Determining an Optimal Fertilization Strategy for No-till Rice-Wheat Cropping

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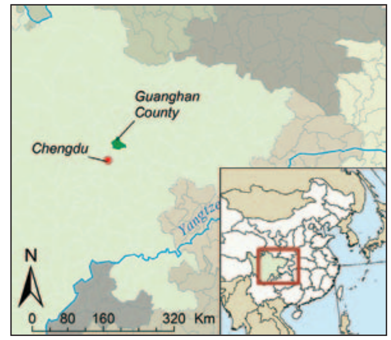

Continuous no-till cultivation is a novel practice that is gaining popularity over conventional methods in the Chengdu Plain and elsewhere in China. The effect of fertilizer rate, balance, and timing on agronomic and environmental parameters is outlined in this multi-year study.

Rice accounts for about one-third of the farmland area used for grain production in Sichuan Province. The majority of paddy rice in the Sichuan Basin, the fertile lowland located in central and eastern Sichuan framed by mountains on all sides, is grown as a single summer crop which is rotated with wheat or rapeseed in the winter season. Prior to 2000, most of these farmlands were plowed (with cattle or by hand with hoes) after each crop harvest before seeding or seedling transplanting. As more and more rural labor has migrated to cities for better incomes, no-till or reduced tillage practices have become popular by necessity. This is especially true for the light-textured alluvial soils of the Chengdu Plain where it is common to find fields under 5 years or more of continuous no-till cultivation. The objective of this study was to provide science-based information for nutrient management in the no-till cropping system.

The experiment was located in Village No. 5, Xigao Town, Guanghan City of Sichuan, from 2005 to 2008 on an alluvial soil typical of the Chengdu Plain. The soil, sampled and analyzed prior to the field experiment in 2005, was acidic (pH 5.4), relatively rich in organic matter (31.2 g/kg determined using H_2SO_4-$K_2Cr_2O_7$ digest), deficient in P (6.2 mg/kg as Olsen extractable P) and Zn (DTPA extractable Zn 1.3 mg/kg), marginally deficient in K (97.4 mg/kg as 1.0 mol/L neutral ammonium acetate extractable K) and Mn (DTPA extractable Mn 3.7 mg/kg), and medium to high in Ca, Mg, S, Fe, Cu, and B. This soil test information was combined with existing knowledge on fertilizer recommendations used in conventional rice cultivation systems to set up an optimal NPK treatment (OPT) of 150-90-120 kg N-P_2O_5-K_2O/ha for rice and 150-75-60 kg N-P_2O_5-K_2O/ha for wheat. An OPT+ 15 kg $ZnSO_4$/ha treatment was tested in rice, as was an OPT+ 15 kg $MnSO_4$/ha treatment in wheat, to validate soil test values with crop response data and verify the effects of annual applications of Zn and Mn. Nutrient deletion plots individually omitted N, P, and K for both rice and wheat. And lastly, two treatments individually tested reduced N and K rates (75% N and 50% K).

A randomized plot design was used with seven treatments and three replications, all planted no-till into fields that were also previously no-till. The plot size was 12 m^2 (4 m x 3 m). Urea, monoammonium phosphate, and potassium chloride were used as sources of N, P, and K.

In the rice season, all P and Zn rates were applied basally prior to rice transplanting; N fertilizer was split twice with 40% applied basally and 60% as a topdressing at the tillering stage.

Abbreviations for this article: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulfur; Fe = iron; Cu = copper; B = boron; Zn = zinc; Mn = manganese; OPT = optimum.

Table 1. Rice yields as affected by soil test-based OPT recommendation and its variations.

	---------------- Rice yield, kg/ha ----------------				
Treatment	2005	2006	2007	2008	Cumulative
OPT	9,500 a	11,852 a	10,998 a	11,004 a	43,353
-N	8,505 b	9,500 d	9,609 c	8,784 c	36,396
-P	9,240 a	10,595 b	10,907 a	10,175 b	40,914
-K	8,742 b	10,100 c	10,158 b	9,492 c	38,490
75% N	9,521 a	10,230 c	10,508 ab	10,545 ab	40,803
50% K	9,599 a	10,805 b	10,365 b	10,205 b	40,973
+Zn	9,678 a	10,511 bc	10,880 a	10,749 a	41,820

Means in each column followed by the same letter are not significantly different at p = 0.05.
The same applies to the following tables when applicable.

Potassium fertilizer was also split twice with half applied at rice transplanting and the remainder at tillering. In wheat, P and Mn were applied basally at seeding; N fertilizer was split between the basal application (30%) and a side dressing (70%) at tillering stage. Potassium fertilizer was split equally between the basal and tillering stage applications. The plant density was 400,500 hills/ha (dug manually at 2 cm depth) for wheat variety Chuanmai 42 in 2007 and Mianmai 39 in 2008; density was 225,100 seedlings/ha for hybrid rice variety II-You 7 in 2006 and variety Chuanxiangyou 9838 in 2007-2008.

Crop Yields

Rice yields from the 4 individual years and a cumulative total are provided in **Table 1**. Year-to-year fluctuations in rice (and wheat) yields were most likely due to changes in cultivars and weather variation (Xu et al., 2006). The OPT produced a highest rice yield among treatments in 2006 only. Rice yields when no N or K was applied were usually among the lowest, indicating that these two nutrients were the two most prominent yield-limiting factors for no-till paddy rice production. The 75% N treatment was equivalent to the OPT in the first, third, and fourth years, while the 50% K treatment was equal to the OPT in the initial year. Relatively high yields within these reduced rate treatments could be attributed to high soil N and K carry-over from nutrient applications in crops grown just prior to this experiment. In 2004, the region's winter season experienced a severe drought and crops grew poorly, required less nutrients, and yields suffered. Yields from the -P treatment were equal to the OPT in the first and third years despite initial indications of low soil test P. Evidence of significant benefits for Zn could not be detected and it is likely that continuous

Table 2. Wheat yields as affected by soil test-based OPT recommendation and its variations.

Treatment	Wheat yield, kg/ha 2005	2006	2007	Cumulative
OPT	9,270 a	7,322 a	6,510 a	23,102
-N	5,477 e	4,728 c	3,677 e	13,880
-P	8,759 bc	5,562 a	5,336 c	19,654
-K	8,402 d	4,904 b	4,188 d	17,493
75% N	8,940 b	5,636 ab	5,642 bc	20,217
50% K	8,441 d	5,133 b	5,397 c	18,970
+Mn	8,730 bc	6,792 a	6,408 a	21,930

application of Zn fertilizer to paddy rice may be inappropriate since one application is known to correct soil Zn deficiency over several years (Martens and Westermann, 1991).

Wheat yield data from the 3 years of research are provided in **Table 2**. Similar to observations in rice, N, K, and P were identified (in that order) as primary nutrient limitations. Wheat yields fell significantly under the reduced N rate in the first and third year. The reduced K treatment generated yields that were comparable to those with complete omission of K. Though soil Mn was considered marginally deficient, addition of Mn showed a yield loss in year 1, but no effect in year 2 or 3.

The yield reduction caused by the omission of nutrients was more severe in wheat than in rice. The drier winter seasons with lower temperatures appears to have magnified the effect of any nutrient limitations due to increased crop stress, less nutrient diffusion, hampered soil microbial activities, and microbial associated nutrient mineralization, as well as chemical reactions related to soil nutrient chemistry (Jansson and Persson, 1982; Balasubramanian et al., 2004; Havlin et al., 2005). Thus, seasonal differences in temperature and water availability between cropping seasons must be considered to achieve better crop yield and nutrient utilization.

Nitrogen Use Efficiency

Apparent crop recovery efficiency data for N in rice is calculated as: $(U-U_0)/F$; where U = total cumulative N uptake in aboveground crop biomass with N applied and U_0 = total cumulative N uptake in aboveground crop biomass with no N applied, and F = cumulative amount of N applied (Snyder and Bruulsema, 2007) shows a clear effect of reduced N efficiency when K application was omitted or reduced **(Table 3)**. Potassium is crucial in enhancing N uptake by crops and N use efficiency (Dibb and Thompson, 1985; Aulakh and Malhi, 2004). Nitrogen recovery in the 75% N treatment was improved to this study's high of 48.5%. Numerous reports have found decreased N use efficiency with increased N input (Zhu, 1990; Sun et al., 2009). Without proper nutrient balance and timing, higher rates of N do not contribute to improved yields and can lead to higher risk of N loss to the surrounding environment. Nitrogen recovery under the P omission treatment was similar to that observed under the OPT. Uptake of N by paddy rice was not significantly affected by the soil P status at this site. Zinc fertilization had a positive impact on N recovery by rice compared to the OPT. This could be attributed to its function in plants where it forms tetrahedral complexes with N-, O-, and S-ligands (Vallee Auld, 1990), thereby influencing both the tertiary structure of proteins and enzymatic activity. Zinc deficiency was also linked to disorders in N metabolism in rice plants by Kitagishi and Obata (1986).

No-till rice plots in Sichuan were most limited by N, followed by K and P. Yields from the K-deficient rice plants (right) were partially hampered by advanced heading which took place one week prior to other treatments.

Table 3. Nitrogen use efficiency of rice as affected by soil test-based OPT recommendation and its variations.

Treatment	Cumulative N uptake, kg/ha Grain	Straw	Total	N recovery, %
OPT	568.9	223.8	793	38.5
-N	400.6	161.0	562	-
-P	544.1	254.6	800	39.6
-K	531.9	226.5	759	32.9
75% N	543.2	250.5	795	48.5
50% K	557.1	215.6	771	34.9
+Zn	554.3	285.5	840	46.3

Table 4. Nitrogen use efficiency of wheat as affected by soil test-based OPT recommendation and its variations.

Treatment	Cumulative N uptake, kg/ha Grain	Straw	Total	N recovery, %
OPT	328.5	26.4	355	35.4
-N	170.8	14.1	185	-
-P	280.8	35.7	316	27.4
-K	268.6	31.5	300	24.0
75% N	291.7	29.0	321	30.2
50% K	294.3	30.6	325	29.2
+Mn	331.2	40.7	372	39.0

Compared to rice, wheat had much lower N recovery values regardless of treatment **(Table 4)**. This could be attributed to seasonal differences in temperature and water availability between the two cropping systems.

Soil Nutrient Balance

The partial soil N balance after four seasons of rice and three seasons of wheat is shown in **Table 5**. Considering the entire system, negative soil N balances were calculated for all treatments. However, the N balance was strictly in deficit in rice and in surplus during the winter wheat season (excluding

Table 5. Soil partial N balance as affected by a soil test-based OPT recommendation and its variations after four seasons of rice and three seasons of wheat.

	- - N input, kg/ha - -			- N removal, kg/ha -			Balance,
Treatment	Rice	Wheat	Total	Rice	Wheat	Total	kg/ha
OPT	600	450	1,050	793	355	1,148	-98
-N	0	0	0	562	185	747	-747
-P	600	450	1,050	800	316	1,116	-66
-K	600	450	1,050	759	300	1,059	-9
75% N	480	360	840	795	321	1,116	-276
50% K	600	450	1,050	771	325	1,096	-46
+Zn or +Mn	600	450	1,050	840	372	1,212	-162

The amounts of N input shown do not account for N derived from atmospheric deposition, irrigation water, and microbial fixation. Similarly, N removal lost through runoff or leaching, volatilization, or denitrification is not accounted for.

the -N treatment). Paddy rice generally removed at least twice as much N as was removed by winter wheat. The -N treatment generated the highest N deficit followed by the reduced N treatment, while the -K treatment had the lowest N deficit.

Summary

This study showed the degree to which no-till rice and wheat yields, and fertilizer use efficiency, are affected by fertilizer treatment. Rice produced much higher grain yields and N use efficiency than wheat no matter if the treatment was balanced or imbalanced. These results offer science-based information for improving nutrient management in the rice-wheat system under no-till. BC

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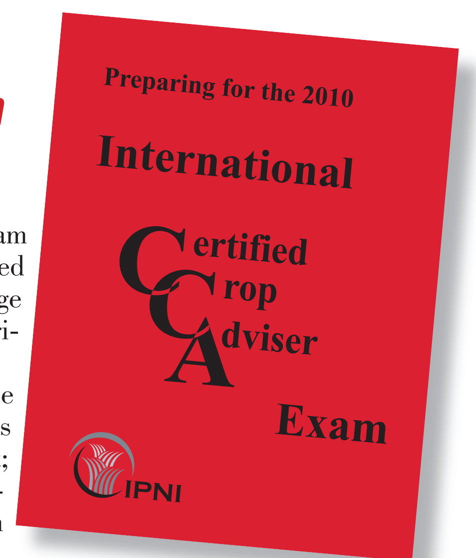

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