



Research Article

Physiological comparison of *Panicum sarmentosum* and *Panicum maximum* forage crops: stomata density, chlorophyll, and herbage nitrogen contents

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Abstract

This article reports two descriptive studies—a field sampling and a controlled glasshouse experiment—on *Panicum sarmentosum* and *Panicum maximum*. While *P. maximum* is a well-known forage grass, *P. sarmentosum* is a potential new feed source for ruminants. This study aims to evaluate and compare the chlorophyll content, stomatal density, and nitrogen (N) content of both species. Well-developed leaf samples were collected using standard sampling methods. Chlorophyll and stomatal density were analyzed following standard procedures, while leaf and stem N contents were determined via the Kjeldahl digestion method. Data were analyzed descriptively using Statistix Software for Windows. The results showed that both species possess high stomatal density, enabling them to adapt well to open areas. While both grasses had high chlorophyll content, it was significantly higher in *P. sarmentosum* than in *P. maximum*. This higher chlorophyll content explains why *P. sarmentosum* produces more tillers and herbage under coconut shade than *P. maximum*. However, the two grasses did not differ in their leaf or stem N contents. In conclusion, these physiological traits effectively explain the differing performance of these morphologically similar plants.

Keywords: grass, species, physiological traits, leaf and stem fractions

Introduction

Panicum maximum and *Panicum sarmentosum* are two tall-growing grass species that are very similar in plant size and morphology, clumpy growth form and their potential use as forage for ruminants. *P. maximum* has long been well known and used as forage crops in many countries and on different agroecosystems (Stur and Shelton 1990; Seresinhe and Pathirana 2000; Aganga and Tshwenyane 2004; Carnevalli et al. 2006; Tarsono et al. 2009; Nasca et al. 2015; Dias et al. 2020; Abegunde et al. 2021; Bilgin 2021; Marcillo et al. 2021; Pereira et al. 2022; Kisambo et al. 2023; Farooq et al. 2024; Junges et al. 2024; Atumo et al. 2026). On the other hand, *P. sarmentosum* has still limited studied and published, though has been used as a forage crop in some locations in Sulawesi

Tengah, Indonesia (Tarsono et al. 2009; Amar et al. 2020; Tarsono et al. 2021; Tarsono et al. 2022).

These two morphologically similar grasses also share very similar nutrient attributes. Amar et al. (2020) reported similarities in some of their major and minor mineral contents. Nevertheless, the two *Panicum* grasses exhibit a few differences in their agronomic attributes. When grown between coconut trees under the same agronomic management, *P. sarmentosum* was reported to produce a significantly higher number of tillers and a higher dry-herbage yield than *P. maximum* from repetitive cuts, both in grass monoculture and in a grass-*Desmanthus virgatus* mixture (Tarsono et al., 2009).

The similarities in morphological and some nutritive properties, but different in agronomic attributes, promote curiosity about how the physiological comparison of these two grasses is. This article reports and discusses the leaf chlorophyll contents and stomatal densities of these two *Panicum* species, both grown naturally in the fields and those that were grown in a glasshouse study. In the latter study, the leaf and stem nitrogen contents were also compared. This is based on some publications that leaf chlorophyll and nitrogen contents are positively correlated. The close correlation of chlorophyll and nitrogen content in plant leaf has been reported by many studies, such as in gramineae/poaceae plant species (Gaborcik 2003; Bojovic and Markovic 2009; Ata-Ul-Karim *et al.* 2016; Dordas 2017; Msiza *et al.* 2022; Ferreird *et al.* 2024; Linders *et al.* 2024; Mohamed *et al.* 2026) and in other plants (Amaliotis *et al.* 2004; Ghasemi *et al.* 2011; Garcia-Caparrós *et al.* 2023; Xu *et al.* 2025).

Finally, comparing the internal physiological traits of these two closely related grass genotypes is of significant interest. This study, therefore, compares and discusses their differences, focusing specifically on stomatal density, leaf chlorophyll, and nitrogen contents in leaf and stem fractions.

Methods and Materials

Forage grasses of *Panicum maximum* and *P. samentosum* are compared in two studies for their internal physiological properties, including stomatal density, chlorophyll and nitrogen contents. The two studies are: 1) The physiological traits of the two species leaf collected from the field of their natural growth, and 2) The physiological traits of the grasses grown in a glasshouse.

Study 1: The leaves of grasses grow naturally in the field

a) Plant materials and sampling sites

The grass species studied were *Panicum maximum* and *Panicum sarmentosum*. The plant material used to determine physiological attributes was leaf samples from these two grass species collected from various locations where they were found to grow in the fields across three administrative areas: Palu City, Sigi Regency, and Donggala Regency. The leaf sampling sites are listed in Table 1. These sites were purposively selected based on observational notes regarding species presence from previously published research (Amar *et al.* 2023).

b) Leaf sampling method

The leaf samples collected consisted of fully developed, mature leaves (the third from the tip) from each species at every sampling site. These samples comprised only the leaf blades—free from defects and/or damage caused by insects or other herbivores—and excluded the leaf sheaths. The leaf blades were harvested by cutting at the base of the blade, specifically at the junction of the ligule and the blade. At each

sampling point, the sample for each grass species consisted of five leaf blades, with one blade taken from each of five different clumps. Samples intended for the determination of stomata density and chlorophyll content were placed in sealable plastic bags, labeled with sample codes, and stored temporarily in an ice box for transport from the field to the Biology Laboratory at the Faculty of Mathematics and Natural Sciences, where they were subsequently kept in a laboratory refrigerator.

c) Leaf sampling method

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d) Determining Stomatal Density and Leaf Chlorophyll Content

Stomatal density and chlorophyll content were determined at the Biology Laboratory of the Faculty of Mathematics and Natural Sciences, Tadulako University. Determination was done using method and following, respectively, stomatal density (Abdulrahman *et al.* 2009; Taylor *et al.* 2012; Paul *et al.* 2017; Mahfut *et al.* 2023), and chlorophyll content (Azmat *et al.* 2016; Chan-Juan *et al.* 2023; Memon *et al.* 2024; Taha *et al.* 2024). The calculations of stomata density and chlorophyll content were performed sequentially as follows.

Determination of stomata density

- Samples were prepared from fully expanded leaves (as explained above)
- Specimen preparation entails the examination of the abaxial leaf surface
- A fresh specimen is prepared on a microscope slide (with the leaf underside facing upward) using distilled water as the mounting medium
- Observations were conducted using a light microscope at 400x magnification (10x eyepiece and 40x objective)
- Area measurements were performed using a calibrated micrometer
- The number of stomata was counted directly under the microscope

Table 1 Leaf sampling sites of the grasses in the fields in the three regencies

No.	The leaf sampling sites			<i>Panicum</i> species
	Location names	Geographical position	Altitude (m asl)	
1	Livestock Park, Sidera, Sigi Regency	S: 1° 00' 19.68" E: 119° 36' 26.17"	75	<i>P. maximum</i> <i>P. sarmentosum</i>
2	Roadside, Sidera, Sigi Regency	S: 1° 00' 19.68" E: 119° 36' 26.17"	75	<i>P. maximum</i>
3	Mpanau village, Sigi-Biromaru, Sigi Regency	S: 00° 57' 19.80" E: 119° 55' 44.70"	101	<i>P. maximum</i>
4	Loru village, Sigi-Biromaru, Sigi Regency	S: 00° 57' 31.50" E: 119° 56' 29.30"	126	<i>P. sarmentosum</i>
5	Makmur village Palolo-Roadside Sigi Regency	S: 01° 08' 17.20" E: 120° 03' 09.00"	586	<i>P. sarmentosum</i>
6	Salusumpu village, Mosque Backyard Donggala Regency	S: 0°50' 00.20" E: 119°36' 58.80"	2	<i>P. maximum</i> <i>P. sarmentosum</i>
7	Salusumpu village,, Farmer Plot, Donggala Regency	S: 0° 49' 56.00" E: 119° 37' 2.20"	2	<i>P. sarmentosum</i>
8	Malonas, Roadside Donggala Regency	N: 0° 15' 44.20" E: 119° 54' 55.50"	6	<i>P. sarmentosum</i>
9	Enu, Roadsite Donggala Regency	S: 0°28' 10.30" E: 119°45' 49.20"	2	<i>P. sarmentosum</i>
10	Tondo village, Bushland, Palu City	S: 00° 50' 36.90" E: 119° 53' 25.20"	72	<i>P. sarmentosum</i>
11	Tondo village, Roadsite, Palu City	S: 00° 50' 36.20" E: 119° 53' 28.20"	74	<i>P. sarmentosum</i>
12	Faculty of Agriculture Block, Tadulako University in Tondo, Palu City	S: 00° 50' 51.75" E: 119° 53' 44.76"	112	<i>P. maximum</i>
13	Faculty of Animal Husbandry and Fishery Block, Tadulako University in Tondo, Palu City	S: 00° 50' 16.30" E: 119° 53' 59.60"	114	<i>P. sarmentosum</i>

Determination of chlorophyll content

Chlorophyll content was measured using the Wintermans and De Mots (1965) method, employing 96% ethanol (ethyl alcohol) as the solvent and measuring the absorbance (A) of the chlorophyll solution at wavelengths (λ) of 649 and 665 nm.

- Samples are prepared from fully expanded leaves (as explained above)
- A 1 g sample was ground using a mortar with the aid of liquid nitrogen
- The thoroughly ground sample was dissolved in 10 mL of 96 alcohol
- The mixture was stirred until homogeneous
- Insoluble material was then precipitated by centrifugation at 1200 rpm for 3 minutes

- Chlorophyll content in the supernatant was measured based on absorbance using a spectrophotometer at wavelength of 649 nm and 665 nm
- Chlorophyll content per mL of a sample was determined using the following equation.
-

Chlorophyll a (Chl. a) = $13.7 D_{665} - 5.76 D_{649}$ (mg/L)

Chlorophyll b (Chl. b) = $25.8 D_{649} - 7.60 D_{665}$ (mg/L)

Final data are converted to mg chlorophyll/g of fresh weight of leaf sample

Study 2: Grasses grown in a glasshouse

a) The plant materials and sampling method

Two species of *Panicum* grasses, *P. maximum* and *P. sarmentosum*, were evaluated in a pot trial conducted in a greenhouse at the Faculty of Agriculture, Tadulako University.

The experiment directly compared the two grass species, using 20 plants per species, made up of 40 polybag plants, as experimental units—with 10 replicates to determine stomata density and chlorophyll content, as well as 10 replicates for nitrogen content analysis—to minimize variance caused by uncontrollable factors. Each of the experimental units was grown from a young tiller planted in a polybag containing 17 kg (dry weight) of silt loam soil that had been passed through a 2 mm sieve. A single young tiller (one plant per polybag) was planted for each observation unit (see Azmat et al. 2016). These plants from 40 experimental units were grown for 5 weeks and then cut at the soil surface (Tarsono, 2020) to obtain leaf samples of uniform regrowth age. The plants were then left to regrow for 6 weeks before the final sample collection (Amar et al. 2020). Leaf samples for each grass species consisted of 10 replicates for physiological attributes (stomata and chlorophyll) and 10 replicates for nutritional content attributes, with the quantity of each sample as follows:

- One (1) leaf blade, the second from the base fully developed mature leaf, from each of 10 replicates for stomatal density and chlorophyll content; and
- All above-ground vegetative parts of the plants were harvested at the soil surface within the polybags—separately for each grass species across ten replicates—to analyze the nutritional attributes of the stems and leaves.

Sample handling and the determination of stomata density and chlorophyll content were carried out using the same methods as those described in Study 1 above.

b) Analysis of leaf and stem nitrogen contents

Separately, each of the leaf and stem fraction samples of each experimental unit was prepared for Kjeldahl digestion using a block digester, then nitrogen contents of each of the samples were analysed following the AOAC method (1995).

The determinations of stomata density and chlorophyll content were conducted at the Biology Laboratory of the Faculty of Mathematics and Natural Sciences; while nitrogen analyses were undertaken at the Animal Nutrition and Feed Laboratory, Faculty of Animal Science and Fisheries, Tadulako University. Each of the samples was analysed in duplicates. Summary statistics using Statistix 4.1 determined the effect of grass species on each of the grass traits ($P = 0.05$).

Results and Discussion

Study 1: The leaves of grasses grow naturally in the field

This study compares the physiological traits of the two grass species on the leaf attributes only by sampling the most appropriate leaves to be considered of the same age, i.e. the third mature leaf from the tip of each plant. The physiological traits of each species are presented separately in Table 2 and Table 3, respectively for *P. maximum* and *P. sarmentosum*, due to an imbalanced number of samples. Therefore, the comparison is going to be a descriptive discussion. The tables show the mean of each of the attributes, and have indicated very slight differences among the plant species.

Means of the parameters have indicated 2 different trends. Firstly, *P. maximum* indicates higher stomata density and nitrogen content of the leaf than those of *P. sarmentosum*. Secondly, *P. sarmentosum* on the other hand, has indicated higher levels in all 3 chlorophyll attributes.

Study 2: Grasses grown in a greenhouse

Species comparison based on the leaf stomata density and chlorophyll content, as well as nitrogen content of the herbage

that were represented by the total sample independently, leaf and stem fractions (Table 4). Each of these attributes was statistically compared, that has revealed mostly non-significant differences, but for leaf chlrophyll-a and the total chlorophyll, that *P. sarmentosum* possesses higher in both parameters than *P. maximum*. Quantitatively, Table 4 indicated the latter species tends to have lower in all chlorophyll attributes than the first one.

The results from the 2 studies have suggested that the physiological traits of both species show consistent trends that biologically, apart from statistical determination, are: i) *P. maximum* higher than *P. sarmentosum* in stomata density; and the latter species has confirmed higher in all chlorophyll parameters than the first species. There is no consistent trend in nitrogen content of the two grass species, though both species show general trend of higher nitrogen in the plant leaf than in the stem (Amar, 1991; Mahyuddin et al. 2007; Hare et al. 2015; Mganga et al. 2021, 2025?). Nitrogen is a key

component of important biomolecules like proteins (Qaderi et al. 2025), which leaf nitrogen levels remain higher due to metabolic activity and chloroplast concentration, whereas stems accumulate more structural cell wall components that dilute total nitrogen per unit of dry matter (Perchlik and Tegeder, 2018; Hou et al. 2020; Cooney et al. 2021; Xing et al. 2021; Farhan et al. 2024; Amoah et al. 2025). Leaf nitrogen allocation plays a crucial role in determining both photosynthetic function and structural development of plants (Peinado-Torrubia, et al. 2025).

Table 2. Leaf physiological traits of *P. maximum* naturally growing at different sites

No.	Location names	No of stomata/mm ²	Chlorophyll-a (mg/g FW)	Chlorophyll (a+b) (mg/g FW)	N content (% of DM)
1	Livestock Park, Sidera, Sigi Regency	400	18.52	9.93	1.84
2	Roadside, Sidera, Sigi Regency	500	20.00	10.90	1.90
3	Mpanau village, Sigi-Biromaru, Sigi Regency	200	12.03	7.60	1.35
4	Salusumpu village, Mosque Backyard Donggala Regency	500	9.43	5.32	1.07
5	Faculty of Agriculture Block, Tadulako University in Tondo, Palu City	700	9.13	5.48	1.27
		460	13.82	7.85	1.48
Mean Total Chlorophyll (a+b)			21.67		

Table 3. Leaf physiological traits of *P. sarmentosum* naturally growing at different sites

No.	Location names	No of stomata/mm ²	Chlorophyll-a (mg/g FW)	Chlorophyll (a+b) (mg/g FW)	N content (% of DM)
1	Livestock Park, Sidera, Sigi Regency	300	18.48	10.75	1.67
2	Loru village, Sigi-Biromaru, Sigi Regency	300	14.05	8.39	1.18
3	Makmur village Palolo-Roadside Sigi Regency	300	12.19	7.72	1.21
4	Salusumpu village, Mosque Backyard Donggala Regency	400	7.15	4.76	1.05
5	Salusumpu village, Farmer Plot, Donggala Regency	300	23.22	16.58	1.85
6	Malonas, Roadside Donggala Regency	400	24.62	16.84	1.01
7	Enu, Roadside Donggala Regency	400	17.19	11.71	1.37
8	Tondo village, Bushland, Palu City	400	9.69	6.27	1.51
9	Tondo village, Roadside, Palu City	400	13.36	10.31	1.88
10	Faculty of Animal Husbandry and Fishery Block, Tadulako University in Tondo, Palu City	500	6.88	4.67	1.47
Mean		370	14.68	9.80	1.42
Mean Total Chlorophyll (a+b)			24.48		

Table 4. Physiological traits of the two *Panicum* species in a greenhouse

Plant Attributes (n=10)	<i>Panicum</i> species	
	<i>P. maximum</i>	<i>P. sarmentosum</i>
Leaf Stomata Density (No. of stomata/mm ²)	336.67 ^a	316.67 ^a
Chlorophyll-a (mg/g FW leaf)	14.20 ^a	15.53 ^b
Chlorophyll-b (mg/g FW leaf)	13.77 ^a	15.19 ^a
Total chlorophyll (a + b), (mg/g FW leaf)	27.96 ^a	30.73 ^b
Leaf Nitrogen content (% dry weight basis)	1.43 ^a	1.52 ^a
Stem Nitrogen content (% dry weight basis)	1.08 ^a	1.12 ^a

Means in a row followed by the same lower-case letter do not differ significantly (P<0.05)

The physiological traits of these grasses indicate distinct biological strategies. *P. maximum* features a higher stomatal density for rapid gas exchange, whereas *P. sarmentosum* contains higher chlorophyll content for enhanced low-light capture. Both show species variable nitrogen levels with no clear pattern, reflecting flexible nutrient use across different environments. Further, the grasses show that nitrogen does not differ in a clear way between leaf and stem. Generally, forage grass leaves consistently contain significantly higher concentrations of nitrogen (or crude protein) than stems across different maturity stages and species. Leaf nitrogen levels remain higher due to metabolic activity and chloroplast concentration, whereas stems accumulate structural cell wall components that dilute total nitrogen per unit of dry matter (Lawlor, 2002; Hou *et al.* 2020; Qaderi *et al.* 2025; Zong *et al.* 2026).

It is necessarily to be kept in mind that real plant function matters, such as chlorophyll and stomata, more than strict math rules. The implication of the results and discussion above, therefore, can be highlighted as follows.

- Higher stomatal density in *P. maximum* suggests a higher capacity for gas and water exchange compared to *P. sarmentosum*.
- On the other hand, a higher chlorophyll content in *P. sarmentosum* potentially enables greater light energy absorption for photosynthesis than *P. maximum*.
- Meanwhile, tissue nitrogen concentrations do not reveal a significant difference between the two species.

The implication of these can be explained in three parts of the following discussion.

Firstly, these two grasses are known as good forage crops in the open areas, especially *P. maximum* in many different countries and agroecosystems. Green panic (*P. maximum*) is also widely used and accepted for uses in dry areas (de Lima Veras *et al.* 2020; Alsunaydi *et al.* 2024; Rabieli *et al.* 2025).

In addition, it does well under tree shaded sites or plantation trees, such as (Durr and Rangel, 2000; Tarsono *et al.* 2009; Choudhary, *et al.* 2012; Herdiawan and Widodo, 2022; Monegi, 2025; Herdiawan *et al.* 2026). The present findings contribute to this adaptability by revealing physiological traits of high stomatal densities and high chlorophyll content, whether grown under natural field conditions or in a greenhouse experiment.

P. sarmentosum and *P. maximum* demonstrate high stomatal densities, though *P. maximum* slightly indicates higher in this attribute than its counterpart species, but both possess more stomata pores per unit leaf area compared to many previous studies on the grass family. Stomatal density in grasses typically ranges widely from 50 to over 600 stomata per mm², or even more extreme values up to 890 per mm², depending on the species and environmental stress (Anderson and Briske, 1990; Sun, *et al.* 2021). Many published studies show stomatal densities range between 60.0 to 300 pores/mm² (Anderson and Briske, 1990; Matsumoto *et al.* 2025; Márquez-Godoy *et al.* 2026). These two presented studies found that *P. sarmentosum* and *P. maximum* possess average stomatal densities of 316-370 and 336-460, respectively, which are higher than those common ranges in previous publications. Therefore, these two species reported in the present studies can be categorized as high stomatal density grasses. Regarding this finding, present studies demonstrate the high adaptability and acceptability of these *Panicum* species in open agroecosystems, particularly *P. maximum* (Eriksen and Whitney, 1981; Bilgin, 2021; Pereira *et al.*, 2022; Alsunaydi *et al.*, 2024; Rabieli *et al.*, 2025), as well as *P. sarmentosum* in Central Sulawesi, Indonesia, although documentation for the latter remains scarce (Tarsono *et al.*, 2020; 2021; 2022). However, the slightly higher stomatal density in *P. maximum* compared to *P. sarmentosum* raises a new hypothetical question: does this enable *P. maximum* to adapt and grow better than *P. sarmentosum* in open areas? Indeed, this hypothesis warrants further investigation.

Thirdly, these grasses are characterized by high chlorophyll content as shown by this presented report compared to published references before. Purbajanti *et al.* (2010) had found that *P. maximum* revealed the highest total chlorophyll content among five species of tropical grasses. Other published studies indicated total chlorophyll contents of various grasses ranged between less than 1 to 6 mg/g fresh leaves (Chinachit *et al.* 2012; Purbajanti *et al.* 2016). Present studies have just showed

that the two *Panicum* grasses own much higher chlorophyll contents, where *P. sarmentosum* consistently demonstrates its superiority compared to its counterpart species, 24.48-30.73 mg/g fresh weight and 21.67-27.96 mg/g fresh weight respectively. This is revealing a physiological trait that proves the higher number of tiller and herbage production than *P. maximum* under the shade of coconut trees (Tarsono et al. 2009). Nevertheless, *P. maximum* is widely recognized for its adaptability and performance as a forage grass under the shaded conditions of agricultural systems (Amar, 1991; Durr and Rangel, 2000; Paciullo et al., 2017; González Marcillo et al., 2021; Monegi, 2025). Consequently, further research is needed under both controlled and field conditions.

Finally, *Panicum sarmentosum*, in Sulawesi Tengah, is now already well acceptable by farmers, though in many other places it is known only as a medicine plant, such as in Chhattisgarh, India (Oudhia, 2010), and mostly considered it as a weed (Watson and Dallwitz, 1992; Clayton, et al. 2008). Recently, *P. sarmentosum* is growing popular as a forage in Sulawesi Tengah, with its good quality of herbage (Amar et al. 2020). While both grasses thrive in both open full sun and shaded niches, it can be highlighted that the results have indicated that *P. maximum* is better suited for open environments, whereas *P. sarmentosum* performs better under shelter. This also warrants further confirmation studies.

Conclusion

These two grass species display divergent physiological attributes, allowing contrasting adaptation strategies for survival. *Panicum maximum* invests heavily in gas exchange and high stomatal density for rapid growth in open areas, while *P. sarmentosum* maximizes light capture and shade tolerance through superior chlorophyll content. Simplisity, *P. maximum* might suggest it would be better in open full sun-light sites compared to *P. sarmentosum*, on the contrary in shaded niches, though it needs to be explored in more advanced and detailed studies. This means that further studies under contrasting controlled conditions and in the field growth conditions are warranted.

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Conflicts of Interest

The authors state that there are no financial, personal, or professional conflicts of interest associated with this research.

Ethical Approvals

This research did not involve the use of human participants or animal subjects and therefore did not require ethical clearance

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References

- Abdulrahman, A.A., Egbede, F.O. & Oladele, F.A. (2009). Stomatal complex types, stomatal density, and stomatal index in some species of *Dioscorea*. *Archives of Biological Sciences*, Belgrade, **61**(4), 847-851.
- Abegunde, T.O., Babalola, S.O., Adeoye, B.T., Usman, A.O. & Akinyemi, O.M. (2021). Nutritive value and preference of guinea-grass ensiled with or without additive by West African dwarf (WAD) goats. *Tropical Animal Science Journal*, **44**(2): 173-182.
- Aganga, A. A. & Tshwenyane. (2004). Potentials of guinea grass (*Panicum maximum*). *Pakistan Journal of Nutrition*, **3**(1): 1-4.
- Alsunaydi, S., Alharbi, A.B., Al-Soqeer, A.A. & Motawei, M.I. (2024). Nutritional composition and productivity of *Panicum maximum* cv. "Mombasa" under different levels of nitrogen fertilization and water deficit. *Life*, **14**(12): 1614; <https://doi.org/10.3390/life14121614>
- Amaliotis, D., Therios, I. & Karatissiou, M. (2004). Effect of nitrogen fertilization on growth, leaf nutrient concentration and photosynthesis in three peach cultivars. *Acta Horticulturae*, 449: 36-42.
- Amar, A.L. (1991). *Tree Legume Canopy Effects on Pasture Production and Quality with Reference to Albizia lebbbeck*. M.Sc. Thesis, Graduate School of Tropical Veterinary Science and Agriculture, James Cook University of North Queensland, Townsville.
- Amar, A.L., Tarsono, Muliati, Mustaring & Kasim, K. (2020). Exploring the potential of *Panicum sarmentosum* for use as a forage grass based on its nutritive properties. *Plant Archives*, **20**(2): 5065-5071.
- Amar, A.L., Tarsono, Kasim, K., Pamulu, M. & Mustaring (2023). Identification of some herbaceous central sulawesi naturally spread plants potentially used as forage species. *International*

- Journal of Multidisciplinary Research and Development, **10(7)**: 67-73.
- Amoah, J.N., Keitel, C. & Kaiser, B.N. (2025). Nitrogen deficiency impacts growth and modulates carbon metabolism in maize. *Planta*, **262(94)**: 18 pages. <https://doi.org/10.1007/s00425-025-04814-x>
- AOAC (1995). *Official Methods of Analysis*. 16th Edition. Association of official analytical chemists. Washington DC, USA.
- Atumo, T.T., Samago, T.Y., Yada, T.A., Teko, O.O., Kalsa, G.K., Hibebo, D.K., Heliso, M.F., Ekule, M.Z. & Wamatu, J. (2026). Genotype by environment interaction effect on yield and forage quality of native panic grasses: AMMI, GGE biplot and correlation analysis. *Discover Sustainability*, **7**:224. <https://doi.org/10.1007/s43621-025-02459-0>
- Ata-Ul-Karim, S.T., Cao, Q., Zhu, Y., Tang, L., Rehmani, M.I.A. & Cao, W. (2016). Non-destructive assessment of plant nitrogen parameters using leaf chlorophyll measurements in rice. *Front. Plant Sci.*, **7**: 1829. <https://doi.org/10.3389/fpls.2016.01829>
- Azmat, M.A., Khan, A.A. & Niaz, S. (2016). Stomatal density and chlorophyll concentration as an indicator of powdery mildew resistance in pea (*Pisum sativum* L.). *Pakistan Journal of Agricultural Science*, **53(4)**: 871-877.
- Bilgin, F.D. (2021). Guinea grass (*Panicum maximum*) forage: a review. *MAS Journal of Applied Sciences*, **6(1)**: 77–82.
- Bojovic, B. & Markovic, A. (2009). Correlation between nitrogen and chlorophyll content in wheat (*Triticum aestivum* L.). *Kragujevac J. Sci.* **31**: 69-74.
- Carnevali, R.A., Da Silva, S.C., Bueno, A.A.O., Uebele, M.C., Bueno, F.O. Hodgson, J. Silva, G.N. & Morais, J.P.G. (2006). Herbage production and grazing losses in *Panicum maximum* cv. Mombaca under four grazing managements. *Tropical Grasslands*, **40**: 165–176.
- Chan-juan, T., Ming-zhao, L., Shuo, Z., Guan-qing, J., Sha, T., Yan-chao, J., Hui, Z. & Xian-min, D. (2023). Variations in chlorophyll content, stomatal conductance, and photosynthesis in *Setaria* EMS mutants. *Journal of Integrative Agriculture*, **22(6)**: 1618-1630.
- Cooney, L.J., Beechey-Gradwell, Z., Winichayakul, S., Richardson, K.A., Crowther, T., Anderson, P., Scott, R.W., Bryan, G. & Roberts, N.J. (2021). Changes in leaf-level nitrogen partitioning and mesophyll conductance deliver increased photosynthesis for *Lolium perenne* leaves engineered to accumulate lipid carbon sinks. *Front. Plant Sci.*, **12**:641822. doi: 10.3389/fpls.2021.641822
- de Lima Veras, E.L., dos Santos Difante, G., Gurgel, A.L.C., da Costa, A.B.G., Rodrigues, J.G., Costa, C.M., Neto, J.V.E., de Gusmão Pereira, M. & Costa, P.R. (2020). Tillering and structural characteristics of *Panicum* Cultivars in the Brazilian semiarid region. *Sustainability*, **12**: 11 pages, 3849; doi:10.3390/su12093849. www.mdpi.com/journal/sustainability
- Dias, M.B. de Castro, Costa, K.A. de Pinho, Severiano, E. da Costa, Bilego, U.O., Neto, A.E.F., Almeida, D.P., Brand, S.C. & Vilela, L. (2020) Brachiaria and *Panicum maximum* in an integrated crop–livestock system and a second-crop maize system in succession with soybean. *The Journal of Agricultural Science*, **1–12**. <https://doi.org/10.1017/S0021859620000532>.
- Dordas, C. (2017). Nitrogen nutrition index and leaf chlorophyll concentration and its relationship with nitrogen use efficiency in barley (*Hordeum vulgare* L.). *Journal of Plant Nutrition*, **40(8)**: 1190-1203. <http://dx.doi.org/10.1080/01904167.2016.1264596>
- Eriksen, F.I & Whitney, A.S. (1981). Effects of light intensity on growth of some tropical forage species. I. Interaction of light intensity and nitrogen fertilization on six forage grasses. *Agronomy Journal*, **73(3)**: 427-433.
- Evan, J.R. (1983). Nitrogen and Photosynthesis in the Flag Leaf of Wheat (*Triticum aestivum* L.). *Plant Physiology*, **72(2)**: 297-302, <https://doi.org/10.1104/pp.72.2.297>
- Farhan, M., Sathish, M., Kiran, R., Mushtaq, A., Baazeem, A., Hasnain, A., Hakim, F., Syed Atif Hasan Naqvi, S.A.H., Mubeen, M., Iftikhar, Y., Abbas, A., Hassan, M.Z. & Moustafa, M. (2024). Plant nitrogen metabolism: balancing resilience to nutritional stress and abiotic challenges. *Phyton International Journal of Experimental Botany*, **9(3)**: 581-609.
- Farooq, A., M. Salim, Z. Rauf, M.T. Khan and A.A. Khan. 2024. Nutritional evaluation of three panicum forage species at different growth stages. *Pakistan Journal of Forestry*, **74(2)**: 101-107. <https://dx.doi.org/10.17582/journal.PJF/74.2.101.107>
- Ferreir, A.M., Fariaa, A.P., Vasconcelosa, H.L., Bruna, E.M., Costad, V.E. & Moreira, A.S.F.P. (2024). Does chronic nitrogen deposition have effects on grass physiology of natural habitats? *South African Journal of Botany*, **165**: 339-348.
- Field, C. & Mooney, H.A. (1986). The photosynthesis–nitrogen relationship in wild plants. In: *On the Economy of Form and Function* (ed. T.J. Givnish), pp. 25–55. Cambridge University Press, Cambridge, UK.
- Gaborcik, N. (2003). Relationship between contents of chlorophyll (a+b) (SPAD values) and nitrogen of some temperate grasses. *Photosynthetica*, **41(2)**: 285-287.
- Garcia-Caparrós, P., Llanderal, A. & María Teresa Lao, M.T. (2023). Correlations between R, G, and B values, pigment concentration, and nitrogen status in three ornamental potted plants. *Agronomy*, **13**, 177. <https://doi.org/10.3390/agronomy13010177>
- Ghasemi, M., Arzani, K., Yadollahi, A., Ghasemi, S. Sarikhani Khorrami, S. (2011). Estimate of leaf chlorophyll and nitrogen

- content in Asian Pear (*Pyrus serotina* Rehd.) by CCM-200. *Notulae Scientia Biologicae*, **3(1)**: 91-94.
- Hare, M.D., Phengphet, S., Songsiri, T. & Sutin, N. (2015). Effect of nitrogen on yield and quality of *Panicum maximum* cvv. Mombasa and Tanzania in Northeast Thailand. *Tropical Grasslands-Forrajes Tropicales*, **3**: 27-33. DOI: 10.17138/TGFT(3)27-33 www.tropicalgrasslands.info
- Herdiawan, I. & Widodo, S. (2022). Utilization of various levels of shading and organic fertilizer on morphology, production, and nutrient composition of *Panicum maximum* cv. Mombasa. *Buletin Peternakan*, **46(4)**: 222-227. <http://buletinpeternakan.fapet.ugm.ac.id/>
- Herdiawan, I., Zulchi, T., Sutedi, E., Fanindi, A., Hutasoit, R., Sirait, J., Pamungkas, F.A. & Hau, D.K. (2026) Productivity of *Pennisetum purpureum* and *Panicum maximum* grass at different oil palm age levels to support forages availability in an intensive livestock production system. *IOP Conf. Series: Earth and Environmental Science*, 1616 (2026) 012089 IOP Publishing, doi:10.1088/1755-1315/1616/1/012089
- Hou, W., Tränkner, M., Lu, J., Yan, J., Huang, S., Ren, T., Cong, R. & Li, X. (2020). Diagnosis of nitrogen nutrition in rice leaves influenced by potassium levels. *Front. Plant Sci.* **11**:165. doi: 10.3389/fpls.2020.00165
- Junges, L., Gomes, E.N.O., Candido, A.R., Ítavo, L.C.V., Ítavo, C.C.B.F., Coelho, E.M., Difante, G. dos S., dos Santos, G., Tadeu, G. & Dias, A.M. (2024). cutting intervals on the characteristics of Guinea grass: morphogenetic, productive, and nutritional traits. *Acta Scientiarum. Animal Sciences*, **46**: e60358. Doi: 10.4025/actascianimsci.v46i1.60358
- Kisambo, B., Wasonga, O.V., Kipchirchir, O.K., Karuku, G.N. & Kirwa, E.C. (2023). Forage yields and quality of *Cenchrus ciliaris* and *Panicum maximum* ecotypes under varied harvest intervals in a semi-arid environment in Kenya. *International Journal of Drylands*, **7(2)**: 102-111.
- Lawlor, D.W. (2002). Carbon and nitrogen assimilation in relation to yield: mechanisms are the key to understanding production systems. *Journal of Experimental Botany*, **53(370)**, Inorganic Nitrogen Assimilation Special Issue: 773-787.
- Linders, K.M., Santra, D., Schnable, J.C. & Sigmon, B. (2024). Variation in leaf chlorophyll concentration in response to nitrogen application across maize hybrids in contrasting environments. *MicroPubl Biol.*, **4** pages. 10.17912/micropub.biology.001115. doi: 10.17912/micropub.biology.001115
- Mahfut, Putri Kendari, Admi Syarif, Sri Wahyuningsih, Endah Susiyanti, 2023. Stomata characters of sugarcane (*Saccharum officinarum* L.) mutants of GMP3 variety at PT Gunung Madu Plantations, Lampung, Indonesia. *Journal of Tropical Biodiversity and Biotechnology*, 08/03: jtbb79860 DOI: 10.22146/jtbb.79860
- Mahyuddin, P. (2007). Chemical composition of leaf and stem of tropical grasses of different stages of growth. *Animal Production*, **9(3)**: 153-159.
- Marcillo, R.L.G., Guaman, W.E.C., Pincay, A.E.G., Zambrano, P.A.V., Naveda, N.R.O. & Rivera, S.A.G. (2021). Assessment of Guinea Grass *Panicum maximum* under Silvopastoral Systems in Combination with Two Management Systems in Orellana Province, Ecuador. *Agriculture*, **11(2)**: 117; <https://doi.org/10.3390/agriculture11020117>.
- Memon, A.A., Rajpar, I., Jamro, G.M. & Shah, J.A. (2024). Effect of potassium sources and soil calcareous levels on sunflower (*Helianthus annuus* L.) growth at the early stage. *Pakistan Journal of Agricultural Research*, 37(1): 13-22. DOI | <https://dx.doi.org/10.17582/journal.pjar/2024/37.1.13.32>
- Mganga, K.Z., Ndathi, A.J.N., Wambua, S.M., Bosma, L., Kaindi, E.M., Kioko, T., Kadenyi, N., Musyoki, G.K., van Steenberg, F. & Musimba, N.K.R. (2021) Forage value of vegetative leaf and stem biomass fractions of selected grasses indigenous to African rangelands. *Animal Production Sciences*, 61(14): 1476-1483. <https://doi.org/10.1071/AN19597>
- Mohamed, A.G., Mourad, A.M.I., Atif Aboelwafa, A., Helmy M. Youssef, H.M. & Sayed, M.A. (2026). From seedling architecture to grain: linking root and shoot traits with yield potential for climate-resilient wheat breeding. *Plants*, 15(19), 30 pages. 2900; <https://doi.org/10.3390/plants15192900>
- Monegi, P. (2025) Morphological and productivity responses of Guinea grass (*Panicum maximum*) under large trees in a South African savanna. *Flora*, 323: 8 pages 152669, 10.1016/j.flora.2024.152669
- Msiza, N.H., Ravhuhali, K.E., Mokoboki, H.K., Mavengahama, S. & Motsei, L.E. (2022). Chlorophyll, nitrogen and mineral concentration of grass species found in semi-arid rangelands of South Africa. *Range Mgmt. & Agroforestry*, **43(2)**: 299-308, 2022 ISSN 0971-2070.
- Nasca, J.A., Feldkamp, C.R., Arroquy, J.I. & Colombatto, D. (2015). Efficiency and stability in subtropical beef cattle grazing systems in the northwest of Argentina. *Agricultural Systems*, **133**: 85-96.
- Paciullo, D.S.C., Gomide, C.A.M., Castro, C.R.T., Mauricio, R.M., Fernandes, P.B. & Morenz, M.J.F. (2017). Morphogenesis, biomass and nutritive value of *Panicum maximum* under different shade levels and fertilizer nitrogen rates. *Grass and Forage Science*, **72(3)**: 590-600.
- Paul, V., Sharma, L., Pandey, R. & Meena, R.C. (2017). Measurements of stomatal density and stomatal index on leaf/plant surfaces. *Manual of ICAR Sponsored Training Programme on "Physiological Techniques to Analyze the Impact of Climate Change on Crop Plants"* 16-25 January, 2017, Division of Plant Physiology, IARI, New Delhi.
- Peinado-Torrubia, P., Franco-Navarro, J.D., Lucas, M., Romero-Jimenez, D., Moreno-Racero, F.J., Diaz-Rueda, P., Rosales, M.A., Lindah, M., Diaz-Espejo, A., Alvarez, R. & Colmenero-Flores, J.M. (2025). Plants maximise chloride uptake during early vegetative development to stimulate cell expansion, maturation of the photosynthetic apparatus, and

- growth. *The Plant Journal*, **123**: 18 pages. e70378 doi: 10.1111/tpj. 70378
- Pereira, M. de G., Difante, G. dos S., Ítavo, L.C.V., Rodrigues, J. G., Gurgel, A.L.C., Dias, A.M., Ítavo, C.C.B.F., Veras, E.L. de L., da Costa, A.B.G. & Monteiro, G.O. de A. (2022). Production potential and quality of *Panicum maximum* cultivars established in a semi-arid environment. *Tropical Animal Science Journal*, **45**(3):308-318 DOI: <https://doi.org/10.5398/tasj.2022.45.3.308>. Available online at <http://journal.ipb.ac.id/index.php/tasj>
- Perchlik, M. & Tegeder, M. (2018). Leaf amino acid supply affects photosynthetic and plant nitrogen use efficiency under nitrogen stress. *Plant Physiology*, **178**: 174-188. www.plantphysiol.org/cgi/doi/10.1104/pp.18.00597
- Qaderi, M.M., Evans, C.C. & Spicer, M.D. (2025) Plant nitrogen assimilation: a climate change perspective. *Plants*, **14**: 1025. <https://doi.org/10.3390/plants14071025>.
- Rabiel, K.E., Leonard, L.D. & Wilson, C.W. (2025). Morphological characterisation of *Panicum maximum* (Guinea Grass) across selected agro-ecological zones of Tanzania. *Journal of Plant Sciences*, **13**(6): 238–248.
- Seresinhe, T. & Pathirana, K.K. (2000). Associative effects of tree legumes and effect of cutting height on the yield and nutritive value of *Panicum maximum* cv. Guinea. *Tropical Grasslands*, **34**(2):103-109.
- Stur, W.W. & Shelton, H.M. (1990) Review of forage resources in plantation crops of Southeast Asia and the Pacific. In: *Forages for Plantation Crops* (eds. H.M. Shelton and W. W. Stur). Proceedings of a workshop, Sanur Beach, Bali, Indonesia 27-29 June, 1990.
- Taha, M.F.; Mao, H.; Wang, Y.; ElManawy, A.I.; Elmasry, G.; Wu, L.; Memon, M.S.; Niu, Z.; Huang, T.; Qiu, Z. (2024). High-Throughput Analysis of Leaf Chlorophyll Content in Aquaponically Grown Lettuce Using Hyperspectral Reflectance and RGB Images. *Plants*, **13**: 392. <https://doi.org/10.3390/plants13030392>
- Tarsono, Mustaring, Amir, A.M. & Amar, A.L. (2009). Early growth of *Panicum sarmentosum* Roxb. – a promising grass in livestock - coconut integration system. *Proceedings of an International Seminar*, Bogor Agriculture University, Bogor, 202-205.
- Tarsono, Amar, A.L., Muliati, Poetri, E. & Mustaring (2021). Effects of watering on agronomical attributes of *Panicum sarmentosum* Roxb. at four week age of defoliation. Original title, Pengaruh penyiraman terhadap beberapa atribut agronomi rumput *Panicum sarmentosum* Roxb. pada umur defoliasi empat minggu. *Pastura*, **10**(2): 118-121.
- Tarsono, Amar, A.L., Kasim, K., Mulyati & Mustaring (2022). Agronomic study of *Panicum sarmentosum* on open dryland agroecosystems in Palu Valley: The effect of different defoliation intervals on several forage production parameters. *Agroland*, **9**(2): 66-72.
- Wintermans, J.E.G. & De Mots, A. (1965). Spectrophotometric characteristics of chlorophyll a and b and their pheophytins in ethanol. In *Biochimica et Biophysica Acta*, **109**(2): 448–453. [http://dx.doi.org/10.1016/0926-6585\(65\)90170-6](http://dx.doi.org/10.1016/0926-6585(65)90170-6)
- Xu, Y., Zhang, Z., Guo, Q., Feng, H., Qin, F., Zhang, G. & Ding, H. (2025). Effects of nitrogen allocation and photosynthetic proteins response in peanut leaves on photosynthesis under conditions of water scarcity and nitrogen deficiency. *BMC Plant Biology*, **25**:1366 <https://doi.org/10.1186/s12870-025-07232-z>
- Zong, Y., Wang, X., Rosenqvist, E., Wang, W., Wang, Y., Hou, J. & Liu, F. (2026). Low nitrogen supply decreases the mesophyll conductance and limits the effects of elevated CO₂ on photosynthesis in winter wheat across multiple generations. *Environmental and Experimental Botany*, **247**: 13 pages. <https://doi.org/10.1016/j.envexpbot.2026.106372> .

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