Estimating Nutrient Uptake Requirements for Soybean

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Soybean (*Glycine max* [L.] Merr) production in China has been declining steadily due to the lower yields and lagging technological progress. Fertilizer application has played an important role in increasing soybean yields. However, fertilizer recommendations could at times be misleading since soybean nutrient requirements are usually based on single values summarized from limited data extrapolated over large areas (Vitousek et al., 2009).

The QUEFTS model can quantify crop nutrient requirements for a target yield using a large number of data (Janssen et al., 1990) and can fully account the interactions between N, P, and K. To date, the model has been successfully implemented to match nutrient supply with maize, rice, and wheat crop demand in many countries including China (Pampolino et al., 2012). This model had not yet been tested in soybean, which was the objective of a study combining data from thousands of soybean field experiments from the International Plant Nutrition Institute (IPNI) China Program, the Modern Agricultural Industry Technology System for Soybean, and scientific literature between 2001 and 2015. On-farm field validation was conducted between 2014 and 2015 at 20 sites across northeast China, including Heilongjiang, Jilin, and Liaoning provinces.

Yield and Nutrient Uptake

The average seed yield of soybean was 2,470 kg/ha, according to the experiments carried out in China between 2001 and 2015, with the range being very wide at 525 to 6,515 kg/ha. The average harvest

Data from field experiments conducted in China were used to assess the relationship between soybean seed yield and nutrient uptake using the QUantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model. Field validation indicated that QUEFTS could be used to estimate nutrient requirements and help develop fertilizer recommendations for soybean.

KEYWORDS:
QUEFTS; internal efficiency; balanced nutrient requirement; fertilizer recommendation

ABBREVIATIONS AND NOTES:
N = nitrogen; P = phosphorus; K = potassium.

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Setting the Parameters for the QUEFTS Model

The maximum nutrient accumulation (*a*) and dilution (*d*) were calculated as the ranges of internal efficiency (IE, seed yield per unit of nutrient uptake in the aboveground parts) based on the actual N, P, and K uptake levels. These *a* and *d* values were then used as parameters to estimate the nutrient requirements of soybean through the application of the QUEFTS model.

Sets of *a* and *d* values for N, P, and K were calculated by excluding the upper and lower percentiles (Set 1 = 2.5, Set II = 5, Set III = 7.5) of nutrient IE for all soybean data in China. The curves of N, P, and K in the three sets were similar until the targeted yield approached the yield potential of 6.0 t/ha (**Figure 1**). In this study, Set I was used to estimate balanced nutrient uptake and the relationship between soybean seed yield and nutrient accumulation in the aboveground parts because it included a wider range of variability. The constant *a* and *d* values derived from all soybean data in Set I were 13.5 and 21.4 kg/kg for N, 60.4 and 234.6 kg/kg for P, and 27.8 and 79.9 kg/kg for K, respectively.

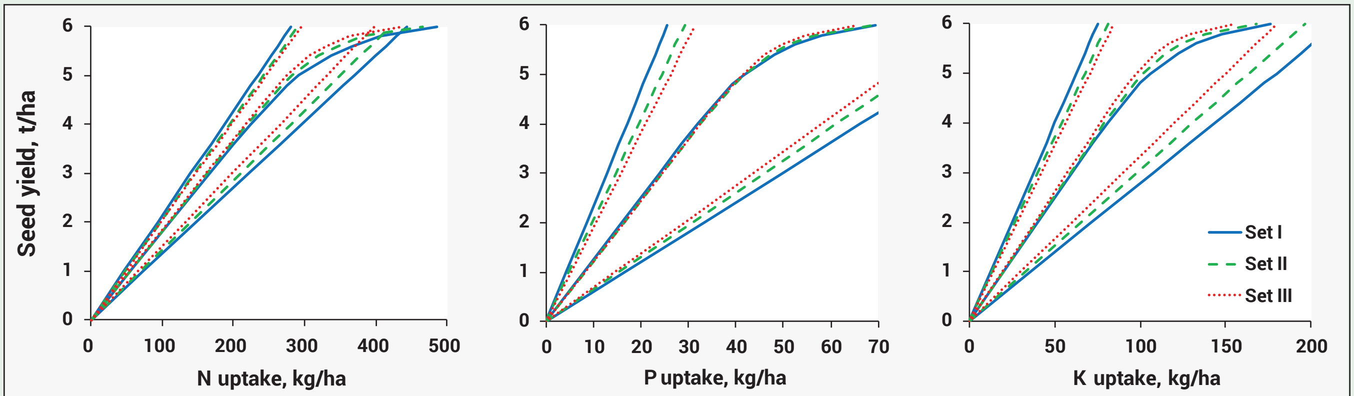

Figure 1. The relationship of seed yield and nutrient uptake of soybean at different sets of constants *a* and *d*. YD, YA, and YU represented the maximum dilution, maximum accumulation, and balanced uptake of N, P, or K in aboveground parts, respectively. The yield potential was set at 6.0 t/ha for the present study as an example.

index (HI), a term used to quantify the yield of a crop versus the total amount of biomass produced, was 0.46 kg/kg (range of 0.26 to 0.66 kg/kg) and more than 90% of the HI values were between 0.40 and 0.60 kg/kg. The average aboveground nutrient accumulation of N, P, and K was 132, 22, and 48 kg/ha, and ranged from 21 to 435, from 5.6 to 73, and from 8.2 to 194 kg/ha, respectively. This range in nutrient concentrations in grain and straw resulted in tremendous variation for HI values of P and K, which were 0.42 to 0.95 and 0.36 to 0.88 kg/kg, respectively. However, the HI of N was more consistent and ranged between 0.71 to 0.94 kg/kg (**Table 1**).

Table 1. Characters of yield and nutrient uptake of soybean (2001-2015) in China.

Parameter	*n*[a]	Mean	SD[b]	Minimum	Maximum
Seed yield (13.5% moisture), kg/ha	9,318	2,470	683	525	6,515
Harvest Index (HI), kg/kg	5,277	0.46	0.06	0.26	0.66
Shoot N, kg/ha	2,193	132	39	21	435
Shoot P, kg/ha	2,199	22	8.6	5.6	73
Shoot K, kg/ha	2,192	48	22	8.2	194
HI for N, kg/kg	1,570	0.84	0.04	0.71	0.94
HI for P, kg/kg	1,579	0.67	0.09	0.42	0.95
HI for K, kg/kg	1,576	0.58	0.08	0.36	0.88

[a] n = number of observations. [b] SD = standard deviation.

Estimating the Optimum Nutrient Requirement

The relationship between soybean yield and nutrient accumulation in the aboveground parts at maturity was estimated using the QUEFTS model under different potential yields (3.0 to 6.0 t/ha). The model predicted a linear increase in seed yield, until the yield reached about 60 to 70% of the yield potential, if the N, P, and K were taken up in a balanced manner. In other words, whatever the yield potential was, the optimal nutrient accumulation required to produce 1000 kg seed was the same when the yield reached about 60 to 70% of potential yield (**Figure 2**).

The QUEFTS model predicted a balanced nutrient accumulation of 55.4 kg N, 7.9 kg P, and 20.1 kg K per t of seed when the yield reached about 60 to 70% of the potential yield and an IE of 18.1 kg seed/kg N, 126.6 kg seed/kg P, and 49.8 kg seed/kg K for soybean in China. The optimal N: P: K ratio in the aboveground parts was about 7: 1: 2.5.

Seed nutrient removal could be also simulated by the QUEFTS model. The model indicated that the balanced N, P, and K removal required to produce 1000 kg seed was 48.3 kg N, 5.9 kg P, and 12.2 kg K when the targeted yield reached 60 to 70% of the potential yield. Compared to the total nutrient uptake in aboveground plant parts, approximately 87, 74 and 61% of N, P, and K accumulated in seed and was removed

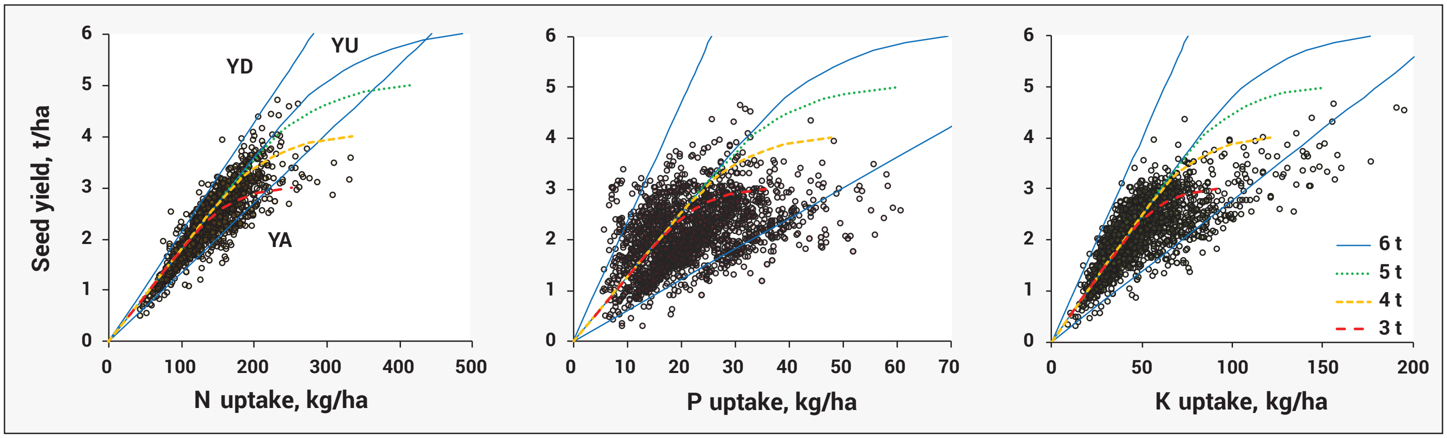

Figure 2. The relationship between seed yield and nutrient accumulation of N, P, and K in aboveground parts at different target yields simulated by the QUEFTS model for soybean in China. YD, YA, and YU represented the maximum dilution, maximum accumulation, and balanced uptake of N, P, or K in aboveground parts for a specific target yield, respectively. The range of yield potential for soybean was from 3.0 to 6.0 t/ha.

from the field with harvest. In addition, biological N_2 fixation should be also considered for N fertilizer recommendation, because soybean is partly relying on biological N_2 fixation.

Field Validation

The relationship between observed and simulated nutrient uptake was analyzed using field experiments conducted in 2014 and 2015 in Northeast China.

While there was some deviation for P and K, the observed and simulated N, P, and K uptake in the aboveground parts occurred near the 1: 1 line, suggesting that the measured values agreed well with the simulated nutrient uptake and there was no significant deviation between each other (**Figure 3**).

Summary

The large datasets from a variety of growing environments were used to estimate the balanced nutrient requirements for soybean using the QUEFTS model. The model predicted a linear increase in aboveground dry matter or seed yield if nutrients were taken up in balance until yield reached about 60 to 70% of the yield potential. To produce 1000 kg seed of soybean in China, 55.4 kg N, 7.9 kg P and 20.1 kg K (N: P: K=7.0: 1: 2.5) were required in the aboveground parts, and the corresponding IEs were 18.1, 126.6, and 49.8 kg seed per kg of N, P, and K, respectively. The QUEFTS model also simulated 48.3 kg N, 5.9 kg P, and 12.2 kg K nutrient in seed per 1000 kg seed, accounting for 87, 74, and 61% of the N, P, and K in total aboveground parts, respectively. The field validation indicated that the QUEFTS model can be used to estimate balanced nutrient requirement and help develop robust fertilizer recommendations for soybean. **BC**

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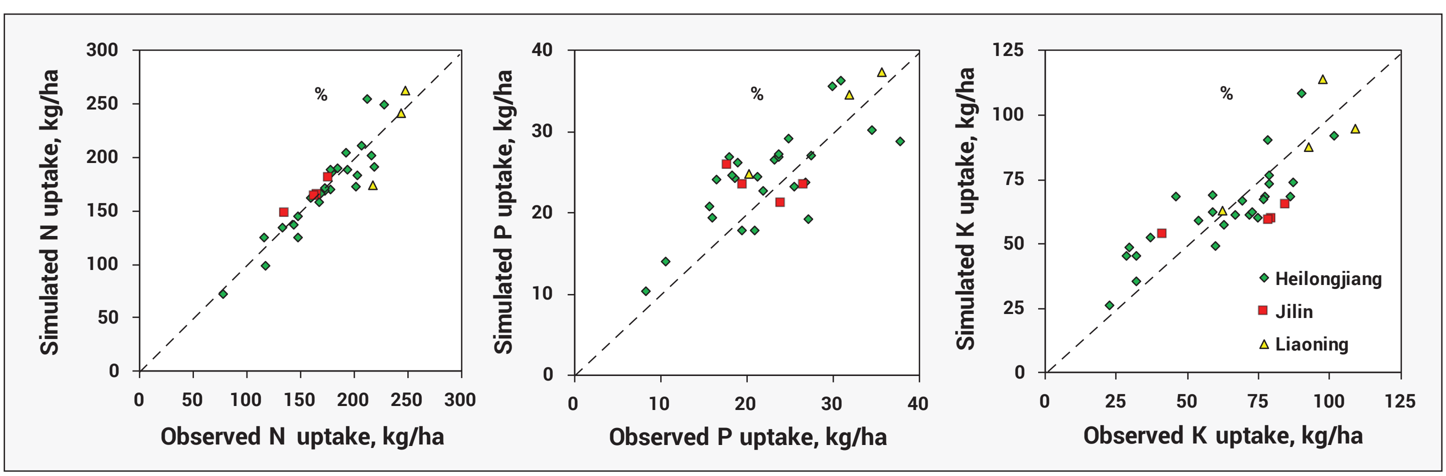

Figure 3. Comparisons of the simulated and observed N, P, and K uptake in soybean. The observed nutrient uptake was from field experiments, and the simulated data was from the QUEFTS model.