Estimating Nutrient Uptake Requirements for Wheat

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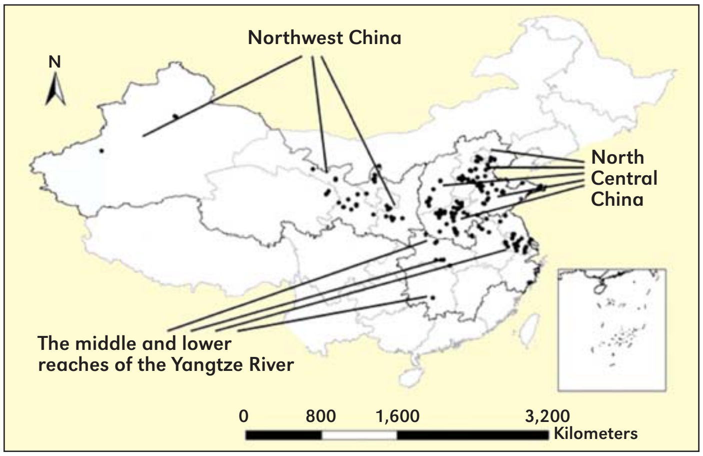
Over a decade's worth of data collected for winter and spring wheat in China revealed that most crop N uptake could be classed as luxury (excessive) consumption. Data for P showed a mix of both excessive and deficient crop uptake, while some K uptake data indicated a deficiency situation. These results collectively reflect the current status of fertilizer application practices in China—considerably less than site-specific. Field validation trials showed that the Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model could be a practical tool for making balanced fertilizer recommendations in China.

The total wheat production in China has remained fairly stagnant in the last decade or so, with some decrease reported due to the changes in wheat planting area. One of the reasons for stagnating wheat yields is that the current fertilizer management approaches do not usually apply nutrients in balance (i.e., to match the crop demand) resulting in wasted fertilizer resources and low nutrient use efficiency.

To improve the efficiency of fertilizer inputs, a computer software program, Nutrient Expert® (NE) was developed by IPNI as a decision support tool to make fertilizer recommendations (Pampolino et al., 2012). The NE system is based on improved SSNM guidelines and the QUEFTS model that consider a balanced input of all essential plant nutrients.



Geographical distribution of studied locations in north central China (NC), the middle and lower reaches of the Yangtze River (MLYR), and northwest China (NW). The black solid lines are the boundaries of each region.

Strategies for SSNM that assess crop nutrient requirements, indigenous nutrient supply and recovery efficiency (RE) of applied fertilizer could be used to increase crop yields and nutrient use efficiency. However, there are many uncertainties about N, P and K requirements of crops because the internal efficiency (IE) varies greatly depending on variety, nutrient supply, crop management, and climate. This makes it difficult to extrapolate results to small farm fields.

The QUEFTS model was selected to resolve this problem since the model takes into account the interactions of N, P and K (Janssen et al., 1990). The model provides a generic empirical relationship between grain yield and nutrient accumulation in plants and also uses two linear boundaries to describe the range between maximum and minimum nutrient accumulation situations (Witt et al., 1999). The model has proven to be a practical SSNM tool in major crops (Setiyono et al., 2010).

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; SSNM = site-specific nutrient management; OPT = optimal practice treatment; IPNI = International Plant Nutrition Institute.

Nutrient use efficiency indicators used in this article

Recovery Efficiency (RE) = increase in nutrient uptake in above-ground biomass per unit of nutrient applied

Internal Efficiency (IE) = grain yield per unit of nutrient accumulated in above-ground plant dry matter

Reciprocal Internal Efficiency (RIE) = kg nutrient uptake in above-ground plant dry matter per t grain produced

The objective of this study was to estimate the optimal requirements of N, P and K in wheat for a specific target yield using the QUEFTS model. For this, data was collected from 2000 to 2011 covering a wide range of wheat yields, soil types and climates. Datasets for grain yield, N, P and K uptake in above-ground plant dry matter, harvest index (HI, kg grain per kg total above-ground dry matter) and fertilizer application were compiled from literature published from China between 2000 and 2011, and unpublished datasets from research trials conducted by the IPNI China Program.

Yield optimizing (OPT) trials for wheat in Hebei (32 plots), Henan (50 plots), Shandong (30 plots), and Shanxi provinces (10 plots) in north central China were also conducted by IPNI cooperators from 2010 to 2011 to validate the QUEFTS model. Fertilizer N recommended by NE was estimated from the yield response to applied N fertilizer and agronomic efficiency of N, while fertilizer P and K were determined from the target yield and yield response combined with optimal reciprocal internal efficiency (RIE) and nutrient balance sufficient to replace P and K removed from harvested product. Urea was applied in two or three splits, depending on soil fertility or expected yield response to N, while P and K fertilizers were both broadcast and incorporated as a basal application before seeding. The rates of fertilizer application are listed in **Table 1**.

Table 1. Rates of fertilizer application in optimal practice treatment (OPT).

	Fertilizer application, kg/ha		
Province	N	P	K
Hebei	135 (130-150)[a]	23 (22-24)	50 (40-58)
Henan	150 (140-170)	32 (29-34)	62 (50-66)
Shandong	140	34	58 (50-66)
Shanxi	137 (125-140)	29	65 (50-66)

[a] Data in parentheses indicates the range of fertilizer application. Irrigation and other cultural practices were applied using the best local management practices.

Estimating Nutrient Uptake and Removal with QUEFTS

The QUEFTS model was able to simulate balanced nutrient uptake requirements for N, P and K assuming conditions where the yield was not limited by any nutrients and the crop produc-

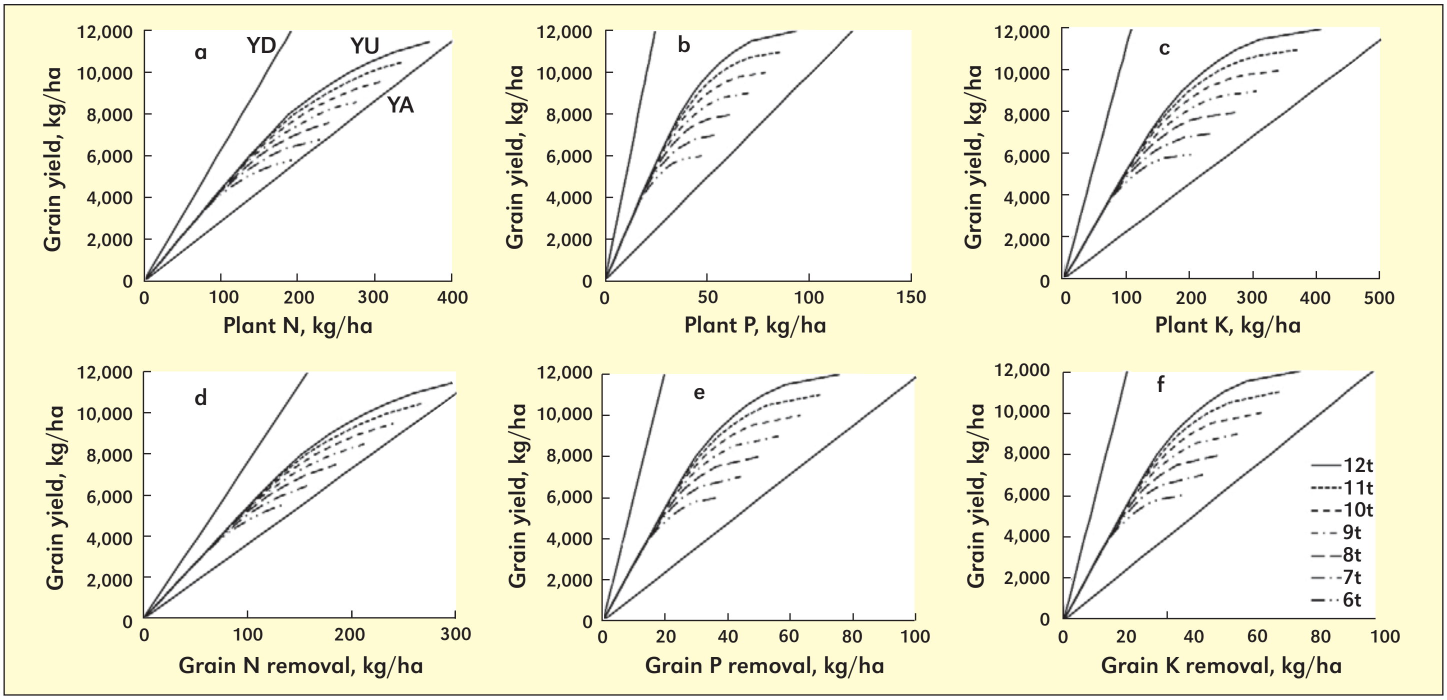


Figure 1. Balanced nutrient requirement (a to c) and grain nutrient removal (d to f) for N, P and K under different yield potentials simulated by the QUEFTS model. YD = maximum nutrient dilution; YA = maximum nutrient accumulation; YU = balanced nutrient uptake.

tion was managed using best practices. QUEFTS predicted that the balanced nutrient accumulation required to produce 1,000 kg grain was 22.8 kg N, 4.4 kg P, and 19.0 kg K, respectively, when the yield reached about 60 to 70% of the potential yield, with an N:P:K ratio of 5.2:1.0:4.3. The corresponding optimal IE values were 43.9 kg grain/kg N, 227.0 kg grain/kg P and 52.7 kg grain/kg K. Interestingly, regardless of the yield potential, the N:P:K ratio in the plant that was required to produce 1,000 kg grain was always the same within the linear part of the response curve (**Figure 1a to c**).

Results showed that the balanced grain nutrient removal curve was very similar to the balanced nutrient requirement for the total aboveground plant under yield potentials ranging between 6 to 12 t/ha (**Figure 1d to f**). Regardless of the yield potential, in the linear part of the curve, the balanced N, P and K removals by 1,000 kg grain were 18.3, 3.6 and 3.5 kg, respectively, and the N:P:K ratio in the grain was 5.1:1.0:1.0. Compared to the balanced nutrient uptake in the total aboveground plant, approximately 80, 82 and 18% of N, P and K, respectively, accumulated in the grain and were removed from

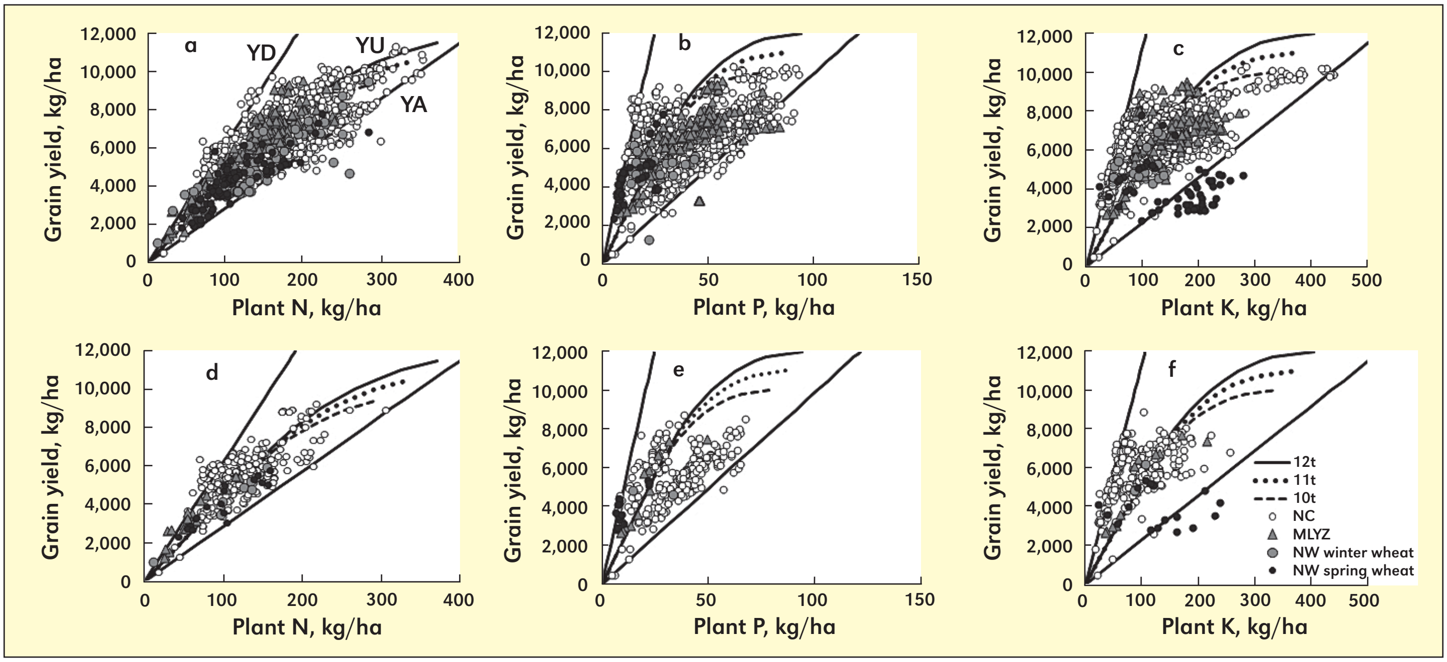


Figure 2. Observed relationships between grain yield and N, P and K uptake in the NC, MLYR and NW regions of China. Figures 2a to c are based from all experimental datasets, while Figures 2d to f are based from available CK (unfertilized plots) and N, P or K omission plot studies. YD = maximum nutrient dilution; YA = maximum nutrient accumulation; YU = balanced nutrient uptake.

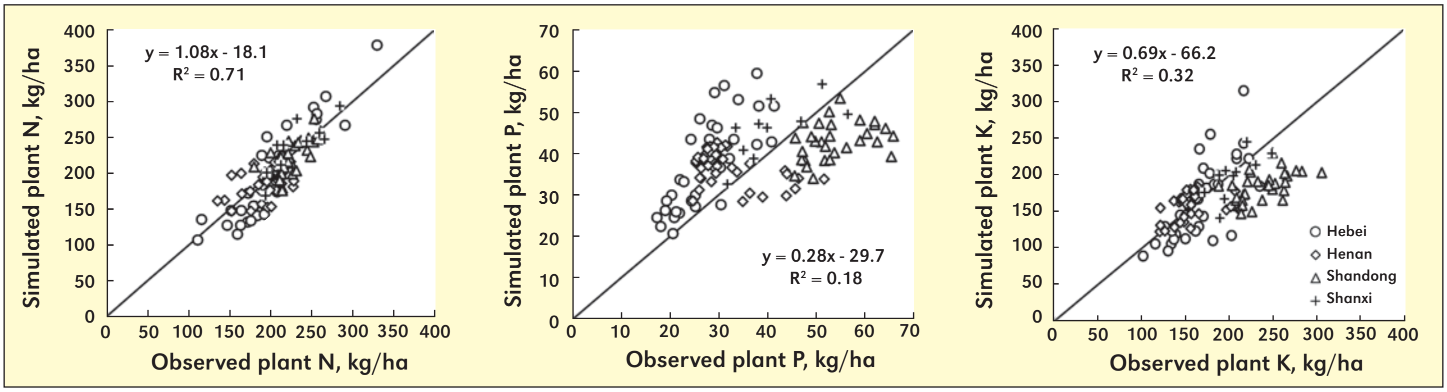


Figure 3. Relationship between observed and simulated NPK uptake in the above-ground plant dry matter for wheat.

the field. These values should provide practical algorithms for fertilizer recommendations that can sustain soil fertility.

Regional Relationships between Wheat Yield and Nutrient Uptake

The datasets in **Figure 2** are from field experiments conducted from 2000 to 2011 dealing with N, P and K treatments in different wheat production areas of China. Datasets above the balanced nutrient uptake line and close to the upper boundary indicate a deficient supply. In contrast, datasets below the balanced nutrient uptake line and close to the lower boundary indicate excessive supply such that yield is limited by growth factors other than the nutrient concerned.

Figure 2a reveals that most of north central China had luxury N uptake in wheat. In the northwest, N uptake was also excessive both in winter and spring wheat. In the MLYR region, N uptake could not be dominantly classed as either excessive or deficient, which suggests that N application in this region may be more rational.

Phosphorus accumulation data for winter wheat in north central China showed both examples of deficiency and excess, indicating that P fertilizer application has not been balanced (**Figure 2b**). Some P uptake in the MLYR region showed excessive supply, and in the northwest, most spring wheat data indicated an inadequate supply of P. Phosphorus is mainly applied as calcium superphosphate or calcium magnesium phosphate, or is added with N or K fertilizer. For example, compound fertilizers with a $N:P_2O_5:K_2O$ ratio of 15:15:15 that are used frequently in China would all include more P nutrient than is required for an optimum ratio.

For K, the majority of data showed deficiency in north central China with only a few data sets indicating an excess K supply. In the northwest, spring wheat showed a greater tendency for excessive uptake compared to the more balanced K uptake observed in winter wheat (**Figure 2c**). The difference might be due to the environment where spring wheat was grown. Northwestern soils tend to be higher in K, which could result in luxury uptake.

Verification via Omission Plot Study

In comparison, observations for yield versus nutrient uptake extracted from omission plot studies are shown in **Figure 2d to f**. Many observations were concentrated near the upper boundary line of high IE values reflecting maximum yield dilution (minimum nutrient accumulation) or severe nutrient deficiency. Some N but more P accumulation datasets, hover close to the lower boundary line, which suggests considerable available N and P in the soil from an unbalanced nutrient supply. These observations confirm a situation of long-term imbalanced fertilization practice within traditional wheat cropping systems (Chuan et al., 2013).

As validation of the QUEFTS model, observed N, P and K uptake for the above-ground plant dry matter were scattered more or less equally around the 1:1 line. Measured values for N agreed well with values for simulated nutrient uptake while this relationship for P and K was not as well defined (**Figure 3**). Liu et al. (2006) observed similar results in his experiments. Given such results, it is apparent that QUEFTS can be safely used to calibrate the predicted nutrient uptake and improve fertilizer recommendations.

Summary

Our results generally reflect the status of wheat fertilizer application practices in China and serve as a tool to help recommend balanced fertilization. Results from the field validation of the QUEFTS model in four different provinces of China showed that it could be used to support the NE system in wheat to recommend balanced fertilizer practices for farmers.

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