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[illegible] late seasons in the subtropical environment of Wuxue County, Hubei Province, China in 2013 and 2014. On average, grain yield in ICM was 13.5% higher than that in FP. A maximum grain yield of 9.40 and 10.53 t ha^{-1} [illegible] ICM [illegible] of double-season rice with ICM was achieved with the combined effects of increased plant density and [illegible] ICM [illegible] leaf area index, leaf area duration, radiation use efficiency, crop growth rate, and total nitrogen [illegible] FP [illegible]

Rice is the staple food for more than half of the world's population and for more than 65% of the China's population[1,2]. Increasing world rice production in a sustainable manner is vital for ensuring global food security[3]. Global crop production can be increased by expanding the area of croplands, increasing crop yield, and increasing multiple cropping index[4]. Cropland expansion is not feasible because of urbanization and environmental concerns such as biodiversity loss and greenhouse gas emission[4]. It is essential to maintain the increase of rice yield at an annual rate of 1.5%[5] and at the same time to increase the harvest frequency of existing cropland[4] in order to keep pace with the food demand of the growing human population.

Grain yield can be increased by breeding new rice varieties with greater yield potential and by improving crop and resource management to enhance actual farm yield[6,7]. Optimum crop management especially nutrient management has proven to be highly effective in improving rice grain yield[7,8]. Other management practices such as planting methods and plant density, cultivars, quality of seed and seedlings, and irrigation regime can also affect grain yield to some extent[9–11]. Qin *et al.* argued that testing single components of management practice independently may not capture the impact a holistic package would have on enhancing rice grain yield[12]. Ladha *et al.* argued that closing the yield gap is becoming increasingly difficult to achieve by testing a component technology in isolation[13]. A more integrated approach involving nutrients, water, and other agronomic management factors will allow the maximization of rice grain yield. Furthermore, simultaneously applying a number of the best compatible individual technologies could maximize overall benefits to farmers. Depending on the need and possibility of new technologies, farmers generally integrate new technologies with their existing farmers' practice (FP), which has been referred to as integrated crop management (ICM) or best management practice[13]. Several recent studies have reported greater yield improvement with ICM compared with individual crop production factors[10,12,14].

In the subtropical climate, rice can be grown up to two times per year on the same field. In the subtropical environment of Hubei province in China, for example, double-season rice cropping is usually practiced with an early-season crop from April to July and a late-season crop from July to October[15]. The wide adoption of

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double-season rice system in both China and elsewhere in Asia increases multiple cropping index and thus contributes substantially to global rice supply[4]. However, the area of double cropping rice has decreased substantially in the last decade in China due to the dramatic increase in labor cost and low grain yield[15,16].

Grain yield of single-season rice crop is higher than that of double-season rice crop[17]. Within the double-season rice cropping system, the early-season rice has lower grain yield than the late-season rice[12,15]. The relatively lower yield under early season mainly resulted from lower crop growth during the vegetative phase, which was caused by lower temperature. Reduction in grain filling period due to higher temperature was also responsible for lower grain yield in the early-season rice[12]. Wu *et al.* demonstrated that grain yield of double-season rice can be increased with improved nitrogen (N) management and proper plant density, especially for the early-season rice[15]. It is necessary to determine if ICM can further increase grain yield of double-season rice crop.

Grain yield, radiation use efficiency (RUE), and N use efficiency (NUE) under various crop management practices have been intensively studied for single-season rice crop in China[18–20]. However, relatively little is known about yield performance, yield attributes, and resource use efficiency of double-season rice crop under ICM. Objectives of this study were to (i) compare grain yield and RUE between ICM and FP, (ii) determine maximum grain yield of double-season rice crop in central China, and (iii) identify the traits for improving yield potential of double-season rice.

Results

C[illegible] There was relatively small difference in seasonal average daily minimum and maximum temperature between the early- and late-season rice (Table 1). However, temperature displayed an increasing trend in the early season, but a decreasing trend in the late season from transplanting to maturity. There was also small difference in seasonal average daily minimum and maximum temperature between 2013 and 2014. However, higher average temperature was observed in 2013 than in 2014 in the early-season rice from flowering to maturity and in the late-season rice from transplanting to panicle initiation. The opposite was true in the late-season rice from flowering to maturity. Average temperature from panicle initiation to flowering was relatively stable across the two seasons and the two years. There was no clear difference in average daily solar radiation between the early and late seasons. Growing period from flowering to maturity generally had lower average daily solar radiation than other growing periods. Seasonal average daily solar radiation in 2013 was higher than that in 2014 (Table 1).

C[illegible] Relatively small difference in duration from transplanting to flowering was observed across seasons and years (Table 2). The early-season rice had 7 to 9 d longer duration in the seedbed than the late-season rice, whereas the late-season rice had 14–21 d longer duration in the ripening phase (from

	Season	SW–TR	TR–PI	PI–FL	FL–MA	SW–MA	TR–MA
2013	Early	45	24	31	27	127	82
	Late	36	28	29	48	141	105
2014	Early	43	25	28	32	128	85
	Late	36	23	26	46	131	95

Table 2. G[illegible] ([illegible]) [illegible] 2013 [illegible] 2014. [a]SW, TR, PI, FL, and MA are sowing, transplanting, panicle initiation, flowering, and maturity, respectively.

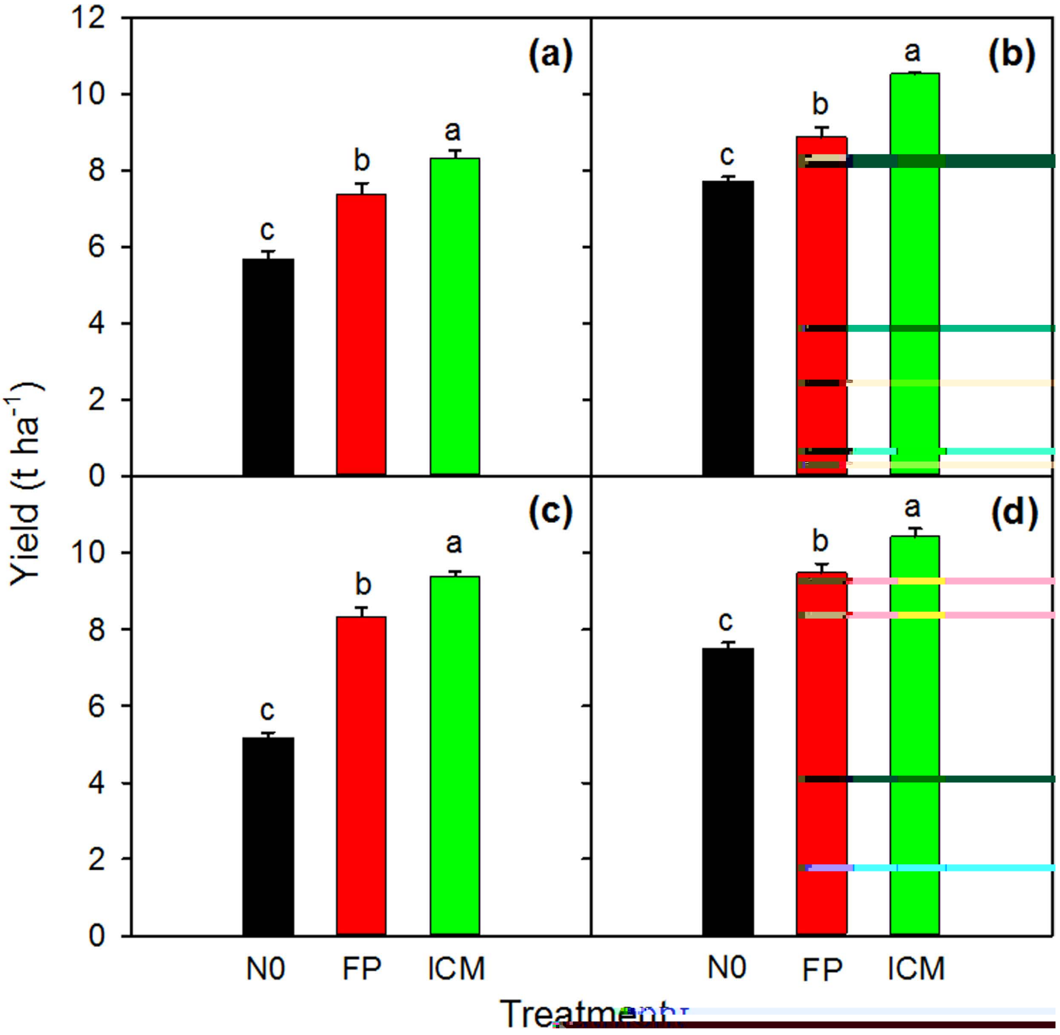

Figure 1. Grain yield in early (a) and late (b) seasons in 2013, and in early (c) and late (d) seasons in 2014. Different lowercase letters denote statistical difference between treatments of each season according to LSD test (0.05). Error bars represent ±1 s.e. (n = 4, standard error of four replications).

Grain yield and its components. Crop management treatments had a significant effect on grain yield in both seasons in the two years (Fig. 1). On average, grain yield in ICM was 12.8% and 14.1% higher than that in FP in the early and late seasons, respectively. Grain yield of ICM and FP were 1.60–3.45 t ha^{-1} higher than that of zero-N control (N0). The late-season rice produced 40.3% higher grain yield than the early-season rice in N0, but only 16.9–18.3% higher grain yield than the early-season rice in FP and ICM (Fig. 1). There was a small and inconsistent difference in grain yield between 2013 and 2014.

Higher grain yield of ICM over FP was mainly attributed to higher spikelets per m^2 (i.e. sink size), which was caused by the difference in panicles per m^2 between the two treatments (Table 3). Sink size of ICM was 10.5–18.7% and 18.5–19.9% higher than that of FP in early and late seasons, respectively. At the same time, ICM had 16.3–61.7% and 36.7–54.2% more panicles per m^2 than FP in early and late seasons, respectively (Table 3). Higher grain yield of late over early season was also due to higher sink size. The difference between the two seasons in sink size was attributed to the difference in panicle size (i.e. spikelets per panicle) instead of panicle number. The

Year	Season	Treat.	Panicles m^{-2}	Spikelets panicle^{-1}	Spikelets m^{-2} (×10^3)	Grain filling (%)	1000-grain weight (g)
2013	Early	N0^a	255.3^c	108.6^b	27.7^c	81.2^a	23.3^a
		FP	308.5^b	138.7^a	42.8^b	70.0^b	22.2^c
		ICM	498.8^a	102.0^b	50.8^a	65.1^c	22.7^b
		Mean	354.2	116.4	40.4	72.1	22.7
	Late	N0	241.2^c	166.8^a	40.2^c	82.3^a	22.2^a
		FP	289.5^b	164.0^a	47.5^b	76.7^b	22.4^a
		ICM	395.7^a	142.4^b	56.3^a	78.3^b	22.4^a
		Mean	308.8	157.8	48.0	79.1	22.3
2014	Early	N0	229.8^c	88.6^c	20.3^c	92.2^a	25.2^a
		FP	341.6^b	120.3^a	41.1^b	81.9^b	24.1^b
		ICM	397.2^a	114.3^b	45.4^a	82.2^b	24.1^b
		Mean	322.8	107.7	35.6	85.4	24.5
	Late	N0	205.5^c	166.5^a	34.2^c	84.2^a	22.8^b
		FP	244.8^b	173.1^a	42.3^b	84.0^a	22.9^b
		ICM	377.4^a	134.3^b	50.7^a	80.7^b	23.2^a
		Mean	275.9	158.0	42.4	83.0	22.9

Table 3. [illegible] 2013 and 2014. Within a column for each season and year, means followed by the same letters are not significantly different according to LSD (0.05). ^{a}N0, FP, and ICM are zero-N, farmers' practice, and integrated crop management, respectively.

[illegible]	Season	Treat.	M [illegible]	L [illegible] (m^2 m^{-2})	M [illegible] m^{-2}	H [illegible] (%)	D [illegible] (

Sink size of the late-season rice was 19.0% higher than that of the early-season rice, and the panicle size of the late-season rice was 35.6–46.7% higher than that of the early-season rice (Table 3). Grain filling percentage and 1000-grain weight were not responsible for the yield difference between ICM and FP or between the two seasons (Table 3). Averaged across seasons and years, daily grain yield of ICM and FP was 105.6 and 93.1 kg ha^{-1} d^{-1}, respectively (Table 4). There was no consistent difference in daily grain yield between the early and late seasons. Daily grain yield was higher in 2014 than in 2013, except for N0 in the early season (Table 4).

Yield difference between ICM and FP was due to the difference in aboveground total dry weight (TDW) rather than in harvest index (HI) (Tables 4 and 5). The TDW of ICM at maturity was 13.9–38.9% higher than that of FP (Table 5). From tillering to booting, the late-season rice exhibited larger difference between ICM and FP in TDW than the early-season rice (Fig. 2a–d). Across the entire growing season, ICM had consistently higher crop growth rate (CGR) than FP in three out of the four field experiments (Fig. 2e–h). Yield advantage of the late season over the early season was due to both TDW and HI in 2013, but was due to TDW alone in 2014 (Tables 4 and 5). Overall, the early-season rice in 2013 had the lowest grain filling percentage and HI among the

Year	Season	Treatment	Incident radiation (MJ m^{-2})	Intercepted radiation (%)	Intercepted radiation (MJ m^{-2})	Total dry weight (g m^{-2})	Radiation use efficiency (g MJ^{-1})
2013	Early	N0[b]	1230.2	57.8[c]	710.6[c]	1136.0[c]	1.60[b]
		FP	1230.2	71.3[b]	877.4[b]	1376.1[b]	1.57[b]
		ICM	1230.2	73.4[a]	902.6[a]	1911.5[a]	2.12[a]
		Mean	1230.2	67.5	830.2	1474.5	1.76
	Late	N0	1564.4	72.7[c]	1136.5[c]	1354.4[c]	1.19[b]
		FP	1564.4	80.3[b]	1255.3[b]	1537.0[b]	1.22[b]
		ICM	1564.4	84.7[a]	1325.8[a]	1976.3[a]	1.49[a]
		Mean	1564.4	79.2	1239.2	1622.6	1.30
2014	Early	N0	1206.2	49.1[b]	591.6[b]	865.4[c]	1.47[c]
		FP	1206.2	70.1[a]	845.2[a]	1494.8[b]	1.77[b]
		ICM	1206.2	70.1[a]	845.5[a]	1702.2[a]	2.01[a]
		Mean	1206.2	63.1	760.8	1354.1	1.75
	Late	N0	1221.3	75.2[c]	918.3[c]	1185.0[c]	1.29[c]
		FP	1221.3	82.1[b]	1003.1[b]	1488.8[b]	1.48[b]
		ICM	1221.3	86.4[a]	1055.1[a]	1860.7[a]	1.76[a]
		Mean	1221.3	81.2	992.2	1511.5	1.51

Table 5. S[illegible] early- and late-season [illegible] 2013 and 2014. Within a column for each season and year, means followed by the same letters are not significantly different according to LSD (0.05). [a]Incident radiation, percent of intercepted radiation, intercepted radiation, aboveground total dry weight, and radiation use efficiency were calculated from transplanting to maturity. [b]N0, FP, and ICM are zero-N, farmers' practice, and integrated crop management, respectively.

for field experiments, which was due to high temperature stress during flowering (daily maximum temperature of 36.2–37.0 °C on June 17–19).

Plant growth and radiation use efficiency. Maximum leaf area index (LAI) and leaf area duration (LAD) of ICM were significantly higher than those of FP (Table 4). The ICM treatment had higher LAI than FP throughout the growing season except for the vegetative stage in the early-season rice in 2014 (Supplementary Fig. 1). Higher LAI was responsible higher CGR and TDW in ICM compared with FP. The ICM treatment also had higher stems per m^2 than FP throughout the growing season except for the vegetative stage in the early-season rice in 2014 (Supplementary Fig. 2). The maximum stems per m^2 of ICM were higher than that of FP (Table 4). Higher panicles per m^2 of ICM was attributed to higher stem number, which was due to higher plant density with narrow hill spacing and more seedlings per hill compared with FP.

The RUE of ICM was 13.6–35.0% higher than that of FP (Table 5). The difference between ICM and FP in light interception percentage and intercepted radiation were relatively small compared with the difference in TDW between the two treatments. Higher RUE was observed in the early-season rice than in the late-season rice. There was no consistent difference in RUE between 2013 and 2014 (Table 5).

Nitrogen uptake and use efficiency. The ICM treatment had higher N uptake at maturity but lower N harvest index (NHI), N use efficiency for grain production, and partial factor productivity of applied fertilizer N than FP (Table 6). Agronomic N use efficiency was higher in ICM than in FP in the late-season rice, but no difference in the early-season rice. There was no consistent difference between ICM and FP in N recovery efficiency and physiological N use efficiency (Table 6), because no significant difference between ICM and FP were found in RE in the early season of 2014, and in PE in the late season of 2013. Overall, ICM tended to reduce NUE due to higher rate of N fertilizer application compared with FP. The early-season rice demonstrated higher N recovery efficiency than the late-season rice, but the reverse was true for NHI, N use efficiency for grain production, and physiological N use efficiency although the difference were relatively small in 2014 compared with in 2013 (Table 6). There was no consistent difference between the two seasons in other NUE-related traits.

Discussion

On average, ICM produced the grain yield of 9.67 t ha^{-1} compared to 8.52 t ha^{-1} from FP, resulting in a 13.5% increase in grain yield over FP. Significant increase in grain yield by ICM over FP was also reported in single-season rice in China[10,11,21–23], in double-season rice in China[12], and in double-season rice in India[14] and Bangladesh[9]. The higher grain yield of ICM was attributed to the increase in sink size, which was caused by more panicles per unit area compared with FP. It is interesting to observe that yield enhancement through improved crop management is generally realized through the increase in panicle number, while yield increase by varietal improvement is generally resulted from the large panicle size.

Higher biomass production instead of HI was responsible for higher grain yield of ICM over FP. The ICM had higher CGR than FP throughout the entire growing season in three out of four field experiments, which was associated with higher LAI, LAD, and RUE of ICM. Similar results were reported by Xue *et al.* and Qin *et al.* who attributed the yield gain of ICM to increased LAI and high radiation interception and RUE[12,21]. Notably, the RUE of ICM reached 2.01–2.12 g MJ^{-1} in the early-season rice and 1.49–1.76 g MJ^{-1} in the late-season rice in our study.

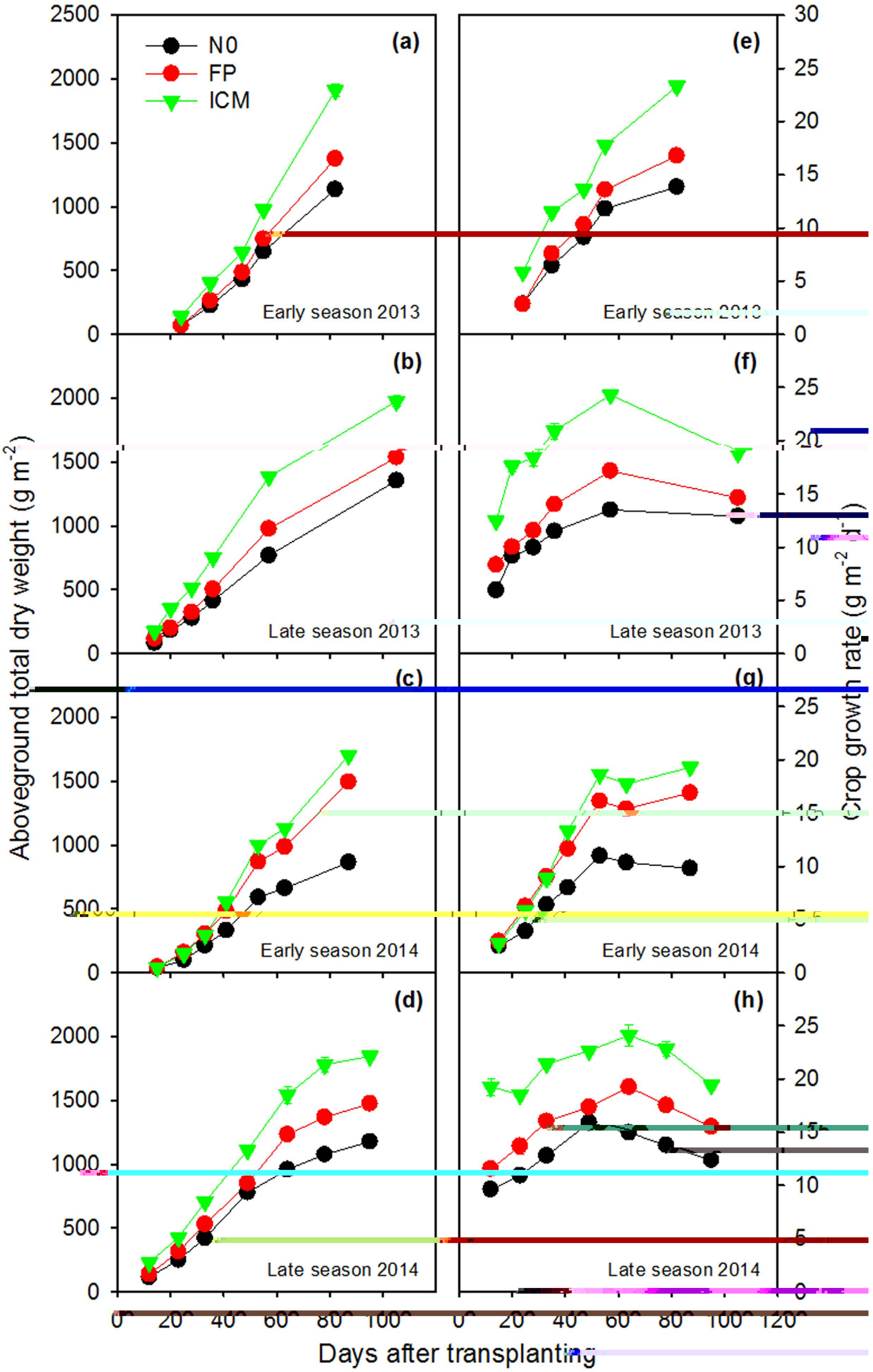

Figure 2. Aboveground total dry weight (a–d) and crop growth rate (e–h) in the early and late seasons of 2013 and 2014. Error bars represent ±1 s.e. (n = 4, standard error of four replications).

Year	Season	Treat.	N uptake (kg ha^{-1})	NHI (%)	NUE$_g$ (kg kg^{-1})	AE (kg kg^{-1})	RE (%)	PE (kg kg^{-1})	PFP (kg kg^{-1})
2013	Early	N0^{b}	109.4^{c}	57.0^{a}	47.8^{a}				
		FP	172.2^{b}	57.8^{a}	38.5^{b}	7.2^{a}	32.2^{b}	22.3^{a}	34.0^{a}
		ICM	237.9^{a}	46.8^{b}	31.5^{c}	9.2^{a}	52.5^{a}	17.4^{b}	30.6^{b}
		Mean	173.2	53.8	39.3	8.2	42.4	19.9	32.3
	Late	N0	114.9^{c}	61.2^{a}	63.7^{a}				
		FP	145.6^{b}	64.3^{a}	56.1^{b}	4.4^{b}	15.7^{b}	26.2^{a}	41.9^{a}
		ICM	212.2^{a}	54.5^{b}	46.6^{c}	9.9^{a}	37.4^{a}	26.4^{a}	38.1^{b}
		Mean	157.6	60.0	55.5	7.1	26.6	26.3	40.0
2014	Early	N0	89.6^{c}	62.1^{b}	53.5^{a}				
		FP	176.4^{b}	63.2^{a}	46.9^{b}	17.8^{a}	44.5^{a}	39.9^{a}	42.4^{a}
		ICM	205.7^{a}	59.1^{c}	44.2^{c}	17.6^{a}	47.4^{a}	37.1^{b}	37.2^{b}
		Mean	157.3	61.5	48.2	17.7	45.9	38.5	39.8
	Late	N0	128.4^{c}	67.1^{a}	51.4^{a}				
		FP	162.8^{b}	69.1^{a}	50.4^{a}	8.1^{b}	17.7^{b}	49.4^{a}	42.0^{a}
		ICM	208.3^{a}	55.1^{b}	45.9^{b}	11.3^{a}	30.7^{a}	36.9^{b}	36.8^{b}
		Mean	166.5	63.8	49.2	9.7	24.2	43.1	39.4

Table 6. N[illegible] **2013 and 2014.** Within a column for each season and year, means followed by the same letters are not significantly different according to LSD (0.05). ^{a}Nitrogen uptake at maturity, nitrogen harvest index (NHI), nitrogen use efficiency for grain production (NUE$_g$), agronomic nitrogen use efficiency (AE), nitrogen recovery efficiency (RE), physiological nitrogen use efficiency (PE), partial factor productivity of applied fertilizer nitrogen (PFP). ^{b}N0, FP, and ICM are zero-N, farmers' practice, and integrated crop management, respectively.

were RUE values were similar to the potential values determined under high-yielding environments in previous studies[19,24,25].

Increased plant density with narrower hill spacing and more seedlings per hill in ICM contributed to higher stem number per unit area and higher CGR during the vegetative phase compared with FP. Higher stem number per unit area was the prerequisite for higher panicle number at maturity in ICM. Peltonen-Sainio stated that improved early season growth capacity supported good establishment for high interception of solar radiation, which, in turn, determines total plant biomass and grain yield[26].

Improvement in nutrient management in ICM with increased rates of N, P, and K application, and with more times of N and K application supported higher CGR throughout the growing season and higher N uptake and RUE as well compared with FP. Improved nutrient management in ICM with delayed N application was responsible for lower leaf senescence during ripening phase, as evidenced by higher ratio of flag leaf SPAD reading at maturity to that at heading in ICM than FP (Supplementary Fig. 3). Slower leaf senescence of ICM could ensure the maintenance of higher LAI, CGR, RUE, and N uptake after heading. Sui *et al.* also reported that N application at late reproductive growth stage had a benefit for grain yield, which might prevent and slow down leaf senescence, resulting in high photosynthetic activity[22]. Although the increased rates of N, P, and K application ensured that nutrient did not limit crop growth and yield formation in ICM, decline in nutrient use efficiency in ICM compared with FP would increase the risk of nutrient losses and cause environmental concern.

The late-season rice produced 2.18 t ha^{-1} higher grain yield than the early-season rice in N0. The seasonal yield difference was reduced to 1.33–1.62 t ha^{-1} in FP and ICM. Yield difference was more than 1 t ha^{-1} between the two seasons in several provinces in central China[15]. As reported by Qin *et al.*[12], sink size due to the different panicle size was mainly responsible for the yield difference between the two seasons. The lower grain yield in the early-season rice compared to the late-season rice could be partially attributed to varietal difference and different climatic conditions between the two seasons[12]. There was no doubt that lower temperature of the early-season rice reduced CGR during the vegetative phase, while higher temperature shortened the ripening phase by 14–21 d compared with the late-season rice. One strategy to overcome the limitation of low temperature on early vegetative growth in the early-season rice is to increase the rate of basal N application. However, high rate of N application at the early growth stage when the plant's N uptake ability is still low could maximize the risk of N losses and reduce NUE. Both limited biomass accumulation during vegetative stage and shortened grain filling duration during gain development stage were detrimental to yield formation of the early-season rice. In addition, extremely high temperature may occur during flowering period in the early-season rice, which could induce spikelet sterility and reduce grain filling percentage and HI, and consequently lead to lower grain yield. This had happened in the early-season rice in 2013, as evidenced by lower grain filling percentage and HI compared with the other three field experiments (Tables 3 and 4). It appeared that the reduction in grain filling percentage and HI due to high temperature stress in 2013 early-season rice was more severe in ICM than in FP andN0, suggesting that caution should be taken when high nutrient input is used in ICM to enhance rice yield potential in high temperature-prone seasons or areas.

Double-season rice generally has lower grain yield than single-season rice although its annual grain yield (i.e. summation of grain yield during both early and late seasons) is higher than the single-season rice[12,15,17]. Wu *et al.* stated that the attainable yield under double rice-cropping systems is characterized by relatively lower grain yield of 5.46 t ha^{-1} in the early-season crop and 7.69 t ha^{-1} in the late-season crop[15]. Using data from on-farm experiments conducted in China's major rice-producing regions from 2000 to 2013, Xu *et al.* reported average grain yields of 6.5, 8.0, and 6.9 t ha^{-1} for the early-, middle-, and late-season rice, respectively[17]. Under the best crop management treatments, Qin *et al.* was able to achieve 8.3 and 9.5 t ha^{-1} grain yield in the early- and late-season rice, respectively[12]. Similarly, a grain yield of 9.5 t ha^{-1} was produced by the hybrid cultivar Liangyou-287 in the early-season rice[27] and by T-you 207 in the late season rice[28]. In our study, ICM achieved a maximum grain yield of 9.40 t ha^{-1} with hybrid cultivar Liangyou 287 in the early-season rice in 2014 and 10.53 t ha^{-1} with hybrid cultivar Tianyouhuazhan in the late-season rice in 2013. More importantly, daily grain yield in the main field of ICM was more than 100 kg ha^{-1} d^{-1} for both the early- and late-season rice crops. One of the criteria for super rice varieties in China is to produce 100 kg ha^{-1} d^{-1} in the main field excluding the period in the seedbed[29]. This is a plausible criterion because it eliminates the approach of improving yield potential by increasing crop growth duration so that cropping intensity could be maintained in the cropping system[30]. Daily grain yield is also an important criterion for judging the productivity of double-season rice crop due to limitation in total growth duration under subtropical conditions.

To achieve 9.0–10.5 t ha^{-1} grain yield in double-season rice, the following traits and their corresponding values should be considered: >45,000 spikelets m^{-2}, >80% grain filling, >50% in HI, >1,700 g TDW m^{-2}, >18 g m^{-2} d^{-1} in seasonal mean CGR, >7 in maximum LAI, >500 m^{-2} in maximum stem number, >70% in seasonal mean LI, >1.5 g MJ^{-1} in RUE, >200 kg N ha^{-1} in total N uptake, and >100 in kg ha^{-1} d^{-1} in daily grain yield. As suggested by Sui *et al.*, it is difficult to increase rice yield potential by improving a single trait of yield components[22]. For example, increasing grain yield not only needs to enlarge sink size by increasing the number of panicles but also requires adjustment of other yield formation processes. The ICM was effective in breaking the negative relationships among the yield-related traits and achieving an overall improvement in grain yield[22].

In general, implementation of ICM involves increased inputs in labor and resources[9]. Labor-demanding practices are less attractive to farmers as wages and the opportunity costs of labor are increasing with the progress in economic development[31]. Rice farmers in China are reluctant to invest more resources in the rice production because of lower rice prices[32]. The future research on ICM should consider the inclusion of labor-saving technologies, efficient nutrient management, and simplified crop management practices.

Conclusions

Yield improvement of double-season rice with ICM was achieved with the combined effects of increased plant density and optimized nutrient management. A maximum grain yield of 9.40 and 10.53 t ha^{-1} was achieved under ICM in the early- and late-season rice, respectively, indicating the potential to further increase the grain yield of double-season rice following a holistic and integrated agronomic approach[12]. Yield gain of ICM resulted from a combination of increase in sink size due to more panicle number per unit area and biomass production, further supported by the increased LAI, LAD, RUE, CGR, and total N uptake compared with FP. Further enhancement in the yield potential of double-season rice should focus on increasing CGR and biomass production through improved and integrated crop management practices. There was a tendency that nitrogen use efficiency declined under ICM due to higher rate of nitrogen fertilizer application compared with FP. Therefore, future study should consider more efficient nutrient management in ICM.

Materials and Methods

Experimental [illegible] Experiments were conducted in 2013 and 2014 in a farmer's field at Zhougan Village (29°51′N, 115°33′E, 51 m altitude), Dajin Township, Wuxue County, Hubei Province, China. In each year, rice was grown in a double-season cropping system with an early-season rice from March to July and a late-season rice from June to October or November. Detailed dates of sowing, transplanting, and maturity were given in Supplementary Table 1. The soil has the following properties: pH 5.1, 29.7 g kg^{-1} organic matter, 2.7 g kg^{-1} total nitrogen (N), 38.3 mg kg^{-1} Olsen phosphorus (P), and 301.8 mg kg^{-1} exchangeable potassium (K). The soil test was based on samples taken from the upper 20 cm of the soil before the application of basal fertilizers in 2013.

In each experiment, crop management treatments were arranged in a complete randomized block design with four replicates. Crop management treatments included N0, FP, and ICM. The differences in crop management

Both varieties are F1 hybrids and widely grown for double-season rice crop in central China. Pre-germinated seeds were sown in nursery beds to produce uniform seedlings. Forty-three- to 45-day-old seedlings were manually transplanted for the early season, while 36-day-old seedlings were manually transplanted for the late season. A water depth of 5 to 10 cm was maintained until 7 days before maturity when the fields were drained. Weeds, insects, and diseases were controlled as required to avoid yield loss.

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Author Contributions

D.W. was responsible for all of the experimental work and data analyses, and took joint responsibility with S.P. for writing the manuscript and drawing the figures. S.P. was the principal investigator and laboratory leader, and responsible for the experimental design and reviewing final manuscript. J.H., L.N., F.W., X.L., K.C. and Y.L. contributed to experimental work and data analyses.

Additional Information

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