Effects of the herbicide on the weed seed banks of the maize farmlands under different managements

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Abstract. As the theoretical premise of the precision weed management, it is necessary to clear the effects of herbicide on the farmland weed seed banks. In this paper, the plots were carried out different managements in a piece of maize farmland including deep tillage/no-tillage, conventional fertilizer/no fertilizer, using herbicide/no weeding, the characters of the weed soil seed banks were tested; then, the effects of the herbicide on the characteristics of seed banks under different treatments were analysed. The results showed that, there were different levels of interactions between the managements on the characters of weed seed banks; herbicide significantly cut down on the seed density but had few effects on the species abundance of the weed soil seed bank; the highest seed reserve was found in the plot with no-tillage and no herbicide and the farmer conventional fertilizer management was helpful to reduce it.

1. Introduction

In recent years, the traditional deep tillage and fertilization system is gradually replaced by the no-tillage and no-fertilizer system because the latter is more environment-friendly and economical. However, there were more kinds and quantities of weeds in no-tillage farmland, so its consumption of herbicides was much higher [1]. Reducing herbicide consumption and avoiding weed resistance in conservation tillage system have become the key issues of modern sustainable agriculture [2].

It is helpful for reducing herbicide consumption to understand and make full use of the life cycle of weed species [2]. The soil seed bank is one of the life cycle stages of plant. Seed bank, as the potential regeneration community, is the main component of ecosystem resilience [3]. The weed seed bank can not only reflect the management history of farmland, but also predict the future weed dynamics and compared with above-ground community, it is more suitable to express the diversity of weeds [4-6]. Studies shows that the main influencing factors of weed soil seed bank are: 1) rotation system; 2) tillage mode; 3) different fertilization treatment; 4) weeding mode [7-10]. But it is still unclear that how tillage, fertilization and herbicide work together on the weed soil seed bank of maize farmland, though it is important for planning one precision weed management strategy.
2. Methods

2.1. Plots
The experimental field belongs to Shandong Academy of Agricultural Sciences, where had been carried out different tillage and fertilization management in 24 divided plots for three years, including deep tillage (plough to 30cm) and no tillage, conventional fertilization (480 kg.hm⁻² of nitrogen per year) and non-fertilization. Herbicides (Atrazine) were used or unused in these plots in June. There were 8 treatments and each treatment had 3 replicates. The area of each plot was about 50 m².

2.2. Sampling and seed germination test
The soil samples were collected in December. After removing the litter and fallen leaves from the ground surface, four soil cores (the length is 10cm, width 10cm and the depth 15cm) were randomly selected in each plots and were mixed to one sample for seed bank test. All the soil samples had been sealed and saved in a 4°C cabinet until the germination test carried out. Each soil sample was divided into three sub samples by the weight and each sub sample was placed in a 50 cm diameter germination tray. The thickness of soil samples was kept no more than 1 cm. A total of 24 trays were placed in a greenhouse to germinate. These trays were watered regularly to keep the soil surface moist, and rotated timely to keep a consistent illumination condition. The experiment lasted for 6 weeks from March 31 to May 16. The new born seedlings were identified and numbered once per week.

2.3. Data processing analysis
The number of species and seedlings in each germinating tray were counted. The seed density of each germination tray was obtained by dividing the number of seedlings by the surface area of soil sample. The species abundance equaled to the number of species. Multivariate analysis of variance and one-way analysis of variance was used to analyze the effect of the three management factors. All data analysis was calculated through Excel and SPSS18.0.

3. Results

3.1. The characteristics of the weed seed bank in maize farmland
In this study, 10 species of weeds belonging to 7 families were found in the soils seed bank sample. Which were listed in Table 1. The two monocotyledons, Echinochloa crucally and Setaira viridis, were the dominant species in the test soil seed banks. The average seed density of weed soil seed bank in the experimental farmland was 14056±8042 grains/m².

Table 1. The species composition of the weed seed banks in the maize farmland

| No. | Species                  | Ecotype                | Seed density (grain/m²) |
|-----|--------------------------|------------------------|-------------------------|
| 1   | Echinochloa crusgalli    | Annual monocotyledon  | 8697                    |
| 2   | Setaira viridis          | Annual monocotyledon  | 4097                    |
| 3   | Acalypha australis       | Annual dicotyledon    | 488                     |
| 4   | Amaranthus lividus       | Annual dicotyledon    | 231                     |
| 5   | Amaranthus tricolor      | Annual dicotyledon    | 219                     |
| 6   | Chenopodium serotinum    | Annual dicotyledon    | 175                     |
| 7   | Polygonumaviniculare     | Annual dicotyledon    | 138                     |
| 8   | Eclipta prostrata        | Annual dicotyledon    | 6                       |
| 9   | Digitaria sanguinalis    | Annual monocotyledon  | 6                       |
| 10  | Portulaca oleracea       | Annual dicotyledon    | 3                       |
3.2. The interactions between the three management factors on the weed seed bank in maize farmland

As Table 2 showed that the use of herbicide and tillage methods had significant effects on the seed density of weed seed bank separately, also the interactions between any two of the three managements (tillage, fertilization and herbicide) \((P \leq 0.01)\). The tillage, the interaction between herbicide and fertilization, the interaction between cultivation and fertilization all affected the seed density and species abundance significantly \((P \leq 0.05)\).

Table 2. The interactions between the three management factors on the characters of weed soil seed banks in the maize farmlands (* means the significant difference in this table, \(N=12, P \leq 0.05\))

| Management factor            | Seed density | Species abundance |
|------------------------------|--------------|-------------------|
|                              | F  | P      | F  | P      |
| Herbicide                    | 85.02 | 0.000*** | 2.118 | 0.165 |
| Tillage                      | 17.88 | 0.001**  | 5.88  | 0.027* |
| Fertilization                | 2.73  | 0.118   | 2.12  | 0.165 |
| Herbicide×Tillage            | 8.45  | 0.010**  | 2.118 | 0.165 |
| Herbicide×Fertilization      | 12.24 | 0.003**  | 11.53 | 0.004**|
| Tillage×Fertilization        | 19.06 | 0.000**  | 5.88  | 0.027* |

Table 3. The characters of the weed seed banks of the maize farmlands under different treatments (Unused means herbicide unused, Used means herbicide used, D means deep tillage, C means no-tillage and the F means fertilization, N means no fertilization; the different superscript letters in the same line mean significant difference, \(N=3, P \leq 0.05\))

| Treatment | Total Seed density (grain/m²) | Species abundance | Seed density of *Echinochloa rusgalli* (grain/m²) | Seed density of *Setaira viridis* (grain/m²) |
|-----------|-------------------------------|-------------------|----------------------------------------------|-------------------------------------|
| Herbicide | Tillage | Fertilization |                         |                               |                               |
| Unused    | D F   |               | 22275<sup>c</sup> | 6.67<sup>cd</sup> | 14200<sup>e</sup> | 6375<sup>d</sup> |
|           | D N   |               | 8125<sup>ab</sup> | 5.00<sup>ab</sup> | 5075<sup>abc</sup> | 6400<sup>d</sup> |
|           | C F   |               | 17975<sup>c</sup> | 6.00<sup>bcd</sup> | 10650<sup>d</sup> | 5375<sup>cd</sup> |
|           | C N   |               | 28075<sup>d</sup> | 6.33<sup>abcd</sup> | 19500<sup>e</sup> | 2450<sup>ab</sup> |
| Used      | D F   |               | 4175<sup>a</sup> | 4.33<sup>a</sup> | 2300<sup>a</sup> | 3175<sup>ab</sup> |
|           | D N   |               | 12375<sup>b</sup> | 5.33<sup>ab</sup> | 7700<sup>c</sup> | 3525<sup>bc</sup> |
|           | C F   |               | 8175<sup>ab</sup> | 5.00<sup>ab</sup> | 4125<sup>ab</sup> | 1550<sup>a</sup> |
|           | C N   |               | 11275<sup>b</sup> | 7.33<sup>d</sup> | 6025<sup>bc</sup> | 3925<sup>bc</sup> |

3.3. Effects of herbicides on weed seed banks in maize fields with different tillage methods and different fertilization methods

The characteristics of weed seed banks under different treatments were shown in Table 3. The management methods have different effects on weed seed bank. The lowest seed density (4,175 grains/m²) was found in the treatment under conventional managements (deep tillage, fertilization and herbicide use), and the highest seed density (28,075 grains/m²) was found in the treatment under conservation agriculture management (no-tillage, no-fertilizer and no-herbicide use).

Herbicide significantly reduced the seed density of weed soil seed bank except the plots under the deep tillage and no fertilization management and significantly reduced the species abundance of the plots under the deep tillage management with fertilization. When herbicide unused, fertilization significantly increased the weed seed density in soil; when herbicide used, the response of weed soil seed bank density to fertilization was different between deep-tillage and no-tillage farmland.

According to Table 3, compared with the seed density of *S. viridis*, that of *E. rusgalli* had varied between different treatments more significantly, but both them kept similar variation trend with the total seed density.
4. Discussion

4.1. Effect of herbicides on weed seed bank
The results showed that herbicides used management significantly reduced the seed density of farmland weed seed bank except that of the treatment with deep tillage and non-fertilization. Herbicides had no significant effect on the species abundance in the most treatments except that with deep tillage and fertilization used (see Table 3). As known, the use of herbicides can inhibit the density and growth of the target weeds, reduces their seed yield, then lead to a decrease in seed density of weed soil seed bank by affects its replenishment. In this research, the species composition of the tested weed seed bank was simple and the two dominant species both were sensitive to Atrazine, an herbicide was effective in Maize farmland. The herbicide inhibited the germination and growth of the dominant weed species in the topsoil seed bank, thereby reduced the seed density of soil seed bank. However, the persistent dormant seeds in the soil seed bank were not affected, so the species abundance didn’t decreased as significantly as the seed density did.

4.2. Interaction of herbicides and tillage methods on weed seed bank in Maize Field
The main difference among the different tillage methods is the disturbing degree to the farmland soil, which directly leads to the difference of weed seed distribution [11]. Because most of the seeds of the weed seed bank are distributed in the surface soil [12], the disturbance of cultivation on the surface soil will affect their viability and their depth in the soil [11]. Studies showed that the seed density and weed diversity in no-tillage farmland were significantly higher. In the no-tillage farmland, weed seeds are mainly distributed in 0-5 cm depth; in the rotary tillage farmland, the depth is 5-10 cm and in the traditional tillage farmland, it is 10-15 cm [13]. Compared with conventional tillage, no-tillage will lead to a double addition of seed density in the soil seed bank under 0-10 cm and increase the weed biodiversity [14]. In this study, the depth of deep tillage was 30 cm, the new seeds in surface soil were turned into the deep layer of soil. In this study, the depth of seed bank sample was 15 cm. According to Table 3, tillage only had significant effects on seed density (no-tillage > deep tillage) in the plots with no fertilizer and no herbicide used, and had significant effects on species abundance only in the plots with fertilizer and no herbicide used, but the effects were not so obvious in the plots under the other managements. The possible reason is the effect of tillage may be obscured by the interaction of herbicide use, fertilization and tillage mode (Table 2). Therefore, the effect of tillage mode on seed density of soil seed bank cannot be simply declared while should be explained separately by the weed management and fertilization management.

4.3. Interactions of herbicides, nutrient and tillage on weed seed bank in Maize Field
Fertilization increases crop yields and improves the growth of fertilizer-demanding weeds. Our previous study showed that the management of no-tillage and fertilization improved the biodiversity and productivity of weed communities [15]. Seen in Table 2, although fertilization has no significant effect on weed seed bank, but weed management, nutrient management and tillage have significant interactive effects on seed density of weed soil seed bank. The influence mainly included that fertilization increased the weed seed density in soil under deep tillage and no herbicide management, but reduced that under no tillage and no herbicide management (Table 3). The specific life strategy of species and the different species composition of community would lead to the complex response of soil weed seed bank. The effect of fertilization might be weakened as herbicide inhibited the weed seed reserve very significantly. This result implied that fertilization might be helpful to control the excessive seed density of weed soil seed bank to the farmland with no tillage and no herbicide.

5. Conclusion
In this research, the weed seed bank of winter have 10 species and 14,056 (±8,042) grains / m² on average. Herbicide, fertilization and tillage had interactive effects on the weed soil seed bank characteristics in maize farmland. Compared with the species abundance, the seed density of weed soil
seed bank is more susceptible to herbicide and tillage management. In this research, the weed soil seed bank under no tillage and no weed management has the highest seed density and fertilization will help to control it; the farmland under the farmer conventional management had the lest weed seed density. Considering that the influence of herbicide on weed soil seed bank varies with tillage and fertilization methods, it is suggested that special weed control strategies should be formulated for different farmlands under different tillage and fertilization managements in order to effectively control the size of weed soil seed bank, protect weed biodiversity, thus save herbicides, and improve the ecological environment of farmland.

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