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Nitrogen Fertilizer Management and Maize Straw Return Modulate Yield and Nitrogen Balance in Sweet Corn

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Abstract: Nitrogen fertilizer is an important component of crop production; however, its excessive application could result in N loss that could have serious environmental concerns. Straw incorporation in the soil after crop harvest is one of the most feasible straw management techniques, however, the optimization of nitrogen (N) fertilizer management and maize straw incorporation to modulate the crop yield and to maintain N balance in sweet corn is necessary to get better yields on a sustained basis. The present study was comprised of two straw management treatments i.e., (i) no straw return (S0), and (ii) incorporation of crushed corn ears by into the soil using rotary tiller (S100) and four N fertilizer management treatments i.e., (i) common farmer practice with total N applied at 300 kg ha⁻¹ with 50%, 5%, 30%, and 15% splits at basal, 3-leaf stage (V3), at hilling stage (V8) and at tasseling/flowering stage (RT), respectively (FM); (ii) application of total N at 225 kg ha⁻¹ with 40%, 10% and 50% at basal, 3-leaf stage (V3) and at hilling stage (V8), respectively (OMI); (iii) application of total N at 150 kg ha⁻¹ with 40%, 10% and 50% at basal, 3-leaf stage (V3), and at hilling stage (V8), respectively (OMII); and (iv) the treatment without any fertilizer application (N0). The hybrid sweet corn cultivar ‘Yuetian 28’ was grown during the spring and autumn growing seasons of 2016 and 2017. The results showed that the N management treatments substantially improved the fresh ear yield, ear number and ear weight, partial factor productivity from nitrogen (PFP_N), recovery efficiency from nitrogen (RE_N), and agronomic efficiency from nitrogen (AE_N). Compared with FM, the OMI and OMII treatments significantly increased the AE_N and PFP_N whilst decreased the apparent N loss, however, the fresh ear yield, ear number and ear weight in OMI treatment were found to be statistically similar ($p > 0.05$) to FM. Moreover, the S100 treatment did not affect the fresh ear yield and yield components significantly. Overall, straw return combined with an optimized N fertilizer application could improve the yield of sweet corn on a sustained basis with minimum and/or negligible N loss.

Keywords: sweet corn; maize straw; N use efficiency; N loss; yield

1. Introduction

Nitrogen (N) is a critical nutritional element for crops and is considered as one of the main limiting factors that substantially affects crop yields [1]. The application of N fertilizers at higher rates

generally results in higher crop yields [2,3], however, excessive N application can also cause serious environmental issues [4,5]. So, the application of balanced N dose is necessary to meet the challenge of sustainable crop production with better nitrogen use efficiencies (NUE).

Sweet corn is an important crop that is produced and consumed in South China on a large scale [6]. During its growth period, the local farmers are generally applying high doses of N-fertilizers in curse to get high yields [7,8], however, excessive N application could result in N loss into the environment, rather than its better uptake and utilization [9,10], which ultimately leads to serious environmental risks [11]. The crop yield increment is reaching its bottleneck under high N application and fingerprinting the bad impact on ecological safety [12,13]. Therefore, the optimization of N application is needed in order to get better yields of sweet corn with reduced/minimum N loss, to make the crop production ecologically safe. Thus, the application of organic fertilizers is an eco-safe approach in crop production systems [14]. The sweet corn straw with high C:N ratio could release plenty of nutrients after returning into the soil [15]. The straw decomposition absorbs available N in the soil and plays a significant role in reducing N loss [16] whereas the release of straw-based nutrients after its decomposition is beneficial for crop growth [17]. Being cost-effective, farmers often apply more chemical fertilizers rather than applying organic fertilizers to get short-term benefits [18]. On the other hand, farmers often burn the crop residues for on-farm management without knowing its consequences on soil health [19]. With the development of mechanized farming, it is now quite easy to incorporate the crop residues into the soil rather than to burn, however, the effects of returning straw into the soil with optimized N dose and their subsequent effects on crop growth and yield need to be investigated. Moreover, it is also important to meet the nutrient requirements of sweet corn during its growth period; therefore, the local farmers are keen to apply fertilizer several times to grow sweet corn at a higher yield [20]. Therefore, it is necessary to evaluate the N fertilizer management methods to meet the crop nutrient requirements and to reduce the soil N loss and labor cost for fertilization in the dry land maize planting system. The present study was therefore conducted to evaluate the yield and yield components of sweet corn in response to the N and straw return treatment into the soil, and to investigate the nitrogen uptake, its utilization, and N balance for sweet corn with better yields.

2. Materials and Methods

2.1. Experimental Site and Treatments

Field experiments were conducted during 2016 and 2017 at the Experimental Farm, Guangdong Academy of Agricultural Sciences (23°23' N, 113°26' E; 47 m elevation), China. The regional climatic conditions are quite suitable for maize production [21]. The meteorological data during the growth period of the crop were obtained from the meteorological station of the Central Meteorological Bureau, Baiyun District, Guangzhou, China and shown in Table 1. The physicochemical soil properties of the top 30 cm soil layer were determined according to Page et al. [22] The experimental soil was sandy loam, comprising 5.93 g kg⁻¹ organic matter, 0.41 g kg⁻¹ total N content, 96.37 mg kg⁻¹ Olsen-P, and 162.86 mg k 1–3 cm soil depth, with a planting density of 41,619 plants ha⁻¹. The sowing and harvest times are shown in Table 2.

The experimental treatments were comprised of two straw management treatments i.e., (i) no straw return (S0), and (ii) incorporation of crushed corn ears by into the soil using rotary tiller (S100). The detailed information about the timing of straw return, sowing and harvest are shown in Table 2. The N fertilizer management treatments were comprised of: (i) common farmer practice with total N applied at 300 kg ha⁻¹ in the form of urea with 50%, 5%, 30%, and 15% splits at basal, 3-leaf stage (V3), at hilling stage (V8) and at tasseling/ flowering stage (RT), respectively (FM). The N fertilizer i.e., urea was top-dressed. This farmer practice to apply N to sweet corn was commonly observed from the main production areas of sweet corn in 'Shuikou', 'Hengli' and 'Ruhu' towns of Huizhou city, Guangdong province, China, (ii) application of total N at 225 kg ha⁻¹ in the form of urea with 40%, 10% and 50% at basal, 3-leaf stage (V3) and at hilling stage (V8), respectively (OMI); (iii) application of total N at

150 kg ha⁻¹ in the form of urea with 40%, 10% and 50% at basal, 3-leaf stage (V3), and at hilling stage (V8), respectively (OMII); and (iv) the treatment without any fertilizer application (N0). All treatments were applied with P₂O₅ and K₂O at 120 and 180 kg ha⁻¹ in the form of calcium dihydrogen phosphate and potassium chloride, respectively, as basal fertilizer before sowing (Table 3). The N application set up for OMI and OMII was designed according to the results of Huang et al. [23] and Ding et al. [15]

Table 1. Seasonal variations in external environmental conditions during the growth period of sweet corn.

Growing Season	Rainfall (mm)	Sunshine Hours (h)	Mean Temperature (°C)	Maximum Temperature (°C)	Minimum Temperature (°C)	Daily Total Solar Radiation (MJ/m ²)
2016spr	1124.5	224.1	22.80	26.59	20.25	1005.2
2016aut	211.0	438.9	22.20	27.16	19.07	1200.8
2017spr	828.0	273.0	22.61	26.86	19.52	1147.1
2017aut	184.7	530.6	22.81	27.93	19.73	1284.6

spr: spring, aut: autumn.

Table 2. The information regarding the straw return, crop sowing, and harvest during the experimental period.

Growing Season	Intervals (d)			Time (m/d)		
	Straw Returning-Sowing	Sowing-Harvest	Harvest-Straw Returning	Straw Returning	Sowing	Harvest
2016spr	62	99	31	1/4	3/6	6/12
2016aut	61	91	21	7/13	9/14	12/13
2017spr	62	99	26	1/4	3/6	6/12
2017aut	59	92	—	7/8	9/7	12/7

spr: spring, aut: autumn.

Table 3. Description of fertilization management techniques.

	Fertilizer Application				
	Basal (%)	Seedling (%)	Jointing (%)	Earing (%)	Total Fertilizer (kg hm ⁻²)
FM	50	5	30	15	300
OMI	40	10	50	—	225
OMII	40	10	50	—	150
N0	—	—	—	—	0

Farmers' N fertilizer management (FM); application of total N at 225 kg ha⁻¹ in the form of urea with 40%, 10% and 50% at basal, 3-leaf stage (V3) and at hilling stage (V8), respectively (OMI); application of total N at 150 kg ha⁻¹ in the form of urea with 40%, 10% and 50% at basal, 3-leaf stage (V3), and at hilling stage (V8), respectively (OMII); Zero-N control (N0).

2.2. Sampling and Measurements

Plant samples were harvested at the milk-ripe stage (R3). The three randomly selected plants in each plot were taken, divided into ear and straw and oven-dried to a constant weight at 80 °C. The N concentrations in dry grain and straw were measured using the Kjeldahl method [24]. At the maturity stage, an area of 21 m² in the middle of each plot was manually harvested to determine the fresh ear yield (EY) and yield components. The partial factor productivity from nitrogen (PFP_N), recovery efficiency from nitrogen (RE_N), and agronomic efficiency from nitrogen (AE_N) were calculated according to the method of Dobermann [25] by using the following formulae:

$$PFP_N = Y_N/F_N; \quad (1)$$

$$RE_N = (U_N - U_0)/F_N \quad (2)$$

$$PPF_N = Y_N/F_N \quad (3)$$

F_N —Amount of N applied (kg ha^{-1}); Y_N —crop yield with applied N (kg ha^{-1}); Y_0 —Crop yield (kg ha^{-1}) in a control treatment without N; U_N —Total N uptake in above-ground biomass at maturity (kg ha^{-1}) in a plot that received N; U_0 —Total N uptake in above-ground biomass at the milk-ripe stage (kg ha^{-1}) in a plot that received no N.

In addition, the soil samples were collected before sowing and after harvest. Each sample was collected from five sampling locations per plot at 30 and 90 cm soil depth. The $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ were analyzed by using the Continuous Flow Analyzer (TRAACS 2000 system, Bran and Luebbe, Norderstedt, Germany). The apparent N mineralization rate during the sweet corn growing season was calculated as the difference between N output (plant N uptake plus residual soil N_{\min}) and N input (initial soil N_{\min} in the 0–90 cm soil layers) in the N0 treatment [26]. Apparent N losses were calculated as the difference between N input (initial soil N_{\min} plus apparent N mineralization and N fertilizer) and N output (plant N uptake plus residual soil N_{\min}) in the N-applied treatments [27].

2.3. Experimental Design and Data Analysis

Field experiments were arranged in split-plot design, where straw return treatments were kept in the main plots and the N fertilizer managements were randomized in the subplots. The plot size was 70 m^2 with four replicates. The experimental data were analyzed by using the SPSS21 statistical analysis package (version 6.12, SAS Institute, Cary, NC, USA). The differences amongst means of the experimental treatments were separated by using the least significant difference (LSD) test at 0.05 probability level.

3. Results

3.1. Yield and Yield Components

The N management treatments significantly affected the fresh ear yield, ear number and ear weight; however, the seasonal effect also affected the ear number substantially. No significant effect of straw return and the interactions of N \times Straw, N \times Season, Straw \times Season and N \times Straw \times Season on fresh ear yield and yield components was detected (Table 4). Compared with N0, the FM, OMI and OMII treatment resulted in a significant increase in fresh ear yield, ear number and ear weight. The fresh ear yield, ear number, and ear weight in OMI treatment remained statistically similar ($p > 0.05$) to FM. The fresh ear yield and ear weight in both growing seasons and the ear number in 2016spr decreased dramatically in OMII compared to FM. Overall, the fresh ear yield was recorded as 5–13.5, 18.6–19.0, 18.7–19.4 and 15.8–16.4 t ha^{-1} for N0, FM, OMI and OMII treatments, respectively (Table 5).

Table 4. Analysis of variance for the fresh ear yield, ear number and ear weight of sweet corn. Levels of significance indicated as: NS = not significant. * Significant at $p \leq 0.05$; ** Significant at $p \leq 0.01$.

	Fresh Ear Yield	Ear Number	Ear Weight
Tests of Treatment Effect			
Sum of Square	5.74×10^2	4.65	1.48×10^5
Degree of Freedom	31	31	31
F-Value	11.51	5.05	25.49
ANOVA			
N Management	**	**	**
Straw Management Treatments			
Growth Season	NS	*	NS
N \times Straw	NS	NS	NS
N \times Season	NS	NS	NS
Straw \times Season	NS	NS	NS
N \times Straw \times Season	NS	NS	NS

Table 5. Yield and yield components of sweet corn under different N management and straw management treatments.

N Treatment	Straw Return	Fresh Ear Yield (t/ha)				Ear Number (10 ⁴ /ha)				Ear Weight (g)			
		2016spr	2016aut	2017spr	2017aut	2016spr	2016aut	2017spr	2017aut	2016spr	2016aut	2017spr	2017aut
N0	S0	13.9	10.7	8.5	5.0	4.0	3.3	2.8	2.0	343.6	327.2	307.1	247.2
	S100	13.0	11.5	8.9	6.5	4.1	3.6	2.9	2.4	321.2	316.9	311.9	266.2
	Mean	13.5 C	11.1 C	8.7 C	5.8 C	4.1 B	3.5 C	2.8 B	2.2 B	332.4 C	322.0 C	309.5 C	256.7 C
FM	S0	19.0	18.6	18.8	18.5	4.5	4.4	4.5	4.4	424.4	424.4	421.1	424.4
	S100	19.0	18.2	19.2	18.7	4.4	4.3	4.5	4.3	431.8	419.1	428.1	429.9
	Mean	19.0 A	18.4 A	19.0 A	18.6 A	4.4 A	4.4 A	4.5 A	4.4 A	428.1 A	421.8 A	424.6 A	427.2 A
OMI	S0	19.0	18.8	19.1	18.4	4.4	4.5	4.5	4.4	428.1	417.4	420.9	417.0
	S100	18.4	19.1	19.8	19.5	4.4	4.5	4.6	4.6	422.5	420.7	426.6	424.4
	Mean	18.7 A	19.0 A	19.4 A	19.0 A	4.4 A	4.5 A	4.6 A	4.5 A	425.3 A	419.0 A	423.7 A	420.7 A
OMII	S0	16.4	15.6	16.1	15.5	4.3	4.2	4.3	4.2	376.5	373.8	376.5	371.1
	S100	15.8	16.0	16.7	16.2	4.3	4.2	4.3	4.1	370.9	382.4	385.2	391.2
	Mean	16.1 B	15.8 B	16.4 B	15.9 B	4.3 A	4.2 B	4.3 A	4.2 A	373.7 B	378.1 B	380.9 B	381.1 B

Uppercase letters represent significant differences (LSD = 0.05) among the N fertilizer rate. FM, Fertilizer management as common farmer practice; OMI, application of total N at 225 kg ha⁻¹ in the form of urea with 40%, 10% and 50% at basal, 3-leaf stage (V3) and at hilling stage (V8), respectively; OMII, application of total N at 150 kg ha⁻¹ in the form of urea with 40%, 10% and 50% at basal, 3-leaf stage (V3), and at hilling stage (V8), respectively; Control, zero-N control; S0, no straw return to soil; S100, straw return to soil.

3.2. Above-Ground N Uptake and N Use Efficiency

Total nitrogen (T_N) is total nitrogen uptake by the plant. N treatments and growth seasons significantly affected the total nitrogen (T_N), RE_N , AE_N and PPF_N . Besides, straw return treatment and $N \times$ Season remarkably affected the T_N , RE_N and AE_N . Moreover, the interactive effect of $N \times$ Straw on RE_N , Straw \times Season on AE_N and PPF_N and $N \times$ Straw \times Season on AE_N was also found to be significant (Table 6).

The FM and OMI treatment resulted in significantly higher T_N than OMII and N0 in 2016spr, 2016aut and 2017spr. The FM, OMI, and OMII treatment showed significantly higher T_N than N0 in 2017aut. The highest T_N in 2016aut (169.1 kg ha^{-1}), 2017spr (196.1 kg ha^{-1}) and 2017aut (173.8 kg ha^{-1}) were recorded for OMI-S100 treatment. Compared with FM, the OMI and OMII treatment showed higher RE_N , whilst the straw return was found to be beneficial for increased T_N and RE_N in 2016aut, 2017spr and 2017aut. The OMI treatment significantly increased the AE_N and PPF_N compared to FM. The OMII showed substantial improvement in AE_N (2016aut, 2017spr and 2017aut) and PPF_N for all growing seasons compared to FM. Straw return improved AE_N and PPF_N for OMI and OMII treatment in 2016aut, 2017spr and 2017aut (Table 7).

Table 6. Analysis of variance for T_N , RE_N , AE_N , and PPF_N of sweet corn.

	T_N	RE_N	AE_N	PPF_N
Tests of Treatment Effect	—	—	—	—
Sum of Square	2.04×10^4	2.20×10^4	2.15×10^4	2.39×10^4
Degree of Freedom	23	23	23	23
F-Value	28.08	376.8	421.7	112.5
ANOVA	—	—	—	—
N Management	**	**	**	**
Straw Management	**	**	**	—
Treatments	**	**	**	*
Grow Season	**	**	**	*
$N \times$ Straw	NS	*	NS	NS
$N \times$ Season	*	**	**	NS
Straw \times Season	NS	NS	**	*
$N \times$ Straw \times Season	NS	NS	*	NS

Levels of significance indicated as: NS = not significant. * Significant at $p \leq 0.05$; ** Significant at $p \leq 0.01$; T_N , total above-ground N uptake; RE_N , fertilizer-N recovery efficiency; AE_N , agronomic N use efficiency; PPF_N , nitrogen partial factor productivity.

Table 7. Effects of N fertilizer and straw return on T_N and RE_N .

	Straw Return	T_N (kg ha^{-1})				RE_N (%)			
		2016spr	2016aut	2017spr	2017aut	2016spr	2016aut	2017spr	2017aut
N0	S0	101.1 c	83.5 c	61.4 c	28.5 b	—	—	—	—
FM	S100	100.8 c	86.9 c	78.6 c	37.1 b	—	—	—	—
	S0	160.1 a	163.4 a	177.2 a	169.8 a	19.6 bc	26.6 c	38.6 b	47.1 c
OMI	S100	157.1 a	165.8 a	182.1 a	173.3 a	18.7 c	27.4 c	40.2 b	48.3 c
	S0	159.3 a	161.0 a	182.1 a	167.9 a	25.9 a	34.4 b	53.7 a	62.0 b
OMII	S100	153.9 a	169.1 a	196.1 a	173.8 a	23.5 ab	38.0 a	59.9 a	64.6 b
	S0	134.8 b	135.8 b	144.8 b	139.2 a	22.4 b	34.8 b	55.6 a	73.8 a
	S100	129.8 b	140.0 b	151.7 b	144.0 a	19.1 c	37.6 a	60.2 a	77.0 a

Lowercase letters represent significant differences (LSD = 0.05); FM, fertilizer management as common farmer practice; application of total N at 225 kg ha^{-1} in the form of urea with 40%, 10% and 50% at basal, 3-leaf stage (V3) and at hilling stage (V8), respectively (OMI); application of total N at 150 kg ha^{-1} in the form of urea with 40%, 10% and 50% at basal, 3-leaf stage (V3), and at hilling stage (V8), respectively (OMII); control, zero-N control; S0, no straw return to field; S100, straw return to field. T_N , total above-ground N uptake; RE_N , fertilizer-N recovery efficiency.

The T_N in straw return treatments was comparatively lower than S0 during 2016spr and 2016aut, whereas the results were otherwise during 2017spr and 2017aut. On the other hand, the values of

TN for N0, FM, OMI, and OMII were found statistically similar ($p > 0.05$) for S0 and S100 for all the growing seasons.

3.3. Nitrogen Balance

The OMI and OMII treatment decreased the apparent N loss when compared with FM treatment, whereas the apparent N loss under straw return (S100) was lower than without straw return (S0). The apparent N losses for FM-S0, FM-S100, OMI-S0, OMI-S100, OMII-S0 and OMII-S100 were found to be in the range of 167.3–208.3, 164.4–200.8, 89.8–163.2, 80.6–138.7, 40.6–111.9, and 39.4–90.7 kg N ha⁻¹, respectively. The OMII-S100 resulted in the lowest apparent N loss in 2016spr, 2016aut, 2017spr and 2017aut, i.e., 73.8, 90.7, 72.3 and 39.4 kg N ha⁻¹, respectively (Table 8).

Table 8. Components of the N balance in the different treatments for the four growing seasons. N inputs: N applied with fertilizer (N fertilizer), soil mineral N before sowing 0–0.9 m (N min sowing), apparent N mineralization (N mineralize.); N outputs: total above-ground N uptake (T_N), soil mineral N at harvest 0–0.9 m (N min harvest); and apparent N losses (N losses).

N Balance Parameter	S0				S100			
	N0	FM	OMI	OMII	N0	FM	OMI	OMII
2016spr								
N Fertilizer	0	300	225	150	0	300	225	150
N Min Sowing	102.0	102.0	102.0	102.0	102.0	102.0	102.0	102.0
N Mineralize.	59.1	59.1	59.1	59.1	60.9	60.9	60.9	60.9
T _N	101.1c	157.1 a	153.9 a	129.8 b	100.8 c	160.1 a	159.3 a	134.8 b
N Min Harvest	60.0 c	123.0 a	69.0 c	69.4 c	62.1 c	133.0 a	108.0 b	104.4 b
N Losses		181.0 a	163.2 a	111.9 b		169.9 a	120.6 b	73.8 c
2016aut								
N Fertilizer	0	300	225	150	0	300	225	150
N Min Sowing	65.2 d	113.6 a	75.0 c	75.4 c	67.5 d	114.2 a	97.3 ab	91.2 b
N Mineralize.	75.8	75.8	75.8	75.8	78.8	78.8	78.8	78.8
T _N	83.5 c	163.4 a	161.0 a	135.8 b	86.9 c	165.8 a	169.1 a	140.0 b
N Min Harvest	57.4 c	117.7 a	66.0 c	66.4 c	59.4 c	126.4 a	93.3 b	89.4 b
N Losses		208.3 a	148.7 b	99.0 c		200.8 a	138.7 b	90.7 c
2017spr								
N Fertilizer	0	300	225	150	0	300	225	150
N Min Sowing	69.8 c	123.2 a	90.3 b	80.8 bc	72.3 c	118.1 a	95.7 b	83.1 bc
N Mineralize.	55.3	55.3	55.3	55.3	72.3	72.3	72.3	72.3
T _N	61.4 c	177.2 ab	182.1 a	144.8 b	78.6c	182.1 a	196.1 a	151.7 b
N Min Harvest	63.7c	120.7 a	73.3 bc	73.7 bc	66.0c	122.5 a	94.7 ab	81.5 b
N Losses		180.6 a	115.2 b	67.6 c		185.8a	102.3 b	72.3 c
2017aut								
N Fertilizer	0	300	225	150	0	300	225	150
N Min Sowing	79.4 b	132.8 a	84.3 b	81.9 b	82.2 b	120.5 a	93.0 b	81.4 b
N Mineralize.	20.2	20.2	20.2	20.2	28.5	28.5	28.5	28.5
T _N	28.5 c	169.8 a	167.9 a	139.2 a	37.1 c	173.3 a	173.8 a	144.0 a
N Min Harvest	71.1 c	115.8 a	71.8 c	72.3 c	73.6 c	111.4 a	92.0 b	76.6 c
N Losses		167.4 a	89.8 b	40.6 c		164.4a	80.6 b	39.4 c

Lowercase letters represent significant differences (LSD = 0.05); FM, fertilizer management as common farmer practice; OMI, application of total N at 225 kg ha⁻¹ in the form of urea with 40%, 10% and 50% at basal, 3-leaf stage (V3) and at hilling stage (V8), respectively; OMII, application of total N at 150 kg h⁻¹ in the form of urea with 40%, 10% and 50% at basal, 3-leaf stage (V3), and at hilling stage (V8), respectively; control, zero-N control; S0, no straw return to the field; S100, straw return to field.

4. Discussion

In general, farmers focused on obtaining high benefits by obtaining higher crop yields, and ignored the various other factors that are directly and/or indirectly related to sustainable crop production and farmers' income. For example, the application of excess N in order to get higher yields often

leads to low N use efficiencies, whereas straw burning (just for on-farm straw management) causes environmental pollution and could also have severe consequences for soil physicochemical and biological properties [18,28–30]. Moreover, during the 2016 and 2017 growing seasons, the straw returned to the field combined with the appropriate N fertilizer management improved maize yield, i.e., FM > OMI > OMII > N0, whereas the mean values for fresh ear yield were found to be statistically similar ($p > 0.05$) for FM and OMI (Table 5). Previously, Xu et al. [31] reported that the straw returning + fertilizer application treatment increased the yield of the rice. The short-term effect of crop straw return on yield was not that obvious due to the fact that N fertilizer had a stronger effect than straw return [32–35].

The better N balance may possibly be the result of higher N uptake in OMI and OMII. Moreover, it is a practical approach to establish the nitrogen management practices by evaluating the yield, nitrogen absorption and use efficiencies [36]. Integrated fertilizer management has a significant impact on crop production and N balance in the crop-soil system [14]. In this study, the nitrogen absorption in FM and OMI treatment, under no straw return (S0), was 160.1–177.2 kg ha⁻¹ and 159.3–182.1 kg ha⁻¹, respectively (Table 7), which is in accordance with the findings of Gao et al. [20]. The T_N in straw return treatment was comparatively lower than S0 during 2016spr and 2016aut but not during 2017spr and 2017 aut. On the other hand, the values of T_N for N0, FM, OMI, and OMII were found to be statistically similar ($p > 0.05$) for S0 and S100, for all the growing seasons. The T_N in straw return treatments was comparatively lower than S0 during 2016spr and 2016aut, whereas the results were otherwise during 2017spr and 2017aut. On the other hand, the values of T_N for N0, FM, OMI, and OMII were found to be statistically similar ($p > 0.05$) for S0 and S100, for all the growing seasons (Table 7). The previous study reported that N loss has increased due to excessive N-based fertilizers [37]. Compared with S0, straw return (S100) was found to be beneficial in N uptake and use efficiencies in maize. Previously, Liu et al. [37] reported that integrated agronomic practices management improved in yield, nitrogen balance, but reduced nitrogen loss. The N loss due to N leaching is the largest source under the high N application in South China, as a consequence of high-temperature and heavy-rain climate conditions [38]. Thus, FM treatment produced the highest nitrogen loss, due to nitrogen leaching, and besides, the straw return treatment showed lower N loss than no straw return treatment. Further, OMI + S100 treatment showed better N uptake (Table 8), which showed that the addition of straw in combination with N application could substantially improve the N uptake in maize. Alterations in crop production practices due to diversity in cropping systems (specifically the inclusion of leguminous crops) could substantially improve the nutrient use efficiencies [39]. Moreover, the application of organic fertilizers and green manuring also improved the N uptake, use efficiency and crop yield [40]. Moreover, the deep placement of N fertilizer and organic amendments in addition to chemical fertilizers could also improve the overall N use efficiency, thus could also be a potential N management strategy in cereal crops [41–43].

Without a doubt, the common practice followed by farmers could also produce high yield, but often leads to the leaching of N. The optimization of N fertilizer management and maize straw return is thus necessary to get better crop yields with improved N use efficiency. The OMI + S100 treatment may contribute to both high yields with better N use efficiency in long term practice. Therefore, the long term management of N fertilizer is necessary to reduce the N application rate with minimum loss in the double maize cropping system in South China. Further studies are still needed to better understand the saturation value of soil N pool, the different routes for N loss, and soil N dynamics.

5. Conclusions

In summary, the modified application of N coupled with incorporation maize improved the fresh ear yield, ear number and ear weight, partial factor productivity from nitrogen (PFP_N), recovery efficiency from nitrogen (RE_N), and agronomic efficiency from nitrogen (AE_N), as compared to farmers' common practice of the N application in sweet corn. The OMI and OMII substantially enhanced the AE_N and PFP_N, however, the yield and related attributes in OMI treatment were found to be marginally

different than in FM. Therefore, straw incorporation could improve the nitrogen use efficiencies and hence the yield of sweet corn in the long run. Hence, it is feasible to modulate the yield and N balance of sweet corn by optimizing N fertilizer management and maize straw return.

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