University of São Paulo
“Luiz de Queiroz” College of Agriculture

Canopy characteristics and tillering in 'Zuri' guineagrass pastures in response to grazing frequency and severity

Patrícia Luizão Barbosa

Thesis presented to obtain the degree of Doctor in Science. Area: Animal Science and Pastures

Piracicaba
2020

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versão revisada de acordo com a resolução CoPGr 6018 de 2011

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2020

Dados Internacionais de Catalogação na Publicação
DIVISÃO DE BIBLIOTECA – DIBD/ESALQ/USP

Barbosa, Patrícia Luizão

Canopy characteristics and tillering in 'Zuri' guineagrass pastures in response to grazing frequency and severity / Patrícia Luizão Barbosa. - versão revisada de acordo com a resolução CoPGr 6018 de 2011. - - Piracicaba, 2020.

75 p.

Tese (Doutorado) - - USP / Escola Superior de Agricultura “Luiz de Queiroz”.

1. Índice de estabilidade 2. *Megathyrsus maximus* 3. Manejo do pastejo 4. Densidade populacional de perfilhos 5. Interceptação luminosa 6. Altura de resíduo 7. Massa de forragem 8. Acúmulo de forragem 9. Peso de perfilho 10. Meia-vida de perfilhos 11. *Panicum* spp. 12. Forragem I. Título

To my parents Solange and Rildo and my sister Pâmela, for all the support, you are part of it.

To all my relatives and friends.

ACKNOWLEDGMENTS

I would like to thank God, and the two ladies for whom I have so much faith: Nossa Senhora Aparecida e Santa Rita de Cássia. Faith makes me believe anything is possible.

My grandmother Sirlei and great-grandmother Cida (*in memoriam*) who accompanied me from the beginning, had always said they wanted to see me as Doctor Pati. I know they are happy.

To my family, for their help and understanding over the years, specifically my mother who always believed in me, my sister for her unwavering support and friendship, and my father for his continuous guidance. My family has been significant to my graduate school journey.

All my gratitude to my cousins Frank, Mari, Kalú, Kauan and "vó" Luiza. Thanks for everything you all did for me. I love you all.

I would like to offer my special thanks to my grandmother Nair, all my uncles, aunties and cousins.

A very special thanks to my best friends who provided me with support, and advice. They were my companions throughout my entire journey: Glaiciane Pane (João Pedro's mother), Priscilla Lorena (Ana Sophia's mother), Thayse Romualdo (Lívia's mother) and Dieisson Cadore. I love you all, your support and care matters a lot, thank you very much for your friendship on this crazy journey.

To my advisor, Professor Carlos G. S. Pedreira, who is not just an advisor to me, but also a father-like figure and a friend. He took some time to listen and give me advice. No doubt I will miss visiting his office, to wait at the door until I have permission to enter and have a good conversation. The "cake moments" in the kitchen, and his loud laugh. I am very proud to be your student. Thank you for everything, and I am sorry if sometimes I made mistakes. My heartfelt appreciation to you!

I owe a very important debt to Professor André F. Sbrissia. This study has his great contribution. Thank you Professor for your patience during our countless meetings. I am deeply grateful to you.

I would like to express my gratitude to two Professors who have been with me since the first semester of this course: Patrícia M. Santos and Flávia M. A. Gimenes. Thank you for your advice, help, and patience and for being such kindhearted people.

A huge thank you to Professor Lynn Sollenberger, who welcomed me at the University of Florida in Gainesville, Florida. I admired him prior to our initial meeting and I respected him even more after our meetings. Thank you for welcoming me with open arms. May God continue to bless you and your family.

All my gratitude to the gifts that Florida gave me: Avina, Brittany, Laura and Tyler. You all are amazing and will forever be in my life. I also want to thank English teachers Karen and Eirini. In addition to English Corner, special acknowledgments to Bob for the conversation classes.

To the most special couple I have ever met, Bete and Roberto. Thank you for taking the time to create unforgettable memories with me. Thank you for everything, I miss you.

A special thank you to my best friends that I gained as a result from my time in this Ph.D. program: Guilhermo Congio, Liliane S. da Silva, Larissa F. Garcia, Otávio G. Almeida, Juliana de Assis and Fabiane Q. Rosa. I love you all very much.

I would like to express my gratitude to the interns Pedro Moreira Xavier, Marina Miquilini, Juan D. Flores, Giuliana P. Soufia, Carolina F. dos Santos, Isabela S. Sousa, Maria F. Munguia and Juliana A. Assis, for their help with sampling during the experiments. You guys became my friends, and will forever be in my life. Thank you for everything, I love you all.

To all the friends I made over the years in my academic and personal life, who supported me on this journey: Bruna G. Henning, Sindérya Zaiatz, Diego Paixão, Delvan A. Silva, Alessandra A. Silva, Thaís Heloíla, Jessika Chaves, Francielly Ruzafa, Vládia Delmiro, Danilo Pane, Talles Bohnen, Henrique Barbosa, Andréia Petter, Álvaro Burin, Vanessa R. Bach, Erick Camargo, Diana Suckeveris, Mayara Salvian, Sandra Augusto, Pedro Guerreiro, Jéssica Pampolini, José Guilherme, Juliana H. Nishi, José Luiz Dias, Isadora Paraíso, Orlando Lucato, Leonardo Felix, Carol Cerqueira, Hélio Vasco, Eula Carrara, Emanuel Dall'Agnol, Maiara Despotin, Átila Carvalho, Mircéia Mombach, Marcelo Demarchi, Dheyme Bolson, Isadora Macedo, Elismar dos Anjos, Cátia Tesk, Sabrina Félix and Sara Romeiro. Thank you for your friendship and great moments.

To my friends Valdson J. da Silva and Fagner J. Gomes for their help with data analysis, writing advice, and all the support throughout my Ph.D. Thank you all very much.

Thanks to the friends of the ESALQ Pasture Research Group (GP^2-ESALQ): Pedro Xavier, Marina Miquilini, Giuliana P. Soufia, Isabela Sousa, Juliana Assis, Otavio G. Almeida, Liliane S. Silva, Carolina F. dos Santos, Valdson J. da Silva, Diego Pequeno, Fagner Gomes, Marcell Alonso, Junior Yassuoka, Gabriel Pedroso, Carlos Franco, Solange Holschuch, Theysson Maranhão and Paulo C. Santos.

To LAPF members and former members: Eliana V. Geremia, Guilherme Portes, Lucas Carvalho, Marília Chivegato, Cristian Bosi, Bia Anchão, Caio Macret, Alex M. dos Santos and Lilian Pereira.

I would like to thank Richard Fethiere, at the Forage Evaluation Support Laboratory at the University of Florida. Thank you for your friendship and teaching me the English language.

I would like to thank Professors Sila Carneiro da Silva and Gerson Barreto Mourão, Dr. Rodrigo A. Barbosa and Dr. Liana Jank, for sharing information and advice. I appreciate it!

Thanks to Professors Sinval Silveira Neto and Celso Omoto, as well as Carlos Peres, for their advice and information about “cochineal”. Thank you Carlos Peres and his interns for tick control in the experimental area.

To my two undergraduate Professors who introduced me to the world of research and pasture: Dalton Pereira and Bruno Pedreira, thank you very much.

Thanks to the University of São Paulo – “Luiz de Queiroz” – College of Agriculture (USP/ESALQ) and the Department of Animal Science. Thanks to Juscelino and Emerson for always helping me with the Trovão and the tools. I also would like to thank CAPES and CNPq for granting a scholarship.

Thank you!!

Biography

Patrícia Luizão Barbosa, daughter of Rildo Manoel Barbosa and Solange Luizão Barbuio Barbosa, was born in Fernandópolis, São Paulo, on January 26, 1991. She began the undergraduate degree in March 2009, concluding in February 2014 the Bachelor of Animal Science at the Federal University of Mato Grosso / Campus Sinop. In March 2014, she started the Master's degree in Animal Science, by the same university, the dissertation focused on animal nutrition and forage conservation. Joined the Ph.D. in March 2016, at the University of São Paulo - "Luiz de Queiroz" College of Agriculture. Joined a "sandwich" program in October 2018 at the University of Florida (8 months), Gainesville, Florida. The thesis focusing on Forage and Pasture with emphasis on grazing management.

God is above all!

It is all about never giving up!

Loving yourself is not selfishness.

Life does not get easier; it is you who gets stronger.

I know I am on the right path. Because things stopped being easy.

You never know how strong you are until being strong is the only choice you have.

Just keep swimming!

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RESUMO

Características do dossel e perfilhamento em pastagens de capim Zuri em resposta a frequência e severidade de pastejo

Megathyrsus maximus [(Jacq.) B.K. Simon & S. W. L. Jacobs], são gramíneas caracterizadas por alta produtividade e exigências nutricionais. O capim Zuri é um produtivo *M. maximus*, novo no mercado forrageiro, selecionado com base na produtividade, vigor, capacidade de suporte, desempenho animal, resistência a cigarrinhas [*Mahanarva fimbriolata* (Stål) e *M. liturata* (Le Peletier de Saint-Fargeau & Serville)], e principalmente a "mancha foliar", uma doença causada pelo fungo *Bipolaris maydis* (Nisik e Miyake), e não possui estudos científicos sobre as características estruturais e perfilhamento. Os objetivos com este trabalho foram descrever e explicar os efeitos sobre a dinâmica do perfilhamento e suas taxas – aparecimento(TAR), mortalidade (TMR), sobrevivência (TSR) e índice de estabilidade (SI) - densidade populacional de perfilhos (TPD), massa do perfilho (TM), altura do meristema apical (AMH), meia-vida de perfilhos, características estruturais e morfológicas, como massa e composição morfológica da forragem, altura do dossel, índice de área foliar, interceptação de luz, ângulos foliares, do capim Zuri afetados pela severidade e frequência, sob lotação intermitente. O experimento foi realizado em Piracicaba, SP, Brasil, durante dois verões agrostológicos. O delineamento experimental foi em blocos completos casualizados, com arranjo fatorial 2 × 2, correspondendo a duas frequências determinadas por: IL 95% e 70 cm, e duas severidades (29 e 57%). Os anos foram analisados separadamente. Em ambas as estações de crescimento, não houve efeito do tratamento no TPD e na TM (460 e 350 perfilhos m^{-2} / 2.05 e 2.56 g $perfilho^{-1}$ nos anos 1 e 2, respectivamente). No primeiro ano, a TMR, SI e AMH foram afetados pela interação frequência × severidade (*P*= 0,0033, 0,0198 e 0,0397 para as três respostas, respectivamente), o TAR foi afetada apenas pela severidade (*P*= 0,0243). Na segunda estação de crescimento, o AMH e o SI foram afetados apenas pela severidade (*P*= 0,0004 e 0,0491, respectivamente). A meia-vida apresentada no primeiro apresentou entre 75 e 31 dias e no segundo ano 41 e 50 dias, de acordo com esses dados e a literatura, Zuri poderia ser classificado como uma espécie exploradora. Na estação de crescimento, o ciclo de pastejo (GE) e o intervalo de pastejo (RP) foram afetados pelas severidades (*P*<0,0001), a maior severidade (S) apresentou menor GE e maior RP. A altura pre-pastejo (PREht) apresentou a interação freqüência × severidade (*P*<0,0001) no primeiro ano, a altura no IL 95% foi de ~ 77 cm. No segundo ano, o PREht foi afetado apenas pela frequência e teve altura de ~ 77 cm a 95% de IL. A altura pós-pastejo foi afetada pela severidade em ambos os anos e teve a menor altura na maior severidade. A massa de forragem pré-pastejo (PRHM) foi afetada pela frequência e severidade (*P*<0,05) no primeiro ano, os maiores valores foram registrados para a frequência de IL 95% (LI) e os 29% de severidade (L). Não houve efeito de acúmulo de forragem (HA) no primeiro ano, provavelmente devido ao menor período de adaptação. No segundo ano, o PRHM foi afetada apenas pela severidade (*P*= 0,0001), apresentou o maior valor para o tratamento leniente, provavelmente porque toda a massa das partes (massa foliar, massa do caule e massa do material morto) apresentou os maiores valores (*P*<0,005) para a mesma severidade. No segundo ano, o HA foi afetado pela gravidade (*P*= 0,0006), o maior valor para (L), devido ao maior GE. Independentemente da frequência e severidade, o capim ajustou taxas e manteve o perfilhamento estável. Esses dados sugerem que ~ 77 cm para o pré-pastejo e ~ 33 cm para a altura do dossel após o pastejo é ideal para o capim Zuri sob lotação intermitente.

Palavras-chave: Índice de estabilidade, *Megathyrsus maximus*, Manejo do pastejo, Densidade populacional de perfilhos, Interceptação luminosa, Altura de resíduo, Massa de forragem, Acúmulo de forragem, Peso de perfilho, Meia-vida de perfilhos, *Panicum* spp., Forragem

ABSTRACT

Canopy characteristics and tillering in 'Zuri' guineagrass pastures in response to grazing frequency and severity

Megathyrsus maximus [(Jacq.) B.K. Simon & S. W. L. Jacobs] are grasses characterized by high productivity and nutritional requirements. Zuri guineagrass is productive *Megathyrsus maximum,* a new grass in the forage market It was selected based on productivity, vigor, carrying capacity, animal performance, resistance to the spittlebugs [*Mahanarva fimbriolata* (Stål) and *M. liturata* (Le Peletier de Saint-Fargeau & Serville)] and mainly the "leaf spot", a disease caused by the fungus *Bipolaris maydis* (Nisik and Miyake) and has no scientific studies of the structural characteristics and tillering. The objectives of this research were to describe and explain effects on tillering dynamics and their rates - tiller appearance (TAR), tiller mortality (TMR), tiller survival rate (TSR) and stability index (S) - tiller population density (TPD), tiller mass (TM), apical meristem height (AMH), half-life of tillers, structural and morphological characteristics such as herbage mass and herbage morphological composition, canopy height, leaf area index, light interception, leaf angles of Zuri guineagrass affected by severity and frequency, under rotational stocking. An experiment was carried out in Piracicaba, SP, Brazil, during two summer grazing seasons. The experimental design was a randomized complete block, with a 2 × 2 factorial arrangements, corresponding to two frequencies (LI 95% and 70 cm) and two severities (29 and 57%). The years were analyzed separately. In both growing seasons, there was no treatment effect on TPD and TM (460 and 350 tillers m^{-2}, and 2.05 and 2.56 g $tiller^{-1}$ in the years 1 and 2, respectively). In the first year the TMR, SI, and AMH were affected by the frequency × severity interaction (P=0.0033, 0.0198 and 0.0397 for the three responses, respectively), the TAR was affected only by severity (P=0.0243). In the second growing season, the AMH and the SI were affected only by the severity (P=0.0004 and 0.0491, respectively). The half-life presented in the first year values between 31 and 75 days, and the second year 41 and 50 days, according to this data and the literature, Zuri could be classified as an exploitative specie. In both growing season the grazing cycle (GC) and grazing interval (GI) were affected by the severities (P<0.0001), the greatest severity (S) had the lesser GC and greater GI. The pre-graze/height (PREht) had the frequency × severity interaction (P<0.0001) in the first year, the height at the LI 95% were ~77 cm. In the second year PREht was affected only by the frequency, and had the height at the LI 95% ~77 cm. The post-graze height was affected by the severity in both years, and had the shorter height at the greater severity. The pre-graze herbage mass (PRHM) was affected by frequency and severity (P<0.05) in the first year, the greater values were recorded for the LI 95% (LI) frequency and the 29% of severity (L). There is no herbage accumulation (HA) effect in the first year, probably due to the lesser adaptation period. In the second year the PRHM was affected only by the severity (P=0.0001), had the greatest value for the L severity, probably because all the mass of the parts (Leaf mass, stem mass and dead material mass) had the greatest values (P<0.005) for the same severity. In the second year the HA was affected by the severity (P=0.0006), the greatest value for the L severity, due to the greater GC. Regardless of the frequency and severity used, the grass showed up that has adjusted to maintain a stable tilleriring. These data suggest that ~77-cm for the pre-graze and ~33-cm for the post graze canopy height is optimal for rotational stocked Zuri guineagrass.

Keywords: Stability index, *Megathyrsus maximus*, Grazing management, Tiller density population, Light interception, Stubble height, Herbage mass, Herbage accumulation, Tiller mass, Tiller half-life, *Panicum* spp., Forage

1. INTRODUCTION

In recent years Brazil has been a world leader in beef production. In 2018, brazilian beef exports were 1.64 million Mg, 11% greater than in 2017, ranking number 1 in beef exporting in the world (*Boss* spp.). Twenty years ago, Brazil had a herd of 161 million head of beef cattle on 186 million hectares of pasture. In 2017 the total beef herd was 222 million, grazing on 165 million ha of pastures (ABIEC, 2018). The increase in stocking rate was mainly due to progress in grazing management and the release of new forage grasses from breeding programs. The main forage species used are tropical grasses, mainly of the genus *Urochloa* (syn. *Brachiaria*) and *Megathyrsus* (syn. *Panicum*).

The breeding program of guineagrass [(*Megathyrsus maximus* (Jacq.) B.K. Simon & S. W. L. Jacobs)] for productive materials began at Embrapa (Empresa Brasileira de Pesquisa Agropecuária) in Brazil in 1982 (JANK *et al.,* 1990). On example is Tanzania-1 guineagrass which has been widely planted to many States, mainly in the 1990s (JANK, 2003; JANK *et al.,* 2017). Since its release, Tanzania has been widely used in livestock operations. In 2003, however, there was a first report of the incidence of "leaf spot", a disease caused by a fungus (*Bipolaris maydis* Nisik and Miyake) (MUIR & JANK, 2004). Plants affected by *B. maydis* usually show small and elliptic brown leaf spots. In cases of severe damage, the leaves turn yellow and dry prematurely, reducing forage production, due to the loss of photosynthetic leaf area (ANJOS *et al.,* 2004; CHARCAR *et al.,* 2003; CHARCAR *et al.,* 2008). The leaf spot has contributed to the decline in productivity and persistence of Tanzania guineagrass. One example is the areas of seed production of the cultivars of *Megathyrsus* spp. Jank *et al.* (2008) reported for guineagrasses, that Tanzania guineagrass was in second placement in livestock production, just behind the leader Mombaça guineagrass. The 2017/2018 grazing season showed Tanzania occupying fifth place with 774 ha of seed production and Mombaça in first place (20,705 ha of seed production) (Unipasto, 2018; personal communication).

A new guineagrass cultivar has been released in the seed market, and three years after its release it is already the third-largest area in seed production (3,961 ha) (Unipasto, 2018, personal communication). Zuri guineagrass [*M. maximus* (Jacq.) B.K. Simon & S. W. L. Jacobs (syn. *P. maximum* Jacq.) cv. BRS Zuri], was released in 2014 by Embrapa (JANK *et al.,* 2017) and showed similar production potential to that of Tanzania, but with the advantage of resistance to leaf spot disease. This grass has also shown resistance to some spittlebug species [*Mahanarva fimbriolata* (Stål) and *M. liturata* (Le Peletier de Saint-Fargeau & Serville)].

Although Zuri is gaining visibility in the seed market, studies on the grazing management recommendations for this grass are scarce. Recommendations from Embrapa include pre-graze height of 70-75 cm and post-graze of 30-35 cm, a set of management guidelines very close to that used for Tanzania guineagrass (BARBOSA, *et al.,* 2007). Under such management, Zuri should produce 20-40 Mg DM ha^{-1} yr^{-1} (BRASIL, 2014).

Over the years, in the scientific literature, defoliation management studies have proposed a myriad of guidelines and criteria for optimum grazing intervals. One study with perennial ryegrass (*Lolium perenne* L.) was published by Brougham (1956), he related dry matter to light interception by the forage canopy, under rotational conditions, and determined that the regrowth pattern followed a sigmoid curve. It was indicated that the intensity of the defoliation affected the initial phase of the subsequent regrowth curve until there was enough leaf area to intercept 95% of the incident light, where the greater rate of net forage accumulation occurred. The greater intensity of defoliation the longer the return of the canopy to the initial height. This study has been referred to as the basis for many other studies (CARNEVALLI *et al.,* 2006; BARBOSA *et al.,* 2007; PEDREIRA & PEDREIRA, 2007; PORTELA *et al.,* 2011), which emphasized the importance of defoliation management on the productive responses of forage grasses.

Grazing management targets aiming to optimize the balance between grazed forage and herbage production, thus, less forage losses due to high stubble height or dead material (SILVA *et al.,* 2016), may improve the efficiency of pasture-based animal production systems (HODGSON, 1990; Da SILVA & PEDREIRA, 1997). Therefore, its important to identify harvest strategies, such as intensity/severity and frequency of cutting/grazing where forage production is optimal for each species, considering plant phenology and physiology (MARSHALL, 1987). For rotational stocking, the defoliation frequency is determined by the grazing cycle used (grazing period + rest period). The other defoliation component is severity, as an initial percentage of pre-graze height to determine the post-graze height (FONSECA *et al.,* 2013; MEZZALIRA *et al.,* 2014; CONGIO *et al.,* 2018).

In recent years, forage-based livestock production has been intensified through grazing management techniques. Canopy attributes such as height, forage mass, leaf area index (LAI), and tiller population density have been closely associated with responses of plants and animals in pastoral environments and, for this reason, have been widely used for the control and monitoring of grazing management (HODGSON & Da SILVA, 2002).

Among the techniques studied in recent years as decision-makers on grazing management are the use of canopy light interception (LI), based on the concepts of critical and optimal LAI, which represent the physiological basis of crop growth (BROWN & BLASER, 1968). In some cases, associations between canopy LI and height have been proposed as the determinants of the moment when harvesting by cutting/grazing should be done (CARNEVALLI, *et al.,* 2006; PEDREIRA & PEDREIRA, 2007). The use of specific canopy height as a target level of grazing intensity can help improve pasture and animal productivity, as it can affect herbage accumulation, nutritive value and persistence of grazed pastures (SOLLENBERGER *et al.,* 2012).

The release of a new forage cultivar should follow studies to establish specific canopy height targets since morphological and physiological differences can be significant even within species (LARA & PEDREIRA 2011). The need to identify managements that optimize pasture performance calls for studies on tillering dynamics and patterns of accumulation of plant-part components across soil and climate conditions and the identification of factors that may impact forage production. Understanding of the herbage accumulation process in response to management may help achieve greater forage-livestock system efficiency, sustainability, and profitability. The control of tillering dynamics in a pasture, that ensures adequate tiller renewal should be one of the objectives, (although indirect) of grazing management, especially under severe defoliation, when the tiller population density balance tends to be necessary to ensure pasture perenniality (LEMAIRE & CHAPMAN, 1996).

1.1 Hypothesis

Under greater grazing severity, there is great population density and grazing should be less frequent. Under lesser grazing severity, tiller population density is lesser and grazing frequency should be greater.

Zuri guineagrass is an exploitative species (fast-growing), with persistence deriving from growth pattern, regardless of severity. Zuri guineagrass plants have a short tiller half-life.

1.2 Objectives

Describe and explain the effects of grazing frequency and severity on tillering dynamics and canopy characteristics of Zuri guineagrass under intermittent grazing.

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2 TILLERING DYNAMICS AND INDIVIDUAL TILLER CHARACTERISTICS OF ZURI GUINEAGRASS UNDER ROTATIONAL STOCKING

Abstract

The need to identify practices that optimize grazing management generates the demand for studies on grazed plant populations. The objective of this research was to evaluate the effects of two grazing frequencies (regrowth interrupted when the canopy was 70 cm tall or when it intercepted 95% of the incoming radiation 95% LI) and two severities (reduction of 29 and 57% of initial canopy height) in Zuri guineagrass [*Megathyrsus maximus* – (Jacq.) B.K. Simon & S. W. L Jacobs (syn. *Panicum maximum* Jacq.) cv. BRS Zuri], under rotational stocking, on tillering dynamics and the rates of tiller appearance (TAR), mortality (TMR), and survival (TSR), tiller stability index (SI), tiller population density (TPD), tiller mass (TM), apical meristem height (AMH) and tiller half-life during two summer rainy seasons in Piracicaba, Brazil. The experimental design was a randomized complete block, with a 2 x 2 factorial arrangement of treatment factors (frequency and severity). In both years, there were no treatment effects on TPD and TM. In the first year the TMR, SI, and AMH were affected by the frequency × severity interaction (P=0.0033, 0.0198 and 0.0397 for the three responses, respectively), the TAR was affected only by severity (P=0.0243). In the second growing season, the AMH and the SI were affected only by the severity (P=0.0004 and 0.0491, respectively). There were no treatment effects on TSR, TMR, and TAR (P>0.005). The half-life in the first year was between 75 and 31 days, and between 41 and 50 days in the second year, classifying Zuri guineagrass as an exploitative specie. Regardless of the frequency and severity Zuri adapted to the defoliation regime and maintained stable tillering. The half-life response means constant renewal of the population suggesting great mineral nutrient requirement.

Keywords: Stability index; *Megathyrsus maximus*; Grazing management; Tiller density population; Severity; Frequency

2.1 Introduction

In tropical regions, grasses of African origin (genera *Megathyrsus*, *Urochloa*, *Pennisetum* spp.) are the most used in monospecific cultivated pastures. A relatively small number of commercial cultivars are used, representing extensive clonal monocultures, small variability, and genetically vulnerable pastures (VALLE *et al.*, 2009). This leads to an ecosystem imbalance since monocultures favoring the occurrence and propagation of pathogens (VERZIGNASSI & FERNANDES, 2001).

Tanzania guineagrass was for years the main cultivar of *Megathyrsus maximus* (syn. *Panicum maximus* Jacq.) in Brazil. In 2008 ranked second guinegrass in the Brazilian forage seed market and currently fifth in pasture area, (JANK *et al.*, 2008; Unipasto, 2018 – personal communication). In recent years the leaf spot, a disease caused by the fungus *Bipolaris maydis* (Nisik and Miyake) has contributed to the decline in productivity and persistence of this grass (MUIR & JANK, 2004). In 2014, Zuri guineagrass [*Megathyrsus maximus* – (Jacq.)

B.K. Simon & S. W. L Jacobs (syn. *Panicum maximum* Jacq.) cv. BRS Zuri] was released by Embrapa-Brazil, with characteristics similar to those of Tanzania guineagrass (upright growth habit, long dark green leaves, thick stems, medium leaf sheath pubescence, panicle inflorescence, production seasonality and also the productivity of 20-40- Mg of forage DM ha^{-1} yr^{-1}), but with the advantage of being resistant to leaf spot.

Among the many traits of forage grasses, tillering has been regarded as important for establishment and productivity, since it ensures effective propagation, besides showing a relationship with several morphological and physiological processes that determine pasture longevity (Da SILVA & PEDREIRA, 1997). Tillers have their morphological development based on the successive differentiation of phytomers in different growth stages (VALENTINE & MATTHEW, 1999). They develop from the axillary buds of individual leaves and the conditions for bud development are associated with hormonal and environmental characteristics (MURPHY & BRISKE, 1992). Each leaf blade has an axillary bud that can give rise to a new tiller (NELSON, 2000).

Structural attributes of the forage canopy such as height, herbage mass, LAI, and tiller population density have been associated with plant and animal responses in grazed pastures and, for this reason, have been proposed for controlling and monitoring the grazing process (HODGSON & Da SILVA, 2002). Pasture-based systems are known as the lowest-cost alternative for ruminant production. Pasture persistence is key in ensuring system longevity and sustainability and the understanding of the mechanisms that warrant tiller population density and stability must be identified and understood.

The stability of the tiller population in a pasture depends on the constant balance between appearance and mortality, where young tillers replace tillers that were grazed or that have started the reproductive stage (Da SILVA & PEDREIRA, 1997; SBRISSIA *et al.,* 2010). Tiller lifespan varies and the balance between survival, death and appearance determines the tiller population in the field. This balance is strongly dependent on the canopy LAI (VALENTINE & MATTHEW, 1999).

Hodgson (1990) reported on the relationship among defoliation severity, tiller density population, and tiller size, and explained that under greater defoliation severity the canopy LAI is the result of a large population of small tillers whereas under lenient grazing the LAI comes from fewer and bigger tillers. Under severe grazing an increase in tiller population density can initially compensate for the decrease in the LAI. However, with continued severe grazing, the decline in basal area of plants can become so large that tiller density decreases within the population (BRISKE, 1996).

The dynamic equilibrium required to maintain pasture stability and productivity is achieved by a tiller population size/density compensation mechanism, which is associated with the tiller population-dependent death process (KAYS & HARPER, 1974; SBRISSIA *et al.,* 2010). This is influenced by environmental factors such as intraspecific competition, particularly for light. Tillers are initiated by the increased ratio of red to far red (R:FR) light reaching the base of the stem where the tiller buds are located (HEWSON, 2015; MATTHEW *et al.,* 2013).

The lifespan of individual tillers varies from a few weeks to more than a year, so the continued production of new tillers which replace senescent or reproductive tillers ensures the perenniality of the crop. This can be seen in greater detail by monitoring the survival of successive generations (cohorts) of marked tillers in fixed areas over a given period. Detailing such processes would allow for the manipulation and possible increase in pasture productivity and likely animal output of grazed pastures. The control of tiller dynamics in pastures should be one of the objectives of grazing management, especially in situations where tiller population density tends to a minimum necessary to ensure the crop stability (LEMAIRE & CHAPMAN, 1996).

Before Zuri was released, Embrapa defined that the defoliation management of this grass would be similar to that of Tanzania (BARBOSA, *et al.*, 2007), with recommended pre-graze canopy height ranging from 70 to 75 cm and a 30- 35 cm post-graze stubble. Under these management guidelines it would be expected that Zuri guineagrass could accumulate 20-40- Mg of forage DM ha^{-1} yr^{-1} (BRASIL, 2014). There are no published scientific studies, however, reporting on long-term evaluation of this grass, and depicting its tillering characteristics, canopy attributes and how these interact with recommended grazing methods.

Considering that management impacts the tillering dynamics the objective of this study was to describe and explain the effects of the grazing frequency and severity in tillering characteristics of Zuri guineagrass.

2.2 Material and Methods

2.2.1 Site description

The study was carried out in Piracicaba, São Paulo, Brazil (22º42’ S, 47º37’ W, 546 m a.s.l.) at the “Luiz de Queiroz” College of Agriculture, University of São Paulo

(USP/ESALQ). The climate is classified as Cwa characterized as subtropical dry winter and hot summer (KÖPPEN, 1948; ALVARES, *et al.*, 2013). The soil at the experimental site is a highly fertile Kandiudalfic Eutrudox. Average soil chemical characteristics at the time the trial was initiated were P = 26 mg dm^{-3} (ion-exchange resin extraction method); organic matter (OM) = 35 g dm^{-3}; pH (0.01 mol $L^{-1}CaCl_2$) = 5.5; K = 3.9 $mmol_c$ dm^{-3}; Ca = 41 $mmol_c$ dm^{-3}; Mg = 21 $mmol_c$ dm^{-3}; H+Al = 34 $mmol_c$ dm^{-3}; sum of bases = 65.9 $mmol_c$ dm^{-3}; base saturation = 66%. Weather for the experimental period (Table 1) were recorded at a weather station located 2 km from the experimental site.

Table 1. Monthly weather data at the experimental site during 2 yr of evaluation in Piracicaba, SP, Brazil.

Weather variable	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.
				2016/2017				
Max. temperature (ºC)	29.9	29.6	31.4	30.2	32.2	30.6	28.3	26.2
Min. temperature (ºC)	17.1	17.7	19.2	20.3	20.0	18.4	16.7	14.8
Rainfall (mm)	103.1	190.5	190.6	334.5	88.8	137.0	128.5	161.6
				2017/2018				
Max. temperature (ºC)	30.3	29.6	31.0	30.3	30.16	32.0	29.6	27.9
Min. temperature (ºC)	17.3	16.9	19.4	19.4	18.2	19.5	15.9	12.3
Rainfall (mm)	80.5	235.7	148.6	225.0	71.6	204.5	35.1	11.7
				Historic Average†				
Max. temperature (ºC)	29.2	29.7	29.8	30.0	30.0	30.0	29.0	26.0
Min. temperature (ºC)	15.9	16.8	18.4	19.1	19.0	18.0	16.0	12.0
Rainfall (mm)	109.4	133.5	199.3	229.2	180.0	142.0	66.0	56.0

†Historic average weather data from 1917 to 2018.

The area was disked, on Feb 3, 2015. On Feb 3, 2015, the soil was leveled with a rotary hoe, followed by the sowing of Zuri guineagrass in one half of the area (Figure 1), using 4 kg ha^{-1} of pure live seed. After sowing the area was compacted. Two months after sowing, 2,4-dichlorophenoxyacetic acid (2,4-D) was applied using a backpack type sprayer at the rate of 1 kg ha^{-1} of the acid equivalent for control of weeds [Amaranth (*Amaranthus* spp. and Castor Bean (*Ricinus communis* L.)].

Figure 1. General view of the experimental area.

The other half of the experimental area was established in April 2016. The soil was disked, leveled, and sown with 8 kg ha^{-1} of pure live seeds, and lightly compacted. Due to the limited rainfall during that period, the area was irrigated. For the control of Amaranth (*Amaranthus* spp.) and Castor Bean (*Ricinus communis* L.), 2,4-dichlorophenoxyacetic acid (2,4-D) was applied at 3 L ha^{-1} on September 2016.

In November 2017, pastures were attacked by cochineal, identified as *Pinnaspis apidistrae* (Signoret, 1869) (Homoptera, Diaspididae) (Figure 2) and controlled using 10 g of 6-Chloronicotinic acid (133 g ha^{-1}) [1-(6-chloro-3-pyridylmethyl)-N-nitroimidazolidin-2-ylideneamine] for 10 L of water (266 L ha^{-1}), plus 50 mL of mineral oil (0.6 L ha^{-1}), was applied using a backpack type sprayer.

Figure 2. Zuri guineagrass attacked by *Pinnaspis apidistrae*.

2.2.2 Treatments and experimental design

On Dec 17, 2016, the pastures were mowed to 10 cm and the adaptation to the treatments began. This consisted of applying the assigned defoliation regimes. Each paddock received 250 kg N ha^{-1} yr^{-1} (as NH_4NO_3) and 250 kg K ha^{-1} yr^{-1} (as KCl). (Table 2).

Table 2. Quantity of N and K per fertilization and the respective date of application during the experimental period.

	Fertilization	
Date	N	K
	Year 1	
	--------- *kg ha^{-1}* --------	
12/20/2016	50	0
01/10/2017	50	62.5
02/03/2017	50	62.5
02/25/2017	50	62.5
03/10/2017	50	62.5
	Year 2	
	--------- *kg ha^{-1}* --------	
11/27/2017	50	0
12/16/2017	50	50
01/06/2018	50	50
01/27/2018	50	50
03/06/2018	50	50

Treatments were all factorial combinations of two grazing frequencies [grazing initiated when the grass canopy reached 95% light interception (LI), or 70 cm height (H)], with two grazing severities (removal of 29 or 57% of the initial canopy height, the latter being denominated lenient [L] and severe [S] grazing, respectively), with frequency-severity combinations being as follows:

H/L = 70 cm pre-graze height and 50 cm post-graze height (severity of 29%);

H/S= 70 cm pre-graze height and 30 cm post-graze height (severity of 57%);

LI/L= 95% LI at pre-graze with 29% canopy height reduction at post-graze;

LI/S= 95% LI at pre-graze with 57% canopy height reduction at post-graze.

The experimental design was a randomized complete block with four replications. Each of the 16 experimental units was 170 m² in area.

The grazing protocol was mob stocking. Dry crossbred dairy cows (*Bos taurus* L.), (~450 kg BW) were brought onto the paddocks when the average canopy target (70 cm height or 95% LI) was reached (Figure 3). Each grazing event was planned so that the defoliation lasted the shortest possible time (~20 minutes to 29% of severity and, ~1 hour to 57% of severity), to avoid the formation of rejection areas and excessive deposition of dung and urine during grazing. For grazing to be as uniform and as short in duration as possible, the animals grazed in strips, with each paddock divided in three strips (Figure 3).

When they were not grazing the experimental pastures, the animals remained in an adjacent pasture area, with Zuri guineagrass and Mulato II brachiariagrass [(*Brachiaria* hybrid) (*B. ruziziensis* × *B. decumbens* × *B. brizantha*)].

Data were collected in the first year (Year 1), from 6 Jan 2017 through 8 April 2017 (92 days), and in the second year (Year 2) from 29 Nov. 2017 through 19 Mar 2018 (111 days).

Figure 3. Animals in an experimental unit.

2.2.3 Monitoring canopy conditions

Light interception and canopy height were measured three times per week in each regrowth cycle (pasture rest period), starting immediately after grazing and until it was time to graze each pasture again. Canopy height was measured using a light polyethylene sheet and a graduated measuring rod at 40 sites in each pasture (Figure 4). The LI was measured using model LAI-2000 canopy analyzer (Li-Cor, Lincoln, Nebraska, USA), at 30 sites per pasture (locations where the heights represented the average canopy condition at the time of reading), and for every 6 readings at the bottom of the canopy a reference reading was taken above the canopy (Figure 5). The LI measurements were taken at times of predominance of diffuse radiation (overcast skies or low solar elevation in early morning or late afternoon) (WELLES & NORMAN, 1991). As the canopy height and LI approached the treatment target, the measurements were taken daily.

Figure 4. Measurement using a light polyethylene sheet and a graduated measuring stick in grazed Zuri guineagrass.

Figure 5. Measurement using LAI-2000 canopy analyzer (Li-Cor, Lincoln, NE) below grazed Zuri guineagrass canopy.

2.2.4 Tiller population density

Tiller population density (TPD) was characterized at post-graze by counting the total number of tillers inside two metal frames measuring 0.7 ×1 m (Figure 6) per pasture, placed at sites that were representative of the average canopy condition.

Figure 6. Frame used for measuring tiller population density, in Zuri guineagrass.

2.2.5 Tillering dynamics

Tillering dynamics was studied by tagging cohorts of tillers in three tussocks, chosen as representative of the mean tussock of the experimental unit, by visual evaluation, with the evaluations at post-graze. At the first tagging, all the basal tillers of the tussock were tagged with a colored wire (one color), characterizing cohort "one". After regrowth and new grazing, the same tussock was tagged with new wire color. Live tillers of the previous cohort (with the same color wire) were counted, dead tillers of that cohort were counted their wires removed, and the new tillers that appeared in the tussock (new cohort) were tagged with different color wire, characterizing the cohort 2 (Figure 7). Tillers were classified as dead when they were brown and withered (KORTE, *et al.*, 1984). This procedure was repeated at grazing cycle, recording the number of tillers that died from each previous tagging, those that appeared since the last tagging, and those that remained alive in each category (cohort) since the previous tagging. The values for each experimental unit were the means of the three tussocks. Because rest period length was variable in time (i.e., dictated by canopy height or LI) tiller evaluations happened on different dates, so rate values were calculated and adjusted to a standard 30-d period (BAHMANI *et al.*, 2003).

The tiller appearance (TAR), survival (TSR) and mortality (TMR) rates of tillers were calculated as follows (calculation per tussock at each sampling time):

$$\textbf{TAR} = \frac{\text{n° of new tillers tagged}}{\text{Total n° of live tillers in previous tagging}} \times 100/\text{ n° of days in the period}$$

$$\textbf{TSR} = \frac{\text{n° of the previous marking live on the current tagging}}{\text{Total n° of live tillers in previous tagging}} \times 100/\text{ n° of days in the period}$$

TMR = (1 - TSR in the current marking) × 100 / number of days in the period

Figure 7. Tagged tillers with wires of different colors for evaluation of tillering dynamics.

From the survival and appearance rates, the tiller population stability index (SI) was calculated. This index provides a general approach to tiller population stability between two successive evaluations, where values equal or greater than 1, indicate stable pastures and values below 1 indicate instability (MATTHEW & SACKVILLE 2011; DUCHINI *et al.*, 2018). The SI (P_1 / P_0) between two successive cohorts is given by:

$P_1 / P_0 = TAR + TSR$

where: P_1 is the tiller population in the current cohort, P_0 is the tiller population in the previous cohort, and TAR and TSR are the means of tiller appearance and survival rates, respectively. From this data was possible to obtain the survival diagram graphs.

2.2.6 Individual tiller characteristics

Apical meristem height (AMH) and tiller mass (TM) were measured in samples taken before each grazing by clipping 50 randomly selected tillers per paddock at soil level, at representative sites of pre-graze canopy height. Tillers were taken to the laboratory and then sectioned longitudinally to identify the apical meristem. The AMH was measured using calipers, from the meristem to the base of the tiller (Figure 8). Tillers were dried at 60°C and weighed to determine TM. In the first year, no tiller samples were taken in the first grazing cycle (C1) (Appendix).

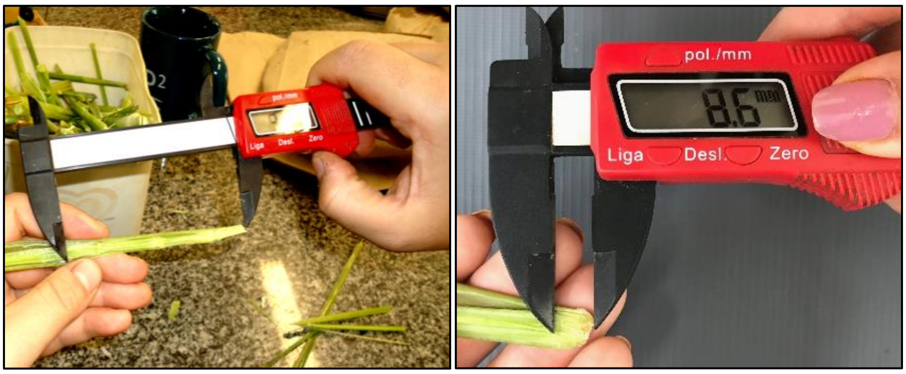

Figure 8. Measuring apical meristem height in Zuri guineagrass tillers.

2.2.7 Tiller half-life

Studying the tiller half-life is an important factor because the half-life is the time required for half of the tiller population to die. Plants with a long half-life, will have longer survival of tillers, are plants that conserve more their resources. Plants with a short half-life are those that have a great renewal of the plant population in a short period, consequently, a greater tiller mortality rate and the stability is mainly attributed to the tiller appearance rate, and this implies a great extraction of soil nutrients for this maintenance, therefore, more demanding plants regarding the management (DUCHINI *et. al*, 2018).

The methodology described by Korte (1986) was used to evaluate tiller age and their survival over time across the cohorts. To make comparisons between treatments and age categories, tiller survival was expressed as the ratio of tiller survival to the initial number of tillers in the age category. From this calculation results the half-life of tillers. This can be expressed mathematically as:

$$N_t/N_o = e^{bt}$$

Where N_o is the number of tillers in the first cohort, N_t the number of live tillers t days after the end of the last cohort (surviving number), and b is a constant. For clarity, b, was converted to half-life ($t_{1/2}$) (KORTE, 1986, DUCHINI *et al*, 2018):

$$t_{1/2=} \text{ In } 2/b$$

2.2.8 Data analysis

Data were analyzed using PROC MIXED of SAS (SAS Institute, 2013) with a model including effects of, frequency, severity, and their interaction. Block (replication) was considered as random effect (LITTEL *et al.*, 2006). Years were analyzed separately because the trial was run for two years to broaden the inference, as opposed of looking for year effects.

The apical meristem height (AMH) was analyzed comparing cycles. The covariance structure was chosen based on Akaike's Information Criterion (AIC) (WOLFINGER, 1993). Shapiro-Wilk test were used to check the normality of the model residuals. Treatment means were compared using probability of the difference (PDIFF) by Student test (P< 0.05).

2.3. Results and Discussion

2.3.1 Tiller population density and tiller mass

There was no treatment effect on TPD and TM (P>0.05), which, on average were 460 and 350 tillers m^{-2}, and 2.05 and 2.56 g tiller^{-1} in the years 1 and 2, respectively. For the present experiment, the first hypothesis, which says about under greater severity there would be a greater tiller population density, was rejected. According to Langer (1979), tillering can be influenced by several factors, such as availability of water, light, temperature, and nutrients, mainly nitrogen and, to a lesser extent, phosphorus and potassium, besides the stage of development of the plant (reproductive or vegetative). In the current study the TPD results may be associated with the edaphic and climatic conditions since the soil was highly fertile, nitrogen was supplied, data were collected during the vegetative stage in the summer rainy season, and the pre-graze canopy height founded at LI 95%, was ~77 cm, close to the pre-graze height H (70 cm). In a study with Tanzania guineagrass under three grazing intensities (post-graze at: 1000, 2500 and 4000 kg DM ha^{-1} - high, medium, and low intensities, respectively), even with contrasting intensity levels, Santos *et al.*, (2006) reported no intensity effects on TPD and justified this result by the high soil fertility, which would be stimulating the emergence of new tillers in the areas where mortality was greater.

Barbosa *et al.*, (2007) reported no differences in TPD (654 and 614 tillers m^{-2}) in grazed Tanzania guineagrass at two stubble height (30 and 50 cm) when pre-graze LI was 95% during the warm, rainy season. Montagner *et al.*, (2012) reported no differences in TPD in Mombaça guineagrass grazed to 30-, 50- and 30/50cm stubbles (with variations in post-grazing height at times of the year to the last height, to control stem elongation in the autumn) The authors attributed this to the pre-graze target of 95% LI. In the current study no differences in TPD were found corroborates with the other authors (CARVALHO *et al.*, 2006; UEBELLE, 2002) in upright-growing plants (*Pennisetum purpureum* Schum. and Mombaça guineagrass).

Interrante *et al.*, (2010), studied the effect of harvest frequencies (7 and 21 d) and stubble heights (4 and 8 cm) in five bahiagrass (*Paspalum notatum* Flügge) entries, they reported an increment in tiller number for two entries (Tifton 9 and PCA Cycle 4) harvested with greater severity and frequency (4 cm every 7 d), but no differences on TPD for other three entries (Argentine, Tifton 7 and Pensacola). All entries had the least tiller mass when harvested at 4 cm stubble. In the current study grazing frequency was dictated by canopy height and LI (and did not exceed 95%LI for either), and with the greater severity (57%) there were differences in TPD and TM.

Sbrissia (2004), reported differences in tiller mass for Marandu palisadegrass under four canopy heights (10, 20, 30 and 40 cm) under continuous stocking, the greatest TM and the lesser TPD recorded in taller canopies. These standard relationships between tiller population density and tiller weight are the reverse of the well-known self-thinning rule (Yoda *et al.,* 1963). The author attributed the differences due to de competition for light, were the lesser TPD on tall canopies and greater TPD on short canopies. In the present study there was probably little competition for light, since LI never exceeded 95% and the two severity levels did not represent a great enough contrast.

Pastures grazed at shorter heights usually have greater TPD of small tillers, whereas taller pasture canopies usually have lesser TPD of heavier tillers. This is known as tiller size/density compensation mechanism (AROSTEGUY *et al.,* 1982; GRANT *et al.,* 1983; MATTHEW *et al.,* 1995; BIRCHAM & HODGSON, 1983; SBRISSIA *et al.,* 2003). Despite evidence in the literature showing that greater grazing severity increases TPD (CRISTIANSEN & SVEJCAR, 1988; BIRCHAM & HODGSON, 1983; PAKIDING & HIRATA, 2003; INTERRANTE *et al.,* 2010; SBRISSIA *et al.,* 2003, 2010), no differences in TPD and TM were found in the present study. In addition to all the characteristics mentioned, such as not exceeding 95% LI, vegetative stage, rainy season and adequate soil nutritional conditions, probably the treatments were not contrasting enough to detect this difference.

2.3.2 Tiller mortality, appearance, survival rate and apical meristem height

In the first growing season, tiller mortality rate (TMR), stability index (SI) and apical meristem height (AMH) were affected by the frequency × severity interaction (P=0.0033, 0.0198 and 0.0397 for the three responses, respectively) (Table 3). The greatest TMR, and the least AMH were recorded for the LI+S combination. Greater SI occurred at the frequency determined by height (H) and S severity. The TAR was affected only by severity (P=0.0243), the greater TAR recorded when pastures were under severe (S) grazing [(0.27 vs. 0.34 tillers

(100 tillers)$^{-1}$ d^{-1})]. There were no treatment effects on TSR [(0.77 tillers (100 tillers)$^{-1}$ d^{-1})] (*P*>0.005) in the first year.

In the second year, the AMH and the SI were affected only by the severity of defoliation (*P*=0.0004 and 0.0491, respectively), with the greater value recorded under lenient (L) grazing, for both (6 vs. 4 cm, and 1.11 vs. 1.09, respectively). There were no treatment effects (*P*>0.005) on TSR, TMR and TAR [(0.74, 0.26 and 0.33 tillers (100 tillers)$^{-1}$ d^{-1}, respectively)] in the second year.

Tillering patterns (TMR, TAR and TSR) are closely associated with pasture production and cannot be considered separately. The TMR, TAR, TSR have important roles in establishing and maintaining the tiller population stability in pastures (MARSHALL, 1987). Changes in TPD can be explained by TAR and TSR, or by the SI (MATTHEW & SACKVILLE HAMILTON, 2011). When SI is less than 1, pastures have relatively lesser TAR than TSR, considered in the same period. According to Parsons & Chapman (2000), in stable pastures, each tiller would only need to form one other during its lifespan to maintain a constant tiller population.

In the first year, the TSR remained constant, suggesting that frequency and severity did not impact this variable. There was, however, a slight instability of the tiller population for the LI/S treatment combination (SI = 0.87), most likely because the TMR under this treatment was greater, and the TAR was great enough to compensate. Despite the slight instability, the SI did not impact the TPD, since it is a dynamic result, characterized by the balance between TAR and TMR throughout the year, which occur at variable rates (BULLOCK, 1996). The TAR for the severe (S) level may have been influenced by the manipulation in the tussocks. Pastures under the S severity had smaller stubble height, and the manipulation allowed the greater light intensity reaching the base of the canopy positively influencing the development of buds in tillers (DEREGIBUS *et al.*, 1985), and resulting in greater TAR.

In the second year, there were no differences in tillering rates (TAR, TMR, and TSR) among treatments, showing that the tiller populations remained stable. Despite the difference in SI between severities, both SI values were above 1. Silva *et al.*, 2020, reported that the apical meristem height was affected only by canopy height, and increased linearly from 3 to 20 cm as canopy height increased from 10 to 40 cm. In the current study, the AMH was lesser under the S severity, the tillers population was younger and therefore with lesser AMH.

The AMH were lesser than the lowest stubble height (57% severity) (Table 3) in both years. Tiller mortality has often been associated with decapitation of meristems by animals during grazing (DAVIES, 1988). The greater grazing severity may have contributed to tiller death (MARSHAL, 1987; VALENTINE & MATTHEW, 1999; BARBOSA *et al.,* 1996), which in turn maybe a result of elongation of internodes and whole stems (CARNEVALLI *et al.,* 2006; PEDREIRA, PEDREIRA, Da SILVA, 2009). This, however, may be more relevant during the reproductive season of Zuri guineagrass, as the AMH was small during the entire experimental period when the grass was mostly vegetative. Tiller death was likely more dependent on plant uprooting, trampling, other mechanical damage, the severe grazing allowed the input of light, and the renewed the tiller population.

It was not possible to detect the participation of tillers with visible inflorescence and aerial tillers in either of the two growing seasons. Tillering dynamics and population density were evaluated at post-graze mainly to avoid lodging the grass before grazing. This means that any reproductive tillers would have been defoliated before they reached the seedhead stage so they were not included in this category. In addition, the first seedhead was observed in the first and second year, after the end of the experimental period (late April).

Table 3. Apical meristem height (AMH), tiller mortality rate (TMR) and stability index (SI) in Zuri guineagrass canopies under two grazing frequencies (H and LI) and two severities (L and S) in the yr 1.

Severity	Frequency H	Frequency LI	*P*†
	------------------------AMH (cm) -----------------------		
L	4Aa	5Aa	
	(0.52) ‡	(0.53)	0.0397
S	3Aa	2Ba	
	(0.56)	(0.58)	
	---------------TMR -Tillers.(100 tillers)$^{-1}$ d^{-1}-----------		
L	0.22 Aa	0.21 Ba	
	(0.021)	(0.021)	0.0033
S	0.21 Ab	0.29 Aa	
	(0.026)	(0.028)	
	----------------------SI -----------------------		
L	1.05 Aa	1.09 Aa	
	(0.029)	(0.027)	0.0198
S	1.15 Aa	0.87 Bb	
	(0.032)	(0.035)	

Means followed by the same lowercase letter in rows and upper case letters in columns, within each variable, are not different by Student test at P=0.05; †P value for frequency × severity interaction effect;
‡SEM= Standard error of the mean.

In the first yr, it was recorded for the lenient treatments (H/L and LI/L) in the first cycle the lesser AMH (*P* <0.0001 and 0.0002, respectively) (Figure 9), and in the last cycle for the same treatments the greater AMH. The first grazing season ended in early April and the first inflorescences appeared by the end of that month, suggesting that AMH was increasing. Even the highest AMH was not greater than or equal to the lower stubble height. There was no cycle effect (*P*>0.005) for the severe treatments (H/S and LI/S), suggesting that even near the reproductive stage of this grass, which is in autumn (SANTOS *et al.*, 1999; BARBOSA, 2004), it was possible to control AMH, probably due to plant uprooting caused by animals at the time of grazing.

In the second year, there was a cycle effect on AMH only for the H/L treatment (P = 0.058), the highest AMH recorded in the last cycle (Figure 10). Similar to the first year, the more lenient treatments showed that as the cool/dry season approached, the apical meristem tended to rise. For the most severe treatments, the AMH did not differ across cycles.

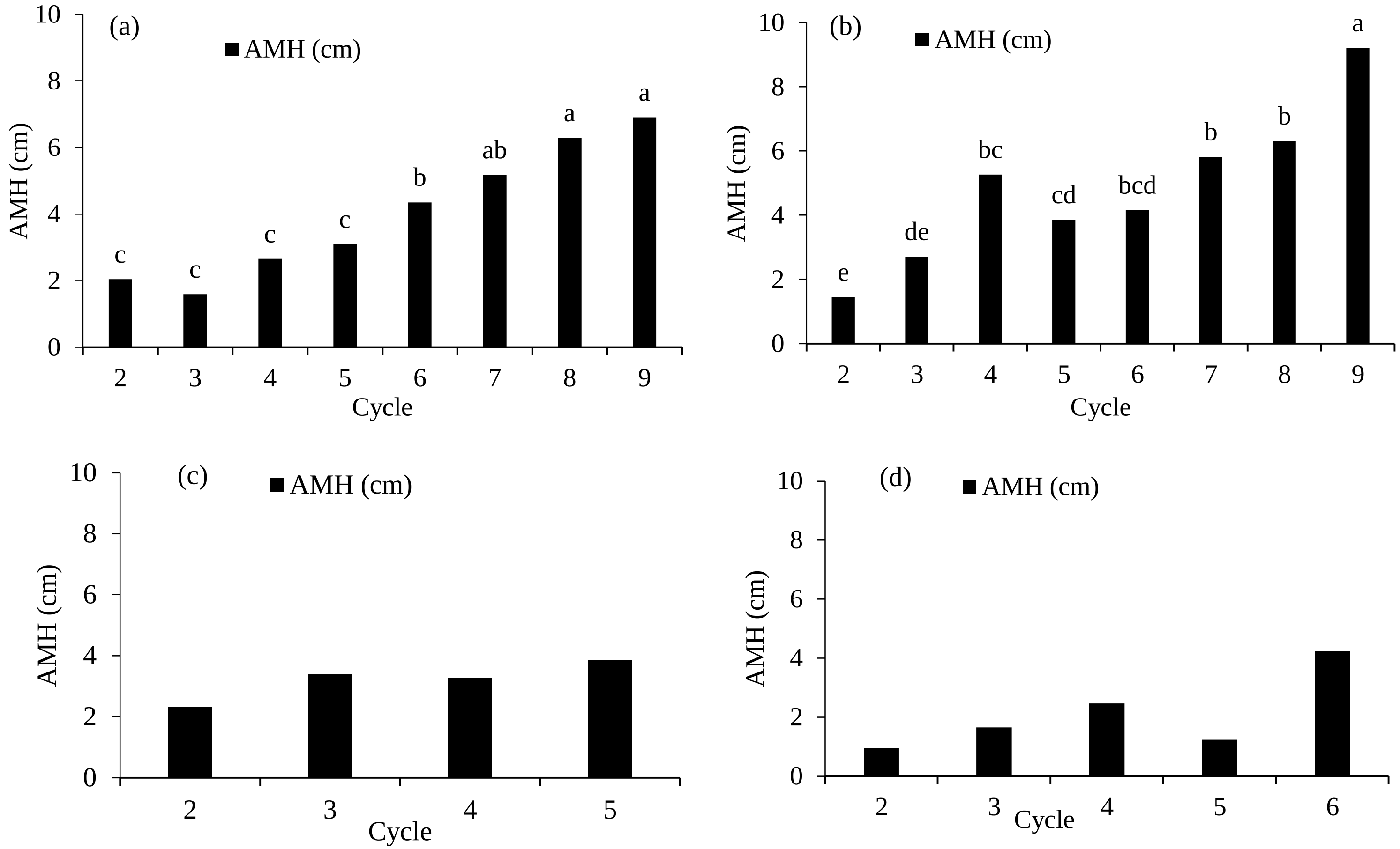

Figure 9. Apical meristem height (AMH) in Zuri guineagrass pastures managed at H/L (a), LI/L (b), H/S (c) and LI/S (d) in the first yr. Each cohort is a mean of the four field replications blocks and each block replication was recorded on a different has a specific date (Appendix), attachment. The tillers in the first yr were sampled from the second cycle. Means followed by the same letters, are not different by Student test at *P*=0.05.

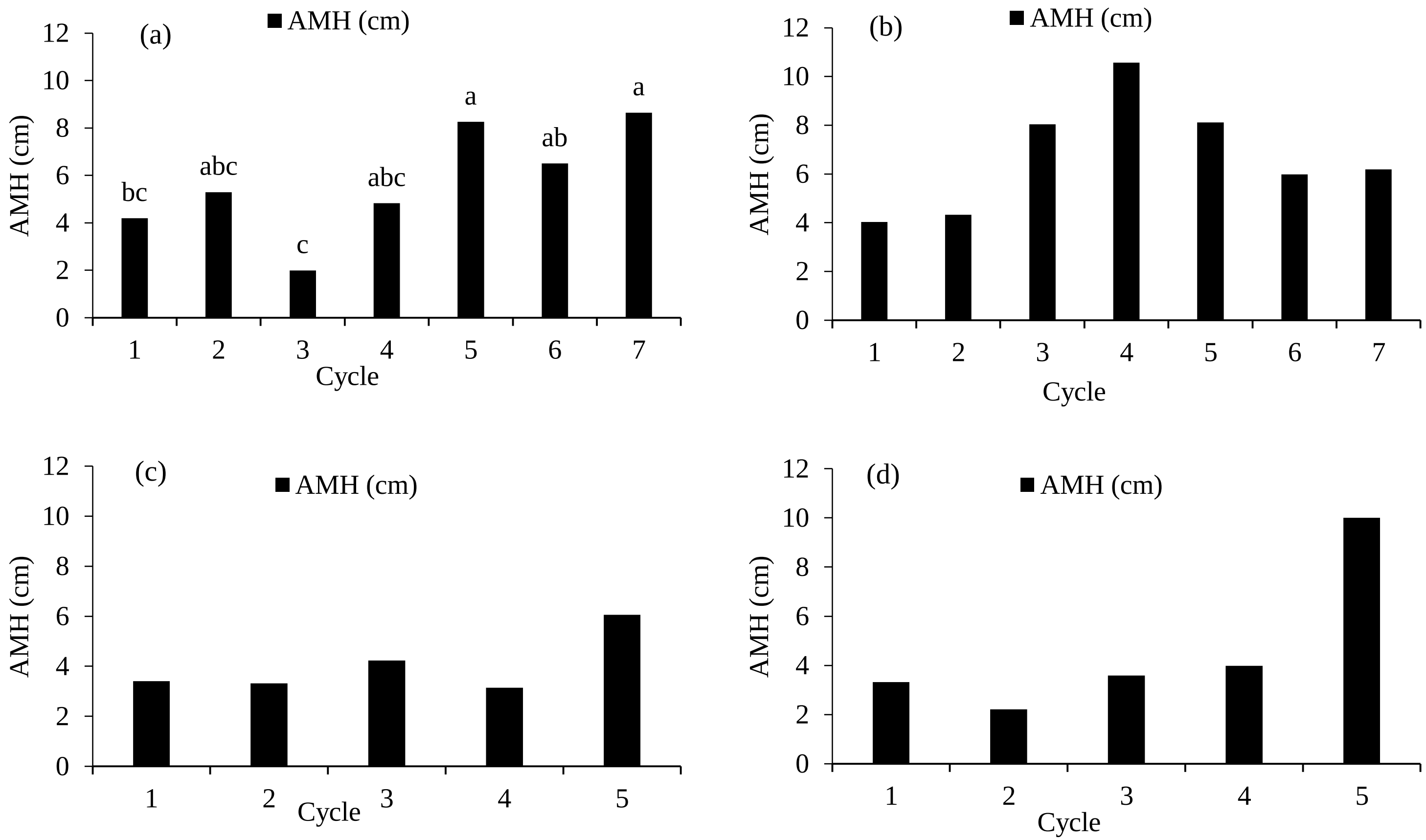

Figure 10. Apical meristem height (AMH) in Zuri guineagrass pastures managed at H/L (a), LI/L (b), H/S (c) and LI/S (d) in the second yr. Each cohort is a mean of the four field replications blocks and each block replication was recorded on a different has a specific date (Appendix), attachment. Means followed by the same letters, are not different by Student test at *P*=0.05.

The TSR and TAR were used to describe survival diagram (Figures 11 and 12). Values equal or above 1 (stability line) indicate that the population was stable. In the first year, there was a greater population instability for the LI/S treatment (Figure 11-d), with all values below 1, these values were responsible for the difference found in SI (Table 3). In the first year, the H/L and LI/L treatments resulted in greater number of stable cohorts. In year 2 a pattern for all treatments was evident, where cohort 2 was above the “stability line”, for all treatments except LI/S. Under this treatment SI fluctuated rather erratically across cohorts. The small number of cohorts studied does not allow for authoritative inferences, but in both years 1 and 2 there were variations in SI for the LI/S treatment.

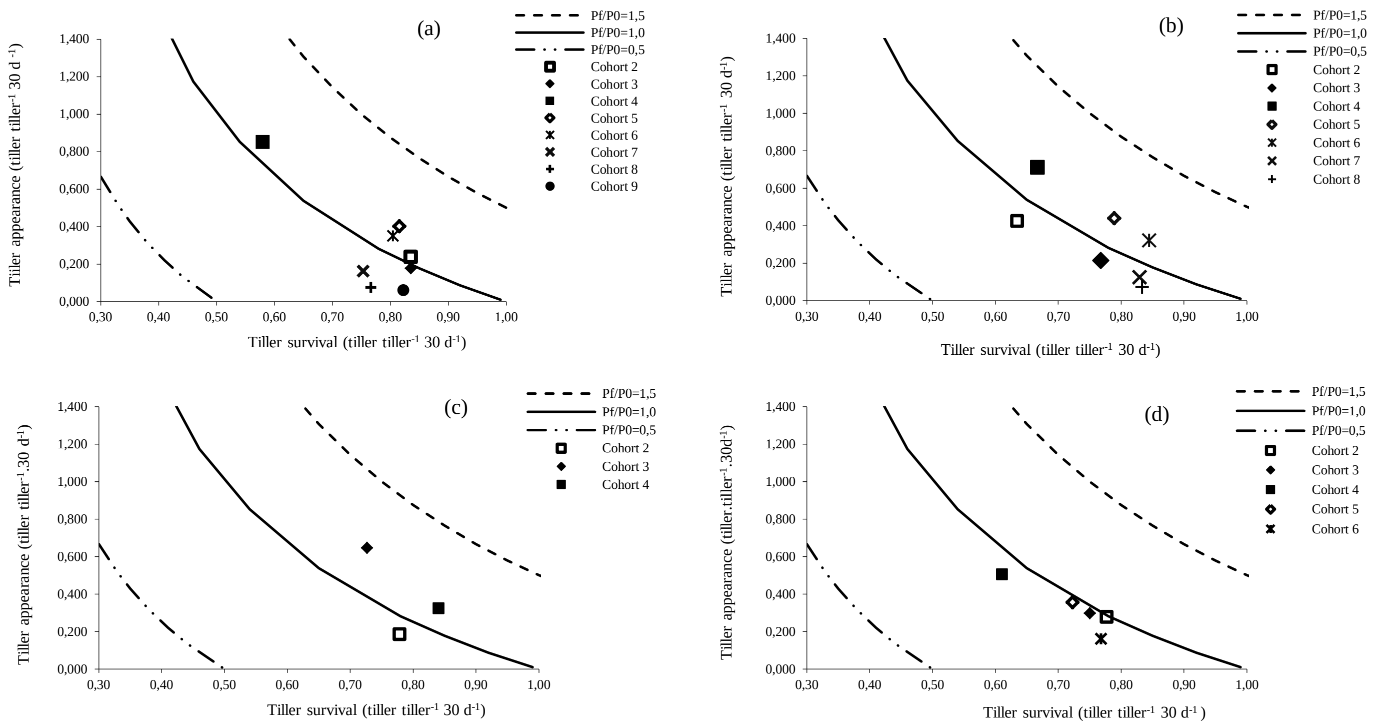

Figure 11. Survival diagram of tillering in Zuri guineagrass pastures managed at H/L (a), LI/L (b), H/S (c) and LI/S (d) in the 2016/2017 grazing season. The symbols indicate the SI (P_1/P_0) resulting from the combination of its TSR and TAR. Each cohort is a mean of the four field replications blocks and each block replication was recorded on a different has a specific date (Appendix), attachment.

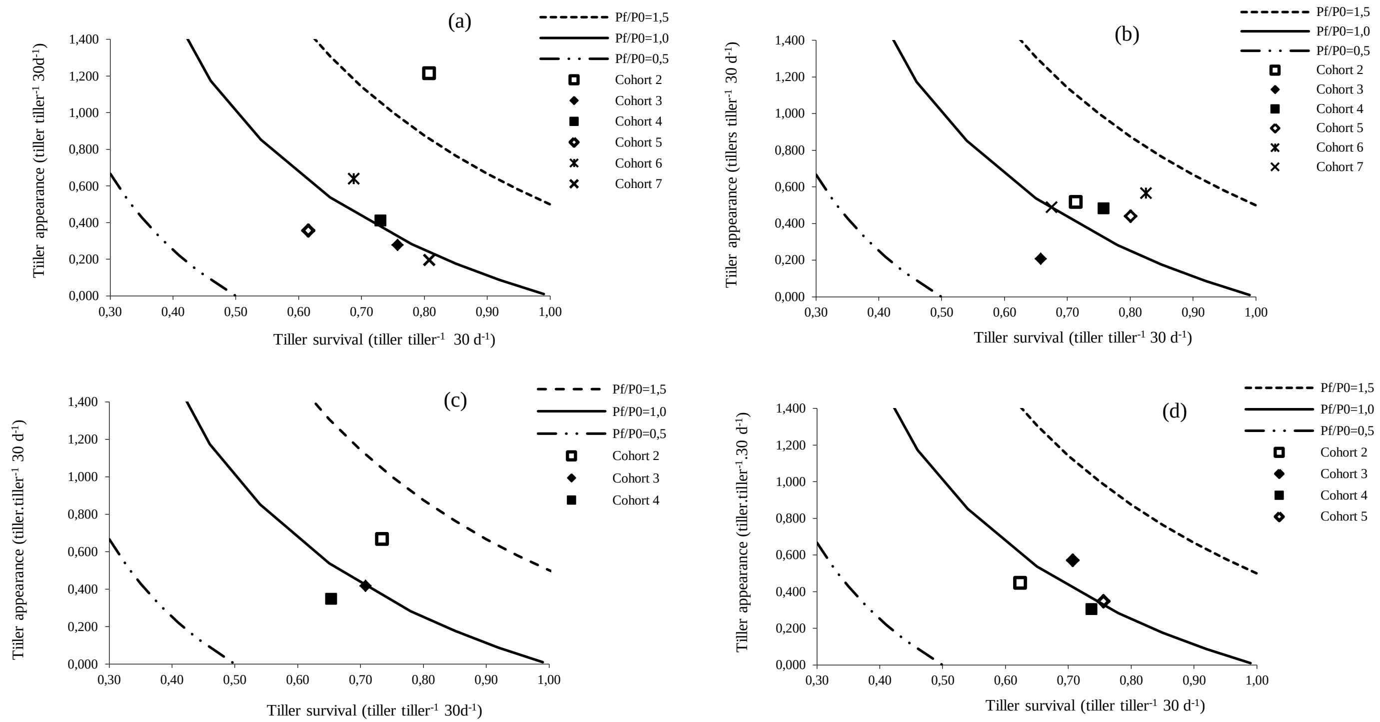

Figure 12. Survival diagram of tillering in Zuri guineagrass pastures managed at H/L (a), LI/L (b), H/S (c) and LI/S (d) in the 2017/2018 grazing season. The symbols indicate the SI (P_1/P_0) resulting from the combination of its TSR and TAR. Each cohort is a mean of the four field replications and each replication was recorded on a different date (Appendix), attachment.

2.3.3 Tillering dynamics and tiller half-life

Tillering dynamics was studied by plotting the relative contribution of each cohort over time (Figures 13 and 14). Because we used a rest-graze stocking method (as opposed to continuous stocking) and the rest period was based on canopy attributes (as opposed to a fixed time interval) the intervals between samplings were variable. For comparison purposes, the tillering dynamics and half-life responses values were all adjusted for a standard 30-d interval.

In the Year 1, due to more favorable weather conditions (Table 1), there were more cohorts (more grazing cycles) and a greater number of tillers per tussock. The tiller populations remained stable, with only slight decreases as the cohorts progressed. It was only under the LI/S treatment that a steep decline in tiller number was observed. Under the H/L treatment, there was a decrease after cohort 8, which can also be seen in the survival diagram (Figure 11-a), where after cohort 7 the tiller number is below the “stability line”. Also, in the first year, once the S treatment had a greater reduction in height, and the handling of the tussock allowed input of light, thus, contributed to the instability in the treatment LI/S (Figure 11-d) once the pastures were in adaptation conditions, the population of the plants were changing continuously.

In Year 2, the tiller number per tussock declined, resulting in a reduction in TPD. There were more tillers per tussock in the more lenient treatments, because in those, there was a greater number of cohorts, and greater manipulation of the tussocks, and likely more light reaching the base of the canopy and stimulating basal tillering.

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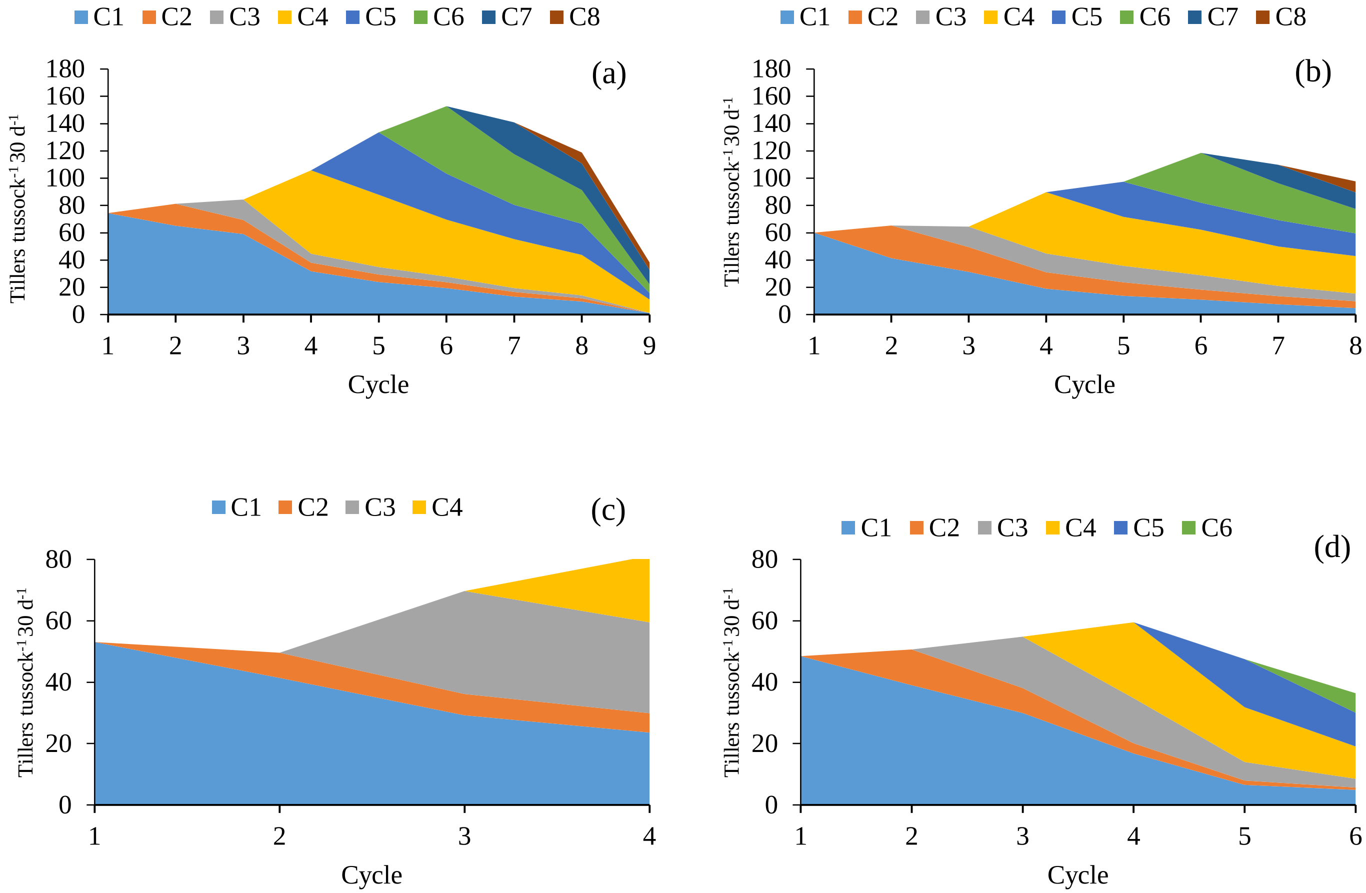

Figure 13. Tillering demographic patterns in Zuri guineagrass pastures managed at H/L (a), LI/L (b), H/S (c) and LI/S (d) in the 2016/2017 grazing season. Different fill patterns represent the tillers tussock^{-1} 30 d^{-1} from each of the tiller cohort (C) (starting with C1). Each cycle is a mean of the four blocks and each block has a specific date, attachment at the appendix.

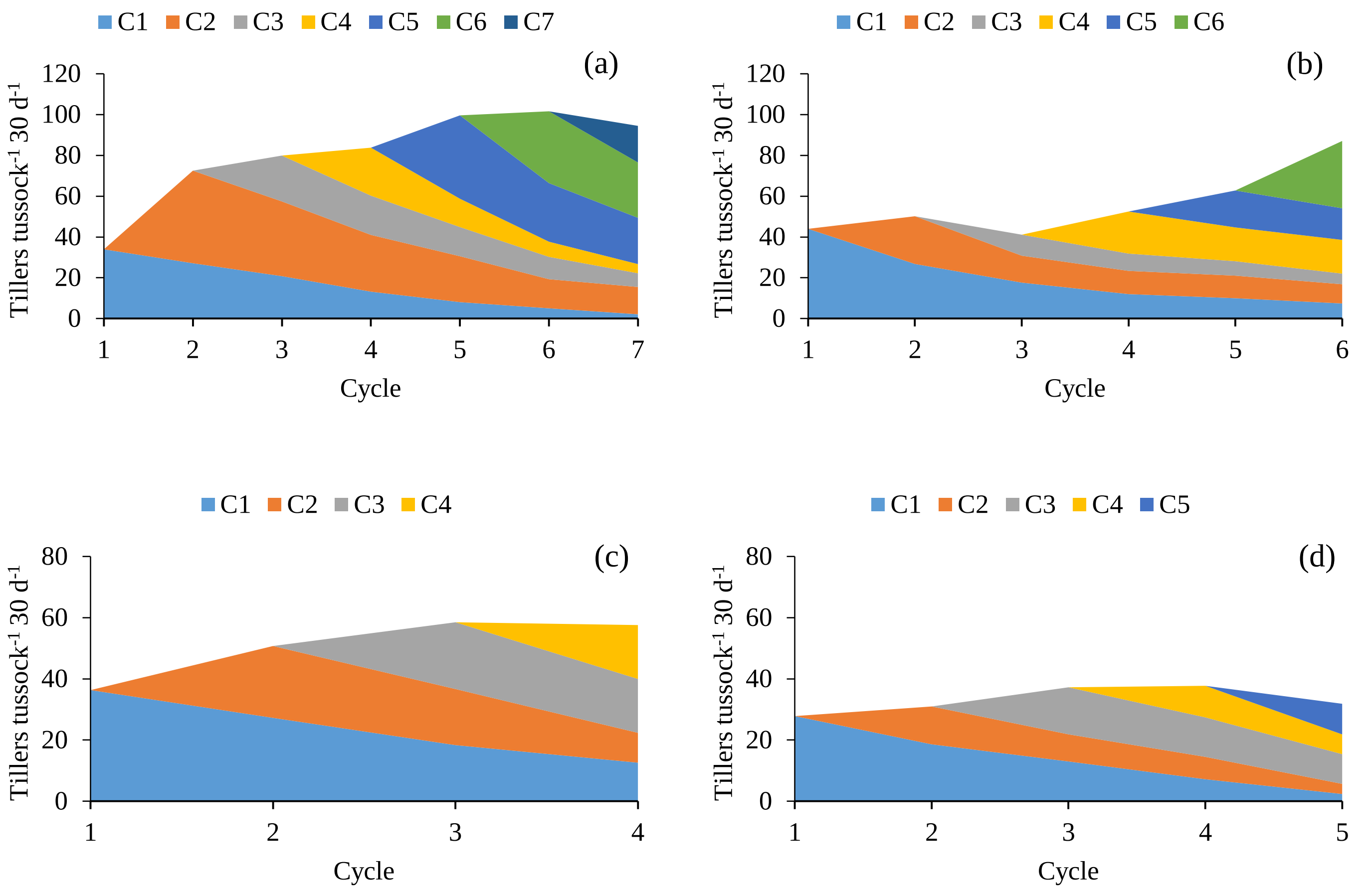

Figure 14. Tillering demographic patterns in Zuri guineagrass pastures managed at H/L (a), LI/L (b), H/S (c) and LI/S (d) in the 2017/2018 grazing season. Different fill patterns represent the tillers tussock^{-1} 30 d^{-1} from each of the tiller cohort (C) (starting with C1). Each cohort is a mean of the four field replications and each replication was recorded on a different date (Appendix)

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From the tillering dynamics data, the tiller half-life was calculated. Half-life of is the time in which half of a tiller population (cohort) dies, which under the influence of both a genetic and a management component. Cohorts with a long half-life, will have longer tiller survival and are associated with plant species/cultivars that are conservative in the use of resources. Cohorts with a short half-life are those that display intense tiller renewal in the stand in a short period, with great tiller mortality. In this case, the stability is mainly a consequence of the rate of tiller appearance, implying in a great extraction of soil nutrients and use of water, and typically more demanding in terms of management (DUCHINI *et. al*, 2018*)*.

In Year 1, the treatments H/L, LI/S and LI/L resulted in tiller half-life of 75, 24 and 31 days, respectively. It was not possible to calculate tiller half-life for the H/S treatment, because there were not enough cohorts. In Year 2, the H/L, H/S and LI/S treatments resulted in 41-, 50- and 50-d, respectively, it was not possible to calculate the half-life data for the LI / L treatment. According to Cruz *et al.,* (2002), plants can “exploit resources” or “conserve resources”. Duchini *et al.,* (2018) studied false oatgrass (*Arrhenatherum elatus* L.) and classified it as an exploratory species with an average tiller half-life of 41 days. From the data obtained, and characteristics exposed by Cruz *et al*. (2002), Zuri guineagrass fits into the category of exploratory species.

Studying bahiagrass pastures, Hirata & Pakiding (2001), reported that the tiller population density remained stable because tillers are long-lived despite low TAR. Tillers formed in the autumn survived longer (half-life = 737 days), and tillers formed in the seasons survived between 403 and 559 days. Duchini *et al* (2018) reported an average half-life of 231 days for tall fescue [(*Festuca arrundinacea* Schreb. syn *Lolium arundinaceum* (Schreb.) Darbysh)], and 121 days for orchardgrass (*Dactylis glomerata* L.), and considered both as conservative species (slow-growing). The authors also reported an average half-life of 41 days for false oatgrass, and classfied it as an exploitative species (fast-growing).

Korte (1986), reported no differences in tiller half-life between frequent and infrequent mowing for perennial ryegrass (*Lollium perenne* L.) canopies, indicating that regardless of the defoliation management, ryegrass shows the same growth pattern. These studies with cool-season plants suggest that their persistence is based on tillering and is little affected by defoliation regime or by environment. Species plants that have their survival-based tillering stability strategy are taken as conservative species.

Summary and Conclusions

Zuri guineagrass TPD was not affected by the grazing treatments imposed in this study, with 460 and 350 tillers m^{-2}, for Years 1 and 2, respectively. The AMH was below the lowest stubble height, in both years. In this case, the TMR was more due to uprooting and trampling. During the summer rainy season, Zuri was able to maintain the stability of the tillers population under management strategies studied. Even under the more severe grazing treatment (57% severity) appeared no to hinder Zuri guineagrass persistence as measured by tillering dynamics, although more severe grazing and longer-term studies are needed to ascertain this. Regardless of the frequency and severity used, the grass showed up that has adjusted to maintain a stable tillering and the half-life means renewal of the population constantly, due to this, it requires nutrient replacement frequently.

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3 HERBAGE ACCUMULATION AND, PLANT-PART COMPOSITION OF ZURI GUINEAGRASS IN RESPONSE TO DEFOLIATION FREQUENCY AND SEVERITY UNDER ROTATIONAL STOCKING

Abstract

Grazing management for optimal pasture and animal productivity under rotational stocking should be based on characteristics of the forage canopy, as opposed to fixed rest periods. The objectives of this research were to describe and explain the structural and morphological characteristics of Zuri guineagrass [*Megathyrsus maximus* – (Jacq.) B.K. Simon & S. W. L Jacobs (syn. *Panicum maximum* Jacq.) cv. BRS Zuri] pastures under two grazing frequencies, and two grazing severities based on canopy characteristics during two summer rainy seasons in Piracicaba, Brazil. The experimental design was a randomized complete block, with treatments in a 2 x 2 factorial arrangement, corresponding to two frequencies (grazing when the grass canopy reached 95% light interception, 95% LI, or when canopy height reached 70 cm) and two severities (29 and 57% reduction in canopy height for terminating grazing). In both years the number of grazing events and the length of the rest period were affected by severity (P<0.0001), the greatest severity resulting in fewer grazing cycles and longer rest periods. The pre-graze canopy height (PREht) was affected by the frequency × severity interaction (P<0.0001) in the first year and the canopy height that corresponded to 95% LI was ~77 cm. In the second year PREht was affected only by the frequency, and the height at 95% LI 95 was ~77 cm. The post-graze canopy height (POSht) was affected by grazing severity in both years, and the shorter POSht was at the greater severity. The pre-graze herbage mass (PRHM) was affected by both frequency and severity (P<0.05) in the first year, the greater values recorded for the 95% LI frequency and the 29% severity. There were no treatment effects on herbage accumulation (HA) in the first year, in part due to the shorter adaptation period. In the second year the PRHM was affected only by grazing severity (P=0.0001), with greatest value for the 57% severity. In the second year HA was affected by grazing severity (P=0.0006), the greatest value measured for the 29% severity, due to the greater number of grazing events. In the first year there were no treatment effects on pre-graze plant-part composition (leaf, stem and dead material) (P>0.005). In the second year there was a grazing severity effect on the pre-graze leaf and dead material proportions (P<0.005). The pre-graze canopy height recommended for Zuri guineagrass is around 77 cm, and the post-graze can be both severities, depending on the specific objectives of the producer.

Keywords: Grazing management, Structural characteristics, Stubble height, *Megathyrsus maximus*, Grazing intensity, Guineagrass

3.1 Introduction

Guineagrass has been widely used in livestock operations in Brazil (MARCOS, *et al.*, 2015). 'Tanzania', is an important cultivar, ranked second guineagrass in pasture area in 2008, just behind Mombaça (JANK, *et al.*, 2008). It is a highly productive grass often accumulating ~15-20 Mg DM ha^{-1} yr^{-1}, when under adequate management guidelines (BARBOSA, *et al.*, 2007). In 2003 leaf spot, a disease caused by the fungus *Bipolaris maydis* (Nisik and Miyake) was reported to attack Tanzania guineagrass (MUIR & JANK, 2004) raising concerns among producers and starting a decline in Tanzania areas.

Considering the decline in the pasture area of Tanzania, in 2014, 'Zuri' guineagrass was released by Embrapa (Empresa Brasileira de Pesquisa Agropecuária) in Brazil, as a new option for pastures. Zuri was selected based on productivity, vigor, carrying capacity, animal performance, resistance to the spittlebugs [*Mahanarva fimbriolata* (Stål) and *M. liturata* (Le Peletier de Saint-Fargeau & Serville)] and mainly to the brown leaf spot. It is a recommended cultivar for medium to high fertility soils and should preferably be managed under rotational stocking (BRASIL, 2014).

Despite the Embrapa recommendation for the management of this grass (pre-graze canopy height ranging from 70 to 75 cm and a 30- 35 cm post-graze stubble), there are no published scientific studies with detailed, long-term evaluation of Zuri under grazing. Guineagrasses are often characterized by vigorous stem elongation even during the vegetative stage (SANTOS *et al.,* 2006; CARNEVALLI *et al.,* 2006; BARBOSA, *et al.,* 2007) and this this has been documented when plants are not managed to control structural and morphological characteristics of the canopy. This may result in greater forage production (VICENTE-CHANDLER & FIGARELLA, 1959), but with lesser forage nutritive value (MORENZ, *et al.,* 2017).

Studies based on structural characteristics of forage grasses are important sources of support for grazing management recommendations. Approaches using "calendar-based" (fixed) rest periods (PEDREIRA *et al*., 2007, 2017*;* PEQUENO *et al.,* 2015; SILVA *et al.,* 2015) is the most common and practical approach for producers. Research, however, has proven that the use of this technique may not optimize many processes and forage characteristics, mainly for species with vigorous stem elongation, resulting in varying forage characteristics through the course of the grazing season (SANTOS *et al.,* 2006; PEDREIRA *et al.,* 2017; PEDREIRA *et al.,* 2018).

The use of canopy light interception (LI) has been proposed to control stem elongation and for making better use of the accumulated herbage allowing it to be harvested with the same structural condition. It has been proposed that canopy LI and canopy height are well enough correlated to allow for this technique to be easily employed by producers (PEDREIRA *et al.,* 2017).

In study with perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.), under rotational stocking, Brougham (1956) reported the relationship between herbage production and canopy light interception. He noted that during the regrowth cycle, herbage accumulation rate was initially slow, subsequently accelerating, and finally decreasing as the pasture approached what is known as the accumulation rate equal to zero. The duration of the initial period in which forage accumulation is slow is longer the greater the severity of defoliation (the greater the removal of leaf area during grazing) (HODGSON, 1966). Thus, increases in the average accumulation rate of the cycle could be achieved with more lenient defoliation and the maintenance of a greater residual leaf area index (BROUGHAM, 1956, 1958). In addition to forage pre-graze goals, it is also important to establish post-graze goals. The use of severity as an initial percentage of pre-grazing height has been studied (FONSECA *et al.,* 2013; MEZZALIRA, *et al.,* 2014; CONGIO, *et al.,* 2018) to aid harvest maximization and monitoring of grazing management.

Identifying optimal canopy heights for different forages may help optimize grazing management, contributing to the development of efficient and sustainable grazing systems. The objective of this study was to describe and explain the canopy structural and morphological characteristics, and, recommend an ideal grazing management reasoned in height, based in characteristics such as herbage mass and herbage plant-part composition, canopy height, leaf area index, light interception, leaf angles of Zuri guineagrass pastures, under combinations between two grazing frequencies and two severities, in order to identify best grazing recommendations.

3.2 Material and Methods

3.2.1 Site description

The study was carried out in Piracicaba, São Paulo, Brazil (22º42’ S, 47º37’ W, 546 m a.s.l.) at the “Luiz de Queiroz” College of Agriculture, University of São Paulo (USP/ESALQ). The climate is classified as Cwa characterized as subtropical dry winter and hot summer (KÖPPEN, 1948; ALVARES, *et al.,* 2013). The soil at the experimental site is a highly fertile Kandiudalfic Eutrudox. Average soil chemical characteristics at the time the trial was initiated were P = 26 mg dm^{-3} (ion-exchange resin extraction method); organic matter (OM) = 35 g dm^{-3}; pH (0.01 mol $L^{-1}CaCl_2$) = 5.5; K = 3.9 $mmol_c$ dm^{-3}; Ca = 41 $mmol_c$ dm^{-3}; Mg = 21 $mmol_c$ dm^{-3}; H+Al = 34 $mmol_c$ dm^{-3}; sum of bases = 65.9 $mmol_c$ dm^{-3}; base saturation = 66%. Weather for the experimental period (Table 1) were recorded at a weather station located 2 km from the experimental site.

Table 1. Monthly weather data at the experimental site during 2 yr of evaluation in Piracicaba, SP, Brazil.

Weather variable	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.
				2016/2017				
Max. temperature (ºC)	29.9	29.6	31.4	30.2	32.2	30.6	28.3	26.2
Min. temperature (ºC)	17.1	17.7	19.2	20.3	20.0	18.4	16.7	14.8
Rainfall (mm)	103.1	190.5	190.6	334.5	88.8	137.0	128.5	161.6
				2017/2018				
Max. temperature (ºC)	30.3	29.6	31.0	30.3	30.16	32.0	29.6	27.9
Min. temperature (ºC)	17.3	16.9	19.4	19.4	18.2	19.5	15.9	12.3
Rainfall (mm)	80.5	235.7	148.6	225.0	71.6	204.5	35.1	11.7
				Historic Average†				
Max. temperature (ºC)	29.2	29.7	29.8	30.0	30.0	30.0	29.0	26.0
Min. temperature (ºC)	15.9	16.8	18.4	19.1	19.0	18.0	16.0	12.0
Rainfall (mm)	109.4	133.5	199.3	229.2	180.0	142.0	66.0	56.0

†Historic average weather data from 1917 to 2018.

The area was disked, on Feb. 3, 2015. On Feb 28, 2015, the soil was leveled with a rotary hoe, followed by the sowing of Zuri guineagrass in on half of the area (Figure 1), using 4 kg ha^{-1} of pure live seed. After sowing the area was compacted. Two months after sowing, 2,4-dichlorophenoxyacetic acid (2,4-D) was applied using a backpack type sprayer at the rate of 1 kg ha^{-1} of the acid equivalent for control of weeds [Amaranth (*Amaranthus* spp. and Castor Bean (*Ricinus communis* L.)].

Figure 1. General view of the experimental area.

The other half of the experimental area was established in April 2016. The soil was disked, leveled, and sown with 8 kg ha^{-1} of pure live seeds, and lightly compacted. Due to the limited rainfall during that period, the area was irrigated. For the control of Amaranth

(*Amaranthus* spp.) and Castor Bean (*Ricinus communis* L.), 2,4-dichlorophenoxyacetic acid (2,4-D) was applied at 3 L ha^{-1} on September 2016.

In November 2017, pastures were attacked by cochineal, identified as *Pinnaspis apidistrae* (Signoret, 1869) (Homoptera, Diaspididae) (Figure 2) and controlled using 10 g of 6-Chloronicotinic acid (133 g ha^{-1}) [1-(6-chloro-3-pyridylmethyl)-N-nitroimidazolidin-2-ylideneamine] for 10 L of water (266 L ha^{-1}), plus 50 mL of mineral oil (0.6 L ha^{-1}), was applied using a backpack type sprayer.

Figure 2. Zuri guineagrass attacked by *Pinnaspis apidistrae*.

3.2.2 Treatments and experimental design

On Dec 17, 2016, the pastures were mowed to 10 cm and the adaptation to the treatments began. This consisted of applying the assigned defoliation regimes.

Each paddock received 250 kg N ha^{-1} yr^{-1} (as NH_4NO_3) and 250 kg K ha^{-1} yr^{-1} (as KCl). (Table 2).

Table 2. Quantity of N and K per fertilization and the respective date of application during the experimental period.

	Fertilization	
Date	N	K
	Year 1	
	---- *kg ha^{-1}* ----	
12/20/2016	50	0
01/10/2017	50	62.5
02/03/2017	50	62.5
02/25/2017	50	62.5
03/10/2017	50	62.5
	Year 2	
	---- *kg ha^{-1}* ----	
11/27/2017	50	50
12/16/2017	50	50
01/06/2018	50	50
01/27/2018	50	50
03/06/2018	50	50

Treatments were all factorial combinations of two grazing frequencies [grazing initiated when the grass canopy reached 95% light interception (LI), or 70 cm height (H)], with two grazing severities (removal of 29 or 57% of the initial canopy height, the latter being denominated lenient [L] and severe [S] grazing, respectively), with frequency-severity combinations being as follows:

H/L = 70 cm pre-graze height and 50 cm post-graze height (severity of 29%);

H/S= 70 cm pre-graze height and 30 cm post-graze height (severity of 57%);

LI/L= 95% LI at pre-graze with 29% canopy height reduction at post-graze;

LI/S= 95% LI at pre-graze with 57% canopy height reduction at post-graze.

The experimental design was a randomized complete block with four replications. Each of the 16 experimental units was 170 m^2 in area.

The grazing protocol was mob stocking. Dry crossbred dairy cows (*Bos taurus* L.), (~450 kg BW) were brought onto the paddocks when the average canopy target (70 cm height or 95% LI) was reached (Figure 3). Each grazing event was planned so that the defoliation lasted the shortest possible time (~20 minutes to 29% severity and, ~1 hour to 57% severity), to avoid the formation of rejection areas and excessive deposition of dung and urine during grazing. For grazing to be as uniform and as short in duration as possible, the animals grazed in strips, with each paddock divided in three strips (Figure 3).

When they were not grazing the experimental pastures, the animals remained in an adjacent pasture area, with Zuri guineagrass and Mulato II brachiariagrass [(*Brachiaria* hybrid) (*B. ruziziensis* × *B. decumbens* × *B.* brizantha)]

Data were collected in the first year (Year 1), from 6 Jan 2017 through 8 April 2017 (92 days), and in the second year (Year 2) from 29 Nov. 2017 through 19 Mar 2018 (111 days).

Figure 3. Animals in an experimental unit.

3.2.3 Monitoring canopy conditions

Light interception and canopy height were measured three times per week in each regrowth cycle (pasture rest period), starting immediately after grazing and until it was time to graze each pasture again. Canopy height was measured using a light polyethylene sheet and a graduated measuring rod at 40 sites in each pasture (Figure 4). The LI was measured using model LAI-2000 canopy analyzer (Li-Cor, Lincoln, Nebraska, USA), at 30 sites per pasture (locations where the heights represented the average canopy condition at the time of reading), and for every 6 readings at the bottom of the canopy a reference reading was taken above the canopy (Figure 5). The LI measurements were taken at times of predominance of diffuse radiation (overcast skies or low solar elevation in early morning or late afternoon) (WELLES & NORMAN, 1991). As the canopy height and LI approached the treatment target, the measurements were taken daily.

Figure 4. Measurement using a light polyethylene sheet and a graduated measuring stick ingrazed Zuri guineagrass.

Figure 5. Measurement using LAI-2000 canopy analyzer (Li-Cor, Lincoln, NE) below grazed Zuri guineagrass canopy.

3.2.4 Herbage mass and accumulation

The herbage mass (HM) were measured pre- and post-graze by clipping the vegetation with a hedge trimmer, inside two metal frames (0.7- x 1-m) in each paddock, at 10 cm from the soil surface (Figure 6). In the first year no herbage mass samples were taken in the first grazing cycle.

The herbage mass sampling sites were chosen to be representative points of the average canopy condition at the time of sampling (visual assessment). The samples collected were weighed fresh, sub-sampled in approximately 400 g and dried in a forced-draft oven for 72h at 60°C to constant weight, and weighed to determine the dry matter (DM) concentration, which was then used to estimate the dry weight of the whole sample. The same procedure was followed to estimate post-graze herbage mass. Herbage accumulation during a rest period was calculated as the difference between pre-graze HM and post-graze HM of the previous cycle. The total herbage accumulation of each year was calculated as the sum of the accumulations of all cycles of that year.

Figure 6. Clipping the Zuri guineagrass with a hedge trimmer.

3.2.5 Plant-part composition

To characterize herbage plant-part composition at pre-graze the forage inside each of the metal frames was subsampled (approximately 200 g) and the subsample separated into leaf, stem + sheath, and dead material (Figure 7-A). Each fraction was dried in a forced-draft oven for 72h at 60°C to constant weight, and weighed. Before drying the fresh leaves (from the leaf fraction) were scanned in a model LI 3100 leaf area meter (Li-Cor, Lincoln, NE) to determine the leaf area (Figure 7-B), and then dried separately oven 72h at 60°C to constant weight and weighed. The dry weight of each fraction was used to determine the relative proportion of leaf, stem and dead material in the HM. The relation of leaf area and leaf weight was used to calculate specific leaf weight and to estimate the total leaf area of the sample, which in turn was used to calculate the LAI ($cm^2\ cm^{-2}$).

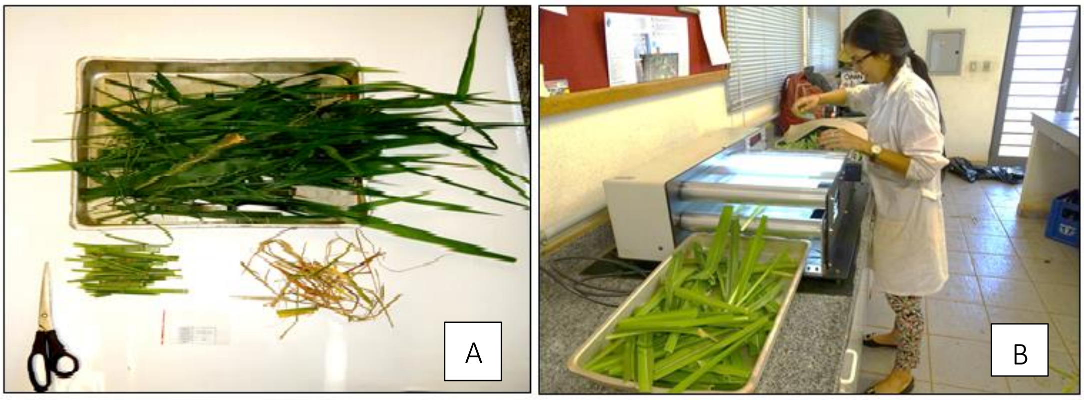

Figure 7. Plant-part composition (leaf blades, stem + sheath, and dead material) (A) and the fresh leaf scanned in a model LI 3100 leaf area meter (Li-Cor, Lincoln, NE) to determine the leaf area (B).

3.2.6 Data analysis

Data were analyzed using PROC MIXED of SAS (SAS Institute, 2013) with a model including effects of, frequency, severity, and their interaction. Block (replication) was considered as random effect (LITTEL *et al.*, 2006). Years were analyzed separately because the trial was run for two years only to broaden the inference, instead of looking for year effects. The covariance structure was chosen based on Akaike's Information Criterion (AIC) (WOLFINGER, 1993). Shapiro-Wilk test were used to check the normality of the model residuals. Treatment means were compared using probability of the difference (PDIFF) by Student test ($P < 0.05$).

3.3 Results and discussion

3.3.1 Length of rest period and number of grazing events

In the first and second year, the rest period (RP) and the number of grazing events (GE) were affected by grazing severity (P<0.0001). In both years, the longest RP was for the lenient (L) level of severity and the most GEs was for the severe (S) grazing (Table 3).

Table 3. Rest period (RP) and grazing events (GE) during two years in Zuri guineagrass subjected to two severities. (L an d S).

Variable	Severity L	Severity S	*P*†
	Year 1		
	---------------------------Number	------------------------	
GE	7	4	<0.0001
	(0.27)‡	(0.27)	
	-----------------------------days	----------------------------	
RP	11	20	<0.0001
	(0.79)	(0.90)	
	Year 2		
	---------------------------Number	------------------------	
GE	6	3	<0.0001
	(0.21)	(0.21)	
	-----------------------------days	----------------------------	
RP	15	24	<0.0001
	(0.64)	(0.98)	

(L = lenient [grazing at the 29% severity]; S = severe [grazing at the 57% severity]).
†*P* value for severity effect;
‡SEM= Standard error of the mean.

The L grazing resulted in 3 more cycles in both years, due to the shorter RP (Table 3). The increase in RP for the severity S was a consequence of the long regrowth period after grazing. On the other hand, in a similar study with Mombaça guineagrass, Carnevali *et al.*, (2006), did not find a post-graze height effect (30 and 50 cm) on the number of GEs through the year. Studying Tanzania guineagrass, Barbosa *et al.*, (2007) reported a similar response found for Zuri in the present study, when the treatments with greater severity (30 cm stubble) resulted in longer RP and fewer GEs than the lenient severity (50 cm).

Pasture recovery after defoliation is dependent on several characteristics, including climate, defoliation severity, and water availability. When the weather conditions were favorable for growth, the recovery rate was faster, reducing the rest period. The minimum and maximum length of the RP was, ~5 and ~31 days in the first year for the L and S, respectively. In the second year, the minimum and maximum RP was ~8 and ~35 days for the

L and S, respectively, showing that Zuri guineagrass has a range variation that may depend on several factors (water, nutrient replacement, temperature, radiation, etc., are some factors that can induce the response).

3.3.2 Canopy structural characteristics

In the first year, pre-graze/height (PREht) and post-graze/light interception (POLI) were affected by the frequency × severity interaction ($P<0.0001$ and $P=0.0046$ for PREht and POLI, respectively), the greatest PREht and the lesser for POLI was recorded under LI × S interaction (Table 4). The pre-graze light interception (PRLI) and pre-graze foliage angle (PRANG), were affected by the frequency ($P<0.0001$ and $P=0.0174$, for PRLI and PRANG, respectively), the greatest PRLI and lesser to the PRANG were recorded for the LI frequency (Table 5). The post-graze height (POSht) was affected only by grazing severity ($P<0.0001$) (Table 6).

In the second year PRLI was affected by grazing frequency ($P<0.0001$) and severity ($P=0.0063$). The PREht was affected by grazing frequency ($P<0.0001$), the greatest PREht recorded for the LI frequency. The POSht was affected by the grazing frequency × severity interaction ($P<0.0408$). The POLI and post-graze foliage angle (POANG) were affected only by severity ($P<0.0001$) (Table 6). There were no treatment effects on the PRANG (mean = 49º) ($P>0.05$).

In both years, stubble heights were easily achieved (Table 4 and 6). Barbosa *et al.*, (2007) and Carnevalli *et al.,* (2006) reported the failure to reach short stubbles heights when grazing commenced at 100% canopy LI for Tanzania and Mombaça guineagrass, respectively. The authors explained that the large amount of coarse stems makes it difficult for the animals to graze the canopy to short stubble. This was not seen in the current study with the 95% LI treatment.

In the first year, the pre-graze height for the LI + S treatment combination was 78 cm, and 76 cm for LI+L (Table 4). Although the difference was only 2 cm, other studies (MELLO & PEDREIRA, 2004; MONTAGNER, 2007; LEMOS, *et al.*, 2014;) reported that there may be greater differences over the years, especially when the adaptation period was insufficient. Mello & Pedreira (2004); Lemos *et al.*, (2014) reported 55 cm as the canopy height for 95% LI in Tanzania guineagrass at pre-graze, and this is different from the value reported by Barbosa *et al.* (2007) and Difante *et al.* (2009) for the same grass (70 cm). In the current experiment, it was not possible to detect this difference, even the adaptation period has been short.

Table 4. Pre and post-graze/height (cm) and post-graze/light interception (%) in Zuri guineagrass canopies subjected to two grazing frequencies (H and LI) and two grazing severities (L and S) in two years.

Severity	Frequency: H	Frequency: LI	*P*†
	Year 1		
	-------------------Pre-graze height (cm) ----------------		<0.0001
L	71 Ab	76 Ba	
	(0.21)‡	(0.26)	
S	70 Ab	78 Aa	
	(0.26)	(0.36)	
	------------------------Post-graze LI (%) ----------------		0.0046
L	89 Aa	90 Aa	
	(1.07)	(1.24)	
S	80 Ba	74 Bb	
	(1.16)	(1.35)	
	Year 2		
	-------------------Post-graze height (cm) ---------------		0.0408
L	50 Ab	54 Aa	
	(0.37)	(0.40)	
S	30 Bb	32 Ba	
	(0.46)	(0.42)	

Means followed by the same lowercase letter in rows and upper case letters in columns, within each variable, are not different by Student test at P=0.05; †P value for frequency × severity interaction;
‡SEM= Standard error of the mean.

The foliage angle indicates the orientation of the foliage and, can range from 0 to 90°. The greater values for the angle, show that leaves are in a more upright position and, lesser values in a more prostrate position. Carnevalli *et al.*, (2006) reported more upright canopies (mean (52.3º angle) in Mombaça guineagrass pastures when grazed at 95% LI at pre-graze, compared with 100% LI (45°), and explained that greater LI was associated with greater tiller weight and a more prostrate canopy. In the current study PRANG was greater for the H grazing frequency (46º), when the leaves were more upright (lower height, compared to the LI frequency) the angle was greater (Table 5). When plants (and the canopy) are taller, the leaves tend to lodge, and the angle tends to be lesser. The position of the leaves may interfere with the amount of light intercepted. The POLI was lesser in the second year when the severity level was S (Table 6). Upright leaves intercept less light compared to more horizontal leaves (PEARCE, *et al*. 1967). Grass canopies have been reported to adapt to defoliation regimes by changing their architecture and this is known as phenotypic plasticity, which is important to ensure plant presence in a given area when under adverse conditions (LEMAIRE & AGNUSDEI, 2000).

Table 5. Pre-graze canopy light interception (PRLI), foliage angle (PRANG) and height (PREht) in Zuri guineagrass canopies subjected to two frequencies (H and LI) in two years.

	Frequency		
Variable	H	LI	*P*†
	Year 1		
	------------------------------%------------------------------		
PRLI	92	96	<0.0001
	(0.21)‡	(0.21)	
	-------------------------degrees--------------------------		
PRANG	46	44	0.0174
	(0.32)	(0.36)	
	Year 2		
	------------------------------cm----------------------------		
PREht	71	77	<0.0001
	(0.40)	(0.41)	
	------------------------------%------------------------------		
PRLI	92	95	<0.0001
	(0.28)	(0.26)	

Means are different when $P<0.05$ by Student test;
†*P* value for frequency effect;
‡SEM= Standard error of the mean.

Table 6. Post-graze height (POSht), pre and post-graze/light interception (PRLI and POLI) and post-graze/angle (POANG) in Zuri guineagrass canopies subjected to two severities, in two years.

Variable	Severity		*P*†
	L	S	
	Year 1		
	----------cm----------		
POSht	49	31	<0.0001
	(0.48)	(0.54)	
	Year 2		
	----------%----------		
PRLI	93	94	0.0063
	(0.25)	(0.29)	
	----------%----------		
POLI	83	74	<0.0001
	(0.60)	(0.78)	
	----------degrees----------		
POANG	54	58	<0.0001
	(0.58)	(0.77)	

Means are different when $P<0.05$ by Student test;
†*P* value for the severity effect;
‡SEM= Standard error of the mean.

3.3.3 Herbage mass, herbage accumulation and plant-part composition

In the first year there were effects of grazing frequency and severity on pre-graze herbage mass (PRHM) (P=0.0011 and 0.0068, for frequency and severity, respectively), and these effects were greater in pastures under the LI frequency (3715 vs. 3282 kg DM ha^{-1} of PRHM) and the L severity (Table 7). Post-graze herbage mass (POHM) was affected by grazing severity, the greatest POHM record for the L severity (Table 7). In the first year there were no treatment effects on herbage accumulation (HA) (mean = 5214 kg DM ha^{-1} yr^{-1}) or daily herbage accumulation rate (HAR) (100 kg DM ha^{-1} d^{-1}.

All the variables following were affected by the severity effect, in the first year: stem accumulation rate [(SR) (P=0.0006)], leaf accumulation [(LA) (P<0.0001)], leaf mass [(LM) (P=0.0058)], stem mass [(SM) (P=0.0018)], dead material mass [(DEM) (P=0.043)], post-graze leaf proportion [(POL) (P=0.0043)], dead material proportion [(POD) (P<0.0001)] and post-graze leaf area index [(POLAI) (P<0.0001)] (Table 8). There were no treatment effects on the pre-graze leaf (PRL), dead material (PRD) and stem proportions (PRS).

In the second year, PRHM, HAR, POHM, and HA were affected only by grazing severity (P= 0.0001, 0.0158, 0.0356, and 0.0006, for the four responses, respectively). All these response variables had the greatest value recorded for the L severity (Table 7). There was a grazing severity effect on SR (P=0.0001), PRL (P=0.0253), PRD (P=0.0354), LM (P=0.0035), SM (P=0.0035) and DEM (P=0.0162), POL (P=0.0026), POD (P=0.0457) and POLAI (P<0.0001) (Table 9). There was a frequency × severity interaction, for the leaf accumulation rate (LR) and LA (P=0.0007) (Table 10).

Table 7. Pre and post-graze/herbage mass (PRHM and POHM, respectively), herbage accumulation rate (HAR) and total herbage accumulation (HA) in Zuri guineagrass canopies subjected to two grazing severities (L and S) in two years (L = lenient [grazing at the severity 29%]; S = severe [grazing at the severity 57%]).

Variable	Severity L	Severity S	*P*†
	Year 1		
	--------------------------kg DM ha^{-1} -----------------------		
PRHM	3768 (86)‡	3230 (120)	0.0011
	-------------------------kg DM ha^{-1} ------------------------		
POHM	2832 (78)	1707 (101)	<0.0001
	Year 2		
	---------------------------kg DM ha^{-1} ----------------------		
PRHM	4740 (113)	3895 (154)	0.0001
	------------------------kg DM ha^{-1}d^{-1} ---------------------		
HAR	146 (16)	81 (22)	0.0158
	--------------------------kg DM ha^{-1} -----------------------		
POHM	2766 (132)	2253 (179)	0.0356
	------------------------kg DM ha^{-1}yr^{-1} --------------------		
HA	11014 (726)	6296 (726)	0.0006

Means are different when P<0.05 by Student test;
†P value for severity;
‡SEM= Standard error of the mean.

In both years, PRHM was greater under the L severity, when the stubble height was taller, making the rest period shorter, and the stubble mass older, due to not being grazed.

Therefore, the stubble mass increased over time (Table 8 and 9). Under rotational stocking, the duration of the rest period is what determines the restoration of the LAI, having a marked impact on forage accumulation.

In the first year PRHM for the LI frequency was greater (3715 vs. 3282 kg DM ha^{-1}), and the pre-graze canopy was higher (70 cm and ~77 cm, for H and LI, respectively). In both years there was greater POHM for the L severity due to the higher stubble.

In the second year, there was no difference in PRHM between frequencies, (4132 vs. 4503 kg DM ha^{-1}, for H and LI, respectively), probably due to the pre-graze heights not being sufficiently contrasting. Conversely, Santos *et al.,* (1999) obtained herbage masses (HM) from 4733 to 7366 kg ha^{-1} for Tanzania guineagrass under three rest periods (28, 38 and 48 days), in this case, HM was greater when the frequency was less, most likely because under fixed rest periods Tanzania guineagrass accumulated more stems under long rest periods resulting in greater pre-graze HM.

In the second year the HAR was greater for the L severity as these pastures were grazed more frequently. This resulted in greater daily accumulation rate. The greater HAR was recorded for the L severity, due to the number of collections performed in the pastures more frequently. The greater quantity of remaining leaves of the highest stubble height (L) contributed to the pre-graze goal being reached faster, increasing the number of grazing events.

The pastures under the L severity were grazed more often because of the greater stubble height, which allowed a greater STAR in both growing season, since POL and POLAI were greater in both years, resulting in fast recovery to the target (Table 8 and 9). Also a greater proportion of POD for the S severity, probably because the pasture took longer to recover to the pre-graze target and accumulated dead material during this period (Table 8 and 9).

Although the pre-graze heights (70 cm and 77 cm) were different, in both years, no differences were found in pre-graze/leaf area index (PRLAI), even as to HA, probably because the difference in PREht was not contrasting enough.

Table 8. Stem accumulation rate (STAR), leaf accumulation (LA), leaf mass (LM), stem mass (SM), dead material mass (DEM), post-graze/leaf and dead material proportion (POL and POD, respectively) and post-graze/leaf area index (POLAI) in Zuri guineagrass canopies subjected to two grazing severities (L and S) in the first yr.

Variable	Severity L	Severity S	*P*†
	-------------------------kg DM $ha^{-1}d^{-1}$ --------------------		
STAR	21 (1.45)‡	11 (2.25)	0.0006
	-------------------------kg DM $ha^{-1}y^{-1}$ --------------------		
LA	647 (57)	1215 (83)	<0.0001
	-------------------------kg DM ha^{-1} -----------------------		
LM	2540 (106)	2186 (123)	0.0058
	-------------------------kg DM ha^{-1} -----------------------		
SM	789 (36)	571 (46)	0.0018
	-------------------------kg DM ha^{-1} -----------------------		
DEM	569 (36)	438 (49)	0.0463
	------------------------------%----------------------------		
POL	62 (1.79)	53 (2.34)	0.0043
	------------------------------%----------------------------		
POD	16 (0.86)	22 (1.20)	<0.0001
	--------------------------cm^2 cm^2------------------------		
POLAI	2.3 (0.12)	0.92 (0.13)	<0.0001

Means are different when *P*<0.05 by Student test;
†*P* value for the severity effect;
‡SE= Standard error of the mean.

The masses of the plant-part components (LM, SM, DEM) were greater in both years for the L severity (Table 8 and 9). A greater proportion of the canopy remained ungrazed under this severity, so a greater amount of dead material and stems accumulated in the stubble, which probably thickened and became heavier over the course of the seasons.

In the first year, the S severity had a greater LA (Table 8), because a greater proportion of leaves were removed by grazing, and more leaves accumulated than under the L severity. Also, the severity × frequency interaction, showed the greater LA for the most severe treatment, in the second year. Conversely, in the second year, the leaf accumulation rate (LR) (Table 10) was greater under the H × L interaction. The LR was greater because the proportion of the residual leaves was allowed a faster accumulation rate, due to photosynthetic residual area.

Table 9. Stem accumulation rate (STAR), pre-graze/leaf and dead proportion (PRL and PRD, respectively), leaf mass (LM), stem mass (SM), dead material mass (DEM), post-grazing/leaf and dead material proportion (POL and POD, respectively) and post-graze/leaf area index (POLAI) in Zuri guineagrass canopies subjected to two grazing severities (L and S) in the second grazing season.

Variable	Severity L	Severity S	*P*†
	-----------------------kg DM $ha^{-1}d^{-1}$ -------------------		
STAR	20	9	0.0001
	(2.08)‡	(2.73)	
	------------------------------%---------------------------		
PRL	58	63	0.0253
	(1.13)	(1.5)	
	------------------------------%---------------------------		
PRD	19	17	0.0354
	(0.82)	(1.05)	
	-----------------------kg DM ha^{-1} --------------------		
LM	2598	2332	0.035
	(72)	(91)	
	-----------------------kg DM ha^{-1} --------------------		
SM	1065	750	0.0039
	(67)	(78)	
	-----------------------kg DM ha^{-1} --------------------		
DEM	1010	739	0.0162
	(63)	(84)	
	------------------------------%---------------------------		
POL	50	44	0.0026
	(1.23)	(1.63)	
	------------------------------%---------------------------		
POD	23	27	0.0457
	(1.16)	(1.45)	
	--------------------------cm^2 cm^2------------------------		
POLAI	1.6	0.74	<0.0001
	(0.08)	(0.09)	

Means are different when P<0.05 by Student test; †P value for severity; ‡SEM = Standard error of the mean.

Table 10. Leaf accumulation rate (kg DM ha^{-1}day^{-1}) and leaf accumulation (kg DM ha^{-1}y^{-1}) in Zuri guineagrass canopies subjected to two grazing frequencies (H and LI) and two grazing severities (L and S) in the second year.

	Frequency		
Severity	H	LI	*P†*
	Leaf acc. rate		
	------------kg DM ha^{-1}day^{-1} ------------		
L	87 Aa	61 Ab	
	(5.32)	(5.58)	0.0146
S	59 Ba	60 Aa	
	(7.29)	(7.28)	
	Leaf accumulation		
	---------------kg DM ha^{-1}y^{-1} ------------		
L	1128 Aa	1042 Ba	
	(66)	(66)	0.0007
S	1367 Ab	1877 Aa	
	(98)	(82)	

Means followed by the same lowercase letter in rows and upper case letters in columns, within each variable, are not different by Student test at P=0.05; †P value for frequency × severity interaction;
‡SEM= Standard error of the mean.

Summary and conclusions

Managing the canopy under the light interception criterion (95% LI) resulted in similar values (76, 77 and 78 cm), maintaining the pre-grazing height around ~ 77 cm, close to the pre-graze height recommendation for Zuri guineagrass. The more severe grazing resulted in greater leaf mass in both years, suggesting this level of severity may be advantageous for leaf accumulation. The proximity of values for plant-part-composition for all treatments and years suggests that the use of more severe defoliation may be a beneficial option. Under rotational stocking Zuri guineagrass should be manage around ~77-cm for the pre-grazing and ~33-cm for the post-grazing canopy height.

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Appendix

Dates when pre-grazing targets were reached and measurements taken in each treatment:

	70 cm/29% of severity			
	Measurements dates			
	Year 1			
Cohort/Cycle	Block I	Block II	Block III	Block IV
C1	01/15/17	01/15/17	01/14/17	01/15/17
C2	01/23/17	01/21/17	01/21/17	01/22/17
C3	01/01/17	01/01/17	01/31/17	01/30/17
C4	02/09/17	02/09/17	02/09/17	02/06/17
C5	03/01/17	02/20/17	02/21/17	02/22/17
C6	03/08/17	03/06/17	03/04/17	03/02/17
C7	03/16/17	03/13/17	03/13/17	03/08/17
C8	03/29/17	03/18/17	03/20/17	03/17/17
C9	-	03/30/17	-	03/29/17
	Year 2			
C1	12/14/17	11/29/17	12/12/17	12/12/17
C2	12/29/17	12/14/17	12/26/17	12/26/17
C3	01/08/18	01/02/18	01/05/18	01/08/18
C4	01/21/18	01/09/18	01/20/18	01/20/18
C5	02/01/18	01/20/18	02/01/18	02/01/18
C6	02/19/18	02/01/18	02/15/18	02/16/18
C7	-	02/19/18	03/03/18	03/12/18

	LI 95%/ 29% of severity			
	Measurements dates			
	Year 1			
Cohort/Cycle	Block I	Block II	Block III	Block IV
C1	01/06/17	01/13/17	01/07/17	01/05/17
C2	01/17/17	01/28/17	01/13/17	01/13/17
C3	01/27/17	02/03/17	01/27/17	01/25/17
C4	02/10/17	02/14/17	02/07/17	02/07/17
C5	02/20/17	02/27/17	02/21/17	02/16/17
C6	03/06/17	03/06/17	03/03/17	03/04/17
C7	03/13/17	03/15/17	03/13/17	03/13/17
C8	03/20/17	03/21/17	03/17/17	03/16/17
C9				04/08/17
	Year 2			
C1	12/27/17	11/29/17	12/15/17	12/15/17
C2	01/15/18	12/27/17	12/29/17	12/29/17
C3	01/25/18	01/15/18	01/08/18	01/12/18
C4	02/07/18	01/25/18	01/16/18	01/29/18
C5	03/06/18	02/07/18	02/01/18	02/22/18
C6	03/15/18	03/01/18	02/22/18	03/12/18
C7	-	03/15/18	03/12/18	-

	70 cm/ 57% of severity			
	Measurements dates			
	Year 1			
Cohort/Cycle	Block I	Block II	Block III	Block IV
C1	01/16/16	01/15/17	01/13/17	01/11/17
C2	01/28/17	01/27/17	01/31/17	01/29/17
C3	02/14/17	02/10/17	03/02/17	02/22/17
C4	03/06/17	03/01/17	03/16/17	03/09/17
C5	03/22/17	03/13/17	-	03/30/17
	Year 2			
	12/26/17	12/20/17	12/20/17	12/20/17
C1	01/15/18	01/08/18	01/10/18	01/10/18
C2	02/05/18	01/24/18	02/05/18	02/01/18
C3	03/12/18	02/15/18	03/06/18	02/26/18
C4		03/12/18		

	LI 95%/ 57% of severity			
	Measurements dates			
	Year 1			
Cohort/Cycle	Block I	Block II	Block III	Block IV
C1	01/11/17	01/13/17	01/05/17	01/05/17
C2	02/03/17	02/03/17	01/13/17	01/13/17
C3	03/02/17	03/02/17	02/03/17	01/27/17
C4	03/17/17	03/15/17	02/17/17	02/16/17
C5	-	-	03/13/17	03/08/17
C6	-	-	-	04/08/17
	Year 2			
C1	01/02/18	12/27/17	12/14/17	12/27/17
C2	01/24/18	01/16/18	01/05/18	01/21/18
C3	02/20/18	02/06/18	01/24/18	02/15/18
C4	03/15/18	03/12/18	02/20/18	03/15/18
C5			03/15/18	