

Integrated crop management practices for maximizing grain yield of double season rice crop -

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Information on maximum grain yield and its attributes are limited for double season rice crop grown under the subtropical environment. This study was conducted to examine key characteristics associated with high yielding double season rice crop through a comparison between an integrated crop management (ICM) and farmers practice (FP). Field experiments were conducted in the early and 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 was achieved under ICM in the early and late season rice respectively. Yield improvement of double-season rice with ICM was achieved with the combined effects of increased plant density and optimized nutrient management. Yield gain of ICM resulted from a combination of increases in sink size due to more panicle number per unit area and biomass production, further supported by the increased leaf area index, leaf area duration, radiation use efficiency, crop growth rate, and total nitrogen uptake compared with FP. Further enhancement in the yield potential of double season rice should focus on increasing crop growth rate and biomass production through improved and integrated crop management practices.

Rice i he a le food fo mo e han half of he o ld' o la ion and fo mo e han 65% of he China' o la ion^{1,2}. Inc ea ing o ld ice od c ion in a ainable manne i i alfo en ing global food ec i s³. Global c o od c ion can be inc ea ed b e anding he a ea of c o land , inc ea ing c o ield, and inc ea ing m l i le c o ing inde ⁴. C o land e an ion i no fea ible beca e of bani a ion and en i onmen al conce n cha biodi e i s⁵lo and geenho ega emi ion⁴. I i e en ial o main ain he inc ea e of ice ield a an ann al a e of 1.5% and a he ame ime o inc ea e he a e f e end⁶ of e i ing c o land ⁴ in o de o kee ace i h he food demand of he g o ingh man o la ion.

[illegible]

In he b o i cal clima e , ice can be o n o o ime e ea on he ame eld. In he b o i cal en i on men of H bei o ince in China, fo am le, do ble- ea on ice co ing i all aciced i h an ea ea on co f om A il o J and a la e- ea on co f om J o Ocobe¹⁵. e ide adon of

SCIENTIFIC REPORTS | 7:38982 | DOI: 10.1038/srep38982

do ble- ea on ice Δ em in bo h China and el e he e in A ia inc ea e m l i le c o ing inde and h con-
ib e b an ial Δ o global ice Δ ¹⁴. Ho e e, he a ea of do ble c o ing ice ha dec ea ed b an ial Δ
in he la decade in China d e o he d ama ic inc ea e in labo co and lo g ain Δ ^{15,16}.

G ain Δ field of ing le- ea on ice c o i highe han ha of do ble- ea on ice c o ¹⁷. Wi hin he
do ble- ea on ice c o ing Δ em, he ea Δ ea on ice ha lo e g ain Δ field han he la e- ea on ice ^{12,15}.
e ela i el Δ lo e Δ field nde ea Δ ea on main Δ e l ed f om lo e c o g o h d ing he ege a i e
ha e, hich a ca ed b Δ lo e em e a e. Red c ion in g ain lling e i o d d e o highe em e a e
a al o e on ible fo lo e g ain Δ field in he ea Δ ea on ice ¹². W *et al.* demon a ed ha g ain Δ field of
do ble- ea on ice can be inc ea ed i h im o ed ni o gen (N) managemen and o e lan den i e e ecial Δ
fo he ea Δ ea on ice ¹⁵. I i nece a o de e mine if ICM can f he inc ea e g ain Δ field of do ble- ea on
ice c o .

G ain Δ field, adia ion e e ciency (RUE), and N e e ciency (NUE) nde a io c o managemen
ac ice ha e been in en i el Δ died fo ing le- ea on ice c o in China ^{18–20}. Ho e e, ela i el Δ li lei kno n
abo Δ field e fo mance, Δ field a ib e, and e o ce e e ciency of do ble- ea on ice c o nde ICM.
Objec i e of hi Δ e e o (i) com a e g ain Δ field and RUE be een ICM and FP, (ii) de e mine ma im m
g ain Δ field of do ble- ea on ice c o in cen al China, and (iii) iden if he ai fo im o ing Δ field o en al
of do ble- ea on ice.

Results

Climatic condition

e e a ela i el Δ mall di e ence in ea onal a e age dai Δ minim m and ma im m
em e a e be een he ea Δ and la e- ea on ice (Table 1). Ho e e, em e a e di l a ed an inc ea ing
end in he ea Δ ea on, b a dec ea ing end in he la e- ea on f om an lan ing o ma i Δ e e a
al o mall di e ence in ea onal a e age dai Δ minim m and ma im m em e a e be een 2013 and 2014.
Ho e e, highe a e age em e a e a ob e ed in 2013 han in 2014 in he ea Δ ea on ice f om o e
ing o ma i Δ and in he la e- ea on ice f om an lan ing o anicle ini ia ion. e o o i e a e in he
la e- ea on ice f om o e ing o ma i Δ . A e age em e a e f om anicle ini ia ion o o e ing a ela-
i el Δ able ac o he o ea on and he o sea e e a no clea di e ence in a e age dai Δ ola adia-
ion be een he ea Δ and la e- ea on. G o ing e i o d f om o e ing o ma i Δ gene all had fo e a e age
dai Δ ola adia ion han o he g o ing e i o d. Sea onal a e age dai Δ ola adia ion in 2013 a highe han
ha in 2014 (Table 1).

Crop growth and development

Rela i el Δ mall di e ence in d a ion f om an lan ing o o e ing
a ob e ed ac o ea on and sea (Table 2). e ea Δ ea on ice had 7 o 9 d longe d a ion in he eed bed
han he la e- ea on ice, he ea Δ he la e- ea on ice had 14–21 d longe d a ion in he i ening ha e (f om

	S	SW	TR	TR	PI	PI	FL	FL	MA	SW	MA	TR	MA
2013	Ea	45	24	31	27	127	82						
	La e	36	28	29	48	141	105						
2014	Ea	43	25	28	32	128	85						
	La e	36	23	26	46	131	95						

Fig. 1. Grain yield (t ha⁻¹) in 2013 and 2014. ^aSW, TR, PI, FL, and MA are sowing, anthesis, panicle initiation, flowering, and maturity dates, respectively.

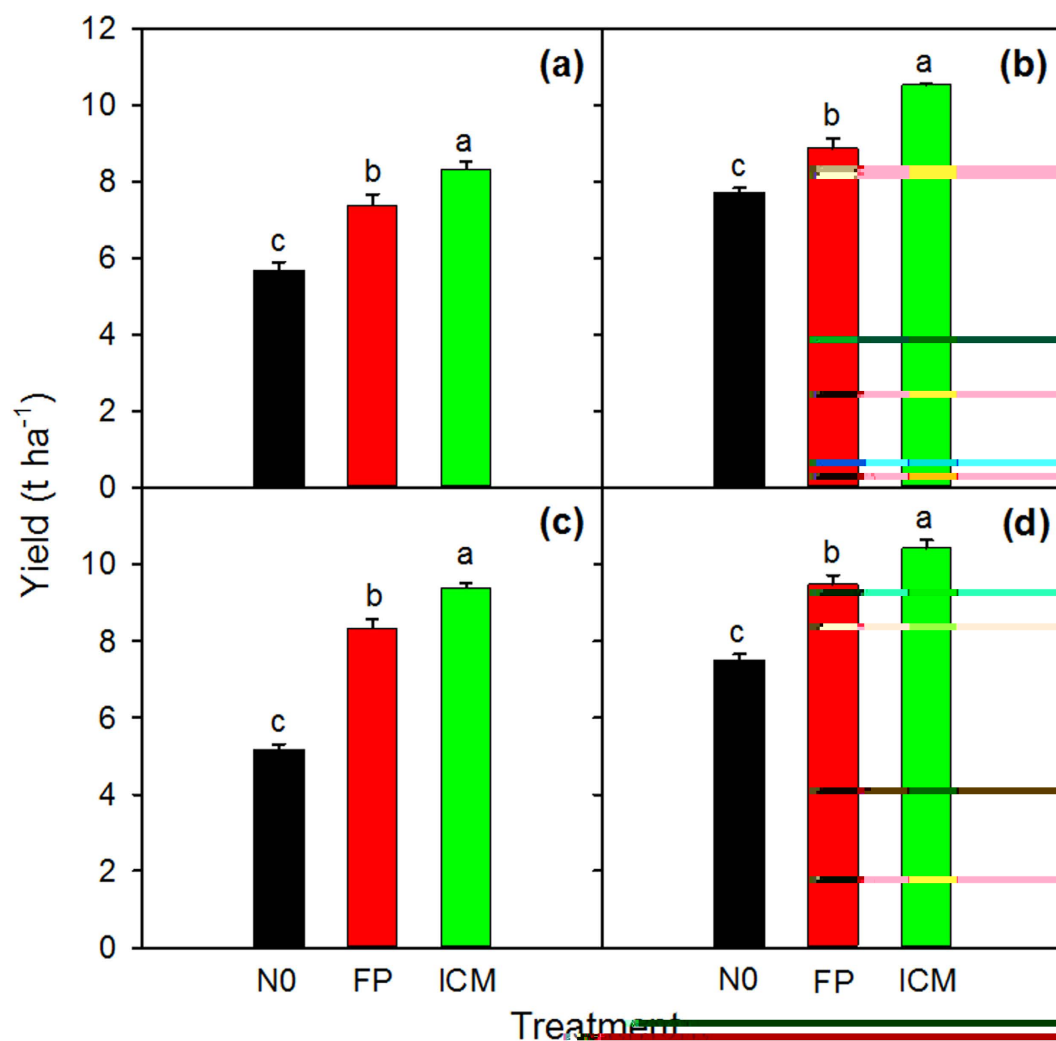


Fig. 1. Grain yield (t ha⁻¹) in 2013 and 2014. ^aSW, TR, PI, FL, and MA are sowing, anthesis, panicle initiation, flowering, and maturity dates, respectively. Different letters denote significant differences between treatments of each year according to LSD test (0.05). Error bars represent ± 1 s.e. (n=4, standard error of replication).

Grain yield and its attributes Crop management treatments had a significant effect on grain yield in both years in the study (Fig. 1). On average, grain yield in ICM was 12.8% and 14.1% higher than in FP in the early and late seasons, respectively. Grain yield of ICM and FP was 1.60–3.45 t ha⁻¹ higher than that of the 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). The small and inconsistent difference in grain yield between 2013 and 2014.

Higher grain yield of ICM over FP was mainly attributed to higher spikelet density (i.e. number of spikelets per m²) in the anthesis stage (Table 3). Sink size of ICM was 10.5–18.7% and 18.5–19.9% higher than that of FP in the early and late seasons, respectively. At the same time, ICM had 16.3–61.7% and 36.7–54.2% more panicle area per m² than FP in the early and late seasons, respectively (Table 3). Higher grain yield of late season rice was also due to higher spikelet density. The difference between the early season rice and late season rice in spikelet density in the anthesis stage (i.e. spikelet density) in favor of late season rice was

	S	T	P	$^{-2}$	S	$^{-1}$	S	$^{-2} (\times 10^3)$	G	(%)	1000-	()
2013	Ea	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					
	La e	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	Ea	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					
	La e	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. Soil N balance and N use efficiency of the maize grown in 2013 and 2014. Within a column for each year and treatment, mean followed by the same letter are not significantly different according to LSD (0.05). ^aN0, FP, and ICM are the N, P, and K fertilizers, respectively, and in the above column management, the effect of

	S	T	M	L	M	H	D
				(² - ²)	⁻²	(%)	()

link of the late-harvested maize. A 19.0% higher than that of the early-harvested maize, and the anthesis of the late-harvested maize was 35.6–46.7% higher than that of the early-harvested maize (Table 3). Grain yield per hectare and 1000-grain weight were not significantly different between ICM and FP or between the two years (Table 3). A significant difference in daily grain yield of ICM and FP was 105.6 and 93.1 kg ha⁻¹ d⁻¹, respectively (Table 4). The average daily grain yield per hectare was significantly higher in 2014 than in 2013, except for N0 in the early-harvested maize (Table 4).

Yield difference between ICM and FP was due to the difference in above-ground and total dry weight (TDW) per hectare index (HI) (Table 4 and 5). The TDW of ICM was 13.9–38.9% higher than that of FP (Table 5). From tillering to anthesis, the late-harvested maize exhibited a greater difference between ICM and FP in TDW than the early-harvested maize (Fig. 2a–d). According to the regression equation, ICM had a significantly higher coefficient of harvest index (CHI) than FP in the early-harvested maize (Fig. 2e–h). Yield at anthesis of the late-harvested maize was significantly higher than that of the early-harvested maize in 2013, but not in 2014 (Table 4 and 5). Overall, the early-harvested maize in 2013 had the lowest grain yield per hectare and HI among the

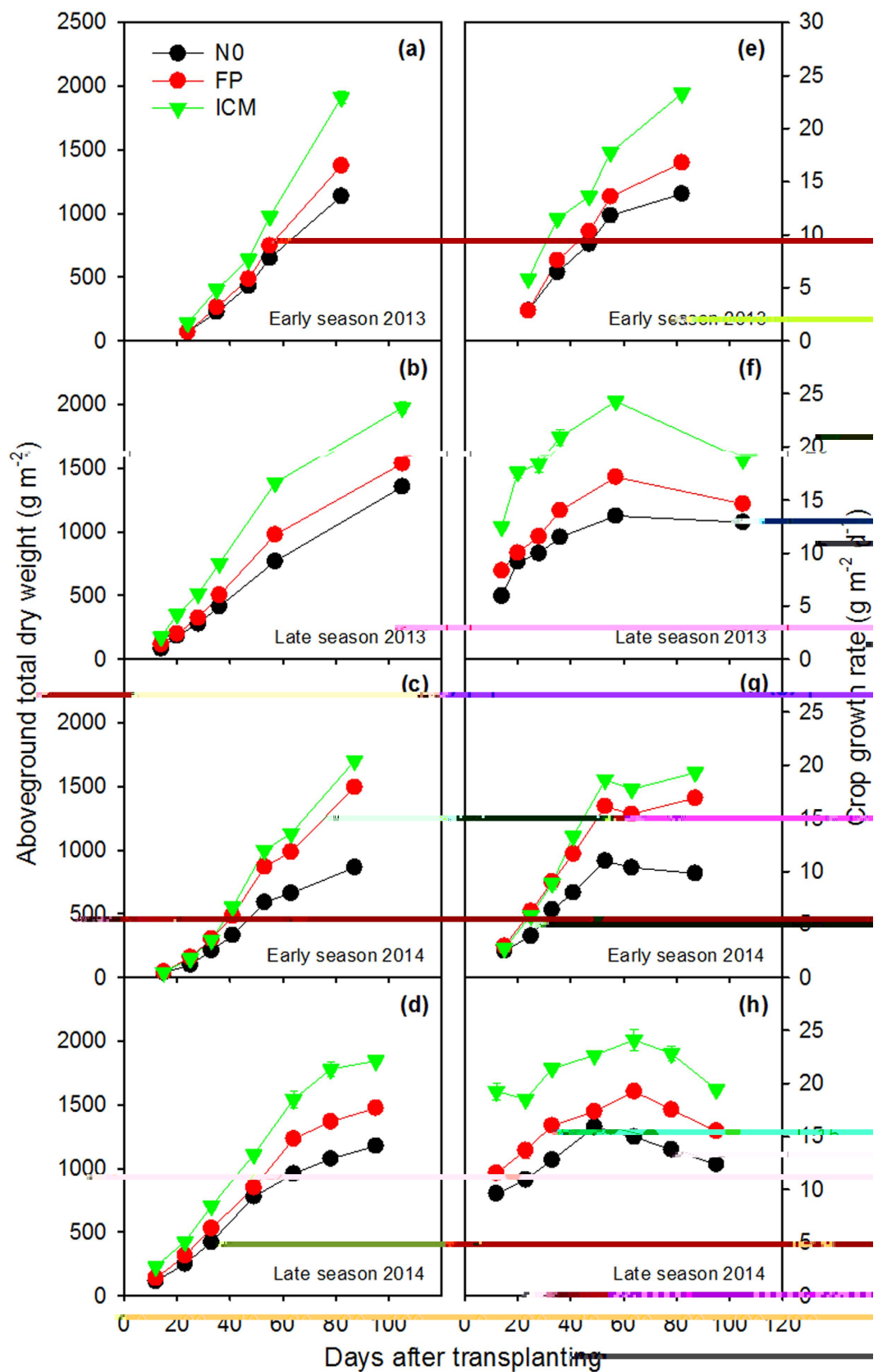


FIG. 2. Aboveground total dry weight (—) and crop growth rate (—) in the early and late season of 2013 and 2014. Error bars represent ± 1 s.e. ($n=4$, standard deviation of four replicates).

	S	T	N (g m ⁻²)	NHI (%)	NUE (g m ⁻²)	AE (g m ⁻²)	RE (%)	PE (g m ⁻²)	PPF (g m ⁻²)
2013	Ea	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
	La e	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	Ea	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
	La e	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

T 6. N 2013 2014. Wi hin a col mn fo each ea on and ea, mean follo ed b he ame le e a e no igni can di e en acco ding o LSD (0.05). ^aNi ogen ake a ma i i ni ogen ha e inde (NHI), ni ogen e e cienc fo g ain o d c ion (NUE_g), ag onomic ni ogen e e cienc (AE), ni ogen eco e e cienc (RE), h iological ni ogen e e cienc (PE), a ial fac o o d c i i of a lied fe ili e ni ogen (PPF). ^bN0, FP, and ICM a e e o-N, fa me ac ice, and in eg a ed c o managemen, e ec i el

e e RUE al e e e imila o he o en ial al e de e mined nde high-ielding en ionmen in e io die ^{19,24,25}.

Inc ea ed lan den i i h na o e hill acing and mo e edling e hill in ICM con ib ed o highe em n mbe e ni a ea and highe CGR d ing he ege a i e ha e com a ed i h FP. Highe em n mbe e ni a ea a he e e i i e fo highe anicle n mbe a ma i i in ICM. Pel onen-Sainio a ed ha im o ed ea ea on g o h ca aci o o ed good e abli hmen fo high in e ce ion of ola adia ion, hich, in n, de e mine o al lan bioma and g ain ²⁶.

Im o emen in n ien managemen in ICM i h inc ea ed a e of N, P, and K a lica ion, and i h mo e ime of N and K a lica ion o ed highe CGR h o gh o he g o ing ea on and highe N ake and RUE a ell com a ed i h FP. Im o ed n ien managemen in ICM i h delaye d N a lica ion a e on-ible fo lo e leaf ene cence d ing i ening ha e, a e idenced b highe a io of ag leaf SPAD eading a ma i i o ha a o e ing in ICM han FP (S lemen a Fig. 3). Slo e leaf ene cence of ICM co ld en e he main enance of highe LAI, CGR, RUE, and N ake a e o e ing. S i et al. al o o ed ha N a lica ion a la e e o d c i e g o h age had a bene fo g ain ield, hich migh e en and lo do n leaf ene cence, e l ing in high ho o n he ic ac i i ²². Al ho gh he inc ea ed a e of N, P, and K a lica ion en ed ha n ien did no limi c o g o h and ield fo ma ion in ICM, decline in n ien e e cienc in ICM com a ed i h FP o ld inc ea e he i k of n ien lo e and ca e en ionmen al conce n.

e la e- ea on ice o d ced 2.18 ha⁻¹ highe g ain ield han he ea ea on ice in N0. e ea onal ield di e ence a ed ced o 1.33–1.62 ha⁻¹ in FP and ICM. Yield di e ence a mo e han 1 ha⁻¹ be e en he o ea on in e al o ince in cen al China ¹⁵. A e o ed b Qin et al. ¹², ink i ed e o he di e en anicle i e a main e on ible fo he ield di e ence be e en he o ea on. e lo e g ain ield in he ea ea on ice com a ed o he la e- ea on ice co ld be a ial a ib ed o a ie al di e ence and di e en clima ic condi ion be e en he o ea on ¹². e e a no do b ha lo e em e a e of he ea ea on ice ed ced CGR d ing he ege a i e ha e, hile highe em e a e ho ned he i ening ha e b ¹⁴ 21 d com a ed i h he la e- ea on ice. One a eg o o e come he limi a ion of lo em e a e on ea i ege a i e g o h in he ea ea on ice i o inc ea e he a e of ba al N a lica ion. Ho e e, high a e of N a lica ion a he ea i g o h age hen he lan' N ake abili i ill lo co ld ma imi e he i k of N lo e and ed ce NUE. Bo h limi ed bioma acc m la ion d ing ege a i e age and ho ned g ain lling d a ion d ing gain de elo men age e de imen al o ield fo ma ion of he ea ea on ice. In addi ion, e emel high em e a e ma occ d ing o e ing e iod in he ea ea on ice, hich co ld ind ce ikele e e ili and ed ce g ain lling e cen age and HI, and con e en i lead o lo e g ain ield. i had ha ened in he ea ea on ice in 2013, a e idenced b lo e g ain lling e cen age and HI com a ed i h he o he h e e eld e e imen. (Table 3 and 4). I a ea ed ha he ed c ion in g ain lling e cen age and HI d e o high em e a e e in 2013 ea ea on ice a mo e e e e in ICM han in FP and N0, gge -ing ha ca ion ho ld be aken hen high n ien in i ied in ICM o enhance ice ield o en ial in high em e a e- one ea on o a ea.

Do ble- ea on ice gene al ha lo e g ain ield han ingle- ea on ice al ho gh i ann al g ain ield (i.e. mma ion of g ain ield d ing bo h ea ea on and la e ea on) i highe han he ingle- ea on ice ^{12,15,17}. W et al. a ed ha he a ainable ield nde do ble ice- o ing i emi cha ac i e d b e la i el lo e g ain ield of 5.46 ha⁻¹ in he ea ea on c o and 7.69 ha⁻¹ in he la e- ea on c o ¹⁵. U ing da a f om

on-fa m e e imen cond ced in China' majo ice- od cing egion fom 2000 o 2013, X *et al.* e o ed a e age g ain f ield of 6.5, 8.0, and 6.9 ha⁻¹ fo he ea l a-, middle-, and la e- ea on ice, e e c i e l²⁷. Unde he be c o managemen ea men, Qin *et al.* a able o achie e 8.3 and 9.5 ha⁻¹ g ain f ield in he ea l a- and la e- ea on ice, e e c i e l²². Simila l a g ain f ield of 9.5 ha⁻¹ a od ced b he h b id c l i a Liang b o- 287 in he ea l a- ea on ice²⁷ and b T- b o 207 in he la e- ea on ice²⁸. In o d ICM achie ed a ma im g ain f ield of 9.40 ha⁻¹. i h h b id c l i a Liang b o 287 in he ea l a- ea on ice in 2014 and 10.53 ha⁻¹. i h h b id c l i a Tian b o h a han in he la e- ea on ice in 2013. Mo'e im o an l a dail g ain f ield in he main f eld of ICM. a mo e han 100 kg ha⁻¹ d⁻¹ fo bo h he ea l a- and la e- ea on ice c o . One of he c i e ia fo e ice a i e ie in China i o od ce 100 kg ha⁻¹ d⁻¹ in he main eld e cl ding he e i od in he eedbed²⁹. i i a la ble c i e ion beca e i eliminae he a oach of im o ing f ield o en al b inc e ing c o g o h d a ion o h a c o ing en i f c o ld be main ained in he c o ing f ield em³⁰. Dail g ain f ield i al o an im o an c i e ion fo j dging he od c i i f of do ble- ea on ice c o d e olimi a ion in o al g o h d a ion nde b o i cal c ondi ion .

To achieve 9.0–10.5 t ha⁻¹ grain yield in double cropping rice, the following are needed: albedo should be considered >45,000 MJ m⁻², >80% grain filling, >50% in HI, >1,700 g TDW m⁻², >18 gm⁻² d⁻¹ in seasonal mean CGR, >7 in maximum LAI, >500 m⁻² in maximum stomatal conductance, >70% in seasonal mean LI, >1.5 MJ m⁻² in RUE, >200 kg N ha⁻¹ in total N uptake, and >100 in kg ha⁻¹ d⁻¹ in daily grain yield. A large eddy simulation model can be used to predict the effect of each parameter on crop growth and grain yield. Furthermore, it is important to note that the above parameters are not independent of each other. For example, increasing albedo will increase the radiation interception by the canopy, which will lead to higher leaf area index (LAI) and thus higher grain yield. Therefore, it is essential to consider the interactions between different parameters when evaluating the potential of different rice varieties or cultivation practices.

In gene al, in l emen a ion of ICM in ol e in inc ea ed in ³¹ in labo and e o ce ³². Labo -demanding ac ice a ele a ac i e o fa me a age and he o o ni sco of labo a e inc ea ing i h he og e in economic de elo men ³¹. Rice fa me in China a e el can o in e mo e e o ce in he ice od c ion beca e of lo e ice ³². ef e e ea ch on ICM ho ld con ide he incl ion of labo - a ing echnologie, e cien n ien managemen, and im li ed co managemen ac ice.

Conclusions

Yield increase of double-crop rice in ICM achieved by the combined effect of increased land use and improved nitrogen management. A maximum gain of 9.40 and 10.53 ha⁻¹ was achieved under ICM in the early and late double-crop rice, respectively, indicating the potential of the increased gain of double-crop rice following a holistic and integrated agro-economic approach¹². Yield gain of ICM resulted from a combination of increased in-lake sedimentation, increased biomass production, increased by the increased LAI, LAD, RUE, CGR, and total N uptake achieved in FP. The enhancement in the potential of double-crop rice should focus on increasing CGR and biomass production through improved and integrated crop management practices. The average annual nitrogen efficiency under ICM decreased by 10% of nitrogen fertilizer application compared with FP. Therefore, the double-crop rice could meet nitrogen management in ICM.

Materials and Methods

[illegible]

In each element, the management element is arranged in a completely random block design. The formula for the management element included NO, FP, and ICM. The difference in management is 6513 and the total is 2009. The difference in management is 27.133 29.67- d 87e4 and the total is 2009. The difference in management is 27.133 29.67- d 87e4 and the total is 2009.

Both varieties are F1 hybrids and ideal for double-cropping rice in central China. Pre-germinated seedlings were grown in the seedbed of rice nursery seedling. For the 45-day-old seedling, the main tillers were transplanted for the early season, while 36-day-old seedling was transplanted for the late season. At a seedling height of 5 to 10 cm, it was maintained for 7 days before main tillers were transplanted. Weed, insect, and diseases were controlled as needed in a rice field.

Measurements

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Acknowledgements

This work was supported by the Program of Innovation of Discipline of University in China (No. 111 Pj02 no. B14032), National High Technology Research and Development Program of China (No. 863 Pj02 no. 2014AA10A605), Special Fund for Agricultural Science Research in the Public Interest of China from the Ministry of Agriculture (No. 201203096), and Major International Joint Research Project of China National Science Foundation (No. 31361140368).

Author Contributions

D.W. was responsible for all of the experimental work and data analysis, and took joint responsibility for writing the manuscript and data analysis. S.P. was the principal investigator and lab leader, and responsible for the experimental design and the international manuscript. J.H., L.N., F.W., X.L., K.C. and Y.L. contributed to the experimental work and data analysis.

Additional Information

Supplementary Information accompanies this article at <http://www.nature.com/scientificreports/>.

Competing financial interests: The authors declare no competing financial interests.

Reprints and permissions: Wang, D. *et al.* Integrated crop management practices for maximizing rice yield and nitrogen efficiency. *Sci. Rep.* **7**, 38982; doi:10.1038/srep38982 (2017).

Paraganglioma: Single Nucleus RNA-seq analysis of paraganglioma and pheochromocytoma in a mouse model of paraganglioma.

