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ARTICLE

Biomass production, water use efficiency and nutritional value parameters of sorghum (*Sorghum bicolor* L.) genotypes as affected by seed hydro-priming and transplanting

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ABSTRACT To investigate hydropriming and transplanting effect on biomass and nutritional content of forage sorghum, a two-year field experiment was conducted in the semiarid condition of Iran. Experimental factor consisted of planting dates (July-1st, July-11th, July-23rd, August-1st) in the main plot and the factorial combination of planting methods (direct planting, hydropriming, transplanting) with cultivars (*Speedfeed* and *Pegah*) in the subplot. Planting date postponement from 1st of July to 10th of July, 23rd of July, and 1st of August, respectively, caused 16.1, 32.5 and 47.2% reduction in dry matter yield (DMY) and 7.4, 20.2, and 35.1% reduction in water use efficiency of DMY production (WUE_{DMY}). Hydropriming and transplanting produced 23.6 and 22.4% more DMY, 24.5 and 21.8% more WUE_{DMY}, 24 and 16.3% more crude protein yield, 22.7 and 20.9% more digestible dry matter (DDM) yield, and 22.2 and 20.1% more metabolic energy (ME) yield, compared to the direct planting. Hydropriming compared to direct planting caused 29% increase in plant growth rate and utilized growing season more productively than transplanting for DMY production. Conclusively, hydropriming and transplanting compensated for delay in planting through enhancing and accelerating germination and plant development but, applying hydropriming on *Speedfeed* and planting in July-1st caused the highest DMY, WUE_{DMY} and the yield of nutritive parameters.
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Abbreviations

$D1_{PD}$: Planting date 1st of July; $D2_{PD}$: Planting date 10th of July; $D3_{PD}$: Planting date 23rd of July; $D4_{PD}$: Planting date 1st of August; D_{PM}: Direct seed planting method; H_{PM}: Hydroprimed seed planting method; T_{PM}: Transplant planting method; S_{CV}: *Speedfeed* cultivar; P_{CV}: *Pegah* cultivar; DMY: Dry matter yield; NDF: Neutral detergent fiber; ADF: Acid detergent fiber; CP: Crude protein; CPY: Crude protein yield; Hem: Hemicelluloses; DDM: Digestible dry matter; DDMY: Digestible dry matter yield; RFV: Relative feed value; WSC: Water soluble carbohydrates; ME: Metabolic energy; MEY: Metabolic energy yield; DOM: Digestible organic matter.

Introduction

Extreme heat (Biswas 2020), limited water and soil resources (Elamin et al. 2019), continuous global population growth (Amouzou et al. 2019), and climate change and its subsequences (Michelon et al. 2020) organizes a set of threatening factors toward agricultural sustainability and food production in arid and semiarid regions (Biswas 2020). On this approach, the second cropping strategy could substantially supply the growing food demands and protect the food safety (Velten et al. 2015; Martin et al. 2017). Thus, the selected forage species must produce an adequate quantitative and qualitative yield in a short period, be adaptable to withstand high temperature and drought conditions (Martin et al. 2017) and allelopathic residue (Costa et al. 2020). Studies in arid and semiarid regions introduced sorghum as a promising option to provide the required forage (Michelon et al. 2020) during different growing seasons and water availabilities.

Sorghum is an annual, low-cost crop with a large size canopy that specialized to grow during warm seasons in the warm regions; it can produce the same biomass as corn by consuming less water (Bhattaraia 2020) in areas with a short growing season (Naoura et al. 2019). Late, uneven, and slow germination in the early stages of growth is the main issue in sorghum cultivation (Bajwa et al. 2018). After harvesting winter crops, it takes time to prepare the soil and seedbed for second cultivation (Junnyor et al. 2015). Delay in planting affects the synchronicity of plant growth stages with environmental conditions, which shortens the growing season, overshadows the vegetative and reproductive phases, and ultimately reduces forage yield (Junnyor et al. 2015; Zandonadi et al. 2017). Seed-hydropriming is a physiological method and because of its considerable effect on seed germination, crop establishment, and growth rate, could get widely used to increase the growing season productivity (Zida et al. 2018; Bajwa et al. 2018; Jatana et al. 2020; Kukal and Irmak 2020). In hydropriming, before sowing, the controlled seed-soaking in water starts primitive germination phases without bud sprouting (Forti et al. 2020). This method reduces the average germination duration (Chen et al. 2021); increases the germination percentage (Zida et al. 2018), seedling establishment and growth (Bajwa et al. 2018), fastens the flowering and maturity and ultimately increases the yield (Zida et al. 2018) in a wide range of environmental conditions (Jatana et al. 2020). Transplanting, as another method that increases the grain and forage yield of sorghum, has been reported from India, Japan, Mali, Cameroon, Chad, Nigeria, and Senegal (Jo et al. 2016; Biswas 2020). Transplanting compared to the conventional planting method significantly increased the established seedling rate (Rattin et al. 2015); caused the proper plant population per hectare (Biswas 2020); maximized the absorbed light and optimum leaf area index and the light use efficiency (Jo et al. 2016; Biswas 2020); improved the productivity of growing season (Jo et al. 2016), seed, and pesticides (Rattin et al. 2015); decreased the days till flowering, weed population and damage (Mapfumo et al. 2013), disease and pest population; increased the grain and biomass yield per capita (Biswas 2020). Therefore, cultivating the forage sorghum by employing planting methods that accelerates the germination and improves the plant establishment for compensating the reprieved planting while increasing the water use efficiency seems unavoidable to attain, maintain, and develop agricultural sustainability. The main objectives of this study are to (i) evaluate the singular and multiple effects of experimental factors on biomass yield, quality, and yield of nutritional components of forage sorghum; (ii) assessing the regression model variation of DMY production based on the obtained GDD under the effect of each experimental factors; (iii) study the correlation coefficient among quantitative and qualitative traits as well as the results of regression analysis with dry matter yield; (iv) specifying an approved PD, PM and, CV for different scenario based on the accessible facilities, growth season and required forage quantity and quality.

Materials and methods

Experimental site

A two-year field experiment was conducted at the Seed and Plant Improvement Institute, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran (35°48'N, 50°57'W, altitude 1312.5 m) during the 2017 (Y1) and 2018 (Y2) growing seasons. The area categorized as a semiarid climate with an average annual precipitation of 251 mm, an annual average temperature of 13.5 °C, an annual average soil temperature of 14.5 °C, and a total annual class "A" pan evaporation of 2184 mm. The meteorological data obtained from the Synoptic Meteorology Station, located beside the experimental farm, are shown in Fig. 1. The experiments were carried out on clay-loam soil in which the average field capacity of the root zone was 23%. Before planting, soil samples were taken from the top 30 cm of soil to test its background nutritional level. Some of the physicochemical properties of the soil of the experimental site are presented in Table 1.

Experimental design and cultural practices

The experiment was arranged as a three-replicated split plot-factorial design with four levels of planting dates (PD) as the main factor consisted of $D1_{PD}$ (planting date 1st of July), $D2_{PD}$ (planting date 10th of July), $D3_{PD}$ (planting date 23rd of July), $D4_{PD}$ (planting date 1st of August) and three planting methods (PM) including the D_{PM} (direct planting), H_{PM} (hydroprimed seeds) and T_{PM} (transplant-

Table 1. Physicochemical properties of the top soil (0 - 30 cm) at the experimental site.

Year	N (%)	$CaCO_3$ (%)	P (mg kg^{-1})	K (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	OM (%)	EC (ds/m)	pH	FC	CEW (%)	AW (%)	Clay (%)	Silt (%)	Sand (%)	Soil texture
2017	0.06	10	12.6	256	0.32	1.47	12.7	5.02	0.58	2.22	7.24	34	11	23	27	49	24	Clay loam
2018	0.05	9	12.1	248	0.29	1.44	18.6	4.89	0.56	2.2	7.24	32	10	21	28	46	26	Clay loam

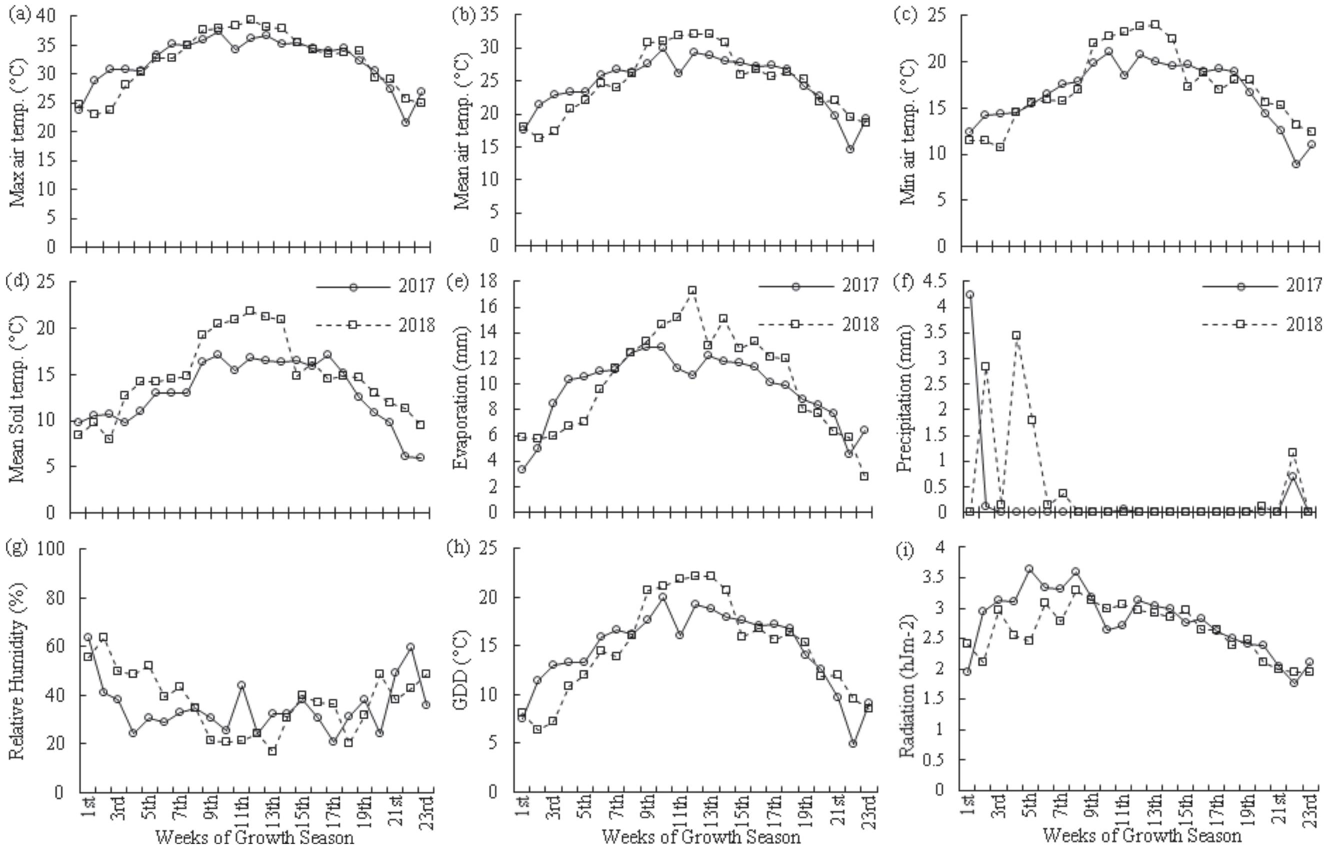

Figure 1. Weekly ombrothermic diagram of growth season for second cultivation during 2017 and 2018 from Karaj (agriculture) synoptic station, Iran. (a) Weekly average of maximum air temperature (°C). (b) Weekly average of air's mean temperature (°C). (c) Weekly average of minimum air temperature (°C). (d) Weekly average of soil's mean temperature (°C). (e) Weekly average of evaporation (mm). (f) Weekly average of precipitation (mm). (g) Weekly average of relative humidity (%). (h) Weekly average of growth degree day for sorghum growth (°C). (i) Weekly average of radiation (hJm^{-2})

ing) were factorially combined with two cultivars (CV) including S_{CV} (*Speedfeed*) and P_{CV} (*Pegah*) as subplots (collectively 24 treatments). S_{CV} is an Australian-originated and improved, multi-cut hybrid forage sorghum with high-yield potential that typically each 60 to 70 days produces one cut. Currently, S_{CV} is the most known forage sorghum cultivar in Iran that has been cultivated for fresh, dry, and direct grazing purposes. P_{CV} (LFS56×Early Orange) is a mid-late open-pollinated (OP) forage sorghum cultivar that each 75 to 90 days produces one cut forage sorghum with fresh, dry, and silage purposes (Golzardi et al. 2019). The seedbed preparation operation in 2017 (Y1) and 2018 (Y2) was included moldboard plow, cultivator, harrow, leveler, furrower, and dividing into three blocks. Each block contained four main plots, and each main plot consisted of 6 subplots. Each subplot consisted of four rows with 6 m length, and the interval between rows and plants considered 60 and 8 cm spacing (208000 plant ha^{-1}), respectively. To prevent the treatment interference between adjacent subplots and main plots and replications, there were 0.6, 1, and 2 m distances, respectively. Based on soil test results (Fig. 3) and both cultivar's requirements, before planting 250 and 100 kg ha^{-1} ammonium-phosphate and urea, respectively, and in the V6 stage, 100 kg ha^{-1} urea was applied. Weed control performed by applying 5 l ha^{-1} Eradikan as pre-planting and 1.5 l ha^{-1} MCPA + 2,4-D as post-emergence in the V6 stage. In the V10 and V12phases, pest control executed by applying 2 l ha^{-1} from the Diazinon source. To applying the H_{PM} treatment, seeds submerged in pure water for 6 h so that the water level was 2 cm above the seed surface, and then with fan-made airflow dried for 24 h at room temperature (close to 25 °C) (Zida et al. 2018). Young and Atokple (2003) reported the 20 days after planting (while seedlings have 2 to 3 leaves) as the suitable time for transferring the seedlings to the field. Thus, 20 days before planting dates, the seeds were planted in the (marked with each treatment information) 72 cells trays filled with a mixture of 60% field soil, 20% fine sand, and 20% rotted manure. After complete emergence of

Table 2. General linear model (GLM) sources, levels of statistical significance in traits.

Components		DMY	DDMY	CPY	MEY	WUE_{DMY}
			(t ha^{-1})		(Gcal ha^{-1})	(kg ha^{-1})
Years	2017	19.1 b	11.3 b	1.83	38.3	5.64
	2018	24.4 a	14.4 a	2.28	48.2	6.96
p Val.		0.0449	0.0437	0.0504	0.0504	0.4858
LSD		5.04	2.96	ns	ns	ns
Planting dates	$D1_{PD}$	28.6 a	16.7 a	2.56 a	55.9 a	7.47 a
	$D2_{PD}$	24.0 b	14.1 b	2.24 b	47.6 b	6.92 b
	$D3_{PD}$	19.3 c	11.5 c	1.90 c	38.6 c	5.96 c
	$D4_{PD}$	15.1 d	9.1 d	1.51 d	30.8 d	4.85 d
p Val.		0.0011	0.0006	0.0006	0.0005	0.0003
LSD		2.28	1.03	0.15	3.28	0.30
Planting methods	D_{PM}	18.1 b	10.8 b	1.75 c	36.6 b	5.42 b
	H_{PM}	23.7 a	14.0 a	2.30 a	47.1 a	6.91 a
	T_{PM}	23.4 a	13.7 a	2.10 b	45.9 a	6.58 a
p Val.		0.0239	0.0215	0.0061	0.0147	0.0273
LSD		2.97	1.59	0.13	4.27	0.80
Cultivars	S_{CV}	23.1	13.3	2.13	44.2	6.69
	P_{CV}	20.4	12.4	1.97	42.2	5.92
p Val.		0.1444	0.2228	0.0569	0.2491	0.1186
LSD		ns	ns	ns	ns	ns

$D1_{PD}$, $D2_{PD}$, $D3_{PD}$, $D4_{PD}$ represent 1st of July, 10th of July, 23rd of July and 1st of August planting dates, respectively. D_{PM}, H_{PM}, and T_{PM} represent Direct, Hydroprime, and Transplant planting methods, respectively. S_{CV} and P_{CV} represent *Speedfeed* and *Pegah* cultivars, respectively. DMY: Dry Matter Yield; DDMY: Digestible Dry Matter Yield; CPY: Crude Protein Yield; MEY: Metabolic Energy Yield; WUE_{DMY}: Water Use Efficiency of Dry Matter production. Means in the same column followed by different letters differ significantly at $P<0.05$.

primary leaves in the nursery, seedlings sprayed with 20-20-20 NPK fertilizer (1×1000^{-1} concentration) and humic acid (0.75×1000^{-1} concentration). Also, the double concentrated solution repeated one week later. Due to the farm's suitable weather and to reduce the transference stress on transplants, the nursery placed nearby the experimental section, and to prevent pest damage, the transplant trays were placed under a frame and covered with a net. To provide the most suitable soil conditions in terms of temperature and moisture, immediately (right after planting), first, and 48 h later, second irrigation was applied. Pressured strip drip (16 mm type strips with 10 cm dropper distance), water mass counter, and shut-off valves formed the distribution, measurement, and control components of the irrigation system, respectively. Calculating the amount of evapotranspiration in different growth stages, based on the following equation, determined the consumed water volume:

$$\text{Equation (1): } ETc = ETo \times Kc$$

Where, ETc is the sorghum evapotranspiration, ETo is the reference-crop evapotranspiration and calculated from the Penman-Monteith method, and Kc is the sorghum crop coefficient (Allen et al. 1998; FAO 2012).

Measurements and data analysis

To eliminate marginal factors, two sidelines and 50 cm from the north-side and south-side of all lines in each subplot were eliminated. Each sub plot was divided into two separate sections: "Section A", which consisted of the 4.5 m^2 of the two main lines and assigned to measuring the final biomass yield parameters. To achieve the highest biomass yield multi-cut principle was employed. Harvesting S_{CV} and P_{CV} before flowering threatens the livestock's health with prussic acid, but by starting the flowering phase, the amount of anti-nutritional compound reduces to the safe balance (Amirsadeghi et al. 2019). "Section B", which consisted of the other remained 4.5 m^2 of the two main lines, was addressed to sampling during the growth season for regression analysis purpose. Collecting data for regression analysis purposes for the T_{PM} treated plants started at each planting date (before planting in the field), and in the ten days paste the samplings carried out until harvesting. To ground a similar situation for all PMs and also to be able to compare them at the same days after planting (e.g., in 10, 20), the D_{PM} and H_{PM} sample collection started 20 days (the same duration of nursery for T_{PM}) after planting in the field. Likewise, the measured amount of the GDD received by the T_{PM} treated plants added to the total GDD. Water use efficiency of dry matter production (WUE_{DMY}) calculated by using the following equation:

$$\text{Equation (2): } WUE_{DMY} = DMY/WU$$

Where, DMY is dry matter yield (kg ha^{-1}), WU is the water used for irrigation (m^{-3}).

In each stage of sampling for regression analysis, five plants were fully cut from above the ground. Before and after drying the samples in a forced ventilation oven at 70 °C for 72 h, the weights were recorded. The final harvest was carried out at the beginning of the flowering; after recording the fresh weight to assess the produced biomass and nutritional factors, the 1 kg fully packed samples in the 4 kg paper bags were dried in the forced-air oven at 70 °C for 72 h.

Laboratory analysis

The taken samples pulverized, milled, sifted (through 0.2 mm sieve), and scanned by using the near-infrared reflectance spectroscopy (NIRS, Informatics Perten 8600 Feed Analyzer) with 6-20 wavelengths ranging from 500 to 2400 nm to determining the NDF (neutral detergent fiber), ADF (acid detergent fiber), WSC (water soluble carbohydrates. The CP (crude protein) was measured by the Kjeldahl method. The gas production method (in vitro) was appointed to extract the data of the metabolic energy (ME) and digestible organic matter (DOM) contents. Three 200 mg dry forage samples were incubated in the sifted rumen fluid (obtained from the Moghani sheep breed) and buffer mixture in 100 ml ceiled glass syringes (Menke and Steingass 1988; Kaplan et al. 2019) in the 39 ± 0.5 °C temperature. Also, three syringes (filled with only the rumen fluid and buffer mixture) were used as the control to determine the correction factor for gas production. Eventually, after 24 hours based on the produced gas data and following equations, the ME (MJ kg^{-1}) and OMD (g kg^{-1}) were computed (Menke et al. 1979; Blümmel et al. 1997):

Equation (3): $ME = 2.2 + 0.136 \times GP + 0.057 \times CP$
Equation (4): $OMD = 14.88 + 0.889 \times GP + 0.45 \times CP + 0.0651 \times CA$

Where, GP is 24-hour net gas production (mL/200 mg), CP is crude protein, CA is crude ash contents

The rest of the traits calculated by using the following formulas:

Equation (5): Hemicellulose = NDF - ADF
Equation (6): DDM = 88.9 – (0.779 x ADF)
Equation (7): RFV = DDM x DMI x 0.775

Where, DDM is Digestible dry matter, DMI is Dray matter intake.

Statistical analysis

Ascertainment from the homogeneity of variance obtained by employing the Bartlett test (Bartlett 1937). Thereafter, the combined data analyzed by general linear model (GLM) SAS procedures (SAS Institute 2003). The least significant differences (LSD) test was used to separate levels of GLM sources. The effect of factors considered significant at *P*-values ≤ 0.05 in the F-test. Interactions in the levels of 0.05 and 0.01 of significance used for the means comparisons. The correlation amongst traits and the results of regression analysis recruited to maximize interpretation accuracy.

Regression analysis

The regression model with the highest coefficient of determination (R^2), least RMSE and components considered the desired model (Anfinrud et al. 2013). Afterward, the results showed the ability of linear regression to model the DMY production at *P*-values ≤ 0.05 level of significance for all PDs, PMs, and CVs.

Results

Yield parameters

The DMY was substantially (P<0.01) affected by PD (Table 2). Simultaneously with delay in planting date from $D1_{PD}$ to $D2_{PD}$, $D3_{PD}$ and $D4_{PD}$, respectively: the DMY was 16.1, 32.5 and 47.2% reduced (Table 2); the a-factor (line slope) or the growth rate was 2.8, 7.1 and 15.7% descended; the b-factor (line intercept) was 0.3, 5.8 and 20.1% increased; the adjusted R^2 was 1.1, 3.2 and 7.4% decreased (Table 8, Fig. 3). The DMY was considerably (P<0.05) influenced by PM (Table 2). Employing H_{PM} instead of D_{PM} resulted in 23.6% elevation in DMY (Table 2); 29% increase in a-factor and 6.6% in the adjusted R^2; the RMSE value 23.94% reduced (Table 8, Fig. 3). Contrary to H_{PM}, applying the T_{PM} instead of D_{PM} caused 8% reduction in a-factor (line slope) and 1.8% inflation in RMSE value (Table 8, Fig. 3). S_{CV}, in comparison with P_{CV}, showed 9.7% higher growth rate (a-factor), 4.2% less line intercept, 27.5% less RMSE value, and 4.1% higher adjusted-R^2 (Table 8, Fig. 3). The dual interaction of PD×PM was significantly (P<0.01) affected the DMY production (Table 4). T_{PM} in $D1_{PD}$ generated the most harvested DMY, and D_{PM} in $D4_{PD}$ produced the least DMY (Table 4). Interestingly, H_{PM} in $D2_{PD}$ produced the same DMY as T_{PM} but, in $D3_{PD}$ and $D4_{PD}$ significantly produced more DMY (Table 4). Likewise, the dual interaction of PM×CV was highly (P <0.05) affected the DMY production (Table 6). Applying H_{PM} and T_{PM} on S_{CV} produced the most, and applying D_{PM} on P_{CV} generated the least DMY. DDMY was significantly affected by PD (P<0.01) and PM (P<0.05) (Table 2). Planting date postponement from $D1_{PD}$ to $D2_{PD}$, $D3_{PD}$, and $D4_{PD}$, respectively, caused 15.6, 31.1, and 45.5 % reduction in the DDMY (Table 2). H_{PM} and T_{PM} compared to D_{PM} caused 22.9 and 21.2 % elevation in DDMY production (Table 2). Also, DDMY significantly (P<0.05) affected by dual interaction of PD×PM (Table 4). T_{PM} in $D1_{PD}$ produced the most, and D_{PM} in $D4_{PD}$ produced the least DDMY (Table 4). H_{PM} in $D2_{PD}$, $D3_{PD}$, and $D4_{PD}$ considerably (P<0.05) produced more DDMY than T_{PM} (Table 4). Also, the dual interaction of PD×CV notably (P<0.05) affected DDMY (Table 5). In $D1_{PD}$, the S_{CV} produced the highest DDMY, and in $D4_{PD}$, both CVs produced the least DDMY (Table 5). The dual interaction of PM×CV significantly (P<0.05) affected DDMY production (Table 6) that with applying the H_{PM} on S_{CV} highest and with applying D_{PM} on P_{CV} least DDMY was generated. CPY and MEY were considerably affected by PD (P<0.01) and PM (P<0.05) (Table 2). Delay in PD from $D1_{PD}$ to $D2_{PD}$, $D3_{PD}$, and $D4_{PD}$, respectively, resulted in 12.5, 25.8, and 41% reduction in the produced CPY and 14.8, 30.9, and 44.9% reduction in MEY production (Table 2). Also, H_{PM}, compared to D_{PM} and T_{PM}, made 23.9 and 8.7% more CPY (Table 2). H_{PM} and T_{PM}

Table 3. General linear model (GLM) sources, levels of statistical significance in quality traits.

Components		ME (Mcal kg^{-1})	NDF	ADF	Hem	CP (g kg^{-1})	WSC	DDM	DOM	RFV (Gcal ha^{-1})
Years	2017	2.02 a	591 b	377 b	214	97.0	96 b	595 a	625 a	93.8 a
	2018	2.00 b	597 a	383 a	215	95.0	107 a	591 b	620 b	92.2 b
p Val.		0.0069	0.0103	0.0089	0.9271	0.0527	0.0345	0.0087	0.0091	0.0002
LSD		0.01	3.73	3.46	ns	2.02	9.97	2.69	2.76	.36
Planting dates	$D1_{PD}$	1.96 c	607 a	391 a	216	90.0 d	107 a	584 c	613 c	89.6 d
	$D2_{PD}$	1.99 bc	599 b	384 ab	215	93.6 c	104 ab	590 bc	619 bc	91.6 c
	$D3_{PD}$	2.02 ab	592 c	377 b	215	99.1 b	100 bc	595 b	625 b	93.8 b
	$D4_{PD}$	2.06 a	579 d	367 c	212	101.2 a	96 c	603 a	632 a	97.0 a
p Val.		0.0153	0.0004	0.0132	0.4194	0.0002	0.0120	0.0136	0.0145	0.0023
LSD		0.04	3.25	9.33	ns	1.09	4.44	7.36	7.65	1.58
Planting methods	D_{PM}	2.04 a	585 c	373 b	212 c	98.4 a	97	599 a	628 a	95.4 a
	H_{PM}	2.00 b	596 b	381 a	215 b	98.6 a	105	592 b	621 b	92.7 b
	T_{PM}	1.98 b	603 a	386 a	217 a	90.9 b	103	588 b	617 b	90.9 b
p Val.		0.0225	0.0092	0.0236	0.0088	0.0236	0.0744	0.0213	0.0223	0.0171
LSD		0.02	5.39	6.21	1.48	4.14	ns	4.66	4.86	1.80
Cultivars	S_{CV}	1.93 b	607	398 a	209	93.6	97 b	579 b	607 b	88.7 b
	P_{CV}	2.08 a	582	361 b	220	98.3	107 a	608 a	637 a	97.3 a
p Val.		0.0129	0.0662	0.0112	0.1004	0.1755	0.0111	0.0119	0.0105	0.0290
LSD		0.04	ns	8.29	ns	ns	2.29	6.88	6.18	4.94

$D1_{PD}$, $D2_{PD}$, $D3_{PD}$, $D4_{PD}$ represent 1st of July, 10th of July, 23rd of July and 1st of August planting dates, respectively. D_{PM}, H_{PM}, and T_{PM} represent Direct, Hydroprime, and Transplant planting methods, respectively. S_{CV} and P_{CV} represent Speedfeed and Pegah cultivars, respectively. ME: Metabolic Energy; NDF: Neutral Detergent Fiber; ADF: Acid Detergent Fiber; Hem: Hemicelluloses; CP: Crude Protein; WSC: Water Soluble Carbohydrates; DDM: Digestible Dry Matter; DOM: Digestible Organic Matter; RFV: Relative Feed Value. Means in the same column followed by different letters differ significantly at *P*<0.05.

compared to D_{PM}, produced 22.3 and 20.3% more MEY, respectively (Table 2). PD×PM interaction effect on MEY was significant (*P*<0.01) (Table 4). T_{PM} in $D1_{PD}$ produced the highest, and D_{PM} in $D4_{PD}$ generated the least MEY; but, with delay in PD H_{PM}, significantly produced more MEY than other PMs (Table 4). PD×CV interaction had a significant effect (*P*<0.05) on CPY (Table 5). In $D1_{PD}$ and $D2_{PD}$, the S_{CV} produced more CPY than P_{CV}, but in $D3_{PD}$ and $D4_{PD}$, the difference between cultivars was insufficient (Table 5). PM×CV interaction also was significant (*P*<0.05) on CPY production that with applying H_{PM} on S_{CV} highest and with D_{PM} on both CVs, the least MEY was generated (Table 6).

Quality traits

NDF content was significantly (*P*<0.05) affected by PD and PM. In $D4_{PD}$, using the D_{PM}, caused the least content of NDF (Table 3). Interaction of PD×PM had a considerable (*P*<0.01) effect on NDF content (Table 4). T_{PM} and H_{PM} in $D1_{PD}$ produced forage with the highest NDF content (Table 4). With the delay in PD substantial difference in NDF production between T_{PM} and H_{PM} occurred; in such a way that T_{PM} in $D2_{PD}$, $D3_{PD}$ and $D4_{PD}$, respectively, produced 0.66, 1.66 and 1.87% more NDF than H_{PM}. Also, must note that in $D4_{PD}$, the existed significant difference between H_{PM} and D_{PM} in the prior PDs faded away and both treatments placed in the lowest statistical grouping (Table 4).

ADF content was significantly (*P*<0.05) influenced by PD, PM, and CV (Table 3). In $D1_{PD}$ compared to $D3_{PD}$ and $D4_{PD}$, respectively, 3.6 and 6.1 % more ADF produced. Applying H_{PM} and T_{PM} compared to D_{PM} produced 2.1 and 3.4 % more ADF content (Table 3). S_{CV} compared to P_{CV} produced 9.3% more ADF (Table 3). Hem content was significantly (*P*<0.01) affected by PM. T_{PM} made 2.3 and 0.9% more Hem content than H_{PM} and T_{PM}, respectively. CP content was notably affected by PD (*P*<0.01) and PM (*P*<0.05) (Table 3). Delay in PD from $D1_{PD}$ to $D2_{PD}$, $D3_{PD}$, and $D4_{PD}$ respectively caused 4, 10.1, and 12.4% elevation in the CP content of forage (Table 3). H_{PM} and D_{PM} compared to T_{PM} respectively, produced 7.8 and 7.6% more CP content (Table 3). WSC content of forage was significantly (*P*<0.05) affected by PD (Table 3). In $D1_{PD}$ compared to $D3_{PD}$ and $D4_{PD}$, forage was produced with 6.5 and 10.3% more WSC (Table 3). The interaction effect of PD×CV on WSC content was considerable (*P*<0.05) (Table 5). In $D1_{PD}$ and $D2_{PD}$, P_{CV} produced forage with the highest WSC content; except in $D4_{PD}$ in all other PDs, the difference between S_{CV} and P_{CV} was notable (*P*<0.05) (Table 5). DDM and DOM content in forage were significantly (*P*<0.05) affected by PD, PM, and CV factors (Table 3). $D4_{PD}$ compared to

Table 4. Effect of planting dates and planting methods on traits.

Planting dates	Planting methods	DMY	DDMY	CPY	MEY	WUE_{DMY}	ME	NDF	ADF	Hem	CP	WSC	DDM	DOM	RFV
			($t\ ha^{-1}$)		($Gcal\ ha^{-1}$)	($kg\ ha^{-1}$)	(Mcal kg-1)				($g\ kg^{-1}$)				($Gcal\ ha^{-1}$)
1st of July	D_{PM}	24.3 d	14.4 e	2.25	48.2 e	6.57 c	2.00	594 d	382	212	93	103	592	621	92.8 e
	H_{PM}	30.2 b	17.6 b	2.76	58.8 b	7.93 a	1.94	613 a	396	218	92	109	581	610	88.3 h
	T_{PM}	31.4 a	18.2 a	2.67	60.8 a	7.92 a	1.94	615 a	396	219	85	110	581	609	87.8 h
11th of July	D_{PM}	20.5 f	12.3 g	1.94	41.4 g	6.08 d	2.03	589 e	375	213	95	101	597	626	94.3 cd
	H_{PM}	25.9 c	15.3 c	2.47	51.1 c	7.46 b	1.98	603 c	386	217	96	106	588	617	91.0 f
	T_{PM}	25.7 c	14.9 d	2.31	50.2 d	7.24 b	1.96	607 b	391	216	90	105	584	613	89.6 g
23rd of July	D_{PM}	15.6 h	9.3 i	1.53	31.8 i	4.95 f	2.05	581 f	369	213	99	96	602	631	96.6 b
	H_{PM}	21.5 e	12.8 f	2.20	42.8 f	6.65 c	2.01	592 d	379	213	104	103	594	623	93.3 de
	T_{PM}	20.8 f	12.4 g	1.96	41.3 g	6.28 d	1.99	602 c	383	219	95	101	590	620	91.3 f
1st of August	D_{PM}	12.3 i	7.3 j	1.30	25.2 j	4.07 g	2.06	574 g	366	209	107	89	604	634	97.9 a
	H_{PM}	17.3 g	10.6 h	1.78	35.9 h	5.59 e	2.08	576 g	363	213	103	102	606	636	98.1 a
	T_{PM}	15.6 h	9.3 i	1.44	31.4 i	4.88 f	2.04	587 e	373	214	94	96	598	627	95.0 c
p Val.		0.0022	0.0004	0.0723	<0.0001	0.0151	0.1163	0.0019	0.1483	0.5858	0.2252	0.1738	0.1401	0.1586	0.0118
LSD		0.74	0.30	ns	0.77	0.22	ns	3.43	ns	ns	ns	ns	ns	ns	1.28

D_{PM}, H_{PM}, T_{PM} represents direct hydroprimed and transplante planting method, respectively. DMY: Dry Matter Yield; DDMY: Digestible Dry Matter Yield; CPY: Crude Protein Yield; MEY: Metabolic Energy Yield; WUE_{DMY}: Water Use Efficiency of Dry Matter production; ME: Metabolic Energy; NDF: Neutral Detergent Fiber; ADF: Acid Detergent Fiber; Hem: Hemicelluloses; CP: Crude Protein; WSC: Water Soluble Carbohydrates; DDM: Digestible Dry Matter; DOM: Digestible Organic Matter; RFV: Relative Feed Value. Means in the same column followed by different letters differ significantly at $P<0.05$.

$D3_{PD}$, $D2_{PD}$, and $D1_{PD}$, respectively, produced forage with 1.3, 2.2, and 3.2% more DDM content and 1.1, 2.1, and 3% more DOM (Table 3). D_{PM}, in comparison with T_{PM} and H_{PM} respectively, produced forage with 1.8 and 1.2% more DDM and 1.8 and 1.1% more OMD (Table 3). P_{CV} produced forage with 4.8% more DDM and 4.7% more DOM content than S_{CV} (Table 3). ME content significantly ($P<0.05$) affected by PD, PM, and CV. The ME content in $D4_{PD}$ was respectively 3.4 and 4.9% higher than the amount that produced in $D3_{PD}$ and $D4_{PD}$. D_{PM} generated 2 and 2.9% more ME than H_{PM} and T_{PM}, respectively. P_{CV} generated forage with 7.2% more ME than S_{CV}.

The forage RFV was significantly affected by PD ($P<0.01$), PM ($P<0.05$), and CV ($P<0.05$) (Table 3). The produced forage in $D4_{PD}$ compared to $D3_{PD}$, $D2_{PD}$, and $D1_{PD}$ respectively had 3.3, 5.6, and 7.6% more RFV (Table 3). D_{PM} compared to T_{PM}, and H_{PM} respectively, had 4.7 and 2.8% more RFV. P_{CV} produced forage with 8.8% more RFV than S_{CV} (Table 3).

Table 5. Effect of planting dates and cultivars on traits.

Planting dates	Planting methods	DMY	DDMY	CPY	MEY	WUE_{DMY}	ME	NDF	ADF	Hem	CP	WSC	DDM	DOM	RFV
			($t\ ha^{-1}$)		($Gcal\ ha^{-1}$)	($kg\ ha^{-1}$)	(Mcal kg-1)				($g\ kg^{-1}$)				($Gcal\ ha^{-1}$)
1st of July	S_{CV}	30.4	17.2 a	2.67 a	56.9	7.92 a	1.88	621	412	209	89	98.9 bc	568	597	85.1
	P_{CV}	26.8	16.3 b	2.45 b	54.9	7.03 b	2.05	593	370	223	91	115.7 a	601	630	94.2
11th of July	S_{CV}	26.2	15.1 c	2.42 b	49.9	7.58 a	1.91	611	404	207	93	95.7 c	575	603	87.4
	P_{CV}	21.8	13.2 d	2.06 c	45.2	6.28 c	2.07	588	365	223	94	112.2 a	605	634	95.8
23rd of July	S_{CV}	20.6	11.9 e	1.99 cd	39.7	6.34 c	1.94	603	395	208	97	95.5 c	581	610	89.7
	P_{CV}	18.0	11.1 f	1.80 d	37.5	5.57 d	2.09	580	359	222	101	104.3 b	610	639	97.8
1st of August	S_{CV}	15.2	9.0 g	1.44 e	30.3	4.91 e	2.00	593	383	211	96	96.1 c	591	620	92.7
	P_{CV}	14.9	9.1 g	1.57 e	31.3	4.79 e	2.12	565	352	213	107	95.3 c	615	644	101.3
p Val.		0. 0569	0.0408	0.0407	0.1151	0.0321	0.1040	0.3009	0.0963	0.1256	0.0665	0.0173	0.0875	0.0980	0.3844
LSD		ns	0.77	0.20	ns	0.44	ns	ns	ns	ns	ns	5.90	ns	ns	ns

S_{CV} and P_{CV} represent Speedfeed and Pegah cultivars, respectively. DMY: Dry Matter Yield; DDMY: Digestible Dry Matter Yield; CPY: Crude Protein Yield; MEY: Metabolic Energy Yield; WUE_{DMY}: Water Use Efficiency of Dry Matter production; ME: Metabolic Energy; NDF: Neutral Detergent Fiber; ADF: Acid Detergent Fiber; Hem: Hemicelluloses; CP: Crude Protein; WSC: Water Soluble Carbohydrates; DDM, Digestible Dry Matter; DOM, Digestible Organic Matter; RFV, Relative Feed Value. Means in the same column followed by different letters differ significantly at $P<0.05$.

Table 6. Effect of planting methods and cultivars on traits.

Planting dates	Planting methods	DMY	DDMY	CPY	MEY	WUE_{DMY}	ME	NDF	ADF	Hem	CP	WSC	DDM	DOM	RFV
			(t ha^{-1})		(Gcal ha^{-1})	(kg ha^{-1})	(Mcal kg-1)				(g kg^{-1})				(Gcal ha^{-1})
D_{PM}	S_{CV}	19.0 c	11.0 d	1.81	37.0 d	5.65 e	1.97	596	390	207	97	93	585	614	91.4
	P_{CV}	17.3 d	10.6 e	1.70	36.3 d	5.18 f	2.10	573	356	217	100	101	612	641	99.4
H_{PM}	S_{CV}	25.5 a	14.7 a	2.39	48.7 a	7.42 a	1.93	610	400	210	95	99	577	606	88.2
	P_{CV}	22.0 b	13.4 c	2.22	45.6 c	6.40 c	2.08	582	362	220	102	111	607	636	97.1
T_{PM}	S_{CV}	24.9 a	14.2 b	2.19	47.0 b	6.99 b	1.90	615	405	210	89	97	573	602	86.6
	P_{CV}	21.8 b	13.2 c	2.00	44.8 c	6.17 d	2.06	590	366	224	93	109	604	633	95.3
p Val.		0.0292	0.0222	0.5232	0.0296	0.0027	0.4608	0.2441	0.5341	0.5772	0.4033	0.2427	0.5184	0.5245	0.5984
LSD		0.72	0.27	ns	0.92	0.06	ns	ns	ns	ns	ns	ns	ns	ns	ns

D_{PM}, H_{PM}, T_{PM} represents direct hydroprimed and transplante planting method, respectively. S_{CV} and P_{CV} represent Speedfeed and Pegah cultivars, respectively. DMY: Dry Matter Yield; DDMY: Digestible Dry Matter Yield; CPY: Crude Protein Yield; MEY: Metabolic Energy Yield; WUE_{DMY}: Water Use Efficiency of Dry Matter production; ME: Metabolic Energy; NDF: Neutral Detergent Fiber; ADF: Acid Detergent Fiber; Hem: Hemicelluloses; CP: Crude Protein; WSC: Water Soluble Carbohydrates; DDM: Digestible Dry Matter; DOM: Digestible Organic Matter; RFV: Relative Feed Value. Means in the same column followed by different letters differ significantly at *P*<0.05.

Water use efficiency

The WUE_{DMY} was considerably affected by PD (*P*<0.01) and PM (*P*<0.05) (Table 2). PD postponement from $D1_{PD}$ to $D2_{PD}$, $D3_{PD}$, and $D4_{PD}$, respectively, caused 7.4, 20.2, and 35.1% reduction. Employing H_{PM} and T_{PM} instead of D_{PM} caused 27.5 and 21.4% elevation in water usage productivity. Dual interaction of PD×PM considerably (*P*<0.05) affected WUE_{DMY} (Table 4). H_{PM} and T_{PM} in $D1_{PD}$ generated the highest, and the D_{PM} in $D4_{PD}$ caused the least WUE_{DMY}. By delay in PD, the WUE_{DMY} of same PMs were significantly decreased, and simultaneously, H_{PM} notably used water more productively than T_{PM} in $D3_{PD}$ and $D4_{PD}$. Also, interaction of PD×CV meaningfully (*P*<0.05) affected WUE_{DMY}. In $D1_{PD}$ and $D2_{PD}$, S_{CV} generated the highest WUE_{DMY}, and only in $D4_{PD}$ the difference between S_{CV} and P_{CV} was insignificant. Interaction of PM×CV notably affected WUE_{DMY}. Highest productivity in water usage was generated by applying H_{PM} on S_{CV} and the least WUE_{DMY} caused by D_{PM} of P_{CV}.

Correlations

Correlation test amongst traits showed that contrary to significantly (*P*<0.01) negative correlation of DMY with CP (60%), DDM (57%), and ME (57%), DMY was positively

Table 7. Correlation coefficient among quantitative and qualitative parameters.

Traits	DMY	WUE_{DMY}	NDF	ADF	CP	Hem	WSC	DDM	RFV	ME	DOM	CPY	DDMY	MEY
DMY	1													
WUEDMY	0.75**	1												
NDF	0.70**	0.48**	1											
ADF	0.57**	0.37**	0.87**	1										
CP	-0.60**	-0.40**	-0.66**	-0.54**	1									
Hem	0.05	0.07	-0.05	-0.52**	-0.05	1								
WSC	0.26**	-0.05	-0.08	-0.21**	-0.03	0.30**	1							
DDM	-0.57**	-0.37**	-0.87**	-0.99**	0.54**	0.53**	0.21*	1						
RFV	-0.65**	-0.44**	-0.97**	-0.96**	0.63**	0.28**	0.14	0.96**	1					
ME	-0.57**	-0.37**	-0.87**	-0.99**	0.54**	0.53**	0.21*	0.99 **	0.96**	1				
DOM	-0.57**	-0.37**	-0.87**	-0.99**	0.54**	0.53**	0.21*	0.99**	0.96**	0.99**	1			
CPY	0.97**	0.75**	0.61**	0.49**	-0.41**	0.06	0.30**	-0.50**	-0.54**	-0.50**	-0.50**	1		
DDMY	0.99**	0.75**	0.65**	0.49**	-0.58**	0.12	0.30**	-0.50**	-0.59**	-0.50**	-0.50**	0.97**	1	
MEY	0.98**	0.76**	0.61**	0.44**	-0.57**	0.15	0.32**	-0.45**	-0.55**	-0.45**	-0.45**	0.97**	0.99**	1

DMY: Dry Matter Yield; WUE_{DMY}, Water Use Efficiency for Dry Matter Production; NDF, Neutral Detergent Fiber; ADF, Acid Detergent Fiber; CP, Crude Protein; CPY, Crude Protein Yield; Hem, Hemicelluloses; DDM, Digestible Dry matter; DDMY, Digestible Dry Matter Yield; RFV, Relative Feed Value; WSC, Water Soluble Carbohydrates; ME, Metabolic Energy; MEY, Metabolic Energy Yield; DOM, Digestible Organic Matter.
* and ** indicate significant at P ≤ 0.05 and P ≤ 0.01, respectively.

Table 8. The linear regression models and their components for dry matter yield (independent variable) production of different treatments as affected by changes in GDD (dependent variable) during growth seasons. Suitable regression equation for 24 treatments: DMY= ax + b; where a = line slope; b = intercept value; R^2= coefficient of determination; Adj-R^2= adjusted coefficient of determination; RMSE= root mean square of errors

Components			a	b	R^2	Adj-R^2	RMSE	p Val.
$D1_{PD}$	D_{PM}	S_C	0.0191	-10.418	0.9795	0.9775	1.4483	<0.0001
		P_C	0.0195	-12.960	0.9314	0.9245	2.7686	<0.0001
	H_{PM}	S_C	0.0243	-10.501	0.9815	0.9797	1.7459	<0.0001
		P_C	0.0217	-12.235	0.9764	0.9741	1.7648	<0.0001
	T_{PM}	S_C	0.0207	-10.053	0.9821	0.9803	1.7734	<0.0001
		P_C	0.0178	-10.868	0.9408	0.9349	2.8287	<0.0001
$D2_{PD}$	D_{PM}	S_C	0.0194	-10.990	0.9702	0.9669	1.4872	<0.0001
		P_C	0.0182	-11.461	0.9153	0.9059	2.4189	<0.0001
	H_{PM}	S_C	0.0257	-11.838	0.9893	0.9881	1.1722	<0.0001
		P_C	0.0214	-12.199	0.9548	0.9498	2.0359	<0.0001
	T_{PM}	S_C	0.0191	-10.646	0.9683	0.9648	1.9107	<0.0001
		P_C	0.0158	-9.7184	0.9368	0.9298	2.2701	<0.0001
$D3_{PD}$	D_{PM}	S_C	0.0186	-10.500	0.9257	0.9164	1.9098	<0.0001
		P_C	0.0168	-9.9055	0.8792	0.8641	2.2503	<0.0001
	H_{PM}	S_C	0.0242	-11.391	0.9903	0.9891	0.8683	<0.0001
		P_C	0.0223	-11.907	0.9544	0.9487	1.7630	<0.0001
	T_{PM}	S_C	0.0176	-10.104	0.9618	0.9570	1.6751	<0.0001
		P_C	0.0149	-9.3567	0.9187	0.9085	2.1252	<0.0001
$D4_{PD}$	D_{PM}	S_C	0.0171	-8.9442	0.8864	0.8702	1.8875	0.0002
		P_C	0.0149	-7.9432	0.8478	0.8261	1.9406	0.0004
	H_{PM}	S_C	0.0226	-9.8810	0.9818	0.9792	0.9483	<0.0001
		P_C	0.0230	-11.396	0.9291	0.9190	1.9557	<0.0001
	T_{PM}	S_C	0.0127	-7.4861	0.8756	0.8578	1.9891	0.0002
		P_C	0.0135	-7.9237	0.9041	0.8904	1.8322	<0.0001

(*P*<0.01) correlated with CPY (97%), DDMY (99%), and MEY. Also, DMY was positively (*P*<0.01) correlated with WUE_{DMY} (75%), NDF (70%), ADF (57%), WSC (26%), and was negatively (*P*<0.01) correlated with RFV (65%) and DOM (57%). NDF was negatively (*P*<0.01) correlated with CP (66%), DDM (87%), RFV (97%), ME (87%) and DOM (87%). Also, ADF had notably (*P*<0.01) negative correlation with CP (53%), Hem (52%), WSC (21%), DDM (99%), RFV (96%), ME (99%) and DOM (99%). RFV had significantly (*P*<0.01) positive correlation with CP (63%), Hem (28%), DDM (96%), ME (96%) and DOM (96%) (Table 7). The correlation amongst the components of the regression illustrated the significantly (*P*<0.01) positive correlation of DMY with line slope (53%) and Adj-R^2 (78%). Although DMY was negatively correlated (*P*<0.01) with line intercept (50%) (Table 9).

Table 9 Correlation coefficient amongst the results of regression analysis with dry matter yield.

	DMY	A	B	Adj-R^2	RMSE
DMY	1				
A	0.53**	1			
B	-0.50*	-0.73**	1		
Adj-R^2	0.78**	0.76**	-0.61**	1	
RMSE	-0.05	-0.50*	-0.03	-0.51*	1

DMY, Dray matter yield; a, line slope; b, intercept value; Adj-R^2, adjusted coefficient of determination; RMSE, root mean square of errors.
* and ** indicate significant at P ≤ 0.05 and P ≤ 0.01, respectively.

Discussion

Yield parameters

Biomass yield production is the core objective in forage cultivation practices (Nematpour et al. 2020). In addition to the GLM and regression analysis, Figure 2 also exhibits the trend of DMY production influenced by variation in PD. The reductions in DMY influenced by delay in PD probably occurred due to (1) the changes in light parameters that affected the ERF protein activity which leads to various physiological reactions and the DMY productions in sorghum (Mathur et al. 2020), and (2) reductions in the adequacy of required environmental characteristics especially GDD for maximum DMY production (Hassan et al. 2020). Figure 2 illustrates the elevation of line-slope in both simulated and produced DMY under the changes in PMs. Figure 2 shows contrary to the equal acquired GDD for both H_{PM} and D_{PM}, but H_{PM} used growth season's ambient factors (specifically GDD) more productive, which lead to more DMY production in all PDs; likewise illustrated the H_{PM}'s ability in producing the same DMY as the T_{PM}, despite the less available GDD in $D1_{PD}$. This result, alongside the produced DMY under further lagged PD ($D2_{PD}$, $D3_{PD}$, and $D4_{PD}$), emphasized the higher productivity of H_{PM} over T_{PM} and D_{PM} in using the available adequate growing season for DMY production. Probably this difference between H_{PM} and T_{PM} occurred because of the Gramineae species sensitivity towards the removal of primary roots (Biswas 2020) during the transference of seedling to the field, which is the prevalent obstacle for transplanting (Lee et al. 2019). Figure 2 shows that in each specific PM and PD, the CV affected the slope and intercept of regression models. Blunt angled lines with more intercepts defined by researchers as the slower crop growth rate and less harvested DMY (Tagarakis et al. 2017). These results assist in clarification of the role of suitable cultivar, planting method, and planting date in maximizing the harvested forage sorghum DMY in a second cropping system. A high-quality forage characterizes by a high level of DDM.

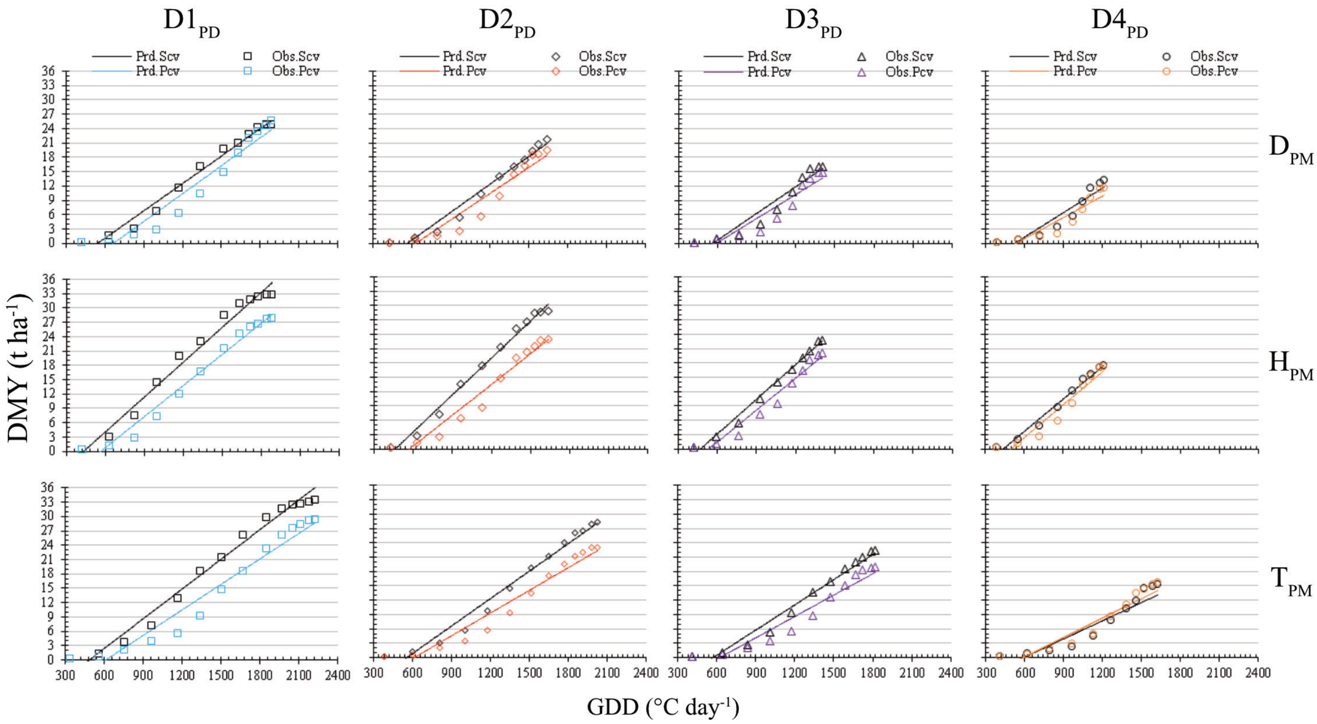

Figure 2. Regression relationship of observed (Obs) and predicted (Prd) dry matter yield (DMY) versus cumulated growth degree day (GDD) during 1st of July ($D1_{PD}$), 11th of July ($D2_{PD}$), 23rd of July ($D3_{PD}$) and 1st of August ($D4_{PD}$) planting dates of Speedfeed (S_{CV}) and Pegah (P_{CV}) cultivars under hydroprimed seeds (H_{PM}), transplanting (T_{PM}) and conventional planting methods (D_{PM}).

Probably hence, $D1_{PD}$ provided a longer growing season (Hassan et al. 2019) highest DDMY recorded, and with delay in PD, the DDMY significantly decreased. Likely, hence $D1_{PD}$ supplied the required duration to compensate for the transplant transference stress (Biswas 2020), T_{PM} produced the highest DDMY. But delay in PD and growth season reduction eliminated the supremacy of T_{PM} (Rattin et al. 2015), and subsequently, in $D2_{PD}$, $D3_{PD}$, and $D4_{PD}$, it was H_{PM} that significantly produced more DDMY (Chen et al. 2021).

Jahanzad et al. (2013) recognized CP as one of the most critical parameters in determining the forage quality. Zanonadi et al. (2017) identified the minimum air temperature and the mean soil temperature as the key environmental factors for sorghum growth and yield production. Therefore, probably reduction in mentioned factors because of the delay in PD was the main reason in CPY and MEY production reduction (Table 2). Zida et al. (2018) explained the hydropriming role in DMY enhancement via crop growth rate acceleration through activating the seed's enzymes prior to sowing. Thus, probably more CPY and MEY were harvested due to the significant effect of H_{PM} on DMY production. On the other hand, Lee et al. (2019) addressed the sowing date as one of the key factors to adjust the plant's growth requirement with suitable ambient characteristics for maximum yield production. Thus, the lag of PD reduced the required environmental competency and affected the CPY and MEY production in $D4_{PD}$ compared to the $D1_{PD}$. Jahanzad et al. (2013) reported the S_{CV} dominance over P_{CV} in growth rate and total protein yield production.

Quality parameters

Lyons et al. (2019a) reported the significant effect of sowing times on the DMY. Chen et al. (2021) and Ibrahim et al. (2020) respectively reported the considerable effect of hydropriming and transplanting effects on DMY. Jahanzad et al. (2013) reported a significant positive correlation between DMY and NDF. Probably hence, amongst the PDs, the highest DMY was obtained in $D1_{PD}$ (due to the most fitted synchronicity between plant growth stages and environmental condition), T_{PM} and H_{PM} also, facilitated and accelerated the plant growth, highest NDF content obtained. But, growing season reduction in $D2_{PD}$, $D3_{PD}$ and $D4_{PD}$, the T_{PM} continued to produce higher NDF compared to the H_{PM}. Probably the 20 days more growth season in the nursery stage was the reason for these distinctions. Bhattarai et al. (2017) and Hassan et al. (2020) recognized the effect of soil and air temperature as the determinative factors in germination and yield production in forage sorghum cultivation. Hence Nematpour et al. (2020) reported the positive correlation between ADF and DMY, and probably hereupon, in $D1_{PD}$, the ambiance condition for growth and development was more desirable, these results recorded. Hassan et al. (2019) reported asynchronous growth season and plant development phases would reduce the potential for DMY production. Probably, the PD postponement by lowering the environmental suitability affected the plant development and caused the considerable reduction in DMY, and hence the direct positive correlation between ADF and DMY was in progress, the forage produced with less ADF content. Chen et al. (2021) and Lee et al. (2019) respectively stated the significant effect of H_{PM} and T_{PM} on DMY; accordingly, more ADF content produced by H_{PM} and T_{PM} compared to D_{PM}. Jahanzad et al. (2013), in addition to positive correlation of NDF and DMY, also reported the higher ADF content of S_{CV} compared to the P_{CV}. The content of CP in forage represents the actual quantity of true protein or amino acid that absorbed by the animal (Das et al. 2014). The elevation in average air temperature optimizes the plant development throughout supplying the ambient requirements for sorghum growth (Lyons et al. 2019a, b). Premier growth rate reduces nitrogen absorption, which eventually compromises the protein production in forage sorghum (Kukal and Irmak 2018). The D_{PM} compared to the H_{PM} and T_{PM} reduced the line slope and increased the line intercept of the regression models (which represents the growth rate) (Figure 2). Therefore, probably more time for absorbing nitrogen and more time for producing proteins that resulted in more CP content production. Lyons et al. (2019b) and Kukal and Irmak (2018) reported higher temperature increases the growth rate and reduces the N absorption and the content of CP. In all likelihood, hence delay in PD reduced the growth rate because of the reduction in mean and minimum air temperature and also the average soil temperature, suitable situation to produce more CP content in $D4_{PD}$ compared to the prior PDs provided. Jahanzad et al. (2013) reported a lower growth rate of P_{CV} compared to S_{CV}. Figure 2 clarifies the blunter line angle and higher line intercept of P_{CV} included treatments compared to the S_{CV} ones; likely, according to this results, P_{CV} was able to produce higher CP than S_{CV}. The forage that is abundant in WSC provides the required sugar for a successful silage process (fermentation) and also supplies the animal needs to energy for high productive digestion. Forage with a high volume of WSC is a promising feedstock to produce bioethanol at the industrial level. Probably hence in $D1_{PD}$, the ambient factors like minimum air temperature and the mean soil temperature stimulated the effect of long days on photosynthesis, subsequently, the level of WSC was higher than other PDs. Nematpour et al. (2020) reported forages that planted at the later dates produced higher net energy content for lactation. Probably suitable environmental condition in $D1_{PD}$ and $D2_{PD}$ alongside the genetic property of P_{CV} induced WSC production. These results are in agreement with the report from Jahanzad et al. (2013).

Kaplan et al. (2019) reported the negative correlation between DMY with OMD. RFV in forage plays the determinative role in portion selection of a specific forage in the ration for feedstock (Tang et al. 2018). RFV and NDF content constantly have a considerable negative correlation (Imoro 2020). Probably because of the desirable ambient condition in $D4_{PD}$ for forage production with less indigestible content like lignin was the main reason for forage production with most DDM, OMD, ME content, and RFV (Kaplan et al. 2019; Hassan et al. 2019). Nematpour et al. (2020) reported a positive correlation between NDF and ADF with growth rate; since D_{PM} caused the growth rate with a blunter angle (Fig. 2) than H_{PM} and T_{PM}, thus, highest content of DDM, DOM, ME content, and RFV generated by D_{PM}. Jahanzad et al. (2013) reported lower NDF and ADF content of P_{CV} compared to the S_{CV}.

Water use efficiency

Globally, 70% of freshwater usage is dedicated to agricultural activities (Michelon et al. 2020). The most restricting factor of farming in arid and semiarid regions are supplying the required water and increasing the "Water Use Efficiency" in production systems (Hao et al. 2014; Teixeira et al. 2017; Bhattaraia et al. 2020). Hassan et al. (2019) reported the unsynchronized growth stage and ambient factors reduce the resource usage productivity. Thus, delay in planting that significantly reduced harvested DMY conclusively caused a notable reduction in WUE_{DMY}. Michelon et al. (2020) acknowledged priming as one of the strategies to increase water usage productivity. Jahanzad et al. (2013) reported the advantage of S_{CV} over P_{CV} in yield production. Thus, probably by applying H_{PM} on S_{CV}, the germination and seedling establishment enhanced, and the plant development rate elevated, which resulted in considerably higher WUE_{DMY} than D_{PM} and even T_{PM}.

Correlation

According to the correlation results between water use efficiency and nutritional parameters with DMY, factors like early planting dates (Hassan et al. 2019), advanced planting methods (H_{PM}, and T_{PM}) (Mapfumo et al. 2013; Pinheiro et al. 2018; Bajwa et al. 2018; Zida et al. 2018; Ibrahim et al. 2020), and early cultivars (Jahanzad et al. 2013; Tirfessa et al. 2020; Hasan et al. 2020; Bhattarai et al. 2020) that significantly increases the DMY production, empowers the forage production systems to generate forage with an acceptable yield of nutritional components and water use efficiency. Based upon the results of correlation among the results of regression analysis with DMY (Table 8), it could be a valid interpretation that with avoiding the delay in PD, using the conventional PM, and utilizing the P_{CV} that reduces the a-coefficient and elevates the b-factor, maximize the probability to reach the most DMY.

Conclusion

The inevitable effect of global warming added to the naturally restricted water and soil resources, population growth, and historic low livelihood state in arid and semiarid regions are the most threatening factors toward the sustainability of resources, agricultural practices, and food safety. A second cropping system by cultivating the water shortage-resistant species under developed planting methods could be worthwhile to introduce another alternative to attain, maintain, and develop the production sustainability and food safety in these regions. The holdup of planting in a second cropping system due to various factors could improvise planting date and consequently yield production. The results showed that in Y2, while the temporal factors increased yield of both S_{CV} and P_{CV} elevated. Studied planting methods revealed the significant elevation in quantity and nutritional traits. Also, the H_{PM} and T_{PM} were able to compensate for the delay in planting dates through accelerating the germination, facilitating the seedling establishment, and advancing the plant development. Conclusively results asserted that the preparedness for executing the H_{PM} process on S_{CV} would produce a hefty forage yield with an acceptable range of quality.

Author contribution statement

IM Collected data (field and lab works), data analysis, writing the article. FG performed the research concept and design, statistical analysis, writing the article. MRA performed the research concept and design, field works, writing the article, critical revision of the article, final approval of article. FP performed the research concept and design, lab works, writing the article. AM contributed lab works and writing the article. No funding was received for conducting this study.

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