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RESEARCH ARTICLE

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Effects of plastic-film mulching and nitrogen application on forage-oriented maize in the agriculture-animal husbandry ecotone in North China

Abstract To counter the actual problems of forage shortage and low quality existing in the agriculture–animal husbandry ecotone in North China, a research was conducted to study the effects of plastic-film mulching and nitrogen application on the production of forage-oriented maize with the aim of producing water-saving forage with high-yield and good quality. Field experiments combined with laboratory experimental estimation and analysis was adopted. Plastic-film mulching increased the dry biomass of forage-oriented maize by 23.8% with effectively improving the maize's nitrogen absorption so that the apparent utilization ratio and output-input ratio of nitrogen were enhanced. The content of crude protein in maize plant was increased and thus, forage nutritive quality was improved. Plastic-film mulching remodeled the maize field water consumption scheduling pattern and increased the water use efficiency by over 10%. Nitrogen application to forage-oriented maize co-improved the biomass and the nutritive quality with the nutritive matter (percentage and yield) several times of the biomass. Nitrogen application increased maize biomass production by 36.1%–39.5% and it increased the contents of crude protein and crude fat in maize plant by 109% and 145%, respectively. The yields of the two nutritive matters increased by 160% and 210%. Nitrogen application at the rate of about 200 kg·hm^{-2} to the uncovered field and the rate less than 300 kg·hm^{-2} to the field with film mulching were considered as the most proper rates to guarantee high yield and good quality of forage-oriented maize and were the rates to keep the available nitrogen balanced in the soil. Plastic-film mulching and nitrogen fertilizer application to forage-oriented maize was an effective way of producing forage with high yield and good quality, relieving the shortage of animal forage and accelerating ecological recovery and economic development in this ecotone in North China.

Keywords agriculture-animal husbandry ecotone of North China, forage-oriented maize, plastic-film mulching, nitrogen application

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1 Introduction

High elevation and a cold-arid climate are specific restrictive factors for vegetation and habitat succession in the agriculture-animal husbandry ecotone of North China. In the area, water resource circulates within a closed-landlocked system due to its high altitude. Agriculture production is rain-fed. The output of grassland and farmland was low and unstable (Zhang, 2001), the sustainable and coordinated development of the farming and animal husbandry was restricted by the severe ongoing forage shortage. Therefore, efficient forage production with high yield and good quality focused on water-saving is of great importance. In recent years, foreign researchers concentrated their works primarily on the breeding of forage-oriented maize varieties with the features of high yield and low cellulose content in forage (Šimić et al., 2003; Xe et al., 2003; Lübberstedt et al., 1998; Argillier et al., 2000). Research in China concentrated on its physiological characteristics (Zhang et al., 2004b; Ma et al., 2005; Liu et al., 2004), elite variety introduction (Zhang et al., 2002) and varieties comparison (Zhang et al., 2004a; Zhang et al., 2003a; Zhang et al., 2001). In the study on improving the production performance by cultivation measures, Zhang et al. (2005,

2002) and Wang et al. (2005a) studied the effects of nitrogen, density and clipping stage on yield and quality of forage-oriented maize in a farming area in North China. Lu et al. (2006) and Gao et al. (2006) studied the growth and development rhythm and the absorption patterns of nitrogen, phosphorus and potassium by different types of forage-oriented maize in dry-land farming area in Northwest China. But in the cold and arid agriculture-animal husbandry ecotone of North China, only Zhang et al. (2004b) studied the double-ear formation mechanism of forage maize. In this area, there remains a blank spot in the study to increase the biomass yield and improve feeding nutritive quality of the maize by cultivation and management measures. In this trial, we studied the effects of plastic-film mulching and nitrogen application on forage-oriented maize growth to increase its biomass yield and improve feeding quality by weakening the restriction of low temperature and drought in early growth stage. The objective of the study was to search for an effective way to produce water-saving and high-yielding forage with good quality, ease the forage shortage and promote ecological recovery and economic development in the agriculture-animal husbandry ecotone in North China.

2 Materials and methods

2.1 Background of the trial

The field experiment was conducted from May to September in 2004 at the No. 2 trial site of Zhangbei experimental station (National dry-land farming experimental project of China), Zhangbei county (41°10.22′ N, 114°51.39′ E) at 1416 m above sea level, in Hebei Province, China. The ecological conditions of the station represent those of the the agriculture-animal husbandry ecotone in North China. This area has a cold and dry climate with an annual average temperature of 2.6°C and an annual precipitation of 400 mm. The non-frost period averaged 103 days. The tested soil was meadow chestnut soil and its physical and chemical characteristics are given in Table 1.

2.2 Experimental design

The forage-oriented maize variety used in the experiment was White Dent, a late-maturing cultivar, seeded on May 18 and harvested on September 9. The design included two main treatments, they were plastic-film mulching and non-mulching with interval arrangement. The non-mulching was used as control and the effects of plastic-film mulching and nitrogen application on forage maize production performance, the fertilizer and water utilization were determined. The main treatments included four nitrogen (urea) application rates based on phosphorus (superphosphate) application at 150 kg·hm^{-2} P_2O_5. The nitrogen application rates were 0, 100, 200, and 300 kg·hm^{-2}, denoted by N0, N100, N200, N300, respectively. Each nitrogen treatment in each main treatment was randomly arranged with three replications with a plot size of 16 m^2 (4 m × 4 m) and totaled 24 plots. The two fertilizers were used as single basal dressing. The forage maize was planted at a plant density of 100000 plant·hm^{-2}. The forage-oriented maize was rain-fed without irrigation during the whole growth period.

2.3 Measurements and methods

The chemical analysis of soil and maize samples were done in the Crop Sample Test Lab in the Agricultural University of Hebei from November, 2004 to April, 2005.

2.3.1 Soil water determination

From May 18 to September 9, soil samples were collected in each growth stage within the depth of 0 cm to 80 cm from each plot and the soil moisture was measured with each 10-cm-soil as one sample by the dry oven method.

Soil moisture (mm) = soil layer thickness (cm) × bulk density (g·cm^{-3}) × 10 × water weight in the soil layer/dry soil weight.

The field water consumption of maize in the growth stage (mm) = the soil water content in the initial growth stage + precipitation − the soil water content in the final growth stage. The precipitation in the whole growth period was 334 mm.

2.3.2 Determination of available nitrogen in soil

Soil samples were collected from each plot before sowing and after harvesting of the forage maize. The available nitrogen content in each soil sample was determined by alkaline hydrolysis diffusion method (Shi, 1994).

2.3.3 Determination of the nutritive ingredient in maize plant

Forage-oriented maize samples were collected in each plot when harvesting, then dried, comminuted and analyzed

Table 1 The physical and chemical characteristics of the tested soil

soil type	depth of soil/cm	organic matter/g·kg^{-1}	total N/g·kg^{-1}	total P/g·kg^{-1}	available N/mg·kg^{-1}	available P/mg·kg^{-1}	< 0.01 mm clay/%	bulk density/g·cm^{-3}	pH
meadow chestnut soil	0–20	26.4	1.71	0.48	112.0	11.0	37.2	1.33	7.7

for the content of total N and crude protein (N × 6.25) by micro-kjeldahl method, crude fat content by residue weight method and crude fiber content by acid-base treatment method (Yang, 1993; He, 1985).

2.3.4 Determination of forage-oriented maize biomass

Forage-oriented maize samples were collected from each plot in each growth stage and then dried, weighted and the dry slice yielding ratio was calculated to get the forage production effect of each treatment. When harvesting, the fresh weight of forage maize in each plot was measured and samples from each plot were taken and dried and the dry slice yielding ratio was calculated and transformed into dry yield.

All the data in the paper were processed and analyzed with SAS 8.02 system. Calculation methods of nitrogen uptake and utilization efficiency are:

N dry matter production efficiency = Dry yield per hm^2/Total N accumulation per hm^2.

N apparent utilization ratio = (Total N accumulation with nitrogen application − Total N accumulation without nitrogen application)/nitrogen application dosage.

N physiological efficiency = (Dry yield with nitrogen application − Dry yield without nitrogen application)/(Total N accumulation with nitrogen application − Total N accumulation without nitrogen application).

3 Results and analysis

3.1 Effects of plastic-film mulching and nitrogen application on the biomass of forage-oriented maize

3.1.1 Effect of plastic-film mulching on the biomass of maize

Table 2 shows the biomass yield of the maize in each treatment. The data were analyzed by paired sample *t*-test. It indicated that there exists a significant difference in forage-oriented maize fresh biomass yield, dry slice yielding ratio and dry matter weight between plastic-film mulching and non-mulching. The average fresh biomass yield under plastic-film mulching was increased by 9772.9 $kg \cdot hm^{-2}$ with an increase of 13.7%. The average dry matter yield was increased by 2200.0 $kg \cdot hm^{-2}$ with an increase of 23.8%. It was concluded that planting forage-oriented maize with plastic-film mulching was an effective technical way to increase forage yield greatly in the agriculture-animal husbandry ecotone of North China.

3.1.2 Effect of nitrogen application on biomass yield of forage-oriented maize

Table 2 indicates that the forage-oriented maize yield with nitrogen application was significantly increased, compared with that of those without nitrogen treatments. The biomass yield of the treatment N200 shows the highest and the yield difference between N200 and others was significant. Compared with N0 the fresh matter yield of N200 was increased by 30.7% in open field and 30.4% in plastic-film mulching field, the dry matter yield increased by 36.1% in the plot without film mulching and 39.5% in film mulched plot, respectively. In the open field, there weren't any significant differences in the fresh and dry yields between N100 and N300. In the plastic-film mulched field, the fresh yield difference between N200 and N300 was not significant nor was the dry yield between N100 and N300. So, proper nitrogen application could increase forage maize biomass yield and its dry slice yielding ratio. Nitrogen application with plastic-film mulching was an effective way for forage-oriented maize to utilize the finite natural resource and increase its yield fast.

3.2 Effects of plastic-film mulching and nitrogen application on the nutritive quality of forage-oriented maize

3.2.1 Effects of plastic-film mulching and nitrogen application on the nutrient content in maize plant

Table 3 shows the nutrient content of forage-oriented maize plant under different treatments. Plastic-film mulching increased the content of crude protein and crude fiber in forage maize plants. By *t*-test, it was clear that there were extremely significant differences of crude protein content and crude fiber content between plastic-film

Table 2 Biomass of forage-oriented maize with and without plastic-film mulching and at different N application rates

treatment	fresh biomass yield/$kg \cdot hm^{-2}$		dry slice yielding ratio/%		dry biomass yield/$kg \cdot hm^{-2}$	
	no mulching	mulching	no mulching	mulching	no mulching	mulching
N0	60776 Bc	69276 Bc	12.7 Ab	13.6 Bb	7703 Cc	9429 Cc
N100	72490 Ab	79867 ABb	12.8 Aab	14.0 ABb	9239 Bb	11134 Bb
N200	79454 Aa	90316 Aa	13.2 Aab	14.6 Aa	10482 Aa	13159 Aa
N300	71612 Ab	83964 Aab	13.4 Aa	14.4 Aa	9567 Bb	12068 ABb
t-test	8.22^{**}		18.15^{**}		12.42^{**}	

Note: ** means significantly different by *t*-test at 0.01 level, $t_{0.05}(22) = 2.07$, $t_{0.01}(22) = 2.82$; Different capital (small) letters denote significantly different at 0.01 (0.05) levels. This is the same for other tables.

Table 3 Forage-oriented maize nutrient percentage in different treatments (%)

treatment	crude protein		crude fat		crude fiber	
	no mulching	mulching	no mulching	mulching	no mulching	Mulching
N0	5.91 Dd	6.09 Dd	1.45 Dd	1.45 Dd	24.45 Bb	26.31 Cc
N100	7.92 Cc	8.17 Cc	1.91 Cc	1.95 Cc	24.95 ABb	26.85 BCc
N200	11.19 Bb	11.54 Bb	2.60 Bb	2.64 Bb	26.15 ABb	27.90 Bb
N300	12.38 Aa	12.74 Aa	3.55 Aa	3.58 Aa	28.84 Aa	30.74 Aa
t-test	4.44**		1.77		5.94**	

mulching and non-mulching, but the difference of crude fat was not significant. In the cold and arid area, plastic-film mulching provided a proper temperature and moisture condition, and laid a biological foundation for forage maize to absorb more fertilizer and water. Plastic-film mulching accelerated maize absorption of nitrogen which was similar to the increase of crude protein content. Mulching effect on accelerating forage maize growth was also similar to the increase of crude fiber content. It was therefore concluded that plastic-film mulching could increase the content of crude protein and crude fiber, but not as crude fat.

Crude protein content, crude fat content, and crude fiber content in forage maize were increased with the increasing nitrogen application rate. The difference of crude protein and crude fat contents among the four nitrogen rates was extremely significant, so was that of crude fiber between N300 and N0. The crude protein content, crude fat content and crude fiber content of N300 increased by 109%, by 145% and by 17% compared with N0. So, this shows that nitrogen application was an important factor to increase crude protein content and crude fat content in forage maize plants.

3.2.2 Effect of plastic-film mulching and nitrogen application on the yield of nutrients

The paired sample *t*-test indicated that there were extremely significant differences in the production of crude protein, crude fat and crude fiber between plastic-film mulching and non-mulching treatments (Table 4). The yield of the three nutrients in the mulched field were increased by 28.1%, 25.9% and 32.6% compared with those in the open field, respectively. It was clearly shown that plastic-film mulching could improve the nutrient yield in forage maize significantly.

Table 4 shows that the effect of nitrogen on the nutrients yield in plastic-film mulching filed was in qualitative agreement with that in the open field, i.e. crude protein yield, crude fat yield and crude fiber yield were increased as the nitrogen application rate increased. There existed an extremely significant difference between the treatments with nitrogen application and control. But the increased rate of the nutrients was decreased as the nitrogen application rate increased, which was related to the decrease of forage maize biomass yield when increasing N application and to the decrease of the nutrient's increasing range. In the open field, crude protein yield, crude fat yield and crude fiber yield of N300 increased 160%, 210% and 47% compared with those of N0, respectively. Nitrogen fertilizer application to forage maize improved the biomass and nutritive quality with nutritive matter (percentage and yield) several times of those of biomass. This indicated that the proper increase of the nitrogen application rate could increase the nutritive quality of forage maize effectively.

3.3 Effects of plastic-film mulching and nitrogen application on the nitrogen uptake and utilization efficiency of forage-oriented maize

Table 5 shows the nitrogen uptake and utilization efficiency of the forage maize under different treatments. Plastic-film mulching increased the N utilization rate and its output-input ratio markedly while there was no significant difference in N dry matter production efficiency and N physiological efficiency between the open field and the plastic-film mulched field. So, it was indicated that plastic-film mulching increased accumulative nitrogen amount in maize plants because mulching could increase biomass yield, but it could not change the effect of the absorbed nitrogen per unit weight on the yield of

Table 4 Forage maize nutrients in different treatments ($kg \cdot hm^{-2}$)

treatment	crude protein		crude fat		crude fiber	
	no mulching	mulching	no mulching	mulching	no mulching	mulching
N0	455 Cc	574 Cc	112 Dd	137 Dd	1884 Cc	2481 Cc
N100	732 Bb	909 Bb	176 Cc	217 Cc	2304 Bb	2990 Bb
N200	1173 Aa	1519 Aa	273 Bb	347 Bb	2741 Aa	3671 Aa
N300	1184 Aa	1537 Aa	340 Aa	432 Aa	2758 Aa	3707 Aa
t-test	7.29**		6.16**		11.77**	

Table 5 Forage-oriented maize N uptake and nitrogen fertilizer use efficiency of different treatments

treatment		total N accumulation in plant/kg·hm^{-2}	N dry matter production efficiency/kg·kg^{-1}	N physiological efficiency/kg·kg^{-1}	N apparent utilization ratio/%	N output-input ratio/%	fluctuation of available N in soil/mg·kg^{-1}
no mulching	N0	72.8 Cc	105.8 Dd	–	–	–	−42.8
	N100	117.1 Bb	78.9 Cc	34.7 Cc	44.2 Bb	117 Cc	−18.3
	N200	187.7 Aa	55.8 Bb	24.2 Bb	57.5 Aa	94 Bb	10.3
	N300	189.5 Aa	50.5 Aa	16.0 Aa	38.9 Bb	63 Aa	33.3
mulching	N0	91.9 Cc	102.6 Dd	–	–	–	−48.2
	N100	145.5 Bb	76.5 Cc	31.8 Cc	53.6 Bb	146 Cc	−34.9
	N200	243.0 Aa	54.2 Bb	24.7 Bb	75.5 Aa	121 Bb	−11.6
	N300	245.9 Aa	49.1 Aa	17.1 Aa	51.4 Bb	82 Aa	17.0

forage maize. At the same time, it was shown that the changing tendency of the six compared items in the open field was in accordance with those in plastic-film mulched field in Table 5. The nitrogen accumulation amount of the forage maize was increased as the nitrogen application rate increased and the difference between the treatments with and without nitrogen application was extremely significant while there was no significant difference between N200 and N300. The N dry matter production efficiency and N physiological efficiency decreased with the nitrogen application rate's increase and the difference of decreasing range among the nitrogen treatments was extremely significant. This embodied the reward descending rule of fertilizer. The apparent utilization ratio of N200 was the highest in all nitrogen treatments because the biomass yield of the treatment was the highest, but the nitrogen application rate was in the middle. The N output-input ratio was increased as the nitrogen application increased, the N output-input ratio of the five treatments, i.e. N0 and N100 in the open field, and N0 and N100 and N200 in plastic-film mulched field was beyond 1, showing that the forage-oriented maize absorbed the reserved nitrogen in the soil pool and there was an available nitrogen deficit in soil pool. The N output-input ratio of the other three N treatments was below 1 and the surplus nitrogen was reserved in the soil. The N output-input ratio affected the sustainable utilization of soil and plant biomass formation directly in the eco-fragile areas and it was important to maintain plant production and prevent soil desertification. In order to maintain the sustainable util-

Table 6 Water utilization status of forage maize in different growth stages under different treatments

growing stage	precipitation/mm	item	N0		N100		N200		N300	
			no mulching	mulching	no mulching	mulching	no mulching	mulching	no mulching	mulching
sowing to jointing, May 18–Jul. 10	126	field water consumption/mm	102.3	53.3	110.2	67.6	103.5	59.8	109.2	59.3
		stage cumulated biomass/kg·hm^{-2}	209.4	836.3	324.7	1117.3	382.6	1366.1	314.8	1269.0
		water use efficiency/kg·mm^{-1}·hm^{-2}	2.0	15.7	2.9	16.5	3.7	22.8	2.9	21.4
		water surplus/mm	–	355.3	–	311.7	–	309.8	–	380.9
jointing to large bugle, Jul. 11–Aug. 1	107	field water consumption/mm	74.4	76.9	84.3	80.6	92.4	78.9	76.0	71.2
		stage cumulated biomass/kg·hm^{-2}	1728.2	2408.7	2580.0	3454.8	3178.1	4322.9	2599.5	3830.0
		water use efficiency/kg·mm^{-1}·hm^{-2}	23.2	31.3	30.6	42.8	34.4	54.8	34.2	53.8
		water surplus/mm	–	26.7	–	32.2	–	46.8	–	40.7
large bugle to harvest, Aug. 1–Sep. 10	101	field water consumption/mm	108.4	184.9	105.9	176.9	109.8	192.5	115.2	187.9
		stage cumulated biomass/kg·hm^{-2}	5767.9	6184.3	6334.1	6561.6	6921.7	7470.0	6652.6	6969.4
		water use efficiency/kg·mm^{-1}·hm^{-2}	53.2	33.4	59.8	37.1	63.0	38.8	57.8	37.1
		water surplus/mm	–	−68.7	–	−67.1	–	−74.0	–	−67.2
whole growth stage, May 18–Sep. 10	334	field water consumption/mm	285.1	315.2	300.4	325.1	305.7	331.2	300.4	318.5
		stage cumulated biomass/kg·hm^{-2}	7705.5	9429.3	9238.8	11133.7	10482.3	13159.0	9566.9	12068.4
		water use efficiency/kg·mm^{-1}·hm^{-2}	27.0	29.9	30.8	34.2	34.3	39.7	31.8	37.9
		water surplus/mm	–	33.7	–	37.0	–	52.6	–	60.5

ization of the soil to get high-yield forage with good quality, the proper nitrogen application amount was at about 200 kg·hm^{-2} in the open filed and less than 300 kg·hm^{-2} in the plastic-film mulching field.

3.4 Effects of plastic-film mulching and nitrogen application on field water utilization status by the forage-oriented maize at different growth stages

3.4.1 Effect of plastic-film mulching on field water utilization status by the forage maize at different growth stages

The growth stage of the forage maize in plastic-film mulched filed was regarded as the standard time, the difference of the effect on filed water consumption in the same time was compared between open field and plastic-film mulching field (Table 6). From Table 6, it was concluded that the earlier the growth stage was, the more obvious the water reserving effect of plastic-film was after forage maize sown. From sowing to jointing (from May 18 to July 10), the filed water consumption by the crops with plastic-film mulching was 42.6–49.9 mm less than that without mulching, and the water use efficiency (WUE) with plastic-film mulching was 5.61–7.67 times higher than that without mulching. This was equivalent to an additional 309.8–380.9 mm supply of rainfall. In this period, the effect of water retention and increasing yield made it clear that plastic-film mulching increased WUE greatly. From jointing to large bugle stage (from July 11 to August 1), the field water consumption by the crops with plastic-film mulching was slightly lower or equivalent with that without film covering, but its advantage of WUE increasing resulted from plastic-film mulching was unchanged. Plastic-film mulching remodeled the maize field water consumption scheduling pattern, the water consumption rate in open field was 1.63–1.92 times of that in plastic-film mulched field at the early growth stage (from May 18 to July 10). In the soil surface, soil water evaporation without mulching was the main reason for field water loss. But, the water consumption rate in mulched field at late growth stage (from August 2 to September 10) was bigger and 1.63–1.71 times of that in open field at the same time. This was attributed to its enormous transpiration and extravagant water absorption because large biomass of forage maize enhanced from increased soil temperature and water conservation effects of plastic-film mulching at the early growth stage, and resulted in consuming more water of 70.9–82.7 mm than that without plastic-film mulching at the late growth stage, and water use efficiency dropped rapidly. In view of the whole growth period, water consumption by the crops in plastic-film mulching field was 18.9–30.1 mm higher than that in the open field, but WUE with plastic-film mulching increased by 10.7%–19.0%, this was an equivalent of additional 33.7–60.5 mm supply of rainfall.

3.4.2 Effect of nitrogen application on field water utilization status by forage maize at different growth stages

It was shown that there was little effect of nitrogen application on field water consumption by the forage-oriented maize whether there was mulching or not (Table 6). Because nitrogen application influenced the biomass accumulation of the forage maize in each growth stage, WUE in each growth stage shows a fluctuation from an initial rising to a drop later on like the fluctuation of biomass when the nitrogen application rate was increased. So, it was concluded that proper nitrogen application could increase not only the biomass yield of forage maize, but also WUE.

4 Discussion

Plastic-film mulching promoted the interaction and coupling of many positive effects, such as increasing soil temperature, conserving soil moisture and mineralizing soil nutrients. With plastic-film mulching, forage maize overcame the restriction of coldness and drought at early growth stage and accelerated biomass yield accumulation which triggered extravagant water absorption from soil in the late growth period. The water consumption scheduling pattern of the forage-oriented maize with plastic-film mulching was different from that of radish in the agriculture-animal husbandry ecotone in North China (Huang and Zhang, 2005). Our study result shows that the water consumption of forage maize in the open field accounted for 89.1% of the precipitation in the same period and soil water content at harvest was higher than that at seeding. The ideology and technology of autumn rainwater accumulation (after maize harvest) for spring crops utilization is set for a breakthrough. In the cold and arid ecotone in North China, the key rationale behind crop high yield is the overlapping effect of the water-heat rhythm and agro-biorhythm. The study utilized the late-maturity maize variety (White Dent) as forage-oriented maize and analyzed several outstanding characteristics of the plant such as large leaf area, high plant, etc. The forage maize variety of White Dent is not sensitive to water-heat stress. It can produce high biomass by making maximal use of the ecological resource. Its biological yield is much higher than those of the other forage grasses in the area. So, the rational choice of forage-oriented maize variety is also a crucial factor for the high yield of forage. Planting late-maturing forage-oriented maize has long been practiced for developing vegetative agriculture in mountainous and cold regions (Ren and Hou, 1999).

In the study, it was shown that the proper nitrogen application to forage maize co-improved the biomass and nutritive quality with nutritive matter (percentage and yield) several times of biomass. The biomass yield of N300 declined compared with that of N200. For biomass yield, it was defined as an ‘‘extravagant nitrogen absorption’’. However, the extravagant nitrogen absorption increased the content and yield of nutritive matters, such as crude protein and crude fat. It was of great importance to improve the nutritive quality of forage maize plant. In the cold and arid agriculture-animal husbandry ecotone of northern china, the planting of forage maize was to resolve the problem of forage shortage for animal husbandry development by increasing biomass yield. The N apparent utilization ratio of the experiment was 38.9%–57.5% in the open field and 51.4%–75.5% in the plastic-film mulched field, much higher than that of wheat with a range of 34%–49% according to Johnson and Raun (2003). The cultivation measures, including the high density of planting group (100000 plant·hm^{-2}) and the earlier sowing with later harvesting, improved the nitrogen absorption amount. It was the reason that made the maize absorb more nitrogen than wheat did. According to Johnson’s viewpoint (Johnson and Raun, 1995), nitrogen loss could not occur until nitrogen supply was beyond what the plant needed. In our experiment, when the nitrogen application rate was at more than 200 kg·hm^{-2} in the open filed and 300 kg·hm^{-2} in the plastic-film mulched field, available nitrogen was accumulated in soil. Under such conditions, nitrogen may leach or be lost to volatilization. But, the nitrogen application rate of 200 kg·hm^{-2} in the open field and 300 kg·hm^{-2} in the plastic-film mulched field was most optimal to ensure a high yield and good quality and to keep the available nitrogen balanced in the soil.

Our study also shows that plastic-film mulching and nitrogen application increased the crude fiber content of forage maize plant which could decrease forage digestibility (Zhang et al., 2003b; Wolf et al., 1993). Zhang et al. (2002), Wang et al. (2005b) and Tai et al. (2006) believed that the optimum fertilizer application time and dosage could not only decrease crude fiber content, but also increase biomass yield, the content of crude protein and crude fat of forage maize plants in their studies. The result of Zhang et al. (2005) and Cusicanqui and Lauer (1999) shows that regulating plant density could also decrease crude fiber content, increase biomass yield and increase the contents of crude protein and crude fat. In the meantime, Zhang et al. (2005) believed that the effect of plant density on improving forage nutritive quality was caused by the ratio of grain to dry matter of the whole plant. In the cold and arid agriculture-animal husbandry ecotone in North China, late-maturing forage-oriented maize was still harvested at the tasselling stage while the first frost arrived. So the effect of plastic-film mulching with proper nitrogen application and regulating plants density on decreasing crude fiber content, increasing biomass yield and improving nutritive quality need further studies in the area. The researchers in animal husbandry found that increasing the crude fiber content appropriately in the feed could increase the milk yield of cows, decrease disease incidence (Zhang, 1999), improve digestive system development of piglets and reduce abnormal animal behavior (Sun, 1999). Especially for ruminants, crude fiber was of more great importance (Li et al., 2006). The regulation measures of crude fiber content in forage-oriented maize plants according to a given animal also needs to be studied further.

5 Conclusions

In the agriculture-animal husbandry ecotone in North China, plastic-film mulching increased biomass yield of forage-oriented maize by 23.8%, compared with that without mulching in meadow chestnut soil, and significantly promoted nitrogen uptake by maize. It also increased the N apparent utilization ratio and N output-input ratio. Plastic-film mulching increased the content of crude protein and crude fat and improved the nutritive quality of forage maize. Plastic-film mulching reduced the soil water evaporation significantly and conserved or stabilized the soil moisture effectively at earlier growth stages with little-precipitation. Because plastic-film mulching remodeled the maize field water consumption scheduling pattern, the effect on adjusting soil water caused extravagant water absorption by forage maize in the late growth periods. In the plastic-film mulched field, the field water consumption was more than that without mulching, but the water use efficiency was increased by over 10%.

Nitrogen application to forage maize co-improved its biomass yield and nutritive quality with nutritive matter (percentage and yield) up to several times of the biomass. Nitrogen application increased forage maize dry biomass by 36.1%–39.5%, and the crude protein and crude fat contents of maize plant by 109% and 145%, respectively, with the yield of the two nutritive matters increased by 160% and 210%. Therefore, proper nitrogen application was an effective way to increase biomass yield and improve nutritive quality. Nitrogen application at about 200 kg·hm^{-2} in the field without film covering, and less than 300 kg·hm^{-2} in the field with film mulching were the most proper rates to guarantee forage-oriented maize high yield and good quality and to keep the available nitrogen balanced in the soil. It was concluded that plastic-film mulching with proper nitrogen fertilizer application to forage-oriented maize was an effective technique to produce water-saving forage with high yield and good quality and to relieve the shortage of animal forage and accelerate ecological recovery and economic development in the ecotone in North China.

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