AP AGRO PRODUCTIVIDAD

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Thermal sum in the determination of the phenological stages of Chihuahua and Cuauhtémoc oats in Güémez Tamaulipas

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ABSTRACT

Objective: To determine the thermal sum requirements of *Avena sativa* (Cuauhtémoc and Chihuahua varieties) as Growing Degree Days (GDD) per phenological stage and their effect on the accumulation of total forage and the accumulation of each morphological component, in Güémez, Tamaulipas.

Design/Methodology/Approach: The mechanical sowing (120 kg ha^{-1} seed dose) was carried out in 6×6 m plots with four replications of Cuauhtémoc and Chihuahua varieties. Subsequently, the plot was irrigated and fertilization works were carried out. The treatments consisted of two varieties and six phenological stages (Zadok's scale: Z2, Z3, Z4, Z7, Z8, Z9) in a randomized complete block design.

Results: It was found that 1,923.5 and 1,831.5 GDD were obtained from November to March, respectively; these results are a crop requirement for the fulfillment of the biological cycle of the Chihuahua and Cuauhtémoc varieties. Yields by morphological component depended on the observed phenological stage. The highest leaf yield ($P<0.05$) was obtained in stage Z3 (stem elongation): 2.7 t ha^{-1} in Cuauhtémoc (accumulation: 1,032 GDD) and 3.6 t ha^{-1} in Chihuahua (accumulation: 980 GDD).

Study Limitations/Implications: These results can only be applied to the evaluation area, as a result of the intervention of the environment on these physiological responses.

Findings/Conclusions: In Güémez, Tamaulipas, the Chihuahua oat variety requires 1,923.5 GDD to complete its biological cycle, while Cuauhtémoc requires 1,831.5 GDD. The difference between the thermal accumulation of the varieties and the phenological stages has an impact on the total forage yield and the yield of each morphological component.

Keywords: Forage, *Avena sativa*, Growing Degree Days, temperature, Güémez Tamaulipas.

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INTRODUCTION

In Mexico, livestock activities are carried out in 56% of the country's surface and 35.6 million heads of cattle are distributed in different milk- or meat-oriented farms

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or livestock production units (SIAP, 2020). The country ranks 8^{th} in world meat production; additionally, it is one of the 10 countries that concentrate 90 % of beef exports (COMECARNE, 2021).

The different farms or livestock production units partly or exclusively depend on the availability of forage in swards or rangelands to satisfy most of their nutritional requirements. This area offers the greatest possibilities of reducing costs with more productive and higher quality species (Zamora *et al.*, 2002). However, greater availability of forage is associated with the quantity and quality of the moisture available in the soil, as well as the temperature and light hours available to the plants. Therefore, a decrease in temperature and light hours during the winter season results in a decrease of forage yield in swards and rangelands (Sosa *et al.*, 2008). This is the result of the effects on the physiological activity of plants, such as the decrease in photosynthetic activity derived from a lower CO_2 absorption caused by the inactivation of the Rubisco enzyme. This enzyme is the protein responsible for the absorption of this gas, a requirement to increase the photosynthetic rate and to obtain the carbohydrates needed to increase plant development (Azcón-Bieto *et al.*, 2008; Yepes and Silveira, 2011).

In addition, daytime temperatures are related to the duration of the crop cycle, since the thermal sum during this period (unit of measure: Growing Degree Days or GDD) determines the period from sowing to ripening. This period can differ from one year to another, while the thermal sum remains relatively stable within the same region (Liu *et al.*, 2020).

The lower availability of forage during winter season can be counteracted by the use of winter crops, such as oats (*Avena sativa* L.), through an efficient use of humidity and temperature. Oats have a short cycle and are resistant to frost, if this phenomenon takes place before flowering and grain filling (CIREN, 1989; Sánchez *et al.*, 2014; Bilal *et al.*, 2017). This crop stands out among the livestock industry: 80% of the national production is used as animal feed, in the form of hay, green forage, silage or grain (Espitia *et al.*, 2012; Villazón *et al.*, 2017). Therefore, the objective of this research was to determine the thermal sum requirements of *Avena sativa* (Cuauhtémoc and Chihuahua varieties) as Growing Degree Days (GDD) per phenological stage and their effect on the accumulation of total forage and the accumulation of each morphological component, in Güémez, Tamaulipas.

MATERIALS AND METHODS

Location of the experimental site and climatic characteristics

The research was carried out from November 2021 to March 2022 at the "Posta Zootécnica Ingeniero Herminio García González", located in the municipality of Güémez, Tamaulipas, Mexico (23° 56' 28" N, 99° 06' 24" W), at 190 m.a.s.l. The local climate is semi-arid warm [BS1 (h') hw]; it mostly rains on summer, but up to 10% of the rains occur in winter (Vargas *et al.*, 2007)]. Temperature data were recorded from the meteorological station of the Centro Nacional de Innovación y Transferencia de Tecnología en Agricultura de Precisión, Facultad de Ingeniería y Ciencias, located in the Posta Zootécnica.

Treatments and experimental unit

The varieties used were Chihuahua and Cuauhtémoc. The sowing was carried out in 6×6 m plots with four replications per variety; the sowing density was 120 kg ha^{-1} of seed with 85% germination. The soil was prepared with a cross harrowing; subsequently, broadcast sowing was carried out and a heavy branch was used to cover the seed. Three sprinkler irrigations were applied at field capacity, at the time of sowing, tillering (beginning), and flowering. The 120-40-00 (NPK) fertilization dose was divided into two applications: half at the time of sowing and half at the tillering stage. A 125 g a.i. ha^{-1} dose of the Propiconazole® fungicide was used to control incidences of rust (*Puccinia* spp.).

The treatments consisted of two varieties of oats and six phenological stages, according to the Zadok's Scale: Z2 (tillering), Z3 (stem elongation), Z4 (booting), Z7 (milk development), Z8 (dought development), and Z9 (ripening). The samplings were carried out when more than 50% of the plants presented the stage described above. To determine the experimental units, the plots were divided into six 6 m^2 areas, one per each stage. A 1 m^2 area was delimited within each of those areas.

Variables

Plant height and light interception: Before each sampling, 10 random measurements were made in each experimental unit with a 100 cm graduated ruler (precision: 1 mm), from the base of the plant to the top, without stretching the leaves or panicles. The rule was then laid on the ground and the length shaded by the leaves was recorded as a percentage (100 cm=100%). Such measurement required that the sun rays hit plants in a straight vertical direction.

Forage accumulation and morphological composition: In each sampling, each experimental unit was harvested 5.0 cm above the ground and the samples were immediately weighed on a CQT 2601 analytical balance (ADAM®, USA). Later, at the laboratory, the harvested forage was placed in an OMS60 forced air stove at 60 °C (Thermo Scientific®, USA) until a constant weight was achieved and the dry matter yield was obtained.

The morphological composition was evaluated with a subsample (20% of the harvested forage), which was separated into leaf (leaf blade+pod), stem, panicle, and senescent material. The dry weight data was used to determine the contribution (t ha^{-1}) of the leaf (DMl), stem (DMs), panicle (DMp), and senescent matter (DMsc) components to the yield of total dry matter (TDM).

Growing Degree Days: The days after sowing were recorded and, subsequently, the GDDs for each phenological stages were calculated. However, each crop has minimum and maximum threshold temperatures within which the crop continues to develop; in the case of oat, the minimum and maximum temperatures are 5 and 30 °C, respectively (Servin *et al.*, 2018). The GDDs were calculated as the difference between the average daily temperature and the minimum threshold temperature, the base temperature required by the crop (Liu *et al.*, 2020).

$$GDD = \sum_{i=1}^{n} \left(\frac{Tmax + Tmin}{2} - TUMin \right)$$

Where *Tmax* and *Tmin* are the maximum and minimum daily temperatures and *TUMin* is the crop's minimum threshold temperature.

Statistical analysis. An analysis of variance was performed with the GLM procedure (SAS, 2003), in a randomized complete block design. The Tukey test was applied for the comparison of means (P=0.05).

RESULTS AND DISCUSSION

Figure 1 shows that the average daily temperatures during the evaluation period ranged from 8 to 31 °C, with variations of the coldest and hottest days in each month. Additionally, it shows the minimum and maximum threshold temperatures of the oat crop (*i.e.*, the temperatures at which the crop develops progressively). For this evaluation, the average daily temperatures were within the range of the threshold temperatures for the oat crop.

The varieties had only numerical differences in terms of the number of days between phenological stages with respect to the sowing date. Likewise, the different DDS for each stage propitiate different GDD between varieties (Table 1). Therefore, the thermal sum between varieties during the crop cycle was different from one variety to another. The Chihuahua variety had 1,803 °C GDD: 92 °C hotter than the Cuauhtémoc variety (which appeared 5 days earlier than the Chihuahua variety, in terms of the length of the crop cycle). Regarding the development cycle of the oat crop (considered a winter crop) in Güémez, Tamaulipas, oats are considered a forage option from November to March, when the temperature mostly ranges from <30 °C to >5 °C. The remainder of the year, the yield and quality of the crop are compromised by the increase in rates with physiological and biochemical variables (Liu *et al.*, 2020). In addition to compromising the CO_2 absorption due to the inefficiency of the Rubisco enzyme and the photosynthetic rate, it is negatively affected as a response variable (Azcón-Bieto *et al.*, 2008).

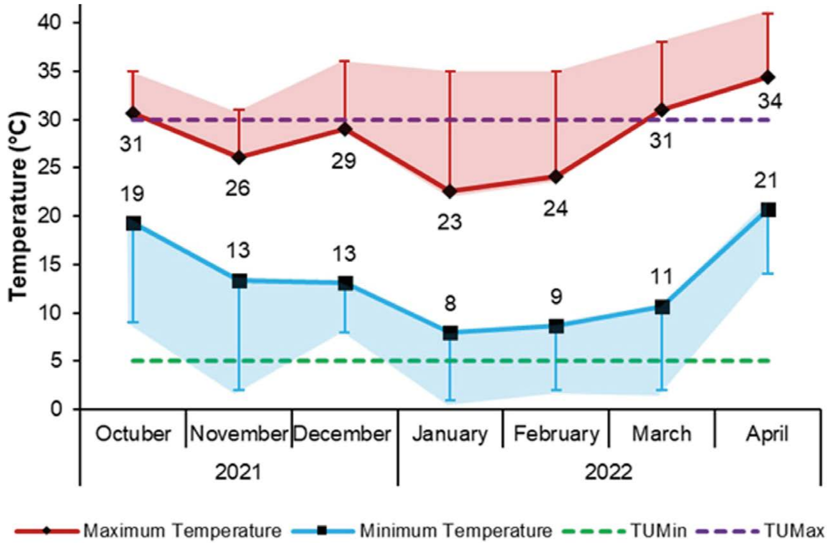

Figure 1. Monthly maximum and minimum temperatures during the evaluation period and maximum (TUMax) and minimum (TUMin) threshold temperatures of *Avena sativa* in Güémez, Tamaulipas, Mexico.

Regarding the plant height variable, differences were found between varieties in stages Z4, Z7, Z8, and Z9; the Chihuahua variety recorded the highest height ($P<0.05$) with 80, 105, 118, and 106 cm, respectively. Meanwhile, there was only a statistical difference ($P<0.05$) in the light interception percentage, between variables in stage Z7 (milk development). However, the highest percentages of interception per variety occurred in stage Z3 (Table 1).

The dry matter yield for the Chihuahua and Cuauhtémoc varieties showed differences in total dry matter and the dry matter of each component ($P<0.05$). Regarding the total dry matter, the Chihuahua variety presented a higher yield with 4.6, 5.4, 5.8, and 4.1 t ha^{-1}, except in stages Z2 and Z7 (Figure 2); this is a response to the longer biological cycle time, which has been reported to obtain a higher dry matter yield in late cycle species (Espitia *et al.*, 2012).

Table 1. Growing Degree Days (GDD), plant height, and light interception in the phenological stages of Cuauhtémoc and Chihuahua oats, in Güémez, Tamaulipas, Mexico.

PS	DAS		DDD (°C)		Height (cm)		Interception (%)	
	Cu	Ch	Cu	Ch	Cu	Ch	Cu	Ch
Z2	34	39	542	617	31 a D	35 a C	67 a DE	67 a ABC
Z3	65	72	439	415	65 a BC	69 a B	93 a A	96 a A
Z4	77	86	94	125	70 b BC	80 a B	92 a AB	96 a A
Z7	105	110	319	285	88 b C	105 a A	78 b BC	90 a AB
Z8	119	124	185	205	99 b A	118 a A	75 a DC	78 a BC
Z9	135	140	254	277	93 b AB	106 a A	60 a E	64 a C

PS=Phenological stages; DAS=Days after sowing; DDD=Degree days of development.
Different letters in the same column (ABC) and same row per component (abc) indicate statistical difference (Tukey, $\alpha=0.05$). PS (EF): Phenological stage, DAS (DDS): Days after sowing, Z2: tillering, Z3: stem elongation, Z4: booting, Z7: milk development, Z8: dough development, Z9: ripening.

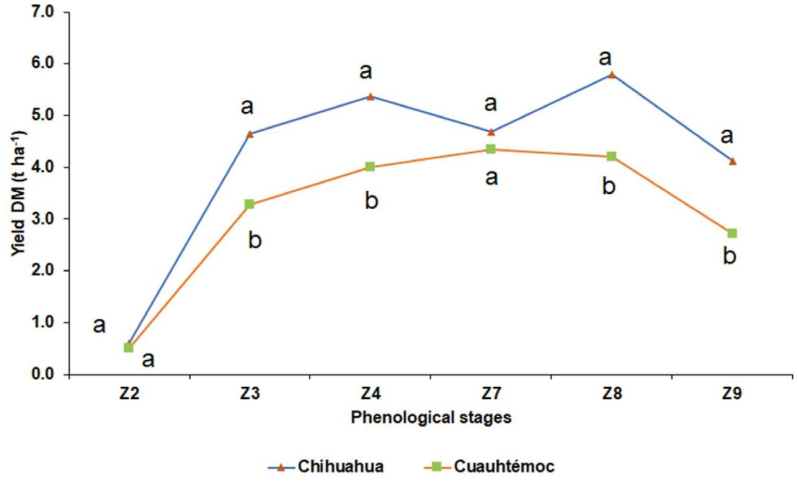

Figure 2. Total dry matter yield of Chihuahua and Cuauhtémoc oats at different phenological stages. Different letters present a statistical difference between cultivars for each phenological stage (Tukey, $\alpha=0.05$). Z2: tillering, Z3: stem elongation, Z4: booting, Z7: milk development, Z8: dough development, Z9: ripening.

Table 2. Morphological composition (t ha^{-1} of dry matter) of Cuauhtémoc and Chihuahua oats at different phenological stages.

PS	Leaf		Stem		Panicle		SM	
	Cu	Ch	Cu	Ch	Cu	Ch	Cu	Ch
Z2	0.5 a C	0.6 a E	0.0 a B	0.0 a B	0.0 a C	0.0 a D	0.0 a D	0.0 a E
Z3	2.7 a A	3.6 a A	0.5 a AB	0.8 a AB	0.0 a C	0.0 a D	0.0 b D	0.3 a DE
Z4	1.7 b B	2.5 a B	1.0 a A	1.3 a A	0.7 a BC	0.9 a C	0.6 a BC	0.7 a C
Z7	1.5 a B	1.7 a C	1.0 a AB	1.2 a A	1.1 a BC	1.2 a BC	0.7 a CD	0.6 a CD
Z8	0.6 b C	1.1 a D	1.0 b A	1.5 a A	1.8 a A	1.9 a A	0.8 b BC	1.3 a B
Z9	0.0 a D	0.0 a F	0.0 a B	0.0 a B	1.1 b AB	1.5 a AB	1.6 b A	2.6 a A

PS=Phenological stages; SM=Senescent Material.
Different letters in the same column (ABC) and same row per component (abc) indicate statistical difference (Tukey, α=0.05). PS (EF): Phenological stage, Msc: senescent matter, Z2: tillering, Z3: stem elongation, Z4: booting, Z7: milk development, Z8: dough development, Z9: ripening.

The highest leaf yields were obtained in stage Z3 for both varieties ($P<0.05$); however, there were no statistical differences between them ($P>0.05$) with 2.7 and 3.6 t ha^{-1} yields for Cuauhtémoc and Chihuahua, respectively. Likewise, higher leaf yields have been related to forage quality; therefore, when higher leaf yields are recorded, higher protein contents are also present, as established by Mendoza-Pedroza *et al.* (2021) for the Chihuahua variety, where the highest leaf yield (5,288 kg) provides 1,100 kg ha^{-1} of protein at 75 DDS. In this research, the highest yield was recorded at 65 and 72 DDS in the Cuauhtémoc and Chihuahua varieties. The higher leaf content in the forage yield favors its digestibility, as a result of the increased efficiency of the ruminal microbiota (Carmona, 2007).

The contribution of each component to the dry matter yield is determined by its phenological stage. Both varieties have a 100% leaf content in the tillering stage, which descends in later stage. Simultaneously to that descent, the dry matter of stem, panicle, and senescent material increases its contribution to the yield, until a higher percentage of senescent matter and panicle is obtained (Figure 3). This behavior is expected from most cereals during their development: the total yield has shown a growth curve, where the highest dry matter yield occurs in the last stages of grain filling; afterwards, the amount of dry matter decreases as a consequence of the increased contribution of senescent matter (Wilson *et al.*, 2020). Likewise, these changes in the morphological proportion determine the quality of the forage, because a higher percentage of leaf results in maximum protein values; otherwise, a higher percentage of senescent matter is recorded during ripening (Ramírez-Ordóñes *et al.*, 2013), increasing the percentage of lignin, a component that hinders its decomposition by means of the ruminal microbiota (Carmona, 2007).

Finally, Sánchez *et al.* (2014) indicate that, between the milky and doughy grain stages, the proportion of the leaf in the yield is approximately 18%. This value is similar to that obtained in this research for both varieties in the Z8 stage. Therefore, the component-ratio behavior is relatively stable between development stages.

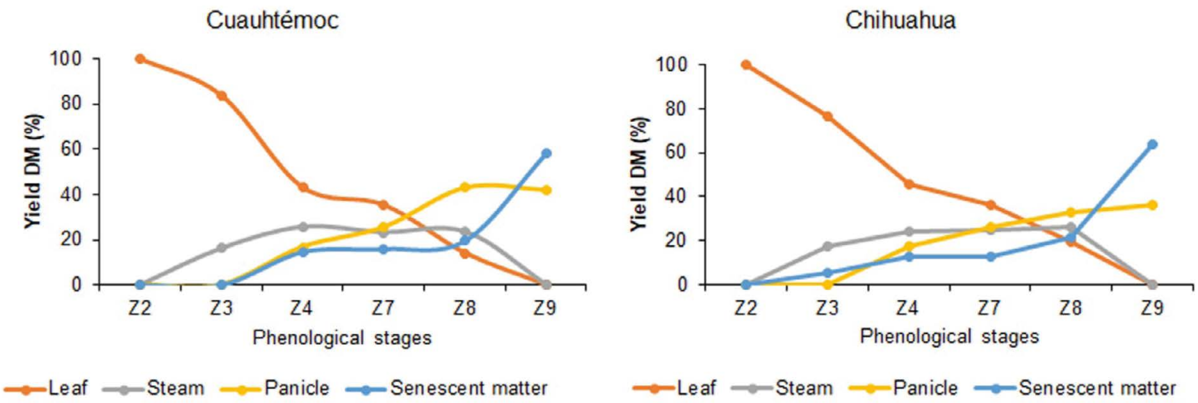

Figure 3. Contribution of each morphological component to the dry matter yield of *Avena sativa* Cuauhtémoc and Chihuahua varieties in different phenological stages. Z2: tillering, Z3: stem elongation, Z4: booting, Z7: milk development, Z8: dough development, Z9: ripening.

CONCLUSIONS

In Güémez, Tamaulipas, the Chihuahua oat variety requires 1,923.5 GDD to complete its biological cycle, while Cuauhtémoc requires 1,831.5 GDD. The difference between the thermal accumulation of the varieties and the phenological stages has an impact on the total forage yield and the yield of each morphological component.

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