The effect of planting date on thermal indices and dry matter yield of different clover genotypes

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Abstract

This study aimed to investigate the changes in thermal indices of various clover genotypes under cold stress. A field experiment was conducted to evaluate the effect of different planting dates (14 Sep., 28 Sep., and 8 Oct.) and clover genotypes (late-maturity Persian clover, mid-maturity Persian clover, early-maturity Persian clover, berseem clover, red clover, and crimson clover). The results showed that delaying the planting date from September 14 to October 8 caused a significant decrease in growing degree-day (GDD), photothermal index (PTI), and heat use efficiency (HUE) in all studied genotypes. Early-maturity Persian clover and crimson clover had the lowest thermal requirements while red clover had the highest GDD in all the investigated planting dates. During the first cut, the early-maturity Persian clover demonstrated the highest HUE (4.09 kg ha^{-1} ℃ days), followed by crimson clover. In contrast, red clover recorded the lowest HUE (1.43 kg ha^{-1} ℃ days) on the last planting date. Early-maturity Persian clover and crimson clover may be preferred for forage production under cold stress because of their higher HUE values. The highest dry matter yield of the first cut (6300 kg ha^{-1}) was obtained on the first planting date and by mid-maturity Persian clover while the lowest yield (2429 kg ha^{-1}) was obtained on the last planting date and by red clover. Overall, delayed planting dates resulted in accelerated development and decreased thermal requirements in clover species. The early-maturity genotypes were found to be more suitable for forage production under environmental stresses such as water shortages.

Keywords: trifolium, growing degree-day (GDD), growth rate, heat use efficiency (HUE), photothermal index (PTI)

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Introduction

Clover (*Trifolium* spp.) is an important and productive forage legume grown in temperate regions worldwide and is distinct from other forage crops owing to its unique properties, including its ability to fix atmospheric nitrogen in the soil through a symbiotic relationship with nitrogen-fixing bacteria, which can reduce the need for nitrogen fertilizers and improve soil health (Ashoori et al., 2021). Clover also has a high protein content and is highly palatable to livestock, making it an important component of many grazing systems. Additionally, clover has been shown to have positive effects on soil erosion control, weed suppression, and

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biodiversity conservation (Bakhtiyari et al., 2020, Balazadeh et al., 2021).

Climate is one of the uncontrollable factors that significantly influence the growth and development of crops (Dinari et al., 2013; Shahrusvand et al., 2020; Pakbaz et al., 2022). Temperature, among other climatic factors, has the most substantial impact on crop development, phenological stages such as flowering, and crop yield (Iannucci et al., 2008). Crops require a certain amount of heat to reach each developmental stage, as per the principle of thermal stability (Nleya et al., 2020; Mirahki et al., 2023). Given the variability of day length and daily temperature, the use of thermal indices, particularly GDD are necessary to estimate crop phenological stages (Butler et al., 2002). Therefore, it is crucial to determine the thermal indices of different phenological stages to exploit the maximum potential of crop production (Mirahki et al., 2023). Growing degree-day (GDD), photothermal index (PTI), and heat use efficiency (HUE) are the most important thermal indices, calculated based on temperature and day length, and are used to predict the phenological stages and yield of crops (Butler et al., 2002; Iannucci et al., 2008; Kumar et al., 2012; Aktar-Uz-Zaman et al., 2022).

Papastylianou and Bilalis (2011) reported that Persian clover requires 322 to 379 ℃ days fewer GDD and 144 to 173 ℃ days day^{-1} fewer PTI to reach the early and full flowering stages than Sulla. Shamsi et al. (2011) reported that different phenological stages of chickpea varieties require specific amounts of GDD and HUE. Alizadeh and Jafari (2011) found that *Dactylis glomerata* ecotypes had a higher heat requirement at the vegetative growth stage than at the flowering stage under cold stress, indicating no effect of cold on the amount of GDD required at the seedling and vegetative growth stages. Kingra and Kaur (2012) reported that HUE increased from vegetative growth to grain filling and physiological maturity in peanuts. They also found that delayed planting reduced HUE, with the highest and lowest values of HUE related to the first and last planting dates, respectively. The PTI decreased gradually from emergence to maturity, with the highest amount occurring at the emergence stage and the lowest at the maturity stage. Also, among the three planting dates, the highest and lowest PTI were recorded for January 1 and July 10, respectively (Kingra and Kaur, 2012). Anil et al. (2008) investigated the growth and yield responses of soybean to temperature and photoperiod and found that HUE increased with increasing crop age and delayed planting. Butler et al. (2002) conducted a study on the effect of planting date on the thermal indices of various cultivars of crimson clover and found that Tibbee required fewer GDD and PTI units than Columbus. The study also revealed that delayed planting date resulted in decreased GDD and PTI values (Butler et al., 2002). In a more recent study, Jan et al. (2022) found that transplanting 22-day-old seedlings and applying poultry manure resulted in higher HUE, indicating a more efficient use of thermal energy for biomass production. Sarparast and Alipour Nakhi (2021) investigated the impact of different planting dates ranging from July 23 to September 6 on the thermal indices of fava bean and found that the highest HUE was observed in crops planted on August 6, indicating that this may be the optimal planting date to maximize the thermal efficiency of fava bean production.

Clover holds a crucial position in forage production in Iran (Bakhtiyari et al., 2020; Ashoori et al., 2021), and therefore, determining its accurate ecological requirements is essential for successful crops and maximum forage production (Balazadeh et al., 2021). Estimating the growth period of different clover species based on thermal indices is crucial in identifying suitable areas for cultivation and developing effective crop management strategies. The objective of the present study was to estimate the thermal indices that affect the phenological stages and yield of clover genotypes at different planting dates in a semi-arid region of Iran, with the aim of optimizing climatic factors for higher forage production.

Materials and Methods

This study was conducted at the Seed and Plant Improvement Institute, Karaj, Iran (N 35°59', E 51°6', 1321 m above sea level) during two cropping seasons (2019-2021). The study region has a cold and semi-cold arid climate. The average annual temperature is 14.97 ℃, with the maximum temperature occurring in July and August, and the

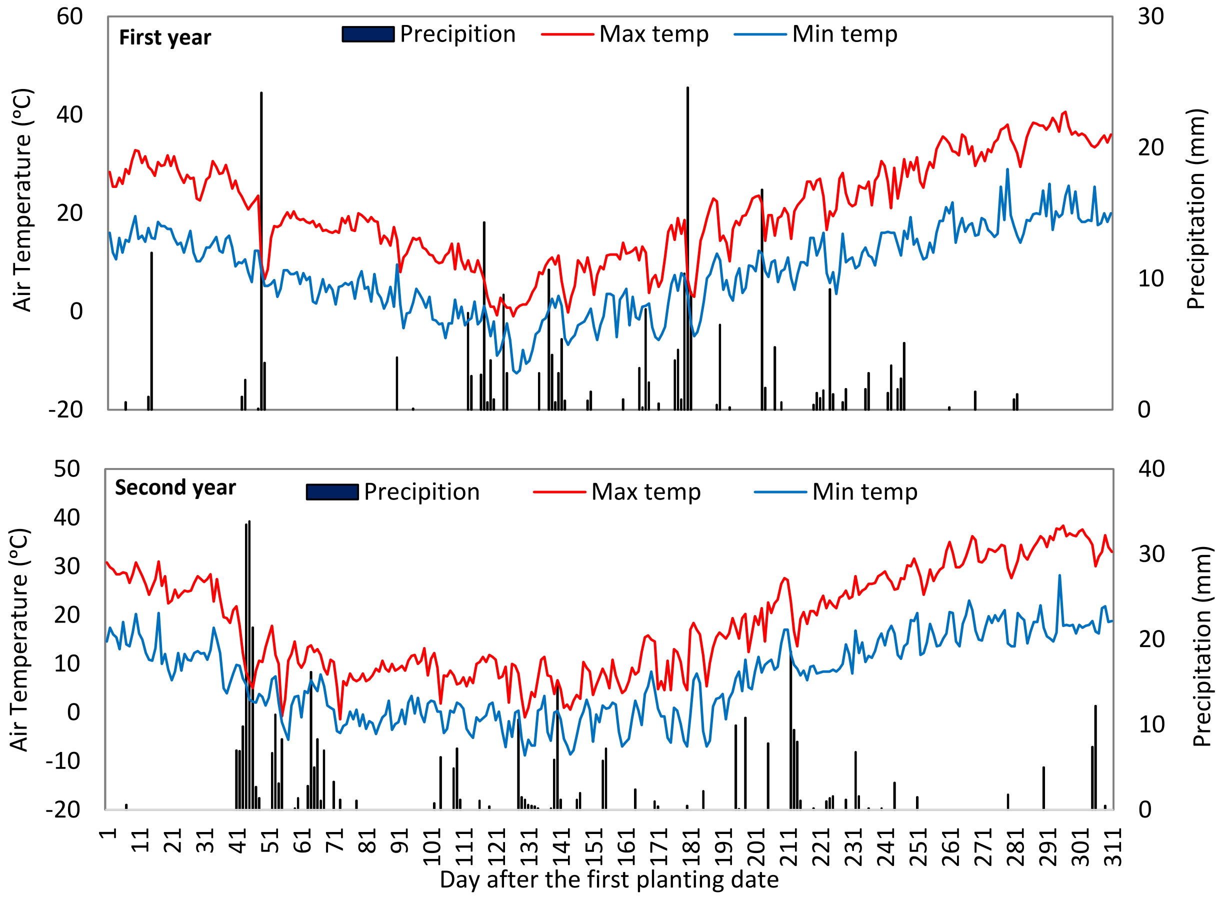

Fig. I. Daily maximum and minimum air temperatures (°C) and precipitation (mm) during the growing seasons

Table 1
Number of frost days and number of sunny days during the growing seasons

Months	Year	Number of Sunny Days	Number of Frost Days	Months	Year	Number of Sunny Days	Number of Frost Days
September	1st	31	0	March	1st	25	12
	2nd	31	0		2nd	27	17
October	1st	30	0	April	1st	29	2
	2nd	30	0		2nd	30	0
November	1st	28	0	May	1st	29	0
	2nd	23	4		2nd	30	0
December	1st	30	3	June	1st	31	0
	2nd	29	20		2nd	31	0
January	1st	26	24	July	1st	31	0
	2nd	26	15		2nd	31	0
February	1st	28	21	August	1st	31	0
	2nd	28	17		2nd	31	0

minimum in January. On average, the highest number of frost days occurs in December and January, with an average of 19.5 frost days. The average rainfall over 30 years is 240 mm, with the most rainfall occurring in late autumn and early spring, and the lowest rainfall in July and August, and the highest in April and November. The meteorological characteristics of the study site during two cropping seasons, including maximum and minimum temperatures and rainfall, are shown in Fig. I. Mean temperatures during the first, second, and third planting dates were 22.4, 19.7, and 18.8 ℃, respectively. Table 1 shows the number of frost days observed during the two

Table 2
Physico-chemical properties of soil at the experimental site during two growing seasons

Year	Depth	Soil Texture	EC (dS m^{-1})	pH	O.M. (%)	N (%)	P (mg kg^{-1})	K (mg kg^{-1})
First	0-20	Loam	3.52	8.10	0.92	0.10	18.7	163.1
	20-40	Loam	2.45	8.16	0.96	0.09	24	155.2
Second	0-20	Loam	4.10	8.10	0.90	0.07	19.3	165.2
	20-40	Loam	2.51	8.20	0.95	0.05	23.00	150.8

EC: electrical conductivity, O.M.: organic matter, N: total nitrogen, P: available phosphorus, K: available potassium

Table 3
Name and origin of clover genotypes

Clover Specie	Scientific Name	Genotype Name	Origin	Growth Type
Persian	*Trifolium resupinatum* L.	KPC-PL	Iran	Late-maturity
Persian	*Trifolium resupinatum* L.	KPC-PM	Iran	Mid-maturity
Persian	*Trifolium resupinatum* L.	KPC-PE	Iran	Very early-maturity
Berseem	*Trifolium alexsandrinum* L.	KBC-Toli. K	Italy	Late-maturity
Red	*Trifolium pratense* L.	Nassim	FAO	Late-maturity
Crimson	*Trifolium incarnatum* L.	Alborz1	FAO	Very early-maturity

cropping seasons. The physico-chemical properties of the soil at the experimental site are presented in Table 2.

A field experiment was conducted as split plots based on a randomized complete block design with four replications. Planting date was considered the main factor, with three levels (14 September, 28 September, and 8 October), and clover genotypes were considered as the sub-factor, with six levels (late-maturity Persian clover, mid-maturity Persian clover, early-maturity Persian clover, berseem clover, red clover, and crimson clover). Table 3 presents the characteristics of the clover genotypes. Each plot consisted of four rows measuring 0.5 m wide and 10 m long. Persian and red clover were sown at a rate of 20 kg ha^{-1} while berseem and crimson clover were sown at a rate of 25 kg ha^{-1}. According to the soil analysis result, 90 kg P_2O_5 ha^{-1} and 40 kg N ha^{-1} were supplied before planting. The criteria for the occurrence and recording of each stage of growth and forage yield harvest at each planting date were the mean of those stages in each plot. The GDD was calculated by recording the growth stages and having day-night time temperatures. The two-year average of the number of days and temperatures required for each growth stage was the criterion for GDD. The GDD was calculated using the following formula (Singh et al., 2014):

$$GDD = \Sigma \{[(T_{max} + T_{min}) / 2] - T_{base}\}$$

where T_{max}, T_{min}, and T_{base} are the daily maximum and minimum temperatures and also the base temperature (5 ℃), respectively. The following formulas were used to measure PTI (℃ days day^{-1}) and HUE (kg ha^{-1}/℃ days) indices (Singh et al., 2014):

HUE = Dry matter yield / GDD

PTI = GDD / Growth days

The effective temperature summation method was employed in this study, where temperatures below 5 and above 30 ℃ were considered ineffective and assigned values of 5 and 30 ℃, respectively (Nleya et al., 2020). Bartlett's test results indicated homogeneity of experimental error variances over two years, and therefore, combined analysis of variance was performed. Since the interaction between year and treatment on traits was not significant, an average of the two seasons was reported, with the year treated as a random effect. Statistical analysis was carried out using SAS 9.1 statistical software, and mean values were compared using the LSD method at the 5% probability level.

Results

Growing degree days (GDD)

GDD was found to be significantly influenced by planting date, genotype and their interaction, as

Table 4
Analysis of variance of thermal indices as affected by experimental treatments

Sources of Variation	df	GDD	PTI	HUE	Dry Matter Yield
Year	1	195300	4.80	1.92	5828120
Replication (Year)	6	129312	2.37	0.531	987734
Planting date	2	766742*	21.3*	16.28*	75314494**
Year × Planting date	2	39038	1.06	0.67	8084860
Error (a)	12	43366	0.810	0.330	6113713
Genotype	5	2834444**	16.68**	6.58**	5173527*
Year × Genotype	5	2725	0.817	0.06	866441
Planting date × Genotype	10	9814**	0.284**	0.428*	1697495*
Year × Planting date × Genotype	10	46	0.029	0.102	494258
Error (b)	90	1442	0.027	0.287	650833
Coefficient of variation (%)	-	5.43	5.48	8.63	12.76

* and **: significant at the 5% and 1% probability levels, respectively.

Table 5
Mean comparison of growing degree-days (GDD, ℃ days) required for forage production of clover genotypes in different cuts

Treatment	To the First Cut	To the Second Cut	To the Third Cut
Genotype			
Late-maturity Persian clover (KPC-PL)	1839[b]	2360[b]	2676[b]
Mid-maturity Persian clover (KPC-PM)	1755[c]	2223[c]	2504[c]
Early-maturity Persian clover (KPC-PE)	1130[e]	-	-
Berseem clover (Karaj)	1632[d]	2178[d]	2513[c]
Red clover (Nassim)	1892[a]	2512[a]	3000[a]
Crimson clover (Alborz1)	1143[e]	-	-

In each column and for each factor, means followed by the same letters are not significantly different at the 5% probability level.

shown in Table 4. Results indicated that red clover had the highest GDD for the first, second, and third cuts (1892, 2512, and 3000 ℃ days) while early-maturity Persian clover had the lowest heat requirement for forage production, with 1130 ℃ days (Table 5). Based on the GDD, clover genotypes were classified into three groups: the late-maturity group including Persian clover cv. KPC-PL and red clover cv Nassim (2676 and 3000 ℃ days, respectively), the mid-maturity group including Persian clover cv. KPC-PM and berseem clover cv. KBC-Toli. K (2504 and 2513 ℃ days, respectively), and the early-maturity group including Persian clover cv. KPC-PE and crimson clover cv. Alborz1 (1130 and 1143 ℃ days, respectively) (Fig. II).

Results indicated that the cold stress resulting from delayed planting reduced the thermal requirement of genotypes. Compared to the first planting date, the second and third planting dates reduced GDD by 5.5 and 10.6%, respectively (Fig. III). In all genotypes studied, a delay in planting led to a decrease in the required GDD. However, the

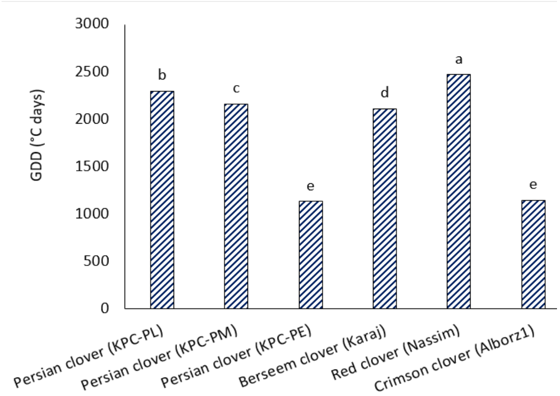

Fig. II. Growing degree-day (GDD) in clover genotypes

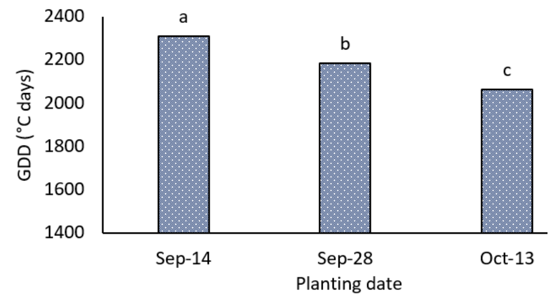

Fig. III. Growing degree-day (GDD) in different planting dates

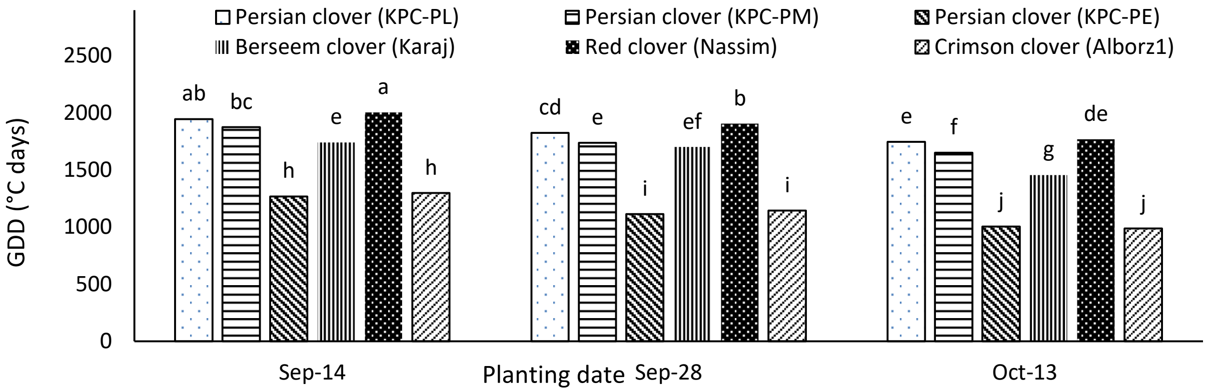

Fig. IV. Interaction effect of planting date and genotype on the growing degree-days of clover

Table 6
Mean comparison of photo thermal index (PTI, ℃ days day^{-1}) for forage production of clover genotypes in different cuts

Genotypes	To first cut	To second cut	To third cut
Late-maturity Persian clover (KPC-PL)	7.28^{a}	8.41^{b}	9.08^{b}
Mid-maturity Persian clover (KPC-PM)	7.10^{b}	8.12^{c}	8.71^{d}
Early-maturity Persian clover (KPC-PE)	5.56^{d}	-	-
Berseem clover (Karaj)	6.87^{c}	8.11^{c}	8.88^{c}
Red clover (Nassim)	7.33^{a}	8.62^{a}	9.57^{a}
Crimson clover (Alborz1)	5.57^{d}	-	-
Mean	6.62	8.32	9.06

In each column and for each factor, Means followed by same letters are not significantly different at the 5% probability level.

amount of reduction varied among genotypes, with the greatest reduction in GDD observed in crimson clover (24.0%), followed by Persian clover cv. KPC-PE (20.7%). Across all planting dates, red clover had the highest thermal requirement followed by Persian clover cv. KPC-PL while the lowest GDD was recorded in crimson clover and Persian clover cv. KPC-PE (Fig IV).

Photo thermal index (PTI)

PTI was found to be influenced by planting date, genotype, and planting date × genotype interaction, as shown in Table 4. PTI also varied across different cuts, with the lowest and highest values recorded in the first and third cuts, respectively (Table 6). Maturity period also affected PTI, with crimson clover cv. Alborz1 and Persian clover cv. KPC-PE exhibiting the lowest PTI (5.57 and 5.56 ℃ days day^{-1}, respectively) in the first cut due to their early maturity and shorter growth period, whereas red clover and Persian clover cv. KPC-PL had the highest PTI (7.33 and 7.28 ℃ days day^{-1}, respectively) (Table 6). Results also indicated that the difference between clover species in terms of the PTI was more pronounced in the first and third cuts compared to the second cut. Red clover and late-maturity Persian clover had the highest PTI while early-maturity Persian clover and crimson clover had the lowest PTI (Fig. V). Cold stress resulting from delayed planting reduced the PTI of genotypes, with the highest and lowest PTI (8.14 and 7.80 ℃ days day^{-1}, respectively) observed in the first and third planting dates, respectively (Fig. VI). The highest

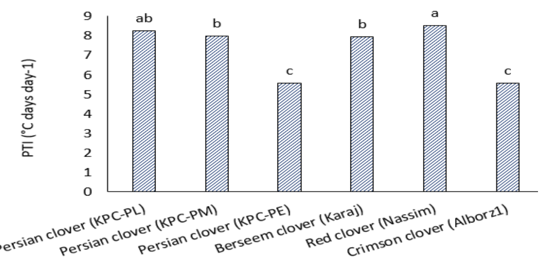

Fig. V. Photo thermal index (PTI) in clover genotypes

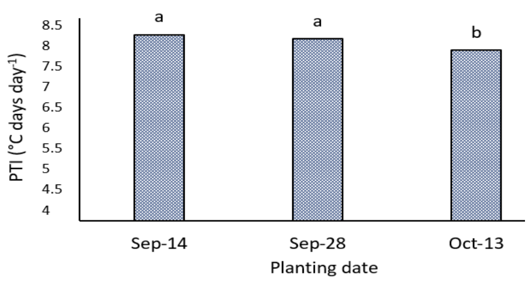

Fig. VI. Photo thermal index (PTI) in different planting dates

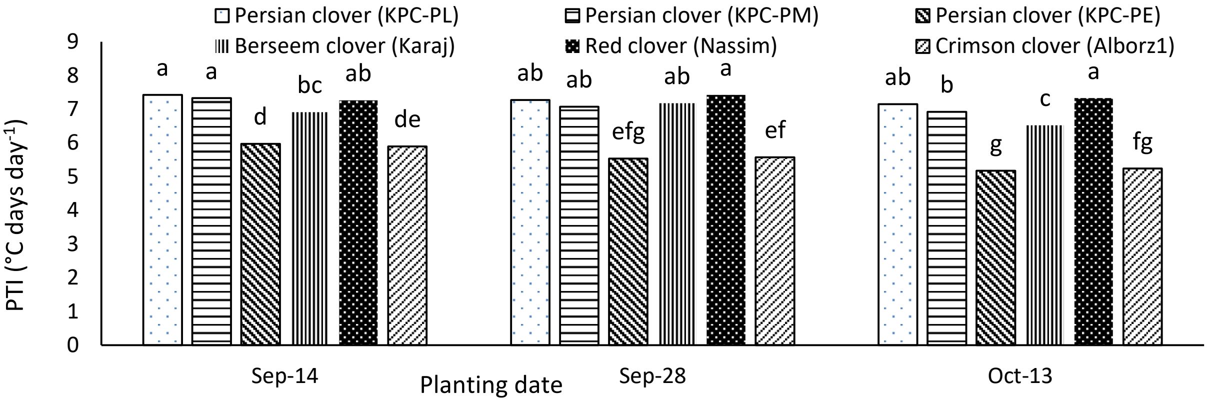

Fig. VII. Interaction effect of planting date and genotype on the photo thermal index of clover

Table 7
Mean comparison of heat unit efficiency (HUE, kg ha^{-1} / ℃ days) in forage production of clover genotypes in different cuts

Genotypes	To the First Cut	To the Second Cut	To the Third Cut
Late-maturity Persian clover (KPC-PL)	2.60^{b}	9.54^{b}	9.91^{a}
Mid-maturity Persian clover (KPC-PM)	2.89^{b}	8.33^{c}	10.71^{a}
Early-maturity Persian clover (KPC-PE)	3.53^{a}	-	-
Berseem clover (Karaj)	2.67^{b}	13.21^{a}	7.12^{b}
Red clover (Nassim)	2.14c	5.91^{d}	7.58^{b}
Crimson clover (Alborz1)	3.40^{a}	-	-
Mean	2.87	9.24	8.83

In each column and for each factor, means followed by same letters are not significantly different at the 5% probability level.

PTI was observed in the first planting date and Persian clover cv. KPC-PL while the lowest PTI was recorded in the last planting date and crimson clover. Delayed planting from September 14 to October 13 resulted in a significant decrease in PTI in Persian clover cv. KPC-PM, Persian clover cv. KPC-PE, and crimson clover, with early-maturity cultivars experiencing the greatest reduction (Fig. VII).

Heat use efficiency (HUE)

HUE was found to be significantly influenced by genotype, planting date, and their interaction, as shown in Table 4. Crimson clover and early-maturity Persian clover had the highest HUE in the first cut (Table 7). In the second cut, berseem clover had the highest HUE (13.21 kg ha^{-1}/℃ days) while red clover had the lowest HUE (5.91 kg ha^{-1}/℃ days). In the third cut, mid-maturity Persian clover and berseem clover had the highest HUE (10.71 kg ha^{-1} / °C days), while berseem clover had the lowest HUE (7.12 kg ha^{-1}/℃ days) (Table 7). The ranking of genotypes in terms of mean HUE across the three cuts was similar to mean GDD and PTI (Fig. VIII). The cold stress resulting from

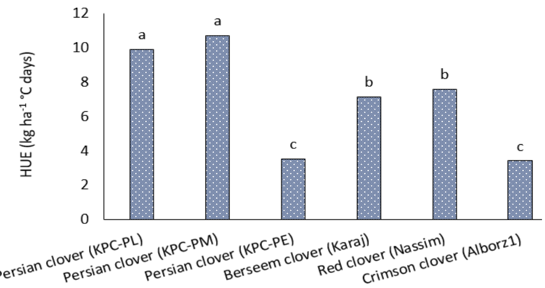

Fig. VIII. Heat use efficiency (HUE) in clover genotypes

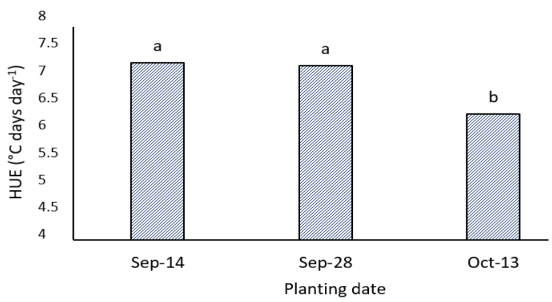

Fig. IX. Heat use efficiency (HUE) in different planting dates

delayed planting reduced the heat use efficiency for forage production, with this decline being more pronounced in the third cut. The first planting date had the highest HUE while the last planting date had the lowest HUE (Fig. IX). The

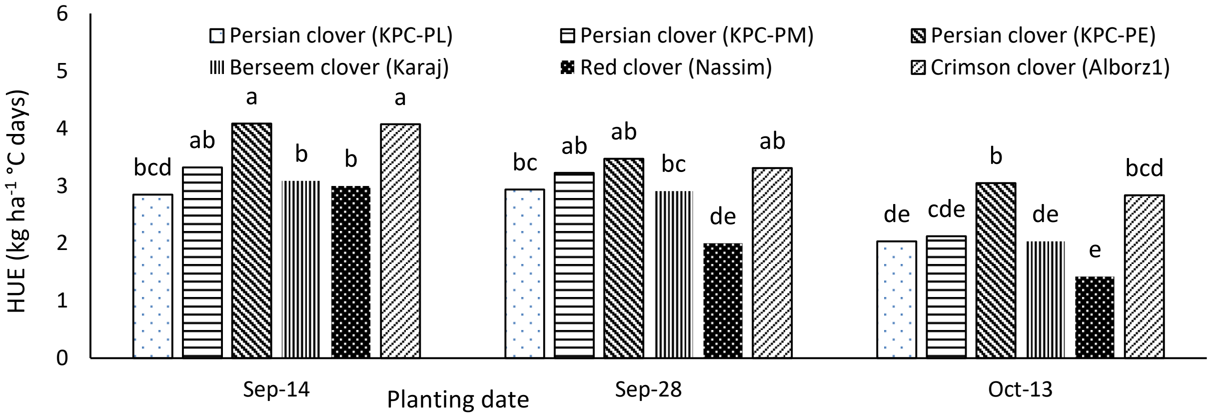

Fig. X. Interaction effect of planting date and genotype on the heat use efficiency of clover

Table 8
Mean comparison of dry matter yield (kg ha^{-1}) of clover genotypes in different cuts

Genotypes	To the First Cut	To the Second Cut	To the Third Cut	Total
Late-maturity Persian clover (KPC-PL)	4934^{ab}	4946^{b}	2354^{b}	12234^{b}
Mid-maturity Persian clover (KPC-PM)	5265^{a}	3966^{c}	2118^{c}	11348^{c}
Early-maturity Persian clover (KPC-PE)	4274^{c}	0^{d}	0^{e}	4274^{d}
Berseem clover (Karaj)	4503^{bc}	7038^{a}	1888^{d}	13429^{a}
Red clover (Nassim)	4115^{c}	3650^{c}	3346^{a}	11119^{c}
Crimson clover (Alborz1)	4160^{c}	0^{d}	0^{e}	4160^{d}
Mean	4542	3268	1617	9427

In each column and for each factor, means followed by same letters are not significantly different at the 5% probability level.

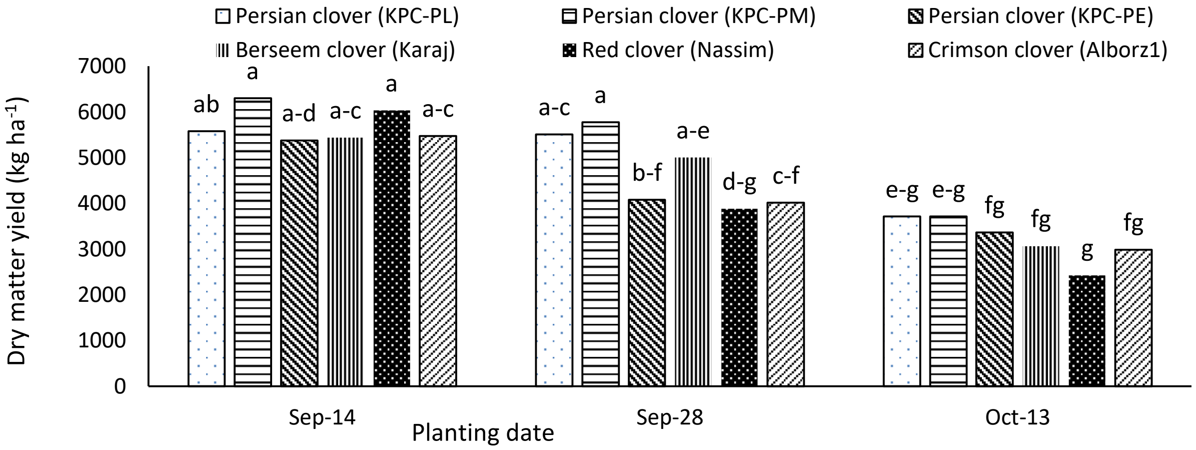

Fig. XI. Interaction effect of planting date and genotype on the dry matter yield of clover

means comparison of interaction effects showed that planting early-maturity cultivars on September 14 resulted in the maximum HUE in the first cut while red clover on the last planting date had the minimum HUE, with the greatest decrease observed in this genotype (Fig. X).

Dry matter yield

The dry matter yield was significantly influenced by planting date, genotype, and planting date × genotype interaction, as shown in Table 4. The mid-maturity Persian clover, berseem clover, and red clover cultivars exhibited the highest dry matter yields in the first, second, and third cut, respectively, with yields of 5265, 7038, and 3346 kg ha^{-1}, respectively (Table 8). Berseem clover had the highest total yield (13429 kg ha^{-1}) while the mono-cut species had the lowest yield, as shown in Table 8. The results also revealed that delaying the planting date had a negative impact on the dry matter yield, with yield decreasing and reaching a minimum on the last planting date (Fig. XI). The highest forage yield in the first cut was obtained by planting the mid-maturity Persian clover on the first planting date while the lowest yield was recorded in red clover and the last planting date. Notably, the delay in planting had the most significant negative effect on the yield of red clover, with each day of delay resulting in a decrease by approximately 120 kg ha^{-1} in dry matter yield (Fig. XI).

Discussion

The obtained results revealed a strong impact of planting date, genotype, and their interaction on the GDD, PTI, HUE and dry matter yield in clover genotypes. Findings clearly highlight the importance of these factors in optimizing forage production, with clear implications for crop management practices (Butler et al., 2002; Kumar et al., 2012). According to our results, there is a distinctive differentiation among clover genotypes based on their GDD requirements, where the genotypes can be grouped into late-, mid-, and early-maturity groups (Aktar-Uz-Zaman et al., 2022). Red clover, with the highest GDD requirement across all cuts, and Persian clover cv. KPC-PL require the maximum heat for forage production, placing them in the late-maturity group. This indicates that these genotypes might be more suitable for regions with longer growing periods and higher temperatures (Clapham and Fedders, 2004). Conversely, early-maturity Persian clover cv. KPC-PE and crimson clover cv. Alborz1, with the least heat requirements, fall into the early-maturity group, implying a potential advantage in cooler climates or shorter growing seasons (Zamanian et al., 2021b). The data also illustrates an inverse relationship between planting date and GDD, with later planting dates causing reduced thermal requirements in all studied genotypes. This was most prominent in crimson clover and Persian clover cv. KPC-PE, highlighting the adaptability of these genotypes to colder conditions or late planting scenarios (Butler et al., 2002). Early-maturity cultivars generally need lower temperatures for flowering compared to late-maturity genotypes. For this reason, early genotypes can also be used for fodder production in cold and semi-cold regions (Papastylianou and Bilalis, 2011). Similar to the present study, Butler et al. (2002) reported that Tibbee cultivar of crimson clover required fewer GDD than other genotypes, and delaying the planting date resulted in reduced GDD values across all cultivars.

The PTI results further expand our understanding of the genotype and maturity differences. Red clover and late-maturity Persian clover consistently showed the highest PTI, suggesting a greater ability to utilize longer periods of light and heat for growth (Iannucci et al., 2008). Conversely, early-maturity Persian clover and crimson clover had the lowest PTI, aligning with their lower GDD requirements. Delayed planting was found to reduce PTI in all genotypes, and this reduction was more pronounced in early-maturity cultivars. The decrease in PTI resulting from delayed planting has been reported by both Butler et al. (2002) and Kumar et al. (2012). In terms of HUE, early-maturity Persian clover and crimson clover demonstrated superior heat use efficiency in the first cut, potentially enabling them to optimize growth under lower temperatures (Kumar et al., 2012; Zamanian et al., 2021b). However, this advantage was not consistent across all cuts, indicating the dynamic nature of HUE across the growing season. Delayed planting was found to reduce HUE, with the third planting date being most affected, reinforcing the importance of careful timing in planting decisions (Kumar et al., 2012). One of the reasons for the low thermal requirements of crimson clover and early-maturity Persian clover is the short duration of their growth period, earliness, and producing only one cut forage per season (Bakhtiyari et al., 2020; Zamanian et al., 2021a). Accordingly, crimson clover and early-maturity Persian clover could be cultivated in areas with water deficit for fresh forage production during spring (Zamanian et al., 2021b). In the first cut, red clover had the highest GDD and the lowest dry matter yield due to their long vegetative growth and lack of stem production (Balazadeh et al., 2021), which resulted in lowest HUE. However, , this trend reversed in the second cut and berseem clover reached a higher rate due to faster growth than other genotypes (Nematollahi et al., 2017). Also, in red clover, due to a more balanced growth rate and forage production in spring and summer (more cuts), HUE showed a more balanced trend than all other genotypes in all cuts (Zamanian, 2018). Similar to the results of the present study, Kingra and Kaur (2012) reported that the HUE decreased in delayed planting, so that the highest and lowest HUEs were recorded at the first and last planting dates, respectively (Kingra and Kaur, 2012). Meanwhile, Anil et al. (2008) reported that HUE and PTI increase with the aging of the plant and the delay in the planting of soybean in warm regions. Therefore, thermal indices may be different based on the species and climatic conditions.

The analysis of dry matter yield further emphasized the impact of genotype and planting date. Mid-maturity Persian clover, berseem clover, and red clover cultivars exhibited the highest yields in the first, second, and third cut, respectively. The variation in yield among different clover cultivars in different cuts can be attributed to several factors, including their growth habits, nutrient requirements, and environmental adaptability (Zamanian, 2018; Balazadeh et al., 2021). The highest total yield was achieved by berseem clover, whereas mono-cut species yielded the least. Berseem clover tends to have a more prostrate growth habit and is better adapted to mid-season production (Clapham and Fedders, 2004). This means that it may not produce as much in the first cut, but can excel in the second cut when conditions are more suitable for its growth (Ashoori et al., 2021; Balazadeh et al., 2021).

Delaying the planting date negatively impacted the dry matter yield of all genotypes, emphasizing the importance of optimal planting timing for maximizing yield. Delayed planting can result in a shorter growing season for the plants, which means they have less time to grow and produce biomass (Nleya et al., 2020; Mirahki et al., 2023). If the plants are also exposed to the first cold of the season during this shortened growing period, it can further reduce their ability to produce dry matter (Alizadeh and Jafari, 2011; Zamanian et al., 2021a). Notably, red clover was the most affected by delayed planting, experiencing a substantial decrease in dry matter yield with each day of delay. These results collectively underscore the significance of genotype and planting date choice in optimizing forage production (Mirahki et al., 2023). They highlight the adaptability of different clover genotypes to various temperature conditions and planting scenarios, providing valuable guidance for farmers and crop managers in their decision-making processes (Balazadeh et al., 2021). Future research should delve deeper into understanding the underlying mechanisms responsible for these observed differences, which would facilitate the development of optimized cropping systems.

Conclusion

The present study highlights the significant influence of the interaction between planting date and genotype on the thermal requirements and dry matter yield of clover. Specifically, the early-maturity Persian clover cv. KPC-PE and crimson clover cv. Alborz1 had lower GDD and PTI across all the planting dates investigated. These results indicate that cultivating early-maturity cultivars could be advantageous for fodder production in areas with a short growing season or under conditions of delayed planting. Furthermore, timely planting is crucial for late cultivars such as red clover, which require more time to establish properly. Delayed planting of late-maturity genotypes, particularly red clover, in autumn cultivation is risky in cold regions due to their high thermal requirement. Therefore, the heat requirement of the studied cultivars should be considered when selecting appropriate species for cultivation, and delayed planting of late-maturity genotypes should be avoided in cold regions. Crimson clover and early-maturity Persian clover genotypes had a minor thermal requirement, and thus, these species can be used in crop rotation systems to produce fodder in short intervals between the cultivation of two main crops. Furthermore, these species are suitable for fodder production in areas facing water shortage crisis, as autumn cultivation provides the possibility of using rain and green water while minimizing pressure on underground water resources.

This study proposes that autumn cultivation of early-maturity clover cultivars can be a practical solution to meet the country's need for fresh fodder in the early growing season. This strategy optimally utilizes available water for spring cultivation while providing fresh fodder and minimizing the pressure on underground water resources. Thus, the findings of this study have important implications for the development of sustainable and efficient forage production systems. Overall, the study suggests that if there is a sufficient growing season, berseem clover and late-maturity Persian clover, with the production of three cuts of forage, are optimal choices, and should be planted without delay, ideally in mid-September. However, in situations where the growing season is limited, or there is an urgent need for fodder, or a forced delay in planting, it is better to choose crimson clover and early-maturity Persian clover. Nonetheless, similar to late-maturity cultivars, it is still advisable to plant early-maturity cultivars as soon as possible.

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