**PAOLA PALAURO SPASIANI**

# SPATIO-TEMPORAL VARIABILITY OF PALISADEGRASS-FORAGE PEANUT PASTURE STRUCTURE UNDER CONTINUOUS STOCKING

**LAVRAS – MG**
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Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós Graduação em Zootecnia, área de concentração em Produção e Nutrição de Ruminantes, para obtenção do título de Doutora em Zootecnia

Prof. Dr. Daniel Rume Casagrande
Orientador

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**VARIABILIDADE ESPAÇO-TEMPORAL DA ESTRUTURA EM PASTO DE BRACHIARIA COM AMENDOIM FORRAGEIRO SOB LOTAÇÃO CONTÍNUA**

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**2020**

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*Aos meus pais, Paulo e Rosa, pelo amor incondicional*

*Dedico*

# AGRADECIMENTOS

*O que sabemos é uma gota; o que ignoramos é um oceano. Mas o que seria o oceano se não infinitas gotas?*

Isaac Newton

# RESUMO INTERATIVO E RESUMO GRÁFICO

A introdução de forrageiras leguminosas em pastagens tem se mostrado uma opção promissora para acrescentar N no sistema e aumentar a produção de carne por unidade de área, diminuindo prejuízos ao meio ambiente. Porém, um grande desafio dessas pastagens mistas é a compatibilidade entre as espécies de plantas, que determina a persistência da mistura. Uma das preocupações se refere ao manejo do pastejo adequado e à presença do animal, que tem a oportunidade de escolher o que ingerir, o que pode afetar a competição entre a gramínea e a leguminosa. Um dos pontos em destaque é a escolha das espécies de forma que estas tenham mecanismos de crescimento semelhantes, para que a competição seja justa. Outra questão é a heterogeneidade que existe numa área de pastagem mista que é manejada sob lotação contínua. Os padrões de deslocamento e escolha dos animais tanto para busca de alimento quanto locais de descanso, pode impactar no desenvolvimento das plantas, favorecendo ou prejudicando uma em relação a outra. Esse trabalho abordou como a presença do animal pode influenciar a altura das plantas, que irá afetar a quantidade e qualidade de luz disponível para ambas leguminosa e gramínea, fazendo com que estas desenvolvam formas de se adaptar à condições adversas e também como suas estruturas mudam quando não há limitação do recurso luminoso, resultando em aumento ou diminuição na proporção da leguminosa no sistema. Usando a geoestatística, uma ferramenta que auxilia estudar a variação de fenômenos no espaço, nós verificamos como a estrutura das plantas muda ao longo do espaço e do tempo. As forrageiras utilizadas foram o capim Marandu e o amendoim forrageiro. Estas plantas podem se desenvolver de forma clonal, ou seja, sem que dependam da produção de sementes para se propagarem, assim havendo maiores chances de compatibilidade. Utilizamos nesse estudo novilhas da raça Nelore, manejadas sob lotação contínua. A meta de manejo foi manter o pasto na época das chuvas com altura média de 20 a 25 cm. Nós observamos que a estrutura do pasto é heterogênea ao longo do espaço e também se modifica ao longo das estações por causa das variações na condição climática. Mas, embora haja essa variabilidade, o pasto tendeu a se homogeneizar ao longo do tempo, conferindo estabilidade à população de plantas. Nós constatamos que, mesmo mediante a presença dos animais, onde o pasto era mais alto, o amendoim forrageiro teve seu desenvolvimento limitado pela quantidade insuficiente de luz que o alcançava, Por outro lado, nas regiões onde o pasto era mais baixo, havia grande proporção de leguminosa e pequena quantidade de capim, mostrando que quando não há limitação luminosa, o amendoim forrageiro é beneficiado. Com a meta te manter o pasto entre 20 e 25 cm nas chuvas, nós conseguimos manter a proporção adequada de leguminosa da mistura ao longo do tempo, o que aponta para um dossel estável.



Pasto misto sob lotação contínua

Heterogeneidade

Pasto + baixo

+ amendoim forrageiro

Altura (cm)
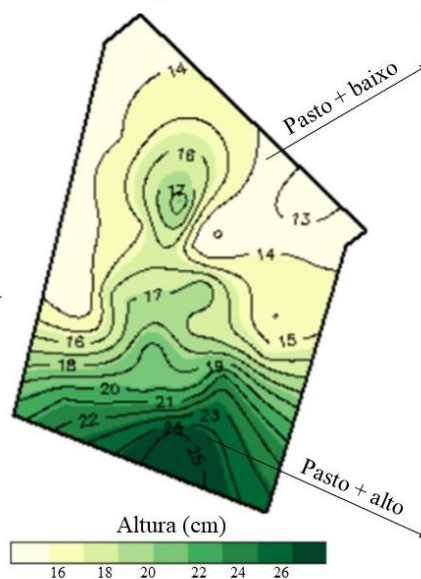
Pasto + alto

+ capim Marandu

# RESUMO GERAL

O uso de pastos mistos de gramíneas e leguminosas tem sido uma alternativa promissora, permitindo a entrada de nitrogênio através da fixação biológica. O capim Marandu (*Brachiaria brizantha* [syn. *Uruchloa brizantha*] cv. Marandu [Hochst. ex A. Rich.] Stapf), gramínea hábito de crescimento ereto e mecanismo de propagação clonal, e o amendoim forrageiro (*Arachis pintoi* Krapov. & W.C. Greg.), leguminosa estolonífera, também com o mesmo mecanismo de propagação, são opções de genótipos com potencial para serem compatíveis em misturas. As descrições da estrutura do dossel em pastagens mistas são essenciais para entender os processos de desenvolvimento e competição entre plantas. Assim, o estudo da ecologia em pastagens mistas pode ancorar estratégias favoráveis à estabilidade do dossel. O estudo objetivou avaliar a variabilidade espacial das características estruturais e morfogênicas e a ecologia das plantas em dossel misto de capim Marandu com amendoim forrageiro submetido à herbivoria por bovinos de corte sob lotação contínua. A pastagem (1 ha) foi manejada para manter a altura média do dossel entre 20 - 25 cm durante a estação chuvosa. Foram utilizadas novilhas Nelore com $214 \pm 17$ kg de peso corporal e $11 \pm 3$ meses de idade. Uma grade amostral foi permanentemente estabelecida na área com 50 pontos georreferenciados, em torno dos quais as avaliações foram realizadas. Foram avaliadas a estrutura do dossel (alturas média e máxima do dossel e da leguminosa, biomassa, densidades populacionais de perfilhos e estolões, zona de sombra, interceptação luminosa [IL], índice de área foliar [IAF] e composição botânica), bem como a morfogênese (taxas de aparecimento, alongamento e senescência das folhas, e taxas de alongamento de colmo e estolão) e estrutura morfológica (comprimentos de folha e colmo [gramínea], área foliar e comprimentos de pecíolo, entrenó e estolão [leguminosa]). A interpolação dos dados amostrados, separadamente em cada estação, foi realizada por krigagem ordinária. Os coeficientes de correlação de Pearson entre a altura do dossel e as demais variáveis foram calculados. Foi observada dependência espacial em todas as variáveis. No entanto, para algumas variáveis, não foi detectada autocorrelação espacial durante algumas estações. O modelo esférico foi o que melhor explicou o comportamento dos semivariogramas. Variações na altura do dossel influenciaram as características estruturais e morfogênicas, em que a competição pela luz causou estiolamento da leguminosa (maiores comprimentos de pecíolo, entrenó e estolão) em regiões com maior altura do dossel. O amendoim forrageiro mudou sua direção de crescimento quando submetido a maior sombreamento, desenvolvendo-se perpendicularmente ao solo. A densidade de perfilhos da gramínea respondeu positiva e linearmente às variações da altura do dossel. Em regiões de menor altura do dossel, a leguminosa proliferou próximo à superfície do solo, aumentando sua densidade de estolão e biomassa, mesmo nas regiões extremamente baixas. Apesar dessas variações, a estrutura do dossel tendeu a se homogeneizar ao longo do tempo. Os resultados apontam que a comunidade de plantas é afetada pelas variações da altura do dossel no espaço. Dosséis mais altos causam competição por luz entre as plantas. Nessas condições, a gramínea foi favorecida, diferentemente da leguminosa, que teve sua proporção reduzida. Já em locais de dossel mais baixo, a leguminosa é beneficiada, sendo estimulada a se desenvolver mais efetivamente por propagação clonal.

**Palavras chave**: Pasto misto. Leguminosa estolonífera. Forragens tropicais. Ecologia de pastagem.

# GENERAL ABSTRACT

The use of grass-legume mixed pastures has been a promising alternative, allowing nitrogen input through biological fixation. Palisadegrass (*Brachiaria brizantha* [syn. *Uruchloa brizantha*] cv. Marandu [Hochst. ex A. Rich.] Stapf), a forage with an erect growth habit and clonal propagation mechanism, and forage peanut (*Arachis pintoi* Krapov. & W.C. Greg.), a stoloniferous legume, also with the same propagation mechanism, are genotypes alternatives with potential to be compatible in mixtures. Canopy structure descriptions in mixed pastures are essential to understand the development and competition processes between plants. Thus, ecology studies in grass-legume mixed pastures can anchor strategies in favour of canopy stability. The objective of this study was to evaluate the spatial variability of structural and morphogenic characteristics and plant ecology in a palisadegrass-forage peanut mixed canopy submitted to herbivory by beef cattle under continuous stocking. The experimental area (1 ha) was managed to maintain the canopy average height between 20 - 25 cm during the rainy season. Nellore heifers weighing $214 \pm 17$ kg BW and $11 \pm 3$ months in age were used for stocking. A permanent sample grid was established in the area with 50 georeferenced points, around which the assessments were performed. Canopy structure (average and maximum canopy and legume heights, biomass, tiller and stolon population densities, shade zone, light interception, LAI and botanical composition) were evaluated, as well as morphogenesis (leaf appearance, elongation and senescence rates in both species, and stem and stolon elongation rates) and morphological structure (leaf and stem length [palisadegrass], leaf area and petiole, internode and stolon lengths [forage peanut]). Sampled data interpolation by season was performed by ordinary kriging. Pearson's correlation coefficients between canopy height and the other variables were calculated. There was a spatial dependence structure in all variables. However, in some variables, spatial autocorrelation was not detected during some seasons. The spherical model best explained the semivariogram shape. Variations in canopy height influenced structural and morphogenic characteristics, in which competition for light caused legume etiolation (greater petiole, internode and stolon lengths) in areas with higher canopy height. Forage peanut changed its growth direction under greater shading, developing perpendicularly to the soil surface. Palisadegrass tiller population density responded positively and linearly to canopy height variations. In regions of lower canopy heights, the legume proliferated close to the soil surface, increasing its stolon density and biomass, even in those extremely low areas. Despite such variations, the canopy structure tended to homogenize over time. The results indicate that plant community is affected by variations in canopy height over space. Taller canopies cause competition for light between plants. Under these conditions, grass was favored, unlike the legume, which had its proportion declined community. On the other hand, in places with lower canopy height, forage peanut is benefited, as it is stimulated to develop by clonal propagation.

**Keywords**: Mixed pasture. Stoloniferous legume. Tropical forages. Grassland ecology.

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# SUMMARY

**CHAPTER 1**

**1 INTRODUCTION**

Pastures are the main feed source for ruminants in Brazil, a country with high potential in livestock industry due to availability of natural resources and favourable climatic conditions for forage production. Nevertheless, general ruminant production in Brazil exhibits low efficiency, with large degraded pasture areas and low stocking rate (de Oliveira et al., 2020). There is therefore potential for increased production efficiency via recovery of those degraded area and its suitable maintenance in terms of soil fertility and correct grazing management.

The most limiting nutrient for forage biomass production is nitrogen (N) and N fertilizers use is the easiest way to ensure increased productivity (Sollenberger, 2008). However, if the minimum mineral fertilization (50 kg ha$^{-1}$ N yr$^{-1}$) were adopted in the entire Brazilian pasture area, it would be difficult to meet production demand for this fertilizer (Casagrande, 2016). Moreover, most mineral N sources are produced by burning fossil fuels, which causes damage to the environment (Cardoso et al., 2016). Therefore, grass-legume mixed pastures use has been a prominent alternative, since it provides N input through biological fixation (Muir et al., 2014).

Besides having high nutritional value, legumes have a symbiotic association with *Rhizobium* bacteria. Such microorganisms transform atmospheric nitrogen into forms that can be used by plants. Thus, through the nutrient cycling in those systems where legumes are introduced, there is forage production increase, positively reflecting on animal production (Santos et al., 2001).

Forage peanut (*Arachis pintoi* Krapov. & W.C. Greg.) is prominent among tropical forage legumes due to its clonal propagation habit, favouring its ability to compete with grasses in mixed pastures (Homem et al., 2019, Tamele et al., 2017). Mixed pastures with legumes with clonal propagation habit can have canopy stability, depending on grazing management. Compatible canopies are mainly determined by controlling light competition between species. (Pereira et al., 2017).

Light competition is a direct function of canopy structural conditions (Tamele et al., 2017). Therefore, investigating structural characteristics in space and time is important for understanding how the establishing and persisting processes in mixed canopies work. Moreover, plant-animal interactions in grasslands are affected by canopy structure (Palhano et al., 2006). The pattern of animal ingestive behaviour under grazing is changed according to spatially dependent variables which influence the efficiency of pasture use and consequently animal performance (Pascoa & Costa, 2007). Spatial pattern characterization of structural characteristics may benefit grasslands management. Thus, pasture heterogeneity investigation is important, including mixed pasture systems, which can be performed by spatial patterns modelling (Grego et al., 2012).

The spatio-temporal variability of structural characteristics in mixed pastures has never been investigated before. In addition, there is a need for knowledge about how the mixed canopy under continuous stocking would respond to the presence of the animal regarding its structure and competition strategies between plant species. Thus, the objective of this study was to evaluate spatial variability over time of plant structural and morphogenetic characteristics and the ecology of plant communities in a palisadegrass-forage peanut mixed canopy under herbivory by beef cattle in continuous stocking.

## 2 LITERATURE REVIEW

### 2.1 Palisadegrass - *Brachiaria brizantha* [syn. *Uruchloa brizantha*] cv. Marandu (Hochst. ex A. Rich.) Stapf

*Brachiaria* spp. originate from East of Africa and occur naturally in African savannas (Valle & Milles, 1994). There are more than 100 *Brachiaria* spp. are distributed mainly around the tropics. In tropical America the most disseminated species are *B. arrecta*, *B. brizantha*, *B. decumbens*, *B. dictyoneura*, *B. humidicola*, *B. mutica* and *B. ruziziensis* (Keller-Grein et al., 1996).

The total grassland area in Brazil is 160 M ha and *Brachiaria* spp. represent 85% of cultivated pasture in the country (IBGE, 2017). Palisadegrass (*Brachiaria brizantha* [syn. *Uruchloa brizantha*] cv. Marandu [Hochst. ex A. Rich.] Stapf) is originally from Zimbabwe (Africa) and was released in Brazil in 1984 by the Brazilian Agricultural Research Corporation (EMBRAPA). Palisadegrass still occupies ~50 M ha and has been considered the largest monoculture in terms of area covered (Jank et al., 2014).

Palisadegrass growth habit is erect, and the propagation mechanism is clonal (i.e. tillering; Sbrissia et al., 2010). There is trichome presence on the leaves ventral face and absence on the dorsal face, hairy sheath and raceme inflorescence. Moreover, palisadegrass has agronomic characteristics such as: high forage yield and regrowth capacity, high response to fertilization, good seed production and soil coverage, ability to compete with weeds, fast establishment, resistance to the main grasshoppers species typical in pastures and low adaptation to poorly drained soils. Palisadegrass implantation is recommended for areas with medium to high fertility soils (Valle et al., 2010), with impaired development when subjected to temperatures below 11°C (Pezzopane et al., 2018).

### 2.2 Forage peanut - *Arachis pintoi* Krapov. & W.C. Greg. cv. BRS Mandobi

The *Arachis* genus, family Fabaceae, is originally from South America, specifically Argentina, Bolivia, Paraguay, Uruguay but primarily Brazil (Rincon et al., 1992). There are about 81 species, but the most widely used specie worldwide is *A. pintoi* (forage peanut). Forage peanut is mainly found in the central region of Brazil (Purcino et al., 2004).

Forage peanut seeds are developed underground (geocarpism) from flowers located above soil (Ramos et al., 2010). This perennial herbaceous legume is characterized by a stoloniferous, creeping growth habit, with a strong taproot. Leaves are alternate and composed of four leaflets. Forage peanut is a small plant, not exceeding 30-40 cm in height. As a stoloniferous plant, the principal stolons may develop secondary stolons emitting roots from internodes, thus generating multiple growth points (Gregory et al., 1980). This clonal propagation mechanism favours its competition with other plants and persistence in mixed pastures; plants not only produce seeds, but develop vegetative propagation (Andrade et al., 2006).

*Arachis pintoi* cv. BRS Mandobi belongs to Caulorrhizae section and has high productive potential in mixed pastures. This cultivar was released in 1999 by EMBRAPA Acre (Assis & Valentim, 2009) and presents long and wide leaflets, with high intensity of bristles on the abaxial face of basal leaflets. The basal leaflet apex is acute, whereas the predominant form of the apical leaflet apex is obtuse, and its form is obovate. Flowers are yellow and the hypanthium is long. Mandobi presents large stipules in the free portion, not welded to the petiole. Its fruits are large comparing to cv. Amarillo and Alqueire-1. This cultivar also has high seed production and vigour, good biomass productivity and establishment, tolerance to well-drained or low permeability soils, good leaf growth rate and high leaf availability (Assis et al., 2011).

## 2.3 Pasture canopy structure and morphogenic characteristics

Descriptions of canopy structure are essential to achieving an understanding of plant processes because of the profound influence that structure has on plant-environment interactions (Norman & Campbell, 1989). According to Laca & Lamaire (2000), forage canopy structure is defined as plant component arrangement and distribution, above soil level, within a pasture community. The objective of characterizing pasture structure is to understand important phenomena such as plant growth, biomass production, nutritional value, animal intake and performance under grazing.

The grazing process is both cause and consequence of pasture structure. The pasture structure resulting from the defoliation process affects the grazing process, representing a continuous cycle of the cause-effect relationship (Savian et al., 2020). Thus, each animal bite extraction continuously changes the canopy structure regarding light interception, plant growth and plant morphological composition among other characteristics (Carvalho, 2013). As other important descriptors, some structural variables are used such as canopy height, populational tiller density and leaf area index (LAI).

Canopy height has been used as a management tool for determining optimum grazing intensity and frequency (Santos et al., 2016) and is considered a connection between sward structure and light interception processes (Silveira et al., 2016). Plant height determines canopy light input affecting its growth pattern. The plant community under varying grazing management conditions (intensity and frequency) seeks to use light efficiently by reducing or accelerating morphogenic processes which result in canopy structure adjustment to herbivory.

In grass monoculture pastures managed for taller canopies (lenient grazing), leaf tissue partial removal or non-removal can cause excessive light competition within the canopy, promoting senescence, stem elongation and self-thinning. As consequence, tiller density and leaf mass decreases, negatively affecting the structure (Sbrissia et al., 2010, Sbrissia et al., 2003). On the other hand, when pasture height is kept lower (relatively severe grazing), there is intense basal tillering, with shorter and lighter tillers; as a consequence, canopies become denser and per leaf mass increases (Sbrissia et al., 2010). In grass-legume

mixed pastures where there is shading at the canopy base, there are changes regarding plants growth habit, vertical stolon elongation, reduced stolon density, and decreasing legume proportion in botanical composition (Homem et al., 2019, Pereira et al., 2017, Tamele et al., 2017). When canopy height is lower, if there is a stoloniferous legume, stolon density increases, and legume percentage is favoured (Homem et al., 2019, Tamele et al., 2017).

Canopy structure can also be studied vertically, when vertical distribution pattern of the morphological components (leaf, stem and dead material) is investigated. Several studies with forage grasses in which the sward structure was evaluated reported a vertical distribution pattern of morphological components characterized by leaf predominance on the top half of the canopy and stem and dead material in the bottom half (Silva et al., 2017). However, this vertical distribution pattern can change depending on canopy height and environment conditions (mainly weather), which can change light quantity intercepted in the canopy both at a single grass pasture (Silveira et al., 2016), or at a grass-legume mixed pasture (Tamele et al., 2017). Usually in a homogeneous plant community, tall plants have lower assimilatory organs proportion in relation to support structures, representing a disadvantageous structure in terms of animal intake and nutritional value. In mixed pastures, taller plants may shade the canopy base, limiting shorter plant growth (Warren Wilson, 1961).

Studying vertical structure in mixed pastures among other approaches, Tamele et al. (2017) developed the "shade zone" concept, defined by the height above which 90% of the canopy LAI is distributed. This is a useful concept concerning mixed canopies where there is inter-species light competition. The authors found that, in different canopy heights, the vertical distribution and leaf range change over the canopy profile, therefore changing the shade zone which impacts light competition.

Light interception is a pasture structural characteristic closely related to LAI and depends on the angle at which the foliage is inclined to horizontal and vertical dispersion of the foliage area (Warren Wilson, 1965). After a grazing event, when plant regrowth occurs, canopy forage accumulation is characterized by leaf increase until reaching 95% of light interception. Thereafter, there is leaf biomass decrease, high stem biomass and dead material increase, characterizing an unfavourable condition for grazing animal herbage intake (Pedreira et al., 2009).

As plants optimize light-capturing leaf surface, there is an interrelation between structural and morphogenic characteristics in order to arrange canopy architecture according to limitations imposed by grazing events (Lemaire, 2001, Nabinger & Pontes, 2001, Lemaire & Chapman, 1996). Morphogenesis is the dynamics of generating and expanding the plant shape in space. This concept includes organs appearance, elongation and senescence rates. However, as plants do not grow individually, but as competing community members, studies must consider competition interactions and tissue removal responses (Lemaire & Chapman, 1996). Concerning tropical forages, stem and stolon elongation rate is a particular morphogenic

characteristic, highly relevant to species interaction, since it affects canopy structure and consequently light competition processes (Pereira et al., 2018, Cruz & Boval, 2000).

Grass morphogenesis defines important structure characteristics such as number of live leaves per tiller, leaf size and tiller populational density, which together will determine canopy LAI (Sbrissia & Silva, 2001). Similarly, in forage legumes the main structural characteristics are number of live leaves per stolon, leaf size and stolon populational density (Tamele et al., 2017). Both morphogenetic and structural characteristics are not only determined by genetics, but also by environmental variables such as light, temperature, soil fertility and grazing management conditions such as grazing intensity and frequency.

Among structural pasture characteristics, tillering may positively or negatively affect the global characteristics in grassland systems. According to Stebbins (1972), tillering is a perennialization tool that grasses have developed as clonal production and survival mechanisms. The balance between tiller appearance and senescence relates to defoliation management and determines LAI evolution, which controls the whole tillering dynamic (Valentine & Matthew, 1999). In pastures managed under continuous stocking, the LAI in which the canopy is maintained defines the tiller populational density. Canopies under severe defoliation usually have greater tiller density compared to those where defoliation is lenient (Grant et al., 1983).

In grass-legume mixed pastures, the structural scenario changes due to the presence of different species which can interact through competition or complementarity of resource use. The structural dynamics of these pastures depends on genotype choice, management and environmental conditions. The persistence of grasses and legumes in grazed pastures is strongly dependent on the population's establishment and maintenance of the basic plant growth units, namely tillers and stolons (Langer 1973; Valentine & Matthew 1999). Tiller and stolon population densities are subject to within- and between-year variation and are strongly influenced by defoliation management through processes such as competition for light, and size-density trade-offs mediated by self-thinning processes (Edwards & Chapman, 2011).

**2.4 Grass-legume mixed pastures – General considerations**

The use of grass-legume mixed pastures is an alternative to improve the economic and ecological benefits of livestock industry. These mixtures have been widely evaluated and used in both temperate and tropical regions, such as north-eastern North America and Queensland, Australia, respectively (Muir et al., 2011). Legumes establish a symbiotic relationship with microorganisms that perform biological nitrogen fixation, introducing this nutrient to the pastoral system at low cost (Muir et al., 2014). In addition to the economic advantages, livestock production in mixed pastures is more sustainable when compared to systems with intensive use of N fertilizers (Phelan et al., 2015, Cardoso et al., 2016).

Despite the several advantages previously mentioned, grass-legume mixed pastures are still rarely used in Brazil. Failures in the past were mistakenly attributed to the physiological differences between tropical grasses (C4) and legumes (C3). As a result, mixed pastures were considered an impracticable technique. However, more recent studies have verified that the compatibility between grasses and legumes is not determined by their metabolic differences, but, rather, by genotype choice and grazing management based in ecological aspects of those forages (Homem et al., 2019, Tamele et al., 2017, Andrade et al., 2015). Besides compatibility factors, the success of grass-legume mixed pasture depends on persistency, adaptability to local weather and soil aspects and resistance against plagues and diseases (Valle & Zimmer, 2013).

## 2.5 Palisadegrass-forage peanut mixed pastures

Palisadegrass and forage peanut are both clonal species (Sbrissia et al., 2010, Gregory et al., 1980), reproducing asexually via the production of daughter tillers or stolons which at some stage may become physically separated from the 'parent' tiller or stolon thereby resulting in the recruitment of a 'new' plant into the community (Chapman, 1983). Therefore, pastures containing their mixtures can have high harmony and canopy stability, depending on grazing management.

According to Briske and Richards (1993), defoliation disrupts plant energy supply and triggers responses such as carbon assimilate re-distribution to leaf meristematic zones and carbohydrate reserves mobilisation. Pasture persistence strongly depends on how the growth units respond to the frequency, severity and timing of defoliation (Edwards & Chapman, 2011).

Canopy height is a structural characteristic widely used as a grazing management criterion. In mixed pastures, for each grass and legume combination, the canopy height recommendation will be different. In continuous stocking, the goal is to keep the canopy structure relatively constant over time. In palisadegrass-forage peanut pastures, Tamele et al. (2017) observed that light competition starts when canopy height is around 20 cm under continuous stocking. Forage peanut growth habit is stoloniferous, occupying the layer near the soil surface, where the shade directly affects its architecture. Most of leaf area is located on the canopy top, so the light that reaches the layer near the soil surface is scarce, and the higher the canopy, higher the shade zone (Tamele et al., 2017).

The lack of light at the canopy base causes growth habit changes in forage peanut. Instead of growing parallel to the ground, forage peanut starts to grow perpendicularly to seek light, reducing its clonal propagation capacity because meristems move away from the soil and lose rooting capability (Tamele et al., 2017). According to Homem et al. (2019), when canopy height is lower, it allows more light input at the base, which favours clonal propagation, increasing stolon density. The authors verified that when there is

high light input at the canopy base, forage peanut is favoured and grass tiller density decreases, reducing grass participation on the botanical composition.

The season of the year also can influence the botanical composition in palisadegrass-forage peanut pastures. Tamele et al. (2017) verified that during summer, even in those canopies below 20 cm in height, greater palisadegrass forage mass was observed. Thus, for continuous stocking it is worth considering if, when the canopy is managed using different heights throughout the year, species compatibility would be improved.

Under intermittent stocking, the canopy structure of palisadegrass-peanut forage pasture is very variable over time, even within each grazing period. Pereira et al. (2017) found that, at the beginning of the regrowth period, there is no limitation due to lack of light regarding forage peanut growth. If the rest period is too long, there will be light competition. Although forage peanut percentage can be reduced at the end of rest period, swards can be compatible, once the grazing period starts, the light can reach the canopy base again. However, the compatibility also depends on grazing intensity, since forage peanut regrowth can be harmed if the grazing intensity is too great (Pereira et al., 2017).

Pereira et al. (2017) verified that there is light competition between palisadegrass and forage peanut when the canopy intercepts 90% of incident light. Between 90-95% of light interception, legume mass distribution still has a pyramidal canopy layer shape, which means that a greater proportion of peanut biomass is distributed from the ground level up to 25% of the canopy height. The same authors noticed that, when canopy interception is higher than 95%, canopy architecture changes and the greater legume mass proportion is in the middle layer, 50 to 75% of the canopy height. Under those conditions, stolons grow perpendicular to the ground seeking light (Pereira et al., 2017).

In established palisadegrass-forage peanut pastures under continuous stocking, Homem et al. (2019) verified an increased forage peanut proportion in the botanical composition when canopy height was reduced to 10 cm at the beginning of the rainy season. If that defoliation intensity is maintained for the whole season as a temporary defoliation management, it will favour forage peanut establishment. After reaching an ideal legume mass in the botanical composition (~40%), the 20-cm canopy height can be used to maintain the pasture compatibility, according to Tamele et al. (2017).

In summary, the persistence of legumes in mixed-species pastures depends basically on two mechanisms: those that ensure the continuity or maintenance of pasture plant population, and those that regulate the plant adaptation to grazing. Plant replacement, a factor related to perennially through vegetative propagation, is the most efficient and desirable mechanism to ensure the forage legumes persistence in mixed pastures (Andrade, 2010).

**2.6 Geostatistics analysis**

Precision agriculture was defined as agricultural practices application based on information technologies for spatial variability treatment, as a way to increase crop productivity and quality, increase the economic return and reduce the negative environmental impacts (Inamasu et al., 2011). Geostatistics use in precision agriculture is based on variable characterization and modelling in space and time. Such procedures result in the production of accurate maps for information to guide management that leads to optimal herbage accumulation (McBratney et al., 2005). According to Vieira (2000), geostatistical analysis is the most correct tool to analyse spatial variability.

The study of geostatistics and spatial change in vegetation and associated environmental / biotic controls is of fundamental importance to ecologists. This research area may provide vital insights into how plants are distributed in pastures and is of relevance to management strategies for ecosystems (Kent et al., 2006).

Geostatistics was initiated in South Africa in mining research, when Krige (1951) understood that, to find meaning in the variances under study, it was necessary to take into account the distances between the samples, thus giving rise to the concept of spatial dependence. Years later, Matheron (1965) put this idea in mathematical terms and developed geostatistics.

Geostatistics is not limited to obtaining only a spatial dependence model, it also intends to estimate point values in places where they were not sampled (Srivastava, 1996, Goovaerts, 1997). Succinctly comparing classical statistics and geostatistcs, the first one generally advocates data normality and spatial independence, while geostatistics requires spatial self-correlation. Classical statistics assume that observation points are independent, which, in most natural ecosystem cases, does not happen in studies involving earth sciences (Srivastava, 1996) and, more specifically, in grassland systems as recently verified in the literature (Gross Filho et al., 2016, da Silva Neto et al., 2016, Paula Neto et al., 2014, Grego et al., 2012). In this context, as consolidated in soil studies and regardless of the sampled area size (Warrick & Nielsen, 1980; Goovaerts, 1997; Grego & Vieira, 2005), geostatistics has potential for many applications involving earth and environmental sciences (Soares, 2006).

A primary factor for geostatistics application is obtaining data with corresponding geographical coordinates. Georeferenced data can be obtained through on-site collection, thematic maps, satellite images or aerial photographs. (Grego et al., 2014). It is necessary to analyze and plan the data collection number, mainly through cost / benefit, since a large number of sample points increases the operation cost and can make process implementation unfeasible (Vieira, 2000). However, samples must be close enough to be able to characterize the possible variability spots. Therefore, auxiliary data and area historical information can help to determine adequate sample number (Vieira, Xavier & Grego, 2008). Greater observed data amount

favours the spatial autocorrelation representativeness of production attributes at different scales (Vieira et al., 1983).

Before being subjected to geostatistical analysis, it is important to perform data exploratory analysis which aims to previously identify discrepant values, frequency distribution normality and data variation (Grego et al., 2014). Thereafter, steps for calculating semivariation, semivariogram construction and adjustment and interpolation by kriging are highlighted in geostatistic. According to Vieira (2000), semivariogram allows spatial variability identification. This author highlights that the fundamental hypothesis on which geostatistics is based is that neighboring data is more similar than distant data. Thus, semivariogram is a "meter" of similarity degree between neighbors, and can be calculated by equation 1:

$$\gamma^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[ Z(x_i) - Z(x_i + h) \right]^2 \qquad \textbf{Eq. 1}$$

where N (h) is the number of measured value pairs Z $(x_i)$, Z $(x_i + h)$, separated by a vector h. In order for the evaluated variable to have spatial dependence, it is necessary that the semivariogram increases with distance.

The semivariogram graph is a series of discrete points for which a continuous function must be adjusted (Vieira et al., 2010). Nugget effect $(C_0)$, structural variance $(C_1)$ and range (a) are parameters used to adjust the model to the semivariograms (Shafer & Varljen, 1990). Model adjustment to the semivariogram is the most important aspects of geostatistics applications because geostatistics calculations depend on the semivariogram model value for each specified distance (Gotway, 1991). McBratney and Webster (1986) indicate that the most suitable models for the most varied types of situations, in most cases, will be spherical, exponential or Gaussian (Figure 1). Pure nugget is a distinct model of semivariogram that indicates the absence of spatial correlation, which means that the phenomenon under study is distributed completely randomly in space (Ceddia et al., 2009).
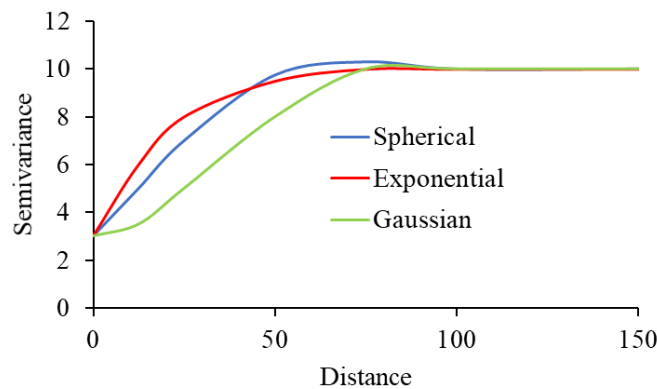


**Figure 1.** Behavior of main semivariogram models (spherical, exponential and Gaussian). Adapted from Grego et al. (2014).

Kriging is a geostatistical estimator and this name was made by Matheron in honor of Daniel Krige's pioneering work in the 50s (Soares, 2006). Kriging process allows the estimate of values where sampling was not performed. In other words, kriging consists of predicting neighbours closer to the point to be estimated, obeying trendless criteria and minimal variance (Varouchakis, 2019). After kriging interpolation, the results are subjected to spatialization engendering isoline maps, usually in geographic information system environments.

Interpretation of precise maps derived from data interpolation by kriging allows to identify the regions in the field where the studied phenomenon is more uniform than in others. Thus, the use of technologies such as geostatistics allows technically supporting strategic and complex decisions in relation to the management system adopted, its environmental effects and the productivity of different cultures (Grego et al., 2014).

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**CHAPTER 2**

**SPATIO-TEMPORAL VARIABILITY OF PALISADEGRASS-FORAGE PEANUT PASTURE STRUCTURE UNDER CONTINUOUS STOCKING**

**ABSTRACT**

Understanding ecology in grass-legume mixed pastures can help support strategies aimed at maintaining canopy stability. This study evaluated spatial variability over time, focusing plant structural and morphogenetic characteristics and the ecology of plant communities in a palisadegrass {*Brachiaria brizantha* (Hochst. Ex A. Rich.) R.D. Webster [syn. *Urochloa brizantha* Stapf cv. Marandu]}-forage peanut (*Arachis pintoi* Krapov. & W.C. Greg. cv. BRS Mandobi) mixed canopy under herbivory by beef cattle in continuous stocking with variable stocking rate over a 2-yr experiment. Nellore heifers (214 ± 17 kg BW, 11 ± 3 months in age) were used for stocking. The experimental grassland was managed under continuous stocking (1.71 ± 0.86 AU ha$^{-1}$) maintaining average canopy height between 20 and 25 cm during the rainy season. The experimental area (10,000 m$^2$) had a permanent sample grid containing 50 points which were systematically pre-established, and georeferenced using Real-Time Kinematic (RTK) GPS. Canopy structure and morphogenetic characteristics were measured. The interpolation was performed by ordinary kriging. Pearson's correlation coefficients between canopy height and other variables under study were calculated. Spatial dependence structure was observed in all studied variables, although there was no spatial autocorrelation during some seasons. The spherical model was the one that best fit the semivariograms. Variation in the canopy height influenced the structural and morphogenic characteristics, where competition for light caused forage peanut etiolation (greater petiole, internode and stolon lengths) in the canopy taller regions. The legume changed aerial growth direction under greater shading, developing perpendicularly to the soil surface. The population density of palisadegrass tillers responded positively and linearly to canopy height variations. In lower canopies, forage peanut proliferated closer to the soil surface, increasing its biomass and stolon density, even in extremally low regions. Despite such variations, the canopy structure tended to homogenize over time. Results indicate that plant community is affected by variations in canopy height over space. Higher canopies cause competition for light between plants. Under these conditions, grass was favoured, unlike the legume, which had its proportion reduced in the community. On the other hand, in places with lower canopy height, forage peanut benefited, as it was stimulated to develop more effectively by clonal propagation.

**Keywords**

*Uruchloa brizantha*, *Arachis pintoi*, warm-season legume, spatial variability, mixed pasture

**INTRODUCTION**

Mixed grass-legume pastures are an alternative to improve forage productivity in sustainable systems (Muir et al., 2014, Phelan et al., 2014). However, some factors have limited the interest concerning those systems (Shelton et al., 2005, Muir et al., 2011). Scarce information on the ecology of grasses and legumes sharing the same space, an important aspect in warm environments, has limited the adoption of grass-legume mixtures (Pereira et al., 2017).

Failures in the past were mistakenly attributed to the physiological differences between tropical grasses (C4) and legumes (C3). As a consequence, the use of mixed pastures was widely considered an impracticable technique (Boddey et al., 2020). However, more recent studies have verified that the compatibility between grasses and legumes is not determined by their metabolic differences but, rather, by genotype choice and grazing management based on ecological aspects of those forages (Homem et al., 2019, Tamele et al., 2017, Andrade et al., 2012).

The persistence mechanism of tropical perennial grasses is often clonal propagation, i. e., tillering (Sbrissia et al., 2010). Stoloniferous legumes also have clonal propagation mechanisms, a fundamental characteristic for compatibility with perennial grasses in mixed swards (Black et al., 2009, Assis et al., 2013). The study of palisadegrass {*Brachiaria brizantha* (Hochst. Ex A. Rich.) R.D. Webster [syn. *Urochloa brizantha* Stapf cv. Marandu]}-forage peanut (*Arachis pintoi* Krapov. & W.C. Greg. cv. BRS Mandobi) pastures structural characterization and grazing management is relevant to many tropical regions where perennial pastures predominate (Tamele et al., 2017, Gomes et al., 2018, Homem et al., 2019). Population dynamics in mixed pastures composed by palisadegrass, with an upright growth habit, and forage peanut, a stoloniferous legume, is dominated by light competition among plants (Pereira et al., 2017). Understanding the processes inherent to pasture communities provides conceptual bases for suitable manipulation of botanical composition and pasture production (Marshall et al., 2016).

Most of the pastures in Brazil are managed under continuous stocking, a consequence of easier operation inherent in this grazing method (Santos et al., 2011). In a study simulating continuous stocking on the palisadegrass-forage peanut mixture, Tamele et al. (2017) observed that canopies kept above 30 cm resulted in a lower legume proportion in the herbage mass compared to those kept below that height. Conversely, when canopies were kept below 10 cm, forage peanut predominated. The authors reported that defoliation management may be the key to maintaining the adequate legume proportion in the mixture. However, the study was performed by mechanical cutting, without the animal presence and its consequences on the pasture. Leaf-selective grazing habits can affect botanical composition, and animals may also show greater preference for legume components (Benvenutti et al., 2016).

Plant-animal interactions in grasslands are affected by canopy structure (Palhano et al., 2006). The pattern of animal ingestive behaviour under grazing is changed according to spatially dependent variables which influence the efficiency of pasture use and, consequently, animal performance (Pascoa & Costa, 2007). Spatial pattern characterization of structural characteristics may guide efficient

grassland management. Thus, pasture heterogeneity investigation is important, including mixed pasture systems, which can be performed by spatial patterns modelling (Grego et al., 2012).

The spatio-temporal variability of structural characteristics in mixed pastures has not been investigated. There is a need to understand how the structure and competition strategies among plant species in mixed canopy under continuous stocking responds to the presence of the animal over a growing season. We hypothesize that there is a spatial dependence on the canopy structure of a palisadegrass-forage peanut mixture. We further hypothesize that, in places with taller canopies, there will be competition for light, favouring palisadegrass, while in places with shorter plants, forage peanut proliferation will be promoted. Thus, the objective of this study was to evaluate spatial variability over time of plant structural and morphogenetic characteristics and the ecology of plant communities in a palisadegrass-forage peanut mixed canopy under herbivory by beef cattle in a continuous stocking system.

## MATERIALS AND METHODS

### Experimental site

The experiment was conducted at the Experimental Farm of the Federal University of Lavras, Brazil (21°14'S, 45°00W); 918 m above sea level. The climate is subtropical humid mesothermal with rainy summers and dry winters (Köppen climate classification: Cwa; Sá, Carvalho, Silva & Carvalho Alves, 2012). Meteorological data were obtained from a weather station 1000 m from the experimental area (Figure 2). A 2-yr experimental period (from December 2016 to December 2018) was divided in eight seasons (Figure 2).
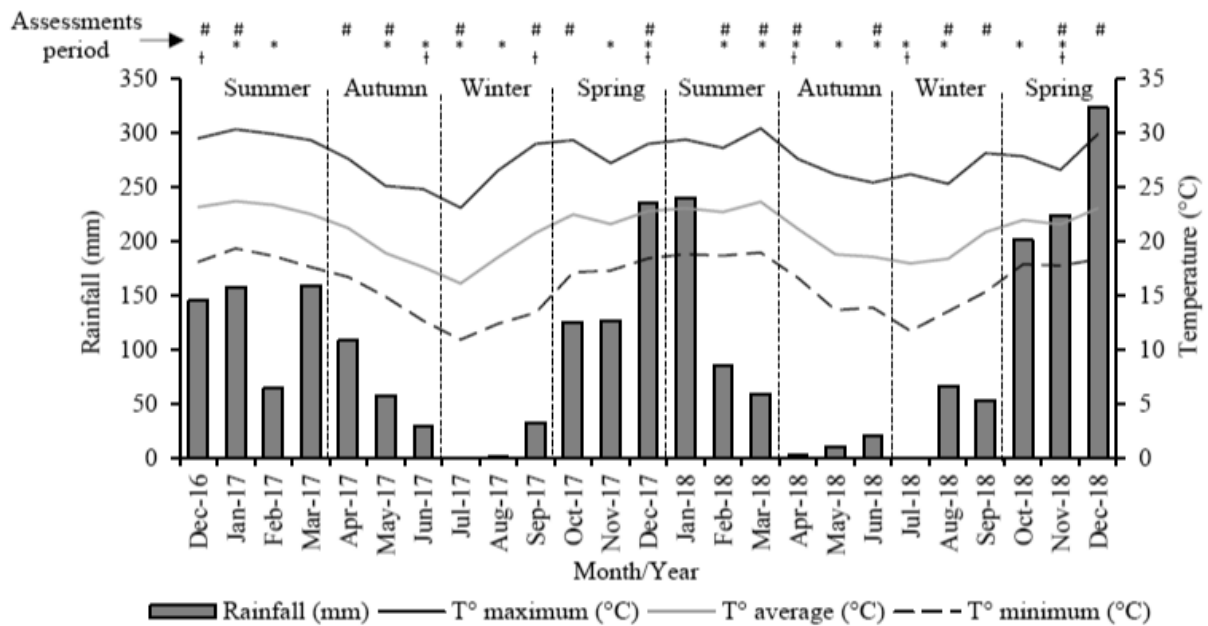


**Figure 2.** Meteorological data during the experimental period in Lavras/MG; Assessments period of forage mass, canopy height, density and IL (#); morphogenetic and structural characteristics (*); vertical canopy structure (Ɨ).

The experimental area soil is classified as Ferralsol (WRB/FAO classification) or "Red Latossolo" according to the Brazilian System of Soil Classification with loamy texture. Soil characteristics at establishment were as follows: 55% clay, pH = 5.5, organic matter = 2.8%, P = 5.2 mg dm$^{-3}$, K$^+$ = 63.5 mg dm$^{-3}$, Ca$^{2+}$ = 2.0 cmol$_c$ dm$^{-3}$, Mg$^{2+}$ = 0.4 cmol$_c$ dm$^{-3}$, H + Al = 2.6 cmol$_c$ dm$^{-3}$, Al$^{3+}$ = 0.1 cmol$_c$ dm$^{-3}$, cation exchange capacity = 5.1 cmol$_c$ dm$^{-3}$ and base saturation = 49.2%. The palisadegrass pasture was established in January 2014. Initially, 2,500 kg ha$^{-1}$ of lime was applied (dolomitic lime) to increase the base saturation up to 60%. One month after soil amendment, 52.0 kg ha$^{-1}$ of P$_2$O$_5$ (single superphosphate) and 41.5 kg ha$^{-1}$ of K$_2$O (potassium chloride) were applied. Soon after fertilization, the pasture was sown with 6 kg ha$^{-1}$ of pure viable seeds of palisadegrass (*Brachiaria brizantha* [syn. *Uruchloa brizantha*] cv. Marandu). In December 2015, the paddock was sown with forage peanut (*Arachis pintoi* Krapov. & W.C. Greg. cv. BRS Mandobi). The line-seeding rate was 10 kg ha$^{-1}$ of forage peanut pure live seeds through a no-till seeder with four lines. Six seeds of forage peanut for a linear meter with 0.5 m row spacing were planted. Maintenance fertilizations were

performed annually in early spring by applying 50 kg ha$^{-1}$ of P$_2$O$_5$ (single superphosphate) and 50 kg ha$^{-1}$ of K$_2$O (potassium chloride).

**Experimental management**

The grassland of 10,000 m$^2$ was managed under continuous stocking with variable stocking rate (Table 1, Allen et al., 2011). Nellore heifers used for stocking had a mean body weight of 214 ± 17 kg and an mean 11 ± 3 months in age. The grassland management had as criterium to maintain the canopy height between 20 to 25 cm during the spring, summer and autumn and 15 cm during the winter before the animals were removed from the area on 4 August 2017 and 25 July 2018. The stocking rate adjustment was performed weekly and was calculated considering 1 AU equivalent to 500 kg BW (Allen et al., 2011). Canopy height was checked regularly once a week using the sward stick method (Barthram, 1985).

The spatial sampling design in the experimental area had a permanent sample grid containing 50 points. The sample points were systematically pre-established and each one was georeferenced using Real-Time Kinematic (RTK) GPS. The sample grid was configured to give both large and small distances between pairs of sample points (Figure 3). A wooden stake was fixed at each georeferenced point which was the centre of the plot where sampling was done. Assessments were made within a 2.30 m radius around the stake (Figure 3).
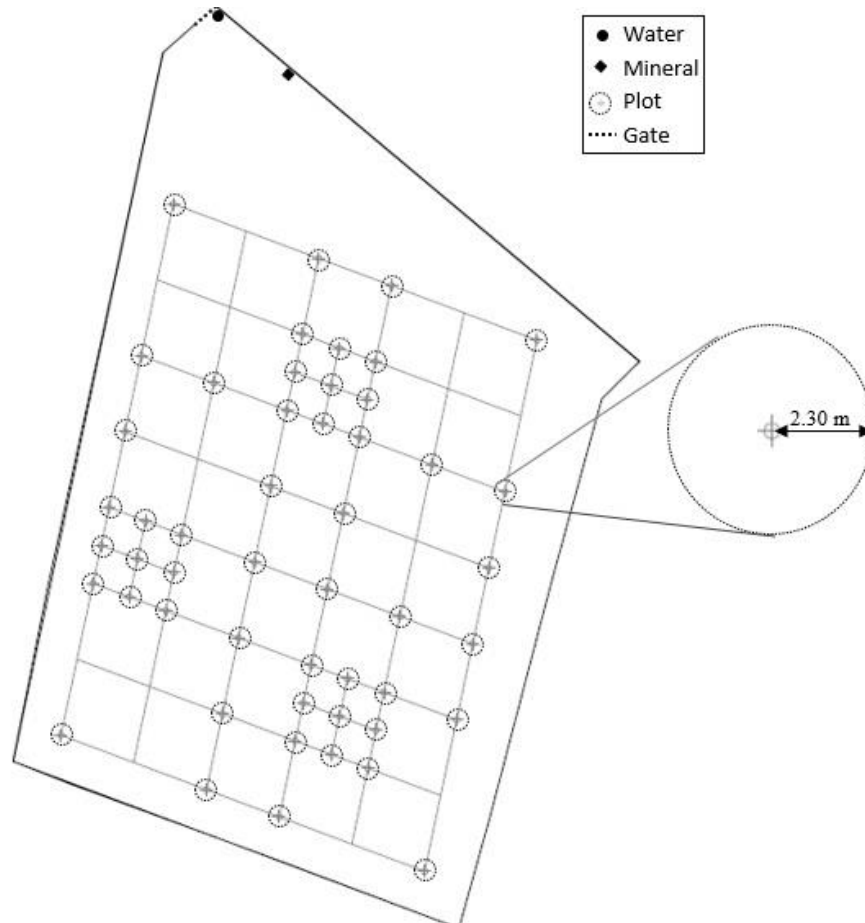


**Figure 3.** Sample grid and plots.

**Experimental evaluations**

Canopy heights were measured twice a season on 23 December 2016, 27 January 2017, 18 April 2017, 26 May 2017, 13 July 2017, 5 September 2017, 24 October 2017, 14 December 2017, 7 February 2018, 12 March 2018, 1 May 2018, 6 June 2018, 8 August 2018, 13 September 2018, 6 November 2018 and 11 December 2018, in 20 points within each plot using a sward stick (Barthram, 1985). Forage mass was sampled using one frame of $0.5 \times 0.3$ m twice a season, on 23 December 2016, 27 January 2017, 18 April 2017, 26 May 2017, 13 July 2017, 5 September 2017, 24 October 2017, 14 December 2017, 8 February 2018, 13 March 2018, 2 May 2018, 6 June 2018, 8 August 2018, 13 September 2018, 7 November 2018 and 11 December 2018,  (Figure 2). After sampling the forage, botanical (palisade grass and forage peanut) and morphological separations were performed. The biomass results presented in this work were herbage, green or dead material, and palisadegrass or forage peanut mass. Grass samples were separated into stem, leaf and dead material. Forage peanut samples were separated into stalk, leaflet, petiole and dead material. Samples were dried in a forced-air oven at 55°C until constant weight. Morphological separations were made so that it was possible to obtain total, palisadegrass and forage peanut leaf area index (LAI). The leaf area was calculated using a LI-3100 model LI-COR device (LI-COR Biosciences, Lincoln, NE, USA) to subsequently determine LAI. Botanical composition was obtained by determining proportion of the forage peanut in the green mass and was expressed as percentage of legume within the total herbage mass.

The vertical canopy structure was characterized using an inclined point quadrat (Laca & Lemaire, 2000; Lantinga et al., 1999; Warren-Wilson, 1960) once a season, on 21 December 2016, 15 June 2017, 8 September 2017, 17 December 2017, 16 March 2018, 16 April 2018, 17 July 2018 and 28 November 2018 (Figure 2). Each touched structure was identified and the height at which the touch occurred was marked by reading the device's graduated ruler, in centimetres. The procedure was repeated for at least 80 touches. Maximum canopy and forage peanut height were obtained by the first touch in the upper strata. Vertical distribution of LAI was obtained by multiplying LAI by the percentage of touches on leaves per one centimetre of the canopy, and shade zone corresponds to the height above which 90% of the LAI of the canopy is distributed through vertical structure evaluation (Tamele et al., 2017). Light interception was measured using Accupar LP-80, reading 5 points above sward and at the ground level, twice a season in each plot, on 22 December 2016, 25 January 2017, 14 April 2017, 24 May 2017, 11 July 2017, 1 September 2017, 19 October 2017, 11 December 2017, 2 February 2018, 7 March 2018, 25 April 2018, 4 June 2018, 3 August 2018, 10 September 2018, 1 November 2018 and 5 December 2018,  (Figure 2).

To study the morphogenetic characteristics, three stolons of forage peanut and three tillers of palisadegrass were marked at each of the 50 experiment point (Grant & Marriott, 1994). To characterize each season (Figure 2), evaluations were performed twice a week to characterize spring/summer and once a week to characterize autumn/winter. Evaluations were performed from 9 January to 8 February 2017 (Summer), 22 May to 5 July 2017 (Autumn), 19 July to 30 August 2017 (Winter), 3 November to

6 December 2017 (Spring), 13 February to 6 March 2018 (Summer), 26 April to 22 June 2018 (Autumn), 12 July to 20 August 2018 (Winter) and 25 October to 11 December 2018 (Spring)  For palisadegrass, the following morphogenetic characteristics were measured: leaf appearance, elongation and senescence rates (Bircham & Hodgson, 1983) as well as stem elongation rate. The structural characteristics included leaf and stem lengths. For forage peanut, the following characteristics were measured: leaf elongation and senescence rates (Tamele et al, 2017) calculated using a leaf area estimative model described by Homem et al. (2017), leaf appearance rate and stolon elongation rate. The structural characteristics included leaf area (Homem et al., 2017), length of petiole (petiole + rachis), number of green leaves per stolon, length of the internode and final length of stolons (Bircham & Hodgson, 1984). Twice in each season, on 23 December 2016, 26 January 2017, 17 April 2017, 25 May 2017, 12 July 2017, 4 September 2017, 23 October 2017, 12 December 2017, 6 February 2018, 9 March 2018, 30 April 2018, 5 June 2018, 6 August 2018, 11 September 2018, 5 November 2018 and 7 December 2018,  tiller density and stolon density were estimated by counting the number of tillers and stolons within two frames of 0.15 $m^2$ and 0.5 $m^2$, respectively.

**Statistical Analyses**

The data were submitted to exploratory data analysis through the calculations of sample mean, standard deviation, minimum and maximum values, which were added to the figures containing the maps, except for the sample mean, shown in the Table 1. Moreover, frequency distribution of the data were made through the construction of a histogram to analyse the variation observed and mapping was made using quartiles, in which the presence or absence of outliers were detected. The spatial dependence structure was characterized by geostatistical analysis, calculating the semivariance with the equation proposed by Matheron (1963). The usual models of semivariograms were tested and the adjusted model of the semivariograms was chosen based on the method of least squares.

The data were interpolated using ordinary kriging to generate maps in order to define the spatial pattern of the pasture structural and morphogenetic variables. The geoR package of the R version 3.4.0 program was used. The sill, nugget, and range values, which were used to model the semivariograms, are gathered in the Appendices.

Pearson correlation coefficients used as measurement of dependence between canopy height and morphogenetic/structural characteristics were estimated using ISwR package of the R version 3.4.0 program. All values were submitted to by t-test up to 0.05 probability. The following criteria were used to interpret the correlation coefficients: r = 0.10 to 0.30, low; r = 0.40 to 0.6, moderate; r = 0.70 to 1, strong.

**RESULTS**

The sample mean data of canopy height, botanical composition and stocking rate over the seasons in 2017 and 2018 are presented in Figure 4. Mean stocking rate remained close to 1.8 AU ha^{-1} during the summer and autumn of 2017, with a decrease in the following season, requiring animal removal from the area in September and October 2017 to maintain the canopy height target. Animals were gradually added to the area during the rainy season of 2018, reaching a stocking rate mean of approximately 2 AU ha^{-1} during the summer and autumn (Figure 4). As in 2017, to maintain pasture height management in 2018 it was necessary to remove the animals from the area during the winter, which occurred that year in August and September, decreasing mean stocking rate to 0.5 AU ha^{-1} for that season. Animals were then reintroduced to the area in October 2018, reaching a stocking rate mean of 2.1 AU ha^{-1} for spring (Figure 4).
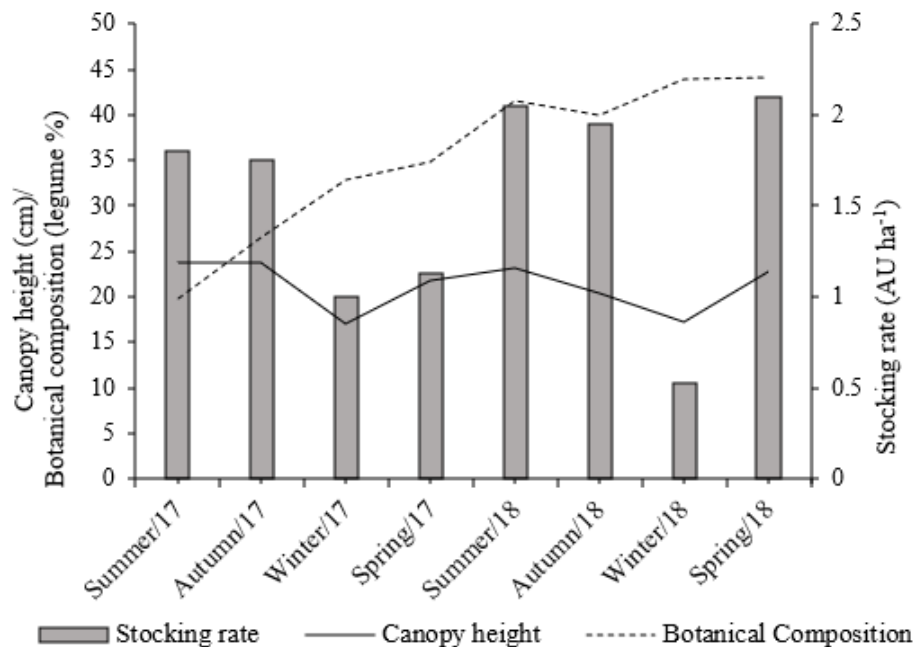


**Figure 4.** Seasonal mean stocking rate, canopy height and botanical composition in palisadegrass-forage peanut mixed pasture.

As predicted by the target canopy height management, the canopy height mean was kept between 20 and 25 cm in most seasons of the experiment, except for winter, when the pasture reached a height mean of 17 cm (Figure 4, Table 1). Forage peanut proportion in pasture botanical composition increased from 34.1% in 2017 to 40.9% in 2018, with the greatest values reached during the spring (Figure 4, Table 1).

Table 1 contains the sample means of biomass, structural and morphogenetic characteristics over the seasons of 2017 and 2018. The highest and lowest herbage mass sample mean was obtained during the spring and winter, respectively, both years. However, the highest green biomass sample mean was observed during summer 2017 and spring 2018, with the lowest values during winter both years.

There was a gradual increase in the sample mean of dead material biomass over the seasons in 2017, reaching the highest value during the spring (6399 kg DM ha$^{-1}$). On the other hand, in 2018 the lowest and highest sample means of dead material biomass were obtained during the summer and winter (3957 and 6549 kg DM ha$^{-1}$), respectively. Palisadegrass mass sample means during the summer, autumn and winter of 2017 were 33.3%, 43.7% and 29.5% respectively higher compared to 2018, while values were similar during the spring of both years. Forage peanut mass sample mean increased from 1347 kg DM ha$^{-1}$ in 2017 to 2061 kg DM ha$^{-1}$ in 2018, and the highest values were found during the spring in both years. There was an increase of 32.8% in legume participation in the green mass when comparing sample means of 2017 to 2018. (Table 1).

The sample mean of palisadegrass tiller density was the same during the summer and winter of 2017 (522 tillers m$^2$), with the highest sample mean density found during the autumn of that year (Table 1). On the other hand, the highest and lowest tiller density sample means of 2018 were obtained during the summer and winter (606 and 445 tillers m$^2$), respectively. Tiller density sample mean during spring was 21.2% lower compared to the same season in 2018. The lowest forage peanut stolon density means were observed during the dry season (autumn and winter) and the highest during the spring in both years. However, stolon density sample mean during spring 2018 was 28.8% higher compared to the same season in 2017 (Table 1).

Maximum canopy and forage peanut heights had lower sample means during dry season (autumn and winter) in both years (Table 1). There was an 11.4% drop from 2017 to 2018 for the maximum height sample mean reached by the canopy, while the maximum height of the forage peanut was similar in both years. Similar to the maximum canopy height, the shade zone sample mean in 2017 was approximately 11% smaller than in 2018. The highest and lowest shade zone sample means were observed during the summer and winter, respectively, in both years (Table1). In 2017, the highest and lowest LI sample means were observed during the summer and winter, 83.3 and 76.1%, respectively. However, LI sample mean in 2018 was higher during the spring (90.9%) and lower during the autumn (81.8%), this variable being 7.4% higher in 2018 compared to 2017 (Table 1).

The lowest sample means of LAI were observed during the winter in both years (Table 1). Total LAI sample means were similar during the summer and spring (3.74 and 3.75, respectively) in 2017. In 2018, total LAI mean declined from summer to winter and then a marked increase during the spring (4.98). The highest palisadegrass LAI means were observed during the rainy (summer and spring) season in both years. The highest forage peanut LAI means were found during the spring in both years but increasing 41.7% in 2018 compared to 2017. When comparing the general forage peanut LAI sample mean for each year, there was a 11.1% increase in forage peanut contribution to the total LAI.

Palisadegrass leaf and stem lengths were greater in 2017 compared to 2018 (Table 1). The highest leaf length sample means were verified during the spring in both years, but in 2017 it was 19.3% higher than in 2018. The greatest palisadegrass stem length mean was observed during the summer in both years.

**Table 1.** Biomass, structural and morphogenetic characteristics means of palisadegrass-forage peanut mixed pastures under continuous stocking over 2-year experiment

| Variable | Summer/17 | Autumn/17 | Winter/17 | Spring/17 | 2017 | Summer/18 | Autumn/18 | Winter/2018 | Spring/2018 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| Canopy height, cm | 23.8 | 23.8 | 17.1 | 21.8 | 21.7 | 23.1 | 20.3 | 17.2 | 22.8 | 20.8 |
| Herbage mass, kg DM ha$^{-1}$ | 10637 | 10642 | 9541 | 11278 | 10525 | 9409 | 9903 | 9810 | 10053 | 9794 |
| Green mass, kg DM ha$^{-1}$ | 5808 | 4983 | 3585 | 4879 | 4809 | 5452 | 4162 | 3261 | 5919 | 4699 |
| Dead material mass, kg DM ha$^{-1}$ | 4732 | 5659 | 5956 | 6399 | 5687 | 3957 | 5741 | 6549 | 4134 | 5095 |
| Palisadegrass mass, kg DM ha$^{-1}$ | 4638 | 3641 | 2445 | 3120 | 3455 | 3094 | 2450 | 1723 | 3273 | 2635 |
| Forage peanut mass, kg DM ha$^{-1}$ | 1147 | 1342 | 1140 | 1759 | 1347 | 2358 | 1712 | 1538 | 2637 | 2061 |
| Palisadegrass tiller density, tiller m$^{-2}$ | 552 | 761 | 522 | 619 | 613 | 606 | 513 | 445 | 488 | 513 |
| Forage peanut stolon density, stolon m$^{-2}$ | 132 | 98.8 | 101 | 152 | 121 | 166 | 81.6 | 72.1 | 213 | 133 |
| Maximum canopy height, cm | 29.1 | 27.1 | 26.6 | 29.1 | 29.8 | 27.1 | 25.4 | 24.1 | 29.0 | 26.4 |
| Maximum legume height, cm | 20.8 | 20.5 | 17.1 | 22.0 | 20.1 | 23.1 | 18.4 | 17.0 | 23.0 | 20.4 |
| Shade zone, cm | 9.02 | 6.91 | 6.03 | 6.06 | 7.01 | 7.55 | 5.61 | 5.38 | 6.55 | 6.27 |
| Botanical composition, % legume | 19.8 | 26.6 | 32.9 | 34.8 | 28.5 | 41.6 | 39.9 | 43.9 | 44.2 | 42.4 |
| Light interception, % | 83.3 | 82.0 | 76.1 | 81.0 | 80.6 | 85.8 | 81.8 | 83.9 | 90.9 | 86.6 |
| Total leaf area index | 3.74 | 3.36 | 1.67 | 3.75 | 3.13 | 3.84 | 1.98 | 1.53 | 4.98 | 3.09 |
| Palisadegrass leaf area index | 2.94 | 2.43 | 1.11 | 2.50 | 2.24 | 2.38 | 1.44 | 0.879 | 2.73 | 1.86 |
| Forage peanut leaf area index | 0.804 | 0.933 | 0.563 | 1.30 | 0.89 | 1.45 | 0.566 | 0.623 | 2.23 | 1.22 |
| Palisadegrass leaf length, cm | 17.9 | 17.0 | 14.5 | 18.1 | 16.9 | 14.2 | . | 13.8 | 14.6 | 14.1 |
| Palisadegrass stem length, cm | 17.4 | 9.94 | 8.52 | 10.9 | 11.7 | 9.58 | . | 8.14 | 7.21 | 8.30 |
| Palisadegrass LELR[a], cm day$^{-1}$ | 1.25 | 0.610 | 0.229 | 1.06 | 0.786 | 1.39 | . | 0.417 | 1.32 | 1.04 |
| Palisadegrass LAPR[b], cm day$^{-1}$ | 0.082 | 0.044 | 0.027 | 0.100 | 0.063 | 0.102 | . | 0.042 | 0.090 | 0.077 |
| Palisadegrass LSR[c], cm day$^{-1}$ | 0.471 | 0.221 | 0.240 | 0.345 | 0.319 | 0.312 | . | 0.133 | 0.216 | 0.220 |
| Palisadegrass SELR[d], cm day$^{-1}$ | 0.048 | 0.014 | 0.001 | 0.028 | 0.023 | 0.034 | . | 0.007 | 0.034 | 0.025 |
| Forage peanut leaf area, cm$^2$ | 8.10 | 7.08 | 6.60 | 8.77 | 7.64 | 10.2 | 7.15 | 5.01 | 6.53 | 7.21 |
| Forage peanut petiole length, cm | 1.95 | 1.94 | 1.65 | 1.87 | 1.85 | 2.32 | 2.16 | 1.50 | 1.57 | 1.89 |
| Forage peanut stolon length, cm | 20.7 | 12.1 | 10.4 | 27.6 | 17.7 | 23.6 | 12.7 | 6.94 | 15.5 | 14.7 |
| Forage peanut internode length, cm | 2.20 | 1.11 | 1.02 | 2.24 | 1.64 | 2.08 | 1.34 | 0.865 | 1.43 | 1.43 |
| Forage peanut LELR, cm day$^{-1}$ | 1.23 | 0.388 | 0.363 | 1.74 | 0.931 | 1.25 | 0.190 | 0.329 | 1.24 | 0.754 |
| Forage peanut LAPR, leaf day$^{-1}$ | 0.132 | 0.062 | 0.062 | 0.143 | 0.100 | 0.116 | 0.042 | 0.066 | 0.177 | 0.100 |
| Forage peanut LSR, cm day$^{-1}$ | 0.712 | 0.489 | 0.346 | 0.473 | 0.505 | 0.660 | 0.346 | 0.110 | 0.203 | 0.330 |
| Forage peanut SELR, cm day$^{-1}$ | 0.285 | 0.071 | 0.039 | 0.544 | 0.234 | 0.356 | 0.009 | 0.019 | 0.416 | 0.201 |

[a]Leaf elongation rate; [b]Leaf appearance rate; [c]Leaf senescence rate; [d]Stem/Stolon elongation rate

Palisadegrass morphogenetic LELR and LAPR in 2018 were greater than those observed in 2018, except during the spring, with a slightly lower mean in 2018, compared to the same season in 2017 (Table1). Greater LSR means were observed in 2017, with the greatest value during the summer (0.471 cm day$^{-1}$). The highest SELR sample means were observed during the summer and spring in both years (Table 1).

The greatest forage peanut leaf area was observed during the summer of 2018 (10.2 cm$^2$), while in 2017 this occurred during the spring (8.77 cm$^2$), with the lowest mean estimated during the winter in both years (Table 1). In 2017, the greatest sample means of petiole length were observed during the summer and autumn (1.95 and 1.94 cm, respectively), decreasing during the winter (1.65 cm) and increasing again during the spring (1.87 cm). In 2018, petiole length sample means were similar during the winter and summer (1.50 and 1.57 cm, respectively), lower than those observed during the summer and autumn (2.32 and 2.16 cm, respectively). Average yearly stolon and internode length means were 17 and 12.8 % greater in 2017 compared to those observed in 2018, with lower sample means during the winter in both years (Table 1).

Forage peanut LELR were greater during the spring and summer and decreased during autumn and winter in both years, 19% higher in 2017 than in 2018 (Table 1). Forage peanut LAPRs were the same during the autumn and winter of 2017 (0.062 leaf day$^{-1}$) and the greatest value was observed during the spring in that year (0.143 leaf day$^{-1}$). Similarly, in 2018 the season with the highest forage peanut LAPR sample mean was spring (0.177 leaf day$^{-1}$), followed by summer (0.116 leaf day$^{-1}$), winter (0.066 leaf day$^{-1}$) and autumn (0.042 leaf day$^{-1}$), the latter the lowest sample mean of that year. The highest forage peanut LSRs were observed during the summer, followed by autumn, spring and winter in both years, and in 2017 the average was 34.7% higher compared to 2018. The greatest forage peanut SELR were observed during the spring in both years (0.544 and 0.416 cm day$^{-1}$ in 2017 and 2018, respectively), and during the winter in 2017 (0.039 cm day$^{-1}$) and autumn in 2018 (0.009 cm day$^{-1}$).

Regarding spatial analysis, when "pure nugget" model is the best semivariogram fit, it is assumed that there is no spatial dependence among sampled points, making it impossible to construct contour map by kriging. The darker the map shades, the higher the numbers, and the spherical model best fit the semivariograms that generated the contour maps.

Figure 5 contains spatial distribution maps of canopy height, herbage, green and dead material masses over seasons. Spatial dependence structure was observed in all seasons of both years of experiment, except autumn/2018 for herbage mass, and summer/2018 and autumn/2018 for green mass (Figure 5). In general, the highest canopy height, herbage mass, green mass and dead material mass were concentrated in the southern extremity of all maps, with displacement of such darker outlines from left to right over the seasons (Figure 5). The maps of dead material mass follow the same pattern of displacement as the canopy height over the seasons, only differing in the summer/2017 map, where a diagonal strip going from northwest to southeast occurred where the largest dead material mass quantities are located. That strip gradually dispersed over the following seasons, concentrating the
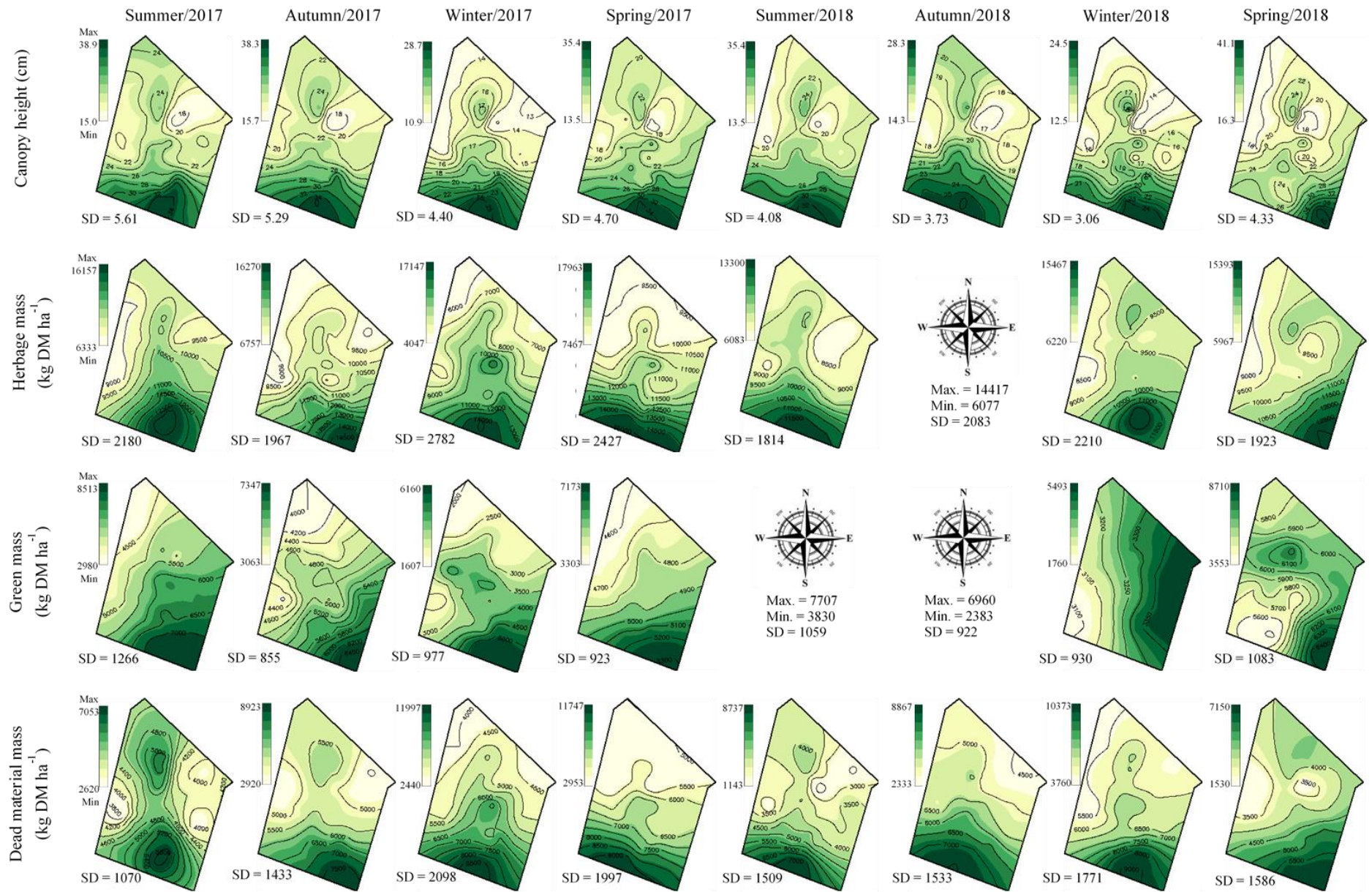
**Figure 5.** Spatial distribution, standard deviation (SD), minimum (Min) and maximum (Max) values of canopy height (cm), herbage mass, green mass and dead material mass (kg DM ha-1) in a palisadegrass-forage peanut mixed pasture over seasons of 2-year experiment.

highest dead material mass in the paddock southern extremity (Figure 5). There was a reduction of 21.4 and 17.0 % in sample standard deviation of canopy height and herbage mass, respectively, from 2017 to 2018.

Spatial variability maps are shown in Figure 6. Spatial dependence structure was observed in all seasons of both years for all Figure 6 variables. Basically, the same pattern of shades distribution observed in the Figure 6 maps occurred in the maps of palisadegrass mass and density, where greater amounts were concentrated in the southern / southeast paddock extremity. The opposite occurs in forage peanut mass and density maps, in which lighter shades are located at the south / southeast paddock extremity, with small variation in such distribution pattern throughout the seasons. As with the spatial mass distribution of dead material during the summer/2017 (Figure 5), the same diagonal strip is observed from northwest to southeast, but in opposite tones, where the smallest forage peanut mass and stolon amounts were observed in that region (Figure 6). Standard deviations of palisadegrass mass and density decreased by 28.5 and 16.5%, respectively, and forage peanut increased by 24.5 (mass) and 36.9% (density) from 2017 to 2018.

Figure 7 gathers spatial variability maps of shade zone, botanical composition (legume %) and maximum heights reached by the canopy and forage peanut. Spatial dependence structure was observed in all seasons of both years of experiment for all Figure 7 variables. Similar to the spatial distribution concerning palisadegrass observed in the Figure 6, the darker shades are mainly concentrated in map lower portions due to greater canopy and forage peanut heights. Botanical composition spatial distribution exhibited the same pattern as those observed in the forage peanut mass maps (Figure 6), in which lighter shades are located at the south / southeast paddock extremity, with small variation in such distribution pattern throughout the seasons. Moreover, the same northwest-southeast strip in the summer/2017 map where smaller values were found. Standard deviations observed in 2017 for maximum canopy height and botanical composition were around 20% lower compared to 2018.

Spatial variability maps of LI and total palisadegrass and forage peanut LAI are shown in Figure 8. Spatial dependence structure was observed in all seasons of both years of experiment for all Figure 8 variables. The darker shades on LI maps range from spots in the central portion to the paddock's south region, where the greatest LIs are concentrated. Standard deviation of LI was 24% smaller from 2017 to 2018. When checking the second map line (Figure 8), darker shades are concentrated over the east paddock portion, where total LAIs were greater, except for winter/2017, when the darker shades were limited to the south region. There was a more dispersed distribution of total LAI along the paddock during summer/2018 and a shift from east to the map centre from winter/2018 to spring/2018. Palisadegrass LAI maps basically followed the same contour pattern observed in palisadegrass mass maps (Figure 6), with the highest values located in the southeastern paddock portion. Superficially, the opposite of what was observed in the palisadegrass LAI maps occurred with forage peanut LAI maps, therefore, the lowest values are found from south to southeast of the paddock throughout most seasons (Figure 8).

**Figure 6.** Spatial distribution, standard deviation (SD), minimum (Min) and maximum (Max) values of palisadegrass and forage peanut densities (tiller m$^{-2}$; stolon m$^{-2}$) and green mass (kg DM ha$^{-1}$) in a palisadegrass-forage peanut mixed pasture over seasons of 2-year experiment.
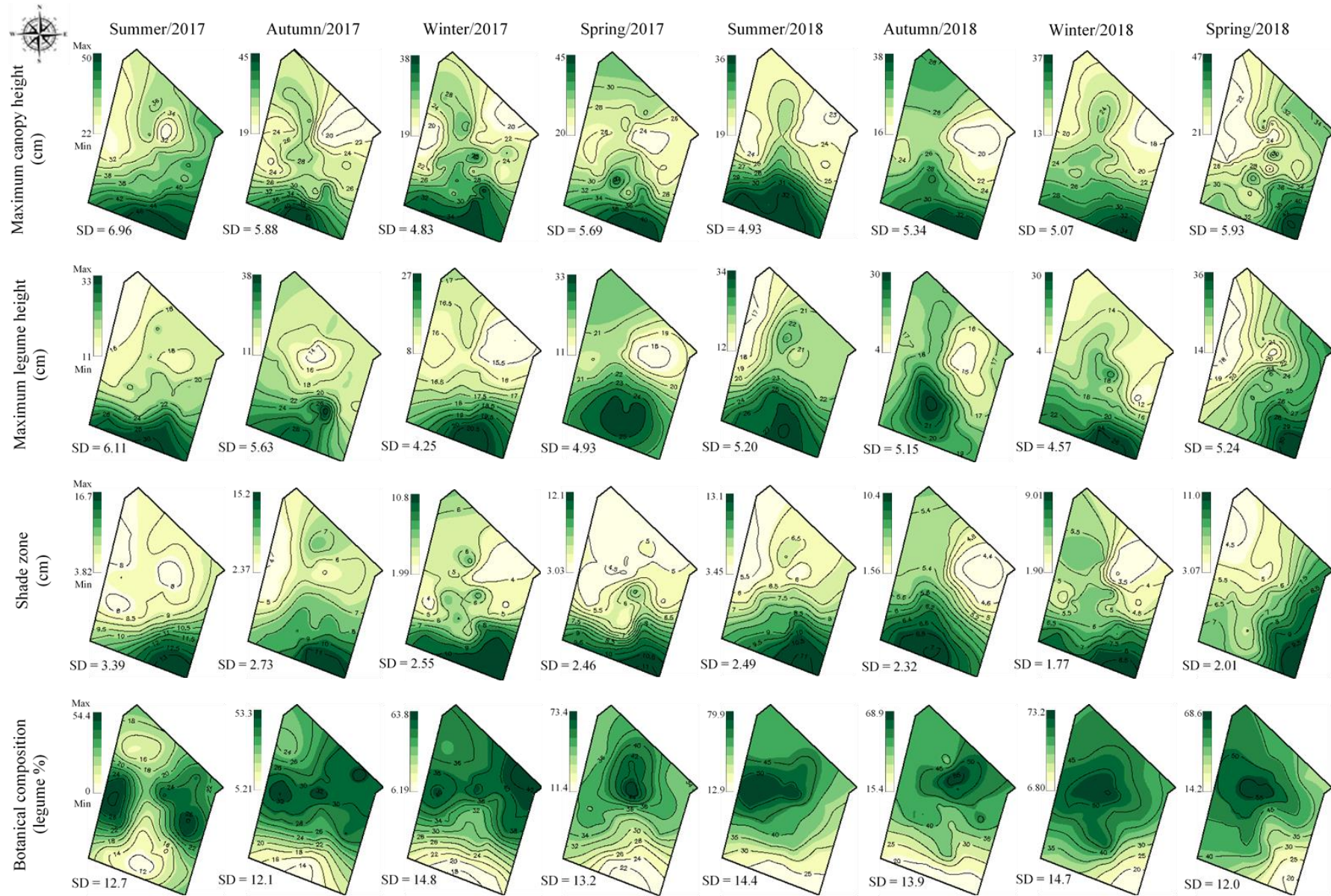
**Figure 7.** Spatial distribution, standard deviation (SD), minimum (Min) and maximum (Max) values of maximum canopy and legume heights (cm), shade zone (cm) and botanical composition (legume %) in a palisadegrass-forage peanut mixed pasture over seasons of 2-year experiment.
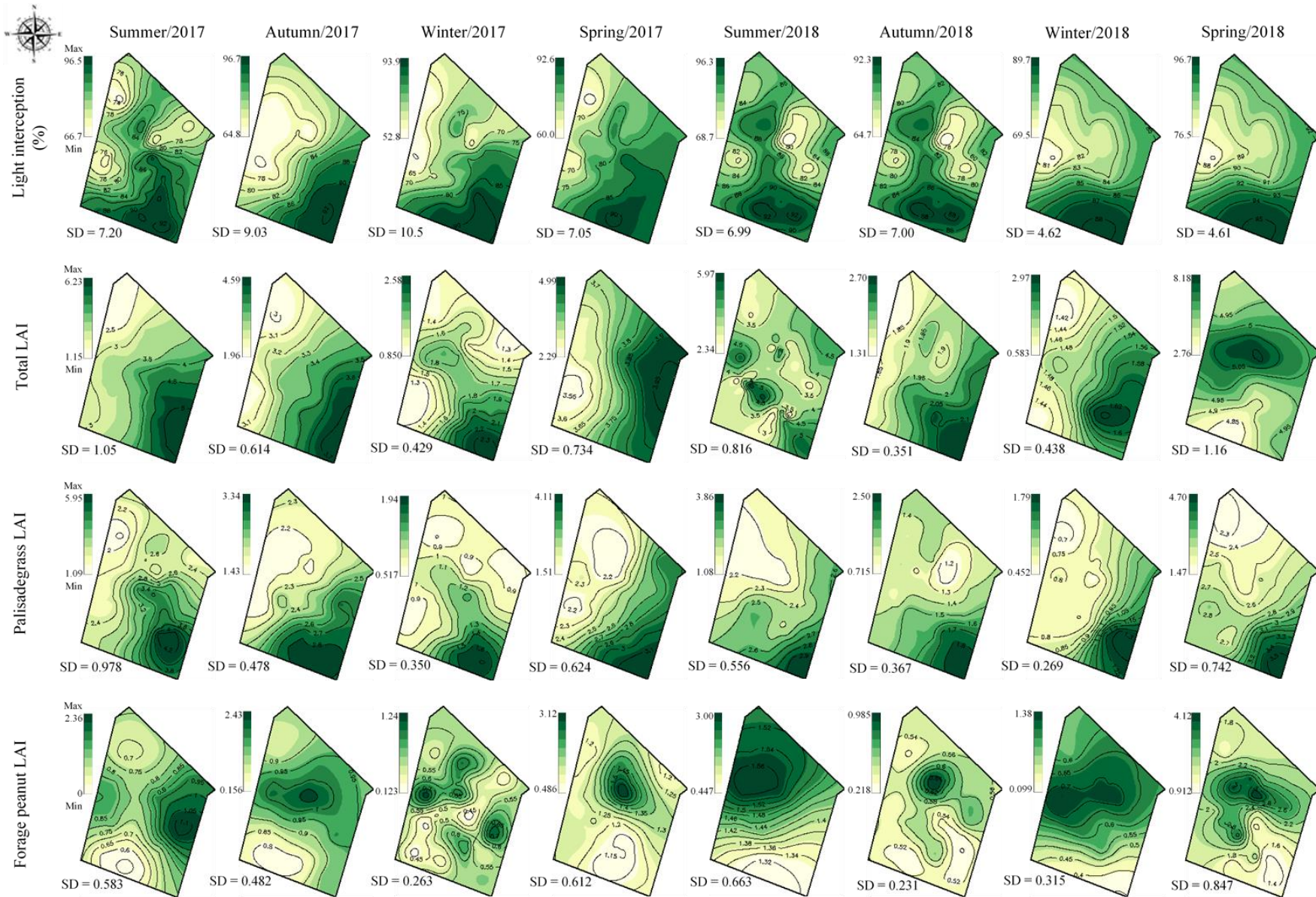
**Figure 8.** Spatial distribution, standard deviation (SD), minimum (Min) and maximum (Max) values of light interception (%), total, palisadegrass and forage peanut leaf area index (LAI) in a palisadegrass-forage peanut mixed pasture over seasons of 2-year experiment.

Figure 9 contains the spatial variability of palisadegrass leaf and stem lengths. Spatial dependence structure was observed in all seasons of both years except autumn/2017 for leaf length. Both leaf length and stalk followed essentially the same pattern of spatial variability as that observed for canopy height (Figure 5). Darker shades representing higher leaf length were concentrated further south of the paddock in all evaluated seasons, with projections of these shades extended towards the centre during the summer/2017, spring/2017 and spring/2018 and north-eastern direction during winter/2018 (Figure 9). In general, what is observed in the leaf length maps, is repeated in the stem length maps, with slight differences where the longest stem lengths appear in the paddock's south region, without much extension to the other map regions throughout the seasons, except during the spring/2017, when there was a more scattered distribution of the longest stem across the paddock (Figure 9). Standard deviation of stem length was 37.3% shorter from 2017 to 2018.

Spatial variability of palisadegrass morphogenetic characteristics appear in the Figure 10. There were spatial structure absences for all the variables in several seasons. There was spatial dependence structure for LELR only during the winter/2017, summer/2018, and winter/2018 seasons. During summer/2018 and winter/2018, the areas with greater palisadegrass LELR were concentrated in the paddock southern portion (Figure 10), a pattern similar to the canopy height maps (Figure 4). The opposite happened with palisadegrass LAPR during the same seasons, with lighter shades concentrated in southern regions of the paddock. During the summer/2017, smaller palisadegrass LAPRs were also located further south, with a small light spot projected in the paddock centre. Although there was spatial dependence structure in both years for most of seasons (except autumn/2017), palisadegrass LSR was extremely diverse over time and space, dissimilar to sequential location and displacement for darker (or lighter) shades over seasons (third maps line). Regarding palisadegrass SELR, a large proportion of the summer and autumn/2017 map areas were occupied by lighter shades, representing lower rates, while during the winter/2017, these lower rates started being more limited to the north-centre paddock region, extending towards the northeast, with the largest palisadegrass SELRs limited to the south. Darker spots in the SELR maps during spring/2018 were spread more heterogeneously across the paddock (Figure 10). The standard deviations of three variables shown in Figure 10 were smaller in 2018, compared to 2017.

Spatial variability of structural forage peanut characteristics is shown in Figure 11. Spatial dependence structure was observed for all variables in all seasons, except for internode length during autumn/2017 and spring/2017, and for stolon length during autumn/2017, winter/2017, spring/2017, and spring/2018. Greater forage peanut leaf areas and petiole, internode and stolon lengths were observed again further south of the paddock in most seasons, except darker shades of petiole length map during autumn/2018, which extended from southeast to centre-west (Figure 11).
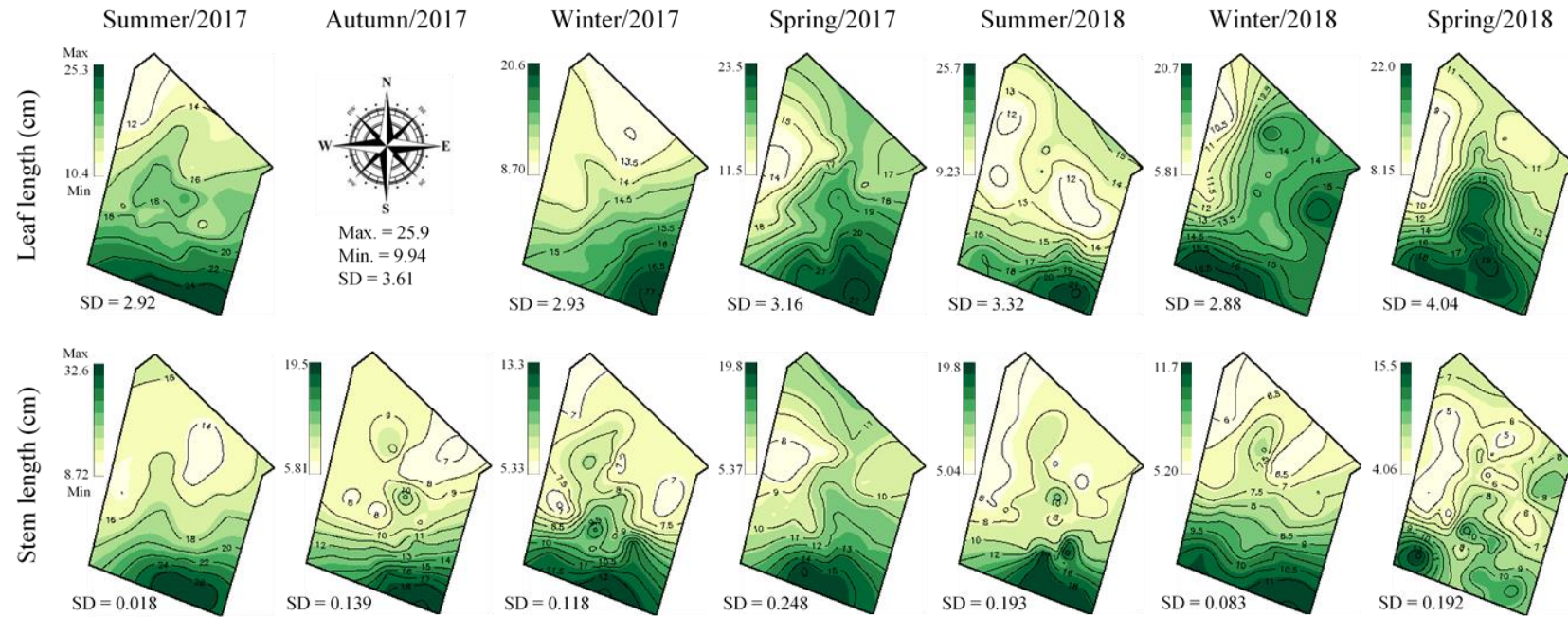
**Figure 9.** Spatial distribution, standard deviation (SD), minimum (Min) and maximum (Max) values of palisadegrass structural characteristics in a palisadegrass-forage peanut mixed pasture over seasons of 2-year experiment.
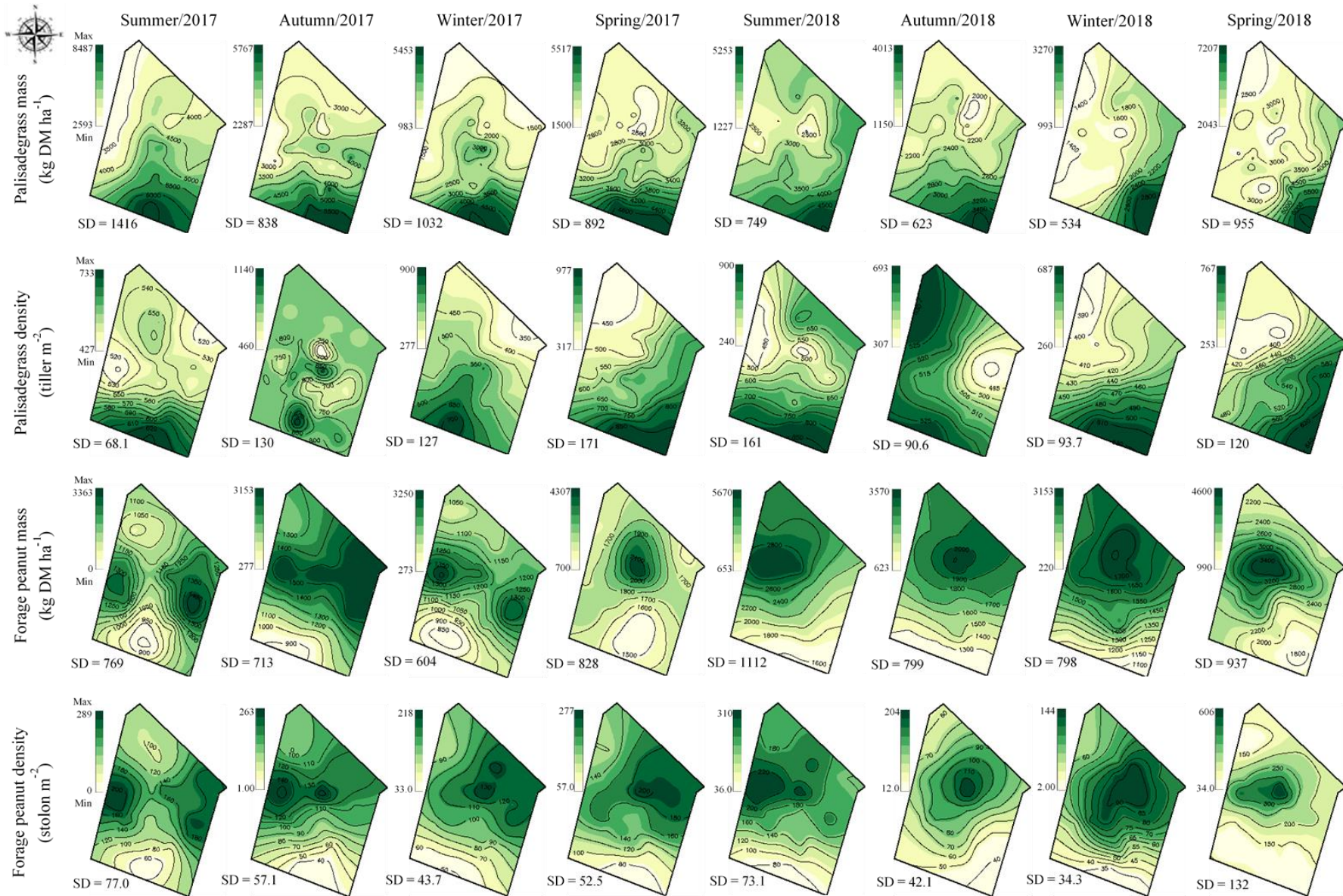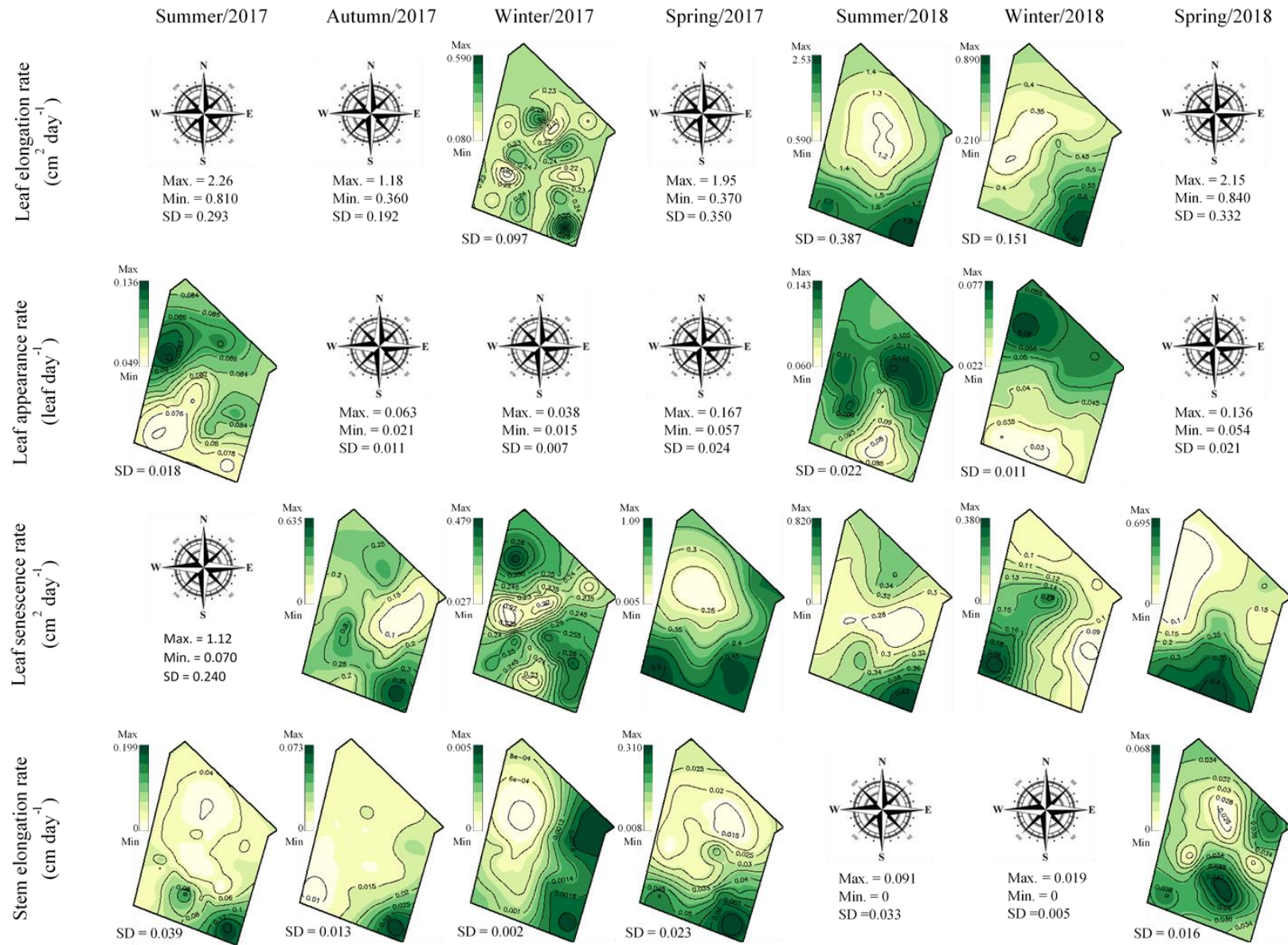
**Figure 10.** Spatial distribution, standard deviation (SD), minimum (Min) and maximum (Max) values of palisadegrass morphogenetic characteristics in a palisadegrass-forage peanut mixed pasture over seasons of 2-year experiment.

Spatial variability maps are shown in the Figure 12. Spatial dependence structure was observed in all seasons of both years for all variables, except for LAPR during autumn/2017, for LSF during the winter of both years, and for SELR during spring/2018. Greater LELR tended to be located mainly in the southern region of most maps, except during the first two seasons evaluated, with darker spots more spread out. The opposite pattern was observed in the LAPR maps, in which the southern region had lower rates represented by lighter shades, with a slight variation of this pattern observed during spring/2017 and autumn/2018. As with palisadegrass LSR spatial variability, map contours were extremely diverse over time and across space, which did not show similar and sequential location and/or displacement for darker (or lighter) shades over seasons (third map line). Darker and lighter patches were more widely distributed across the area in most SELR maps, except during winter/2017 and summer/2018, with larger SELR located further southeast and south paddock regions, respectively. Lower SELR standard deviations were observed during the dry season (autumn and winter) in both years (Figure 12).

Figure 13 contains correlations between canopy height and biomass variables. Strong correlation was observed between canopy height and herbage mass over most seasons. Correlations between canopy height and green were moderate during the summer (r = 0.609) and winter/2017 (r = 0.658), and weaker (r < 0.50) during the other seasons. From autumn/2017 to winter/2018 there was a strong correlation (r > 0.700) between canopy height and dead material mass, and moderate during the summer/2017 (r = 0.644) and spring/2018 (r = 0.653). Palisadegrass mass and canopy height observations were strongly correlated over seasons and-years, except during winter/2018 (r = 0.562). Correlations between canopy height and forage peanut mass were negative and moderate to low. The strongest and lowest correlations between canopy height and forage peanut mass were observed during summer/2017 (r = -0.493) and winter/2018 (r = -0.154), respectively.

Figure 14 includes correlations between canopy height and shade zone, LI, total LAI, palisadegrass LAI and forage peanut LAI. Approximately 64% of canopy height variations could explain shade zone variations throughout the 2 years. Light interception variation was strong and positively explained by canopy height variation during summer/2017 (r = 0.792), winter/2017 (r = 0.726), summer/2018 (r = 0.731) and autumn/2018 (r = 0.807) and moderately explained during autumn/2017 (r = 0.617), spring/2017 (r = 0.669), winter/2018 (r = 0.648) and spring/2018 (r = 0.678). Total and forage peanut LAI variations are poorly explained by canopy height variations (r < 0.500) over seasons and years. Correlations between canopy height and palisadegrass LAI were moderate during summer/2017 (r = 0.599), autumn/2017 (r = 0.498), winter (r = 0.620) autumn/2018 (r = 0.617), while the other correlations were below 0.500. Correlations between canopy height and botanical composition were negative and remained close to -0.60 during most seasons, except winter/2018 (r = -0.456).
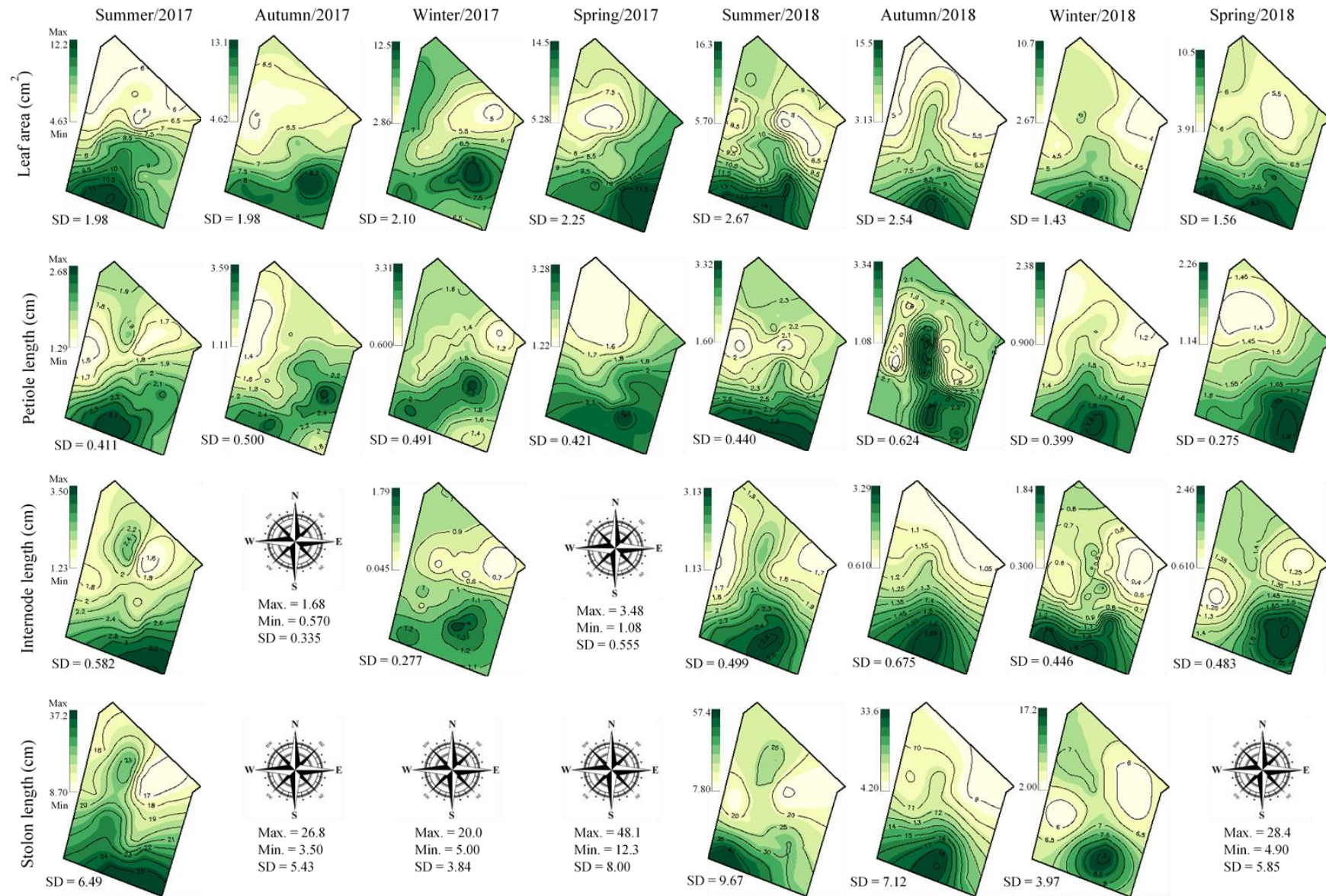
**Figure 11.** Spatial distribution, standard deviation (SD), minimum (Min) and maximum (Max) values of forage peanut structural characteristics in a palisadegrass-forage peanut mixed pasture over seasons of 2-year experiment.
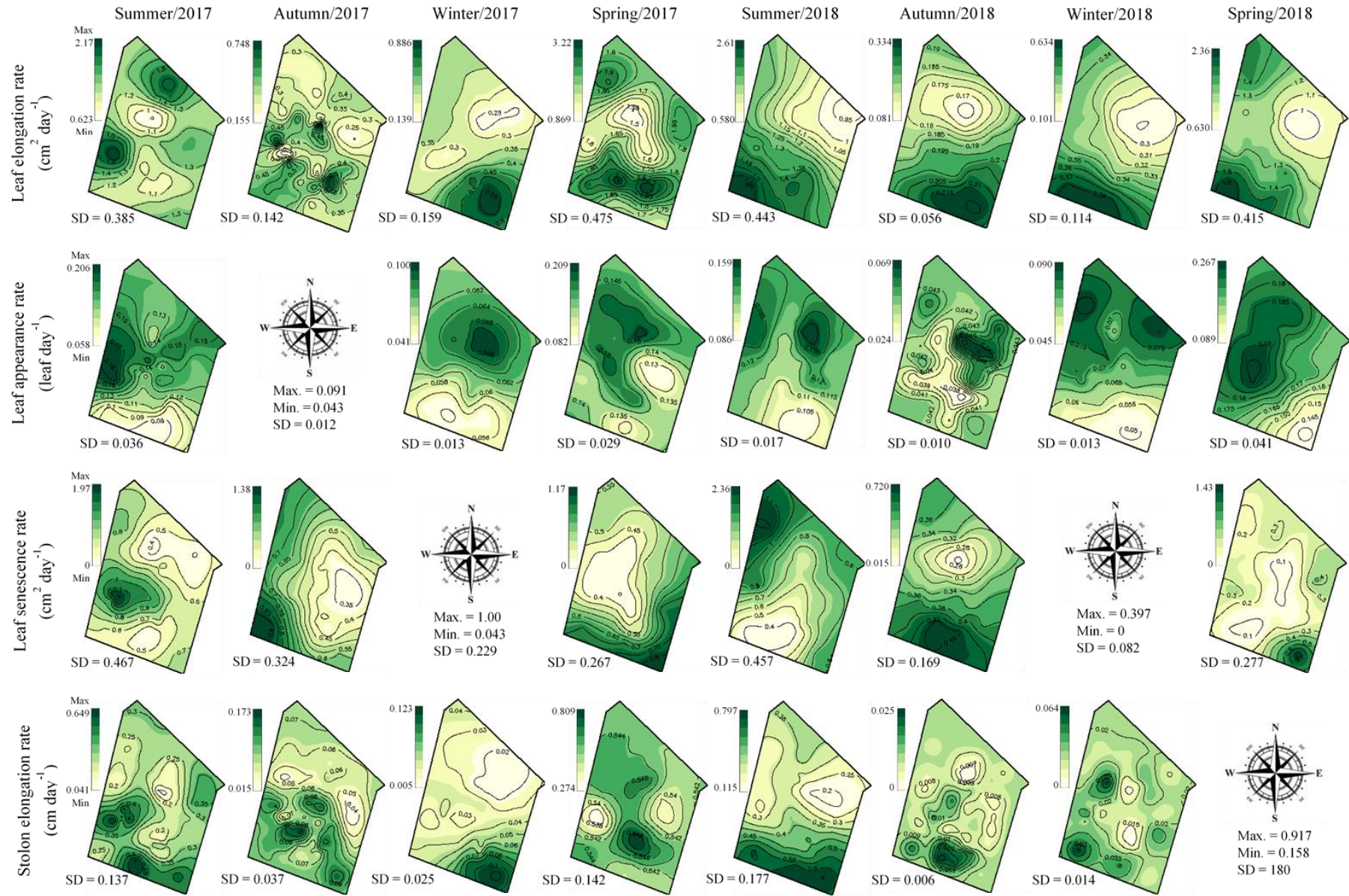
**Figure 12.** Spatial distribution, standard deviation (SD), minimum (Min) and maximum (Max) values of forage peanut morphogenetic characteristics in a palisadegrass-forage peanut mixed pasture over seasons of 2-year experiment.
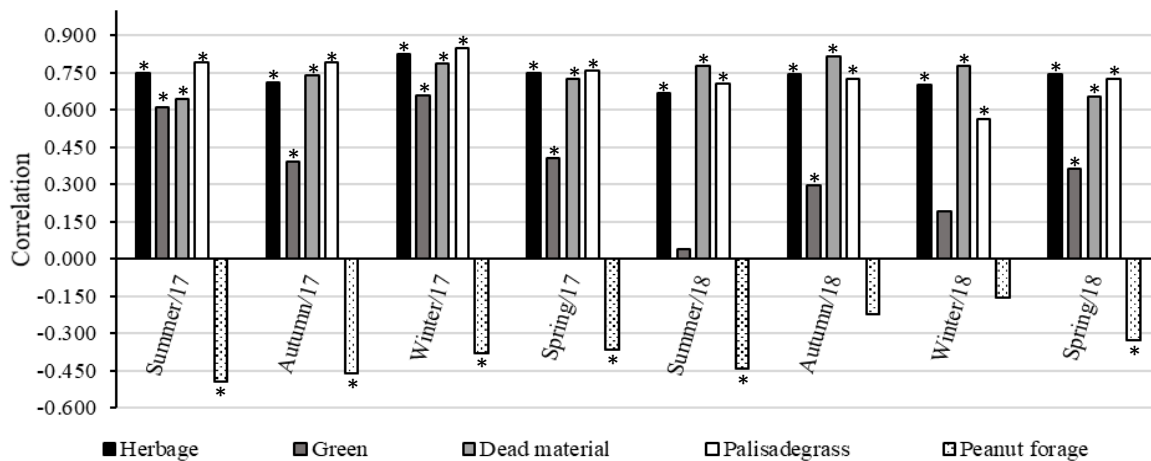
**Figure 13.** Correlations between canopy height and herbage, green, dead material, palisadegrass and forage peanut mass in a palisadegrass-forage peanut mixed pasture over 2-year experiment seasons. (*r is significant, $\alpha = 0.05$).
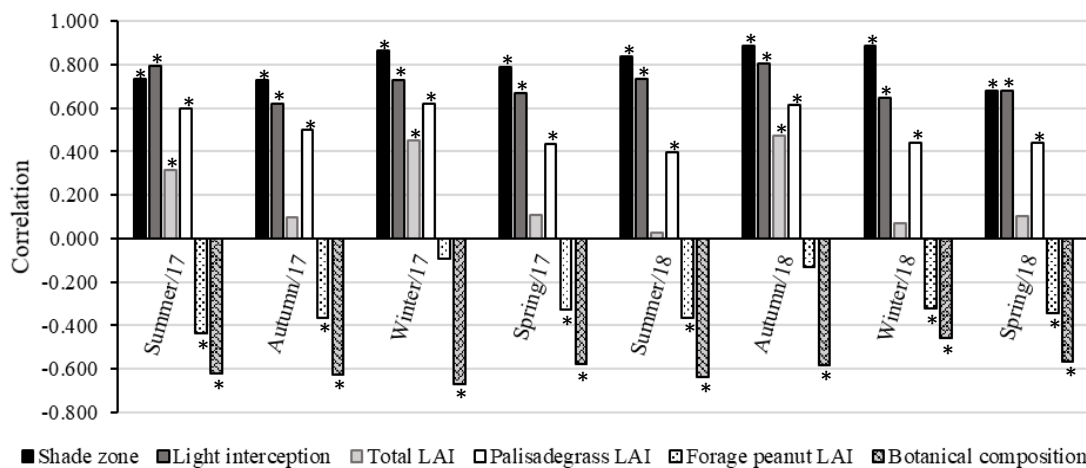


**Figure 14.** Correlations between canopy height and shade zone, light interception, total LAI (leaf area index), palisadegrass LAI, forage peanut LAI and botanical composition (legume %) in a palisadegrass-forage peanut mixed pasture over seasons of 2-year experiment. (*r is significant, $\alpha = 0.05$).

There were positive correlations between canopy height and palisadegrass structural characteristics, as shown in Figure 15. Canopy height and density were strongly correlated during summer/2017 (r = 0.741) and summer/2018 (r = 0.812), moderate during winter/2017 (r = 0.626), spring/2017 (r = 0.648) and winter/2018 (r = 0.510) and low during autumn/2017 (r = 0.416) and spring/2018 (r = 0.346). Canopy height variations explain 59% of palisadegrass leaf length variations during the summer (r = 0.768 in 2017 and r = 0.764 in 2018), approximately 32% during the spring (r = 0.768 in 2017 and r = 0.764 in 2018) and less than 12% during other seasons. Palisadegrass stem length was strongly correlated with canopy height (r > 0.700) throughout the entire experiment except during spring/2017 (r = 0.472).
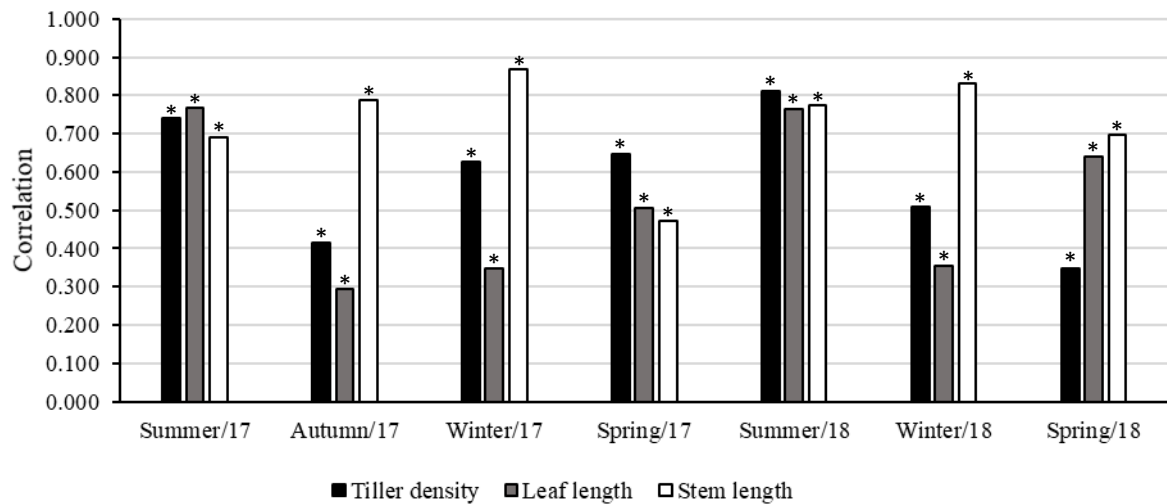
**Figure 15.** Correlations between canopy height and palisadegrass structural characteristics in a palisadegrass-forage peanut mixed pasture over seasons of 2-year experiment. (*r is significant, α = 0.05).

Correlations between canopy height and palisadegrass morphogenetic characteristics can be observed in Figure 16. These were low over the first three seasons evaluated. Canopy height and palisadegrass SELR were moderately correlated during spring/2017 (r = 0.639) and poorly correlated until the experiment end (r < 0.500). Correlations between canopy height and palisadegrass LELR remained low throughout the experiment, as well as palisadegrass LSR. Low and negative correlations were found between canopy height and palisadegrass LAPR throughout the experiment, ranging from -0.253 to -0.426, except during summer/2018, when a moderate correlation was observed (r = -0.584).
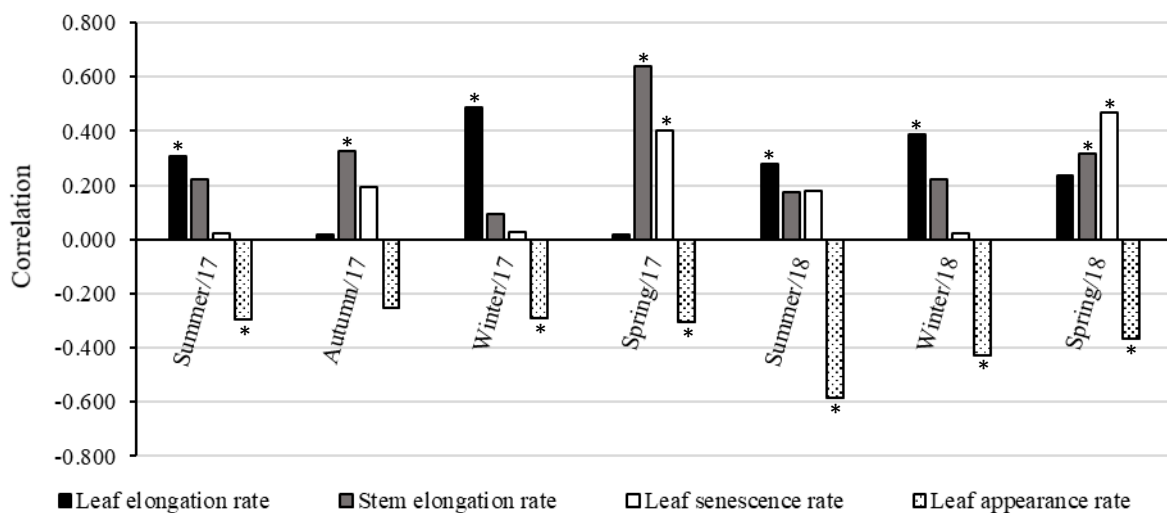


**Figure 16.** Correlations between canopy height and palisadegrass morphogenetic characteristics in a palisadegrass-forage peanut mixed pasture over seasons of 2-year experiment. (*r is significant, α = 0.05).

Correlations between canopy height and forage peanut structural characteristics are presented in Figure 17, all of them positive, except for stolon density which were negative. Analysing canopy

vertical structure, it was observed that canopy height variations explained on average more than 50% of maximum legume height variation (r > 0.700) throughout the 2-year experiment. Correlations between canopy height and forage peanut leaf area were on average low (r = 0.453) and moderate (r = 0.677) over seasons in 2017 and 2018, respectively, reaching 0.699 only during autumn/2018. Petiole length and canopy height were strongly correlated during summer/2017 (r = 0.742) and winter/18 (r = 0.725), moderately during the summer (r = 0.691), autumn (r = 0.685) and spring (r = 0.563) in 2018 and poorly correlated during the other seasons (r <0.500). The strongest correlations between canopy height and forage peanut internode length were observed during summer/2017 (r = 0.876), summer/2018 (r = 0.779) and winter/2018 (r = 0.805), moderate during winter/2017 (r = 0.529), autumn/2018 (r = 0.638) and spring/2018 (r = 0.609), and low in other seasons. Canopy height and stall length were more strongly correlated in 2018 than in 2017, with the highest value observed during the summer (r = 0.701) and gradually decreasing until spring (r = 0.451). The strongest correlations between canopy height and stolon density were obtained from summer/2017 to summer/2018, ranging between -0.628 and -0.758; during the other seasons these variables were poorly correlated.
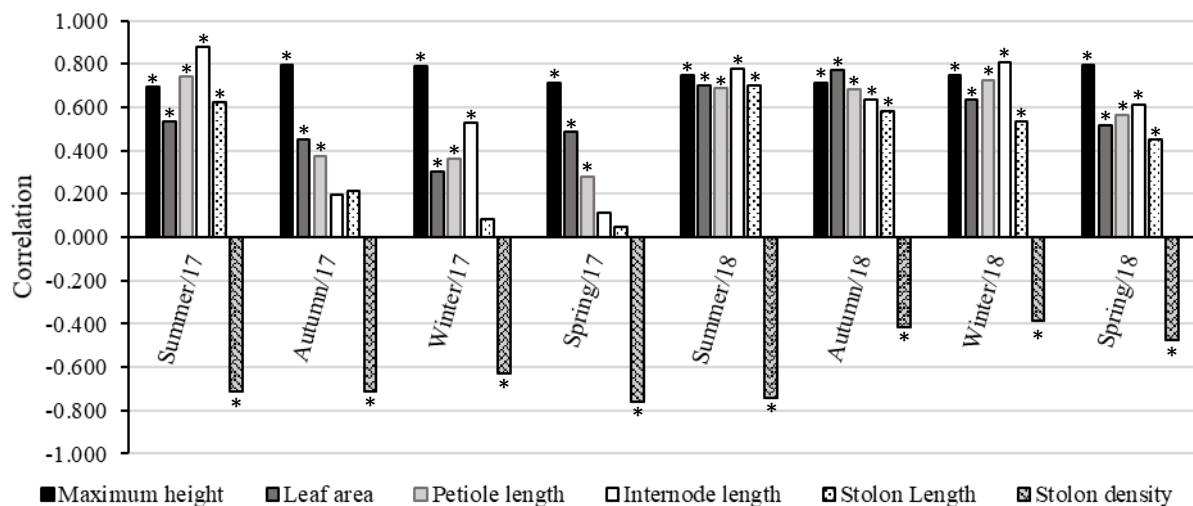


**Figure 17.** Correlations between canopy height and forage peanut structural characteristics in a palisadegrass-forage peanut mixed pasture over seasons of 2-year experiment. (*r is significant, α = 0.05).

Correlations between canopy height and forage peanut morphogenetic characteristics can be seen in Figure 18. Canopy height variation explained forage peanut leaf elongation and senescence rates poorly throughout the experiment. Correlations between canopy height and forage peanut SELR were moderate and strong during winter/2017 (r = 0.616) and summer/2018 (r = 0.708), respectively, and low during the other seasons (r < 0.500). More than 50% of canopy height variation explain forage peanut LAPR variations during summer/2017 (r = -0.850) and winter/2018 (r = -0.775). These variables correlated moderately during winter/2017 (r = -0.616), summer/2018 (r = -0.609) and autumn/2018 (r = -0.529) and weakly during the other seasons.
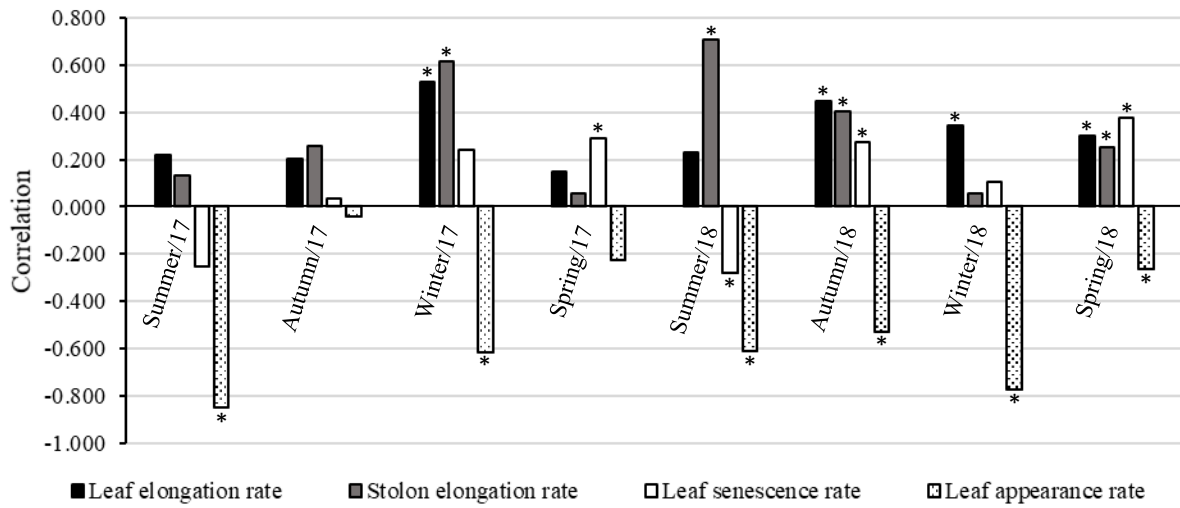
**Figure 18.** Correlations between canopy height and forage peanut morphogenetic characteristics in a palisadegrass-forage peanut mixed pasture over seasons of 2-year experiment. (*r is significant, α = 0.05).

**DISCUSSION**

In geostatistics, spatial dependence means that neighbouring sampling points had more similar values compared to more distant sampling points (Kent et al., 2006). In other words, observations are not distributed randomly in space. Regarding the other variables, no spatial dependence structure was detected for some seasons, without spatial autocorrelation (Lima et al., 2009). When constructing semivariograms, the spherical was the most adequate mathematical model to describe the point clouds for all variables in the present study. The literature has a few studies in which canopy height and herbage mass in *Brachiaria* pasture also obtained a better data adjustment to the spherical model (Paula Neto et al., 2014, Grego et al., 2012), indicating similarity in spatial dependence between single canopies and mixtures with legumes. Spatial dependence was detected at all seasons for canopy height, dead material mass (Figure 5), palisadegrass and forage peanut masses and densities (Figure 6), maximum canopy and legume heights, shade zone, botanical composition (Figure 7), LI, LAI (Figure 8), palisadegrass stem length (Figure 9), forage peanut leaf area and petiole length (Figure 11) and forage peanut LELR (Figure 12).

As intended by the target of canopy height management, canopy height mean was kept between 20 and 25 cm in most seasons of the experimental period, except for winter, when the pasture reached a height mean of 17 cm (Figure 4, Table 1). It is important adjusting the stocking rate to maintain the height targets established for different seasons of the year (rainy and dry) thereby the pasture is kept productive in long-term (Santos et al., 2011). Tamele et al. (2017) found a more stable plant community the palisadegrass-forage peanut canopy was maintained around 20 cm, although under mechanical cutting.

Mixed canopy height was spatially heterogeneous (Figure 5), just as in monospecific canopies under continuous stocking, with wide amplitude in its structural conditions (Hirata, 2002). Animal grazing behaviour is uneven, with choice opportunity under continuous stocking (Mezzalira et al., 2013). Animals modify grazing patterns, since they are induced to alter their displacement by any characteristic with spatial dependence (Páscoa & Costa, 2007). Moreover, the different conditions of important factors such as distinct soil fertility along space, probably result in plant morphophysiological spatial variation (Machado et al., 2007).

Beyond heterogeneous grazing behaviour, deposition of excreta represents another factor influencing canopy height variability (da Silva Neto et al., 2011, Barthram et al., 2005), which may form rejection areas, where animals avoid grazing. Near the lower corner on the right of the paddock, where the highest canopy heights were mainly located (Figure 5), there was an idleness area. In that location, animals associated with other animals from neighbouring paddocks, causing localized excreta deposition. Thus, probably plant growth (mainly palisadegrass, Figure 7) was favoured, maintaining a taller canopy in that region.

Average canopy height is an important characteristic, which is highlighted in the literature, as it influences most plant structural and morphogenic characteristics, both in monoculture (Benvenutti at

al., 2016, Araujo et al., 2015, Sbrissia et al., 2010) and grass-legume mixed pastures (Homem et al., 2019, Tamele et al., 2017, Castillo et al., 2015). Even on a smaller scale, this fact was also observed in the present study, in which the canopy height affected the majority of variables evaluated (Figures 13, 14, 15, 16, 17 and 18).

The highest herbage mass sample means were observed during spring in both years, probably due to the increase in forage peanut mass production during that period (Table 1). After the canopy reached 17 cm during the winter, light quality and quantity that reached the canopy lower portion, coupled with favourable climate for growth, likely caused an increase in forage peanut development, raising its participation in the herbage mass during that season. Correlations between canopy height and herbage mass were strong in most seasons (Figure 13). It is well established in the literature that canopy height can be used as an indirect measure of herbage mass in single grass pastures (da Silva et al., 2013, da Silva et al., 2009, Aiken & Bransby, 1992). The same linear and positive relationship was found by Tamele et al. (2017), testing targets of average canopy height, kept under mechanical cut. Therefore, height may be a dependable estimator of herbage mass in a palisadegrass-forage peanut mixed canopy.

Monoculture canopies managed under continuous stocking almost always show spatial variability in their structure, mainly due to the presence of the animal grazing selectively and its excreta deposition unevenly as previously pointed (Santos et al., 2012, da Silva Neto et al., 2011). Within the same area, there are places with taller or shorter canopy, plant densities and forage masses. Moreover, there are often spaces where the ground is bare with low plant density, especially in more extensive systems with restricted soil nutrients (Paula Neto et al., 2014). In an erect grass-stoloniferous legume mixture, there is possible legume proliferation in those empty spaces, where there is no light limitation, important for its growth. However, at the beginning of the mixture establishment, grass proportion is generally higher, due to more efficient metabolism, which permits faster establishment (Phelan et al., 2015). Thus, forage peanut is initially at a disadvantage, because of its slow establishment (Cassal et al., 2013, Castillo et al., 2015). In this context, at the beginning of the experiment, the forage peanut proportion in the canopy was lower, with a few places where the density of stolon was greater (Figure 5). There was, then, concern that the animals, with their selective grazing behaviour, could preferentially consume the legume, changing the canopy botanical composition, and hence that would hurt the mixture resilience. Nevertheless, the results obtained in the present study indicate that the grazing management applied, instead of harming, favoured legume botanical contribution (Figure 4), as verified by Tamele et al. (2017) as well, in their assessments under cutting. In those places where the canopy height was lower and, therefore, shade diminished (Figure 14), forage peanut grown via clones close to the soil surface, increase the chances of rooting at the nodes (Andrade et al., 2006).

When forage peanut roots its nodes, new stolons can be raised from these buds, originating new plants, eventually independent of the parent (Andrade et al., 2006). Thus, there was a gradual increase in forage peanut population density and hence an increase in its mass production in those regions where canopy height was lower (Figure 6). Hence, the legume was more competitive in the lowest canopy

levels, as shown in the botanical composition maps (Figure 7). On the other hand, places where the canopies were higher, they were characterized by high palisadegrass density and mass and dead material mass (Figures 5 and 6), shading the canopy basal portion (Figure 7). Shade increase negatively impacts quality and quantity of the light that reaches the place where the forage peanut would develop. As a result, legumes seeking light start to grow vertically, losing the opportunity for clonal propagation and exposing its meristem to grazing (Tamele et al., 2017). Therefore, in those regions with the tallest canopy (Figure 5), forage peanut density and consequent mass were reduced (Figure 6). In contrast, palisadegrass tiller density was greater at those location where canopy was higher (Figure 6) with linear and positive correlations (Figure 15), a response pattern contrary to that observed in single palisadegrass canopies (Sbrissia et al., 2010). Tamele et al. (2017) found the same positive correlation during seasons when a high forage peanut proportion was observed. Perhaps such behaviour is a differentiated response from the grass in competition with a stoloniferous legume. When the canopy height is low, forage peanut proliferates more aggressively compared to palisadegrass (Tamele et al., 2017). Thus, palisadegrass tiller population density in the present study decreased in those lower canopy height regions (Figure 6), thereby becoming less competitive.

Light interception sample mean in 2018 was greater compared to 2017, contrary to what was observed for shade zone sample means (Table 1). That happened probably due to the greater legume LAI participation in 2018, since the forage peanut places its leaves in a planiferous arrangement (Castro et al., 2007), thereby intercepting greater light (Table 1). Forage peanut development was optimized during the spring, even more than during the summer (Figure 4, Table 1). Tamele et al. (2017) observed greater forage peanut participation in the herbage mass during the spring as well. Stimulated by the increase in photoperiod, temperature, and humidity (Figure 1), combined with the average canopy height lowering during the dry period (Figure 4, Table 1), legume had its growth driven by greater possibility of clonal propagation.

There was spatial variability in the palisadegrass (Figure 9) and forage peanut (Figure 11) morphology, in response to the canopy height spatial variability (Figure 5). The higher the canopy, the greater the leaf area and length of the stolon, petiole and internode, with such correlations being generally stronger during the second year of experiment (Figure 17). Pasture height variations cause changes in the canopy base illumination, activating forage peanut phenotypic plasticity (Gobbi et al., 2011), in response to light restriction (Tamele et al., 2017), as this legume has a typical prostrate growth (Andrade et al., 2006). In addition, the maximum height that the forage peanut reached (Figure 7) was higher in regions where canopy was higher (Figure 5). In mixed pastures, the amount of light intercepted by the canopy directly affects the size of the shade zone, and when it is high, forage peanut is light stressed (Tamele et al., 2017). The legume starts to develop perpendicularly to the ground and increases its leaf area and length of petiole and stolon, seeking to increase light capture (Gobbi et al., 2009). Palisadegrass also responded to canopy height variation, as seen in Figure 15 and in the spatial distribution pattern of leaf and stem lengths shown in Figure 9. Increasing the stem length, called

etiolation, is a way for the grass to place its leaves at the canopy top in order to improve light interception efficiency, and consequently the leaves become longer as they go through a longer distance from the connection point with the meristem to the stem end (Skinner & Nelson, 1995).

The spatial variability observed in structural characteristics previously discussed were possibly a reflection of the spatial variability of the morphogenic processes, in response to the canopy height (Figures 16 and 18), causing plants to modify generation and expansion dynamics of their shape in space (Chapman & Lemaire, 1993). Although it was not possible to detect spatial dependence in all seasons during the experimental period of this study (Figures 10 and 12), even if low, it was still possible to observe correlations between canopy height and the morphogenetic characteristics of both grass and legume (Figures 16 and 18). Positive correlations between canopy height and LELR of both species were observed in the present study (Figures 16 and 18). Such a relationship is generally observed in monospecific palisadegrass canopies (Araujo et al., 2015, da Silva et al., 2015). Conversely, canopy height was negatively correlated with LAPR of both species (Figures 16 and 18). As there is an increase in shading under higher canopies, plants invest their photoassimilates for organs lengthening in order to increase their chances of capturing light, and thus there is a decrease in the LAPR (Silveira et al., 2016, da Silva et al., 2013). It was also observed that, as the height of the canopy increased, the LSR of palisadegrass increases (Figure 16). Greater LSR probably induced a dead material mass increase, which was observed in those map regions where canopy was higher (Figure 5). Generally, older leaves and tillers located in the lower canopy portion accelerate senescence rates in taller pastures (Gastal & Lemaire, 2015).

The grazing management applied influenced dynamics in the canopy structure and botanical composition throughout the experiment, so that the legume had the opportunity to proliferate, increasing its contribution to forage mass by 33% in 2018. Similarly, Tamele et al. (2017) found a forage peanut increase in botanical composition in canopies with lower light competition (10 and 20 cm) after one year of mixture establishment. Furthermore, those authors recommended keeping the height canopy average around 20 cm under continuous stocking, in order to achieve an ideal botanical composition for tropical mixed pastures, which is between 20 and 45% of legume (Thomas, 1992, 1995). In the present study, legume botanical composition average in 2017 and 2018 were 28.5 and 42.4% (Table 1), respectively, complying with other published results.

There was a reduction of standard deviation in most of the variables evaluated over time, indicating a pasture structure homogenization. Standard deviation of canopy height, a variable that frequently influenced most of the other variables, showed a 21.6% decline until the end of the experiment, probably driving the canopy stabilization in the horizontal plane.

**CONCLUSION**

There was spatial and temporal variation of plants structure in a palisadegrass-forage peanut mixed canopy, under herbivory by beef cattle in continuous stocking. Despite such variations, the canopy structure as a whole tended to homogenize over time. Plants use phenotypic plasticity to adjust to light competition determined by canopy height. In higher canopies, palisadegrass was favoured, unlike the forage peanut, which had its proportion reduced in the community. On the other hand, in places with lower canopy height, forage peanut was benefited, as it was stimulated to develop more effectively by clonal propagation.

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**APPENDICES**

**APPENDIX A**

Construction values of semivariograms for the variables canopy height, botanical composition (% Forage peanut) maximum Forage peanut height and shade zone in each season of 2017 and 2018.

| Variable | Season/Year | Max. Dist. | Nugget | Sill | Range |
|---|---|---|---|---|---|
| Canopy height | Summer/2017 | 0.8 | 8.99 | 45.0 | 127 |
| | Autumn/2017 | 0.8 | 8.79 | 33.4 | 94.4 |
| | Winter/2017 | 0.8 | 4.70 | 34.8 | 134 |
| | Spring/2017 | 0.8 | 6,05 | 26.2 | 107 |
| | Summer/2018 | 0.8 | 5.03 | 23.0 | 112 |
| | Autumn/2018 | 0.8 | 4.67 | 16.3 | 112 |
| | Winter/2018 | 0.8 | 2.71 | 14.6 | 119 |
| | Spring/2018 | 0.8 | 0.00 | 35.1 | 117 |
| Maximum canopy height | Summer/2017 | 0.8 | 9.69 | 71.7 | 103 |
| | Autumn/2017 | 0.8 | 10.7 | 37.8 | 102 |
| | Winter/2017 | 0.8 | 4.75 | 34.6 | 109 |
| | Spring/2017 | 0.8 | 6.22 | 53.9 | 124 |
| | Summer/2018 | 0.8 | 5.44 | 31.3 | 95.9 |
| | Autumn/2018 | 0.8 | 14.1 | 32.0 | 115 |
| | Winter/2018 | 0.8 | 0 | 21.5 | 43.7 |
| | Spring/2018 | 0.8 | 7.22 | 48.2 | 112 |
| Maximum Forage peanut height | Summer/2017 | 0.7 | 14.7 | 49.0 | 107 |
| | Autumn/2017 | 0.5 | 3.22 | 35.4 | 66.9 |
| | Winter/2017 | 1.0 | 10.3 | 17.0 | 136 |
| | Spring/2017 | 0.8 | 15.4 | 12.8 | 72.1 |
| | Summer/2018 | 0.8 | 14.6 | 24.3 | 119 |
| | Autumn/2018 | 0.7 | 13.5 | 14.7 | 52.5 |
| | Winter/2018 | 0.9 | 5.18 | 30.8 | 118 |
| | Spring/2018 | 0.8 | 10.3 | 33.7 | 107 |
| Botanical Composition (Forage peanut %) | Summer/2017 | 0.6 | 105 | 73.2 | 50.8 |
| | Autumn/2017 | 0.6 | 97.7 | 76.0 | 99.6 |
| | Winter/2017 | 0.7 | 141 | 202 | 109 |
| | Spring/2017 | 0.8 | 92.8 | 179 | 117 |
| | Summer/2018 | 0.8 | 110 | 210 | 132 |
| | Autumn/2018 | 0.6 | 60.6 | 473 | 119 |
| | Winter/2018 | 0.7 | 162 | 75.8 | 138 |
| | Spring/2018 | 0.7 | 50.6 | 164 | 125 |
| Shade Zone | Summer/2017 | 0.6 | 8.33 | 4.93 | 94.0 |
| | Autumn/2017 | 0.6 | 2.08 | 7.43 | 92.1 |
| | Winter/2017 | 0.9 | 2.36 | 9.44 | 126 |
| | Spring/2017 | 0.7 | 1.56 | 8.14 | 107 |
| | Summer/2018 | 0.8 | 2.12 | 7.73 | 114 |
| | Autumn/2018 | 0.8 | 3.04 | 4.23 | 119 |
| | Winter/2018 | 0.7 | 0.624 | 5.00 | 112 |
| | Spring/2018 | 0.6 | 1.45 | 4.22 | 95.9 |

**APPENDIX B**

Construction values of semivariograms for the variables light interception, total leaf area index, palisadegrass leaf area index and Forage peanut leaf area index in each season of 2017 and 2018.

| Variable | Season/Year | Max. Dist. | Nugget | Sill | Range |
|---|---|---|---|---|---|
| Light Interception | Summer/2017 | 0.6 | 6.65 | 53.2 | 60.1 |
| | Autumn/2017 | 0.8 | 45.2 | 58.1 | 64.6 |
| | Winter/2017 | 0.7 | 17.1 | 148 | 85.3 |
| | Spring/2017 | 0.7 | 8.08 | 78.7 | 101 |
| | Summer/2018 | 0.7 | 22.3 | 34.3 | 72.2 |
| | Autumn/2018 | 0.7 | 22.3 | 32.6 | 32.8 |
| | Winter/2018 | 0.9 | 13.3 | 11.0 | 63.0 |
| | Spring/2018 | 0.9 | 13.3 | 11.8 | 71.2 |
| Total Leaf Area Index | Summer/2017 | 0.8 | 0.420 | 1.53 | 127 |
| | Autumn/2017 | 0.7 | 0.270 | 0.120 | 89.7 |
| | Winter/2017 | 0.6 | 0.050 | 0.220 | 97.7 |
| | Spring/2017 | 0.9 | 0.490 | 0.130 | 121 |
| | Summer/2018 | 0.9 | 0.640 | 0.040 | 79.5 |
| | Autumn/2018 | 0.8 | 0.090 | 0.070 | 121 |
| | Winter/2018 | 0.9 | 0.180 | 0.110 | 123 |
| | Spring/2018 | 0.7 | 0.910 | 0.630 | 116 |
| Palisadegrass Leaf Area Index | Summer/2017 | 0.7 | 0.440 | 0.880 | 83.1 |
| | Autumn/2017 | 0.8 | 0.140 | 0.190 | 102 |
| | Winter/2017 | 0.6 | 0.050 | 0.100 | 73.3 |
| | Spring/2017 | 0.6 | 0.180 | 0.260 | 67.7 |
| | Summer/2018 | 0.8 | 0.210 | 0.210 | 104 |
| | Autumn/2018 | 0.8 | 0.050 | 0.180 | 106 |
| | Winter/2018 | 0.7 | 0.030 | 0.070 | 101 |
| | Spring/2018 | 0.7 | 0.380 | 0.260 | 107 |
| Forage peanut Leaf Area Index | Summer/2017 | 0.5 | 0.200 | 0.270 | 80.9 |
| | Autumn/2017 | 0.7 | 0.190 | 0.070 | 65.6 |
| | Winter/2017 | 0.5 | 0.040 | 0.040 | 26.3 |
| | Spring/2017 | 0.8 | 0.320 | 0.070 | 62.1 |
| | Summer/2018 | 0.6 | 0.360 | 0.010 | 37.6 |
| | Autumn/2018 | 0.6 | 0.045 | 0.010 | 33.8 |
| | Winter/2018 | 0.8 | 0.070 | 0.060 | 122 |
| | Spring/2018 | 0.7 | 0.160 | 0.710 | 27.0 |

**APPENDIX C**

Construction values of semivariograms for the variables palisadegrass tiller density and Forage peanut stolon density in each season of 2017 and 2018.

| Variable | Season/Year | Max. Dist. | Nugget | Sill | Range |
|---|---|---|---|---|---|
| Palisadegrass tiller density | Summer/2017 | 0.9 | 1427 | 5911 | 126 |
| | Autumn/2017 | 0.9 | 597 | 16128 | 27.4 |
| | Winter/2017 | 0.7 | 4766 | 20651 | 109 |
| | Spring/2017 | 0.8 | 8824 | 52239 | 127 |
| | Summer/2018 | 0.7 | 9738 | 34084 | 105 |
| | Autumn/2018 | 0.6 | 6432 | 2680 | 86.5 |
| | Winter/2018 | 0.8 | 6056 | 5383 | 122 |
| | Spring/2018 | 0.9 | 5812 | 17436 | 123 |
| Forage peanut Stolon Density | Summer/2017 | 0.7 | 3615 | 3164 | 54.7 |
| | Autumn/2017 | 0.7 | 1316 | 3683 | 112 |
| | Winter/2017 | 0.8 | 1065 | 2131 | 124 |
| | Spring/2017 | 0.6 | 969 | 3027 | 88.3 |
| | Summer/2018 | 0.7 | 2462 | 6401 | 101 |
| | Autumn/2018 | 0.7 | 776 | 1862 | 120 |
| | Winter/2018 | 0.8 | 565 | 1233 | 112 |
| | Spring/2018 | 0.6 | 11430 | 9525 | 47.0 |

**APPENDIX D**

Construction values of semivariograms for the variables total herbage mass yield, green herbage mass yield, palisadegrass mass yield, Forage peanut mass yield and dead material mass in each season of 2017 and 2018.

| Variable | Season/Year | Max. Dist. | Nugget | Sill | Range |
|---|---|---|---|---|---|
| Total Herbage Mass | Summer/2017 | 0.8 | 2487930 | 3317239 | 82.0 |
| | Autumn/2017 | 0.8 | 1546619 | 5670936 | 112 |
| | Winter/2017 | 0.8 | 2086264 | 12404810 | 139 |
| | Spring/2017 | 0.8 | 3643838 | 5668192 | 94.4 |
| | Summer/2018 | 0.8 | 1058884 | 3781728 | 114 |
| | Autumn/2018* | - | - | - | - |
| | Winter/2018 | 0.8 | 1292300 | 5464583 | 109 |
| | Spring/2018 | 0.8 | 1613850 | 4034626 | 109 |
| Green Mass | Summer/2017 | 0.8 | 895176 | 1546213 | 109 |
| | Autumn/2017 | 0.7 | 350510 | 637290 | 91.9 |
| | Winter/2017 | 0.7 | 238940 | 1529215 | 96.2 |
| | Spring/2017 | 0.9 | 772113 | 491345 | 134 |
| | Summer/2018* | - | - | - | - |
| | Autumn/2018* | - | - | - | - |
| | Winter/2018 | 0.8 | 601406 | 367526 | 112 |
| | Spring/2018 | 0.8 | 711089 | 666646 | 122 |
| Palisadegrass Mass | Summer/2017 | 0.7 | 315474 | 25233789 | 30.4 |
| | Autumn/2017 | 0.7 | 208574 | 834295 | 105 |
| | Winter/2017 | 0.7 | 189698 | 1871688 | 120 |
| | Spring/2017 | 0.7 | 356371 | 752339 | 114 |
| | Summer/2018 | 0.7 | 156864 | 928636 | 144 |
| | Autumn/2018 | 0.7 | 229442 | 305923 | 87.5 |
| | Winter/2018 | 0.7 | 134939 | 323853 | 109 |
| | Spring/2018 | 0.7 | 220081 | 1760649 | 27.0 |
| Forage peanut Mass | Summer/2017 | 0.6 | 583241 | 124980 | 84.6 |
| | Autumn/2017 | 0.8 | 261250 | 301442 | 30.6 |
| | Winter/2017 | 0.6 | 274787 | 219829 | 94.0 |
| | Spring/2017 | 0.8 | 582622 | 134451 | 91.9 |
| | Summer/2018 | 0.8 | 964068 | 819458 | 119 |
| | Autumn/2018 | 0.7 | 544805 | 363203 | 116 |
| | Winter/2018 | 0.8 | 413729 | 468892 | 119 |
| | Spring/2018 | 0.8 | 472690 | 567228 | 74.4 |
| Dead Material Yield | Summer/2017 | 0.8 | 585415 | 919939 | 87.0 |
| | Autumn/2017 | 0.7 | 1223010 | 1572441 | 109 |
| | Winter/2017 | 0.7 | 1814345 | 3991560 | 105 |
| | Spring/2017 | 0.8 | 2348569 | 6262851 | 147 |
| | Summer/2018 | 0.9 | 776604 | 3727701 | 126 |
| | Autumn/2018 | 0.7 | 1399189 | 1998842 | 118 |
| | Winter/2018 | 0.7 | 1407573 | 3199028 | 98.4 |
| | Spring/2018 | 0.7 | 1571832 | 1664293 | 89.7 |

*Semivariogram model = pure nugget

**APPENDIX E**

Construction values of semivariograms for the palisadegrass variables live leaf number, leaf length and stem length in each season of 2017 and 2018.

| Variable | Season/Year | Max. Dist. | Nugget | Sill | Range |
|---|---|---|---|---|---|
| Live leaf number | Summer/2017 | 0.6 | 0.420 | 0.000 | 1.88 |
| | Autumn/2017 | 0.5 | 0.490 | 0.030 | 1.55 |
| | Winter/2017 | 0.8 | 0.570 | 0.000 | 4.97 |
| | Spring/2017 | 0.7 | 0.410 | 0.000 | 2.19 |
| | Summer/2018 | 0.7 | 0.370 | 0.000 | 2.19 |
| | Winter/2018 | 0.9 | 0.310 | 0.000 | 2.74 |
| | Spring/2018 | 0.5 | 0.360 | 0.000 | 1.55 |
| Leaf length | Summer/2017 | 0.6 | 0.390 | 11.5 | 99.6 |
| | Autumn/2017* | - | - | - | - |
| | Winter/2017 | 0.8 | 5.48 | 5.82 | 96.9 |
| | Spring/2017 | 0.8 | 5.18 | 13.2 | 117 |
| | Summer/2018 | 0.5 | 2.88 | 7.21 | 57.5 |
| | Winter/2018 | 0.6 | 3.22 | 7.57 | 99.6 |
| | Spring/2018 | 0.7 | 2.93 | 21.8 | 112 |
| Stem length | Summer/2017 | 0.5 | 11.8 | 7.84 | 88.6 |
| | Autumn/2017 | 0.6 | 0 | 12.5 | 92.1 |
| | Winter/2017 | 0.9 | 0.240 | 7.05 | 121 |
| | Spring/2017 | 0.8 | 3.61 | 13.4 | 117 |
| | Summer/2018 | 0.7 | 0 | 31.7 | 120 |
| | Winter/2018 | 0.5 | 0.450 | 2.98 | 91.7 |
| | Spring/2018 | 0.5 | 0.682 | 5.03 | 49.8 |

*Semivariogram model = pure nugget

**APPENDIX F**

Construction values of semivariograms for the Forage peanut variables live leaf number, leaf area, petiole length, stolon length and internode length in each season of 2017 and 2018.

| Variable | Season/Year | Max. Dist. | Nugget | Sill | Range |
|---|---|---|---|---|---|
| Live leaf number | Summer/2017 | 0.8 | 1.85 | 1.26 | 44.7 |
| | Autumn/2017 | 0.7 | 1.10 | 0.440 | 96.2 |
| | Winter/2017 | 0.6 | 0.350 | 0.780 | 99.6 |
| | Spring/2017 | 0.8 | 1.32 | 1.29 | 114 |
| | Summer/2018* | - | - | - | - |
| | Autumn/2018* | - | - | - | - |
| | Winter/2018 | 0.8 | 0.230 | 0.160 | 99.4 |
| | Spring/2018* | - | - | - | - |
| Leaf area | Summer/2017 | 0.6 | 1.15 | 4.59 | 99.6 |
| | Autumn/2017 | 0.7 | 1.95 | 2.55 | 48.1 |
| | Winter/2017 | 0.7 | 3.32 | 1.58 | 78.7 |
| | Spring/2017 | 0.7 | 1.78 | 5.96 | 87.5 |
| | Summer/2018 | 0.7 | 2.83 | 8.49 | 120 |
| | Autumn/2018 | 0.7 | 3.13 | 6.25 | 114 |
| | Winter/2018 | 0.7 | 1.17 | 2.97 | 103 |
| | Spring/2018 | 0.8 | 1.30 | 3.38 | 122 |
| Petiole length | Summer/2017 | 0.7 | 0.100 | 0.13 | 98.4 |
| | Autumn/2017 | 0.6 | 0.070 | 0.300 | 90.2 |
| | Winter/2017 | 0.6 | 0.130 | 0.110 | 47.0 |
| | Spring/2017 | 0.7 | 0.090 | 0.120 | 59.0 |
| | Summer/2018 | 0.7 | 0.060 | 0.240 | 114 |
| | Autumn/2018 | 0.5 | 0.270 | 0.160 | 90.2 |
| | Winter/2018 | 0.9 | 0.050 | 0.200 | 121 |
| | Spring/2018 | 0.6 | 0.050 | 0.040 | 107 |
| Stolon length | Summer/2017 | 0.8 | 26.6 | 32.7 | 94.4 |
| | Autumn/2017* | - | - | - | - |
| | Winter/2017* | - | - | - | - |
| | Spring/2017* | - | - | - | - |
| | Summer/2018 | 0.9 | 30.3 | 126.1 | 128.8 |
| | Autumn/2018 | 0.8 | 45.4 | 17.8 | 96.9 |
| | Winter/2018 | 0.6 | 13.8 | 3.45 | 97.7 |
| | Spring/2018* | - | - | - | - |
| Internode length | Summer/2017 | 0.8 | 0.110 | 0.400 | 96.9 |
| | Autumn/2017* | - | - | - | - |
| | Winter/2017 | 0.8 | 0.020 | 0.086 | 79.5 |
| | Spring/2017* | - | - | - | - |
| | Summer/2018 | 0.9 | 0.120 | 0.280 | 123 |
| | Autumn/2018 | 0.8 | 0.390 | 0.120 | 104 |
| | Winter/2018 | 0.7 | 0.070 | 0.240 | 112 |
| | Spring/2018 | 0.7 | 0.140 | 0.100 | 65.6 |

*Semivariogram model = pure nugget

**APPENDIX G**

Construction values of semivariograms for the palisadegrass variables leaf appearance rate, leaf elongation rate, leaf senescence rate and stem elongation rate in each season of 2017 and 2018.

| Variable | Season/Year | Max. Dist. | Nugget | Sill | Range |
|---|---|---|---|---|---|
| Leaf appearance rate | Summer/2017 | 0.8 | 0.00022 | 0.00012 | 57.1 |
| | Autumn/2017* | - | - | - | - |
| | Winter/2017* | - | - | - | - |
| | Spring/2017* | - | - | - | - |
| | Summer/2018 | 0.7 | 0.00026 | 0.00026 | 48.1 |
| | Winter/2018 | 0.5 | 0.00004 | 0.00008 | 88.6 |
| | Spring/2018* | - | - | - | - |
| Leaf elongation rate | Summer/2017* | - | - | - | - |
| | Autumn/2017* | - | - | - | - |
| | Winter/2017 | 0.5 | 0.006 | 0.002 | 21.8 |
| | Spring/2017* | - | - | - | - |
| | Summer/2018 | 0.6 | 0.100 | 0.070 | 88.3 |
| | Winter/2018 | 0.7 | 0.013 | 0.020 | 98.4 |
| | Spring/2018* | - | - | - | - |
| Leaf senescence rate | Summer/2017* | - | - | - | - |
| | Autumn/2017 | 0.7 | 0.012 | 0.0071 | 39.4 |
| | Winter/2017 | 0.5 | 0.011 | 0.004 | 19.2 |
| | Spring/2017 | 0.8 | 0.045 | 0.030 | 99.4 |
| | Summer/2018 | 0.7 | 0.020 | 0.030 | 104.9 |
| | Winter/2018 | 0.9 | 0.0043 | 0.0048 | 112.3 |
| | Spring/2018 | 0.8 | 0.015 | 0.040 | 116.8 |
| Stem elongation rate | Summer/2017 | 0.7 | 0.0003 | 0.0018 | 96.2 |
| | Autumn/2017 | 0.6 | 0.0001 | 0.0001 | 99.6 |
| | Winter/2017 | 0.8 | $2.00e^{-6}$ | $8.72e^{-7}$ | 99.6 |
| | Spring/2017* | - | - | - | - |
| | Summer/2018 | 0.6 | $2.20e^{-4}$ | $4.40e^{-4}$ | 94.0 |
| | Winter/2018* | - | - | - | - |
| | Spring/2018 | 0.8 | $1.90e^{-4}$ | $8.13e^{-5}$ | 44.7 |

*Semivariogram model = pure nugget

**APPENDIX H**

Construction values of semivariograms for the Forage peanut variables leaf appearance rate, leaf elongation rate, leaf senescence rate and stolon elongation rate in each season of 2017 and 2018.

| Variable | Season/Year | Max. Dist. | Nugget | Sill | Range |
|---|---|---|---|---|---|
| Leaf appearance rate | Summer/2017 | 0.7 | 0.00026 | 0.00150 | 85.3 |
| | Autumn/2017* | - | - | - | - |
| | Winter/2017 | 0.8 | 0.00013 | 0.00061 | 69.6 |
| | Spring/2017 | 0.9 | 0.00061 | 0.00022 | 43.8 |
| | Summer/2018 | 0.7 | 0.00015 | 0.00025 | 96.2 |
| | Autumn/2018 | 0.7 | 0.00080 | 0.00036 | 27.0 |
| | Winter/2018 | 0.7 | 0.00050 | 0.00019 | 120 |
| | Spring/2018 | 0.8 | 0.00120 | 0.00085 | 104 |
| Leaf elongation rate | Summer/2017 | 0.8 | 0.030 | 0.150 | 49.7 |
| | Autumn/2017* | - | - | - | - |
| | Winter/2017 | 0.8 | 0.015 | 0.020 | 67.1 |
| | Spring/2017 | 0.5 | 0.100 | 0.180 | 43.5 |
| | Summer/2018 | 0.6 | 0.100 | 0.120 | 69.5 |
| | Autumn/2018 | 0.5 | 0.002 | 0.001 | 57.5 |
| | Winter/2018 | 0.8 | 0.010 | 0.007 | 117 |
| | Spring/2018 | 0.7 | 0.110 | 0.110 | 103 |
| Leaf senescence rate | Summer/2017 | 0.5 | 0.110 | 0.160 | 48.2 |
| | Autumn/2017 | 0.9 | 0.060 | 0.080 | 107 |
| | Winter/2017* | - | - | - | - |
| | Spring/2017 | 0.9 | 0.040 | 0.080 | 126 |
| | Summer/2018 | 0.8 | 0.090 | 0.280 | 119 |
| | Autumn/2018 | 0.6 | 0.024 | 0.020 | 92.1 |
| | Winter/2018* | - | - | - | - |
| | Spring/2018 | 0.5 | 0.040 | 0.030 | 45.1 |
| Stolon elongation rate | Summer/2017 | 0.7 | 0.0100 | 0.010 | 48.1 |
| | Autumn/2017 | 0.8 | 0.0002 | 0.0004 | 30.6 |
| | Winter/2017 | 0.5 | 0.0009 | 0.0006 | 73.1 |
| | Spring/2017 | 0.5 | 0.0150 | 0.005 | 38.9 |
| | Summer/2018 | 0.5 | 0.0100 | 0.026 | 85.5 |
| | Autumn/2018 | 0.5 | 0.00002 | 0.00001 | 19.2 |
| | Winter/2018 | 0.7 | 0.0002 | 0.00018 | 27.0 |
| | Spring/2018* | - | - | - | - |

*Semivariogram model = pure nugget