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Effects of mulching and nitrogen on soil temperature, water content, nitrate-N content and maize yield in the Loess Plateau of China

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ABSTRACT

In the semi-arid region of the Loess Plateau in China, the use of alternative field management practices is essential for sustainable agriculture. The purpose of this study was to investigate the effect of mulching and fertilization on the soil temperature, soil water content, soil nitrate-N content and grain yield of maize. The experiment was conducted over three consecutive years and used randomly assigned field plots with five replicates. The six treatments consisted of no fertilizer without plastic film (CK), no fertilizer with plastic film (ZM), basal fertilizer without plastic film (BN), basal fertilizer with plastic film (BM), basal and top dressing without plastic film (BTN) and basal and top dressing with plastic film (BTM). The soil temperature of the 10-cm mulching treatment was significantly higher than that of the no-mulching treatment, and the average soil temperature of the mulching treatment increased by 2.3 °C before July and nearly 1.2 °C after July. The soil water content in the mulching treatment was significantly higher than that in the no-mulching treatment at 0–60 cm, which was not significantly different from the 140–200 cm depth. The trend in the soil nitrate-N content distribution revealed symmetrical shapes along the center of the furrows, and the standard symmetrical distribution reduced gradually with an increase in soil depth under the plastic film mulching conditions. The soil nitrate-N content under basal fertilizer was 1.65 times higher than that without fertilizer at 0–10 cm at 36 days after sowing. The soil nitrate-N content in the topsoil was reduced from 48.67 to 30.77 mg/kg after 58 days. We found that plastic film mulching with basal fertilizer increased maize yield by 10.61%, 9.48%, and 15.36%, and top dressing increased the yield by 16.61%, 20.94%, and 12.24% over the three consecutive years. A treatment involving plastic film mulching, basal fertilizer and top dressing is recommended. Further studies are required to investigate the effect of mulching on increased soil temperature, soil water content and soil nitrate-N content, which simultaneously affect yield, and to determine the effects on the field microclimate.

1. Introduction

The success of agriculture in keeping pace with the population explosion has been depended on hybrid crops varieties, fertilization, irrigation and innovations in field management (Godfray et al., 2010). In particular, plastic film mulching has proven to be one of the most effective methods to increase water use efficiency and grain yield in dry farming agricultural areas (Fisher, 1995; Wang et al., 2009). The advantages of plastic film mulching have been reported since the middle of the last century, and the technique has reduced harvest time by up to nine days (Andrew et al., 1976) and has almost doubled grain yield (Hopen, 1964). Studies have indicated that mulching is conducive to crop growth by improving the soil water content and soil temperature in dryland agriculture (Cook et al., 2006). Mulching also has the benefit of improving soil physical conditions, including the protection of topsoil stability (De Silva and Cook, 2003). A higher soil temperature and better soil moisture increase seed fertility and individual plant yield under plastic film mulching (Zhou et al., 2009). Studies have demonstrated that the benefits of plastic mulching result from the adjustment of the soil environment caused by an increase in soil temperature and a reduction in evaporation, weed competition, soil compaction, and soil erosion. These changes in the soil environment are good for crop root growth, and the stronger ability of

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roots results in increased absorption of water and nutrients, which improves plant growth rates (Clark et al., 2003).

On the Loess Plateau, the field management practice of plastic film mulching has been extensively applied to crop production (Wang et al., 2009; Zhang et al., 2011). Maize yield has been increased by plastic film mulching for two major reasons. First, plastic film mulching reduces soil evaporation by intercepting the steam that is released when water moves from deeper soil layers to the topsoil by capillarity and maintains the stability of the topsoil water content, which increases crop transpiration. Second, plastic film mulching increases the soil temperature through the greenhouse effect, which absorbs solar radiation above the mulching and reduces heat loss, improving crop production.

Increased yield in response to plastic film mulching not only results in improved soil water content and increased soil temperature but also directly changes soil biological characteristics and fertility (Grassini et al., 2009; Liu et al., 2013). The soil nitrate-N content is an important indicator of soil fertility and productivity (Reeves, 1997). In the semi-arid region of Tunisia, nitrogen (N) fertilization was shown to increase durum wheat production under dry conditions with poor water supply (Barron et al., 2003; Latiri-Souki et al., 1998). However, grain yield may be reduced with the excessive application of N fertilizer. In addition, N fertilization should be modulated because excessive N fertilization can pose a danger to the environment and is wasteful in terms of economic efficiency (Morell et al., 2011). The variation in crop yield response to fertilizer application, which occurs because of unstable precipitation and differences in the fertilizer rate and disposal of crop residues, might result in loss of fertilizer under traditional farming systems (Wang et al., 2010). Thus, it is important to quantify the relationship between N fertilization and the vertical distribution of the soil nitrate-N content.

Previous studies have been conducted to quantify N removal and mulching in maize site-specific field experiments, mainly at research stations. Very few have attempted to investigate the relationships between N removal and mulching and soil water and nitrate-N contents across widely varying field environments, especially in high-yielding systems (Cai and Sharma, 2010; Knoth et al., 2013; Li et al., 2013; Miriti et al., 2012). This study evaluated the feasibility of using alternative field management practices to contribute towards food security and sustainable agriculture. Therefore, the aim of the study was to evaluate the effect of plastic film mulch on the vertical distribution of soil temperature, soil water contents, and soil-N content in a maize crop on the Loess Plateau of China.

2. Materials and methods

2.1. Experimental site

The field experiment was conducted at the Changwu Experimental Station (35°12′N, 107°40′E and altitude 1206 m) on the Loess Plateau in Changwu county of Shaanxi Province, China. The climate is temperate semi-arid with a mean annual air temperature of 9.1 ± 2.3 °C, a mean monthly maximum temperature of 22 °C (July) and a mean monthly minimum temperature of −7 °C (January). The average annual sunshine duration is 2230 h with more than 171 frost-free days. The mean annual precipitation from 1990 to 2012 was 571 ± 74 mm, of which approximately 55% fell during the growing season between July and September. The rainfall during the experimental period was measured using an automatic weather station (Changwu experimental station meteorological observatory, WS-STD1, England) at the experimental site. According to the USDA textural classification system, the soil has a silty loam texture, which is derived from loess with a deep and even soil profile. Soil sample was dried at room temperature (75 °C) in the laboratory to a constant weight and sieved (2 mm) to eliminate coarse soil particles. Soil acidity (pH) was measured in an aqueous soil extract in de-ionized water (1:2.5 soil:water). Bulk density was measured by the core method, using cores that measured 3 cm in diameter, 10 cm in length, and 70.68 cm^3 in volume. Field capacity at 33 kPa was determined using a pressure-membrane extraction apparatus. Soil organic matter was determined using the Walkley–Black method (Antonio et al., 2010). The topsoil (0–80 cm) is 35% clay, 62% silt, and 3% sand with a pH of 8.3, and has a bulk density of 1.28 g/cm^3, a field capacity of 24.5% cm^3/cm^3, an organic matter content of 11.8 g/kg, a total nitrogen content of 0.81 g/kg, an available phosphorus content of 14.2 g/kg, an available potassium content of 145.8 g/kg and an inorganic nitrogen content of 4.12 g/kg.

2.2. Experimental design

In this experiment, six treatments were designed and applied: (1) a flat plot (8 × 4 m) with no basal fertilizer, no top dressing and no mulching (CK); (2) plastic film mulching with no basal fertilizer and no top dressing (ZM); (3) basal N (80 kg/ha) and P (80 kg/ha) (Murungu et al., 2011) with no top dressing and no mulching (BN); (4) plastic film mulching and basal N (80 kg/ha) and P (80 kg/ha) with no top dressing (BM); (5) basal N (80 kg/ha) and P (80 kg/ha) and top dressing N (80 kg/ha) with no mulching (BTN); and (6) plastic film mulching with basal N (80 kg/ha) and P (80 kg/ha) fertilizer and top dressing N (80 kg/ha) (BTM).

The experiment was laid out using a randomized block design with five replications; each plot was 8 m long and 4 m wide. The entire experimental area was ploughed and leveled each year during the three-year period over which the experiment was conducted. Following dividing and ridging of 30 experimental plots, basal fertilizers (80 kg N/ha and 80 kg P/ha) were mixed in the soil for the BN, BM, BTN, and BTM treatments. Maize was planted at a 30- cm row and 60-cm line spacing, and a sketch showing the width direction arrangement is presented in Fig. 1. Mulching was laid over the soil surface layer of the ridges, 80 cm wide and 0.008 mm thick (Yonggu suye Co., Ltd., Shaanxi, China).

The maize breed (*Zea mays* L., cv. 'Liyu 18') was sown on 22 April 2010, 26 April 2011, and 21 April 2012, using a hole-sowing tool (3-cm diameter). Top dressing N (80 kg ha^{-1}) fertilizer was applied in late June (BTN, BTM). The maize crop was harvested on 17 September 2010, 21 September 2011, and 18 September 2012. After harvest, the plastic film was gathered and recycled by the manufacturer. Traditional tillage in dry farming areas of northern China involves mouldboard ploughing (motorized) to a depth of 16–18 cm, followed by a sequence of harrowing, smoothing, rolling, and hoeing.

2.3. Sampling and measurements

Soil temperature measurements (*N* = 3 repeated three times per treatment)

- A batch of rectangular geothermometers (Jingda Thermal Instruments, Wuqiang County, Hebei Province, China) was placed in the middle of a ridge and furrow in every treatment plot at depths of 0, 5, 10, and 20 cm.
- On bright sunny days, the soil temperature (Dwyer et al., 1990) was recorded hourly from 08:00 to 20:00, i.e., on 26 June 2010 (65 days after sowing), 29 June 2011 (64 days after sowing), and 22 June 2012 (62 days after sowing).
- For three consecutive field seasons, the soil temperature was recoded at nearly 15-day intervals from sowing to harvesting.

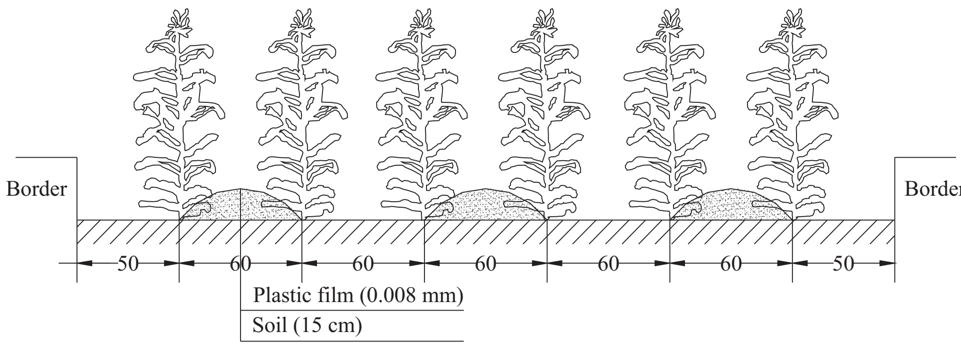

Fig. 1. A sketch of the experimental arrangement system (cm).

- The mean soil temperature was calculated as the mean of the mulching and no mulching temperatures, using the average value at 8:00, 14:00, and 20:00 on the detection day.

During the growing season, the soil water content ($N = 3$) was measured using a the gravimetric method, and the depth interval spacing was 10 cm (from 0 to 100 cm) and 20 cm (from 100 to 200 cm). The soil water content was measured in the middle of the furrows, and the distance from a plant was 10 cm. The measurements were performed for nearly one month within the entire growth period. The soil nitrate-N content ($N = 3$) was measured using a spectrophotometer (UV–vis 8500II, China), with sampling a depth interval of 10 cm, down to 100 cm. First, 0.5 g of fresh soil was placed in a 100-mL triangular flask. Then, 50 mL of a 2-mol/L potassium chloride solution was added. The solution was shaken for half an hour until uniformity was reached. The solution was filtered, and 5 mL was placed in a spectrophotometer and examined at a wavelength of 210 nm (Griffin et al., 2009). The nitrate content was determined using colorimetric analysis. The soil water content measurements were performed at the same time as the measurements of the soil nitrate-N content.

2.4. Statistical analysis

Analysis of variance was conducted on the soil temperature, soil water content, soil nitrate-N content and grain yield using SAS 9.2 (SAS Institute Ltd., North Carolina, USA). Duncan's multiple range test was used for paired mean comparisons at a 0.05 probability level (McCullough and Wilson, 2002).

3. Results

3.1. Weather conditions

The total rainfall during the growing season was 339 mm in 2010, 346 mm in 2011, and 351 mm in 2012 (Fig. 2), and this accounted for 61.2%, 66.1%, and 73.2% of the annual rainfall, respectively. There was less rainfall in August over the three consecutive years. The amounts of rainfall varied from season to season, and there was a larger proportion of rainfall in June and September in 2010 and 2011 compared with the other months of the growing season, and there was considerably higher rainfall in July 2012 than in June–September.

During the maize growing season, the average daily temperature generally ranged from 15 to 25 °C, and the highest daily temperature in 2010, 2011, and 2012 was 27 °C (Fig. 2). The mean daily air temperature was higher than 15 °C for 128 days in 2010, 125 days in 2011, and 116 days in 2012, accounting for 86.5%, 84.5%, and 77.3% of the whole maize growth period. The differences in rainfall and air temperature in the maize growing season might affect maize growth, soil temperature, soil water content, and grain yield.

3.2. Soil temperature

The soil temperature exhibited temporal and spatial variations (Fig. 3). The soil temperature at 10 cm in the plastic film mulching treatments was significantly higher than that without mulching. The average temperatures from 8:00 to 20:00 without mulching were 2.08 °C, 2.60 °C, and 2.00 °C lower than those measured in the corresponding mulching treatments in 2010, 2011, and 2012, respectively. The average soil temperature of the plastic film mulching treatment at 0 cm, 5 cm, 10 cm, and 20 cm were 1.12 °C, 0.87 °C, 2.08 °C, and 1.6 °C higher, respectively, than the no-mulching treatments in 2010; similar results were observed in 2011 and 2012. The daily surface layer temperature decreased after 14:00 and was slower in declining in the film mulching treatment compared with the no-mulching treatment. Three years of continuous field experiments indicated that the maximum soil temperature occurred around midday and in the topsoil; and the peak time occurred later with increased soil depth. In particular, the amplitude of the diurnal variation decreased with depth, and peak soil temperatures were not obvious at 20 cm. The variation in soil temperature from 8:00 to 20:00 was similar to a sine curve (Fig. 3). The chord height of the sine curve decreased with soil depth, and the variation of soil temperature at 20 cm was nearly a gentle smooth line, which may indicate that the soil temperature response to surface solar radiation energy was delayed. The results indicate that mulching delayed the temperature reduction. There was no significant treatment difference in soil temperature at 20:00, but the soil temperature in the plastic film mulching treatment was slightly higher than that without mulching. The results indicate that plastic film mulching preserves heat, which leads to a slowing of temperature transmission from belowground into the atmosphere.

The soil temperatures under plastic film mulching were higher than those without mulching over the three growing seasons (Fig. 4). The highest soil temperature was measured in July across all treatments, and the variation in soil temperature followed a quadratic parabola-like curve over the growth period. The plastic film mulching effect on the soil temperature in the earlier period was greater than that in the later period, and the effect decreased over growth time. The soil temperature of the plastic film mulching treatment increased approximately 2.3 °C before July, which is better for germination and growth, compared to the treatment without mulching. However, the soil temperature decreased from July to September, and the plastic film mulching treatment increased the soil temperature by nearly 1.2 °C during this period.

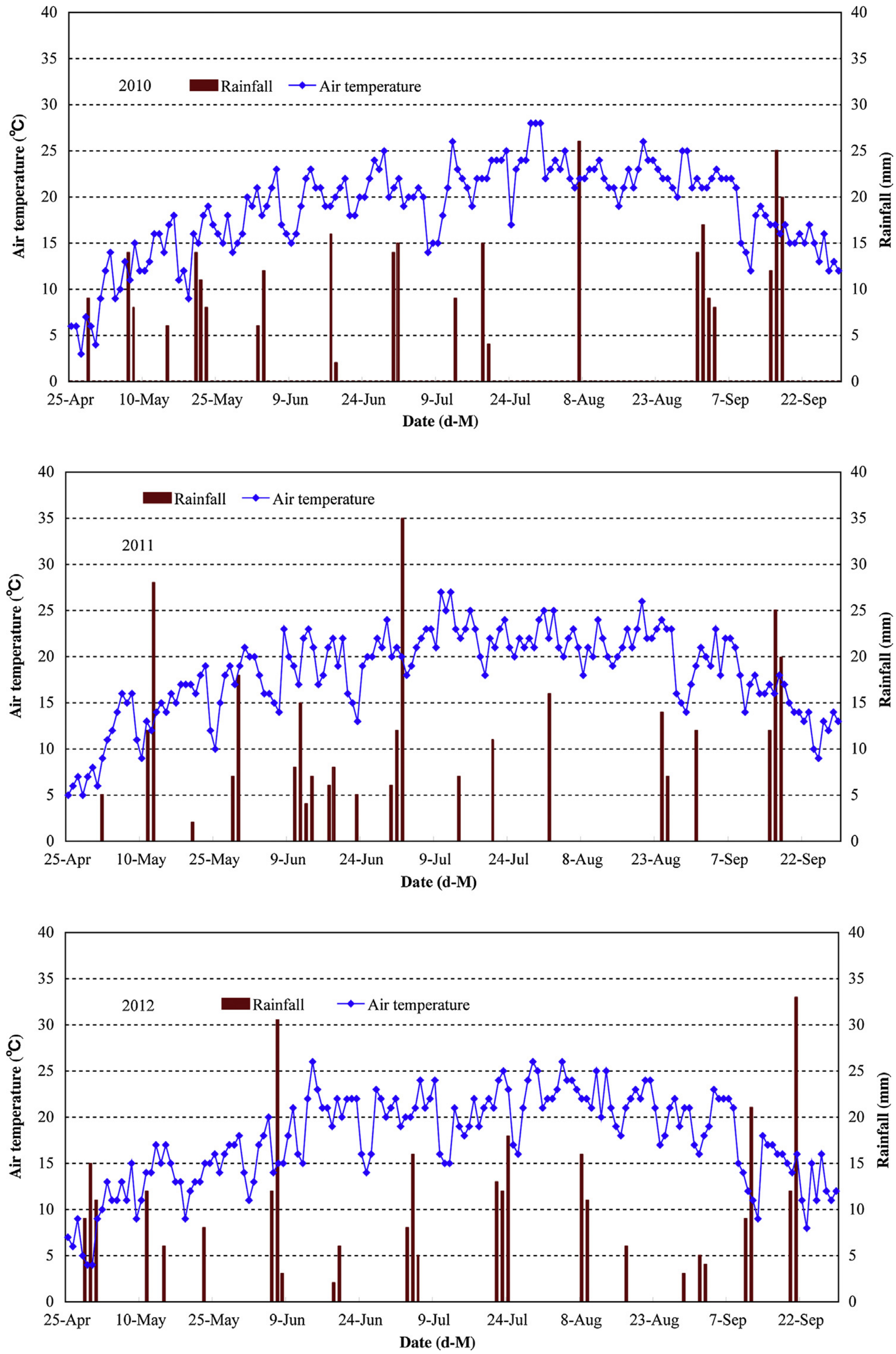

Fig. 2. In maize growing season, the distribution of air temperature and rainfall were recorded in the study years.

3.3. *Soil water content*

We focused on three successive years to visualize the annual differences in soil water content caused by plastic film mulching and fertilization, as shown in Fig. 5. The BM and BTM treatments had the highest average soil water content at 0–80 cm at 36, 39, and 31 days after sowing in 2010, 2011, and 2012, respectively. The average soil water content (0–200 cm) in the CK treatment was 0.42%, 2.23%, and 4.45% lower than that in the ZM, BM, and BTM treatments, respectively, approximately one month after sowing for the three consecutive years. However, there was no significant treatment difference in the average soil water content at 140–200 cm (*F*-test, $P > 0.05$). Three months after sowing, the average soil water content (0–200 cm) in the CK treatment was lower than that measured in the plastic film mulching treatments, i.e., 3.33%, 4.75%, and 4.61% lower than the ZM, BM, and BTM treatments, respectively, in 2010. Unexpectedly, the average soil water content in the CK treatment was higher than in the ZM treatment from 0 to 80 cm, and this phenomenon changed from a depth of 80 cm. The soil water content ranged from 15% to 20% one month after maize sowing, whereas

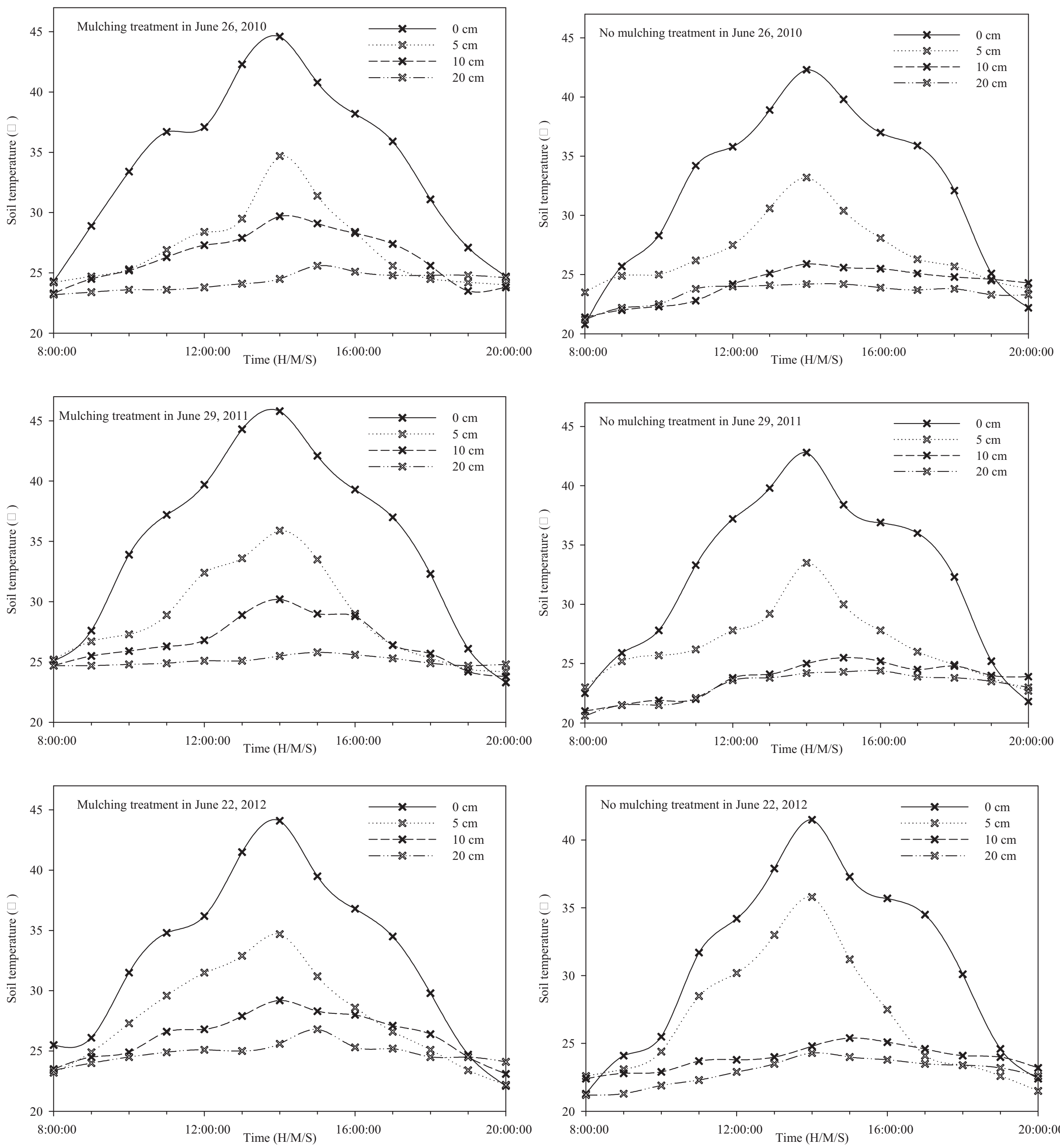

Fig. 3. The average soil temperature with mulch and no mulch at different times and soil depths in the study years.

the values increased over the three month period after sowing and increased by 17% to 23% over the three-year study period. These results can be explained by the fact that the rainfall was mainly distributed in the summer months.

The average soil water contents were significantly higher in the mulch than in the no-mulch treatments. There was no significant difference between the same fertilizer treatments. The linear relationships between the soil water content and soil depth and the plastic film mulching, basal fertilizer and top dressing in the maize growing season over the three years are shown in Table 1.

3.4. Soil nitrate-N content

The dynamics of the soil nitrate-N content in the root region soil of the no-fertilizer treatment with plastic film mulching in 2010 are shown in Fig. 6. There was a large horizontal difference in the soil nitrate-N content in the top layers (0–60 cm) at 36 days after sowing. The trend in the soil nitrate-N content distribution exhibited symmetrical shapes along the center of the furrow. The standard symmetrical distribution reduced gradually with the soil depth, but persisted under the plastic film mulching conditions. The nitrate-N concentration in the root absorption area was lower than

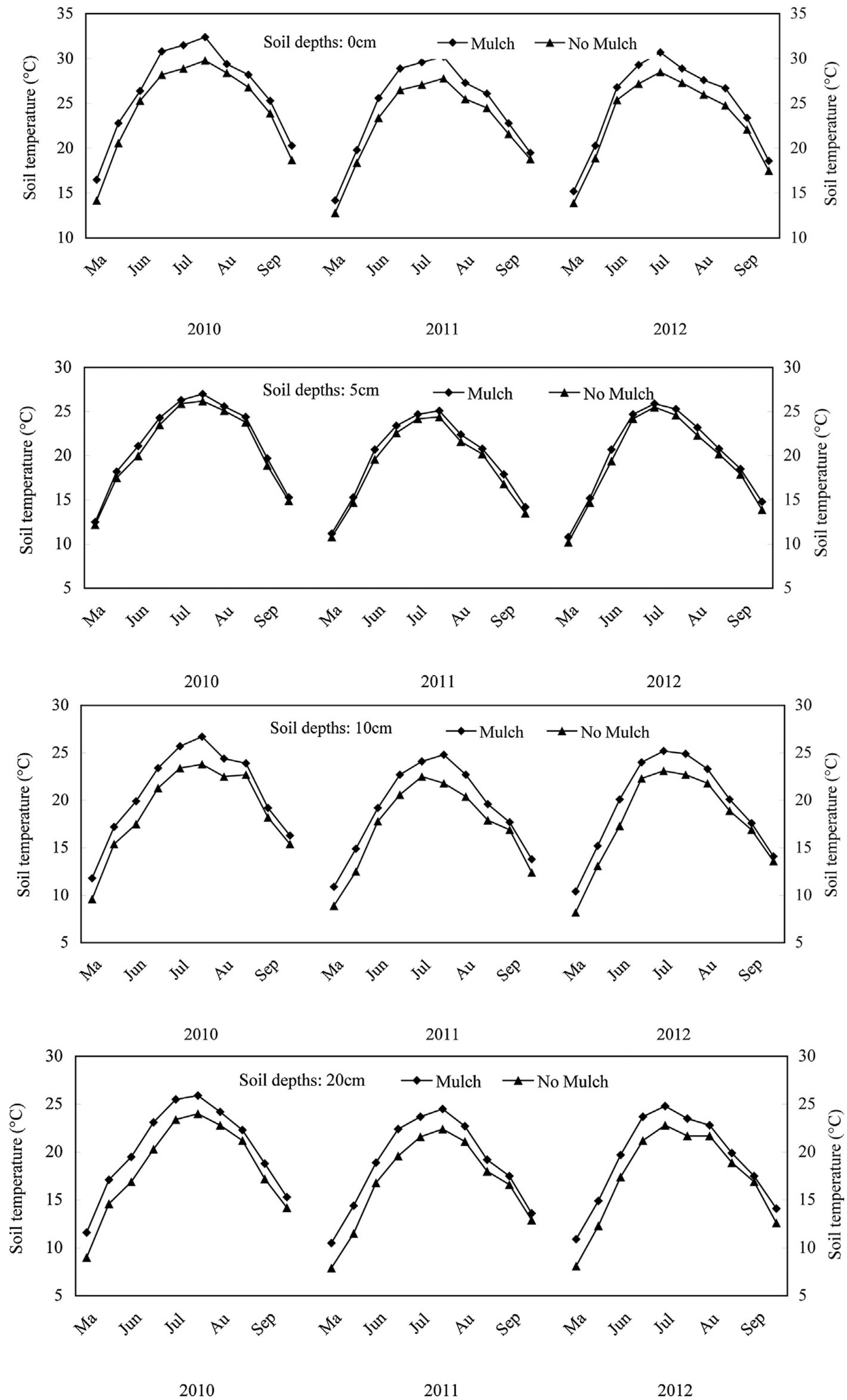

Fig. 4. Soil temperature effect on mulch and no mulch during the growing season in the study years.

in the other areas. The results indicate that high levels of nitrate-N were mainly distributed at 0–10 cm at 36 days after sowing, and the nitrate-N concentration in the basal dressing treatment was 1.65 times higher than in the treatment that did not receive fertilizer (Fig. 6(a)). The nitrate-N in the root zone was reduced in the soils of the basal and top dressing treatments with the plastic film mulching. There was no significant difference in the soil nitrate-N content below 50 cm, and the symmetrical distribution was the same as that observed in the ZM treatment in the top layers (0–40 cm). The soil nitrate-N content in the topsoil was reduced to 30.77 from 48.67 mg/kg at 58 days after sowing. There was a statistically significant difference in soil nitrate-N content under the ridge, and a small area of soil nitrate-N appeared at 40 cm.

The soil nitrate-N content in the subsoil (60–100 cm) increased at 58 days after sowing compared with 36 days after sowing (basal fertilizer treatment). These results were related to nitrogen migration and root absorption. In particular, there was a nitrate-N accumulation area at 50 cm. The soil nitrate-N content had

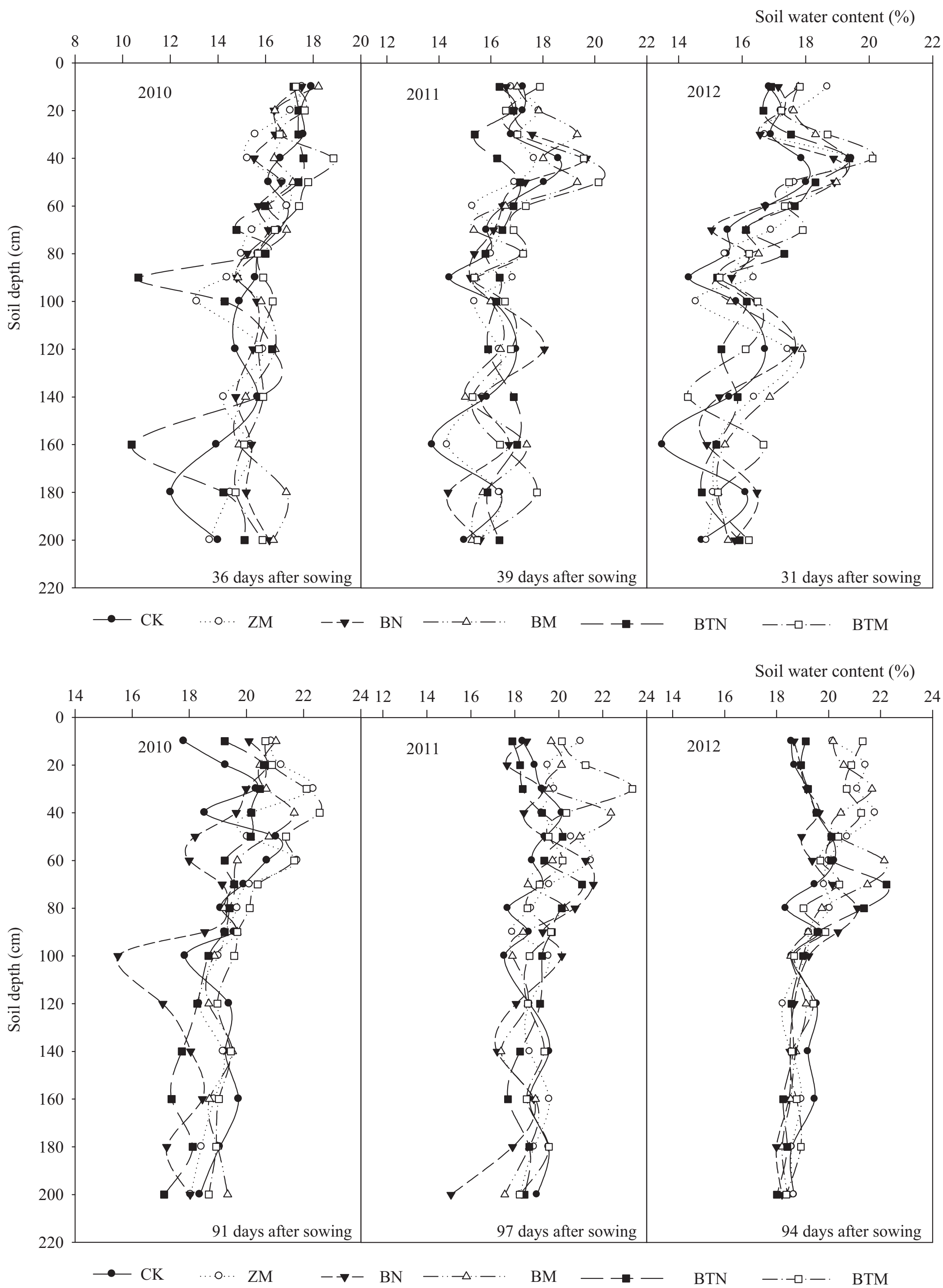

Fig. 5. Soil water content effect on six treatments during the growing season in the study years.

gradually reduced by 91 days after sowing. However, the vertical distribution of the soil nitrate-N content was not statistically significant during the harvest. The soil nitrate-N content decreased significantly in the top layers (0–40 cm) at 58 days after sowing (Fig. 6(b)). The rate of the nitrate-N content decline in the middle of the ridges was slower than in the furrows. A higher concentration area existed at a 40-cm depth, and the nitrate-N content had a horizontal and parallel distribution below 60 cm. The results indicate that the important drivers for soil mineral nitrogen migration are leaching and surface runoff. There were no significant differences in the soil nitrate-N content at 91 days after sowing (Fig. 6(c)). and there was almost the same nitrate-N content as the horizontal soil profile at 138 days after sowing.

The topsoil nitrate-N content increased to approximately 60 mg/kg at 91 days after sowing compared with 58 days after sowing (BTM). In addition, top dressing greatly increased the soil nitrate-N content in the upper layer of soil (0–40 cm), and the soil nitrate-N content decreased with increasing soil depth. The soil

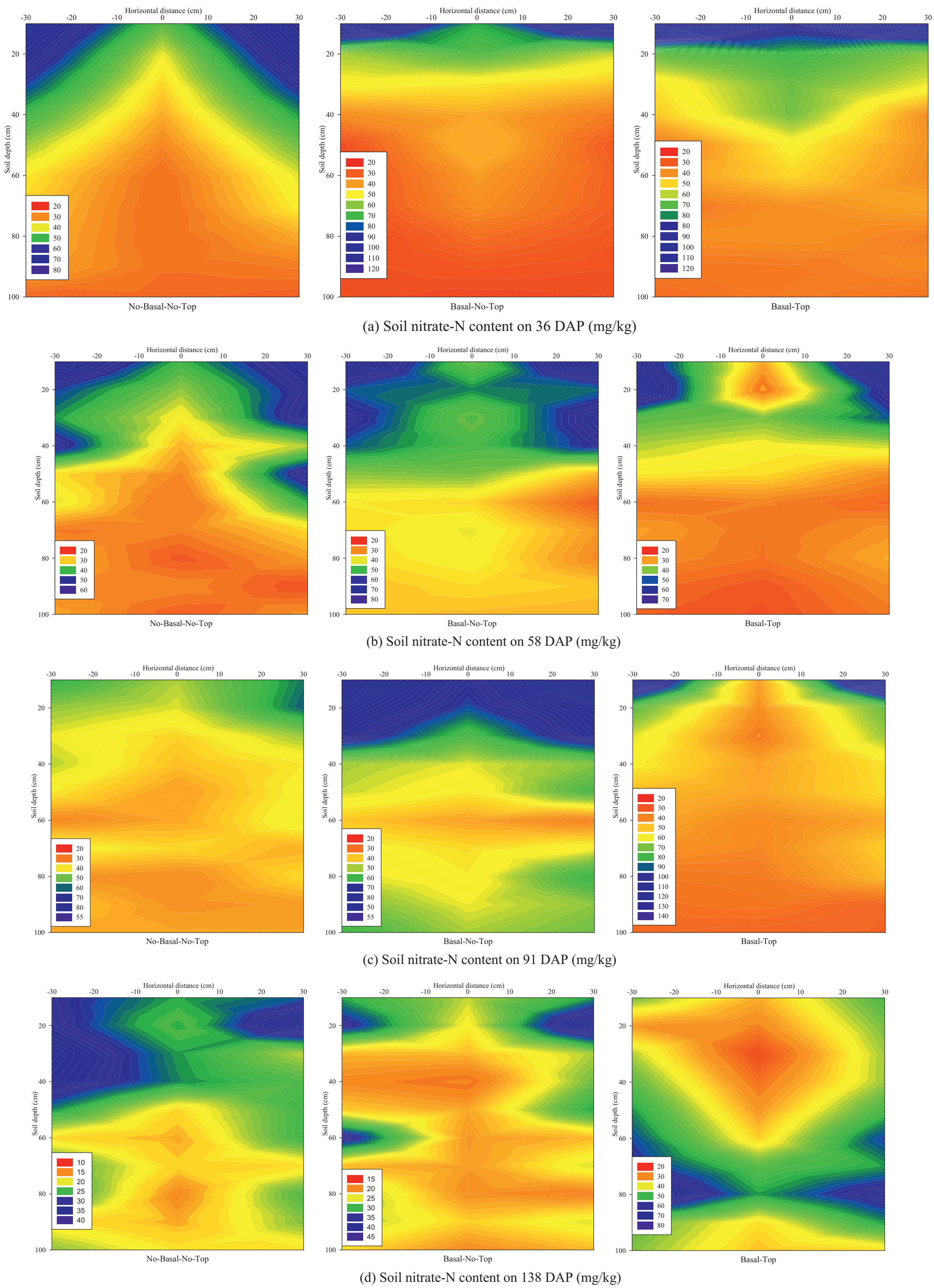

Fig. 6. Dynamics of nitrate-N content in root zone soil of different treatments in 2010, no Basal and no Top dressing fertilizer (No-Basal- No-Top), Basal fertilizer and no Top dressing fertilizer (Basal-No-Top), Basal and Top dressing (Basal-Top).

Table 1
Linear models for predicting soil water content (y) with soil depth (x) in mulch and fertilizer treatment in the study years.

Treatment		CK (%)	ZM (%)	BN (%)	BM (%)	BTN (%)	BTM (%)	Mulch (%)	No Mulch (%)
2010	y	$-0.0027x+19.575$	$-0.0165x+19.082$	$-0.0105x+18.106$	$-0.0092x+18.849$	$-0.0193x+18.927$	$-0.0160x+19.814$	$-0.0145x+18.598$	$-0.0139x+19.248$
	R^2	0.0285	0.6981	0.4713	0.472	0.5702	0.7005	0.7611	0.7874
2011	y	$-0.0067x+18.193$	$-0.0100x+18.756$	$-0.0122x+18.797$	$-0.0147x+19.337$	$-0.0016x+17.849$	$-0.0127x+19.514$	$-0.0068x+18.279$	$-0.0125x+19.202$
	R^2	0.2223	0.7608	0.462	0.457	0.0331	0.5135	0.4647	0.6135
2012	y	$-0.0080x+18.364$	$-0.0169x+19.736$	$-0.0085x+18.640$	$-0.0165x+19.864$	$-0.0122x+19.081$	$-0.0158x+19.735$	$-0.0096x+18.695$	$-0.0164x+19.778$
	R^2	0.3925	0.7411	0.4694	0.6763	0.5003	0.645	0.5855	0.7534

nitrate-N content ranged from 40 mg/kg to 60 mg/kg because the nitrogen fertilizer was converted into mineral nitrogen as a result of the high temperatures during this time. The soil nitrate-N was concentrated at 80 cm at harvest time, and there was no difference along the entire soil profile (Fig. 6(d)).

3.5. Maize grain yield

The grain yield varied considerably between the different plastic film mulching and fertilization treatments (Table 2). Higher grain yield was observed in the no-plastic film mulching treatment compared with the mulching treatment without basal fertilizer or top dressing. When there was no basal fertilizer or top dressing, there were no significant differences in maize grain yield between the mulching and no-mulching treatments, but mulching had a negative effect on yield compared with the CK treatment. However, there was a significant difference for the plastic film mulching treatment with basal fertilizer or top dressing, and plastic film mulching had a positive effect on grain yield. The yield increased with an increase in the basal fertilizer, top dressing and plastic film mulching, and the grain yield increase ranged from 23.41% to 83.23% compared with the CK treatment.

4. Discussion

The maize grain yield increased in response to plastic film mulching and the addition of basal fertilizer and top dressing. The plastic film directly increased the soil water content and soil temperature and changed the soil nitrate-N content and dynamic migration.

4.1. Soil temperature

The soil temperature differences between the film mulching treatments and those without mulch gradually increased with an increase in the soil depth, except for the 5-cm depth, over the three years of field experiments. These results are the same as those presented by Davidoff et al. (1986), who observed significant differences in the temperature measurements at the 10-cm soil depth. Comparative studies of these relationships have produced inconsistent results. For example, Bocock et al. (2006) have showed that the mean temperatures at a 5-cm soil depth were significantly different in the ridges compared with the adjacent flat areas. We propose that the effects of the plastic film mulching on soil temperature at 5 cm was related to the plastic film absorbing and reflecting solar energy, but this requires further study.

The soil temperature increased by approximately 2.3 °C and 2.1 °C with plastic mulching at depths of 10 cm and 20 cm, respectively, in the early growth period, and these values decreased to 1.2 °C in the later growth period. Ramakrishna et al. (2006) found that mulching increased soil temperature by approximately 6 °C at a depth of 5 cm and 4 °C at a depth of 10 cm. Our findings indicated that the midday soil temperature under plastic mulching was 3.6 °C higher than without mulching at a depth of 10 cm, and the difference between the presence and absence of mulch gradually decreased and was no longer significant at sunset. This finding agrees with the results of Liu et al. (2009), who found that plastic film mulching applied 30 days before sowing significantly increased the soil temperature (10 cm) and improved the soil water content during the early growth stage compared with conventional tillage. This result will help farmers to accurately determine the maize planting depth in agriculture practice.

The variation in soil temperature followed a quadratic parabola-like over the growth period. The results indicated that lower soil temperatures occurred before mid-May and after September, mainly because of the meteorological environment. The results

Table 2
Effect of basal fertilizer, top dressing and mulching on maize grain yield in the study years.

Treatment	2010			2011			2012		
	Maize yield (kg ha-1)	Increasing (%)	Mulch effect (%)	Maize yield (kg ha-1)	Increasing (%)	Mulch effect (%)	Maize yield (kg ha-1)	Increasing (%)	Mulch effect (%)
CK	3795.7d (245.8)		−10.23	3627.1d (263.1)		−8.17	3711.4e (301.3)		−9.55
ZM	3407.2d (194.8)	−10.23		3330.7d (224.7)	−8.17		3356.8e (232.2)	−9.55	
BN	4880.9c (288.5)	28.59	10.61	4858.6c (275.3)	33.95	9.48	4580.4d (230.3)	23.41	15.36
BM	5398.8b (277.2)	42.24		5319.3b (169.4)	46.66		5284.0c (339.9)	42.37	
BTN	5587.3b (232.7)	47.2	16.61	5495.4b (193.7)	51.51	20.94	5778.5b (369.5)	55.7	12.24
BTM	6515.5a (451.7)	71.66		6645.9a (347.7)	83.23		6485.7a (255.4)	74.75	

Significant at $P < 0.05$.

may be related to the weather conditions, e.g., the average daily temperature generally ranged from 15 to 25 °C, and the highest daily temperature recorded in maize growing season was 27 °C. This result may provide a reference value for maize seeding time in agricultural practice.

4.2. Soil water content

In the present study, the average soil water content of the CK treatment over the three years was lower than that measured in the ZM, BM, and BTM treatments approximately one month after sowing, and there was no significant treatment difference in the mean soil water content at 140–200 cm. The weather conditions may have reduced the soil water content before June, and low rainfall in the growing season did not improve the soil water content. There was a negative linear relationship between soil water content and depth, and mulching, basal fertilizer and top dressing over the three years. The BTM and BTN treatments provide a good example. After three growing seasons, the soil water content with mulching was significantly higher in the 0–60 cm soil layer in the ZM treatment and the 0–80 cm soil layer in the BM and BTM treatments compared with no mulching. These results indicate that the correlation coefficient of the distribution of the average soil water content without mulching was higher than that with the plastic film mulching treatment. We may conclude that plastic film mulching adjusts the regulation of the vertical distribution of the soil water. In addition, the soil water content was significantly decreased in the 140–200 cm soil layer in the mulching treatment compared with the treatment without mulching (with the same fertilizer) in June, and there was no significant difference in September. These results are compatible to those of previous studies. A higher soil water content was observed in the surface layer in the mulching treatment, which was probably due to lower surface run-off and evaporation because there was no change in surface soil porosity (Ssali et al., 2003; Jovanovic et al., 2013). The soil water content in the mulching treatment was higher than that of a bare plot at the time of seeding; after one month, however, these soil water contents were similar (Liu et al., 2010; Wang et al., 2009). Collectively, these results indicate that the soil water content in the mulching treatment was higher than in the no-mulching treatment at the time of seeding.

4.3. Soil nitrate-N content

High levels of nitrate-N were mainly distributed at 0–10 cm at 36 days after sowing, and the mean nitrate-N content in the basal dressing treatment was 1.65 times higher than that in the no-fertilizer treatment. There are two possible explanations for this difference; one reason is that the basal fertilizer was mainly in the surface layer due to low rainfall, and the other reason is that the soil organic matter content in the surface layer resuted from nitrate-N via digestive functions. Similar nitrogen application and nitrate-N content results were reported by Pandey et al. (2001).

Our study also found that the soil nitrate-N content in the topsoil was reduced at 58 days after sowing. This occurred because of the high maize growth during this period, when the plants required a greater amount of soil nutrients. In addition, the plastic film intercepted the rainfall, causing it to flow into the furrows, and this water infiltration resulted in the migration of nitrate-N from the topsoil to the subsoil. Moreno and Moreno (2008) discovered that the ability of the plastic mulch to improve the soil water content simultaneously improved the plant nitrogen availability. After sowing, the soil nitrate-N content continually decreased until 91 days (around shoot elongation), probably because there was no topdressing and soil fertility decreases with rainfall infiltration leaching. The soil nitrate-N content decreased slightly until the top dressing fertilizer was applied in late June. The topsoil (0–30 cm) nitrate-N during the sowing or top dressing period was consistently higher compared with the rest of the soil profile. Thorup-Kristensen (2001) showed that the amount of soil nitrate-N content in the topsoil (0–50 cm) was significantly different from that in the subsoil (50–100 cm), and the subsoil nitrate residues were well correlated with root intensity. We found that the nitrate-N concentration in the root absorption area was lower than in the other areas.

4.4. Maize grain yield

Other studies found that film mulching in field experiments increased the maize grain yield by approximately 20–30% in very wet years, 60–95% in average and drought years (Li et al., 2013; Zhou et al., 2009). Additional mulch in furrows increased the maize grain yield by 8–25% in the semi-arid Loess region of northwestern China (Li et al., 2001). Our findings indicated that the soil temperature was lower in the CK treatment than the ZM treatment, but had no negative impact on the soil water content or maize yield. Therefore, the hypothesis that plastic film mulching increases grain yield was accepted when basal fertilizer or top dressing were added but was rejected when basal or top dressing were not added.

In this experiment conducted over three consecutive years, relatively higher grain yield was obtained in the BTM treatment in 2011, which can probably be attributed to the well- distributed and average rainfall described above. Another possible reason is the BTM experimental plot had residual fertilizer from basal and top dressing fertilizer treatments in 2010. Nutrient management should consider these types of variable conditions. In rainfed areas, the utilization of water and other resources was better under mulching conditions, and the maize grain yield of the plastic film mulching and maize straw mulching treatments was 8–24% and 13–24% higher, respectively, than that of the CK treatment (Liu et al., 2010; Zhang et al., 2011).

In a separate study, lower grain yield responses to nitrogen fertilizer in the third year probably occurred because the repeated application of nitrogen fertilizer to a sandy soil led to soil acidification (Gandah et al., 2003). This may relate to the fertilizer application rate, as a previous study demonstrated that a surplus of 115–121 kg/ha occurred at a nitrogen fertilizer level of 270 kg/ha (Zavattaro et al., 2012). Other studies have also reported that a surplus of 60 kg/ha of nitrogen occurred at a nitrogen supply of 213 kg/ha (Maltas et al., 2007; Wang et al., 2013). In our study, the maize grain yield at a fertilizer rate of 160 kg N/ha (basal, 80 kg N/ha and top dressing, 80 kg N/ha, which is recommended for the Loess Plateau of China) was significantly higher than that measured at other levels of N. Further studies may be required to investigate the effects of mulching on increased soil temperature, soil water content and soil nitrate-N content, which simultaneously affect maize yield, and to determine the effects on the field microclimate.

5. Conclusions

In the topsoil layer, the soil water content in the mulching treatment was significantly higher than in the treatment without mulching. A high soil nitrate-N content was mainly distributed in the topsoil layer at 36 days after sowing, and the treatment with top dressing fertilizer had a higher soil nitrate-N content compared with the treatment where top dressing was not applied. The grain yield increased between 23.41% and 83.23% with basal fertilizer, top dressing and plastic film mulching. The use of plastic film mulching has shown promising results. Compared with the no-mulching treatment, these practices have been shown to increase soil temperature and improve maize yield. Regardless of the research achievements and promotional activities of field management, traditional cultivation without mulching remains common practice, and considerable efforts will have to be made to achieve widespread application of plastic film mulching. The BTM treatment is recommended because it increased the grain yield by 71.66%, 83.23%, and 74.75% in 2010, 2011, and 2012, respectively, compared with the CK (no mulching and no fertilizer) treatment.

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