Effects of tillage and weed management on the vertical distribution of microclimate and grain yield in a winter wheat field

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ABSTRACT

This paper presents results of a field study of the influence of tillage and weed on the vertical distribution of microclimate in the upper, middle, and deeper layers of a winter wheat population and grain yield during the 2008–2009 and 2009–2010 winter wheat growing seasons. The results showed that the microclimate of the winter wheat canopy was different among the upper, middle, and deeper layers. Illumination was higher in the upper layer of the canopy than in the middle and deeper layers; under no-tillage + weed-reserving, a greater difference was found among the 3 layers. In the upper layer, illumination was the highest and lowest under no-tillage + weed-control and conventional tillage + weed-control, respectively. In the upper layer, air temperature was higher under no-tillage + weed-control than under conventional tillage + weed-control. The effects of air temperature in the middle and deeper layers were relatively low with tillage and considerably higher with weeds. Relative humidity was the highest and lowest under no-tillage + weed-reserving and conventional tillage + weed-control, respectively. During the winter wheat growing seasons, illumination and air temperature were lower at the heading stage and increased to a maximum at the filling stage, whereas the trend for relative humidity was the opposite. With weed-control, grain yield was significantly (*LSD*, $P < 0.05$) higher under conventional tillage than under no-tillage; with weed-reserving, no significant (*LSD*, $P < 0.05$) differences in grain yield were found between conventional tillage and no-tillage. The results showed that tillage and weed influenced microclimate vertical distribution in the winter wheat canopy and grain yield of winter wheat.

Keywords: conservation tillage; herbicide; illumination; air temperature; relative humidity

No-tillage farming is more than just the elimination of ploughing; it involves the development of a combination of agroecologically sound management practices to fit the overall scheme of farm system trends in specific regions. The concept challenges the scientific basis of ploughing as an original, universal method of soil preparation (Monteiro et al. 2006). Change in technology may affect weed density and weed biology and should be explored. Conventional tillage is widely used to decrease weeds directly by burying weed seeds. Weeds represent one of the most costly and limiting factors in crop production and cause harvesting and storage problems (Rosskopf et al. 1999). Weeds pose a serious threat to companion crops by changing the crop population microcli-

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mate, since they compete for nutrients, water, sun radiation, and space, which causes a considerable reduction in grain yield. Hence, an effective weed management strategy should be implemented.

The North China Plain, one of the China's most important agricultural regions, produces 19% of the nation's food (Zhang et al. 2003). The winter wheat-summer maize double-cropping system is one of the main cropping systems in the plain (Li et al. 2010). The potential yield of winter wheat can be limited by microenvironmental factors such as light interception, air temperature, carbon partitioning, and water and nutrient supply. Climate is the factor with the greatest impact on agricultural productivity. It is, therefore, not surprising that the practice of intentional microclimate modification is as old as the practice of agriculture itself. The effect of soil tillage systems on the vertical distribution of microclimate is of practical interest (Su et al. 2007), both theoretically and practically, as a method of changing the microclimate in a field ecological system, and thus influencing soil water, nourishing substances, and crop yield (Jannie et al. 2006). Under a no-tillage system, microclimate changes can result in yields comparable to the production under a classical conventional tillage system. For winter wheat, production can be even higher under no-tillage than under conventional tillage.

Several physiological traits were associated with increases in the yield potential of wheat under different growing conditions. These traits include increased grain number, early anthesis, leaf area index, plant height, and increased rate and duration of grain filling (Reynolds and Borlaug 2006). Vegetation activity is influenced by luminance, air temperature, and relative humidity at the ground surface, and the opportunity for thermoregulation from shading by weeds and less moisture loss through evaporation can encourage early germination and plant growth and improve the above physiological traits. Zhu et al. (2008) showed that competition for illumination by weeds in a rape field was mainly at 75 cm from the ground, that controlling weeds can significantly reduce crop plant height and density, and that illumination rises significantly at 10 cm from the ground. The effect of weedy rice density on the illumination of cultivated rice was relatively small at 30 cm from the ground, but the intensity of illumination of cultivated rice decreased with an increase in weedy rice density at 60 cm and 90 cm from the ground (Song et al. 2009). In order to increase crop grain yield, conservation tillage has been studied widely. However, the effects of no-tillage and weed management on the vertical distribution of microclimate and grain yield in winter wheat are not completely understood. The goal of this study was to review our current understanding of each of these mechanisms to assess and better understand their effects on the vertical distribution of microclimate and ultimate yield ability in a winter wheat field under 4 cultivation methods (2 tillage methods and 2 weed management methods).

MATERIAL AND METHODS

Experimental site. The experiment was conducted on a brown loam soil at the experimental station of the Shandong Agricultural University (36°10'19''N, 117°9'03''E) located in the North China Plain. The current experiment was conducted during the 2008–2009 and 2009–2010 winter wheat growing seasons. Under conventional tillage, soil organic matter in the 0- to 20-cm soil layer was 13.61 g/kg, total N was 1.38 g/kg, total P was 1.52 g/kg, available N was 91.57 mg/kg, available P was 15.13 mg/kg, soil bulk density was 1.38 g/cm^3, capillary porosity was 37.3%, and total porosity was 46.0%. Under no-tillage, soil organic matter in the 0- to 20-cm soil layer was 14.72 g/kg, total N was 1.28 g/kg, total P was 1.68 g/kg, available N was 93.56 mg/kg, available P was 17.32 mg/kg, soil bulk density was 1.43 g/cm^3, capillary porosity was 37.2%, and total porosity was 43.4%. At the time of sowing, 30.0 g/m^2 of triple superphosphate, 30.0 g/m^2 of urea, and 7.5 g/m^2 of potassium chloride were applied to the soil in each treatment each year. During the 2008–2009 and 2009–2010 winter wheat growing seasons, precipitation was 137.0 and 141.0 mm, respectively, which was considered below average in the study region for both growing seasons.

Experimental design. The experiments were conducted in a split design to study the effects of 2 single practices, weed management and tillage. During the 2008–2009 and 2009–2010 winter wheat growing seasons, the following 4 cultivation methods were applied throughout the entire growth cycle: no-tillage + weed-reserving (NT + WR), no-tillage + weed-control (NT), conventional tillage + weed-reserving (T + WR), and conventional tillage

+ weed-control (T). Weed control was performed by herbicide application once at the beginning of overwintering: applied 0.015 kg 75% dry suspension agent of tribenuron-methyl per hectare and 4.5 kg 25% chlortoluron that included 1.125 kg active ingredient *N*,*N*-dimethyl-*N*-(3-chloro-4-methylphenyl) urea per hectare, watered 450 to 600 kg per hectare, and sprayed using weishi WS-8 compression sprayer. Conventional tillage consisted of 0.15- to 0.20-m-deep mouldboard ploughing (tractor driven) with disc harrowing before ridging. Seeds were manually sown 3 cm deep using a stick. Each experimental plot was 4 m × 15 m in size and was replicated 3 times in a randomized block design. Winter wheat local variety Jimai 20 was sown at a seed rate of 90 kg/ha. Seeding was completed on October 11 in 2008 and on October 16 in 2009, and plants were harvested on June 10 in 2009 on June 15 in 2010, as soon as the weather conditions permitted.

Microclimate measurements. The factors that are the most important indicators for the development of microclimate are illumination, air temperature, and relative humidity. These microenvironmental data were recorded at the heading and filling stages during the 2008–2009 and 2009–2010 growing seasons on a sunny day when air temperature, relative humidity, and wind speed were not significantly different at 14:00. During 2 periods, illumination and air temperature/relative humidity were measured in the centre of 1 plot in each treatment by using an SF 85 illumination meter and an automatic weather collector, respectively.

Vertical microclimate distribution was measured in the 3 layers above the ground from the central row of the winter wheat population. Heights were measured in the upper layer (U, 70 cm above the ground), middle layer (M, 40 cm above the ground), and deeper layer (D, 10 cm above the ground); each height was measured 5 times successively at 10 locations.

When the winter wheat reached maturity, 1-m stretches of 2 rows were selected at random in each experimental plot to measure spike numbers, 1000 kernel weight, and grain yield. The plants were harvested manually and air-dried. An additional 15 plants were harvested to count the grains per spike. All of the data in the study were measured by considering the average of 3 repeated measurements.

Data analysis. The experimental data were evaluated using an analysis of variance (ANOVA). The ANOVA was performed at a significance level of $\alpha = 0.05$ to determine whether differences existed among treatment means. Multiple comparisons were conducted for significant effects by using the least significant difference (*LSD*) test at $\alpha = 0.05$.

RESULTS

Illumination vertical distribution in winter wheat canopy. Illumination can directly affect the photosynthetic rate of the plant leaf. As shown in Figure 1, during the winter wheat development period, illumination between rows increased sharply. From the heading to the filling stage, illumination between the winter wheat rows showed a generally increasing trend. However, illumination varied in the different layers of the wheat canopy and was significantly (*LSD*, $P < 0.05$) higher in U than in M and D. In addition, the different tillage and weed management treatments were performed differently in U, M, and D.

In U of the winter wheat canopy, illumination at the heading stage was lower under no-tillage + weed-control than under conventional tillage + weed-control. Illumination under no-tillage + weed-reserving was lower than that under no-tillage + weed control by 0.52 klx, illumination under conventional tillage + weed-reserving was lower than that under conventional tillage + weed-control by 0.61 klx, and illumination under no-tillage + weed-control was lower than that under conventional tillage + weed-control by 1.91 to 2.0 klx. Compared with weed-reserving, weed-control increased illumination in the winter wheat canopy at the heading stage. At the filling stage, illumination was higher under no-tillage than under conventional tillage. Illumination under no-tillage + weed-reserving was lower than that under no-tillage + weed-control by 0.72 klx, illumination under conventional tillage + weed-reserving was lower than that under conventional tillage + weed-control by 0.82 klx, and illumination under no-tillage exceeded that under conventional tillage by 1.77 to 1.87 klx. Similar to the heading stage results, compared with weed-reserving, weed-control increased illumination in the winter wheat canopy at the filling stage. Illumination in the winter wheat canopy was the highest under no-tillage + weed-control, followed by that under no-tillage + weed-reserving and conventional tillage + weed-control, and was the lowest under

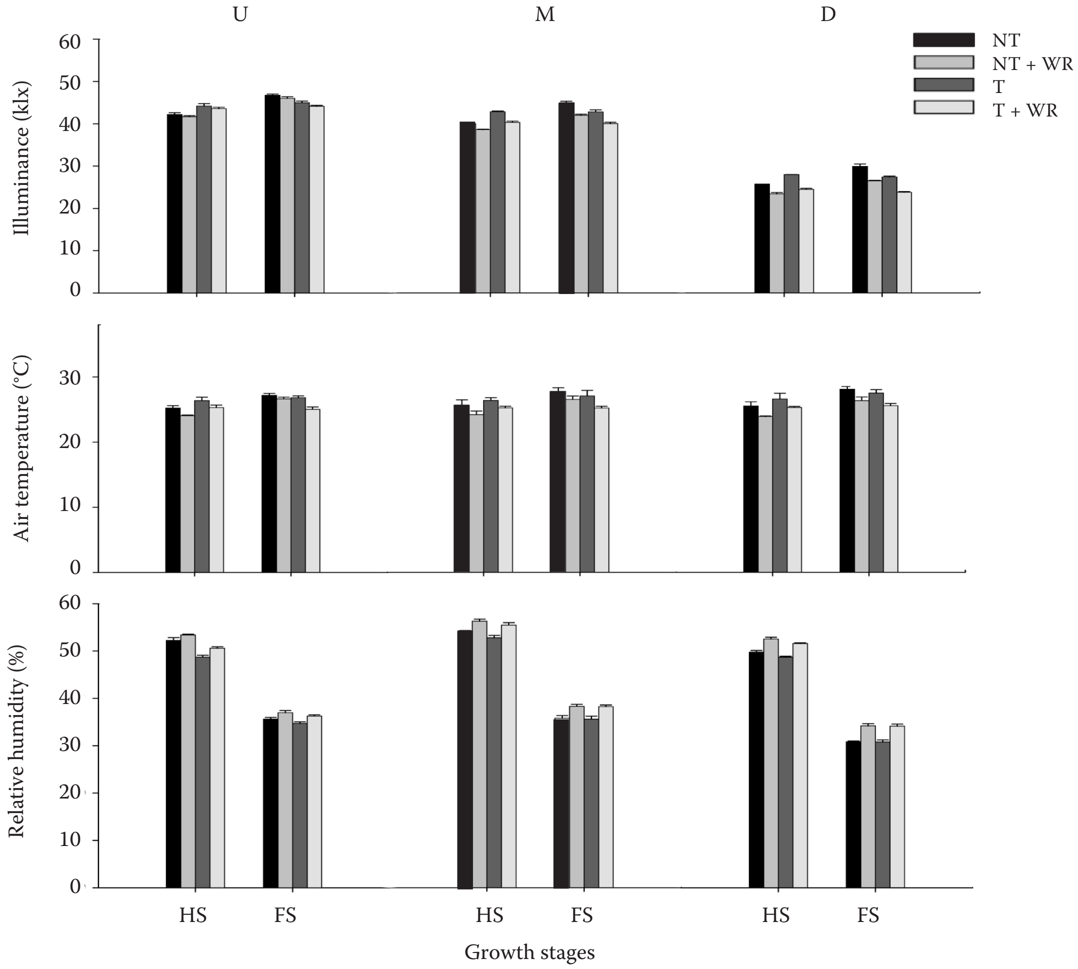

Figure 1. Effects of no-tillage and weed management on illumination, air temperature, and relative humidity vertical distribution in upper (U), middle (M), and deeper (D) layers of winter wheat canopy. HS – heading stages; FS – filling stages; NT – no-tillage; WR – weed-reserving; T – conventional tillage

conventional tillage + weed-reserving. Illumination was higher in U of winter wheat canopy than in M and D, and a greater difference between the 3 layers was found under no-tillage + weed-reserving.

Air temperature vertical distribution in winter wheat canopy. Figure 1 presents a different view of the effect of no-tillage and weeds on air temperature vertical distribution; air temperature in the winter wheat canopy was higher at the heading stage than at the filling stage. Among the different winter wheat layers, the general trend for air temperature was U < M < D, and different tillage and weed management treatments had the same effects on air temperature among the 3 layers. With weed-reserving, at the heading stage, air temperature in U of winter wheat canopy was lower under no-tillage than under conventional tillage by 1.25°C. On the other hand, at the filling stage, air temperature was lower under conventional tillage than under no-tillage by 1.61°C. With weed-control, at the filling stage, air temperature was lower under conventional tillage than under no-tillage by 0.34°C, but the difference was not significant (*LSD*, $P < 0.05$). The greatest effect of weeds under no-tillage and conventional tillage was found under conventional tillage at the filling stage, where the D-value was 1.80°C; and the lowest effect was found under no-tillage at the filling stage, where the D-value was 0.53°C.

The differences in air temperature between M and D were relatively small and, at the different growth stages in winter wheat, the highest temperature under conventional tillage and no-tillage alternated; however, the effects of weed management were greater. At the filling stage, air temperature was lower under conventional tillage + weed-reserving than under conventional tillage + weed-control by 1.93°C, which was the largest D-value. Comparison of air temperature in the winter wheat canopy showed that as height increased, the difference in air temperature decreased from 1.06°C to 1.80°C, 1.13°C to 1.86°C, and 1.64°C to 1.93°C in U, M, and D, respectively.

Relative humidity vertical distribution in winter wheat canopy. Figure 1 shows an opposite trend for relative humidity compared to air temperature in the winter wheat canopy rows. Weed-reserving increased relative humidity, and relative humidity was higher at the heading stage than at the filling stage. Relative humidity was lower in U of the winter wheat canopy than in M and D. The influence of the different tillage methods and weed management on humidity showed the same trend, with a great level of influence in the deeper layer. For example, in U, at the heading and filling stages, relative humidity was higher under no-tillage than under conventional tillage. Further, relative humidity was lower under conventional tillage + weed-reserving than under no-tillage + weed-reserving by 2.8–0.7% and was lower under conventional tillage + weed-control than under no-tillage + weed-control by 1.63–0.9%. Relative humidity was lower with weed-control than with weed-reserving. Relative humidity was lower under no-tillage + weed-control than under no-tillage + weed-reserving by 1.17–1.37% and was lower under conventional tillage + weed-control than under conventional tillage + weed-reserving by 1.87–1.57%. In summary, relative humidity was the highest under no-tillage + weed-reserving, followed by that under no-tillage + weed-control and conventional tillage + weed-reserving, and was the lowest under conventional tillage + weed-control. Under both no-tillage and conventional tillage, weed-reserving increased relative humidity in the winter wheat canopy.

Grain yield and yield components. Soil tillage methods influenced the productivity elements of the microclimate and yields obtained. In the 2 years of experimentation, the change in winter wheat yield showed the same trend and reflected an average of the 2 years (Table 1). An important consideration when evaluating no-tillage systems for land cultivation is that with weed-control, grain yield under conventional tillage + weed-control was 5.85 t/ha, which was significantly (*LSD*, $P < 0.05$) higher than that under no-tillage + weed-control. However, with weed-reserving, there was no significance (*LSD*, $P < 0.05$) difference in grain yield between conventional tillage and no-tillage. Thus, compared to conventional cultivation system, regardless of weed-control, grain yields under no-tillage were low. Spike number was significantly (*LSD*, $P < 0.05$) higher under conventional tillage than under no-tillage, but no significant (*LSD*, $P < 0.05$) effects on grains per ear or 1000 grain weight were found.

As shown in Table 2, the correlation of winter wheat yield with air temperature and relative humidity was low and did not reach a significant (*LSD*, $P < 0.05$) level. However, yield and illumination were positively correlated. Illumination in M and D showed a significant (*LSD*, $P < 0.05$) positive correlation with yield, and illumination in U showed a very significant (*LSD*, $P < 0.05$) positive correlation with yield. Thus, yield and illumination were more closely related in U.

DISCUSSION

The advantage of the no-tillage system is that it can improve population vertical distribution of the microclimate, with reduced illumination and air temperature at the heading stage and increased illumination and air temperature at the filling stage; in addition, relative humidity is higher under no-tillage than under conventional tillage at both the development stages.

Table 1. Effects of no-tillage and weed management on grain yield and yield components of winter wheat

Treatments	Spike number per m^2	Grains per spike	1000 grain weight (g)	Grain yield (t/ha)
NT	589.50^c	25.23^{ab}	32.96^a	4.95^b
NT + WR	562.00^c	26.17^a	32.92^a	4.84^c
T	756.50^a	26.16^a	29.08^{ab}	5.85^a
T + WR	651.50^b	25.17^{ab}	29.00^{ab}	4.76^c

Common letters in columns indicated that the means were not significant at 0.05 level. NT – no-tillage; WR – weed-reserving; T – conventional tillage

Table 2. Correlation of the yield and yield components of winter wheat with illumination, air temperature and relative humidity

Traits		Spike number per m^2	Grains per spike	1000 grain weight (g)	Grain yield (t/ha)
Illumination (klx)	U	0.953**	0.786*	0.776*	0.850**
	M	0.932*	0.628	0.734	0.801*
	D	0.641	0.588	0.670	0.748
Air temperature (°C)	U	0.921**	–0.042	0.720	0.819*
	M	0.825*	–0.095	0.556	0.751
	D	0.806*	–0.092	0.631	0.672
Relative humidity (%)	U	0.986**	–0.078	–0.389	–0.739
	M	0.757	–0.084	–0.369	–0.723
	D	0.710	–0.032	–0.319	–0.692

$r_{0.05}$ = 0.761; $r_{0.01}$ = 0.875. *P < 0.05; **P < 0.01; U – upper layers; M – middle layers; D – deeper layers of winter wheat canopy

In this study, the influence of weed-reserving on the microclimate of canopy shade was opposite to that of weed-control. Similar to changes from cool and humid microclimates to warmer and drier microclimates as the winter wheat developed, weeds shifted from near the ground to the higher canopy. This trend was essentially the same in the winter wheat and, thus, is apparently related to vegetation density rather than to other specific factors. In addition, stem elongation, leaf development, and ear development, which determine ground shading by weeds in winter wheat stands, are completed at the heading stage in late May. Subsequent crop biomasses are largely related to field microclimate.

High illumination and air temperatures promote the development of winter wheat tillers, produce strong stock, and increase the number of productive spikes. With increased hours of sunlight, spikes are more productive, which also indicates a higher yield. Wheat yield may be reduced significantly when weeds compete with wheat plants for light, water, and minerals. Weeds or weed seeds contaminating harvested grain may reduce quality (Vita et al. 2007). In this experiment, shading by weeds directly affected plant growth because of the reduction in photosynthetically active radiation and indirectly because of its effects on soil and air temperatures and evaporation. An increase in diffuse radiation with weed-control, and the resultant improved light transmission into plant canopies, is a mechanism that could enhance photosynthetic activity. Lowering field and canopy temperatures via shading may limit growth (Khalld et al. 2010). Finally, we should note that shading from weeds may decrease evaporation rates and reduce moisture losses. Below ground, no-tillage can improve soil fertility by the addition of carbon (Ibell et al. 2010). However, the roots of weeds occupy the same soil volume as the winter wheat, and competition for nutrients and water will almost certainly limit winter wheat productivity.

Tillage indirectly encourages herbicide decomposition through increased microbial and chemical breakdown. Shapiro et al. (1999) investigated the effects of crop residue on the persistence of *Steinernema carpocapsae*, and his result provided growers with an alternative to chemical control that functions well under no-tillage systems. The use of crop residue will reduce the chemical load in the environment. Further studies are needed to evaluate the effects of crop residue and tillage on the long-term efficacy in agroecosystems.

In this experiment, with weed-control, spike numbers were significantly lower under no-tillage than under conventional tillage, possibly because soil temperature under no-tillage was decreased, and hence affected the growth and development of tillers after spring. Li et al. (2008) indicated that this may be the main reason why spike numbers were significantly lower under no-tillage than under conventional tillage. No-tillage is a special cropping method that minimizes soil disturbance but requires modern machinery and a frequently updated technology adapted to the site. Further, in addition to weed infestation, the proliferation of pests under the no-tillage system must be addressed. All of these considerations will require further investigation.

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