described by Searls (1964) when the *CV* given in References

$$S = CV \times \overline{X} \tag{5}$$

where *S* is the standard deviations; *CV* is the average coefficient of variation within each data set; $\overline{X}$ is the reported means.

The comprehensive effect and confidence interval were calculated by the following equations:

$$W = \frac{1}{V_g} \tag{6}$$