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Full Length Research Paper

Effects of different chemical materials and cultural methods on growth and yield of winter wheat

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To determine the effects of different chemical and cultural methods on the growth of winter wheat, six treatments were carried out: Conservational irrigation, non-irrigation, water absorbent polymers (WAP), liquid mulching film (LMF), water-saving irrigation (WSI) and subsoiling tillage (SST). The results show that winter wheat could use more water from soil profile though WAP, LMF and SST treatments; only LMF could use extra water for yield while both WAP and SST could not increase yield. SST could not increase yield of winter wheat. Both LMF and WAP treatments could help in maintaining leaf chlorophyll content and leaf water content which may help in maintaining photosynthetic ability in late growing periods. Furthermore, more dry matter partitioning to reproductive organs is observed in LMF and WAP treatments. LMF might be favorable for yield when grown under lower soil moisture conditions, while the application of WAP might not help in yield producing in field both in high or low soil moisture conditions. A reasonable irrigation quantity may be needed when applying WAP, while LMF could be used in any meteorological and/or soil water conditions.

Key words: Winter wheat, water absorbent polymers, liquid mulching film, subsoiling tillage

INTRODUCTION

Winter wheat (*Triticum aestivum* L.) is a main crop in Huang-Huai-Hai plain. Huang-Huai-Hai plain locates in north China and is one of the most important grain production regions in China (Zhang et al., 2005, 2006), which accounts for 53% of wheat production in China and about 15% of the total national grain production (Liu and Chen, 2005). Though the average annual precipitation in Huang-Huai-Hai plain is from 500 to 600 mm, the distribution in seasons is not even. More than 70% of the total precipitation was in the period from July to September. As a result, precipitation from October to next June (the winter wheat growing season) ranges only from 100 to 180 mm. About 25 to 40% water shortage for the requirement of wheat production (Zhang et al., 1999). Supplemental irrigation is required in winter wheat growing season. However, Huang-Huai-Hai plain has only 7.2% of the total national water resources, and no sufficient surface water resources are available for irrigation. Shortage of water resources has become the major limiting factor for wheat production (Liu et al., 2002; Zhang et al., 2005, 2006). Thus, it is necessary to adopt water-saving agriculture countermeasures to achieve the largest increase in water use efficiency of winter wheat (Li et al., 2007).

It is reported that in this area, about 60% in the early growth season and 30% in late growth season of total soil evapo-transpiration is from the soil evaporation (Kang et al., 1995; Xie, 1998; Liu et al., 2002; Zhang et al., 2004). Thus, to reduce soil evaporation is an important method to maintain soil moisture. Subsoiling tillage is used in field commonly for maintaining soil moisture (Zhang et al., 2007; Li et al., 2008a, b). In recent years, water absorbent polymers (WAP) were used widely in agriculture, especially in horticulture. Experiments were also done in

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Abbreviations: WAP, Water absorbent polymers; **LMF,** liquid mulching film; **SST,** subsoiling tillage; **WSI,** water-saving irrigation.

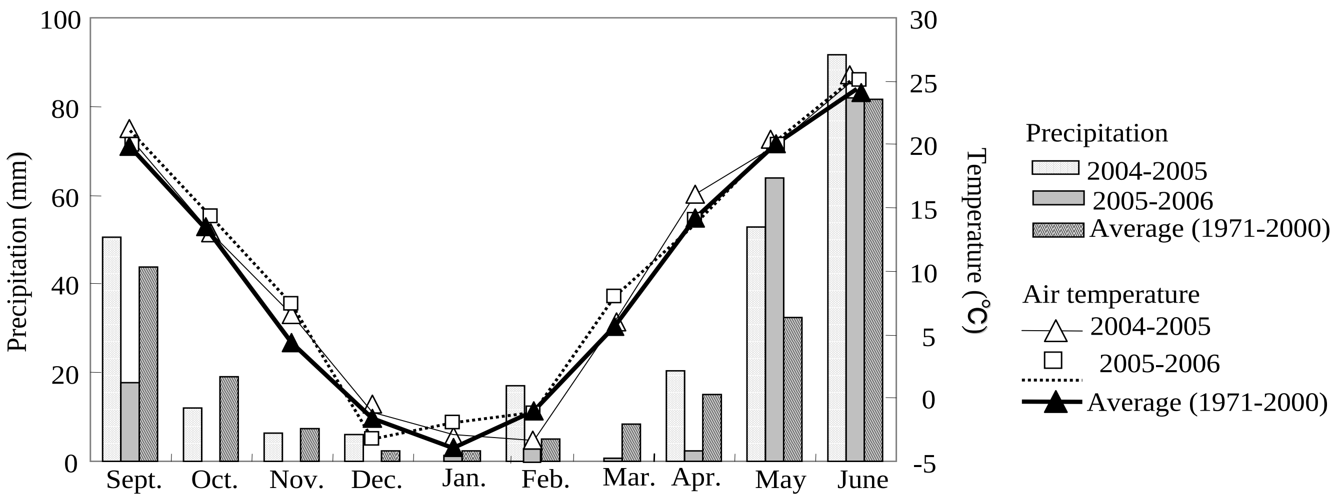

Figure 1. Monthly changes in precipitation and air temperature in Changping, Beijing in 2004–2006.

field crop. The results showed that WAP could improve the crop yield in maize, tomato, and so on (Yu et al., 2006; Zhang et al., 2007; Zhao et al., 2006; Yamane et al., 1990). WAP are less used in field crops not only because of its high price, but also because of its contention about soil physio-chemical properties and ecological environment as it is mainly made from chemical materials. In our alternate research, a new kind of material, liquid mulching film (LMF) has been synthe-sized with biological material which considered harmless to environment. LMF can be directly sprayed on soil surface and form a clear film on soil surface. It is reported that LMF could increase temperature, conserve soil moisture and improve the growth rate of plants (Yu et al., 2003; Zhang et al. 2003). Furthermore, LMF could ignore the plastic pollution and could also be used in the crop that plastic film could not be used, such as winter wheat (Huang et al., 2004; Zhang et al., 2005).

In this study, we intended to make a comparison among physical and chemical (SAP and LMF) methods applying on winter wheat. The objectives were: To determine the yield and yield performances of winter wheat when applied WAP and LMF; to find the effect of WAP and LMF on maintaining soil moisture and to discuss the differences in water efficiency of physical and chemical methods of different water-saving methods on soil moisture and yield.

MATERIALS AND METHODS

The experiments were done in the Changping experimental base (N 40.18°, E 116.23°) of the Chinese Academy of Agricultural Sciences in Beijing, China in winter wheat growth season from September 2004 to June 2005 and from September 2005 to June 2006. The local wheat cultivar (*T. aestivum* L. cv. CA0045) was used in this study. Twenty-four plots were used in this experiment. The area of each plot was 4 × 6 m. The sowing density was 225 kg ha^{-1} and the row distance was 23 cm in both years. Six methods (treatments) were carried out in this study. The treatments were: (1) Conservational irrigation (CI: Control, the same irrigation quantity as the commercial field around the base); (2) Non-irrigation (NI: only precipitation in growing period); (3) Water-saving irrigation (WSI: About 20% and 12.5% less than that of CI in 2004-2005 and 2005-2006, respectively); (4) Water absorbent polymers (WAP); (5) Liquid mulching film (LMF) and (6) subsoiling tillage (SST). The WAP (Bai Jinzi, Boya Co. Ltd., Tangshan, China) was put 20 cm depth under soil under the seedling row. The quantity was 60 kg hm^{-2}. LMF was sprayed equally on the soil surface after seedling. LMF was conducted in the Lab of agricultural disaster mitigation, Chinese Academy of Agricultural Sciences (CAAS). The irrigation quantities of WAP, LMF and SST were the same as that of WSI. Field was irrigated in winter-crossing stage, jointing stage and grain-filling stage. The soil moisture in 10 cm levels (1.4 m depth) was measured in week intervals with time-domain reflectometry (TDR). The actual quantum yield of PSII, the relative leaf water content, the relative values of leaf chlorophyll content were measured at jointing stage, heading stage and grain-filling stage in 2004-2005. The flag leaves were chosen for all above measurements. The actual quantum efficiency of PSII ($\Delta F/Fm'$) was measured using a pulse amplitude modulation chlorophyll fluorometer (PAM-2000, Walz, Effeltrich, Germany). Three leaves from each treatment and 5 places of each leaf were measured. Leaves from each treatment were taken and imme-diately sealed in plastic bags. The leaves were oven-dried for 24 h. The weights before and after drying were measured and the relative water content of each leaf was calculated. The relative values of leaf chlorophyll content were measured by SPAD-502 (Minolta, Japan). Five leaves were chosen for one species, and 5 places were measured in one leaf. The data were all averaged. The dry matter accumulation at different growing stages in 2004-2005, yield and yield components in harvest in both years were determined. The data were subjected to analyses of variance (ANOVA) to determine the effects of treatments, and the mean differences were adjudged by Duncan multiple range test (DMRT) at 0.05 probability level.

RESULTS

Meteorological and irrigation quantity

Figure 1 shows the meteorological condition in Changping meteorological station. The average monthly temperature varied a little among years. There is large

Table 1. Irrigation quantity of six treatments and precipitation in growth period (mm).

Treatment	2004-2005			2005-2006		
	Irrigation	Soil*	Total	Irrigation	Soil	Total
CI	225.0	-7.2	342.3	180.0	46.4	245.6
NI	0.0	32.0	156.5	0.0	88.1	107.3
WSI	180.0	-5.4	299.4	167.5	65.2	251.9
WAP	180.0	-7.3	297.2	167.5	84.4	271.1
LMF	180.0	-4.9	299.6	167.5	80.4	267.1
SST	180.0	-12.3	292.2	167.5	78.4	265.1
Precipitation		124.5**				19.2

*Means soil means the water consumption in soil profile from 0.140 cm, **means the precipitation in the growing season.

difference in precipitation within two growing seasons. It was 124.5 mm in 2004-2005 and 19.2 mm in 2005-2006, respectively.

Table 1 shows the irrigation quantity and total water consumption in both years. In 2004-2005, the total irrigation quantity of CI (Control) was 225 mm and the other treatments were 180 mm. Besides CI, the soil moisture increased at harvest time when compared with those before sowing. The total water consumption with the most in CI and the least in NI was 342.3 and 156.5 mm, respectively. The other treatments ranged from 290 to 300 mm. The total water consumption of NI was 45% that of CI, and other treatments were around 85 to 87% of CI, indicating that 180 mm was enough for wheat growth in 2004-2005. Thus, the irrigation quantity was adjusted to 180 mm for CI in 2005-2006, and the other treatments were 80% of CI, was 167.5 mm. The total water consumption was 245.6 and 107.3 mm for CI and NI, respectively. The other treatments ranged from 250 to 270 mm. The total water consumption of NI was 43% that of CI, and other treatments were around 100 to 110% of CI.

Eco-physiological parameters

Soil moisture

Figure 2 shows the changes of the water content at soil profile in different treatments with time. The water consumption was mainly concentrated in 0 to 50 cm depth. The difference among the treatments and years were not obvious. The soil water content in 0 to 60 cm depth was much higher in 2004-2005 as compared with that in 2005-2006. Oppositely, in 60 to 140 cm depth, the values was lower in 2004-2005 than that in 2005-2006, indicating that the winter wheat might abort more water from soil in upper profiles. The water content of SAP and LMF were higher than those of other treatments both in upper and lower profiles, indicating that both SAP and LMF might help in maintaining soil moisture, especially in deep soil profiles.

SPAD value, relative leaf water content and the actual quantum efficiency of PSII

The SPAD values in Flag leaf, the 2nd leaf and the 3rd leaf from top decrease as time especially in NI (Figure 3). For all treatments, the flag leaf had higher values than those in the 2nd leaf, and the values in 2nd leaf were higher than that in 3rd leaf. The SPAD values decreased as time. The LMF kept higher values as compared with other treatments followed by SAP. NI showed the lowest values in all season.

Figure 4 shows the relative leaf water content in flag leaf in different growing stages. The water contents were highest in jointing stage and decreasing as time. The differences among treatments were not large except for NI. NI showed lower values, while LMF and SAP had higher values. The actual quantum efficiency of PSII showed higher values in heading stage (Figure 4). Values were in jointing stage and grain-filling stage, indicating that the flag leaf of winter wheat had strong ability in photosynthetic ability in heading stage. The NI showed the lowest values in photosynthetic ability in grain-filling stage. Large differences were not found among treatments in other stages.

Yield and yield components

Yield and yield components are shown in Table 2. NI showed the lowest yields in both years (0.333 and 0.293 kgm^{-2}, respectively). Significant differences were not found among the other treatments in 2004-2005, the yields varied from 0.511 to 0.541 kgm^{-2}. On the contrary, the yields had significant differences in 2005-2006. The highest yield was obtained by LMF, WAP obtained the lowest yield. The yields of all treatments in 2005-2006 were higher than those in 2004-2005. The yields were 27, 24, 20, 19, 13 and 12% lower in 2005-2006 than those in 2004-2005 for WAP, SST, CI, WSI, LMF and NI, respectively.

NI had the lowest values in spikes number in both years (430.4 and 426.1 spikes m^{-2}, respectively).

Significant differences were not found among the other

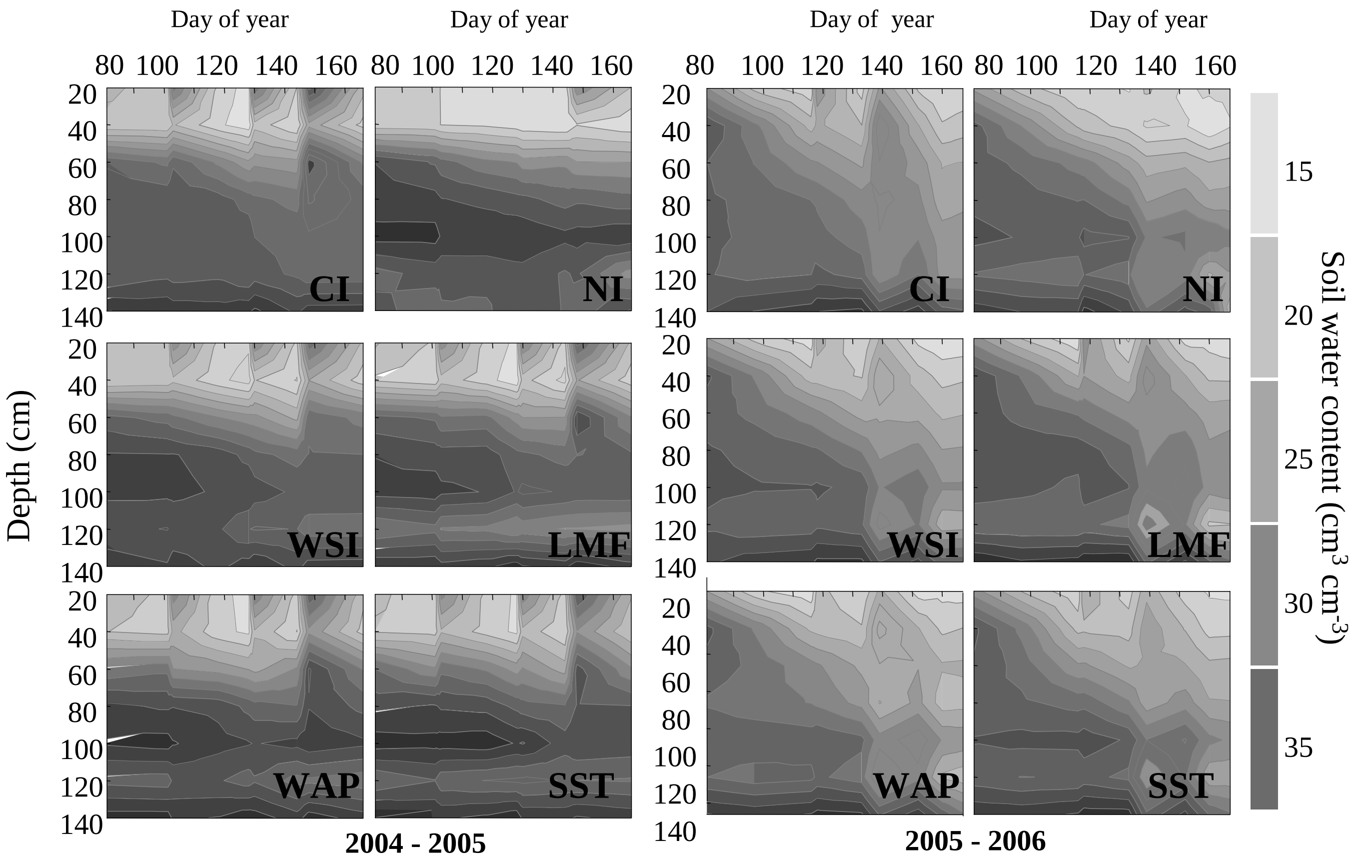

Figure 2. Changes of water content at soil profile in different treatments.

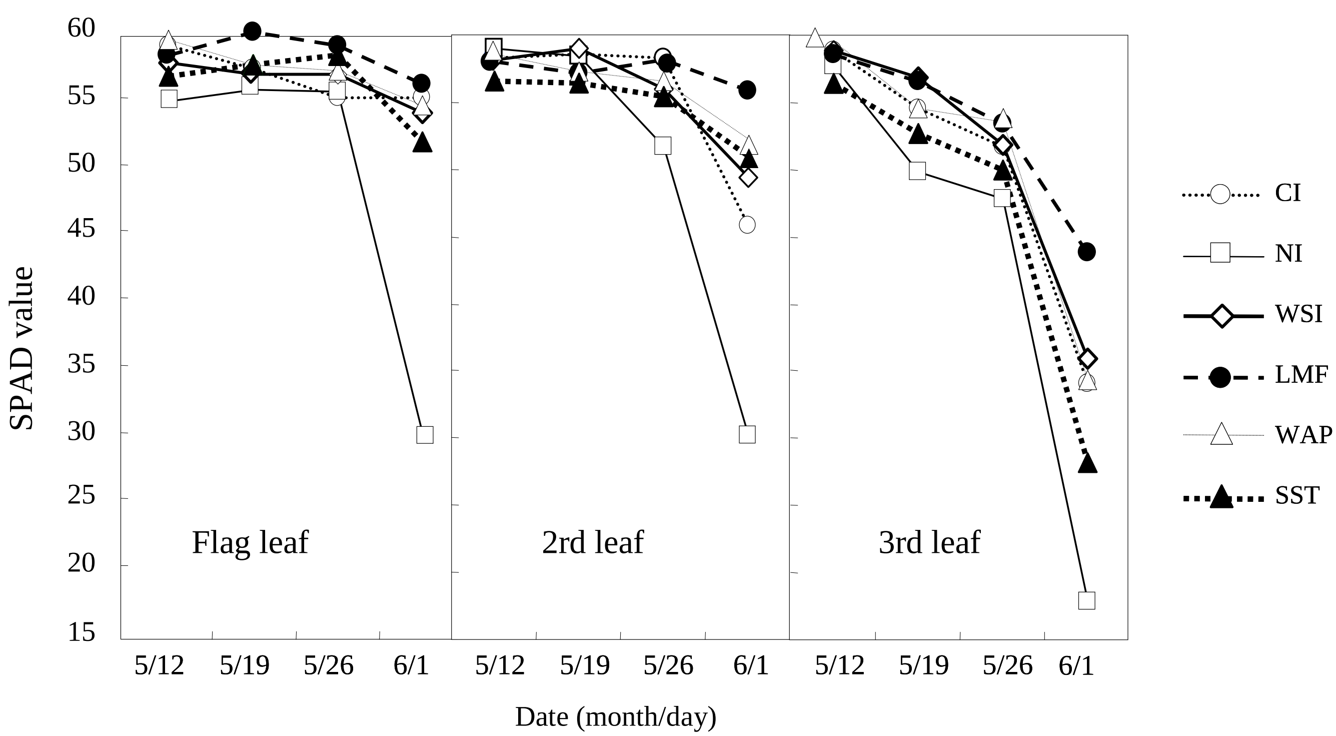

Figure 3. Changes in chlorophyll content of leafs from top in different treatments at different stages in 2004-2005.

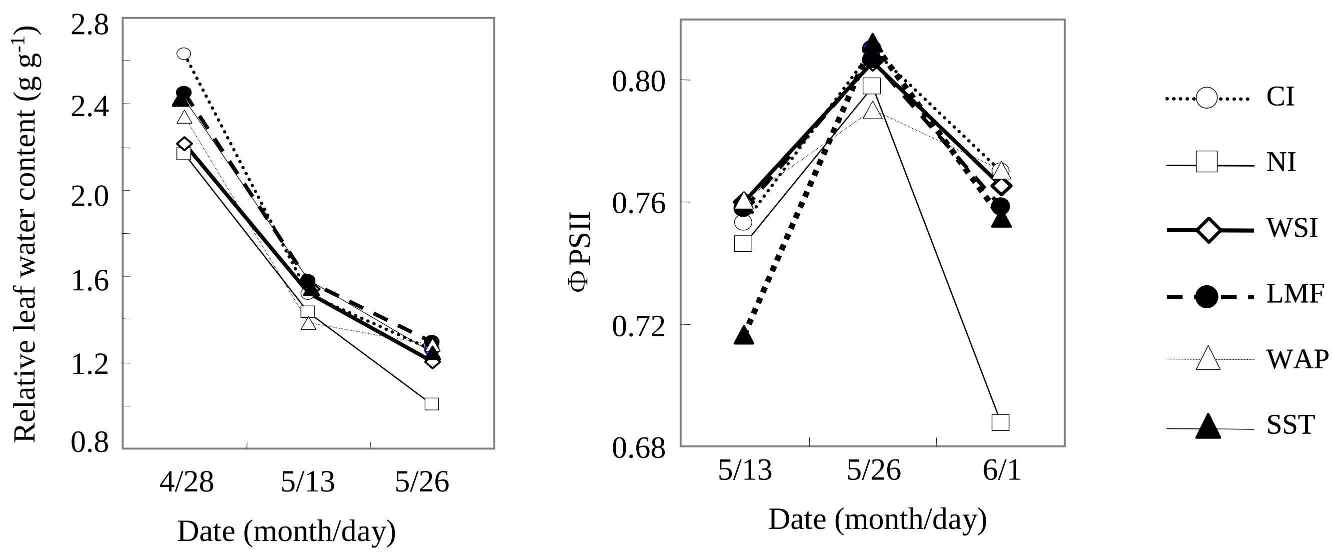

Figure 4. Changes in relative water content of flag leaf and the maximal photosynthetic quantum efficiency in different treatments at different stages in 2004-2005.

Table 2. Yield and yield components.

Treatment	Spikes number (no m^{-2})		Grain number (no $spike^{-1}$)		One hundred Kernel weight (g)		Yield (kg ha^{-1})	
	2004-2005	2005-2006	2004-2005	2005-2006	2004-2005	2005-2006	2004-2005	2005-2006
CI	543.5^{b}	517.4^{b}	34.1^{b}	28.0^{ab}	43.2^{a}	35.1^{a}	0.540^{b}	0.431^{cd}
NI	430.4^{a}	426.1^{a}	29.1^{a}	24.0^{a}	43.8^{ab}	34.5^{a}	0.333^{a}	0.293^{a}
WSI	534.8^{b}	527.5^{b}	31.0^{ab}	29.4^{b}	43.7^{ab}	36.4^{ab}	0.541^{b}	0.395^{bc}
LMF	576.8^{b}	520.3^{b}	32.9^{ab}	27.5^{ab}	46.9^{b}	41.1^{b}	0.534^{b}	0.464^{d}
WAP	526.1^{b}	488.4^{ab}	32.1^{ab}	27.2^{ab}	45.0^{ab}	39.2^{ab}	0.533^{b}	0.388^{b}
SST	552.2^{b}	543.5^{b}	31.9^{ab}	28.6^{b}	43.8^{ab}	39.1^{ab}	0.511^{b}	0.384^{b}

Different mean significant difference at 0.05 level.

five treatments in both years. The values varied from 526.1 to 576.8 spikes m^{-2} in 2004-2005 and from 488.4 to 543.5 spikes m^{-2} in 2005-2006, respectively. The values in 2005-2006 were lower than those in 2004-2005, but less than 10% for all treatments and the difference was not significant among treatments.

The same trend was found in grain numbers per $spike^{-1}$. NI had the lowest values in both years (29.1 and 24.0 grains $spike^{-1}$). The difference was not large among other 5 treatments in both years too. The values varied from 31.0 to 34.1 grains $spike^{-1}$ in 2004-2005 and from 27.2 to 29.4 grains $spike^{-1}$ in 2005-2006, respectively. The values in 2005-2006 were lower than those in 2004-2005, and the difference was significant between years.

The one-hundred kernel weight of CI was the least (43.2 g) in 2004-2005, and that of CI and NI was the least in 2005-2006 (35.1 and 34.5 g). The highest value was obtained by LMF in both years (46.9 and 40.1 g). Significant difference was not found among other 5 treatments in both years. The values in 2005-2006 were lower than those in 2004-2005. The values were 18～21% lower for CI, NI and WSI, 10～14% lower for LMF, WAP and SST in 2005-2006 as compared with those in 2004-2005, respectively.

Dry matter production and water use efficiency (WUE)

The dry matter production and allocation data was only collected in 2004-2005. CI, WSI and WAP had the most dry matter production, followed by LMF and SST, NI had the least value (Table 3). WSI had the highest value in the ratio of spike to leaf and stem, significant difference was not found among other 5 treatments. In 2004-2005, the WUE was the highest in NI, and no difference was found among other 5 treatments. In 2005-2006, NI had the highest WUE, while WAP and SST had the lowest WUE. The CI and NI were higher, WSI and LMF were equal, and WAP and SST were lower in WUE in 2005-2006

Table 3. Dry matter allocation ratio and water use efficiency.

Treatment	Total dry matter and stem ratio (gm^{-2})		Spike to leaf (kg DM mm^{-1})		WUE (kg grain mm)			
	2004-2005	2005-2006	2004-2005	2005-2006	2004-2005	2005-2006	2004-2005	2005-2006
CI	1958.5^{c}	-	1.58^{b}	-	5.49^{a}	-	15.14^{a}	17.55^{b}
NI	1167.5^{a}	-	1.61^{b}	-	7.46^{b}	-	21.28^{b}	27.30^{c}
WSI	1901.1^{c}	-	1.37^{a}	-	6.14^{ab}	-	17.44^{a}	17.27^{b}
LMF	1713.1^{b}	-	1.78^{b}	-	5.54^{a}	-	17.27^{a}	17.37^{b}
WAP	1950.8^{c}	-	1.67^{b}	-	6.26^{ab}	-	17.11^{a}	14.31^{a}
SST	1698.0^{b}	-	1.79^{b}	-	5.74^{a}	-	16.14^{a}	14.48^{a}

The different letters mean significant difference at 0.05 level. CI, Conservational irrigation; NI, non irrigation; WSI, water saving irrigation; LMF, liquid mulching film; WAP, water absorbent polymers; SST, subsoiling tillage. WUE, Water use efficiency.

as compared with those in 2004-2005, respectively.

DISCUSSION

The water consumption of winter in 2005-2006 was less than those in 2004-2005, but difference existed among treatments. It was less 30% for CI, 20% for WSI and 10% for LMF, WAP and SST, respectively. In water use efficiency, the CI and NI were higher, WSI and LMF were equal, and WAP and SST were lower in 2005-2006 as compared with those in 2004-2005, respectively indicating that only LMF could use the extra water for yield, while both WAP and SST did not help in yield producing. As all kind of mulch could help in protecting transpiration from soil surface (Chen et al., 2007; Li et al., 2008b), so more water could be used for winter wheat growth in LMF treatment instead of losing to air, which might happened in WAP and SST treatments, although, WAP could absorb more water from water, and SST method could also concentrate more water to upper soil profile. The higher soil water content in LMF treatment are also consistent with the above discussion. In our experiment, WAP did not help in yield producing both in wet condition (2004-2005) and/or in dry condition (2005-2006). SST also did not show benefit for yield producing, though water content did not show lower values as compared with those in 2004-2005. The water consump-tion is concentrated in the upper 50 cm, indicating that the soil transpiration may much stronger in dry meteorological condition for winter whea field as compared with in wet condition.

On the other hand, though water supply is sufficient in 2004-2005, our experiment showed that both LMF and WAP treatments could help in maintaining leaf chlorophyll content and leaf water content in late growth stage. It is reported that leaf chlorophyll content and leaf water content could help in maintaining photosynthetic ability in late growing periods under deficit irrigation (Maria et al., 2005; Surahmanyam et al., 2006; Zhang et al., 2006; Li et al., 2008b; Schahram et al., 2008). Furthermore, more dry matter partitioning to reproductive organs is observed in LMF and WAP treatments. It is reported that WAP could help in yield producing when water supply is optimal or water stress is light, while no benefit for yield producing when water stress is severe (Yu et al., 2006; Zhang et al., 2007; Rieger et al., 2008). Thus, LMF might be favorable for yield when grown under lower soil moisture conditions, while the application of WAP might not help in yield producing in field both in high or low soil moisture conditions. Thus, a reasonable irrigation quantity may need when applying WAP, while LMF could be used in any meteorological and/or soil water conditions. Further research of LMF when applied on crops at different soil moisture levels should be done.

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