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Effects of mowing regimes on forage yield and crude protein of *Leymus chinensis* (Trin.) Tzvel in Songnen grassland

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Abstract

Forage dry matter (DM) yield and its nutrient content are important in livestock nutrition; however, they have distinct, even opposite responses to mowing regimes. To optimize forage resources, two independent field experiments were conducted to determine effects of initial mowing time (15-d intervals from May 15 to Sept 1) and mowing frequency (one to five times per year) on DM yield and nutritive value of *Leymus chinensis* (Trin.) Tzvel. The greatest cumulative DM yield (cDMY), pre-mowing crude protein yield (pCPY) and cumulative crude protein yield (cCPY) were attained when initial mowing occurrred from July 15 to August 15. The crude protein (CP) concentration of pDMY was higher, whereas fiber concentrations were lower, when initial mowing was from May 15 to June 15, with opposite results when the initial mowing was delayed (July 1 to September 30). When mowing three times annually, cDMY and cCPY of *L. chinensis* were higher ($P < 0.05$) than with less frequent mowing. With more than three mowings, accumulated CP yield of *L. chinensis* was not significantly affected. With four or five yearly mowings, accumulated DM yield of *L. chinensis* decreased significantly compared to mowing one to three times. In conclusion, based on DM yield and nutritive value, the optimal initial mowing date ranged from July 15 to August 15, whereas optimal mowing frequency was three times yearly.

KEYWORDS

Leymus chinensis, initial mowing, frequency, dry matter yield, crude protein

1 | INTRODUCTION

Grasslands account for 25% of the world’s land surface and support the livelihoods of approximately 1 billion people (Kemp et al., 2013). China has some of the world’s largest grasslands, which are mostly used for grazing livestock. Since the 1950’s, sheep numbers in China increased from 7.7 to 249.4 million. Consequently, the grassland area per sheep has decreased from 3.4 ha in the 1950s to 0.6 ha in 2015 (Jiang, & Meurer, 2001; Liu, 2016). Such a marked increase in stocking rate requires more careful management of forage supply and improved forage utilization throughout the year to sustain livestock production (Milne, Durand, Emile, Huyghe, & Lemaire, 2002; Zheng, & Sun, 2011).

Mowing is a common practice in grassland management to increase forage utilization and conserve forage production. Many studies have been conducted to examine effects of initial mowing time and subsequent mowing frequency on grassland productivity under diverse climate and soil conditions (Binnie, Chestnutt, & Murdoch, 2010; Crews, & Sisk, 2004; Donaghy, Turner, & Adamczewski, 2008). For example, early initial mowing (May 20 versus on June 20) increased the total DM yield of *Panicum virgatum* L. in Tennessee, America (Mcintosh et al., 2015). In contrast, the total yield of "Shimanoushie" (a forage sugarcane variety) was lower with early versus late initial mowing (April versus May) (Sakaigaichi, Tarumoto, Hattori, Kamiya, & Yoshida, 2017). Such discrepancies in DM yield production were demonstrate of species × initial mowing time interactions in mowing management. Regarding impact of mowing frequency on DM yield, *Agropyron cristatum* (L.) Gaertn had 49 and 78% more DM yield when mowed three or five times yearly, respectively, compared to mowing once yearly (Abraham, Kyriazopoulos, Parissi, Sklavou, & Tsiouvaras, 2010). In contrast, mowing once yearly provided the highest annual DM yield of *Leymus chinensis* (Trin.) Tzvel compared to mowing twice yearly in a long term (27 y) study (Baoyin, Li, Bao, Minggagud, & Zhong, 2014). However, in other studies, mowing frequency had no obvious effect on DM yield of grasses (Ferraro, & Oesterheld, 2002; Man, & Wiktorsson, 2003). Thus, effects of mowing on forage DM production are dependent on location, pasture species and mowing regimes, e.g. initial mowing time and mowing frequency.

Mowing time and frequency also impacted nutritional content of diverse forages (Askarizad, Heshmati, Pessarakli, & Jouri, 2011; Ball, Hoveland, & Lacefield, 2015; Burton, Primo, & Lowrey, 1986; Pembleton, Rawnsley, Turner, Corkrey, & Donaghy, 2018). For example, crude protein (CP) was lower and acid detergent fiber (ADFom) and neutral detergent fiber (NDFom) of perennial ryegrass pastures were higher when the initial mowing time was delayed from mid-March to mid-April in Ireland (O'Donovan, Delaby, & Peyraud, 2004). In contrast, *Panicum virgatum* CP and total digestible nutrients (TDNs) were greater when the initial mowing was delayed from May 20 to June 20 in temperate grassland in the USA (McIntosh et al. 2016). Regarding impact of mowing frequency on nutritive value, the CP of *Cenchrus clandestinus* (Hochst. ex Chiov.) was lower when mowed every seven leaves per tillers compared to mowing every four leaves per tiller in a Colombian Andean zone in America (Charry, Rocha, & Fornaguera, 2020). Interestingly, frequent mowing (every 3 wk) led to a short-term increase in the CP of *Stipa grandis* P. Smirn. */L. chinensis* grassland in the first year, but it decreased the CP in the second year compared to mowing once yearly in an Inner Mongolia grassland (Schiborra, Gierus, Wan, Bai, & Taube, 2009).

As one grazing or mowing regime is highly unlikely to be suitable for all forage types and grassland locations (Holechek, & Pieper, 2011; Pontes, Carrère, Andueza, Louault, & Soussana, 2010; Rawnsley, Langworthy, Pembleton, Turner, Corkrey, & Donaghy, 2014). Therefore, regional and forage species specific mowing regimes should be developed to support sustainable grazing livestock production.

This study focused on *L. chinensis*, a C_3 perennial rhizomatous grazing grass, widely distributed in Songnen grassland, part of the Eurasian Steppe (1.5 million km^2; one of the largest grazing lands on the planet) (Wang, Du, Zhang, Ba, & Hodgkinson, 2017). *L. chinensis'* biomass accounts for > 85% of total above ground biomass in this area (Chen et al., 2013). Despite the importance of *L. chinensis* as a forage in the region, there is limited knowledge of management practices to optimize mowing regimes that maximize forage yield and nutritive value for animal production. The aim of this study was to determine the DM yield and nutritive value of *L. chinensis* and regrowth performance with various initial mowing times and subsequent mowing frequency in the Songen grassland. The DM yield and CP yield of *L. chinensis* have obvious seasonality. Besides, increased DM yield and CP yield with mowing have been observed in many grassland types. So, we tested the following hypotheses:1) cumulative DM and CP yield decrease with the delay of initial mowing date; and 2) the cumulative DM and crude protein yield increase as mowing frequency is increased.

2 | MATERIALS AND METHODS

2.1 | Site description

This study was comprised of two independent experiments conducted at the Songnen Grassland Ecosystem Research Station, of the Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Jilin Province, China (44°34′N, 123°35′E; 145 m above sea level). The soil type was alkali-saline soil, mainly characterized by sodium bicarbonate ($NaHCO_3$) and sodium carbonate (Na_2CO_3) (**Table 1**) which was classified as a Salic Solonetz in World Reference Base for Soil Resources. The climate is semi-arid, characterized by large inter- and intra-annual variability. Mean daily temperature was 7.0 °C (daily min = 4.9 °C; daily max = 6.4 °C) between 2014 and 2015. Mean annual precipitation was 347 mm, with 85% received between May and September, with a typical annual growing season of ~150 d (April to September). Mean daily temperature and precipitation during the experimental years (2016 and 2017) are shown (**Figure 1)**. Vegetation at the experimental grassland site was dominated by *L. chinensis* and lightly grazed by sheep and cattle during the growing season and/or mowed for haymaking during the 10 y prior to commencement of the study. A flat, non-degraded 0.3 ha grassland area with uniform growth of *L. chinensis* was used.

2.2 | Experimental design and treatments

Both Experiments I and II were conducted using a randomized complete block-design with three replication plots per treatment. Each replication plot was 20 m^2 (4 × 5 m), with a 0.5 m buffer between plots. Mowing (5 cm stubble height) was done with a small-plot harvester (Carter Mfg. Co., Inc. Brookston, IN, USA; Swift Machine and Welding Ltd., Swift Current, SK, Canada).

Grasslands were green on May 1 and duration of growing season was almost 120 d. In Experiment I, initial mowing was done on May 15, June 1, June 15, July 1, July 15, August 1, August 15, and September 1 (2016), respectively. On September 30, 2016, all treatment plots were mowed. Furthermore, control plots were only mowed once on September 30 in 2016. After the final mowing in 2016, no further mowing was imposed. For assessing the effects of different initial mowing time on grassland production in following year, all experimental plots were harvested on August 15, 2017.

Experiment II had variations in mowing frequency in 2016, as folows:1) mowing once a year on August 15, representing current local practice of mid-August hay production; 2) mowing twice a year (June 1 and October 1); 3) mowing three times a year (June 1, August 1 and October 1); 4) mowing four times a year (June 1, July 10, August 20 and October 1); and 5) mowing five times a year (on June 1, July 1, August 1, September 1 and October 1). After the final mowing in 2016, no further mowing was done. For assessing effects of mowing frequency on grassland production in the following year, all experimental plots were harvested on August 15, 2017.

2.3 | Sample collection and measurements

For both Experiments I and II, sampling dates corresponded to treatment mowing times in 2016.. At each sampling date, forage was mowed to 5 cm stubble height in six randomly placed 1 × 1 m sampling quadrates within each plot. Mowed forage was gathered and transferred to the laboratory in an ice box. Samples of mowed forage were weighed fresh and then dried at 65 °C for 72 h in a forced-air drying-oven to a constant weight (to quantify DM%), ground to pass through a 1-mm screen (Wiley mill, Arthur H. Thomas, Philadelphia, PA, USA) and ground samples stored at 4 °C prior to determining nutrient composition. In Experiment I, the pre-mowing DM yield (pDMY) was the DM of forage material collected at each initial date, whereas the regrowth DM yield (rDMY) was the DM harvested at the end of the 2016 growing season (September 30). The cumulative DM yield (cDMY) per treatment in Experiment I was calculated by adding pDMY and rDMY of year 2016. The accumulated DM yield was calculated for every treatment in Experiment II by summing total DM yields of all sampling dates in 2016 and the nutritive value was calculated for every treatment by averaging nutritive value of all sampling dates.

2.4 | Nutritive value analysis

Total nitrogen (N) content was determined by C/N analyzer (Vario Max CN; Elementar Analysesysteme, Hanau, Germany), based on the DUMAS combustion method and thereafter, CP content was calculated (6.25 × N). Pre-mowing CP yield (pCPY) was calculated by pDMY × CP content, whereas regrowth CP yield (rCPY) was calculated by rDMY × CP content. The cumulative CP yield (cCPY) was calculated by summing pCPY and rCPY of all sampling dates in 2016. Both NDFom and ADFom were determined by the method of Van Soest, Robertson, & Lewis (1991) and expressed exclusive of residual ash. Samples for ash analysis were put in a muffle furnace at 500 °C overnight (AOAC, 1990). Total ether extract (EE) content was measured using Foss Soxtec 2043 Fat Extraction System (Foss Tecator AB, Eden Prairie, MN, USA).

2.5 | Statistical analyses

Six randomly mowed samples in each pot were averaged as one replicate for DM yield and 3 replicates (3 plots) were then used in the data analysis. Regression analysis was used to expose the changes of chemistry components, DM yield and crude protein yield for *L. chinensis* with initial mowing time and mowing frequency (Best-fit equation curve was based on highest r^2). Significance for all statistical tests was defined as $P \leq 0.05$. All data were analyzed using SAS 9.1 (SAS 2002).

3 | RESULTS

3.1 | DM Yield under various initial mowing times

As the initial mowing time was delayed, pDMY ($P = 0.001$) and cDMY ($P = 0.005$) of *L. chinensis* increased quadratically and peaked with initial mowing dates ranging from July 15 to August 15 initial (**Figure 2a, c**). However, pDMY and cDMY of *L. chinensis* decreased after August 15. Initial mowing on May 15 or June 1 yielded peak rDMY of *L. chinensis* and as initial mowing was delayed, rDMY decreased linearly ($P = 0.002$; **Figure 2b**). Furthermore, as the initial mowing was delayed, pCPY ($P = 0.01$) and cCPY ($P = 0.006$) of *L. chinensis* increased quadratically, with maximum pCPY and cCPY achieved with initial mowing from June 1 to August 15 (**Figure 2d, f**). In addition, initial mowing time quadratically affected rCPY of *L. chinensis* ($P = 0.027$), with peak yield at June 1 (**Figure 2e**). As initial mowing time was delayed from May 15 to Sep 30, the DM yield of *L. chinensis* in 2017 increased linearly (P = 0.02), with its lowest value (158.2 g. m^{-2}) on May 15 (**Figure 3**).

3.2 | Nutritive Value of *L. chinensis* under various initial mowing times

As the initial mowing was delayed, both CP and ash contents in pDMY of *L. chinensis* decreased cubically (P = 0.002), whereas NDFom (P = 0.001) and ADFom (P < 0.001) contents increased cubically (**Figure 4a, b, c and e**). Furthermore, CP, NDFom, ADFom and ash contents in pDMY of *L. chinensis* changed slowly during July 1 to August 1 initial mowing, but they increased or decreased rapidly before and after this interval. Initial mowing time affected the EE content in pDMY of *L. chinensis* quadratically with lowest values (P < 0.001) when initial mowing was done June 1 to July 1 (**Figure 4d**). It was noteworthy the CP (P < 0.001) and ash (P = 0.022) contents in rDMY of *L. chinensis* increased linearly, whereas the NDFom (P < 0.001), ADFom (P = 0.001) and EE (P = 0.001) contents decreased linearly (**Figure 4f-k**).

3.3 | DM yield under various mowing frequencies

Mowing frequency changed the accumulated DM yield *L. chinensis* cubically (P = 0.032) with the lowest and highest values when mowing two and three times, respectively (**Figure 5a**). However, as mowing frequency increased, the accumulated CP yield increased cubically (P = 0.020) with maximum value achieved when mowing four times (**Figure 5b**). Furthermore, the accumulated CP yield of *L. chinensis* had no obvious variation when mowing from three to five times. The accumulated DM yield of *L. chinensis* in 2017 decreased cubically (P = 0.010) as mowing frequency was increased (**Figure 6**).

3.4 | Nutritive Value of *L. chinensis* under various mowing frequencies

As the mowing frequency increased, both average CP (P < 0.001) and ash (P = 0.017) contents of *L. chinensis* increased linearly whereas average NDFom (P = 0.003), ADFom (P = 0.032) and EE (P = 0.010) contents decreased linearly (**Figure 7**). Furthermore, more mowing frequencies (mowing three, four and five times) obviously increased the nutritive value of *L. chinensis* compared to limited mowing (mowing one and two times).

4 | DISCUSSION

4.1 | How Did Initial Mowing Time Affect DM Yield and Nutritive Value of *L. chinensis* ?

In previous studies, initial mowing in May or June decreased forage yields of various species compared to mowing in September (Kennedy, O'Donovan, Murphy, Delaby, & O'Mara, 2007; McIntosh et al., 2015; Song, Wu, & Zhou, 2018). Similarly, in the present study, the pDMY of *L. chinensis* was lowest (38.8 g.m^{-2}) for a May 15 initial mowing compared to other treatments. Besides, pDMY of *L. chinensis* almost doubled, whereas cDMY of *L. chinensis* only increased 1.3 times from a June 1 to August 15 initial mowing, attributed to a decrease in rDMY of *L. chinensis* when initial mowing was delayed from June 1 to August 15. In this study, DM yield for initial mowing treatment of May 15 was lower compared to an initial mowing treatment of June 1. Premature mowing consumed nutrient reserves in the rhizome and negatively affected regrowth of *L. chinensis* (Li, Kemp, & Hodgson, 2000; Zhang, Shao, Chen, Zhang, & Wang, 2013; Zhao, Chen, Han, & Lin, 2009).

It is well known that initial mowing influences yield and forage nutritive value (Ball et al., 2015). Nutritive value and forage maturity are important considerations when forages are harvested as hay (Delaby, & Peyraud, 2004; Waramit, Moore, & Fales, 2012). The CP concentration of pDMY of *L. chinensis* was halved from 10.79 to 4.86%, and the pDMY was doubled, which resulted in a similar pCPY and cCPY for June 1 vs. August 15 initial mowing treatments. This was consistent with previous studies that the DM yield of *L. chinensis* was generally negatively related to its nutritive value in various initial mowing time treatments (Donaghy et al., 2008; Zhai et al., 2018). In this study, nutritive value of rDMY of *L. chinensis* increased as initial mowing time was delayed from May 15 to September 1. An early initial mowing (e.g. May 15) allowed the plant to have enough time to mature and it accelerated its phenological process to complete its physiological cycle, which increased deposition of lignified material (Acosta-Gallo, Casado, Montalvo, & Pineda, 2011). Overall, for hay production, an initial mowing between July 15 and August 15 seemed to be optimal to maximize cDMY and cCPY.

4.2 | How Did Mowing Frequency Affect DM Yield and Nutritive Value of *L. chinensis* ?

The CP concentration generally increased as mowing frequency increased, whereas forage NDFom and ADFom concentrations were generally decreased. This was consistent with other studies (Donaghy et al., 2008; Fanselow et al., 2011; Hockensmith, Sheaffer, Marten, & Halgerson, 1997). Furthermore, in present study, cDMY of *L. chinensis* was highest for three or four mowings but it was lower when mowed once, twice or five times yearly, in agreement with previous studies (Loeser, Crews, & Sisk, 2004; Turner, Seasteadt, & Dyer, 1993; Walter, Grant, Beierkuhnlein, Kreyling, & Jentsch, 2012; Zhao, Chen, & Lin, 2008). Therefore, a moderate mowing frequency caused a increased DMY of grasslands. Although our hypothesis that DMY increases as mowing frequency increases was rejected, we inferred that forage should be mowed often to enhance forage yield and nutritive value in *L.chinensis* grassland of Songnen plain. In contrast, Guo et al. (2012) and Baoyin et al. (2014) reported that cumulative DMY of *L. chinensis* grassland was highest with mowing once a year compared to frequent mowing in typical steppes of northern China. Perhaps more frequent mowing enabled residual leaves to have better access to light, which simulated plant photosynthesis (Bork, Broadbent, &, Willms, 2016; Liu et al., 2018; Turner, Donaghy, Lane, & Rawnsley, 2006). In the present study, increased CP content and CP yield of *L. chinensis* when mowed three-five times a year compared to only once a year supported this interpretation. In that regard, N-content of plant leaves are strongly related to photosynthetic capacity (Schiborra et al., 2009; Vinther, 2010). However more frequent mowing (i.e. mowing five times yearly) reduced overall photosynthetic capacity and thereby reduced DMY and CPY of *L. chinensis* (Li et al., 2015; Oesterheld, & McNaughton 1991). Mowing three times resulted in an optimal DMY in 2017 (following year). Therefore, if the production cycle is between June the first year and August the following year, mowing three times a year is the best strategy to optimize quality and quantity of *L. chinensis.*

4.3 | How Did Interaction of Initial Time and Frequency Affect DM Yield and Nutritive Value of *L. chinensis*?

In previous studies, initial mowing time and frequency had no interaction on accumulated DM yield and CP yield of grasses in perennial grassland (Donkor, Bork, & Hudson, 2003; Lawrence, O’Donovan, Boland, & Kennedy, 2017), whereas their interaction between initial mowing time and frequency was observed on CP content in a perennial ryegrass sward in Ireland (Kennedy, O'Donovan Murphy, O'Mara, & Delaby, 2006). Although both initial mowing time and frequency had strong effects on accumulated DM yield and CP content of grasses, accumulated CP yield *L. chinensis* was not significant, because the increase in DM yield was offset by decrease in CP content as initial mowing time was delayed from June to August. In a previous study, forage DM yield was increased 1.6 times, whereas CP content of forage was decreased 1.3 times as the initial mowing was delayed from the boot to dough stages (Holman, Obour, Roberts, & Maxwell, 2018). Furthermore, mowing frequency had a strong effect on accumulated CP yield of grasses; in a previous study, accumulated DM yield and CP content of both *Cenchrus ciliaris* L. and *Chloris gayana* K. in the Borana rangelands, southern Ethiopia increased as mowing frequency increased (Tuffa, Hoag, & Treydte, 2017). However, in the present study, this increase was not significant when mowing more than three times yearly. Therefore, we inferred that increased CP content of *L. chinensis* compensated for decreased DM yield, indicating a ceiling in forage CP yield accumulation with more frequent mowing. In our studies, we separately studied initial mowing date and mowing frequency. Conversely, the accumulated CP yield was a more important variable for producers to assess and the interaction between initial mowing time and frequency on accumulated CP yield may not be significant. In addition, in an effort to characterize an interaction between initial time and frequency of mowing, it is simply not possible to include all initial mowing times and frequencies due to limitations inherent in the *L. chinensis* growing season.

5 | CONCLUSION

Base on the current study, an initial mowing between July 15 and August 15 maximized cDMY and cCPY of hay made from *L. chinensis*. Further, mowing three times a year was the best strategy to optimize quality and quantity of *L. chinensis.*

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TABLE 1 Soil characteristics in study area.

Soil characteristics							
pH	Na^+ (mg kg^{-1})	HCO_3^- (mg kg^{-1})	CO_3^{2-} (mg kg^{-1})	SWC (%)	SOC (g kg^{-1})	TN (g kg^{-1})	TP (g kg^{-1})
8.99	1196.7	4188.7	504.5	10.39	10.04	0.91	0.22

Abbreviations: SWC, soil water content; SOC, soil organic carbon; TN, total nitrogen content; TP, total phosphorus content.

FIGURE 1 Precipitation and temperature distribution map of Songnen Plain in 2016 (a) and 2017 (b).

FIGURE 2 The pDMY (a), rDMY (b), cDMY (c) and pCPY (d), rCPY (e), cCPY (f) of *Leymus chinensis* in response to various initial mowing times (all had a second mowing on Sept 30, 2016). pDMY, the pre mowing dry matter (DM) yield in initial mowing time; rDMY, the regrowth DM yield in second mowing on Sept 30, 2016; cDMY, the cumulative DM yield; pCPY, the pre mowing crude protein (CP) yield; rCPY, the regrowth CP yield; cCPY, the cumulative CP yield.

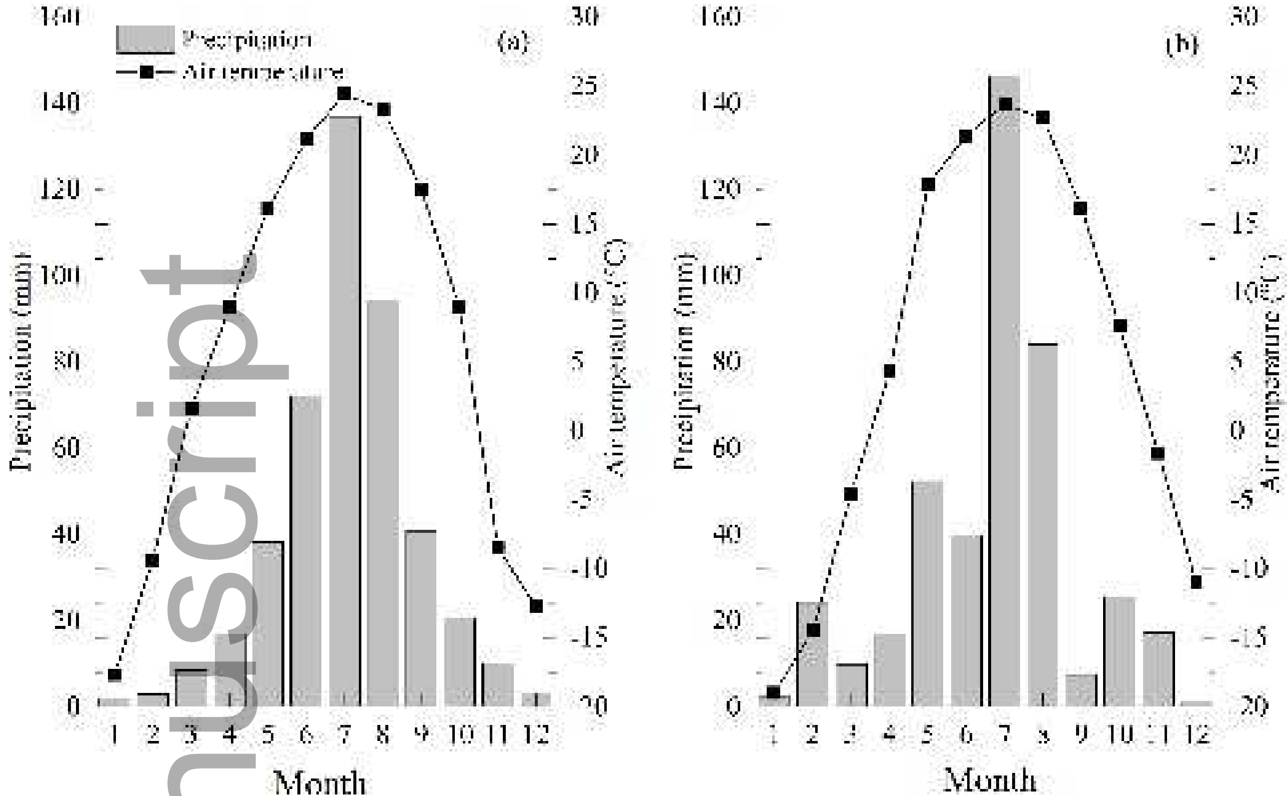
FIGURE 3 Mean (± SD) dry matter (DM) yield of *Leymus chinensis* in 2017 after various initial mowing times in 2016.

FIGURE 4 The crude protein (CP), neutral detergent fiber (NDFom), acid detergent fiber (ADFom), ether extracts (EE) and ash contents of pDMY (a-e) and CP, NDFom, ADFom, EE and ash contents of rDMY (e-k) of *Leymus chinensis* in response to various initial mowing times and each with a second mowing on Sept 30, 2016. pDMY, the pre mowing DM yield in initial mowing time; rDMY, the regrowth DM yield in second mowing on Sept 30, 2016.

FIGURE 5 Mean (± SD) accumulated dry matter (DM) yield (a) and crude protein (CP) yield (b) of *Leymus chinensis* response to various mowing frequencies (1, 2, 3, 4 and 5) (horizontal axis) in 2016.

FIGURE 6 Mean (± SD) dry matter (DM) yield of *Leymus chinensis* in 2017 after various mowing frequencies (1, 2, 3, 4 and 5) (horizontal axis) in 2016.

FIGURE 7 The average crude protein (CP), neutral detergent fiber (NDFom), acid detergent fiber (ADFom), ether extracts (EE) and ash contents of *Leymus chinensis* for various mowing frequencies (1, 2, 3, 4 and 5) (horizontal axis) in 2016.



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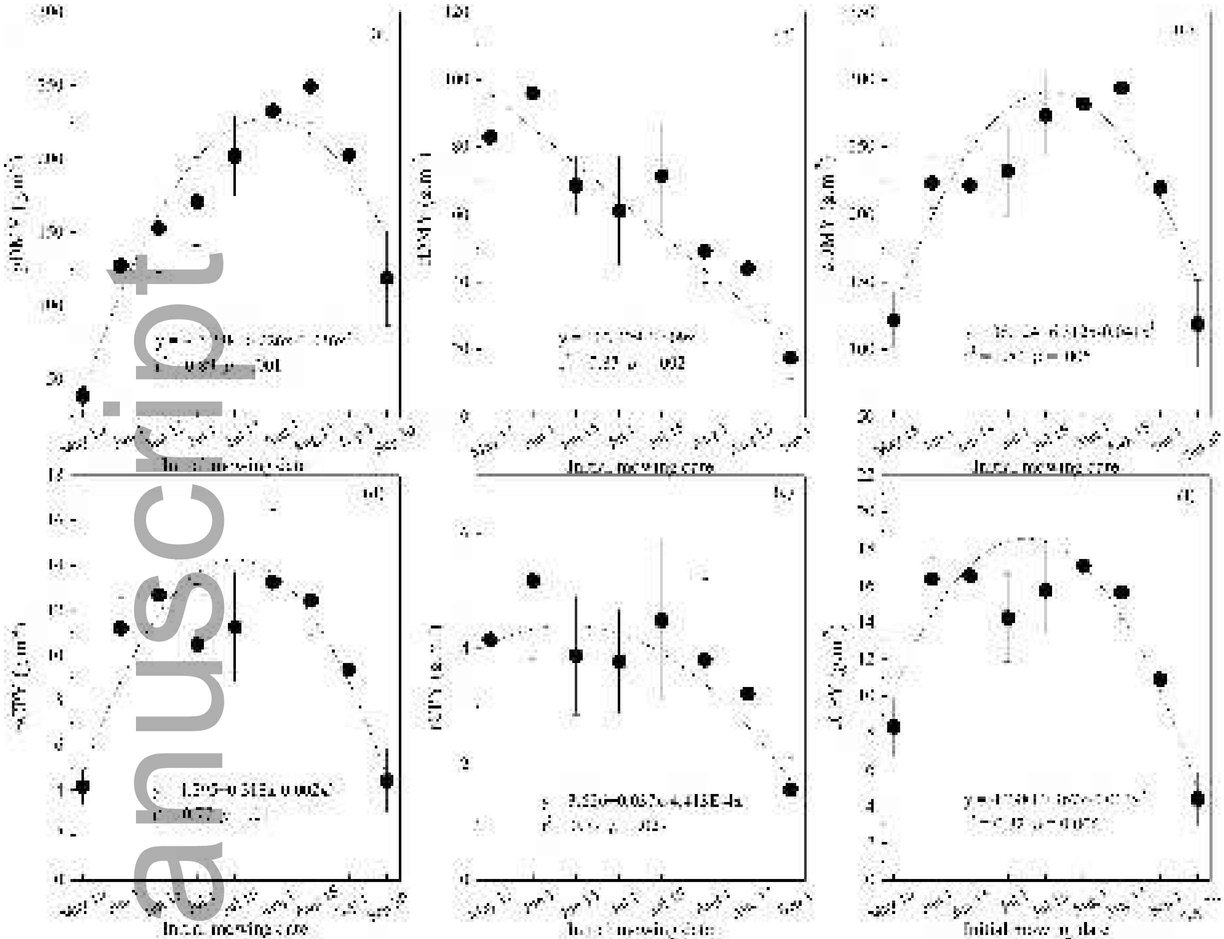

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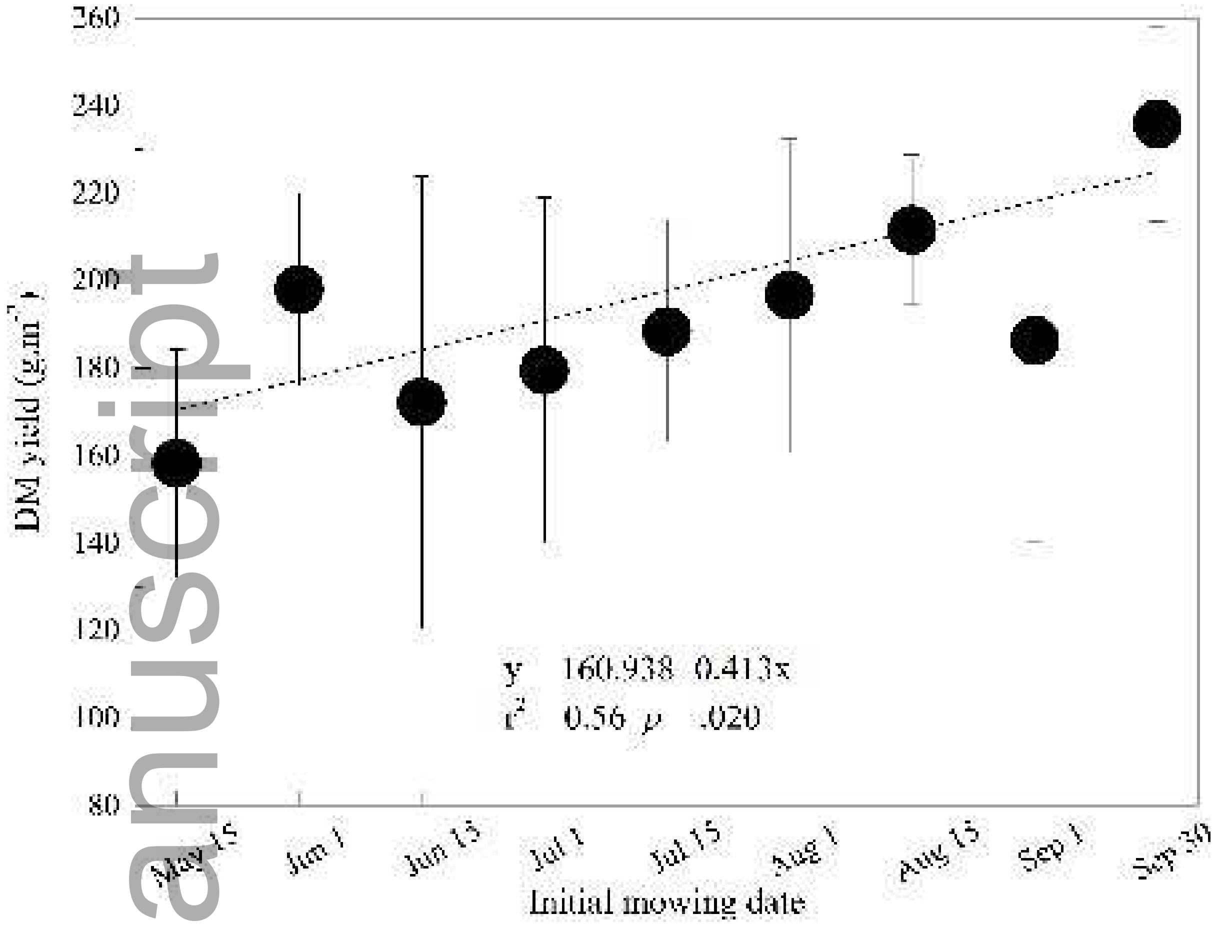

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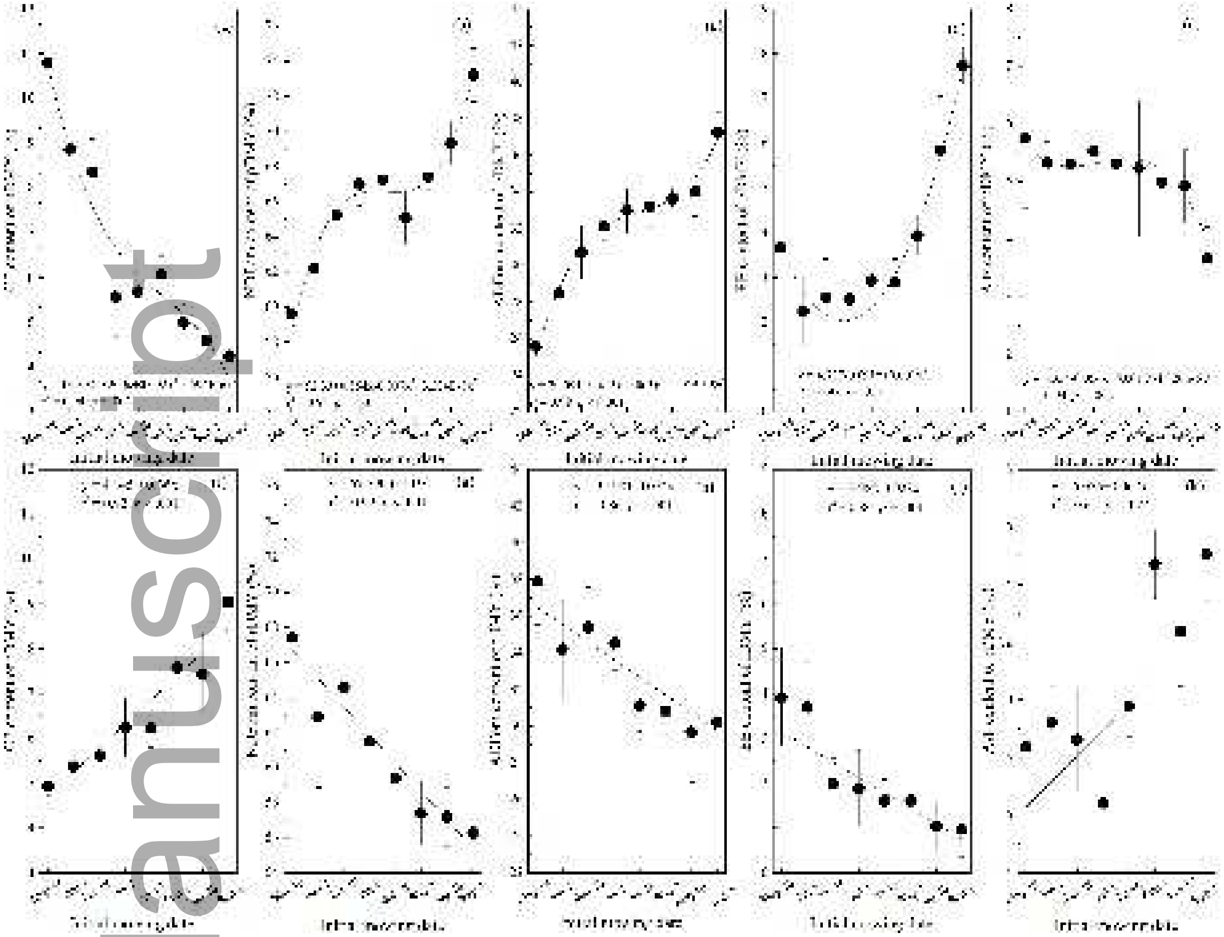

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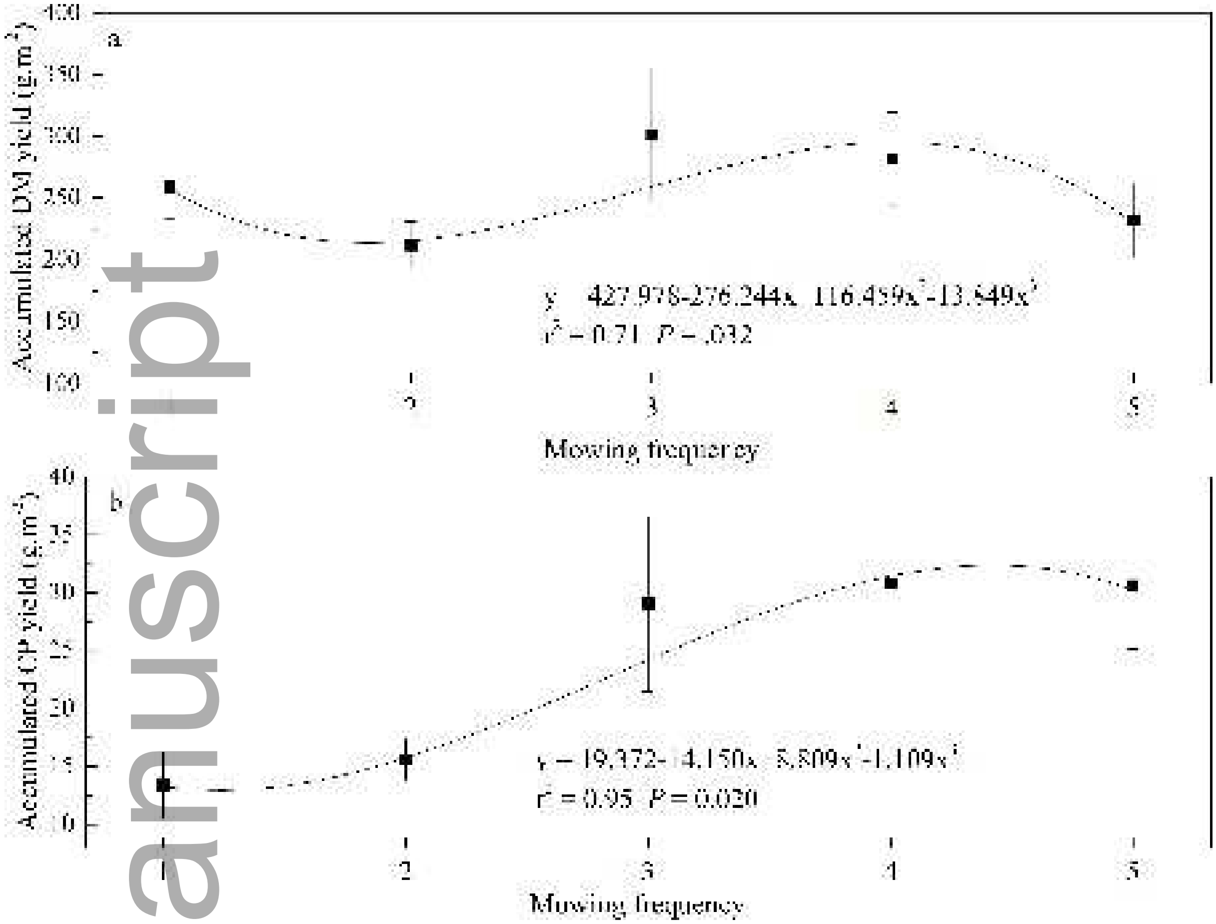

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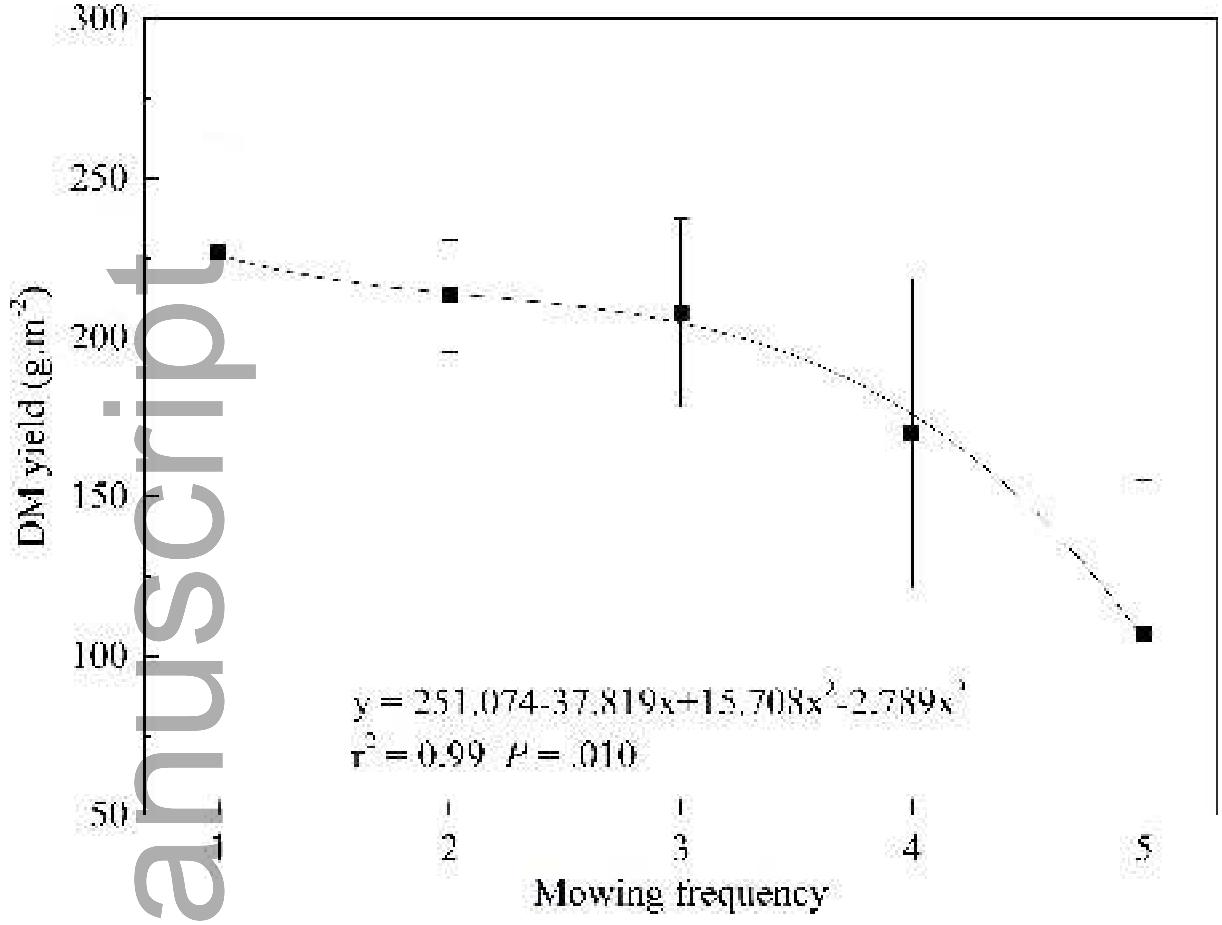

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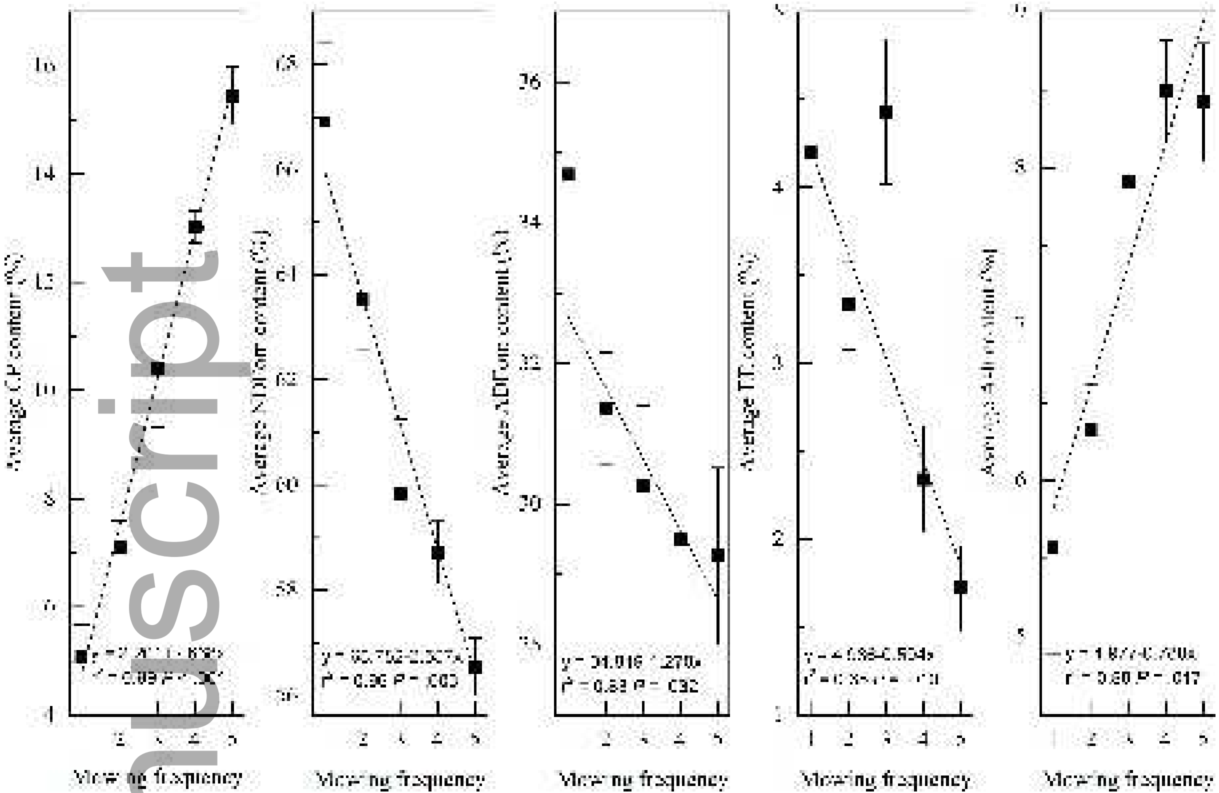

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