AGRO PRODUCTIVIDAD
Colegio de Postgraduados

Forage yield of Guinea grass (*Megathyrsus maximus* Jacq.) using mineral fertilization during two seasons of the year

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ABSTRACT
Objective: To determine the dry matter yield of Guinea grass (*M. maximus* Jacq.) in response to mineral fertilization with N-P-K in a tropical humid climate.
Design/Methodology/Approach: We conducted an experiment with Guinea grass in Loma Bonita, Oaxaca, Mexico, during the cold front season (November 2018 to February 2019) and the dry season (March to May 2019). The following N-P-K fertilization formulations were used: 00-00-00, 100-00-00, 140-20-00, 180-40-20, 200-00-00, 240-40-20, 260-60-40, and 300-00-00. The response variables were: plant height (cm), chlorophyll content, and dry matter yield (kg ha^{-1}).
Results: The fertilization with the highest nitrogen, phosphorus, and potassium levels ($p \leq 0.05$) increased the dry matter yield, the chlorophyll content, and the height of the Guinea grass above the control.
Study Limitations/Implications: Mineral fertilization improved the productive performance of Guinea grass. However, studying more seasons is necessary to validate the results obtained.
Findings/Conclusions: The fertilizer formulas with 260-60-40 and 240-40-20 N-P-K units improved the productive performance of Guinea grass. Consequently, the season of the year had a considerable influence on grass yield in a humid tropical climate.

Key words: Gramineae, humid tropic, chlorophyll, dry matter.

Citation: Sánchez-Hernández, M. A., Valenzuela-Haro, Y. E., Morales-Terán, G., Hernández-Sánchez, S., Mendoza-Pedroza, S. I., & Rivas-Jacobo, M. A. (2022). Forage yield of Guinea grass (*Megathyrsus maximus* Jacq.) using mineral fertilization during two seasons of the year. *Agro Productividad*. https://doi.org/10.32854/agrop.v15i7.2323

Academic Editors: Jorge Cadena Iñiguez and Libia Iris Trejo Téllez

Received: January 05, 2022.
Accepted: June 19, 2022.
Published on-line: August 08, 2022.

Agro Productividad, *15*(7). July. 2022. pp: 35-42.

INTRODUCTION

Given their geographical position on the planet, the humid tropical regions of Mexico concentrate a high diversity and richness of forage resources (Ellis & Martínez, 2010). Nevertheless, livestock currently requires the production and preservation of forage resources that are scarce throughout the year, particularly during the dry season. Ruminant production is important in Oaxaca and it requires forage for animal feed. In 2018, 381,985 ha of forage grasses were reported in this state; they provided an average fresh yield of 34.1 t ha^{-1}. In the district of Tuxtepec, 163,507 ha with 38.0 t ha^{-1} of forage yield were recorded, while, in Loma Bonita, 10,470 ha with 43.6 t ha^{-1} of fresh forage yield were recorded (SIAP, 2019).

Guinea grass is one of the most important forage species used to feed domestic ruminants in regions with tropical and subtropical climates. This is the result of its great potential to produce dry matter per unit of area, wide adaptability, forage quality, easy establishment, and its capacity to support a high stocking rate (Munari *et al.*, 2017). An emerging problem is that the plants are not fertilized, which impacts their development and reduces their quality and biomass yield (Shintate *et al.*, 2017). In this sense, fertilization is an alternative that increases grass productivity by influencing the generation of photoassimilates during photosynthesis (Silveira *et al.*, 2017).

There are few studies about the fertilization of cut tropical grasses in the humid tropical region of Mexico. Throughout the region, Guinea grasslands are fertilized with the 100-00-00 formula (Joaquín *et al.*, 2009). In addition, Joaquín *et al.* (2020) recommended using the 100-50-50 fertilizer formula (N, P_2O_5, and K_2O, respectively) to obtain a better seed yield with the said Poaceae in Loma Bonita, Oaxaca, Mexico. Evidently, in order to increase the biomass yield, the nutritional management of this grass must be identified at different seasons of the year (*e.g.*, cold front and dry seasons).

The objective of the present study was to quantify the biomass yield of Guinea grass fertilized with nitrogen, phosphorus, and potassium under the environmental conditions of Loma Bonita, Oaxaca, Mexico, during the cold front and dry seasons. The assumption was that fertilizing with high levels of these elements improves the components associated with the growth and dry matter yield of this grass.

MATERIALS AND METHODS

Geographical location of the study area

The research work was carried out in Loma Bonita, Oaxaca, Mexico (18° 06' N, 95° 53' W), at 25 m.a.s.l. The weather is warm humid (Am) in 81.7% of the territory, with abundant rainfall in summer, an average temperature of 25 °C, and an annual rainfall of 1,845.2 mm. However, the Papaloapan weather station reported 2,135.3 mm of rain per year. The dominant soil type are acrisols (INEGI, 2005).

Vegetal material and establishment

In June 2018, 24 experimental units were sown with *Megathyrsus maximus* Jacq cv. Guinea vegetative material, after digging 40-cm deep times 20-cm wide holes. In October 30, a uniform cut was made with gardening shears. On November 16, the cold front season samplings of the growth and dry matter yield of the grass began. This season started on November 2018 and finished on February 2019 and is characterized by low intensity rains and low temperature (Figure 1). The dry season was evaluated from March to May 2019. The dry season is characterized by high temperatures and low rainfall. During both seasons, samples were collected every seven days from the same plants.

Treatments and experimental design

Eight fertilizer formulas (FM) with nitrogen, phosphorus, and potassium were applied to Guinea grass: 00-00-00 (FM1), designated as control treatment, 100-00-00 (FM2), 140-20-00 (FM3), 180-40-20 (FM4), 200-00-00 (FM5), 240-40-20 (FM6), 260-

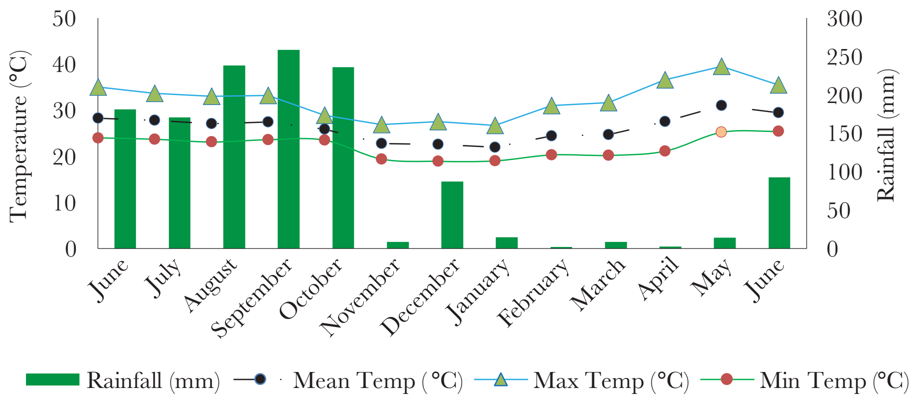

Figure 1. Precipitation (mm), and maximum, minimum, and average temperature (°C), in Loma Bonita, Oaxaca, Mexico (June 2018-June 2019).

60-40 (FM7), and 300-00-00 (FM8). Urea (46-00-00), diammonium phosphate (18-46-00), and potassium chloride (00-00-60) were used as nutrient sources. The tested fertilizer formulas were defined based on a soil analysis that was done prior to the establishment of the grass and contemplated ≤300 units of N, ≤60 units of P, and ≤40 units of K per ha, in order to determine a dose that does not have an economic impact on the producer.

The grass was homogeneously fertilized in November (cold front season) and in March (dry season), before a 15-cm uniformity cut was made in each case and when the regrowth began. In each season, the soil was fertilized after it had rained or when there was enough moisture in the soil.

The experimental design was completely randomized with eight treatments (fertilizer formulas) applied to 3.0-m long × 2.0 m wide (6 m^2) experimental units and three replications. The evaluations were made in the central part of each experimental plot. The size of the useful plot was 4.2 m^2.

Response variables

The response variables were: plant height (cm), chlorophyll content in the leaves, and dry matter yield. Plant height was measured with a flexible metal tape, from ground level to the top of the plant, with its leaves fully extended. The chlorophyll content of leaves was measured in five plants per plot, using a Minolta® portable SPAD-502 chlorophyll meter, that establishes the greenness index, which is directly related to the chlorophyll content of the leaves (Rincón & Ligarreto, 2010). The production of fresh biomass (kg ha^{-1}) was determined by weighing the plant material from the aerial part of the plant on a 5.0-kg digital scale, with a 1.0 g margin of error; this result was used to calculate the dry matter yield (kg ha^{-1}). The methodology consisted of taking a 200-g sample of fresh forage from each of the useful plots and placing it in a forced air stove at 65 °C for 72 hours or until the sample reached a constant weight which could be used to calculate the dry matter percentage.

Statistical analysis

The statistical analysis of the data was carried out separately for each season (cold front and dry season), based on a completely randomized design, with eight fertilization treatments and three repetitions, using the linear model:

$$Y_{ij}=\mu+T_i+E_{ij}$$

where Y_{ij} is the response variable, μ is the general mean of the experiment, T_i is the effect of the fertilization treatments, and E_{ij} is the source of variation associated with the experimental error. The analysis of variance was carried out using Proc GLM for Windows version 9.4 (SAS, 2013) and the means of the variables whose treatments showed them to be statistically different were compared using Tukey's test ($p \leq 0.05$).

RESULTS AND DISCUSSION

Plant height

Table 1 revealed that, when Guinea grass received different doses of fertilization with nitrogen or its combination with phosphorus and potassium, plant height (PH) in the cold front season always was statistically superior than control. The maximum PH was 148.4 cm and was obtained with the 260-60-40 treatment (Table 1), although it was not different from the PH obtained with the 180-40-20 formula on 135.2 cm tall plants ($p \leq 0.05$); in the dry season, the plant height response was lower than in the cold front season (Table 1).

Other researchers suggest that for grasses to grow, vegetative structures, elongation, and development of leaves according to their genetic nature must be present. These characteristics are influenced by rainfall, temperature, light, and soil fertility (Costa *et al.*, 2017). Muñoz *et al.* (2007) indicated that Guinea grass adapts to average annual rainfalls of 800 to 1,200 mm; although it tolerates droughts, Guinea grass recovers quickly at the beginning of the rainy season and it keeps a green foliage. The plant height was different between the cold front and dry seasons, because the rain and temperature data promoted a differential growth between seasons (Figure 1).

Chlorophyll content of leaves

In the cold front season, the chlorophyll content of Guinea grass increased in the treatments that received fertilization. They were statistically different ($p \leq 0.05$) than control, from day 14 to day 84 of sampling (Table 2). Such behavior confirmed that high nitrogen fertilization had a positive correlation with the color (green) of the leaves and it affected their chlorophyll content.

In Brazil, the application of nitrogen doses of 0, 50, 100, 150, and 200 kg ha^{-1} to *Brachiaria decumbens* resulted in an increase of the color (green) of the leaves, with intervals of 32 to 54 and 30 to 48 SPAD units, in the first and second cut, respectively (da Silva *et al.*, 2013). In another study, Salman *et al.* (2016) reported foliar chlorophyll values of 48.4 for marandu grass and 40.7 for Guinea grass; these values are consistent with the results of the present work.

Table 1. Plant height (cm) of Guinea grass (*Megathyrsus maximus*) depending on fertilization in the cold front and dry seasons. Loma Bonita, Oaxaca, Mexico.

F	E	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	Dhs	CV
14	1	54.7e	60.5d	57.4e	67.3b	66.9bc	65.2bc	64.1c	71.0a	2.8	4.5
	2	38.3a	33.0a	40.3a	37.3a	41.00a	37.0a	32.3a	30.0a	11.2	10.9
21	1	66.5e	73.0d	75.7cd	91.0a	77.3c	83.7b	83.6b	84.4b	3.2	4.1
	2	40.7bc	36.0cd	40.7bc	39.3bc	42.3ab	45.7a	38.0bcd	34.3d	4.7	4.2
28	1	69.7d	85.3c	83.0c	98.7a	84.4c	92.1b	96.2ab	92.7b	5.6	10.3
	2	42.3bc	38.3cd	41.3bcd	42.3bc	48.3b	48.0a	41.7bcd	37.7d	4.4	3.7
35	1	72.7e	92.2d	90.3d	106.2a	93.6cd	99.4b	108.7a	98.7bc	6.0	11.3
	2	43.7abc	41.0bc	42.0bc	45.0ab	45.0ab	47.7a	44.0ab	39.0c	4.7	3.8
42	1	80.7e	103.3bcd	96.1d	110.6ab	98.7cd	105.5bc	114.9a	102.2bcd	8.5	10.1
	2	46.0bc	43.0bc	43.3bc	46.7ab	46.7ab	50.3a	47.0ab	41.7c	4.9	3.8
49	1	84.2d	107.1bc	100.3c	115.8ab	107.0bc	112.7ab	121.0a	103.6c	8.4	10.3
	2	46.3cde	43.7e	45.3de	50.0ab	48.3bcd	52.0a	49.3abc	45.7de	3.1	2.3
56	1	89.7e	111.7bcd	103.1d	121.9ab	108.4cd	115.8bc	128.4a	106.7cd	11.3	3.6
	2	48.3c	44.3d	47.3cd	53.0b	47.7cd	57.7a	51.0bc	47.7cd	3.8	2.8
63	1	92.0d	113.3bc	108.9c	126.1ab	110.0c	118.2bc	133.6a	108.4c	14.1	4.3
	2	49.0ef	57.7ab	48.0ef	55.7bc	51.7cde	61.0a	55.0bcd	51.3de	4.3	2.9
70	1	93.6d	116.8c	112.4c	128.1ab	111.4c	119.2bc	136.2a	110.0c	11.4	3.5
	2	50.0b	68.0a	54.7b	57.0ab	53.3b	61.7ab	57.7ab	57.0ab	11.8	7.3
77	1	97.1d	121.7bc	115.1c	129.4ab	115.4c	120.7bc	140.6a	112.3c	11.3	3.4
	2	52.0c	81.0a	61.3bc	62.7bc	60.3bc	66.7b	64.7b	64.0b	11.9	6.4
84	1	99.8c	125.9b	123.1b	135.2ab	126.8b	128.4b	148.4a	126.1b	14.1	6.4
	2	54.7c	87.3a	66.0bc	67.7b	64.7bc	71.0b	71.0b	70.3b	11.6	5.9

F=Sampling date (d), E=Season (1: cold front of november 2018-february 2019), (2: march-may 2019 drought), FM1=00-00-00, FM2=100-00-00, FM3=140-20-00, FM4=180-40-20, FM5=200-00-00, FM6=240-40-20, FM7=260-60-40, FM8=300-00-00 de N-P-K-, Dhs= Significant honest difference (Tukey, p≤0.05), CV=Coefficient of variation (%), a,b,c… different letters in columns mean significant differences.

However, during the dry season, the behavior of chlorophyll in leaves was lower than in the cold front season (Table 2), as a consequence of the scarcity of edaphic moisture from March to May 2019 (Figure 1). C_4 plants (such as *Megathyrsus maximus*) can present biochemical and anatomical modifications whose aim is to increase their photosynthetic efficiency through adjustments in leaf area. These adjustments modify their root/aerial part ratio, potentially increasing the concentration of chlorophyll in the leaves, all intervened by edaphic moisture content and nutrient availability (Barragán & Cajas, 2019).

Guinea grass dry matter yield

During the cold front season, the dry matter production of *M. maximus* increased as a result of fertilization (Table 3). From day 21 to 84, the 240-40-20 and 260-60-40 NPK formulas stood out, with the exception of days 63 and 77, when the presence of strong winds bent plants, modifying the previous tendencies. Overall, these ternary formulas surpassed the control in DM production, including the rest of the fertilization treatments.

Table 2. Chlorophyll (SPAD units) of Guinea grass (*Megathyrsus maximus*), depending on fertilization in the cold front and dry seasons. Loma Bonita, Oaxaca. Mexico.

F	E	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	Dhs	CV
14	1	44.4b	50.7[a]	52.0a	50.0a	45.9b	44.8b	51.6a	50.6a	3.0	4.9
	2	20.6b	38.5[a]	32.5ab	21.6b	25.8b	24.4b	32.5ab	22.3b	11.9	15.4
21	1	40.3c	47.6[a]	46.1ab	46.0ab	47.2a	43.9b	48.2a	47.5a	3.2	4.3
	2	22.3a	32.6[a]	35.9a	37.3a	38.5a	38.5a	35.9a	32.6a	20.5	21.1
28	1	35.0c	40.0bc	40.3bc	50.7a	45.2ab	40.6bc	43.2b	43.2b	5.7	4.8
	2	25.8bc	38.8a	22.0c	32.5ab	32.6ab	32.6ab	21.6c	35.9ab	10.2	11.9
35	1	29.4d	37.3c	38.8abc	40.0abc	37.5bc	43.0ab	44.1a	41.3abc	5.8	5.1
	2	21.6c	25.8bc	38.5a	35.9ab	38.8a	38.8a	43.9a	38.5a	10.7	10.7
42	1	31.9c	41.2b	43.0ab	40.0bc	45.5ab	43.3ab	40.7b	50.0a	8.0	7.2
	2	33.9ab	52.7a	32.5ab	22.3b	20.6b	32.5ab	22.3b	32.5ab	22.2	25.2
49	1	31.0c	43.9ab	42.0ab	40.8ab	44.6ab	44.6ab	39.3bc	47.9a	8.5	7.3
	2	25.8bc	33.7ab	38.8a	25.8bc	21.6c	35.9a	38.5a	38.8a	9.2	10.0
56	1	31.5b	39.6ab	40.7a	43.0a	42.5a	40.9a	43.7a	45.2a	8.4	7.8
	2	35.9a	35.9a	21.6a	38.5a	37.3a	21.5a	32.5a	25.8a	20.5	23.2
63	1	30.7c	43.4b	42.8b	42.6b	39.6b	41.9b	44.6b	50.6a	5.6	4.7
	2	21.6a	38.5a	37.3a	32.5a	22.3a	37.3a	38.8a	21.6a	26.7	30.3
70	1	29.9c	39.6ab	41.9a	43.3a	34.7bc	40.9a	40.8a	43.7a	5.3	5.1
	2	25.9ab	43.9a	25.8ab	38.8ab	32.5ab	22.3b	25.8ab	37.3ab	21.4	24.0
77	1	33.0c	42.7a	41.2ab	40.7abc	32.7c	42.7a	44.1a	41.4ab	8.5	7.5
	2	22.7c	38.3a	22.3c	20.0c	35.9ab	25.8bc	21.3c	23.9c	11.7	15.6
84	1	32.9b	41.0ab	39.1ab	39.9ab	38.5ab	42.9a	41.6a	41.5a	8.4	7.6
	2	23.3c	38.8a	25.6c	26.7c	35.9ab	28.2bc	26.3c	27.3c	8.3	10.2

F=Sampling date (d), E=Season (1: cold front of november 2018-february 2019), (2: march-may 2019 drought), FM1=00-00-00, FM2=100-00-00, FM3=140-20-00, FM4=180-40-20, FM5=200-00-00, FM6=240-40-20, FM7=260-60-40, FM8=300-00-00, Dhs=Significant honest difference (Tukey, $p \leq 0.05$), CV=Coefficient of variation (%), a,b,c... different letters in columns mean significant differences.

At 42 days of sampling, during the cold front season, the Guinea grass yield was 4,674 and 4,449 kg DM ha^{-1} with the 240-40-20 and 260-60-40 formulas, respectively (Table 3). A trial carried out by Homen *et al.* (2010) with *Megathyrsus maximus* in Venezuela (2,450 mm of rain and an average temperature of 26.5 °C) recorded a yield of 4,376 and 5,097 kg DM ha^{-1} on days 35 and 42; they recommended cutting the grass 42 days after regrowth for animal feed. At a greater cutting interval, a PH and forage accumulation increase was reported for Guinea grass, as a possible consequence of the high presence of stems and dead material, which modify the leaf-stem ratio in the grass —a behavior that can affect the efficiency with which animals use the grassland (Ramírez *et al.*, 2009).

The dry matter yield was lower in the dry season than in the cold front season (Table 3), as a consequence of the lack of moisture from March to May 2019 (Figure 1), which hindered the grass' potential to induce the development of meristematic tissues and promote the growth of the grass.

Table 3. Dry matter yield (kg ha^{-1}) of Guinea grass (*Megathyrsus maximus*), depending on fertilization in the cold front and dry seasons. Loma Bonita, Oaxaca, Mexico.

F	E	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	Dhs	CV
14	1	269.1e	535.0b	428.2c	333.4d	307.2de	717.3a	544.7b	551.5b	56.9	15.7
	2	243.5b	99.5b	637.2a	223.3b	226.1b	81.3a	98.1b	44.3b	222.8	28.1
21	1	561.3f	1578.5b	1073.2e	1578.7b	1228.7cd	1768.7a	1779.7a	1192.4d	112.4	13.9
	2	196.0b	466.3ab	683.2a	388.8ab	347.2ab	216.8b	233.7ab	130.3b	454.0	10.2
28	1	705.7e	2296.2b	1415.8d	2000.3c	1945.0c	2952.5a	2929.5a	1827.6c	290.1	14.9
	2	329.0bc	656.8a	504.8ab	537.0ab	453.7abc	328.8bc	452.1abc	193.3c	284.9	23.3
35	1	1398.0d	2617.8bc	2282.0c	2540.0bc	3041.2b	4332.7a	4438.4a	2283.7c	566.4	17.8
	2	789.7ab	513.6bcd	974.1a	713.6abc	493.0bcd	422.9cd	701.2abc	282.4d	306.9	17.7
42	1	1465.0d	3043.0bc	2715.3c	2642.0c	3005.7bc	4674.0a	4449.3a	2460.4c	848.1	10.2
	2	834.1abc	888.8ab	1229.9a	930.7ab	563.0bc	536.5bc	831.2abc	401.3c	448.0	20.4
49	1	1646.0d	3805.8ab	3777.8ab	3055.5bc	3940.7a	4048.9a	4557.3a	2677.8c	853.1	18.8
	2	930.9ab	1254.7a	857.1ab	1263.2a	659.7b	662.7b	1231.5a	580.8b	503.5	19.2
56	1	1443.9e	3712.1cd	3759.7cd	5220.8b	3978.4c	5346.2ab	6110.3a	3069.4d	860.8	17.3
	2	1168.3b	1529.0a	447.2d	1504.8a	772.3c	830.9c	1758.9a	750.1c	261.6	8.5
63	1	2154.9d	6824.8b	6039.1b	6468.0b	6338.1b	4221.7c	9125.5a	4639.7c	848.1	12.3
	2	884.1c	1728.0ab	1225.3bc	1867.5a	1337.3bc	1044.5c	2111.5a	985.3c	518.7	13.1
70	1	3452.0f	4830.0e	6411.0d	7617.0bc	6996.0dc	9156.0a	8340.0ab	5224.0e	1130.7	16.2
	2	1643.5abc	2301.3abc	2513.1ab	2597.1ab	1362.7bc	1445.3bc	2716.0a	1222.9c	1268.1	22.7
77	1	3565.0f	5201.0e	8699.0c	97302.0b	6061.0d	12545.3a	9898.0b	5490.0de	832.2	21.8
	2	2752.0bc	4743.5a	2653.1bc	2727.2bc	1311.6c	1921.9c	3761.1ab	1796.8c	1833.0	23.9
84	1	2023.0e	5832.0c	6067.0bc	5613.0c	4154.0d	7053.0ab	7665.0a	6711.0abc	1130.7	16.9
	2	2885.3bc	5043.5a	2953.1bc	2860.5bc	1711.6c	2155.2c	3961.1ab	2463.5bc	1628.9	19.2

F=Sampling date (d), E=Season (1: cold front of november 2018-february 2019), (2: march-may 2019 drought), FM1=00-00-00, FM2=100-00-00, FM3=140-20-00, FM4=180-40-20, FM5=200-00-00, FM6=240-40-20, FM7=260-60-40, FM8=300-00-00 de NPK, Dhs=Significant honest difference (Tukey, $p \leq 0.05$), CV=Coefficient of variation (%), a,b,c… different letters in columns mean significant differences.

CONCLUSIONS

The productive performance of Guinea grass varied depending on the environmental conditions. Precipitation was a determining factor, because the highest productions of dry matter (DM) occurred in the cold front season, when the 240-40-20 and 260-60-40 formulas generated the highest yield of dry matter and chlorophyll in leaves; the latter formula also promoted greater plant height. In the dry season, the opposite phenomenon occurred, since the dry matter productivity decreased in comparison with the cold front season.

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