Effect of Different Harvest Periods on Dry Matter Accumulation and Quality of Silage Maize

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Keywords: Silage Maize, Harvest Period, Dry Matter, Quality.

Abstract: Harvest period is a key factor affecting the amount and quality of dry matter accumulation in silage maize. To clarify the dry matter accumulation characteristics and quality changes of silage maize in medium maturity areas of Inner Mongolia at different harvest periods, theoretical basis and practical guidance can be provided for determining the appropriate harvesting period of silage maize. In this study, we systematically analyzed the dynamic changes of plant height, leaf area index, dry and fresh weight accumulation and whole plant quality indicators of four maize varieties, Xianyuea 335, Lihe 1, Jinchuang 998 and Zhongxing silage 1, at six different harvest periods. The results showed that there was no significant effect of different harvest periods on silage maize plant height, while leaf area index, fresh weight, dry matter quality and nutritional quality had some differences between harvest periods. The quality of silage maize was excellent from 1/2 to 3/4 of the kernel milk line position, with dry matter quality ranging from 0.68% to 96.71% higher than other harvesting periods and RFV ranging from 15.46% to 49.83% higher than other harvest periods.

1 INTRODUCTION

Silage maize (*Zea mays L.*) is one of the main silages. Silage maize is rich in nutrients, high in sugar, carotene and vitamins, and preserves protein and vitamins more effectively, with a sour smell and good palatability. It can be used as feed for the whole plant and has the advantages of high yield, rich nutrition, good quality and high feeding value compared with other silages, which can effectively improve the meat quality and milk quality and milk yield.

The harvest period is a key factor affecting the quality of silage maize, and has a strong influence on the dry matter accumulation and quality of maize. It was found that the dry matter yield and nutritional value, digestibility and potential intake of forage maize vary with the composition of the seed content and stover (Yu, et al., 2009). Harvesting maize at the full-ripe stage, the corn stalk is highly lignified and the animal digestibility of it is low, which greatly reduces the utilization value. Pan Jinbao et al (Jinbao, et al, 2002) concluded that the lower the plant ADF as well as NDF content is, the higher the animals are fed. If the harvest period is appropriately advanced, the utilization value of corn stalk can be increased significantly with little impact on maize yield (Ning, et al., 1998). Harvest period has a significant effect on maize yield, dry matter

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Bai, L., Zhang, X., Lu, Z., Wang, Y., Liu, Y., Sun, F., Xue, C., Du, X. and Chen, L.
Effect of Different Harvest Periods on Dry Matter Accumulation and Quality of Silage Maize.
DOI: 10.5220/0011381200003443
In *Proceedings of the 4th International Conference on Biomedical Engineering and Bioinformatics (ICBEB 2022)*, pages 1145-1152
ISBN: 978-989-758-595-1

contents and crude protein and fiber contents, etc. As the growth stage of corn advances, corn stalk changes from fresh to dry, and the stalk loses a lot of nutrients with the evaporation of natural water content. The maturation process of maize is complex, the morphological structure and chemical composition of the plant are subject to changes during the growth stage, and the nutrient content of the raw maize varies depending on the time of harvest, thus affecting the silage effect. Zhao Zunyang (Zhao 2003) showed that early harvesting of maize resulted in lower acid and ammoniacal nitrogen content and lower pH in silage. The current research on silage maize at home and abroad mainly focuses on the screening of silage maize varieties and the influence of water and fertilizer, density and other planting methods on the quality of silage maize. The hot spots of foreign research are the mechanization of the whole process of planting and the study of nutrients in the process of silage maize. Fewer studies have been conducted on the effects of different harvest periods on dry matter accumulation and quality variability of silage maize varieties. Therefore, it is important to study the dynamics of dry matter accumulation and quality characteristics of silage maize under different harvest periods.

2 MATERIALS AND METHODS

2.1 Overview of the Experiment Plots

The experimental plot is located at the research base of modern agricultural science and technology park in Heling County Hohhot City, Inner Mongolia. The average annual temperature is 6.7℃, the frost-free seasons are 113-134d, and the altitude is 1,040m. From May to September in 2018 in Hailing County, the maximum temperature was 38°C and the minimum temperature was 3°C; the total rainfall was 852.80 mm. The previous crop was maize, soil PH was 8.26; fast-acting phosphorus was 34.34 mg/Kg; organic matter was 26.9 g/Kg; effective potassium content was 343.00 mg/Kg; and ammonium nitrogen content was 11.53 mg/Kg.

2.2 Tested Varieties and Experimental Design

The trial was conducted with varieties as treatments, with a total of four variety treatments, namely: Lihe 1, Xianyu 335, Jinchuang 998 and Zhongxing silage 1. It was conducted in 2018, and arranged in a randomized blocks with a plot area of 30 m^2, a sowing density of 333.33 plants/ha with three replications and the same field management as in the field. The sowing time was on May 8th, and the emergence date was on May 17th. Sampling and observation of the position of the seed mast line were carried out every 7 days after the tassel stage on August 7th (tassel stage), August 27th (one-quarter of the seed mast line position), September 3rd (one-third of the seed mast line position), September 10th (one-half of the seed mast line position), September 17th (three-quarters of the seed mast line position), and September 24th (completion stage).), and September 24th (completion stage), with the male stalking stage used as a control.

2.3 Measurement Indexes and Methods

2.3.1 Determination of Leaf Area

leaf area index = leaf length x maximum leaf width x 0.75, the leaf area of each unit will be found out and summed up to get the total plant total area.

2.3.2 Determination of Plant Height, Fresh Weight and Dry Matter

Three silage maize plants of uniform growth were randomly selected from each treatment, and the height and fresh weight of the silage maize plants were measured after mowing in the same place, then the maize was chopped and put into the oven, blanched at 105°C for 30 min, and dried at 80°C to constant weight. An electronic balance is used to weigh and record corresponding data.

2.3.3 Determination of Quality

Ten silage maize plants with uniform growth were randomly selected from each treatment, crushed with a grinder (to ensure that the ears were completely crushed), stirred well, from which 1 kg of well-stirred silage maize samples were placed in a cloth bag, blanched at 105°C for 30 min, dried at 60°C to a constant weight, fully crushed with a small grinder, passed through a 40-mesh sieve, and placed in a plastic sealing bag to be sealed.

The nutritional quality of the samples, including crude protein (CP), crude fat (EE), starch (Starch), neutral detergent fiber (NDF) and acid detergent fiber (ADF) was determined using NIR diffuse reflectance spectrometry.

Relative feed value (RFV) is calculated by:

$$RFV = (DDM \times DMI)/1.29$$

DDM = 88.9 - 0.799 × ADF; DMI=120/NDF; DDM is the digestible dry matter (%);

DMI is the Ad libitum food intake of roughage dry matter (%).

2.4 Experimental Data Processing

Excel 2010 was used to organize the data; statistical analysis software SPSS 25.0 was used to conduct ANOVA and factor significance analysis; the least significant difference (LSD) method was used for multiple comparisons among different treatments; SigmaPlot 12.5 was used to analyze the regression equations between different harvest periods and fresh weight and dry matter accumulation.

3 ANALYSIS OF RESULTS

3.1 Effect of Different Harvest Periods on the Height of Silage Maize Plants

The difference in harvest period had no significant effect (p>0.05) on the plant height of each silage maize variety (Table 1).

Table 1: Dynamic changes of plant height of silage maize in different harvest periods (cm).

Sampling period Month/day	Xianyu335	Lihe1	Jingchuang998	Zhongxing silage 1
8/7	315.83±14.95a	354.33±8.39a	294.90±10.56a	363.57±3.54b
8/27	366.50±3.24a	364.73±10.65a	308.40±4.23a	372.47±7.14ab
9/3	366.50±2.86a	359.00±3.24a	303.40±3.10a	373.93±4.21ab
9/10	365.45±2.60a	356.37±1.68a	303.83±3.14a	375.73±3.66a
9/17	361.23±6.81a	356.13±3.12a	300.27±6.34a	371.63±3.11ab
9/24	371.17±5.20a	352.40±2.41a	303.00±9.02a	379.20±5.63a
P	0.37	0.43	0.52	0.10
F	1.20	1.05	0.89	2.43

The plant heights of Xianyu 335, Lihe 1, Jinchuang 998, and Zhongxing silage 1 ranged was 315.82 cm ~ 371.17 cm, 354.33 cm ~ 364.73 cm, 294.90 cm ~ 308.40 cm, and 363.57 cm ~ 379.20 cm, respectively. Among them, from the stalking stage to the maturity stage, there were no significant differences among Xianyu 335, Lihe 1, and Jinchuang 998 at different harvest periods. And the highest plant height of 375.73 cm was achieved on September 24 for Zhongxing silage 1, which was significantly higher than that on August 7th (p < 0.05).

3.2 Effect of Different Harvest Periods on Leaf Area Index of Silage Maize

The difference in harvest period significantly affected the leaf area index of each silage maize variety (p < 0.05) (Table 2).

Table 2: Dynamic changes of leaf area index of silage maize in different harvest periods.

Sampling period Month/day	Xianyu335	Lihe1	Jingchuang998	Zhongxing silage 1
8/7	4.86±0.88a	5.45±0.65a	3.89±0.11a	6.24±0.41a
8/27	4.53±0.32a	5.99±0.09a	4.07±0.36a	5.80±0.53ab
9/3	4.34±0.33a	3.97±0.97b	3.89±0.54a	5.21±0.01b
9/10	3.15±0.21b	3.89±0.20b	2.67±0.02b	3.83±0.69c
9/17	2.99±0.53b	2.94±0.38bc	2.60±0.19b	3.32±0.13cd
9/24	0.00±0.00c	2.10±0.46c	1.27±0.66c	2.48±0.20d
P	**	**	**	**
F	29.71	13.72	15.82	26.96

With the extension of the growth stage, the leaf area index of Xianyu 335 and Zhongxing silage 1 showed a gradual decrease in the trend, with the highest of 4.86 and 6.24 on August 7th, respectively. The leaf area index of Lihe 1 and Jinchuang 998 showed a trend of increasing and then decreasing with the extension of the growing period, and the highest leaf area index was 5.99 and 4.07 on August 27th, respectively. The leaf area index of each maize variety was not significantly different on August 7th and August 27th, and was significantly higher than on September 10th, September 17th and September 24th.

3.3 Effect of Different Harvest Periods on the Fresh Weight of Silage Maize

The difference in harvest period significantly affected the fresh weight of Xianyu 335 and Lihe 1 ($p < 0.05$) (Table 3). With the extension of the maize harvest period, the fresh weight of all varieties of maize showed the pattern of single peak curve, with the lowest fresh weight on September 24th (full-ripe stage).

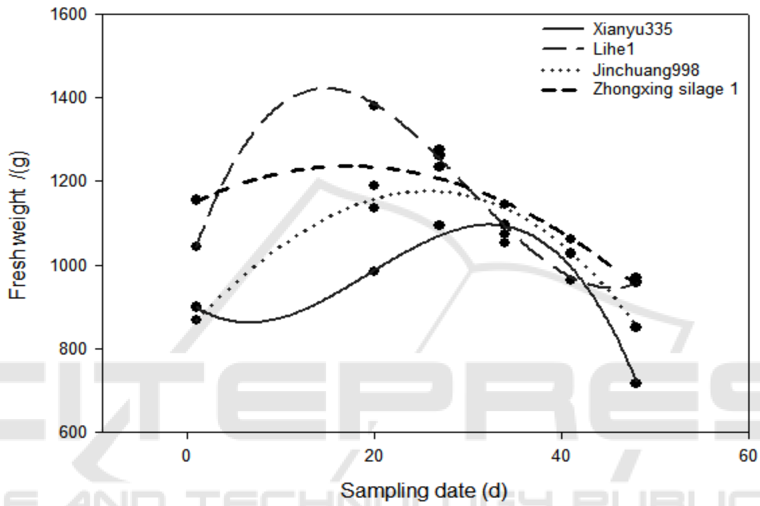


Figure 1: Regression equation analysis of fresh weight of silage maize under different harvest periods.

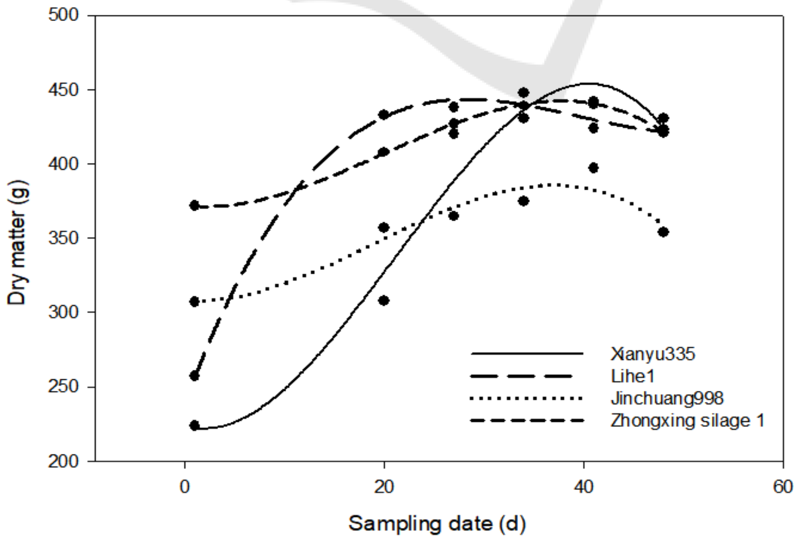


Figure 2: Regression equation analysis of dry matter of silage maize under different harvest periods.

Table 3: Dynamic changes of fresh weight of silage maize in different harvest periods (g).

Sampling period Month/day	Xianyu335	Lihe1	Jingchuang998	Zhongxing silage 1
8/7	899.02±29.00ab	1043.51±22.65bc	867.62±23.71a	1155.00±27.69ab
8/27	982.60±55.22a	1379.08±35.16a	1136.70±46.03a	1189.35±37.31ab
9/3	1094.54±31.34a	1262.33±28.78ab	1233.80±38.07a	1275.80±48.63a
9/10	1051.43±23.70a	1095.57±4.17bc	1072.98±50.84a	1143.88±10.69ab
9/17	1025.13±22.94a	962.53±17.40c	1061.90±1.92a	1026.71±37.68ab
9/24	715.20±23.91b	958.40±82.11c	849.25±47.95a	968.90±64.00b
P	**	**	0.50	0.15
F	5.24	5.11	1.00	1.99

The highest fresh weights were 1094.54 g, 1233.80 g and 1275.80 g on September 3rd for Xianyu335, Jinchuang 998 and Zhongxing silage 1, which were 4.10% to 53.04%, 8.54% to 45.28% and 7.27% to 31.66% higher than the other harvest periods, respectively. From August 27th to September 17th, there was no significant difference in the fresh weight of each harvest period; the highest fresh weight of Lihe 1 was 1379.08 g on August 27th, which was 9.25% to 43.89 % higher than that at other harvest periods.

The relationship between harvest period and fresh weight of each maize variety is shown in Figure 1. Fresh weight (Y) increased with harvest period (X) in a cubic correlation curve.

The regression equations between fresh weight (Y) and harvest period (X) of maize for Xianyu335, Lihe1, Jinchuang998 and Zhongxing silage 1, respectively, were as follows:

$Y_{Xianyu\ 335}$=-0.028X^3+1.609 X^2-17.517X+915.153 (R^2 = 0.966)

$Y_{Lihe\ 1}$= 0.033X^3-3.018 X^2+67.321X+978.617 (R^2 = 0.999)

$Y_{Jinchuang\ 998}$=-0.003X^3-0.346X^2+23.897X+ 843.144 (R^2 = 0.924)

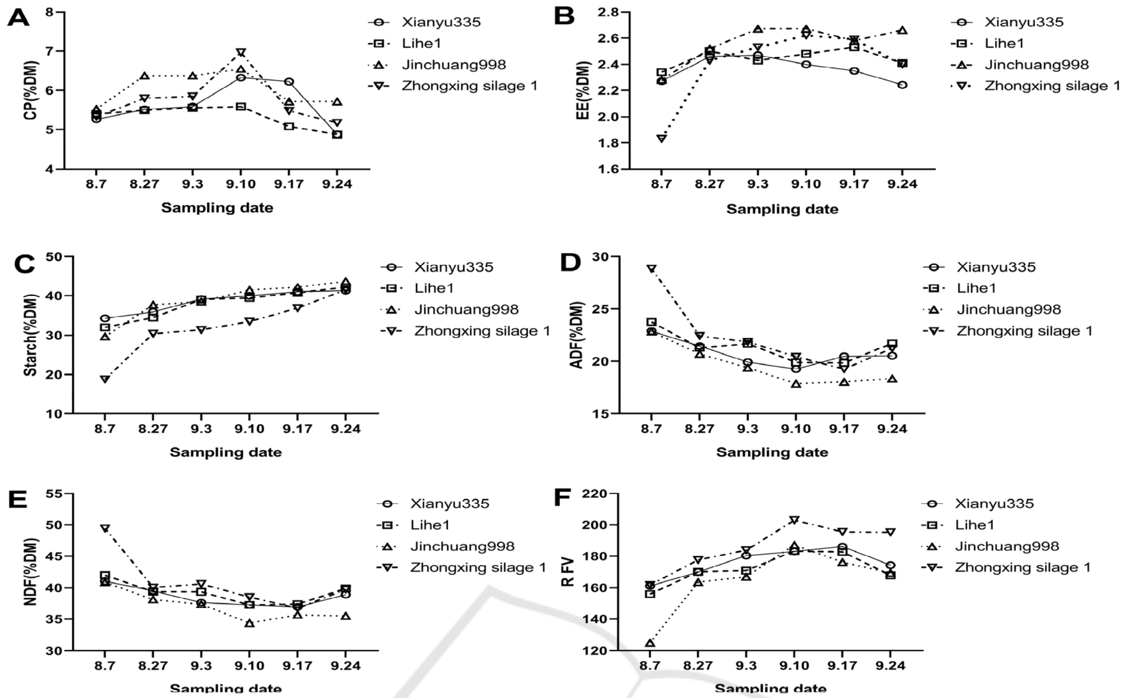
$Y_{Zhongxing\ silage\ 1}$=0.001X^3-0.347 X^2+11.435X+ 1140.12 (R^2 = 0.863)

3.4 Effect of Different Harvest Period on the Dry Matter Quality of Silage Maize

The difference in harvest period significantly affected the dry matter quality of Xianyu 335and Lihe 1 (p < 0.05) (Table 4).

Table 4: Dynamic changes of dry matter of silage maize in different harvest periods (g).

Sampling period Month/day	XianYu335	Lihe1	Jingchuang998	Zhongxing silage 1
8/7	223.58±46.03c	257.03±27.13b	306.99±25.12a	371.49±13.69a
8/27	307.72±24.56b	432.89±0.64a	356.79±35.03a	407.84±16.61a
9/3	420.13±40.65a	438.20±3.99a	364.59±10.30a	426.53±16.04a
9/10	430.33±0.21a	447.75±12.59a	374.76±1.84a	439.12±6.57a
9/17	439.79±38.20a	424.12±7.11a	396.93±4.51a	442.09±8.80a
9/24	430.67±0.26b	423.13±30.73a	354.03±36.44a	420.77±29.22a
P	**	**	0.72	0.80
F	16.40	14.23	0.60	1.99



Note: A, B, C, D, E, F respectively indicate the dynamic changes of crude protein, ether extract, starch, acid detergent fiber, neutral detergent fiber and relative feed value under different harvest periods.

Figure 3: Dynamic changes of silage maize quality under the same harvest period.

With the extension of maize harvest period, the dry matter quality of each variety of maize showed a trend of increasing and then stabilizing, with the maximum value in September 10-17th, which was 0.68%-96.7% higher than that at other harvest periods. The highest dry matter mass of Xianyu335 was 439.79 g on September 17th, which was significantly higher than that of the control, on August 27th and September 24th. The highest dry matter mass of Lihe1 was 447.75 g on September 10th, which was significantly higher than that of the control, but not significantly different from other harvesting periods; the dry matter quality of Jinchuang998 and Zhongxing silage 1 were not significantly different from each other during harvest periods, and the order of dry matter quality was: September 17th>September 10th>September 3rd>August 27th>September 24th>August 7th, September 17th>September 10th>September 3rd>September 24th>August 27th>August 7th. The dry matter quality of Jinchuang998 and Zhongxing silage 1 was the highest on September 17th, with 5.91%-29.30% and 0.68%-19.00% higher than other nitrogen fertilization treatments, respectively.

The relationship between harvest period and dry matter mass for each maize variety is shown in Figure 2. The dry matter mass (Y) increased with the harvest period (X) and showed an “S” shaped cubic positive correlation.

The regression equations between dry matter mass (Y) and harvesting period (X) for Xianyu335, Lihe1, Jinchuang998 and Zhongxing silage 1, respectively, were as follows:

$Y_{Xianyu\ 335}$= $-0.008X^3+0.508X^2-1.747X+223.246$ ($R^2 = 0.959$)

$Y_{Lihe\ 1}$= $0.004X^3-0.490X^2+17.739X+239.761$ ($R^2 = 0.995$)

$Y_{Jinchuang\ 998}$=$-0.003X^3+0.193X^2-0.425X+307.945$ ($R^2 = 0.908$)

$Y_{Zhongxing\ silage\ 1}$= $-0.003X^3+0.187X^2-0.74X+372.118$ ($R^2 = 0.999$)

3.5 Effect of Different Harvest Periods on the Quality of Silage Maize

With the extension of harvest period, EE, CP, showed a trend of increasing and then decreasing, Starch showed a trend of gradually increasing, ADF and NDF showed a trend of decreasing and then increasing for each silage variety (Figure 3). EE, CP maxima were distributed from September 3rd to

September 17th, ranging were 2.3 5% DM ~ 2.67% DM, 5.08% DM ~ 6.97% DM, respectively, and on September 24th, the Starch content of silage maize variety ranged were 41.3% DM ~ 43.69 % DM. The lowest ADF and NDF levels were found from September 10th to 17th, ranged were 17.88% DM ~ 20.47% DM, 34.36% DM ~ 37.29 7% DM, respectively. The RFV of each maize variety ranged from 125 to 203 in different harvest periods, with the highest RFV from September 10th to 17th, which was 15.46% ~ 49.83% higher than the other harvest periods.

4 DISCUSSION

Bal and Coors et al (1997) concluded that obtaining high dry matter yield of whole plant maize and feeding it to dairy cows for higher milk yield depends on harvesting maize at the right fertility period. In this study, it was found that the maximum dry matter mass of all silage varieties was concentrated from September 10th to 17th, at the 1/2-3/4 position of the kernel milk line of grains, while the maximum fresh weight of the whole plant was mainly concentrated from August 27th to September 3rd. This is due to the gradual decrease in whole-plant fresh matter weight as the water content of stalks and kernels decreases as the maize kernels mature (Yu, et al., 2009). Previous studies also found that harvesting at 2/3 milk line stage can realize the highest whole-plant maize dry matter yield (Ganoe, et al., 1992). In this study, both fresh weight and dry matter mass increased with harvest period (X) in a cubic term correlation, and the dry matter mass increased with the extension of harvesting period in an “S” curve. Ding Xiquan (1984) showed that the accumulation of assimilated products in storage organs of cereal crops, like other crops, showed an “S” shaped curve. This is due to the fact that whole maize dry matter is the result of the joint action of the root system and photosynthesis, and the rate of accumulation gradually becomes slower with the extension of the growth stage and the aging of various organ functions. There is no significant difference in plant height among maize varieties in this study at different harvest periods. The leaf area index gradually decreases with the extension of the growth stage, and the dry matter accumulation capacity weakens, so the rate of dry matter accumulation slows down after the 1/2 position of the maize kernel milk line.

As feed, the main indicator of the merit of the product of silage is the feeding quality. Proper harvest period is an important measure to improve high yield and quality of maize (Zhu, et al., 2015). The results of this study showed that EE, CP, and RVF showed an overall trend of increasing and then decreasing with the increase of harvest period. Wang YH et al. (2005) determined the yield and quality of silage maize at different maturity stages and also obtained the same variation characteristics. Hallauer (2001) studied the chemical composition of whole maize plants at different maturity stages and showed that from 1/3 milk line stage to finish maturity, the plant dry matter content, neutral detergent fiber content, and lignin contents increased rapidly due to stalk aging, and the total sugar, starch, and total digestible nutrient content decreased significantly, and crude protein content decreased with the extension of the growth stage. The accumulation of assimilation products in the kernels is not yet complete when silage maize is harvested, and therefore, assimilation products accumulate rapidly as the morphology of maize storage organs is built up (Oikeh et al., 1998). Ma Cunjin et al. (Ma 2012) showed that the CP and EE content gradually increased and ADF and NDF gradually decreased with the extension of harvest period. Fan Lei (Fan 2007) also showed that the accumulation of each nutritional quality increased with the extension of the growth stage, as influenced by the accumulation of dry matter. The results of the present study were not consistent. This may be due to the decline in leaf area index and chlorophyll content of ears position Lihe 1 in the late growth stage of maize, which makes the Lihe 1 senescent and the stalk to leaf ratio decreases, thus affecting its quality and yield. Besides, the nutrients of maize are mainly enriched in the seeds, and silage maize is harvested as a whole plant. When the position of the seed milk line is in the 3/4 to full-ripe stage, the dry matter is still accumulating in the stalk. As the fertility stage of maize advances, the stalks change from fresh to dry. The stover also loses a lot of nutrients with the evaporation of the natural water content (Fan, 2020), thus affecting the quality of maize later in the harvest. RFV is a very important indicator to evaluate roughage, the higher this indicator, the greater the nutritional value of the feed. When RFV index exceeds 100, it indicates that the feed has an overall good nutritional value (Wang, 2020). The results of this study showed that the RFV of all varieties of maize showed a trend of increasing and then decreasing with the extension of harvest period. RFV was 15.46% ~ 49.83% higher, ADF and NDF were the lowest, EE, CP and Starch were at high levels compared to other harvesting periods at 1/2 to 3/4 of the kernel milk line position, thus making it suitable for silage maize harvest.

5 CONCLUSION

There was no significant effect of different harvest periods on silage maize plant height, while leaf area index, fresh weight, dry matter quality and nutritional quality had some differences between harvest periods. With the extension of the harvest period, the fresh weight of silage maize all showed the pattern of single peak curve, with the maximum value concentrated at the tassel stage to the 1/4 of the milk line position of the grains. The dry matter mass showed a trend of increasing and then stabilizing, with the maximum value concentrated in 1/2 to 3/4 of the milk line position, which was 0.68% ~ 96.71% higher than the other harvest periods. The EE, CP, and Starch contents were at higher values in the 1/2 to 3/4 of the kernel milk line position, with the lowest ADF, and NDF, and the highest RFV, which was 15.46% ~ 49.83% higher than the other harvest periods. Therefore, the suitable harvesting period for silage maize in the medium maturity zone of Inner Mongolia is from 1/2 to 3/4 of the grain milk line position.

ACKNOWLEDGMENTS

This work was financially supported by the National Key R&D Program of China (2016YFD0300305-3), and Major Science and Technology Projects of Inner Mongolia Autonomous Region (2019ZD009).

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