

## Winter cropping improves yield, dry matter accumulation and translocation and nitrogen uptake of double-cropping rice

Haocheng WANG<sup>1</sup>, Binjuan YANG<sup>1</sup>, Haiying TANG<sup>2</sup>,  
Athar MAHMOOD<sup>3</sup>, Rizwan MAQBOOL<sup>3</sup>, Muhammad U. HASSAN<sup>1</sup>,  
Tahir A. KHAN<sup>1</sup>, Muhammad M. IQBAL<sup>4</sup>, Guoqin HUANG<sup>1\*</sup>

<sup>1</sup>Jiangxi Agricultural University, Research Center on Ecological Sciences, Nanchang 330045, P.R. China; [18279196706@163.com](mailto:18279196706@163.com);  
[yangbinjuan@jxau.edu.cn](mailto:yangbinjuan@jxau.edu.cn); [tahirsargani@gmail.com](mailto:tahirsargani@gmail.com); [mubassanuaf@gmail.com](mailto:mubassanuaf@gmail.com); [hgqjxes@sina.com](mailto:hgqjxes@sina.com) (corresponding author)

<sup>2</sup>Hunan University of Humanities, Science and Technology, College of Agriculture and Biotechnology,  
Loudi 417000, P.R. China; [39661026@qq.com](mailto:39661026@qq.com)

<sup>3</sup>University of Agriculture, Department of Agronomy, Faisalabad, 38040 Pakistan; [athar.mahmood@uaf.edu.pk](mailto:athar.mahmood@uaf.edu.pk);  
[rizwan.maqbool@uaf.edu.pk](mailto:rizwan.maqbool@uaf.edu.pk)

<sup>4</sup>Agronomy (Forage Production) Section, Ayub Agricultural Research Institute, Faisalabad, Pakistan; [mahmkhokbar@gmail.com](mailto:mahmkhokbar@gmail.com)

### Abstract

Winter cropping is widely considered as an effective way to increase rice yield. Therefore, this study was performed to find optimal winter cropping patterns in middle and lower reaches of the Yangtze River, China. Five experimental treatments were set up based on the long-term field experiment including winter fallow (CK), Chinese milk vetch winter cropping pattern (CRR), rapeseed winter cropping pattern (RRR), garlic winter cropping pattern (GRR), and winter multiple cropping rotation (ROT). The effects of different winter cropping patterns on the yield, dry matter accumulation and translocation, and plant nitrogen uptake were explored in double-cropping rice. The results showed that compared with CK, winter cropping increased the early and late rice yield by 7.91-10.70% and 3.57-6.89%, respectively. Similarly, compared with CK, winter cropping patterns also increased the number of spikes in early rice by 19.36-25.81% and CRR and ROT increased the effective number of spikes in late rice by 25.58% and 23.26% respectively. The dry matter (DM) translocation by stem and leaf of early rice under CRR was highest, with a 36.2% increase compared with CK, however, DM accumulation after heading in early rice under CRR was lowest. GRR decreased the dry matter translocation by stem and leaf in early rice but increased DM accumulation after heading in early and late rice by 65.28% and 13.44% as compared to CK. Moreover, ROT increased the dry matter translocation by stem and leaf in late rice by 112.63%. Additionally, GRR and ROT treatments increased the stem nitrogen uptake in early rice by 61.76% and 58.61% as compared to control, while CRR increased the nitrogen uptake by stem, leave and spike in late rice by 40.76%, 49.51% and 42.92%. In conclusion, CRR is more beneficial to increase DM accumulation and translocation by stem and leaf in double-cropping rice, and nitrogen uptake by rice plants.

**Keywords:** Chinese milk vetch; cropping patters; dry matter; nitrogen; rice; yield

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## Introduction

Rice is a staple food for more than 50% world's population and it is also a rich source of proteins and nutrients (Dong *et al.*, 2016; Wei *et al.*, 2022). China is a leading country for rice production and consumption and it has a share of 30% in global rice production (Elert *et al.*, 2014). The middle and lower reaches of the Yangtze River (including Hubei, Hunan, Jiangxi, Anhui, Jiangsu and Zhejiang Provinces) are one main rice producing area in China (Li *et al.*, 2020a; Song *et al.*, 2022). The rich climatic resources of the Yangtze River region allow most areas to grow three crops in a year to meet their food needs. Over the past decades, rice cropping patterns in this region have changed from double-cropping rice to single-cropping rice, and winter fallow field abandonment is becoming more common which is causing a significant reduction in rice production (Chen *et al.*, 2013). The rational choice of farmers, low agriculture profits, urbanization and economic development, costly labour and labour shortages, and farmer's perception of more attack of insects, birds, and crop diseases are the main reasons for decline in multiple cropping in this region (Li *et al.*, 2021). The decline in the cropping index in this region is unfavourable to the guarantee of food security, both for China and globally (Hao *et al.*, 2021).

Winter cropping is an important practice that can improve the multiple cropping index, and allow to make full use of natural resources in winter (Yang *et al.*, 2022a). In addition, winter cropping can also promote the sustainable development of paddy systems by improving soil's physical, chemical properties and biological properties (Wang *et al.*, 2006; Wang *et al.*, 2018; Lawal, 2020) and reducing the soil compaction, and soil erosion (Sharma *et al.*, 2018; Blanco *et al.*, 2015) and suppressing the weeds, insect pest and diseases (Mirsky *et al.*, 2011; Bowers *et al.*, 2020). However, various factors including winter cropping itself (Wang *et al.*, 2021; Saleem *et al.*, 2020), straw returning to the field (Ren *et al.*, 2021; Huang *et al.*, 2015), and tillage methods (Tang *et al.*, 2012) affect double-cropping rice fields. These factors affect soil physical and chemical properties (Song *et al.*, 2021) and DM accumulation and translocation (Guo *et al.*, 2022), and finally rice productivity. Therefore, while promoting the resumption of double-cropping rice cultivation in areas where conditions permit, it is very important to explore suitable winter cropping patterns for the rice in the middle and lower reaches of the Yangtze River.

At present, many studies have been carried out on winter cropping in rice fields. Research on straw returning of winter crops in the double-cropping rice region in South China showed that the potato double-cropping rice pattern can improve DM contribution of plant leaf and stem at maturity stages of early rice (Zhang *et al.*, 2019). Likewise, rapeseed double-cropping rice pattern improved DM translocation rates of leaf and stem at maturity stages of late rice, and the Chinese milk vetch double-cropping rice pattern was proved beneficial to the nutrient accumulation and translocation in rice (Zhang *et al.*, 2019). Winter cropping patterns also significantly increased the yield and yield traits by improving DM accumulation and translocation. For example, rapeseed winter cropping improved effective spikes; potato winter cropping increased the number of grains per spike, and vegetable winter cropping increased the seed-setting rate of rice (Song *et al.*, 2021). In another research, rapeseed winter cropping and Chinese milk vetch winter cropping significantly improved grains per spike of rice (Tang *et al.*, 2018). Further, CMV green manure also significantly increased soil fungal and bacterial community structure and led to significant improvement in crop yield and soil quality (Zhang *et al.*, 2022). Besides, planting Chinese milk vetch also exploit natural resources, improves carbon flux and carbon sequestration, fix atmospheric nitrogen, and improves phosphorus and potassium availability, resulting in significant improvement in crop growth and yield (Zhou *et al.*, 2019; Zhou *et al.*, 2023). Some scholars conducted studies on the mixed cropping of green fertilizer in double-cropping rice fields and reported that green manure can increase leaf area index, leaf soil plant analysis development (SPAD) value and dry matter accumulation of rice at the filling stage and spikes seed-setting rate (Wu *et al.*, 2021). In addition, green manure

returning to the field improves photosynthetic efficiency, and DM accumulation at the earlier and later stages which substantially improves rice yield (Liu *et al.*, 2018).

Up until now, most researchers have focused on a few typical cropping patterns of green manure. Considering the complexity of cropping patterns in the middle and lower reaches of the Yangtze River, more diversified patterns still have to be explored. Therefore, in the present study, we selected not only typical winter cropping patterns such as Chinese milk vetch winter cropping pattern, rapeseed winter cropping pattern, but also garlic winter cropping pattern and winter multiple cropping rotation pattern, which have rarely been studied before. This study was based on the hypothesis that winter cropping can improve yield, DM accumulation and translocation and nitrogen uptake in rice. Thus, this study was performed to determine the effect of winter cropping patterns on yield, DM accumulation and translocation, and nitrogen uptake in double-cropping rice.

## Materials and Methods

### *Study site*

The present study was performed at the experimental field (28° 41'N, 116° 55'E) of the Institute of Agricultural Science and Technology of Wannian County, Jiangxi Province for 8 consecutive years from 2012 to 2020. The experiment site is situated in the typical double-cropping rice region in northeast Jiangxi Province. The study site has a subtropical monsoon and humid climate. The experiment site has average maximum and minimum temperature of 38.3 °C and -5 °C and average annual rainfall of 1908.4 mm. The experimental soil has pH 6.08, organic matter 41.81 g·kg<sup>-1</sup>, total nitrogen 1.97 g·kg<sup>-1</sup>, available phosphorus 16.38 mg·kg<sup>-1</sup> and available potassium 130.00 mg·kg<sup>-1</sup>.

### *Experimental design*

The experiment adopted a single-factor randomized block design with 5 treatments, which were winter fallow - early rice - late rice (CK), Chinese milk vetch - early rice - late rice (CRR), rapeseed - early rice - late rice (RRR), garlic - early rice - late rice (GRR), winter multiple cropping rotation (ROT), the winter crop planted under ROT treatment in 2020 was Chinese milk vetch. There were 15 experimental plots with 3 replications. Each plot has an area of 66.0 m<sup>2</sup> and protective belts with a width of 1.5 m were set up around the experimental plot for isolation, and plastic plates with a height of 30 cm were used to separate the plots.

**Table 1.** Experimental design used in study

Treatment	Cropping pattern
WRR(CK)	Winter fallow – early rice – late rice
CRR	Chinese milk vetch – early rice – late rice
RRR	Rapeseed – early rice – late rice
GRR	Garlic – early rice – late rice
ROT	Winter multiple cropping rotation (Interannual rotation of Chinese milk vetch, rapeseed and potato)

### *Experimental varieties and field management*

The Chinese milk vetch variety ('Chinese milk vetch no. 1'), rapeseed variety ('Sanyuehuang'), and garlic variety ('Shandong Jinxiang') was used for study. Before planting, the soil was furrowed and ploughed to make the seed bed and sowing was done with a seeding drill. Winter crops were supplied with a compound fertilizer named Sanyuan (N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O=15%: 15%: 15%). According to the fertilizer requirements of different winter crops, the Chinese milk vetch was not fertilized, rapeseed was fertilized with 375 kg·hm<sup>-2</sup> compound fertilizer, and garlic was fertilized with 450 kg·hm<sup>-2</sup> compound fertilizer. The Chinese milk vetch at the flowering stage

was returned to the field; the straw of rapeseed was chopped and returned to the field and the stalk and leaf of garlic were only harvested, without straw return. The early rice variety 'Zhong Zao 37', and the late rice variety 'Jing Liangyou Hua Zhan' was used for study. The fertilization amount of early and late rice in each plot was the same and NPK fertilizers were applied in the form of urea (N, 46%) superphosphate (P<sub>2</sub>O<sub>5</sub>, 12%) potassium chloride (K<sub>2</sub>O, 60%) at the rate of 135.58, 50.91 and 122.73 kg·hm<sup>-2</sup> respectively. Among them, P was applied as basal dose and N and K was applied three splits (at sowing, tillering and spike emergence). The early and late rice was manually planted by maintaining row to row space of 20×20 cm. After the rice harvest, the straw of early rice was chopped and returned to the field in full quantity, while the straw of late rice was covered and returned to the field in full quantity.

#### *Data collection*

At the maturity stage of rice, five holes of rice plants were selected from each plot as a sample, which was naturally air-dried indoors as seed test material. During the test, each sample of rice was threshed by hand, and the effective spike number and average spike length were recorded. Then, the number of grains per spike was measured by a grain counting machine, and the weight of 1000 grains was taken. The early and late rice samples at tillering, heading, full heading stage, and maturity stages were taken and brought back to the room. 3 holes (avoiding marginal effects of the plot) were selected as a sample and brought back to the room. They were immediately separated into stems, leaves, and spikes and placed in envelope bags and heated for 30 minutes at 105 °C and dried at 80 °C until constant weight. The dry mass of the population was obtained by weighing. After grinding the samples at the maturity stage, Kjeldahl nitrogen analyser was used to measure the nitrogen concentration of each part of the plant. After that nitrogen absorption amount of each part of the plant was calculated on the bases of DM quality.

The spike rates were calculated as ratio of effective spikes to numbers of tillers at maturity, and stem and leaf dry matter translocation (kg·hm<sup>-2</sup>) was calculated by subtracting the stem and leaf DM accumulation at the heading stage from stem and leaf DM accumulation at maturity stage. On the other hand, stem and leaf DM translocation rate (%) was calculated by using the following equation: stem and leaf DM translocation/DM accumulation at the heading stage × 100. The contribution rate of DM translocation to grain yield (%) was determined with following procedure = stem and leaf DM translocation/dry weight of grain at the maturity stage × 100. Then, DM accumulation after heading (kg·hm<sup>-2</sup>) was determined as: DM accumulation at maturity stage — DM accumulation at heading stage. Moreover, the accumulation rate of DM after heading (%) was calculated with DM accumulation after heading/DM accumulation at maturity stage × 100 and the contribution rate of DM accumulation after heading to grain yield (%) was determined as: DM accumulation after heading/dry weight of grain at maturity stage × 100 (Tang *et al.*, 2018; Sun *et al.*, 2020; Yang *et al.*, 2022c).

#### *Data analysis*

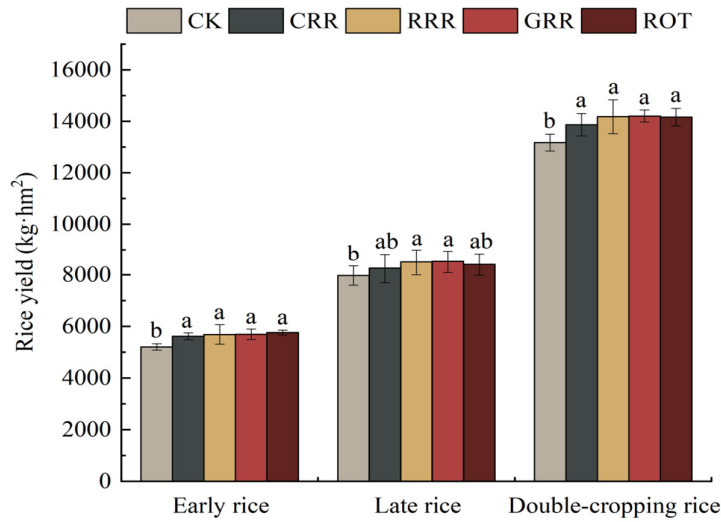
The experiment data were analysed by single factor analysis of variance (One-way ANOVA) using SPSS 20.0 software. Moreover, Duncan method was conducted to compare the significance of each value (P = 0.05), were considered statistically significant. Lastly, Origin 2018 was used for drawing the figures.

## **Results**

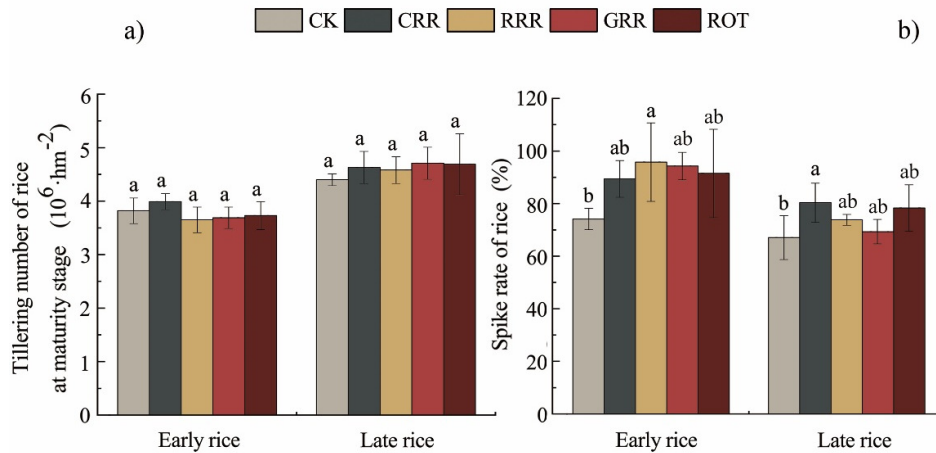
### *Effect of winter cropping on yield characteristics of double-cropping rice*

The results indicated that under each winter cropping pattern, the yield of early rice was significantly increased by 7.91%-10.70% (Figure 1). The yield of late rice under RRR and GRR was increased by 6.59% and 6.87% compared with CK, respectively. Each winter cropping pattern significantly increased double cropping rice yield and GRR showed the best performance (Figure 1). Winter cropping also had a significant impact on the yield traits of rice and the effective spike number of early rice was significantly increased by 19.36%-25.81%

under each winter cropping pattern (Table 2). The effective spike number of late rice also increased in different degrees, among which the CRR and ROT treatment increased effective spike by 25.58% and 23.26% compared with CK, respectively (Table 2). The average spike length of ROT was greater than that of RRR and CK, respectively. In summary, all winter cropping treatments had significantly increased the yield of late rice as compared to early rice. Tillers of early rice under CRR was the highest, while the tiller number of late rice under GRR was the highest, with no significant difference among treatments (Figure 2a). The spike rate of early rice and late rice increased by 20.61%-29.17% and 3.37%-19.8% under the winter cropping pattern, among which the spike rate of early rice under RRR and late rice under CRR increased significantly (Figure 2b).



**Figure 1.** Effect of different winter cropping patterns on rice yield  
Different lowercase letters meant significant differences at 0.05 level ( $P < 0.05$ )

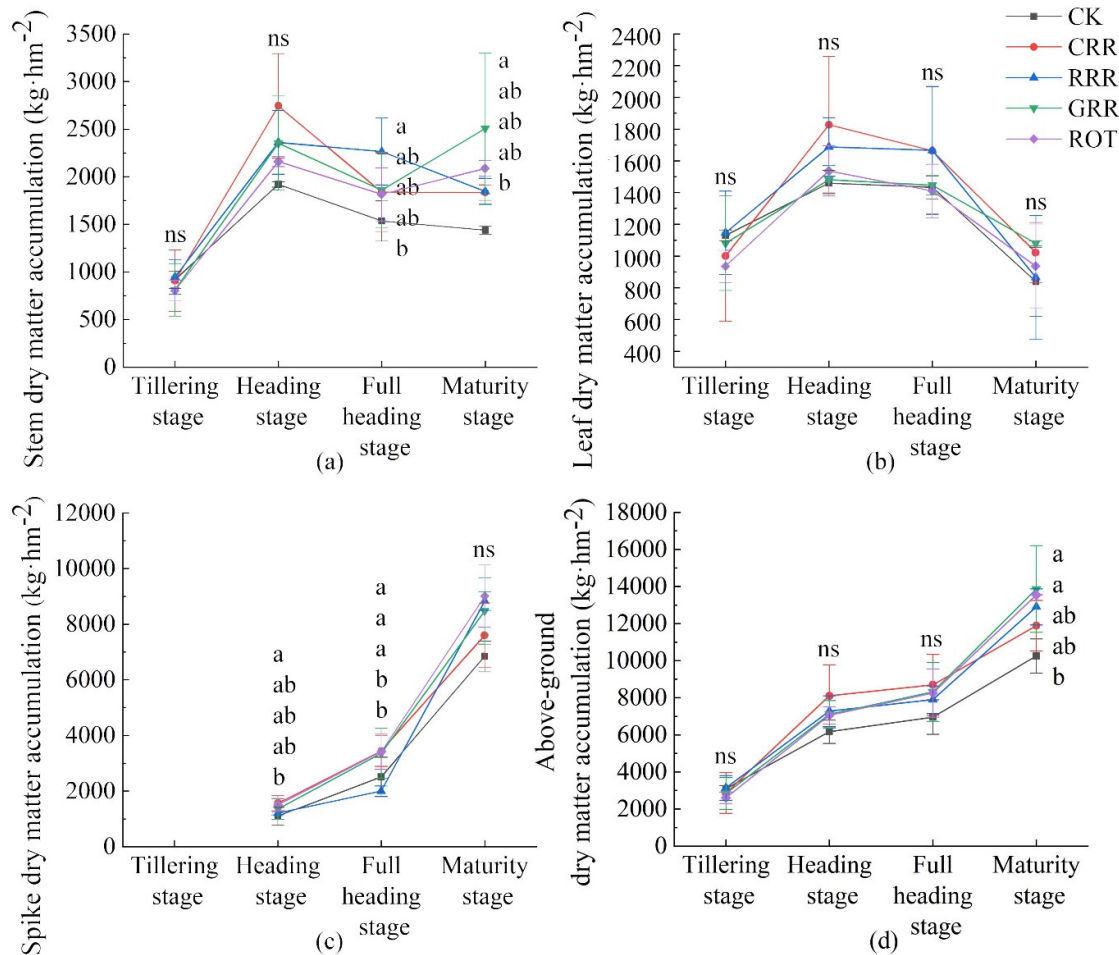


**Figure 2.** Effect different winter cropping patterns tillers number of rice at maturity (a) and spike rate of rice (b)

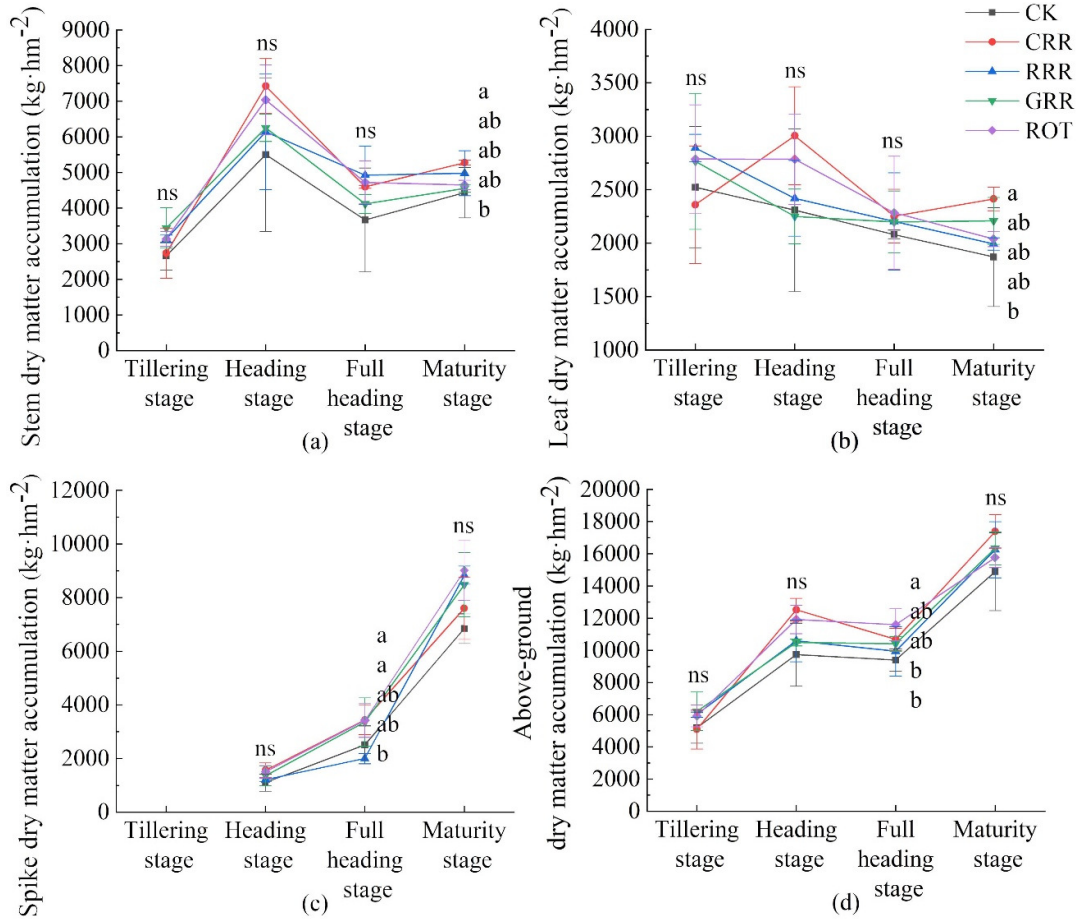
*Effects of winter cropping on dry matter accumulation of early and late rice*

Among different treatments, DM of leaf, spike, and above-ground part of early rice at different stages showed a uniform trend, and except for GRR, stem dry DM was firstly increased and then declined, while GRR showed a significant trend of increase after full heading stage, indicating that garlic winter cropping pattern was

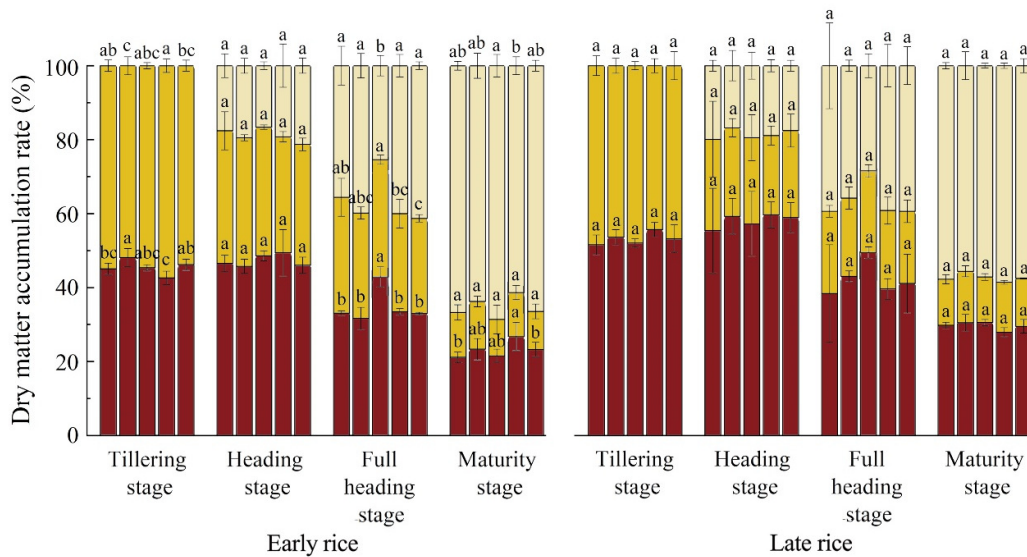
conducive to promoting stem dry matter accumulation after the full heading stage (Figure 3). Among all treatments, DM accumulation of stem, leaf, spike, and above-ground part at the heading stage of CRR was the highest, which was increased by 28.93%, 28.99%, 14.68%, and 31.37% compared with CK, respectively (Table 2). The stem DM accumulation of RRR was maximum at the full heading stage, which was significantly increased by 47.60% compared with CK (Figure 3a). GRR significantly increased stem DM accumulation at full heading as well as maturity stages by 39.97% and 74.33%, and DM accumulation of the above-ground part at the maturity stage was significantly increased by 35.18% compared with CK (Figure 3d). In the case of late rice, leaf dry matter accumulation under CRR increased to maximum value at the heading stage and then quickly decreased while the leaf dry matter accumulation under other treatments decreased gently during the growth period (Figure 4b). Dry matter accumulation of stem, leaf, spike, and above-ground parts at the heading stage was increased by 35.04%, 30.20%, 8.85%, and 28.72% under CRR compared with CK (Figure 4). However, the improvement was not significant, it indicated that CRR has promoted dry matter accumulation at the heading stage. The leaf and stem DM accumulation at the maturity stage was also significantly increased under CRR compared with CK. Leaf dry matter accumulation under GRR and ROT increased by 45.37% and 63.28% compared with RRR (Figure 4b).



**Figure 3.** Dry matter accumulation of early rice stem (a), leaf (b), spike (c), and above-ground dry matter accumulation at tillering, heading, full heading and maturity stages



**Figure 4.** Dry matter accumulation of late rice stem (a), leaf (b), spike (c), and above-ground dry matter accumulation at tillering, heading, full heading and maturity stages



**Figure 5.** Dry matter accumulation of early and late at tillering, heading, full heading and maturity stages

The stem DM accumulation ratio of early rice at tillering stage under CRR was increased by 6.48% and 12.90% compared with CK and GRR, respectively (Figure 5). The stem dry matter accumulation ratio of early rice at tillering stage under GRR was significantly increased by 26.57% compared with CK (Table 3). For early rice, stem DM accumulation rate under RRR was significantly increased by 28.30% to 35.45% compared with other treatments, and leaf DM accumulation rate was improved by 19.36% and 23.30%, respectively compared with GRR and ROT treatment, while spike DM accumulation rate was significantly lower than other treatments (Figure 5).

For early rice, the DM translocation volume of stem and leaf under CRR was significantly increased by 513.08% compared with GRR, and the DM translocation rate of stem and leaf under other treatments was significantly increased by 372.98%-380.64% compared with GRR, and the contribution rate of DM translocation to yield under other treatments were significantly increased by 164.88%-471.87% compared with GRR (Table 3). In terms of dry matter accumulation after heading, GRR significantly increased by 78.55% compared with CRR, and other treatments increased by 37.10%-51.95% compared with CRR.

For late rice, DM translocation of stem and leaf was increased by all winter cropping treatments. ROT treatment significantly increased DM accumulation by 108.67% compared with CK, and ROT treatment significantly increased by 68.00%, 75.06%, and 54.54% compared with CK, RRR, and GRR, respectively. In terms of DM accumulation after heading, compared with ROT treatment, DM accumulation under GRR was significantly increased by 45.99%, DM accumulation rate under GRR was significantly increased by 45.99%, and DM contribution to yield under GRR was significantly increased by 51.27%.

#### *Effect of winter cropping on N uptake of rice*

For early rice, nitrogen uptake of stem under GRR was significantly increased by 61.76% compared with CK, and nitrogen uptake of aboveground part under CRR and ROT treatment was significantly increased by 29.32% and 38.18% compared with CK. For late rice, compared with CK, nitrogen uptake of stem and leaf under CRR was significantly increased by 40.76% and 49.51%; nitrogen uptake of spike under CRR and ROT treatment was significantly increased by 42.92% and 32.35%, and nitrogen uptake of above-ground part under CRR and ROT treatment was significantly increased by 43.36% and 29.63% (Table 4).

**Table 2.** Effect of winter yield components of rice under paddy

Rice season	Winter cropping pattern	Effective spikes ( $10^4 \text{ hm}^{-2}$ )	Grains per spike	Spike length (cm)	Seeding rate (%)	1000-grain weight (g)
Early rice	CK	283.57±28.56b	147.45±12.11a	20.64±0.30b	54.22±10.82a	25.66±0.34a
	CRR	356.75±23.77a	150.51±10.64a	21.40±0.52ab	45.74±9.23a	25.57±0.51a
	RRR	347.61±41.92a	142.89±18.75a	20.50±0.56b	57.47±3.15a	25.67±0.29a
	GRR	347.61±20.96a	137.91±11.24a	21.16±0.68ab	47.75±10.11a	25.94±0.50a
	ROT	338.46±39.61a	147.36±15.94a	21.88±0.20a	57.83±3.17a	25.80±0.25a
Late rice	CK	295.01±36.30b	180.52±17.88a	23.23±0.18a	59.77±1.00a	26.48±0.17a
	CRR	370.48±11.88a	184.99±7.59a	23.73±0.08a	58.69±1.45a	26.69±0.33a
	RRR	338.46±22.05ab	190.61±15.15a	23.40±0.03a	61.35±0.58a	26.93±0.46a
	GRR	327.03±41.35ab	196.91±11.33a	23.40±0.44a	59.49±1.26a	26.48±0.39a
	ROT	363.62±6.86a	190.94±7.33a	23.67±0.34a	59.14±1.42a	26.30±0.42a

**Table 3.** Effects of winter cropping on dry matter translocation and accumulation of rice

Rice season	Treatment	Dry matter translocation by stem and leaf (100 kg·hm <sup>-2</sup> )	Translocation rate of stem and leaf (%)	Contribution rate of dry matter translocation to yield (%)	Dry matter accumulation after heading (100 kg·hm <sup>-2</sup> )	Dry matter accumulation rate after heading (%)	Contribution rate of accumulated dry matter to yield (%)
Early rice	CK	16.52±0.87ab	32.73±3.49a	48.51±7.34a	40.90±3.93bc	38.89±2.12ab	118.98±0.60a
	CRR	22.50±10.93a	33.05±9.33a	55.30±18.42a	37.86±13.65c	31.86±11.55b	103.87±59.6a
	RRR	20.07±1.55a	33.26±3.45a	43.88±1.50a	56.24±3.65ab	43.68±2.83a	123.49±13.5a
	GRR	3.67±4.14c	6.92±7.46c	9.67±10.88b	67.60±15.91a	48.41±3.07a	159.56±14.4a
	ROT	10.10±1.40bc	18.33±3.43b	21.85±3.23b	64.97±10.55a	47.76±2.53a	140.72±25.1a
Late rice	CK	15.04±6.18b	18.84±3.90b	24.82±9.77a	51.63±6.22ab	34.89±3.17a	85.44±8.92a
	CRR	27.40±9.27ab	25.85±6.89ab	37.77±13.62a	48.61±16.17ab	27.67±8.01ab	65.64±17.98b
	RRR	15.87±6.22b	18.08±5.05b	21.87±8.22a	56.80±5.53ab	34.97±2.02a	78.66±6.42a
	GRR	17.39±2.06ab	20.48±2.68b	23.63±2.66a	58.57±8.73a	35.71±3.20a	79.75±13.39a
	ROT	31.38±7.48a	31.65±5.40a	42.49±8.43a	38.52±6.04b	24.46±4.05b	52.72±10.17b

**Table 4.** Effect of winter cropping on N uptake and its distribution percentage at the maturity stage of rice

Rice season	Treatment	Stem		Leaf		Spike		N uptake of above-ground part (kg·hm <sup>-2</sup> )
		N uptake (kg·hm <sup>-2</sup> )	Percent (%)	N uptake (kg·hm <sup>-2</sup> )	Percent (%)	N uptake (kg·hm <sup>-2</sup> )	Percent (%)	
Early rice	CK	17.66±1.96b	14.77	15.13±3.40a	12.35	88.70±13.21a	72.87	121.49±15.12b
	CRR	24.32±3.26ab	14.74	24.92±4.94a	14.93	117.84±25.34a	70.32	167.08±32.64a
	RRR	22.17±1.93ab	16.11	17.29±8.24a	12.07	99.56±10.96a	71.83	139.02±18.65ab
	GRR	28.57±8.92a	18.48	19.27±1.36a	12.47	109.27±27.66a	69.05	157.11±27.58ab
	ROT	28.01±1.17a	17.02	22.65±8.32a	13.21	117.21±23.71a	69.77	167.87±32.83a
Late rice	CK	35.69±2.97b	19.88	23.55±5.17b	13.01	120.43±6.51b	67.10	179.72±13.11c
	CRR	50.24±5.26a	19.49	35.21±4.80a	13.65	172.13±9.49a	66.85	257.57±10.79a
	RRR	40.62±6.29ab	18.89	27.12±1.81ab	12.69	147.17±16.74ab	68.42	214.91±19.65bc
	GRR	34.28±3.83b	16.96	27.66±5.52ab	13.57	140.91±19.85ab	69.47	202.86±28.45bc
	ROT	44.39±4.96ab	19.14	29.14±1.34ab	12.53	159.39±15.78a	68.33	232.91±10.75ab

**Table 5.** Correlation analysis of yield characteristics, dry matter accumulation and translocation and plant nitrogen uptake for early rice

	Effective spikes	Grains per spike	Average spike length	1000-grain weight	Spike rate	Dry matter translocation by stem and leaf	Dry matter accumulation after heading	Above-ground dry matter accumulation	N uptake
Grains per spike	-0.197								
Average spike length	0.394	0.288							
1000-grain weight	0.133	-0.794	0.269						
Spike rate	0.917*	-0.471	0.263	0.371					
Dry matter translocation by stem and leaf	-0.013	0.687	-0.344	-0.980**	-0.215				
Dry matter accumulation after heading	0.35	-0.732	0.301	0.890*	0.64	-0.823			
above-ground dry matter accumulation	0.746	-0.59	0.458	0.702	0.900*	-0.721	0.672		
N uptake	0.79	0.099	0.869	0.232	0.633	-0.81	0.338	0.883*	
Yield	0.897*	-0.305	0.532	0.396	0.952*	-0.439	0.672	0.929*	0.796

Note: \* $P < 0.05$ ; \*\* $P < 0.01$ , the following are in accordance with this.

*Correlation analysis of rice yield characteristics, dry matter translocation and plant nitrogen uptake*

For early rice, the spike rate and the number of effective spikes, and the above-ground DM accumulation were positively correlated (Table 6). DM translocation by stem and leaf had a very significant negative correlation with 1000-grain weight (Table 5). Moreover, we also noted a positive correlation between DM accumulation after heading and 1000-grain weight. Further, N uptake and spike rate also had a positive association with above-ground DM and there was also a positive association with above-ground DM. There was also a significant positive correlation between yield and effective spikes, spike rate, and above-ground DM. Thus, winter cropping can improve early rice yield mainly by increasing the spike rate, effective spikes, and above-ground DM accumulation.

In case of late rice, effective spikes had a significant positive correlation with average spike length, spike rate and N uptake. Average spike length had a very significant positive correlation with spike rate and N uptake, and a significant positive correlation with DM translocation by leaf and stem (Table 6). Spike rate had a very positive correlation with N uptake. Additionally, there was a positive correlation between rice yield and grains per spike, indicating the late rice yield was mainly improved by increasing the grains per spike.

**Table 6.** Correlation analysis of yield characteristics, dry matter accumulation and translocation and plant nitrogen uptake for late rice

	Effective spikes	Grains per spike	Average spike length	1000-grain weight	Spike rate	Dry matter translocation by stem and leaf	Dry matter accumulation after heading	Above-ground dry matter accumulation	N uptake
Grains per spike	0.262								
Average spike length	0.971**	0.14							
1000-grain weight	0.067	-0.061	-0.102						
Spike rate	0.970**	0.03	0.959**	0.108					
Dry matter translocation by stem and leaf	0.846	0.046	0.924*	-0.421	0.856				
Dry matter accumulation after heading	-0.523	0.247	-0.633	0.579	-0.609	-0.866			
Above-ground dry matter accumulation	0.748	0.293	0.694	0.448	0.678	0.374	0.11		
N uptake	0.971**	0.094	0.965**	0.155	0.973**	0.802	-0.466	0.819	
Yield	0.476	0.930*	0.306	0.206	0.282	0.141	0.189	0.47	0.322

## Discussion

There have been many studies showing that winter cropping can improve rice yield through the measures of fertilization and straw returning (Wu *et al.*, 2021; Liu *et al.*, 2018, Chen *et al.*, 2021a) and results of the current study are similar to those previous studies. The yield of early and late rice was increased to varying degrees under winter cropping because the straw of winter crops returning to the field increases the soil organic matter and nutrient status which improved the growth and yield of rice. However, the garlic winter cropping pattern did not return straw to the field in winter, the late rice yield under this pattern was still 6.87% more as compared to winter fallow and it was the maximum among the winter cropping treatments. This may be due to the larger stem and leaf biomass production by early rice under this pattern, thus leading to more straws of early rice returning to the field and resulting in a substantial increase in rice yield (Tang *et al.*, 2010; Zhang *et al.*, 2022).

Nitrogen is an essential nutrient element for rice and its application plays an important part in regulating rice growth, development and yield formation (Xin *et al.*, 2017; Hussain *et al.*, 2023). In winter cropping, soil nitrogen is supplemented mainly by straw returning and fertilizer application, ensured adequate nitrogen supply for subsequent crops. In this study, the nitrogen uptake of different parts of early and late rice at the maturity stage was increased by winter cropping treatments to varying degrees. It was because, returning the straw of winter crops to the field can promote DM accumulation in diverse rice plant, but also can facilitate nitrogen translocation to various parts of plants (Tang *et al.*, 2018; Fan *et al.*, 2022). The garlic winter cropping pattern significantly increased the nitrogen uptake of early rice stem. It may be due to the nutrient surplus caused by the larger amount of fertilization while planting winter garlic. The nitrogen uptake of early and late rice was increased under Chinese milk vetch winter cropping pattern and winter multiple cropping rotation pattern owing to returning of Chinese milk vetch to the field which increases the soil organic carbon and thus improved the nitrogen uptake by rice (Liu *et al.*, 2017; Zhang *et al.*, 2022).

Rice DM accumulation is the material basis of rice yield formation. Previous studies have shown that green manure return and rational fertilizer application can promote DM accumulation in early and late rice (Yang *et al.*, 2022b; Zhang *et al.*, 2018; Zhang *et al.*, 2021; Saquee *et al.*, 2023). In this study, winter cropping was beneficial to DM accumulation in different parts of early and late rice at different growth periods. The correlation indicates a positive association between above-ground DM and early rice yield which shows that winter cropping increased the yield by increasing DM accumulation. The legume green manure effectively improves the DM accumulation of rice at earlier growth stages owing to its faster decomposition rate (Huang *et al.*, 2017; and Yi *et al.*, 2013; Gatsios *et al.*, 2021). The DM accumulation of early and late rice at the heading stage was higher under the Chinese milk vetch winter cropping pattern owing to the fact that legume green manure (Chinese milk vetch) decomposed quickly and returning of green manures effectively improves the soil organic matter and nitrogen which can improve the growth and yield of rice (Tang *et al.*, 2018; Liu *et al.*, 2021). DM accumulation of vegetative organs of early rice at the full heading stage was highest under the rapeseed winter cropping pattern, which may be due to the decomposition of rape straw that had been returned to the field. The proportion of DM accumulation in rice vegetative parts of early rice under rapeseed winter cropping pattern showed a substantial decline at the maturity stage, while at the same stage the proportion of dry matter accumulation in spike becomes the highest, indicating that there may be a large number of DM translocation from vegetative organs to spike after the full heading stage under this pattern.

DM translocation and accumulation of rice are closely connected with grain filling. Up until now, it is controversial whether rice grain filling mainly depends on DM translocation or dry matter accumulation. For example, Fu *et al.*, (2021) believed that under the condition of dense planting and rice grain filling mainly depends on dry matter translocation. Conversely, Sun *et al.* (2020) believed accumulation DM after anthesis is responsible for an increase in the yield of rice. In this study, there was a significant difference in DM accumulation and translocation amid diverse studied winter cropping patterns. Research has shown that excessive return of Chinese milk vetch can improve the growth of stem and leaf (Qian *et al.*, 2017; Chen *et al.*, 2021b), thus providing a material basis for the translocation of dry matter from stem and leaf to grain. We have obtained results similar to the previous research. The DM accumulation under CRR was higher than in other treatments, while DM translocation by stem and leaf as well as contribution rate of dry matter translocation to yield were higher than other treatments, especially in early rice.

As for the rapeseed winter cropping pattern, previous research showed that rape straw could promote DM translocation at the late rice maturity stage due to its slow decomposition rate (Tang *et al.*, 2018). However, in this study, rapeseed winter cropping pattern was more conducive to DM accumulation at the early rice full heading stage, which may be due to different returning methods of rape straw leading to a faster decomposition rate in this experiment. DM translocation of stem and leaf of late rice was significantly increased under winter multiple cropping rotation pattern, which may be due to input of diverse winter crop stubble and straw. Diverse straw inputs can increase soil microbial activity, and accelerate the decomposition process and

nutrient release of early rice straw (Song *et al.*, 2013), thus improve the growth and DM translocation. Among all the winter cropping patterns, the garlic winter cropping pattern had the most noticeable promoting effect on DM accumulation in early and late rice after heading, and double-cropping rice yield was the highest under this pattern. This may be related to improved soil nutrient status at the higher fertilizer application rate and the higher straw return rate. Since there are few previous studies on garlic winter cropping patterns, the mechanism of increasing yield under this pattern has yet to be further explored.

## Conclusions

Winter cropping increased the effective spike number of early rice and improved the grain number per spike of late rice, which effectively increased the yield of early and late rice. In terms of dry matter accumulation, winter cropping was advantageous to increase DM accumulation of early and late rice. Winter cropping patterns have significant differences in DM accumulation and translocation. Chinese milk vetch winter cropping pattern was beneficial to promote DM translocation in the stem and leaf of both early and late rice and the garlic cropping pattern improved the DM accumulation of early and late rice after heading. So far, there are few studies conducted to determine the effect of garlic winter cropping pattern on dry matter accumulation and rice yield. Therefore, more studies are direly conducted to determine the impacts of garlic winter cropping pattern on dry matter accumulation as well as on yield despite no straw returning.

## Authors' Contributions

Data curation and Formal analysis: Haocheng WANG and Binjuan YANG, Funding acquisition: Guoqin Huang, Methodology: Haiying TANG, Writing - original draft: Haocheng WANG, Writing - review and editing: Muhammad Umair HASSAN, Tahir Abbas KHAN, Athar Mahmood, Rizwan Maqbool and Muhammad Mahmood Iqbal. All authors read and approved the final manuscript.

## Ethical approval (for researches involving animals or humans)

Not applicable.

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## Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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