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Research Paper

Forage characterization of Carajás grass (*Cenchrus purpureus* × *C. americanus*) fertilized with a range of doses of protected urea under irrigation during the growing season

Caracterización de forrajes de híbridos de Cenchrus purpureus *fertilizados con dosis de urea protegida en diferentes estaciones*

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Abstract

The objective of this study was to assess the agronomic and nutritional responses of Carajás grass (*Cenchrus purpureus* × *C. americanus*, syn. *Pennisetum purpureum* × *P. glaucum*, cultivar 'Carajás') fertilized with protected urea. The experimental design was completely randomized blocks in split-plot arrangement over time. The treatments consisted of 5 levels of nitrogen (0, 100, 200, 400 and 800 kg N/ha/year) and measurements were made over 2 seasons (spring 2015 and summer 2016), with 8 replicates. Leaf and stem elongation and senescence rate of tillers increased as N dosage increased, while tiller density, leaf:stem ratio, live:dead material ratio and phyllochron declined. Forage biomass increased with N dosage reaching 47 t DM green forage/ha at 800 kg N/ha but DM production per unit of N applied declined dramatically as level of N applied increased. There was no effect of season. For crude protein (CP) and fiber concentrations, a positive effect was observed with increasing N application, with maximum CP% of 172 g/kg with 800 kg N/ha in spring. Further studies are warranted to determine if economics indicate that the higher fertilizer levels are justified and even protected urea should still be applied on a number of occasions, but still less often than conventional urea, rather than as a single dose at the beginning of spring.

Keywords: Biomass, chemical composition, elephant grass, nitrogen fertilizer, tropical pasture.

Resumen

El objetivo de este estudio fue evaluar las respuestas agronómicas y nutricionales del pasto Carajás (*Cenchrus purpureus* × *C. americanus*) fertilizado con urea protegida. El diseño experimental fue de bloques completos al azar en un arreglo de parcelas divididas en el tiempo. Los tratamientos consistieron en cinco dosis de nitrógeno (0, 100, 200, 400 e 800 kg/ha/año) y las mediciones se realizaron durante 2 temporadas (primavera de 2015 y verano de 2016), con 8 repeticiones. Las tasas de senescencia de macollas y de elongación de hojas y tallos aumentaron junto con las dosis de nitrógeno. La densidad de macollos, la relación hoja/tallo, la relación material vivo/muerto y el filocrón se redujo junto con las dosis de nitrógeno. La biomasa del forraje se incrementó con las dosis de N, obteniendo 47 t/ha de biomasa total del forraje verde y no mostró ningún efecto debido a las estaciones para la dosis de 800 kg/ha/año, pero la producción de materia seca por unidad de N aplicada disminuyó drásticamente a medida que aumentó el nivel de N aplicado. No se detecto efecto de la temporada en que se efectuó la cosecha. Para el contenido de proteína cruda y fibra, se observó un efecto positivo al aumentar la dosis de nitrógeno, con

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un PC% máximo de 172 g/kg a una dosis de 800 kg N/ha/año en la primavera. Se justifican más estudios para determinar si la economía indica que los niveles más altos de fertilizantes están justificados e incluso si la urea protegida debe aplicarse en varias ocasiones, pero con menos frecuencia que la urea convencional, en lugar de una dosis única al comienzo de la primavera.

Palabras clave: Biomasa, composición química, nitrógeno, pasto elefante, pastura tropical.

Introduction

Carajás grass is a hybrid generated by crossbreeding of *Cenchrus purpureus* (Schumach.) Morrone (syn. *Pennisetum purpureum* Schumach.) and *Cenchrus americanus* (L.) Morrone (syn. P*ennisetum glaucum*) and is cultivated through seeds, a distinct advantage when compared with vegetative propagation of other varieties of *C. purpureus*. The cultivar was recently released by the company MATSUDA® and there is a need to study its productive potential.

Most grasses respond significantly to application of nitrogen (N) fertilizer. Urea is one of the main sources of N used in forage production due to its lower cost per unit of N and high concentration of N compared with other N sources (Mota et al. 2015). However, N losses via volatilization in the form of ammonia can be a problem, as they decrease the efficiency of use by crops (Tasca et al. 2011), especially if urea is supplied in large quantities to the soil at any given time.

In order to increase efficiency of use of N from urea, especially at high dosages, urease and nitrification inhibitors and polymer coating are being used (Okumura and Mariano 2012). Release of N from such protected urea in the soil for uptake by plants is slow, so this fertilizer can be applied in a single dose during the grass growth cycle, reducing application costs and allowing the use of high application rates. This contrasts with application of conventional urea, which normally occurs in smaller doses at intervals during the grass growth cycle to avoid/reduce N losses (Silva et al. 2011), resulting in higher labor usage.

We hypothesized that applying protected urea would result in efficient usage of N with high quality of forage from Carajás grass for animal feeding and would allow high application rates at any one time with minimal seasonal differences in growth, production and chemical composition of the grass. Therefore, the objective was to evaluate the morphogenic and structural characteristics, production and chemical composition throughout the growing season of Carajás grass fertilized with varying doses of protected urea in a dry tropical environment. The study is a complement to an experiment in which fertilization of Carajás grass with protected urea was compared with that of non-protected urea (Alves et al. 2018).

Materials and Methods

Location and experimental design

The study was carried out at the Experimental Farm of the Federal University of Piauí, Cinobelina Elvas Campus, located in Alvorada do Gurgueia, Piauí, Brazil (8°22'30" S, 43°50'48" W; 239 masl). The region has a climate classified as Tropical Dry (Nunes 2011). The climatic data observed during the experimental period were recorded at a meteorological station located in that region (Table 1).

Table 1. Mean values of climatic conditions throughout the study.

Climatic variable	2015			2016		
	Oct	Nov	Dec	Jan	Feb	Mar
Maximum temperature (°C)	38.4	37.0	38.0	31.1	34.6	34.8
Mean temperature (°C)	31.5	30.3	30.7	26.3	27.7	28.2
Minimum temperature (°C)	24.1	23.5	22.9	22.5	21.2	22.5
Precipitation (mm)	31.1	144.8	18.1	348.4	38.7	108.4
Relative humidity (%)	38.0	48.2	43.9	78.8	62.7	66.4

The experimental design was completely randomized blocks with split-plots in time. Treatments consisted of 5 nitrogen doses (0, 100, 200, 400 and 800 kg N/ha/year) and subplots were 2 evaluation seasons (spring 2015 and summer 2016), with 8 replications (4 blocks and 2 replications in time, 2 harvests, for each season). Spring (characterized by irregular rains and high temperatures) extended from the beginning to the middle of the rainy season of the region (October–December 2015), while summer (characterized by much heavier rainfall and lower temperatures) represented the second half of the rainy season (January–March 2016). The source of nitrogen used was protected urea (FH Nitro Mais®, developed by the company Fertilizantes Heringer®), applied in a single dose in October 2015. This fertilizer consists of urea granules coated with boron and copper containing inhibitors.

Before starting the experiment, a compound soil sample was collected from the 0–20 cm horizon, representative of the area, for soil chemical analysis and characterization. Results obtained in the analysis were: pH (H_2O) - 5.40; P and K - 9.6 and 21.2 mg/dm^3, respectively; Ca, Mg, Al and H + Al - 2.4, 0.6, 0.0 and 3.5 cmol/dm^3, respectively; sum of bases - 3.1 cmol/dm^3; effective cation exchange capacity (CEC) - 3.1 cmol/dm^3; CEC at pH 7.0 - 6.5 cmol/dm^3; and base saturation - 46.8 %. Based on these results, soil correction and fertilizer application were performed according to Vilela et al. (2002), applying dolomitic limestone (PRNT 80 %) to elevate soil saturation levels to 60 % and applying 40 kg P/ha (as single superphosphate, 18 % P_2O_5) and 60 kg K/ha (as potassium chloride, 48 % K_2O).

The experimental area of Carajás grass was planted in 2013. Seed was sown in rows at 0.64 g/m, with inter-row spacing of 80 cm, as recommended by the company MATSUDA®. In October 2015 a uniformity cut was performed at 20 cm above ground level. The grass was irrigated every 3 days with a 10 mm water blade through a sprinkler system, following the recommendations of the company which supplied the hybrid. Manual weeding was conducted to remove undesirable plants.

The experimental area was divided into 15 plots of 4 m^2 (4 × 1 m), with 5 rows of grass per plot. Plots were separated by uncultivated spaces of 1 m with 2 m between blocks. Forage was harvested 4 times during the evaluation period, twice during each season (spring and summer) every 40 days at a height of 20 cm above ground, according to the recommendation of the company MATSUDA® for Carajás grass.

Measurement of morphogenesis, structural variables and biomass production

For measuring morphogenesis 2 grass clumps were identified at random in each plot and colored rings were applied to 3 tillers/clump. Evaluations commenced 3 days after the uniformity cut and were repeated every 3 days throughout. Appearance, elongation and senescence of leaf blades and elongation of stems were recorded. Length of the expanded leaf blade was measured from its ligule to its apex using a rule.

Length of the emergent leaf blade was measured from its apex to the ligule of the last exposed leaf blade, while length of the senescent portion was the difference between the total length of the leaf blade and the remaining green portion. Length of stem was the distance from its ligule to the base of the tiller. From data obtained the following indexes were calculated: leaf elongation rate (LER); stem elongation rate (SER), referring to the mean daily elongation on half of the sheaths and true stem of the tiller; total leaf senescence rate (TSR); and phyllochron.

Grass structure was recorded before each harvest. The following evaluations were carried out at each harvest: population density of tillers per clump (PDT), obtained by counting the number of live tillers in a clump from the central row of each plot; leaf:stem ratio (L:S); and live material:dead material ratio (L:D). Weights were obtained using a digital electronic scale, with capacity of 1 g to 5 kg, model Sf-400 UNICASA®.

At each harvest forage from a linear meter of the central row was collected to determine: total forage biomass (TGB); green leaf biomass (GLB); and green stem biomass (GSB) by separating harvested material into live and dead material, before live material was separated into leaf blade and stem. The L:S ratio was determined by dividing GLB by GSB, while L:D was determined by dividing green biomass by dead forage biomass. Following each harvest, remaining forage on all plots was cut at 20 cm above ground and removed.

Chemical composition

To determine the chemical composition of Carajás grass, forage samples were dried in paper bags in a forced-air circulation oven at 60 ± 5 °C for 72 hours and then milled with a Willey Mill using a 1 mm sieve.

Dry matter (DM), organic matter (OM), ether extract (EE), crude protein (CP) and mineral matter (MM) were determined according to the methods of AOAC (2005). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined according to Van Soest et al. (1991).

Statistical analysis

Results were submitted to analysis of variance, mean comparison test and regression analysis. Interactions were determined when significant ($P<0.05$) by the F test. The means were compared by Tukey's test ($P<0.05$). In regression analyses, the choice of models was based on the significance of the linear coefficient ($P<0.05$). As a tool, SISVAR® version 5.0 software was used according to Ferreira (2011).

Results

Morphogenic and structural characteristics

For morphogenic characteristics, there was no significant interaction ($P>0.05$) between fertilizer level and season and no effect of season for any variable evaluated, whereas for nitrogen doses there were significant responses ($P<0.001$) for all characteristics (Table 2).

For LER, an increasing linear behavior was observed, with an increase of 0.0042 cm/day for each additional kg N applied (Table 2). By contrast, phyllochron declined with increasing doses of N, where for each additional kg N applied there was a reduction of 0.0024 days. For SER, a positive linear response occurred with increasing nitrogen doses. The same behavior was observed for TSR, which showed an increase of 0.0007 cm/day/kg N applied (Table 2).

For structural characteristics there was no significant interaction between fertilizer level and season and no significant effect of season was observed ($P>0.05$). Fertilizer level had an effect ($P<0.05$) for all characteristics evaluated (Table 2).

For PDT, a decreasing linear response was observed with increasing level of N (Table 2), resulting in a decrease of 18 tillers per clump for an increase from 0 to 800 kg N/ ha/year. L:S ratio decreased linearly as N level increased, where for each additional kg N applied there was a reduction of 0.0015 in L:S ratio. For L:D ratio, there was a decreasing linear response with increase in N dosage, with a reduction of 0.0023 in L:D ratio for each additional kg N applied.

Biomass production

Significant interaction between N dosage and season for GLB ($P<0.001$) was observed. Nitrogen dosage had a significant positive effect ($P<0.001$) on TGB and for GSB there were significant effects of N dosage ($P<0.001$) and season ($P = 0.014$) (Table 3).

For GLB, there was a positive linear effect in both seasons with increasing yield as N dosage increased, reaching 26,000 kg DM/ha in spring and 25,800 kg DM/ha in summer at 800 kg N/ha/year (Table 3). Seasonal differences occurred for only Control and 200 kg N/ha/year treatments with higher yields in summer. TGB increased linearly as N application rate increased, with an increase of 2.29 kg DM/ha for each additional kg N applied (Table 3), with the highest yield of 47,900 kg DM/ha for the highest application rate of 800 kg N/ha/year. Although TGB showed this positive response to N fertilizer application, most of the response occurred with the first 400 kg N/ha, producing 83.2 % of the total response.

For GSB, there was an increasing linear response with increasing N dose rate, with an increase of 1.21 kg DM/ha for each additional kg N applied.

Chemical composition

There was significant interaction between N dosage and season ($P<0.001$) for concentrations of CP, EE, NDF, ADF and MM. However, DM concentration was affected ($P = 0.003$) by only N dose rate (Table 4).

Dry matter concentration in forage increased by 0.002 g/kg for each unit of additional N applied (Table 4). Crude protein concentration increased progressively

Table 2. Morphogenic values and structural characteristics of Carajás grass (*Cenchrus purpureus* × *C. americanus*) following different rates of nitrogen fertilizer application

Variable	N rate (kg/ha/year)					s.e.	P-value	Equation
	0	100	200	400	800			
LER[1]	4.6	6.0	6.8	7.4	8.5	0.20	<0.001	$\hat{Y}=5.4373+0.0042x$; $r^2=86.6$
Phy	6.7	6.7	6.1	5.5	4.9	0.15	<0.001	$\hat{Y}=6.7506-0.0024x$; $r^2=95.3$
SER	0.2	0.2	0.3	0.4	0.5	0.03	<0.001	$\hat{Y}=0.2415+0.0004x$; $r^2=97.3$
TSR	0.7	1.0	1.1	1.2	1.3	0.03	<0.001	$\hat{Y}=0.9025+0.0007x$; $r^2=75.7$
PDT	94.8	87.8	86.9	84.4	76.8	4.53	0.002	$\hat{Y}=92.1375-0.0191x$; $r^2=58.7$
L:S	2.9	3.0	2.3	2.4	1.7	0.08	<0.001	$\hat{Y}=2.9483-0.0015x$; $r^2=83.3$
L:D	9.3	9.5	9.1	8.4	7.7	0.27	0.001	$\hat{Y}=9.5419-0.0023x$; $r^2=94.8$

LER = leaf elongation rate (cm/tiller/day); Phy = phyllochron (day); SER = stem elongation rate (cm/tiller/day); TSR = total senescence rate (cm/tiller/day); PDT = population density of tillers per clump; L:S = leaf:stem ratio; L:D = live material:dead material ratio.

Table 3. Growth rates (kg DM/ha) of Carajás grass (*Cenchrus purpureus* × *C. americanus*) in spring and summer following different application rates of nitrogen.

Variable	Season	Fertilizer (kg N/ha)					s.e.	P-value	Equation
		0	100	200	400	800			
GLB	Spring	17,700b	19,600a	21,400b	23,900a	26,000a	1.90	<0.001	$\hat{Y}=19.213+9.2124x$; $r^2=94.9$
	Summer	18,800a	19,500a	22,600a	23,900a	25,800a		<0.001	$\hat{Y}=19.065+9.6358x$; $r^2=84.9$
TGB		26,500	36,400	39,300	44,300	47,900	1.19	<0.001	$\hat{Y}=32.028+2.29x$; $r^2=78.5$
GSB[1]		9,500	12,700	15,600	17,300	20,000	0.102	<0.001	$\hat{Y}=11.444+1.21x$; $r^2=86.4$
GSB[2]	Spring			14,800B			0.070	0.014	
	Summer			15,100A					

GLB = green leaf biomass (kg DM/ha); TGB = total green forage biomass (kg DM/ha); [1]GSB = green stem biomass (kg DM/ha); [2]GSB = green stem biomass (t DM/ha). Means for GLB with the same lower-case letter within columns and for GSB with the same upper-case letter within rows did not differ according to Tukey's test (P>0.05).

Table 4. Chemical composition of Carajás grass (*Cenchrus purpureus* × *C. americanus*) in spring and summer following application of different doses of nitrogen.

	Season	Rate of N (kg/ha)					s.e.	P-value
		0	100	200	400	800		
DM[1]		190	190	191	195	205	2.9	0.003
CP	Spring	116bC	122aC	139aC	151aB	172aA	1.5	<0.001
	Summer	126aBC	112bC	138aB	145aAB	159bA		<0.001
EE	Spring	23.7bB	32.1aA	33.2aA	26.2bAB	34.6aA	0.6	<0.001
	Summer	34.7aA	27.7bAB	24.3bB	30.3aA	33.2aA		0.003
NDF	Spring	604bB	625aB	676aA	672aA	665aAB	2.9	<0.001
	Summer	618aAB	626aA	665aA	595bB	583bB		<0.001
ADF	Spring	364aAB	365aAB	344bB	372aA	388aA	1.8	<0.001
	Summer	336bB	340bB	367aA	347bB	354bB		<0.001
MM	Spring	95.1aB	90.7bC	100.5aA	104.0aA	97.0aAB	2.2	<0.001
	Summer	95.2aB	107.5aA	84.9bC	76.2bC	87.6bB		0.123

[1]$Y = 188.3+0.002x$; $R^2=97.3$. DM = dry matter (g/kg); MM = mineral matter (g/kg DM); EE = ether extract (g/kg DM); CP = crude protein (g/kg DM); NDF = neutral detergent fiber (g/kg DM); ADF = acid detergent fiber (g/kg DM). Means within columns and parameters with the same lower-case letter and within rows with the same upper-case letter did not differ according to Tukey's test (P>0.05).

with increasing N application rate in both seasons. While significant differences in MM, EE, NDF and ADF concentrations as a result of N application were recorded, there were no consistent patterns in the responses.

Discussion

This study has shown that high doses of protected urea can be applied in a single dose at the beginning of the growing season and still produce significant responses in DM production during the summer. Whether or not these levels of N fertilizer are warranted will depend on the value of increases in forage production per unit of N applied as the amount of N applied increases.

Morphogenic and structural characteristics

During both spring and summer all treatments received irrigation at the same level to minimize moisture stress as a variable, which may explain the absence of seasonal differences in morphogenic characteristics independent of N doses. Despite high temperatures and low relative humidity in spring (Table 1), pasture growth in spring equaled that in summer. The absence of differences in structural characteristics of Carajás grass between the evaluated seasons (Table 2) was possibly also due to the influence of regular irrigation applied, which eliminated effects resulting from moisture deficits commonly experienced.

The increase in LER as N fertilizer application increased is a reflection of the positive response in cell division and expansion to additional N supply (Skinner and Nelson 1995).

The positive responses in morphogenic characteristics obtained even at high N dosages (400 and 800 kg/ha/year) would be due to the slow release of N provided by protected urea, which was also reported by Alves et al. (2018). Lima et al. (2016) found positive effects from applying N to *Urochloa ruziziensis* as protected urea up to the maximum (300 kg N/ha/year) dose evaluated.

The reduction in phyllochron as N fertilizer level increased can be explained by the fact that N stimulates plant growth, conferring greater regrowth capacity and faster recovery of the photosynthetic apparatus (Martuscello et al. 2006) following harvesting. Increases in SER would be a response to greater shading caused by increased growth with increasing N doses, promoting elongation of stems to access light. Total leaf senescence rate also increased with increasing N fertilizer levels in line with the positive effect of N on LER, where increased shading of the older leaves may result in more rapid senescence of leaves.

Shading caused by higher growth of plants at increasing N application rates promoted the reduction in population density of tillers, because low luminosity interferes negatively with tillering potential, since decreasing light at the base of plants can also suppress the generation of tillers (Martuscello et al. 2015). Despite lower tiller numbers at higher N application rates, total green biomass yield increased and L:S ratio declined indicating that individual tillers were larger at high N rates with greater stem development, which was reflected in the higher NDF concentration as N level increased.

Reduction in live:dead ratio at higher N application rates would be a function of higher senescence rate observed with the higher doses of nitrogen fertilizer. This effect was reported previously by Alves et al. (2018) for Carajás grass under different N dosages.

Biomass production

Like other C_4 grasses Carajás grass showed good responses in forage production following application of N fertilizer (Lopes et al. 2020; Oliveira et al. 2020; Domingues et al. 2021). These significant responses to N fertilizer application in DM production in both spring and summer and the overall absence of differences between seasons indicate that the primary limiting factor was available N supply, with factors like temperature, soil moisture and light intensity being adequate for growth. According to Valente et al. (2011) the optimum temperature amplitude which causes most enzymatic carboxylation in C_4 grasses is 30–35 °C. While mean temperature in spring fell within this range, mean temperature in summer fell below the range but minimum temperatures in both seasons were similar. In addition, relative humidity in summer was much higher than in spring. Application of irrigation prevented the expression of any differences between seasons in terms of available soil moisture levels experienced in the area under rainfed conditions.

The aim of applying protected urea is to reduce the rate of N release from the fertilizer so response to added N is extended for a longer period than expected with conventional urea and response per additional 100 kg N is more uniform. When increasing levels of N fertilizer are applied to crops or pastures there is normally a reduced response to each additional kg N applied, a phenomenon known as the Law of Diminishing Returns (Guimarães et al 2011). Despite the urea in this study being protected the same principle applied, with responses in green leaf production in spring to the initial 200 kg N being 1,850 kg DM/100 kg N compared with 425 kg DM/100 kg N when the last 400 kg N was applied. In summer the comparable responses were 1,900 kg DM/100 kg N and 475 kg DM/100 kg N applied. When total green forage production is considered for the complete study, response to the first 200 kg N was 4,675 kg DM/100 kg N, while response to the final 400 kg N was 1,175 kg DM/100 kg N applied. We cannot conclude from this study how well the urea was protected from rapid release of N but the fact that plants were still responding to urea application 6 months after it was applied and DM responses in summer per kg N applied were very similar to those obtained in spring indicates that significant protection was certainly provided and N was being released throughout the total growth cycle.

Chemical composition

The increase in DM concentration with increasing N application rate is a function of high growth provided by increased N availability. According to Mendonça and Rocha (1985), N accelerates metabolism and promotes maturity in the plant, providing a greater accumulation of photoassimilates and transformation of these into plant organs, contributing to an increase in DM concentration in forage.

In both seasons N fertilizer application produced marked increases in CP% in forage from 11.6 % in

Controls to 17.2 % at 800 kg N/ha in spring and from 12.6 % to 15.9 % in summer. This was despite large increases in DM production in treatments receiving N. These values indicate that considerable quantities of N were still available in soil at all fertilizer levels despite the long time elapsed following application of fertilizer. This forage would provide excellent fodder for animals, especially given their ability to select a higher quality diet than is on offer.

However, application of N increased NDF concentration in spring, probably as a result of increased stem proportions in the forage produced. While this would lower digestibility of the forage, highest NDF concentrations recorded were 67 %. In contrast NDF concentrations in forage in summer were lower at the high N fertilizer levels than in Controls. The application of N in high doses along with favorable climatic conditions can favor the growth and production of tissues that have lower levels of structural carbohydrates (Vitor et al. 2009), which occurred in summer.

As might be expected, application of N at high doses had no significant impact on mineral concentration in forage in spring, while mineral concentration in forage in summer was significantly reduced as N level increased. This is scarcely surprising given the high yields of forage produced at high N application rates, which would have resulted in removal of large quantities of minerals from the soil.

This study has demonstrated that Carajás grass responds well to application of protected urea. However, despite the urea being protected, the Law of Diminishing Returns still operated, with responses per unit of N applied declining dramatically as amount of fertilizer applied increased. Economic assessments are needed to determine if the high application rates are justified. Similarly, studies seem warranted to assess the overall responses when multiple applications of lower doses are applied as opposed to single heavy doses at planting. The reduced responses in DM production to additional N applied at high doses might mean that overall financial returns could be better with lower application rates and multiple applications of smaller amounts of fertilizer, and even with increased labor costs involved, could be more efficient. Economic assessments would provide data to prove or disprove these hypotheses.

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(Note of the editors: All hyperlinks were verified 18 July 2022).

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