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Effects of decomposed and undecomposed straw of three crops on clubroot disease of Chinese cabbage and soil nutrients

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Aims: Straw turnover plays an important role in reducing soil diseases, improving the ecological environment of plowland and realizing the effective ecological utilization of straw. Methods: Pot and field experiments were carried out to investigate the effects of maize, rice and wheat straws on the growth, clubroot disease of Chinese cabbage and soil nutrients. Undecomposed and decomposed maize, rice and wheat straws were quantitatively added to the monocultural soil of Chinese cabbage, and the crops without straw were taken as the control. Results: The results showed that the addition of maize, wheat and rice straws could promote the growth of monocultural Chinese cabbage, inhibit the occurrence of clubroot disease, increase soil pH value, the content of soil organic matter, alkaline hydrolyzable nitrogen and available potassium in pot experiment. Exogenous straw application could reduce the incidence rate by 22.54 ~ 47.85%, increase the plot yield of field 95.15 ~ 365.81%. Conclusions: In terms of inhibiting clubroot disease and improving soil properties, undecomposed rice straw is superior to maize and wheat straw, while decomposed maize straw is superior to rice and wheat straw.

Keywords Chinese cabbage, Monocultural soil, Gramineous crop straws, Soil nutrients, Clubroot

Monoculture of Chinese cabbage results to deficiency or imbalance of soil nutrient, and aggravated the occurrence of clubroot disease of Chinese cabbage. Clubroot disease is a soil-borne disease caused by *Plasmodiophora brassicae* Woron, which threatens the global production of Chinese cabbage and leads to crop failure of Chinese cabbage[1]. Plants release some substances to inhibit the growth of plants of the same species or family in the same or the next crop through above-ground eluviation, root exudates and plant residues[2,3]. This phenomenon is called autotoxicity. The accumulation of self-toxic substances is one of the main causes of monocultural obstacles[2,3]. Soil-borne diseases are difficult to control through conventional methods such as using fungicides or breeding resistant varieties[4]. Therefore, in the process of agricultural production, we can alleviate monocultural obstacles by means of crop rotation, intercropping or exogenous addition, so as to regulate the stability of soil-plant-microbial ecosystem[5]. The occurrence of clubroot disease of Chinese cabbage can be reduced by wheat planting in the previous crop[6]. The application of other crop straws can promote the degradation of crop residues in soil, reduce the accumulation of self-toxic substances, and alleviate monocultural obstacles[7]. Exogenous application of rice straw can stabilize soil bacterial community composition and inhibit the occurrence of Chinese cabbage clubroot disease[8]. Wheat straw can reduce the occurrence of watermelon wilt and promote the growth of watermelon[9]. Exogenous application of maize, rice and wheat straw can reduce the incidence of cabbage clubroot disease[10].

Straw application can increase organic carbon in soil aggregates by enhancing the metabolism of soil bacteria, thereby increasing carbon fixation in soil and mitigating climate change[11–13]. Straw turnover can increase soil organic carbon content and reduce carbon footprint, increasing crop yield[14]. Exogenous straw application can not only effectively increase soil organic matter, but also increase soil carbon and nitrogen pool, promote soil microbial community, and improve field ecosystem[15,16].

The decomposition of returned straw is completed by soil microorganisms, which have a bias for material decomposition, so the decomposition characteristics of different kinds of crop straw are also different. The appropriate carbon to nitrogen ratio for microbial degradation of organic matter is 25:1, and the initial carbon to nitrogen ratio in straw is usually an important indicator to predict the dynamic degradation of straw[17]. The

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carbon-nitrogen ratio of Gramineous crop straws is generally higher than 25:1, for example, the carbon-nitrogen ratio in corn stalks is as high as 40:1[18], which causes soil microorganisms to decompose nitrogen in soil organic matter to meet the demand when using carbon in straws, resulting in the phenomenon of "microbial nitrogen digging" in the process of straw decomposition. The decomposition process of straw is accompanied by the release of straw nutrients. A small percentage of stored nitrogen in straw is easily released from straw, and the main component structural nitrogen must be transformed into inorganic nitrogen by microbial mineralization before it can be released gradually, and the release is relatively slow. Potassium in straw mainly exists in the form of K^+, which is easily dissolved in water and released. About 60% of the phosphorus in the straw exists in the form of inorganic phosphorus, and the rest is difficult to decompose organic phosphorus. Therefore, the rate of nutrient release in straw was K > P > N[19].

At present, there are many studies on the direct application of straw and the return of decomposed straw to field, but there are few studies on the comparison of the two, especially in terms of disease control. In this study, the effects of decomposed and undecomposed maize, rice and wheat straw on soil nutrients, seedling growth and clubroot of Chinese cabbage were investigated by field experiment and pot cultivation. The difference in application performance between decomposed and undecomposed straw of Gramineous crops was compared, in order to provide theoretical basis for alleviating the obstacles of monocultural Chinese cabbage and provide reference for scientific utilization of straw.

Materials and methods

Experimental material

Tested Chinese cabbage (*Brassica rapa* ssp. *Pekinensis*): The variety was "Improved Dongbai No. 1", provided by the Chinese Cabbage Laboratory of Northeast Agricultural University. Straw for test: rice straw, maize straw and wheat straw were provided by our research group. The straws were crushed and stored in cool and ventilated conditions. The straw of maize, rice and wheat was crushed to 1 cm in length with a crusher, and a part of the straw was decomposed.

Experimental design

The soil for pot experiment was from Baicheng village, Acheng District, Harbin. The bulk soil was taken at a depth of 10–30 cm and mix it well, passed through with a 2 mm sieve in reserve. The physical and chemical properties of the soil were determined as follows: pH 6.45, EC (Electrical Conductivity) value 0.18 mS/cm, organic matter content 18.65 g/kg, alkaline hydrolyzable nitrogen content 156.28 mg/kg, available phosphorus content 60.07 mg/kg, available potassium content 374.00 mg/kg, total nitrogen content 1.84 g/kg, total potassium content 2.09 g/kg, total phosphorus content 21.71 g/kg. The carbon nitrogen ratio of the tested undecomposed straw was as follows: maize straw 33.94, rice straw 47.76, wheat straw 41.06. The undecomposed and decomposed maize, wheat and rice straws were mixed with Chinese cabbage monocultural soil (1% w: w), and the monocultural soil without straw was used as the control.

The experiment was carried out at Northeast Agricultural University, Harbin, Heilongjiang Province (45° 74′ N ,126° 71′ E). There were 7 treatments in the experiment: Monocultural control (CK), undecomposed maize straw treatment (M), undecomposed rice straw treatment (R), undecomposed wheat straw treatment (W), decomposed maize straw treatment (DM), decomposed rice straw treatment (DR), and decomposed wheat straw treatment (DW). A completely random design was used to sow the Chinese cabbage seeds directly into 16-hole trays containing test soil. Each treatment was repeated 4 times, with 16 plants per replicate. The hole trays were placed in the solar greenhouse (24℃ during the day, 19℃ at night, 10 h of light). The Chinese cabbage was sown on July 4, the seed emergence rate was measured 3d after seeding, and samples were taken 41 d after seeding. The incidence of Chinese cabbage clubroot was investigated, the fresh weight and dry weight of Chinese cabbage were measured. After sampling, soil samples were collected, dried and pass through a 2 mm sieve, and stored at 4℃ for the determination of soil nutrients.

In addition, to verify the reliability of the pot experiment, we selected Baicheng Village (45° 31′ N ,126° 58′ E), Acheng District, Harbin City, where root disease was seriously affected, to conduct the field experiment. The cultivation system was garlic in spring and Chinese cabbage in autumn. After garlic harvest, the field was ploughed and straw was applied in the same way as the pot experiment. The test consists of 7 treatments: Monocultural soil control (CK1), undecomposed corn straw treatment (M1), undecomposed rice straw treatment (R1), undecomposed wheat straw treatment (W1), decomposed corn straw treatment (DM1), decomposed rice straw treatment (DR1), and decomposed wheat straw treatment (DW1). The experimental plot size was 4 m×2 m, and each treatment was repeated 4 times with conventional management. The yield and incidence of clubroot of Chinese cabbage were counted 57d after sowing.

Experimental methods

Straw decomposition process

The chopped straws of maize, rice and wheat were put into a plastic bag, the straw was mixed with a decomposition agent (the proportion was 8% w: w), poured into water (the water content in the decomposition process was about 60%), and put into a 30℃ incubator for decomposition for 20d.

Determination of dry matter accumulation rate

The dry matter accumulation rate of Chinese cabbage was calculated according to the following formula:

Dry matter accumulation rate (G value) = plant dry weight/seedling days.

Identification and classification of clubroot disease
Remove the cabbage carefully from the hole dish and gently shake off the soil on the root surface to observe the incidence of clubroot disease. The disease severity, incidence grade and disease index (ID) of clubroot were calculated by referring to Sharma Kalpana et al.[20].

Determination of soil nutrients
Soil alkaline hydrolyzable nitrogen was determined by alkali-diffusion-capacity method, available phosphorus was determined by M3 extraction - molybdenum-antimonic resistance colorimetric method, available potassium was determined by M3 extraction - flame spectrophotometry, total nitrogen content was determined by potassium persulfate oxidation - ultraviolet spectrophotometry, total phosphorus content was determined by potassium persulfate oxidation - molybdenum blue colorimetric method, total potassium content was determined by tetraphenylborate potassium gravimetric method. Organic matter content was determined by sulfuric acid-potassium dichromate oxidation-volumetric method. Soil pH was determined in soil suspension with soil: water = 1:2.5[21].

Data processing
Microsoft Office Excel 2016 was used to sort out the original data, SPSS 23.0 was used for data difference analysis, Turkey's HSD method was used to analyze the difference level under $p < 0.05$, and it was used to conduct bivariate correlation analysis of the data. Prism 9.00 was used to make box plots and bar charts. The PCA diagram was made by R studio. The correlation analysis chart was prepared by Origin 2021.

Result and analysis
Effect of undecomposed and decomposed straw on germination rate of Chinese cabbage
Compared with the control, the application of undecomposed maize, wheat and rice straw had no significant effect on the germination rate of Chinese cabbage after 3d sowing ($p > 0.05$). The application of decomposed maize, wheat and rice straw all increased the germination rate of Chinese cabbage, and the promotion effect of decomposed rice and decomposed wheat straw treatment reached a significant level ($p < 0.05$) (Fig. 1).

Effects of undecomposed and decomposed straw on the growth of Chinese cabbage
Effect of straw on seedling growth of Chinese cabbage in pot experiment
Compared with CK, both undecomposed and decomposed straw treatments significantly increased the fresh weight of aboveground part of Chinese cabbage ($p < 0.05$) (Fig. 2a, S1). Undecomposed rice and wheat straw treatments, and all decomposed straw treatments significantly increased the G value of Chinese cabbage compared with CK ($p < 0.05$) (Fig. 2b).

Effect of straw on yield of Chinese cabbage in field experiment
Compared with CK1, the application of undecomposed and decomposed straw of the three crops significantly increased the yield per plant and plot of Chinese cabbage ($p < 0.05$), and the yield per plant and plot of DM1 treatment was significantly higher than that of DR1 and DW1 (Fig. 3a), the plot yield of R1 treatment was significantly higher than that of M1 and W1 (Figs. 3b, S2).

Effect of undecomposed and decomposed straw on clubroot disease of Chinese cabbage
Effect of straw on clubroot disease index of Chinese cabbage in pot experiment
As can be seen from Fig. 4, compared with CK, both the addition of decomposed and undecomposed straw treatments reduced the disease index of clubroot disease.

Undecomposed and decomposed straw have different effects on clubroot disease. Compared with the control, in the treatment of undecomposed straw, the three kinds of straws significantly inhibited the occurrence of clubroot disease ($p < 0.05$) (Fig. 4a). In the treatment of decomposed straw, only the application of rice and wheat straws significantly inhibited the occurrence of clubroot disease ($p < 0.05$) (Fig. 4b). It is worth mentioning that clubroot disease was not found in both undecomposed and decomposed rice straw treatment (Fig. 4).

Effect of straw on Chinese cabbage clubroot disease severity in field experiment
Compared with CK1, the disease severity of clubroot was significantly reduced by the decomposed and undecomposed straws ($p < 0.05$). The disease severity of R1 was significantly lower than W1, and the disease severity of DM1 was significantly lower than DR1 and DW1 ($p < 0.05$) (Fig. 5).

Effects of undecomposed and decomposed straw on soil pH and nutrient
Soil pH values under undecomposed and decomposed straw treatment
Soil pH values of different treatments were measured in the pot experiment 41d after Chinese cabbage sown. The results showed that compared with CK, exogenous application of undecomposed and decomposed maize, rice and wheat straw significantly increased soil pH value (Fig. 6).

Soil nutrient content under undecomposed and decomposed straw treatments
In order to investigate the effect of straw application on soil nutrients, soil organic matter content and nitrogen, phosphorus and potassium content were measured after 41d planting. Compared with CK, both decomposed and undecomposed straw treatments significantly increased the accumulation of soil organic matter, and the content of organic matter under R and W treatments was significantly higher than that under M treatments ($p < 0.05$) (Fig. 7a). The significance analysis of soil alkaline hydrolyzable nitrogen was the same as that of soil organic matter (Fig. 7b). The total nitrogen content in decomposed maize straw treatment was significantly higher

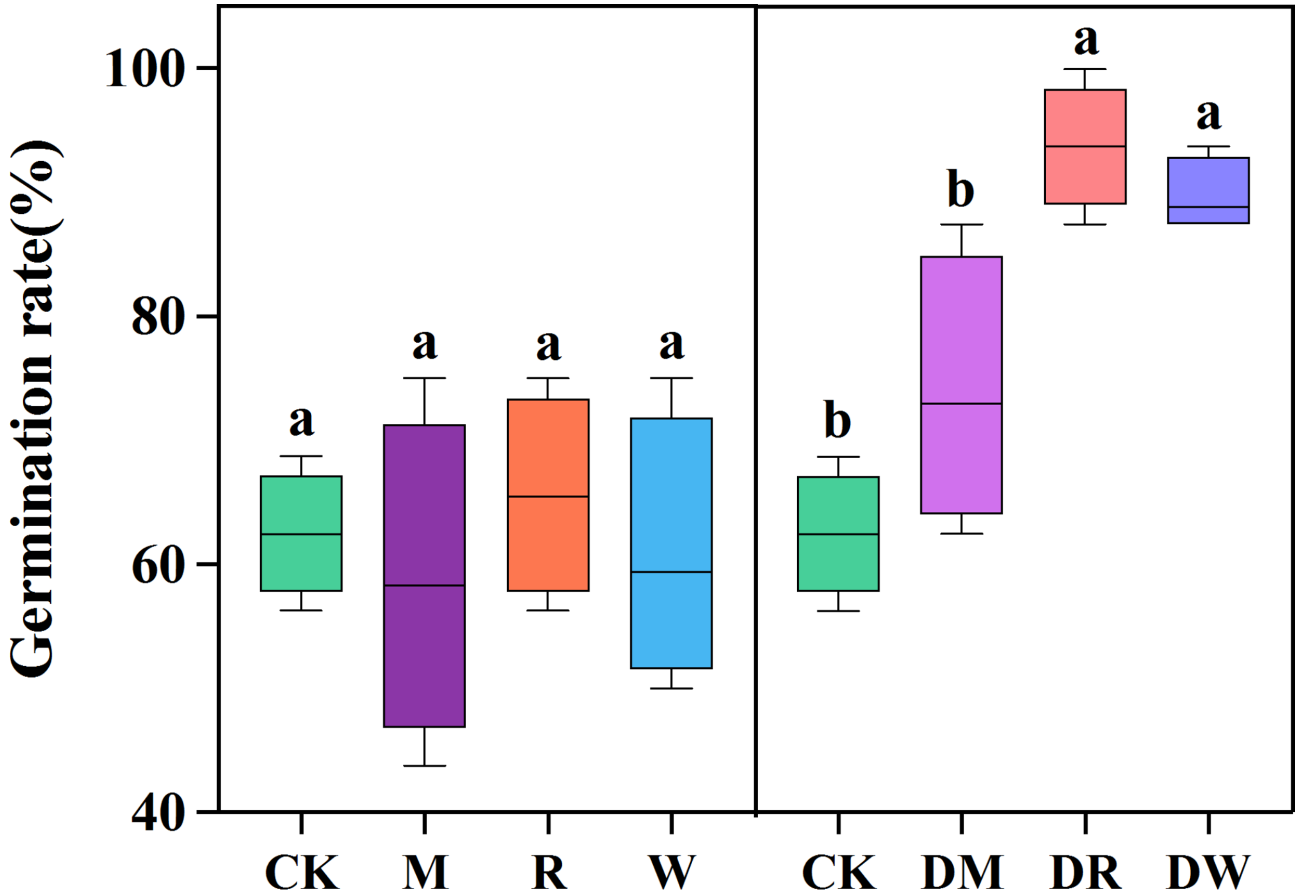

Fig. 1. Germination rate of Chinese cabbage after 3d sowing. M, R, and W represent monocultural soils mixed with undecomposed maize, rice, and wheat straw, respectively. DM, DR, and DW represent monocultural soils mixed with decomposed maize, rice, and wheat straws, respectively. CK is monocultural soil with no straw applied. Different letters are significantly different; the results are for the statistical analysis ($p < 0.05$, Tukey's HSD test).

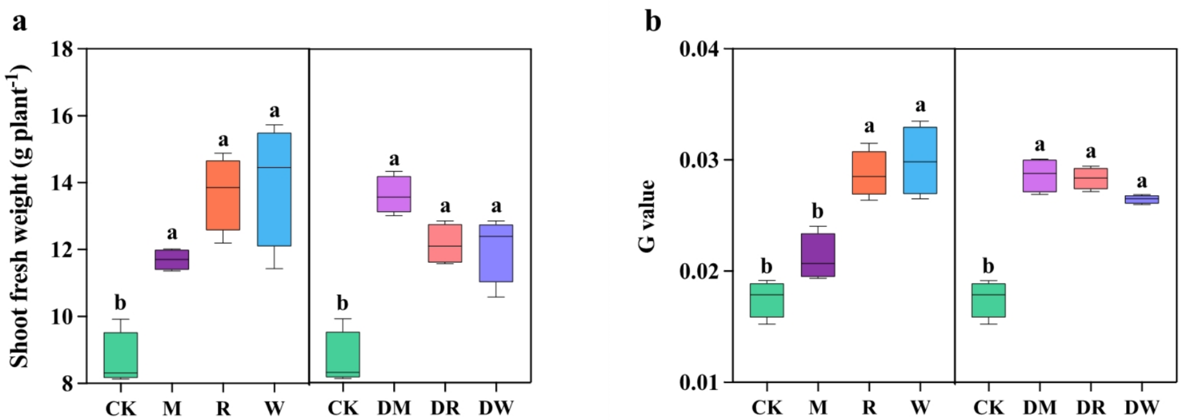

Fig. 2. Influence of straw application on the growth of Chinese cabbage. Figures (a) and (b) represent fresh weight of aboveground and G value of Chinese cabbage at 41d after seeding, respectively. The treatments are the same as Fig. 1. Different letters are significantly different ($p < 0.05$, Tukey's HSD test).

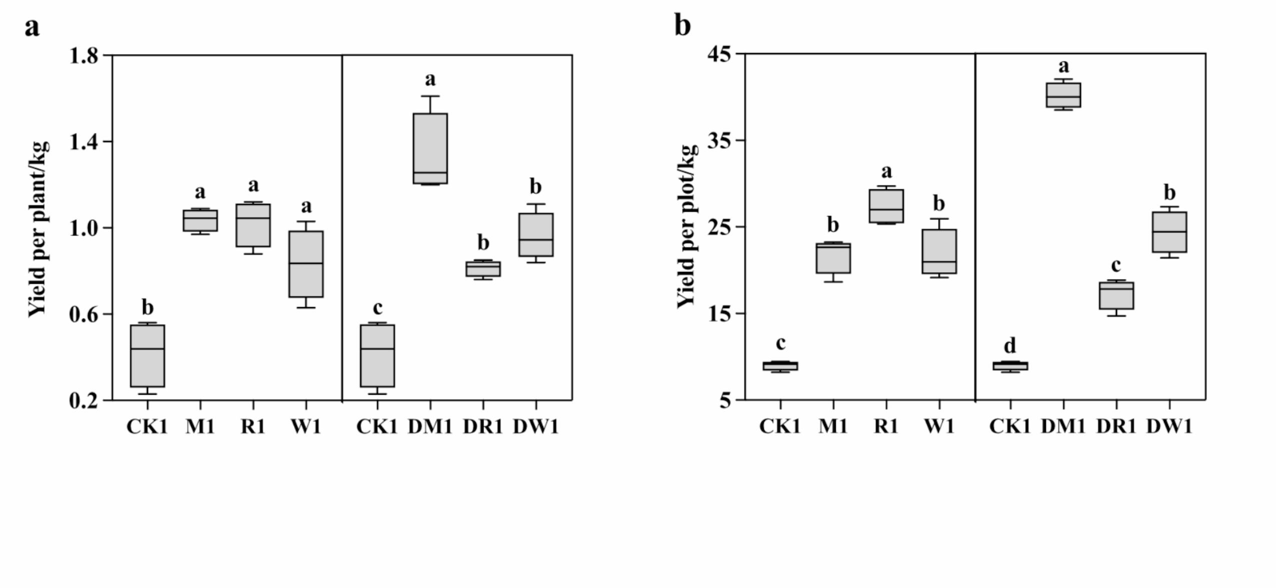

Fig. 3. Effect of straw application on yield of Chinese cabbage in field. Figures (a) and (b) respectively represent the yield per plant and plot of Chinese cabbage during the harvest period. M1, R1, and W1 represent monocultural soils mixed with undecomposed maize, rice, and wheat straw, respectively. DM1, DR1, and DW1 represent monocultural soils mixed with decomposed maize, rice, and wheat straws, respectively. CK1 is monocultural soil with no straw applied. Different letters are significantly different ($p < 0.05$, Tukey's HSD test).

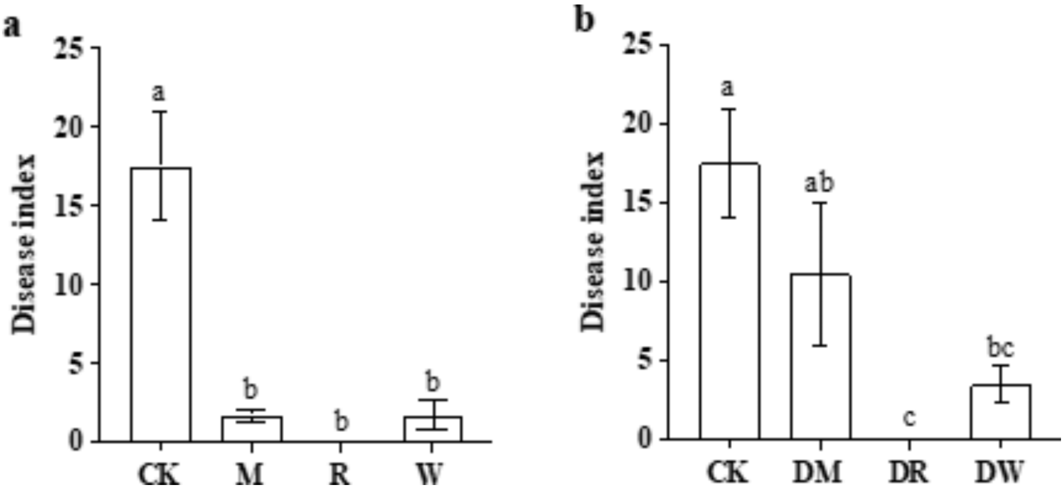

Fig. 4. Disease index of Chinese cabbage sown with 41d. Figures (a) and (b) represent disease index of undecomposed straw and decomposed straw, respectively. The treatments are the same as Fig. 1. Different letters are significantly different ($p < 0.05$, Tukey's HSD test).

than that in CK ($p < 0.05$) (Fig. 7c). The content of available phosphorus in decomposed and undecomposed rice straw treatments was significantly lower than CK ($p < 0.05$) (Fig. 7d). The total phosphorus content of decomposed rice was significantly higher than that of CK ($p < 0.05$) (Fig. 7e). Compared with CK, the three kinds of undecomposed straws, decomposed rice and wheat straws significantly increased the soil available phosphorus content ($p < 0.05$) (Fig. 7f). The soil total potassium content of undecomposed maize and wheat were significantly lower than CK ($p < 0.05$) (Fig. 7g).

Principal component analysis of soil nutrients under undecomposed and decomposed straw treatments

After sowing 41d, CK and M treatments were significantly different from other treatments, while no significant difference was found between R and W (Fig. 8a). CK was significantly separated from DW, DR, and DW treatments, while there was no significant difference among the three decomposed straws (Fig. 8b).

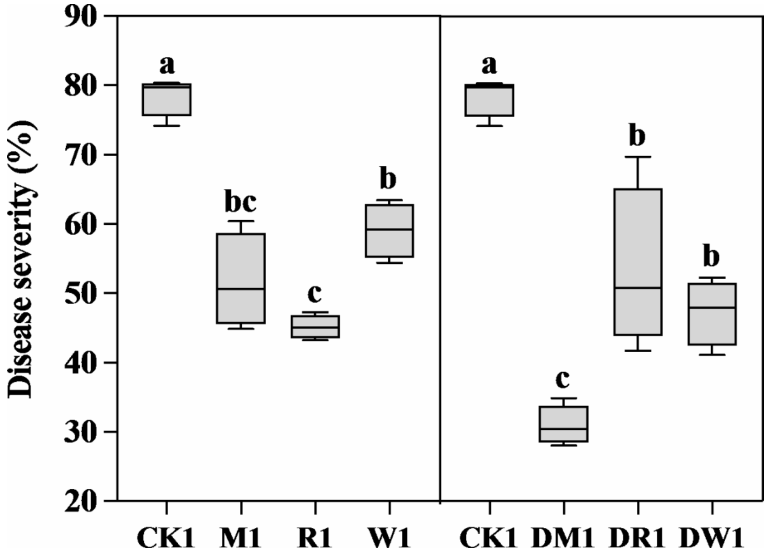

Fig. 5. Disease severity of Chinese cabbage sown with 57d. The treatments are the same as Fig. 3. Different letters are significantly different ($p < 0.05$, Tukey's HSD test).

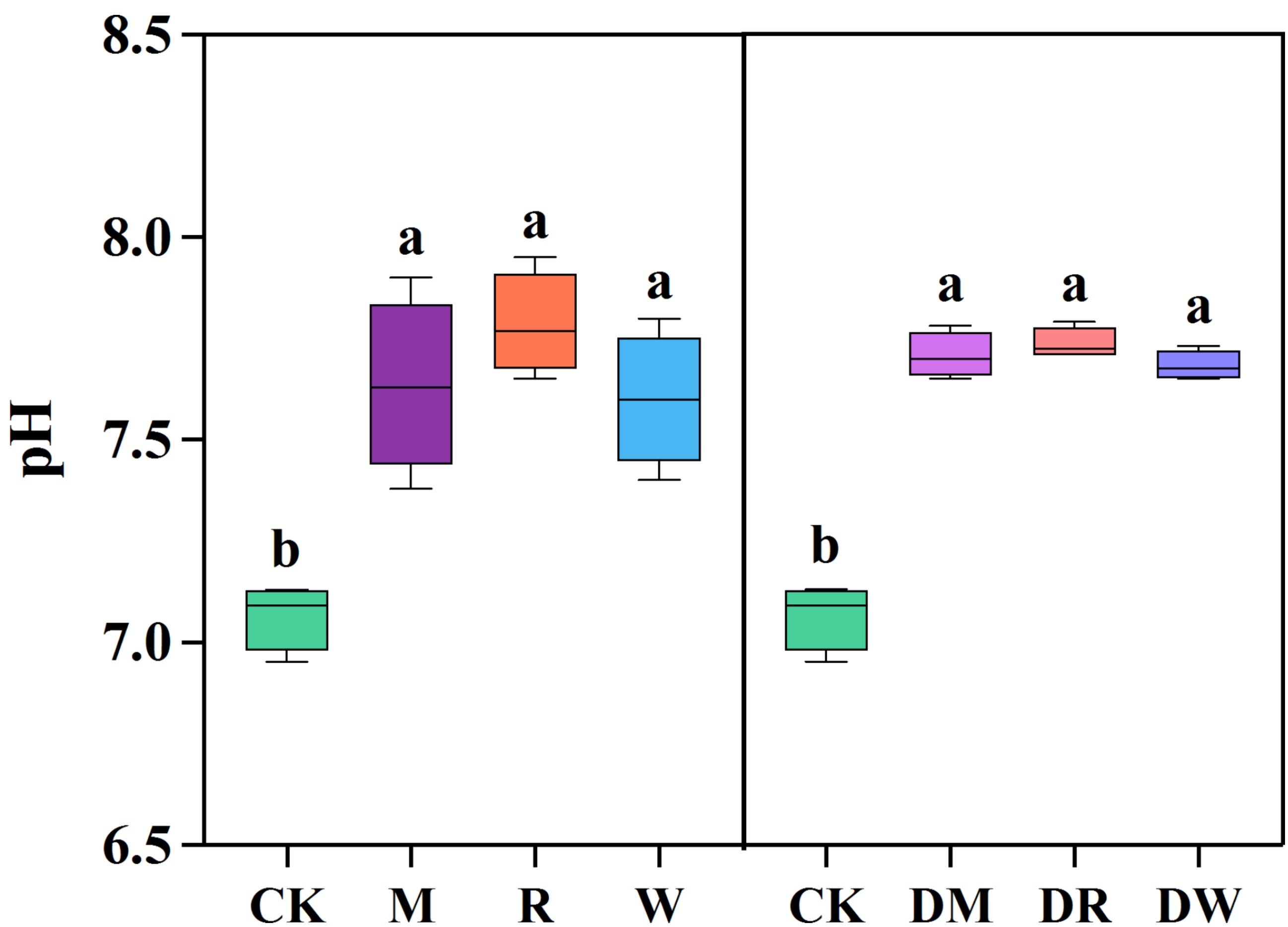

Fig. 6. Influence of different straw treatments on soil pH value. The treatments are the same as Fig. 1. Different letters are significantly different ($p < 0.05$, Tukey's HSD test).

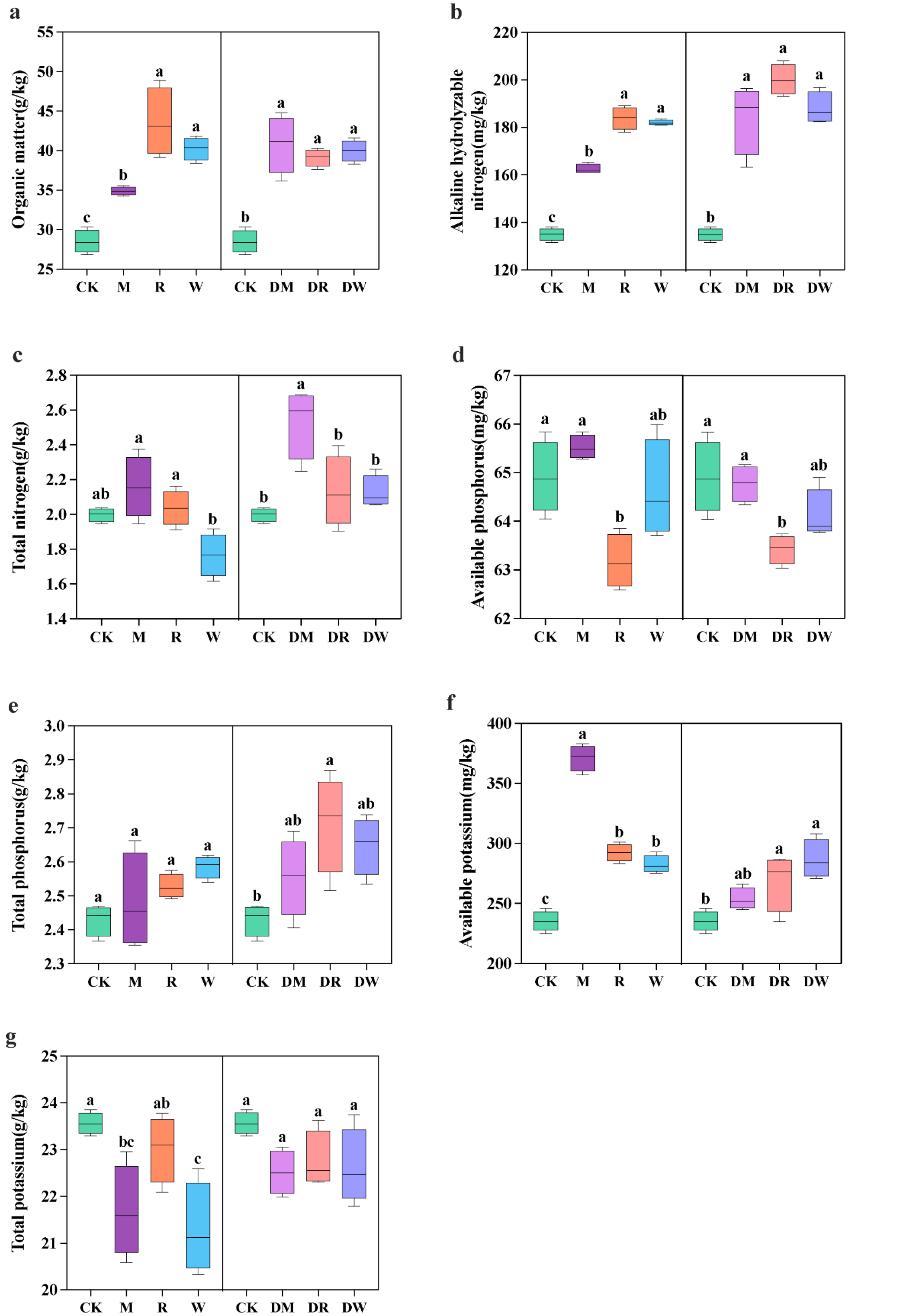

Fig. 7. Effects of undecomposed and decomposed straw on soil organic matter and soil nutrients sown with 41d. (**a**) Effects of straw on soil organic matter content. (**b**) Effects of straw on soil alkaline hydrolyzable nitrogen content. (**c**) Effects of straw on soil total nitrogen content. (**d**) Effect of straw on soil available phosphorus content. (**e**) Effects of straw on soil total phosphorus content. (**f**) Effects of straw on soil available potassium content. (**g**) Effects of straw on soil total potassium content. The treatments are the same as Fig. 1. Different letters are significantly different ($p < 0.05$, Tukey's HSD test).

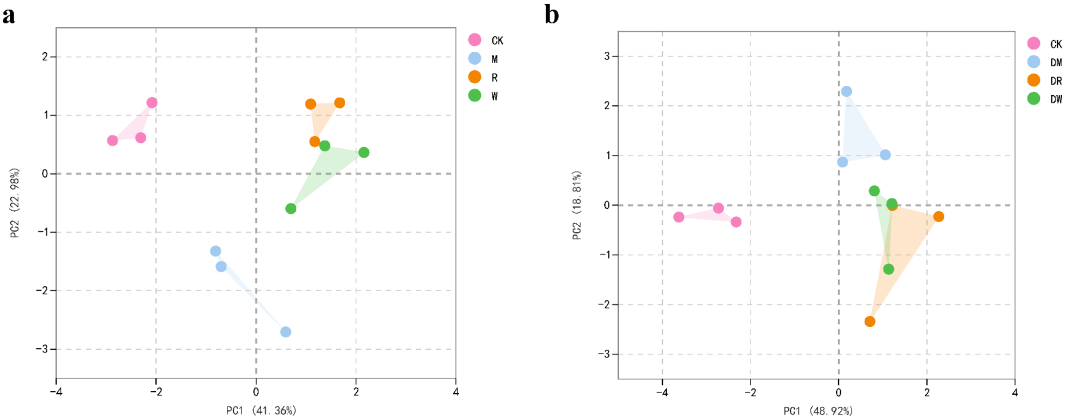

Fig. 8. Principal component analysis of soil nutrients under undecomposed (**a**) and decomposed (**b**) straw treatment sown with 41d. Figures (a) and (b) represent disease index of undecomposed straw and decomposed straw, respectively. PC1 and PC2 represent the rate of variation between the first and second principal components. The treatments are the same as Fig. 1.

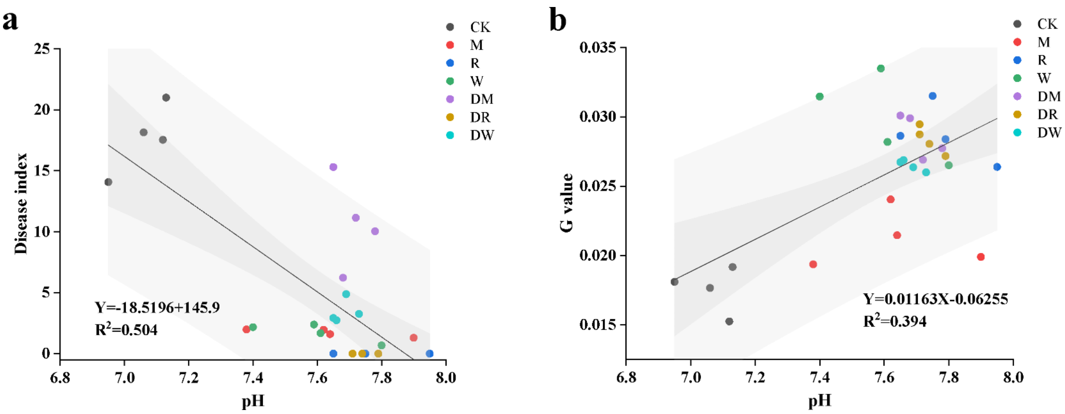

Fig. 9. Correlation between the disease index of Chinese cabbage clubroot disease and soil pH value. Figures (a) and (b) represent the relationship between disease index and G value and pH, respectively.

Correlation analysis between soil pH and both the disease index of Chinese cabbage clubroot and G value of Chinese cabbage

In order to explore the relationship between Chinese cabbage disease index and soil pH value, Spearman correlation analysis was conducted between Chinese cabbage disease index and soil pH value. The results showed that there was a significant negative correlation between the disease index of Chinese cabbage and soil pH value (r=-0.617, $p=0.003$) (Fig. 9a). However, there was no significant positive correlation between G value and soil pH value ($r=0.281$, $p=0.147$) (Fig. 9b).

Correlation analysis between soil nutrients and G value of Chinese cabbage

The regression equation fitting analysis of dry matter accumulation rate of Chinese cabbage and soil nutrients was carried out (Fig. 10). We found a significant positive correlation between both G value and organic matter (r=-0.771, $p=0.001$) (Fig. 10a) and alkaline hydrolyzable nitrogen (r=-0.562, $p=0.002$) (Fig. 10b). There was a significant negative correlation between G value and available phosphorus (r=-0.393, $p=0.039$) (Fig. 10d). There was no significant positive correlation between G value and other soil nutrients ($p>0.05$) (Figs. 10c, e-g).

Discussion

Effects of straw application on germination and growth of Chinese cabbage

After exogenous application of straw, the physical properties of soil were changed, and the water retention and air permeability of soil were improved[22], thus increasing the germination rate of Chinese cabbage seeds. In this study, straw was crushed to 1 cm in length to increase the contact area between soil and straw and increase the decomposition rate. Different organic and inorganic substances that are easy to use by plants will be released from straw in different decomposition stages[23], thus affecting the germination and growth of crops. Substances unfavorable to seed germination were produced in the initial stage of decay[24]. With the increase of straw decomposition time, allelopathy phenomenon will appear, which is low concentration allelopathic substances

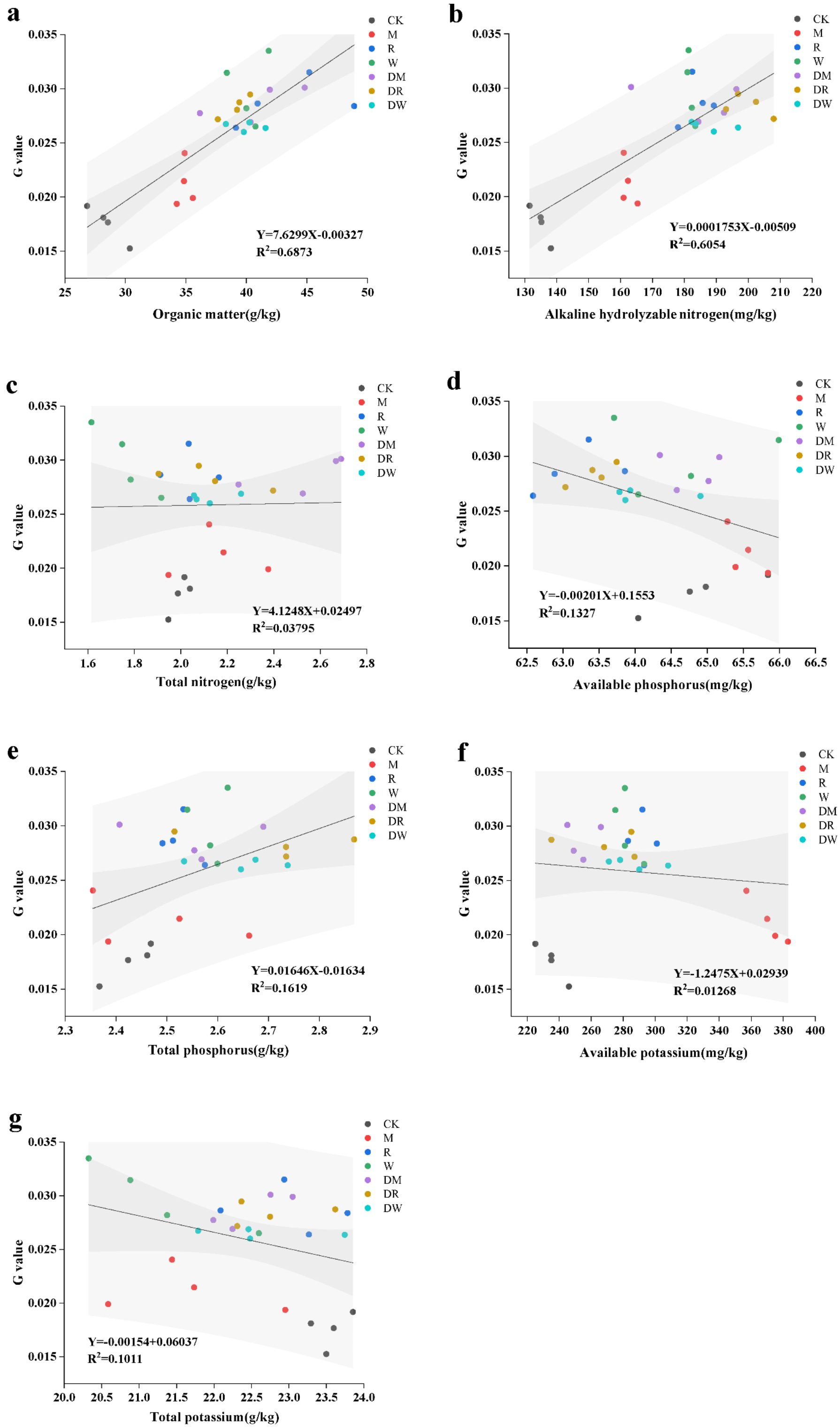

Fig. 10. Correlation analysis between soil nutrients and G value of Chinese cabbage. G value represents dry matter accumulation rate of Chinese cabbage. Figures (a) (b) (c) (d) (e) (f) (g) represent the relationship between G value and soil organic matter content, alkaline hydrolyzable nitrogen content, alkali-hydrolyzed nitrogen, total nitrogen content, available phosphorus content, total potassium content, available potassium content and total potassium content, respectively.

can promote the growth of crops. Substances released during straw decomposition can promote seed germination and crop growth[25,26]. Therefore, in this experiment, the germination rate of cabbage under decomposed straw treatment was higher than that under undecomposed straw treatment. Exogenous application of undecomposed straw can eventually promote the growth of cabbage to a certain extent due to its continuous decomposition in the soil, even better than decomposed straw treatments.

In this experiment, whether in pot or field, the application of three kinds of straws, both decomposed and undecomposed, increased the dry matter accumulation rate of Chinese cabbage seedlings and the fresh weight of Chinese cabbage aboveground, which maybe because that the application of straws increased the content of organic matter and nutrients in the soil to varying degrees. Wheat and rape straw mulching can promote rice dry matter accumulation and significantly promote rice growth and nutrient absorption[27]. Exogenous application of undecomposed straw can eventually promote the growth of cabbage to a certain extent due to its continuous decomposition in the soil, even better than decomposed straw treatments. In addition, the application of straw may promote the growth of plant roots, and thus promote the growth of shoots. Roots and associated rhizosphere activities regulate the mineralization of natural soil organic matter (SOM), which is known as rhizosphere priming effect (RPE)[28]. Straw application may induce rhizosphere priming effect and promote root growth, decomposition and mineralization of organic carbon. In this process, the addition of straw introduces C and N and releases nutrients that can be absorbed by plants to promote plant growth and root extension, while the priming effect improves the conversion rate of C and N in soil through feedback regulation[29].

Effect of straw application on clubroot disease of Chinese cabbage

It was found that both decomposed and undecomposed straw had inhibitory effects on clubroot disease of Chinese cabbage. Soil pH tended to increase after exogenous application of decomposed and undecomposed straw, which was similar to the results of Nkoh et al.[30]. Soil pH value of 5.4–6.5 is the best condition for the germination of dormant spores of rhizome[31]. The application of three kinds of straw increased the soil pH value and changed the soil environment from near-neutral to mildly alkaline, thus inhibiting the germination of dormant spores and alleviating the occurrence of clubroot disease. In addition, Studies have shown that the abundance of *P. brassicae* in 10 spores /g of soil can cause clubroot disease in susceptible cruciferous crops. The abundance of *P. brassicae* spores in the tested soil reached 10^7 spores /g of soil. The addition of straw changed the physical properties of soil, reduced the bulk density of soil[32], and had a certain dilution effect on *P. brassicae* in soil.

Clubroot is more prevalent in soils with low organic matter content, which may be related to soil microbial activity and nutrients[33,34]. The organic matter content in straw treatment is generally higher than that in control, which may be unfavorable to the occurrence of clubroot disease. Phenolic acids may be produced during straw decomposition[35], such as ferulic acid, para-coumaric acid, etc[36]. Most phenolic acids have allelopathic effects, which can affect the activity of pathogenic bacteria, plant growth and soil microbial structure, and then affect the occurrence of diseases[37]. This may be the reason for the difference of clubroot disease between decomposed and undecomposed straw. For example, the decomposed solution of maize straw can promote or inhibit the sclerotium of wheat *Rhizoctonia zeae* to varying degrees[38].

Another possible reason is that the decomposition of straw leads to changes in soil microorganisms[39]. Soil microorganisms affect plant growth and health through symbiotic and pathogenic phenomena and regulation of nutrient cycling[40]. While improving soil microecology, straw turnover can effectively increase the number of antagonistic bacteria in soil and reduce the occurrence of diseases[41]. The factors affecting straw maturation include straw species, water content and management measures. Different straw types lead to different decomposition products and soil microbial succession, and different straw types and treatment methods have different inhibitory effects on clubroot disease of Chinese cabbage. Future research should focus on the effects of straw decomposition products on pathogens and soil microorganisms, as well as the effects of microorganisms on nitrogen fixation during straw decomposition.

In both field and pot experiments, rice straw had the most significant effect on disease control. This is consistent with the findings of Di et al.[10]. For decomposed straw, the results of pot test and field test were slightly different. In pot experiment, decomposed rice straw had the best effect on disease inhibition, while in field experiment, decomposed maize straw had the most significant effect on clubroot disease inhibition. We guessed that this may be because the texture of maize straw is relatively hard and not perishable, while it can be decomposed more completely in the field under the rain.

Effects of straw application on soil nutrients

The application of straw directly or indirectly affects soil quality and nutrients[42–44]. The experiment showed that the content of soil organic matter, alkaline hydrolyzable nitrogen and available potassium increased significantly after straw application, which had a positive effect on the content of available nutrients in the monocultural soil of Chinese cabbage. Straw returning can enhance soil water retention[22], maintain soil fertility, reduce soil water loss, and provide favorable conditions for soil humification process. At the same time, the application of straw increased soil C and N, promoted the microbial process of the transformation of organic materials into organic carbon in the soil, improved soil enzyme activity, activated aerobic metabolism, promoted the transformation of nutrients in the straw, accelerated the mineralization of organic matter and the accumulation of nutrients such as N, P and K, and promoted the C and N cycle. Thus, the content of alkaline hydrolyzable nitrogen in soil can be increased[45,46]. After exogenous straw is applied, the ratio of soil alkaline hydrolyzable nitrogen to total nitrogen content also increases. Xiao et al. found that proper amount of undecomposed rice straw returned to the field can improve soil nitrogen efficiency[47]. Soil pH value and alkaline hydrolyzable nitrogen content showed a very significant positive correlation. We speculated that it might be due to the increase of soil pH value, soil alkalization degree and soil alkaline hydrolyzable nitrogen content by straw application, thus improving the nitrogen efficiency.

However, the concentration of available potassium only increased in the early stage of returning the decomposed straw to the field, which was consistent with the results of Zhang et al.[48]. Potassium mainly exists in the form of free state in straw with high water solubility, and 90% of potassium can be released within a few weeks after straw addition[49], which improves the potassium efficiency in soil. Therefore, the ratio of available potassium to total potassium content increases in the late growth stage of Chinese cabbage. The available phosphorus content varies due to different stubble types, and the amount of soil phosphorus that plants are able to utilize is very low and is released into the soil very slowly. This may explain why straw returning to the field had no effect on soil available phosphorus content in this experiment. In addition, we observed that exogenous application of decomposed and undecomposed straw had no significant effects on soil total nitrogen, total phosphorus and total potassium contents, which was consistent with the findings of Goncalves et al.[50]. In the later stage of cabbage planting, the weighted correlation degree of decomposed straw was greater than that of undecomposed straw, indicating that exogenous application of decomposed straw had better effect on soil nutrient improvement than that of undecomposed straw. This may be due to the fact that decomposed straw can stimulate potentially beneficial microbial communities and increase soil organic matter content[51].

Relationship between soil nutrients applied by straw and dry matter accumulation rate of Chinese cabbage

Studies have shown that the dry matter accumulation rate of plants is closely related to soil nutrients[52], and organic matter affects the recycling of soil nutrients[53]. Correlation analysis showed that the dry matter accumulation rate of Chinese cabbage was significantly positively correlated with the content of and organic matter and alkaline hydrolyzable nitrogen. The results showed that the increase of soil organic matter content could promote the growth of rapeseed[54]. Batista et al. reported that nitrogen application can increase the yield of intercropping plants[55]. Application of undecomposed and decomposed straw increased soil organic matter and available nutrients[56,57], straw itself contains a relatively high carbon to nitrogen ratio, and the application of straw to soil indirectly increases the nitrogen content in soil, thereby increasing the dry matter accumulation rate of plants[58], affect plant growth[59].

On the contrary, there was a significant negative correlation between G value and available phosphorus. This may be due to the high content of available phosphorus in the soil, which inhibits plant growth[60]. In addition, crop yield is closely related to available potassium content in soil[61]. In this study, available potassium content has a negative correlation with dry matter accumulation rate of cabbage. This may be due to the fact that plants absorb potassium from the soil and transport it to their organs, acting as a growth regulator[62].

Conclusion

In conclusion, proper straw addition and management can promote the growth of Chinese cabbage by increasing the content of soil organic matter, basic nitrogen and available potassium, and inhibiting the occurrence of clubroot disease. These factors may be related to straw type and application method. In addition, this study compared the effects of raw stubble and decomposed straw on plant growth and disease, providing guidance for the application of different straws to achieve the best growth promotion effect, in which rice straw can be applied directly to the soil, while maize and wheat straw need to be decomposed before application, and maize straw may take longer to decompose.

Data availability

Zhang Yiping (18846054105@aliyun.com) should be contacted if someone wants to request the data from this study.

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Declarations

Competing interests
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