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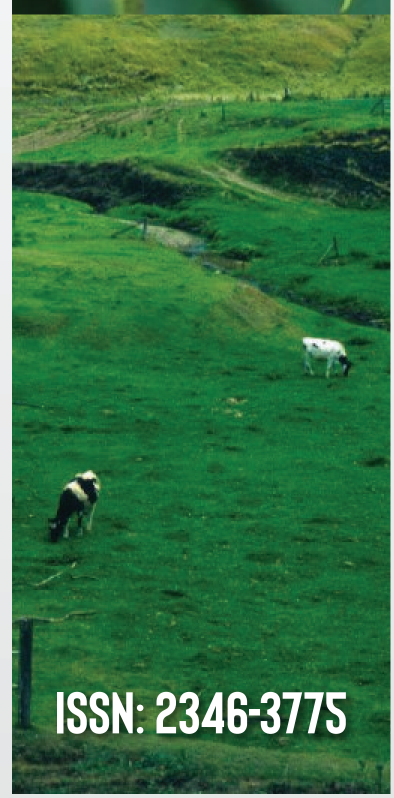

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Cover photos:
Above: *Indigofera zollingeriana* Inflorescences with immature pods developing, by Hai Le.
Below: Heavily grazed *Cenchrus clandestinus* on dairy farm in south-east Queensland, Australia, by Max Shelton.
Back: *Digitaria eriantha* and leucaena, northern Australia, by CSIRO.
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Review Article

The potential role of *Indigofera zollingeriana* as a high-quality forage for cattle in Indonesia

El papel potencial de Indigofera zollingeriana *como forraje de alta calidad para el ganado en Indonesia*

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Abstract

Ownership of cattle in Indonesia is dominated by smallholder farmers, who rely heavily on low-quality mature grasses and crop residues as animal feed. Forage tree legumes (FTLs) provide a practical and profitable option for supplying nutrients limiting cattle growth and reproduction, especially during the dry months. *Indigofera zollingeriana* is a tall, high-yielding plant under investigation as feed, which can produce edible plant material exceeding 4 t dry matter (DM)/ha/harvest, when cut every 68 days. *I. zollingeriana* is adapted to a relatively wide range of climatic conditions and soil-types, with notable high tolerance of acidic soils. Forage quality is high, with high crude protein (265 g/kg DM average) and low fiber (367 g neutral detergent fiber/kg DM) concentrations and high in vitro DM digestibility (72.6%). It contains no identified anti-nutritional compounds but concentration of indospicine, a recognized toxic contaminant in some species of *Indigofera*, is currently unknown. Information on animal responses to feeding *I. zollingeriana* is limited, especially for cattle, but research suggests growth responses in goats are comparable with those for other available FTLs. Research to date suggests *I. zollingeriana* could be a valuable addition to FTLs currently available in Indonesia, especially for acidic soils, but further information is required on performance on saline soils, persistence under regular harvesting, indospicine status, acceptance by cattle and effects on their productivity.

Keywords: Animal production, anti-herbivory, forage-tree legume, growth, nutritive value, preference.

Resumen

En Indonesia, la ganadería está dominada por los pequeños agricultores, que dependen en gran medida de pastos maduros y residuos de cultivos de baja calidad para alimentar a sus animales. Las leguminosas forrajeras arbóreas (FTL en inglés) ofrecen una opción práctica y rentable para suministrar los nutrientes que limitan el crecimiento y la reproducción del ganado, especialmente durante los meses secos. *Indigofera zollingeriana* es una planta de porte alto y de alto rendimiento que se está investigando como forraje, y que puede producir material vegetal comestible superior a 4 t de materia seca (MS)/ha/cosecha, cuando se corta cada 68 días. *I. zollingeriana* se adapta a una gama relativamente amplia de condiciones climáticas y tipos de suelo, con una notable tolerancia a los suelos ácidos. La calidad del forraje es alta, con altas concentraciones de proteína cruda (265 g/kg MS promedio) y baja de fibra (367 g de fibra detergente neutra/kg MS) y alta digestibilidad in vitro de la MS (72.6%). No contiene compuestos antinutricionales identificados, pero actualmente se desconoce la concentración de indospicina, un contaminante tóxico reconocido en algunas especies de *Indigofera*. La información sobre la respuesta de los animales a la alimentación con *I. zollingeriana* es limitada,

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especialmente en el caso del ganado vacuno, pero las investigaciones sugieren que las respuestas de crecimiento en cabras son comparables a las de otros FTL disponibles. Las investigaciones realizadas hasta la fecha sugieren que *I. zollingeriana* podría ser una valiosa adición a los FTL actualmente disponibles en Indonesia, especialmente para suelos ácidos, pero se requiere más información sobre el rendimiento en suelos salinos, la persistencia bajo cosecha regular, el estado de indospicina, la aceptación por el ganado y los efectos sobre su productividad.

Palabras clave: Antiherbivoría, crecimiento, leguminosa arbórea forrajera, preferencia, producción animal, valor nutritivo.

Introduction

Consistent with other developing countries, the demand for red meat, especially beef, in Indonesia is growing with increasing population growth, urbanization, economic strength and per-capita income of the consumer class (Delgado et al. 1999). Currently, the demand for beef markedly outstrips domestic supply with only about half the beef consumed being produced locally (Agus and Widi 2018), despite a long-standing target of self-sufficiency in beef set by successive Indonesian Governments since 1999 (Beef Self-sufficiency Programs, Program Swasembada Daging Sapi PSDS-2005, PSDS-2010 and PSDS-2014) (Chang Hui-Shung et al. 2020). However, an increase in the national cattle herd is restricted by increased urbanization, competition for land for cropping and additional labor inputs required to manage higher cattle numbers (Delgado et al. 1999; Panjaitan et al. 2008). Thus, meaningful increases in beef production in Indonesia in future will be heavily reliant on increasing production per animal, which must be achieved largely within the smallholder farming sector with responsibility for more than 80% of total beef production (Hadi et al. 2002; Agus and Widi 2018).

Beef production systems vary considerably across regions of Indonesia, closely aligned with other demands on the land. In more populated regions of eastern Java, where land availability for cattle production is limited by demands for cropping, feeding systems rely heavily on utilization of crop residues, by-products and available concentrates (Priyanti et al. 2012). In other regions, traditional village systems are based on utilization of native and introduced forages, either grazed or cut-and-carried. Animal productivity is inherently low in these village systems in terms of low growth, calving rates and sale weights of cattle (Dahlanuddin et al. 2019). This is demonstrated in studies carried out with Bali cattle (*Bos javanicus*), a small breed (males 335–363 kg, females 211–242 kg, average body weight) which predominates in the eastern regions of Indonesia. Growth rates of Bali cattle did not exceed 0.3 kg liveweight gain/day where their main feed source was native grass (Damry et al. 2008; Panjaitan et al. 2008; Panjaitan 2012; Quigley et al. 2009; Dahlanuddin et al. 2012; Marsetyo et al. 2012), improved tropical grasses, including elephant grass (*Cenchrus purpureus*) (Quigley et al. 2009; Marsetyo et al. 2012) or corn stover (Marsetyo et al. 2012; 2021). These growth rates are well below the value of 0.85 kg liveweight gain/day reported by Mastika (2003) for Bali cattle fed concentrates, which probably approaches their genetic potential. These findings confirm that locally harvested grasses and crop residues provide insufficient nutrients, especially protein (Quigley et al. 2009), for anything more than modest growth and reproduction. Apart from the low quality of the diet, production is often limited by the inadequate quantity of forage provided, especially during the dry season when availability of forage is limited (Bamualim and Wirdahayati 2003; Pengelly and Lisson 2003; Dahlanuddin et al. 2009; Panjaitan 2012). Furthermore, poor sanitation in crowded pens has led to a high incidence of disease and calf mortality (Dahlanuddin et al. 2009). The modelling of Lisson et al. (2010) showed that it is the integration of the various component feeding options into a smallholder farming system that provides the best chance of adoption and productivity increases. There is ample scope to increase productivity on a per animal basis by the smallholder farming sector (Hadi et al. 2002; Priyanti et al. 2010).

Feeding options for increasing beef production

Nutrient intake of cattle can be increased by feeding concentrates, either produced locally as by-products of agroindustries, including rice bran, copra meal, cassava meals and palm kernel meal, or imported from outside the region, leading to growth rates well in excess of those reported above with low-quality forage or crop residues (Moran 1985; Mastika 2003). However, uptake of concentrate feeding by smallholder farmers is relatively low due to skepticism by farmers about the benefits of feeding and their lack of technical knowledge, unreliable continuity of access to concentrates, variable composition of concentrates, high cost and the need to outlay scarce funds for feeding well in advance of the additional income realized on sale of the animals.

An alternative to feeding concentrates is to provide additional nutrients in the form of nutrient-rich forage. Forage tree legumes (FTLs) have an important role to play in improving nutrition of livestock in Indonesia, although their usefulness goes beyond providing high-quality forage to ruminants and monogastric animals. Additional benefits suggested by Gutteridge and Shelton (1994) included: stabilizing sloping lands against erosion; supplying N-rich mulch for crops; rehabilitation of adverse environments such as saline or arid landscapes; providing a source of firewood; acting as living fences; and providing shade for plantation crops. The extent to which they perform these roles defines their usefulness in a multi-purpose farming situation.

The most widely used FTLs in Indonesia are *Leucaena leucocephala* (Lam.) de Wit, *Sesbania grandiflora* (L.) Poiret and *Gliricidia sepium* (Jacq.) Steud. These tree legumes produce nutrient-rich foliage with crude protein (CP) concentration usually exceeding 200 g/kg dry matter (DM) and dry matter digestibility (DMD) ranging from 55 to 68% (Norton 1994a). However, other factors such as presence of secondary compounds, including mimosine (in *L. leucocephala*), tannins, alkaloids and saponins, can interfere with utilizing nutrients in forage, either directly or through their effects of reducing voluntary intake (Norton 1994a). In an economic analysis of a wide range of feeding strategies investigated in research studies aimed at increasing post-weaning growth of Bali calves, Priyanti et al. (2010) identified that highest profit could be achieved by providing cattle with feeds with high CP concentration, notably *L. leucocephala* in east Java and east Nusa Tenggara and *S. grandiflora* in west Nusa Tenggara and concluded that FTLs had the greatest potential to increase incomes of smallholder farmers in Bali cattle operations. This was confirmed in an economic analysis (Waldron et al. 2019), which showed that a leucaena-based cattle fattening system was profitable for smallholder cattle producers in West Timor, although more so in the wet than the dry season due to higher proportions of FTL in diets and higher growth rates achieved during the wet season.

Indigofera zollingeriana – a viable alternative feed source for cattle?

Indigofera zollingeriana Miq. (synonym *Indigofera teysmannii* Miq.), which belongs to family *Fabaceae*, subfamily *Faboideae* and tribe *Indigofereae*, is one of about 750 *Indigofera* species recognized world-wide (Schrire et al. 2009) that had previously been used in forestry and soil conservation applications (Choudhury et al. 2006) but recently recognized as a possible alternative FTL for feeding to both ruminants and non-ruminants in Indonesia. *I. zollingeriana* is an erect perennial shrub or small tree, growing up to 12 m in height, native to temperate and tropical regions of Asia (Cook et al. 2020), and is well colonized across the major islands of Indonesia (de Kort and Thijsse 1984; GRIN 2023). Other *Indigofera* species, notably *I. tinctoria*, known to have existed in Indonesia for many centuries, have been used to produce indigo dye for the weaving and batik crafts and for export during the Dutch colonial period. While *I. zollingeriana* does not produce the dye (Muzzazinah et al. 2016), it can be used as a green manure, for firewood and as a shade plant for young coffee, tea, cocoa and coconut plants. Several features indicate *I. zollingeriana* could be a valuable plant for commercialized cultivation in Indonesia, particularly its adaptation to a wide range of soil textures ranging from sandy to clay, its tolerance of low soil fertility and moderately dry conditions, despite being better suited to a high rainfall environment, and in particular its ability to grow well on acidic soils (Cook et al. 2020).

I. zollingeriana has been scientifically investigated in Indonesia as a forage for feeding ruminants and monogastrics only since 2009, initiated by the Department of Animal Science and Technology, Bogor Agricultural University (Abdullah et al. 2012). Concurrently, there has been a concerted effort to distribute *I. zollingeriana* more widely through the islands of Indonesia, including Sumatra, Java, Kalimantan, Sulawesi, Maluku and Papua islands, led by the Indonesian Goat Research Station (S. Ginting, unpublished data). In evaluating its potential as an alternative high-quality forage for ruminants in Indonesia, a key question is: does *I. zollingeriana* offer any advantages as a feed source that are not provided by other FTLs already in use?

There is limited literature relating to the growth and nutritive value of *I. zollingeriana*. This situation is exacerbated by the fact that several papers from research in Indonesia refer to a tree legume which was unidentified at time of publication and is generically referred to as *Indigofera* sp. but has since been identified as *I. zollingeriana*. Results from these studies are included in this review only where the plant has been verified as *I. zollingeriana* in follow-up enquiries with the papers' senior authors.

Forage production. The high yield potential of *I. zollingeriana* in a range of environments has been recorded with plants spaced at 1 × 1.5 m in soil of near-neutral pH (6.2), fertilized and irrigated to represent optimal growing conditions giving a yield of edible plant material (leaves, petioles, succulent branches and shoot tips) of 4,096 kg DM/ha/harvest when cut every 68 days (Abdullah and Suharlina 2010). Although total yield was increased by delaying cutting interval to 88 days, the leaf:stem ratio declined at the longer cutting interval. At similar plant spacing and cutting interval of 60 days but on more acidic soil (pH 4.8–5.2), yields of edible forage (leaves, petioles and edible twigs) of up to 7.9 t DM/ha/harvest were measured for *I. zollingeriana* receiving foliar applications of N:P:K fertilizer with trace amounts of magnesium, calcium, copper, iron, zinc, molybdenum and boron (Abdullah 2010). Overall yield of forage can be further increased by reducing plant spacing compared with above plant density, thus increasing number of plants per unit area, despite proportionate reductions in numbers of branches and leaves per plant (Kumalasari et al. 2017). Sirait et al. (2012) harvested *I. zollingeriana* 8 months after planting and recorded total yields of fresh plant material of ca. 52 t/ha (11.4 t DM/ha), demonstrating its high growth potential. Tarigan et al. (2010) subsequently explored effects of cutting height (0.5, 1.0 and 1.5 m above ground) and cutting interval (30, 60 and 90 days) and demonstrated the highest yield of 33.3 t DM/ha/year when *I. zollingeriana* was cut at 1.5 m and 90 days interval.

Tolerance of acidic soils. The ability of *I. zollingeriana* to grow under unfavorable climatic conditions and in marginal areas not suited to cropping, including on saline, infertile and/or acidic soils with the latter being a predominant feature of the Indonesian landscape, defines its potential use. Notohadiprawiro (1989) estimated that acid-mineral soils represented about 38% of Indonesia's land area, located predominantly in Sumatra, Kalimantan, Sulawesi and Irian Jaya, whereas a more recent estimate of Berek (2019) was that acidic soils, including dryland (mainly) and peaty soils, occupied about 55% of the total land area. Acidic soils are often heavily-leached and low in fertility and characterized by aluminum (Al) and manganese (Mn) toxicity with associated deficiencies of essential minerals such as calcium, magnesium, potassium and phosphorus (Foy et al. 1978). Aluminum toxicity, in particular, is a major constraint on these soils for susceptible plants, interfering with plant growth and physiology, especially in the root zone (Foy et al. 1978), leading to reduced capacity for uptake and use of water and key elements and inducing nutrient deficiencies.

In screening a collection of 18 agroforestry species grown on highly acidic (ca. pH 4), Al-toxic soils in southern Cameroon, Kanmegne et al. (2000) reported *I. zollingeriana* to be one of the best for fast growth and high biomass production, outperforming other leguminous species commonly used in Indonesia, *L. leucocephala* and *G. sepium*. *I. zollingeriana* had higher biomass production than either *Calliandra calothyrsus* Meisn. or *G. sepium* when grown in a greenhouse in acidic soil (Ultisol soil type, pH 4.6) with high Al-saturation (Herdiawan and Sutedi 2015). This higher performance of *I. zollingeriana* was associated with no apparent impairment of root growth or root nodulation and lower concentrations of Al in tissues of leaves, stems and roots, indicating greater tolerance of toxic soil conditions. By contrast, root growth was apparently reduced in *G. sepium* and neither it nor *C. calothyrus* displayed any root nodulation. Herdiawan (2016) also found no effect of soil acidity, as modified using dolomite application, on fresh biomass production of *I. zollingeriana* grown under varying light intensities imposed by palm tree shading.

On the slightly acidic peat soils typical of Kalimantan, leaf yields of *I. zollingeriana* over 3 successive harvests at 120-day intervals across a year of 2.6, 8.2 and 6.6 t DM/ha were greater than the 0.2, 0.7 and 0.3 t/ha for *L. leucocephala*, the most widely-grown and successful FTL in Indonesia (Ali et al. 2014). Similarly, on acidic, sandy soils of poor nutrient status in a study in Vietnam, *I. teysmannii* (syn. *I. zollingeriana*) was more productive than 6 other leguminous trees and shrubs, including *L. leucocephala* (a purportedly acid-tolerant cultivar from the Philippines) and *G. sepium* (Ngo et al. 1995). Production of edible leaf and stem over 16 months (cumulative for 3 harvests) was 8.7, 6.4 and 3.7 t DM/ha for *I. zollingeriana*, *G. sepium* and *L. leucocephala*, respectively. Given its demonstrated higher tolerance of acidic soils, *I. zollingeriana* may be one logical option for planting in this environment, providing it also meets the requirement of improving animal production.

Tolerance of drought. There is considerable variation between and within *Indigofera* species in response to stress caused by moisture deficit (Hassen et al. 2007; 2008). *I. zollingeriana* is widely-distributed throughout Southeast Asia, including the major islands of Indonesia, and has been described as 'apparently indifferent to climate', being able to survive over a range from dry to monsoonal areas (de Kort and Thijsse 1984). The

Tropical Forages database factsheet (Cook et al. 2020) refers to *I. zollingeriana* as 'moderately tolerant of dry conditions', being adapted to areas with rainfall as low as 600 mm/annum but recommended for regions of high rainfall. In an investigation into the effects of water deficit on the growth of *I. zollingeriana*, by comparing soil moisture levels of 100, 50 and 25% of field capacity, Herdiawan (2013) found a trend for plant height, number of branches, stem diameter and root weight to decline as moisture level declined, while root length increased and canopy (above-ground plant material):root ratio was not affected, although the effects were not always significant at the intermediate moisture level (50% field capacity). Production of edible plant material (edible leaves, stems and branches) was reduced by 14% (not a significant effect) and 59% at 50 and 25% field capacity, respectively. Despite these negative impacts of soil moisture deficit, results indicated that *I. zollingeriana* will grow under quite severe drought conditions and respond when water availability improved following rainfall.

Tolerance of saline soils. Saline soils comprise at least 13.2 million ha of the total land area in Indonesia (Massoud 1974; cited by Ponnamperuma and Bandyopadhya 1980). A large proportion of these soils is unsuited to cropping and alternative land uses have been proposed, including growing FTLs for livestock feeding. The suitability of these soils for the growth of *I. zollingeriana* is still relatively unknown. In a small nursery investigation, Nadir et al. (2018) observed that *I. zollingeriana* seedlings apparently had restricted growth under saline growing conditions, but no quantitative or long-term measurements were taken, limiting the conclusions that could be drawn. Research into suitability of *I. zollingeriana* for growth on saline soils is a priority as, in addition to its potential use as a forage source, it could provide useful protection against erosion in coastal regions.

Tolerance of shading. I. zollingeriana showed some tolerance of shading at 40% intensity, but plant height, stem diameter and number of branches declined progressively as shade intensity increased from 40 to 80% (Saijo et al. 2018). This moderate shade tolerance suggests *I. zollingeriana* may be a useful stop-gap plant to include in integrated livestock-oil palm/coconut tree systems to offset high establishment costs and delayed production of newly planted oil palm or coconut plantations. However, its usefulness may be short-lived as palm trees grow rapidly and thus continually reduce light intensity for understory plants. An investigation of persistence and production of *I. zollingeriana* under frequent defoliation is required before it could be recommended ahead of other shade-tolerant plants.

Feeding value and animal growth responses

Chemical composition. Chemical composition of *I. zollingeriana* in forage grown across different seasonal conditions, soil types and fertility levels, for a variety of plant components and ages is variable (Table 1). The 'edible' components, including leaves, petioles, shoots and succulent branches and their proportion relative to mature stem (leaf:stem ratio) on the branches fed to animals determine the nutritive value and eventual animal production. Some reports cited in Table 1 refer simply to 'forage' without identification of the components analyzed, a serious oversight considering the large discrepancy in quality in favor of leaf over stem material (Minson 1990; Collins and Newman 2017). It is highly likely that the components analyzed in those studies were also edible parts based on the generally high values for key parameters of forage quality, but this cannot necessarily be assumed.

For simplified examination of these effects, forage quality is aligned directly with CP and inversely with fiber [crude fiber (CF), neutral detergent fiber (NDF) and acid detergent fiber (ADF)] concentrations in the forage. Protein concentration in edible forage is of particular importance, given earlier discussion of protein deficits in diets of animals either grazing or being fed forage comprised of mainly mature grasses for much of the year. Low protein concentration in these grasses during the dry season severely limits animal growth and reproduction (Winks 1984; Hunter and Siebert 1985; Poppi and McLennan 1995). For instance, CP concentrations in diets selected by cattle grazing predominantly tropical grass pastures in northern Australia were less than 60 g CP/kg DM for up to 9 months of the year (Dixon and Coates 2010; Hunt et al. 2013; McLennan 2014), whereas the lower threshold for cattle to maintain weight is ca. 60–70 g CP/kg DM (Milford and Minson 1965; Minson 1990). By comparison, average CP concentration in foliage from *I. zollingeriana* was 265 g/kg DM, with a low of 210 g/kg DM (Table 1), all concentrations seemingly sufficient to support high levels of animal performance. This positions *I. zollingeriana* well for use as either the sole diet for cattle and other ruminants or a supplement to low-protein dietary components in a mixed feeding situation.

Table 1. Chemical composition (g/kg dry matter) of foliage of *Indigofera zollingeriana*

Plant part	CP	Fat	NDF	ADF	CF	Lignin	Tannin	Ca	P	IVDMD	IVOMD	Reference
Leaves, petioles, edible twigs	277		436	352			0.8	11.6	2.6	675	603	Abdullah (2010)
Leaves, petioles, succulent branches	210		494	262						692	708	Abdullah and Suharlina (2010)
Shoot tips	234		561	307						786	776	As above
Forage - NS	231	22			167			3.7	1.3	700	689	Suharlina and Sanusi (2020)
Leaves	231		359	251								Ali et al. (2014)
Leaves and twigs	246		341	289		35	0.6	15.9	2.2	755	760	Herdiawan et al. (2014)
Foliage - NS	218	36			231			11.7	3.5	738	762	Herdiawan and Sutedi (2015)
Foliage - NS	252				171			9.4	2.7	677	637	Herdiawan (2016)
Foliage - NS	264	19	292	276								Kumalasari et al. (2017)
Plant shoots	300	33			85			5.2	3.4			Palupi et al. (2014)
Leaves and shoots	248	48			152			20.8	2.7			Ngo et al. (1995)
Foliage - NS	279	62			153							Nurhayu and Ishak (2015)
Leaves and shoots	232	26			164			35.4	3.3			Quintos et al. (2018)
Foliage - NS	283	19			103							Jayanegara et al. (2016)
Leaves	356		333	258								Jayanegara et al. (2019)
Foliage - NS	318	25			168							Jusoh and Nur-Hafifah (2018)
Foliage - NS	312	35	232	208								Putri et al. (2019)
Leaves and petioles	313		422	234		54	A			785		Tscherning et al. (2005)
Leaves and petioles	238		207	178		39	A					Tscherning et al. (2006)
Average	265	33	368	262	158	43	0.4	14.2	2.7	726	705	

CP=crude protein (N × 6.25); NDF=neutral detergent fiber; ADF=acid detergent fiber; CF=crude fiber; IVDMD=in vitro dry matter digestibility (g/kg DM); IVOMD=in vitro organic matter digestibility (g/kg OM); NS=plant component not specified. A=zero (lignin+bound) condensed tannins but polyphenols present.

Norton (1994b) showed that FTLs varied quite widely in tannin concentration, with some plants like *S. grandiflora* and *S. sesban* having no tannin and others like *C. calothyrsus* having high concentrations (96–111 g/kg DM). The average tannin concentration in *I. zollingeriana* is quite low at less than 10 g/kg DM (Table 1). However, the form of tannin is not stated in most cases and Tscherning et al. (2005; 2006) reported that, although *I. zollingeriana* contained polyphenols at low concentration (~50 g/kg DM), it contained no condensed tannin in either soluble or bound form and thus had no protein-binding capacity. This is a significant finding, suggesting that much of the protein in *I. zollingeriana* is available for degradation in the rumen with potential high loss to the animal as excreted urea.

Very high degradability of protein from *I. zollingeriana* was confirmed in the study of Tscherning et al. (2005), who reported that the available N in *I. zollingeriana* declined by almost 90% after 144 h of anaerobic incubation, compared with less than 5% for *C. calothyrsus*. Tscherning et al. (2006) subsequently explored the practical option of combining a high-tannin plant like *C. calothyrsus* with *I. zollingeriana* in the diet to provide a balance of rumen degradable protein (RDP) and undegraded dietary protein (UDP) and reduce combined-N loss to the animal. They compared combinations of prunings (leaves and petioles) of *C. calothyrsus* (CP: 169 g/kg DM) and *I. zollingeriana* (CP: 313 g/kg DM), mixed in the proportions of 100:0, 75:25, 50:50, 25:75 and 0:100 (w/w; DM), and showed a steep, step-wise increase in N disappearance from plant material in an anaerobic fermentation system as the proportion of *I. zollingeriana* in the mixture increased. Only at the high inclusion rate (75%) of *C. calothyrsus* did it apparently reduce N utilization from *I. zollingeriana*, suggesting no protection of protein from digestion through formation of protein-condensed tannin complexes at lower inclusion rates. Availability of any protein bound by condensed tannin for post-ruminal absorption was not determined.

Averaged across studies, the main components (NDF, ADF, CF and lignin concentrations) describing fiber composition and degradability were relatively low in *I. zollingeriana* (Table 1) compared with concentrations expected in mature grasses, but commensurate with values for other FTLs. NDF and ADF concentrations averaged 367 and 260 g/kg DM, respectively, similar to the averages of 353 and 251 g/kg DM for edible forage of a wide range of FTLs collated by Norton (1994a). There are limited observations for lignin concentration in *I. zollingeriana*, but the average concentration of 43 g/kg DM is lower than the 99 g/kg DM average reported by Norton (1994a) for other FTLs.

The importance of fiber concentration lies in its relationship with digestibility, which is in turn directly related to feed intake (Thornton and Minson 1973; Allison 1985; Minson 1990). Low fiber concentration in *I. zollingeriana* was reflected in high in vitro DM and OM digestibilities [in vitro dry matter digestibility (IVDMD) and in vitro organic matter digestibility (IVOMD)] averaging 72.6 and 70.5%, respectively (Table 1). Of the alternative FTLs fed commonly in Indonesia, Norton (1994a) reported similar high average IVDMD (67.5%) for *G. sepium*, *L. leucocephala*, *S. grandiflora* and *S. sesban*, but a much lower value for *C. calothyrsus* (41.5%). Tscherning et al. (2005) also reported very low IVDMD (21.3%) for (oven-dried) *C. calothyrsus*, compared with *I. zollingeriana* (78.5%), the difference being attributed to high condensed tannin and lignin concentrations in this *Calliandra* species relative to *I. zollingeriana*.

Within plant component type, variability in composition may be partly attributed to differences in growing conditions and agronomic practices applied. Nevertheless, these compositional changes need to be considered in conjunction with the effects on total yield of leaf and its proportion relative to stem. As age of cutting of *I. zollingeriana* increased, CP concentration of forage was reduced significantly, and NDF and ADF concentrations increased, in the study of Herdiawan et al. (2014) at 60–120 days harvest, but these constituents were only marginally and variably affected in the studies of Abdullah and Suharlina (2010) cut at 38–88 days and Tarigan et al. (2010) cut at 30–90 days, perhaps reflecting the older harvesting age in the former study. However, by far the largest effect of increasing harvesting age on plant components was the steep reduction in leaf:stem ratio with increasing plant age (Tarigan et al. 2010).

Increasing the shade intensity on *I. zollingeriana* plants by growing them under palm tree canopies of increasing age (2-, 5- and 7-year-old) was associated with increases in both CP (232 to 270 g/kg DM) and CF (136 to 179 g/kg DM) concentrations in forage, but a reduction in leaf:stem ratio of plants (Herdiawan 2016). The forage sampled was not identified but high CP and low CF concentrations suggest it was predominantly leaf material. When increasing amounts of an N, P, K and mineral fertilizer were applied to the leaves of *I. zollingeriana* plants (Abdullah 2010), there was no effect on concentration of CP in leaves and edible twigs, and variable effects on fiber concentration. NDF concentration increased as level of fertilizer increased, to a maximum of 511 g/kg DM, whereas the effects on ADF concentration were variable and appeared random. However, the main effect of applying fertilizer was a quadratic increase in herbage production, supporting the concept that the changes in amounts and proportions of major agronomic plant components, especially leaf, are more important than changes in composition given the generally high quality of this component.

There is limited information in the literature on macro- and micro-element concentrations in *I. zollingeriana* and only Ca and P concentrations are shown in Table 1. Freer et al. (2007) recommends a minimum P concentration in plants for cattle diets ranging from 1.0 to 2.7 g P/kg DM, unless for lactating animals, when a higher allowance may be required. The corresponding minimum requirement for Ca is 2.0–3.9 g Ca/kg DM. On the basis of these recommendations, P (average 2.7 g/kg DM) and Ca (average 14.2 g/kg DM) concentrations in *I. zollingeriana* are adequate (Table 1), although these will depend on the physiological status of consuming animals and whether FTL is fed as a complete diet or as a supplement to low-quality forage. Mineral composition of plant material might be expected to reflect growing conditions, but when Abdullah (2010) applied increasing amounts of foliar fertilizer to *I. zollingeriana*, including both P and Ca in the mix in addition to N, K, Mg, Cu, Fe, Zn, Mo and B, P concentration in leaf and edible twigs varied only slightly (2.6–3.1 g/kg DM), while there were variable and inconsistent effects on Ca concentrations (range 11.6–17.8 g/kg DM).

Presence of secondary plant compounds. Indospicine, a highly toxic non-protein amino acid found in some *Indigofera* species, is an arginine analogue and has the potential to disrupt arginine metabolic pathways in mammalian species. The occurrence and toxicity for grazing animals of indospicine have been reviewed recently by Fletcher et al. (2015), who reported that livestock ingesting species of *Indigofera* containing indospicine could suffer both hepatotoxicity and embryo-lethal effects and suggested that indospicine may be an often-undiagnosed cause of poor livestock performance, including reproductive losses. Fletcher et al. (2018) showed that indospicine accumulated in muscle and liver tissues of cattle consuming *I. spicata*, so animals consuming these tissues, including humans, could potentially suffer secondary poisoning. Microorganisms in the rumens of herbivores possess the capacity to detoxify indospicine, by absorption and deamination, but the high solubility of indospicine means that some toxin will escape the rumen undegraded and be available in the intestines for tissue absorption (Loh Zhi Hung et al. 2020). The extent of transfer of indospicine to the intestines is likely to increase as retention time in the rumen decreases, i.e. as the quality of the diet improves. Thus, by increasing the proportion of *Indigofera* sp. in the diet, the positive effects of reduced rumen retention time associated with a high-quality diet may be counterbalanced by the higher concentration of indospicine in the total diet and greater post-ruminal absorption of the toxin.

There is limited information currently available on the indospicine status of *I. zollingeriana*. Miller and Smith (1973), using material from a seed collection, found no detectable concentrations of indospicine in the seeds of *I. zollingeriana*, nor in those of 15 of 16 other species of *Indigofera* tested. However, the effects of long-term storage of seeds on indospicine concentration are unknown. We found no other reports on indospicine presence in *I. zollingeriana*, possibly due to the lack of testing to date for this species. At the same time, when researchers in India fed *I. teysmannii* (syn. *zollingeriana*) leaves ad libitum as the sole diet to sheep for 4 weeks, they observed haematuria and damage to liver and kidneys on post-mortem examination of the sheep, which they suggested was strongly indicative of indospicine toxicosis (Singh et al. 1985; Krishna et al. 1986). Although no analyses for indospicine presence in plant material were undertaken in either study to support this presumption, these researchers advised against longer-term feeding of *I. zollingeriana* as a major component of the diet. It seems imperative that a systematic analysis of *I. zollingeriana* for indospicine concentration be undertaken to include different regional, ecoclimatic, growth stage and cultivational regimes, all of which may influence both presence and concentration of the toxin in components of plant material (Fletcher et al. 2015).

Intake by ruminants. Low fiber and high protein concentrations, recognized attributes of *I. zollingeriana* forage (see above), generally support high rates of intake by ruminant animals by stimulating microbial growth and activity in the rumen and promoting rapid digestion and passage of fibrous material through the digestive tract.

There are conflicting reports, both published and anecdotal, on the palatability or acceptance of *I. zollingeriana* by ruminants. Abdullah and Suharlina (2010) report the species as 'highly relished by livestock', while Nurhayu and Pasambe (2016) state that low acceptance of *I. zollingeriana* is an impediment to its general use. Herdiawan and Krisnan (2014) suggest palatability of *I. zollingeriana* is low in the rainy season but higher in the dry season. In some feeding experiments, high intakes of *I. zollingeriana* have been reported where it has been fed in conjunction with tropical grass or concentrates to goats. Boerka (Boer × Kacang) male goats consumed 29–31 g DM/kg BW/day of *I. zollingeriana* when fresh leaves were fed with either high-energy or high-protein concentrate (Ginting et al. 2010), suggesting no acceptance issues with *I. zollingeriana* for goats. In a trial assessing the acceptance by goats of various legumes fed individually or free-choice in conjunction with elephant grass (Ngo et al. 1995), *I. zollingeriana* was consumed at about 36% of the diet, similar to the selection for *G. sepium* (42%) but less than for *L. leucocephala* (53% of diet). Subsequently, Sirait et al. (2012) showed the intake of forage of *I. zollingeriana* by Boerka goats was equivalent to that of *L. leucocephala*, when both legumes were provided free-choice in a palatability study. More observations are required to truly document the acceptance of *I. zollingeriana* by ruminants under varying conditions.

Production responses by ruminants. Responses by herbivores to inclusion of *I. zollingeriana* in the diet are found in only a single published report (Nurhayu and Pasambe 2016) containing statistically analyzed data on the effects of feeding *I. zollingeriana* to cattle (Table 2). In a small study in south Sulawesi with 12 castrated male cattle, the basal diet of elephant grass (65 g CP/kg DM) supported growth rates of 0.36 kg/day. Substitution of *I. zollingeriana* at 40 or 60% (DM basis) for grass in the diet increased growth rate by about 30%. In the absence of other such reports with cattle, further assessment of feeding value of *I. zollingeriana* is based on feeding studies with goats. Where *I. zollingeriana* was increasingly substituted for a low-quality tropical grass (65–81 g CP/kg DM) in the diet of goats, growth rate increased but responses appeared to peak at about 30–40% legume inclusion (DM basis) in the diet (Tarigan and Ginting 2011; Nurhayu and Ishak 2015). By contrast, Simanihuruk and Sirait (2009) recorded no effects on growth rates of male Boerka goats from replacing 25, 50 or 75% of the basal diet of *Ottochloa nodusa* (slender panicgrass; 93 g CP/kg DM) with *I. zollingeriana*. DM intakes did not differ between treatments (mean 3.1% BW/day), perhaps because total feed offered was the same for all groups and restricted to only ca. 3.5% BW/day DM (based on average BW), thereby possibly limiting the expression of intake and weight gain differences between diets.

Other experiments have shown that *I. zollingeriana* can at least partially replace concentrate in rations for goats. For female Etawah × Kacang goats fed a mixed soybean husk-commercial concentrate diet (35:65, DM basis; 129 g CP/kg DM), incorporation of wafers prepared from *I. zollingeriana* into the diet (husks:concentrate:wafers, 30.8:57.1:12.1; DM basis), with only a small change in total CP concentration (144 g/kg DM), increased growth rate from 47 g/day to 73 g/day (Dianingtyas et al. 2017). Growth responses were similar for wafers made from *L. leucocephala* or *C. calothyrsus* when they were prepared to present similar total diet CP concentration. When *I. zollingeriana* was fed ad libitum as sole forage in conjunction with either a high-carbohydrate (70% corn) or high-protein (70% soybean meal) concentrate (both provided at 1.5% BW/day) and constituting about 68% of total DM in the diet of male Boerka goats, growth rate was greater when the legume was fed with high-protein concentrate, despite total CP concentrations of both rations being high at 204 and 274 g/kg DM, respectively (Ginting et al. 2010). This result is surprising and conflicts with the proposal of Poppi and McLennan (1995) of the benefits for rumen microbes of a source of readily degraded energy in the rumen to capture some of the excess ammonia produced from highly-degraded protein sources such as *I. zollingeriana*. Rumen ammonia-N concentration and N retention were higher in goats fed the high-protein versus the high-carbohydrate concentrate as was to be expected. Energy in the soybean meal may have been more readily degraded in the rumen than that in corn, allowing the goats to capture and utilize the additional N from the higher protein diet. A highly fermentable energy source such as cassava may be more suitable to capture excess nitrogen from legumes such as *I. zollingeriana* (Tudor et al. 1985; Harper et al. 2019).

Table 2. Growth rate responses (average daily gain; ADG) by ruminants to inclusion of *I. zollingeriana* in the diet.

Animal species/ genotype	Gender/ class	Age	Initial live weight (kg)	Basal diet	Basal diet CP (g/kg DM)	Legume	Legume inclusion rate (% of diet DM)	ADG (g)	Reference
Cattle/NR[1]	castrated males	1.5–2 yr	172	*Cenchrus purpureus*	65	*I. zollingeriana*	0	360a[2]	Nurhayu and Pasambe (2016)
							40	460b	
							60	500b	
Goats/Boerka	male	6–7 mo	11	*Ottochloa nodusa*	93	*I. zollingeriana*	0	37	Simanihuruk and Sirait (2009)
							25	41	
							50	44	
							75	43	
Goats/Boerka	male	3–4 mo	10.2	*Urochloa ruziziensis*	81	*I. zollingeriana*	0	28a	Tarigan and Ginting (2011)
							15	39b	
							30	51c	
							45	52c	
Goats/Kacang	females - lactating	NR	23	Native grass	65	*I. zollingeriana*	0	33a	Nurhayu and Ishak (2015)
							40	82b	
							60	91b	
	kids	NR	1.4	Native grass	65	as above	0	57a	
							40	72b	
							60	76b	
Goats/Etawah × Kacang	female	4 mo	13	35% Forage (F) /65% concentrate (C)	na[3]	*I. zollingeriana*	0	47a	Dianingtyas et al. (2017)
				30.8% F/57.1% C	na		12.1	73b	
Goats/Boerka	male	6 mo	16	High-carbohydrate concentrate	94	*I. zollingeriana*	68	60a	Ginting et al. (2010)
				High-protein concentrate	317	*I. zollingeriana*	69	81b	

CP=crude protein (N × 6.25); DM=dry matter; [1]NR=not reported; [2]Within experiments, means within a column followed by the same letters are not different (P>0.05); [3]na=not applicable.

General conclusions

Published work suggests that *I. zollingeriana* may have a role to play in improving productivity of ruminants in Indonesia and other tropical countries. This review assessed the potential of *I. zollingeriana* for use as a high-quality forage for feeding cattle in Indonesia, for how well *I. zollingeriana* is suited to the varied growing conditions in Indonesia, and what it offers nutritionally to cattle that other FTLs, already well-established in agro-ecological production systems there, do not already provide.

I. zollingeriana provides an extremely high yield of leaf and other edible components under good growing conditions but also survives and is productive in less-ideal conditions, including under drought stress, in saline conditions and, most importantly, on acidic soils. These Al-toxic acidic soils, which constitute a substantial proportion of the total landscape in Indonesia, perhaps represent a major ecological niche for *I. zollingeriana*, since it is more suited to these soils than other FTLs currently used in the country. Further studies to determine its long-term performance under regular harvesting on these soils are warranted. An additional advantage is the apparent absence of pests and diseases. The nutritive value of the edible components of the plant is at least equal to that of other FTLs currently in use, as indicated by its high protein, low fiber and low condensed tannin concentrations and high digestibility. The high protein concentration of *I. zollingeriana* foliage alone underlines its potential as a protein supplement for herbivores otherwise restricted to consuming low-quality tropical grasses or crop by-products. Although there are limited studies to date on feeding of *I. zollingeriana* to cattle, positive performance responses when fed to goats indicate the likelihood that it will substantially improve production of cattle. Well-designed feeding experiments with cattle to provide information on optimum dietary inclusion rates of *I. zollingeriana* (dose response) and comparisons against other FTLs are a high research priority. Most current indications are that *I. zollingeriana* will be a valuable alternative FTL for use in cattle production systems in parts of Indonesia and may contribute to the desired increase in local beef production.

There are conflicting reports on palatability of the plant material for herbivores, which needs further elucidation, although acceptance may be enhanced through a process of education and experience with target animals. However, research is necessary to resolve whether or not *I. zollingeriana* contains the hepatotoxin indospicine, common to some species of this genus and, if so, in what concentrations. The presence of high levels of indospicine can have a major influence on the longer-term health of the animals and has profound implications on the health of humans consuming animal products. This question can be resolved through a systematic analysis of plant material from different sources from a range of growing conditions (soils and seasons) and is highly recommended before further widespread dissemination of the plant is undertaken.

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Research Paper

Seedling emergence of tropical perennial pasture species in response to temperature used to determine sowing time recommendations

Emergencia de plántulas de especies de pasto perennes tropicales en respuesta a la temperatura utilizada para determinar recomendaciones de época de siembra

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Abstract

Tropical pasture grasses and legumes can be highly productive and persistent and fill the summer-autumn feed gap typical of temperate pasture systems in southern Australia. However, more information is needed on optimum temperature range for seedling emergence because this will influence sowing time recommendations. A replicated field experiment was conducted at 5 locations in New South Wales over a 12-month period to determine the optimum temperature for emergence of a range of tropical species: Rhodes grass (*Chloris gayana* Kunth), Makarikari grass (*Panicum coloratum* L. var. *makarikariense* Gooss.), kikuyu grass (*Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone), digit grass (*Digitaria eriantha* Steud.), panic grass (*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs), paspalum (*Paspalum dilatatum* Poir.), *Urochloa* hybrid (*Urochloa decumbens* × *U. ruziziensis* × *U. brizantha*), 2 cultivars of *Desmanthus virgatus* (L.) Willd. (cultivars 'Marc' and 'JCU2'), *D. bicornutus* (S. Watson), *D. leptophyllus* (Kunth) and *D. pernambucanus* (L.) Thell.). Rhodes grass emerged satisfactorily over the longest time across all sites, exhibiting the greatest temperature range over which emergence occurred, while Makarikari grass and panic grass had the narrowest temperature range for emergence. The temperature for 50% emergence differed between the tropical species and whether the soils were warming or cooling. Rhodes grass had the lowest 50% emergence temperature (17 °C) while paspalum had the highest (22 °C). Results showed that temperature for 50% emergence is a useful indicator for determining sowing time in warming soils.

Keywords: C4 species, drought, heat, optimum emergence, pasture.

Resumen

Las gramíneas y leguminosas de pastos tropicales pueden ser altamente productivas y persistentes, llenando la falta de alimentos en verano y otoño típico de los sistemas de pasturas templadas en el sur de Australia. Sin embargo, se necesita más información sobre el rango óptimo de temperatura para la emergencia de plántulas, ya que esto influirá en las recomendaciones sobre la época de siembra. Con ese propósito se condujo un experimento de campo replicado

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en 5 ubicaciones en Nueva Gales del Sur, durante un período de 12 meses, para determinar la temperatura óptima para la emergencia de un grupo de especies tropicales: pasto Rhodes (*Chloris gayana* Kunth), pasto Makarikari (*Panicum coloratum* L. var. *makarikariense* Gooss.), pasto kikuyu (*Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone), pasto pangola (*Digitaria eriantha* Steud.), pasto guinea (*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs), paspalum (*Paspalum dilatatum* Poir.), híbrido de *Urochloa* (*Urochloa decumbens* × *U. ruziziensis* × *U. brizantha*), 2 cultivares de *Desmanthus virgatus* (L.) Willd. (cultivares 'Marc' y 'JCU2'), *D. bicornutus* (S. Watson), *D. leptophyllus* (Kunth) y *D. pernambucanus* (L.) Thell.). El pasto Rhodes emergió de manera satisfactoria durante un período más largo en todos los sitios, exhibiendo el mayor rango de temperatura en el que ocurrió la emergencia, mientras que el pasto Makarikari y el pasto guinea tuvieron el rango de temperatura más estrecho para la emergencia. La temperatura para el 50% de la emergencia difirió entre las especies tropicales y si los suelos se estaban calentando o enfriando. El pasto Rhodes tuvo la temperatura de emergencia del 50% más baja (17 °C), mientras que el paspalum tuvo la más alta (22 °C). Los resultados mostraron que la temperatura para el 50% de la emergencia es un indicador útil para determinar la época de siembra en suelos que se están calentando.

Palabras clave: Calor, emergencia óptima, especies C4, pasto, sequía.

Introduction

Tropical pasture grasses and legumes are an important component of grazing systems globally, due to their productivity and persistence within tropical and sub-tropical environments (Moser et al. 2004). In northern Australia, they are an integral part of livestock systems. Their higher production, nutritive value and longer growing season, compared with native grassland species, can significantly improve the productivity and profitability of northern Australian grazing enterprises (Quirk and McIvor 2006). Over recent decades adoption of these species has extended into the frost-prone summer dominant rainfall region in northern inland New South Wales (NSW) (Boschma et al. 2008, 2009; Nie et al. 2008) and the medium-low rainfall zone of southern Western Australia (Moore and Barrett-Lennard 2006; Moore et al. 2021). Over the last few years, there has been increasing interest in tropical grasses in temperate areas in southeastern Australia. In this region the growth pattern of tropical grasses allows them to utilise summer rainfall, with potential to assist with filling the traditional summer–autumn feed gap. Tropical pastures also reduce soil erosion and provide ground cover and competition to reduce weed invasion (Descheemaeker et al. 2014).

The success of pasture establishment is influenced by a range of factors including ground preparation, sowing depth and seed quality. The time from sowing until emergence is highly influenced by temperature (Angus et al. 1980), however, limited information is available on the optimal temperatures for sowing tropical pasture species in sub-tropical and temperate environments. Sowing when temperatures are optimal or near optimal will improve germination and, subsequently, success of establishment. In the absence of species-specific information, the recommended sowing temperature for forage sorghum (*Sorghum bicolor* (L.) Moench), when soil temperatures are above 15 °C, is sometimes used for tropical perennial pasture species (Cook et al. 2020). Field studies with tropical perennial grasses, such as, Rhodes grass (*Chloris gayana* Kunth cultivar 'Katambora'), kikuyu grass (*Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone synonym *Pennisetum clandestinum*, cultivar 'Whittet'), Makarikari grass (*Panicum coloratum* L. var. *makarikariense* Gooss.), digit grass (*Digitaria eriantha* Steud.) and paspalum (*Paspalum dilatatum* Poir.) suggest optimal soil temperatures for germination in the range of >15–18 °C (Moore and Barrett-Lennard 2006; Nie et al. 2008) with day-time temperatures of 20 °C and night-time temperatures of 10 °C (Harris et al. 2014). Lodge and Harden (2009) investigated the effect of sowing time and depth on seedling emergence for several tropical grasses and recommended spring sowing when mean daily soil temperatures are >22 °C and mean maximum and minimum temperatures are >26 and >16 °C, respectively.

Several studies have shown that emergence temperature requirements of tropical forages differ between species. Watt and Whalley (1982) investigated optimum germination temperature using germination pads and found the optimum germination temperature range for Rhodes grass cultivar 'Katambora' was 20–30 °C while Makarikari grass ranged from 25–35 °C. Nichols et al. (2012) used a water agar medium and reported optimum germination temperature for kikuyu grass cultivar 'Whittet' ranged between 20–35 °C, Rhodes grass between 25–30 °C and digit grass cultivar 'Premier' between 20–25 °C. Egan et al. (2017) tested seedling emergence using a sand and peat mix in a growth cabinet and reported that optimum temperature for seedling emergence for Makarikari grass was between 24–35 °C, digit grass between 21–32 °C, panic grass (*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs cultivar 'Gatton') between 24–32 °C and Rhodes grass between 24–35 °C. Egan et al. (2017) also identified temperatures for 50% of maximum emergence to determine recommended sowing time. These temperatures were between 12–14 °C for Rhodes grass and between 17–18 °C for digit grass and Makarikari grass. Angus et al. (1980) identified the base temperature for emergence for a range of temperate and tropical crop species under field conditions and found no emergence of tropical species below 10–14 °C.

Seedling emergence in the field is affected by several factors, including soil type, soil moisture content, wind and temperature. Controlled studies are highly effective at illustrating germination rates, however, the contrived conditions in which they are conducted have limited field application. Determining optimum temperatures for emergence under more variable conditions, such as in the field, are considered more robust for determining sowing times for specific localities. Therefore, an experiment was conducted at 5 locations, including novel growing environments, to quantify field emergence and determine optimum temperatures for emergence that could be used to recommend the earliest sowing time of a range of tropical species.

Materials and Methods

Experiments were conducted at 5 contrasting sites across NSW, which represent existing and potential areas of adaptation for the selected tropical pasture species. These sites were Tamworth, Trangie, Orange, Cowra and Wagga Wagga (Table 1). Four core species were sown at all sites with additional species sown at Trangie and Tamworth (Table 2). The species tested were included based on a distribution modelling study that indicated suitability at the selected study sites at current and future climate scenarios (Simpson et al. unpublished). The distribution modelling study was Australia wide and shows the extent of suitability for the continent. Horticultural seedling trays (330 × 280 × 50 mm deep) used at each site were filled with brown Chromosol soil (Isbell 2021) sourced from 0–50 mm depth at a single location at NSW Department of Primary Industries' Agricultural Research Institute, Trangie, NSW. This soil had a history of summer weed control with no residual herbicide. The soil was passed through a 5 mm sieve to remove large debris before filling trays. The filled trays were moistened to prevent soil from settling in the tray prior to sowing. Seeds were obtained from commercial suppliers, so their age and pre-treatment were unknown, with the exception of the desmanthus lines, which had been mechanically scarified. The same seed batch for each species was used for the duration of the experiment to avoid any potential differences in seed size and vigour between batches. A germination test was conducted in a growth cabinet with 12 hourly alternating 30/20 °C day/night temperatures each month to monitor any change in seed viability during the experiment. For each species, 50 randomly selected seeds were placed into petri dishes lined with filter paper moistened with distilled water with 3 replicates. Average germination of the species after 14 days ranged from 41% (panic grass) to 89% (kikuyu grass) over the 12 months of the experiment (Table 2). The exception was the *Urochloa* hybrid which had poor germination in the laboratory, although seedlings emerged when sown in soil (0% germination in the laboratory compared to 35% emergence in the field). The number of seeds sown were not adjusted for germination percentage due to the poor relationship between germination and emergence. Germination percentages were common for commercially available seed, except for the *Urochloa* hybrid.

Sowing of seeds in the trays commenced in August 2019. Rhodes grass was sown with spikelets from August until December 2019 and from January 2020 spikelets were removed and the seeds were passed through a 0.5 mm sieve. One hundred uncoated seeds of each species were placed in 1 or 2 rows per species. After sowing, soil was added to the trays so that all seeds were covered to a depth of 10 mm (equal to the height of the tray rim). This is the optimum sowing depth for several tropical grasses (Lodge and Harden 2009). This process was repeated at monthly intervals over the ensuing 12 months. The experiment at each site was a randomised complete block design with 3 replicates. Each tray represented a replicate, except at Trangie and Tamworth where additional species necessitated using 2 trays per replicate.

The trays were buried in the soil in the field so that the tray rim was aligned with the soil surface to allow water movement over the trays without ponding, if significant rainfall was received. Micro-dataloggers (Thermochron iButon, Whitewater USA) were placed into each tray at a depth of 10 mm to monitor soil temperature. The soil surface was kept moist over the

14 days of the experiment by applying 80% of the daily potential evapotranspiration, recorded at the nearest Bureau of Meteorology site, using an automatic watering system with microsprays. Minimum and maximum air temperature was obtained from the nearest Bureau of Meteorology site. The number of emerged seedlings were counted on days 3, 7, 10 and 14 after sowing. The soil in all trays was then discarded.

Data analyses

Seedling emergence contour plots. The cumulative number of plants that emerged over the 14-day assessment period in each month from August 2019 to July 2020 were adjusted to a percentage of the maximum emergence achieved for each sown species at a given site. These emergence percentages were plotted to produce

Table 1. Location, elevation and long-term average (LTA) annual minimum and maximum temperature of the 5 experimental sites.

Location	Latitude	Longitude	Elevation (masl)	LTA annual minimum temperature (°C)	LTA annual maximum temperature (°C)
Tamworth	31°04’12” S	150°50’24” E	404	9.8	24.9
Trangie	31°59’24” S	147°57’00” E	215	10.9	24.7
Orange	33°19’12” S	149°04’48” E	922	6.2	18.4
Cowra	33°48’00” S	148°42’00” E	360	8.3	23.0
Wagga Wagga	35°03’00” S	147°21’00” E	219	9.1	22.2

Table 2. Tropical species sown at each site and their average laboratory seed germination range (%) over the 12 months of the study.

Species	Tamworth	Trangie	Orange	Cowra	Wagga Wagga	Lab germ (%)
Rhodes grass (*Chloris gayana* Kunth) cultivar ‘Katambora’	X	X	X	X	X	74±10.5
Digit grass (*Digitaria eriantha* Steud.) cultivar ‘Premier’	X	X	X	X	X	45±8.0
Makarikari grass (*Panicum coloratum* var. *makarikariense* L.) cultivar ‘Bambatsi’	X	X	X	X	X	75±8.2
Panic grass (*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs[1]) cultivar ‘Gatton’	X	X	X	X	X	41±9.4
Kikuyu grass (*Cenchrus clandestinus* Hochst. ex Chiov.) Morrone[2]) cultivar ‘Whittet’		X				89±5.0
Common paspalum (*Paspalum dilatatum* Poir.)		X				53±5.5
Urochloa[3] hybrid (*Urochloa decumbens* × *U. ruziziensis* × *U. brizantha*) cultivar ‘Mulato II’	X					0±0.2[4]
Desmanthus (*Desmanthus virgatus* (L.) Willd.) cultivar ‘JCU2’	X					60±3.2
Desmanthus (*Desmanthus bicornutus* S. Watson) cultivar ‘JCU4’	X					71±4.0
Desmanthus (*Desmanthus leptophyllus* Kunth) cultivar ‘JCU7’	X					86±1.7
Desmanthus (*Desmanthus pernambucanus* (L.) Thell.) cultivar ‘JCU9’	X					88±4.7
Desmanthus (*D. virgatus* (L.) Willd.) cultivar ‘Marc’	X					49±6.3
Total number of species tested	10	6	4	4	4	

[1]Synonym *Panicum maximum* Jacq.
[2]Synonym *Pennisetum clandestinum* Hochst. ex Chiov.
[3]Synonym *Brachiaria*
[4]Field emergence was superior to laboratory germination.

annual emergence contour plots using the filled.contour function in the R graphics package (R Core Team 2020). Bivariate interpolation was used [interp function in R package akima (Akima et al. 2022)] to smooth the contour plots, with the jitter option used to account for collinear points due to having 3 replicate emergence values for each sample day by month.

Emergence response to temperature. Day 10 cumulative emergence data were used to model response to temperature representing the period during which emergence is commonly observed. For each species at each site, total emergence on day 10 for each month was calculated as a percentage of the maximum emergence across all sites. These values were averaged to determine monthly emergence. The monthly soil temperature for days 1–3 at each site, hereafter called average soil temperature, was calculated by averaging the daily maximum and minimum temperatures for the 3 days following sowing. Emergence of each species was plotted against average soil temperature. Peak soil temperatures were recorded in January therefore each plot was divided into warming soil temperatures (August–January) and cooling soil temperatures (January–July). Combining all site data, provided a total of 30 and 35 data points in the warming and cooling temperature ranges respectively, for each species. Curves and standard errors were fitted to the data for warming and cooling soil temperatures using the "lowess" command from R (R Core Team 2020).

The same procedures were used to plot emergence for the additional species sown at Trangie and Tamworth. For each grass species, curves were fitted to warming and cooling soils using 6 and 7 data points, respectively. Data for the 5 desmanthus entries were pooled because usually species are blended to form regionally specific mixes (Gardiner 2016) and curves were fitted to warming and cooling soils using 30 and 35 data points.

To provide recommendations of the minimum temperatures required for sowing and to determine the emergence 'window' for each species, temperatures at which 50% of maximum emergence occurred in both warming and cooling soils were determined following the method of Egan et al. (2017).

Results

Emergence response surfaces

Rhodes grass had the widest emergence window of the 4 grasses, which were tested at all sites, emerging over the greatest number of months of the year at all sites (Figure 1A). Emergence occurred 11 and 12 months of

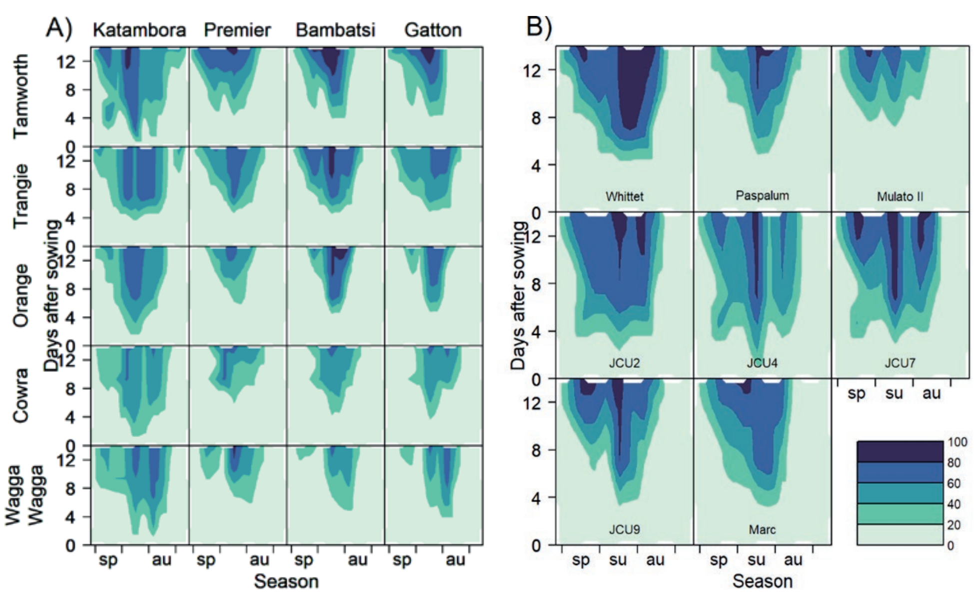

Figure 1. Plots of average cumulative seedling emergence (%) assessed 4 times over 14 days across the 12 months of the year from August to July for (A) Rhodes grass cultivar 'Katambora', digit grass cultivar 'Premier', Makarikari grass cultivar 'Bambatsi', panic grass cultivar 'Gatton' at 5 sites: Tamworth, Trangie, Orange, Cowra and Wagga Wagga, and (B) kikuyu grass cultivar 'Whittet' and paspalum at Trangie, *Urochloa* hybrid cultivar 'Mulato II' and desmanthus cultivars 'JCU2', 'JCU4', 'JCU7', 'JCU9' and 'Marc' at Tamworth. Emergence of each species was adjusted to the maximum achieved at any site. X-axis labels are spring (sp=September–November), summer (su=December–February), autumn (au=March–May) and winter (wi=June–August).

the year at Trangie and Tamworth, respectively, albeit only in low proportions in the final days of assessment during the coolest months of the year. Across all sites, Makarikari grass and panic grass had the smallest emergence window, emerging over the fewest months of the year, while digit grass was intermediate. Of the 5 sites, seedling emergence for all species generally occurred over a greater period of the year at Tamworth, and least at Orange and Cowra. Maximum total emergence also tended to occur at Tamworth, the most northerly site, while lowest emergence was at Cowra and Wagga Wagga, the 2 most southerly sites.

Kikuyu grass and paspalum sown at Trangie had an emergence window similar to Makarikari grass and panic grass respectively, both emerging from September–October until May (Figure 1B). Paspalum emergence peaked in January while kikuyu grass peaked in January–March. At Tamworth, *Urochloa* hybrid cultivar 'Mulato ll' emerged between September to April, similar to Makarikari grass. Seedlings of the cultivar 'Mulato II' were also slower to emerge than the other species at this site, with the first seedlings generally emerging >7 days after sowing. The 5 desmanthus cultivars sown only at Tamworth emerged from September until April, with peak emergence generally occurring in December and seedlings of all 5 cultivars emerging within 4 days of sowing in January.

Emergence response to temperature

There was no seedling emergence of Rhodes grass after 10 days when average soil temperatures were ≤11 °C (Figure 2A). After the temperature peak (>28 °C) in January, emergence was variable, ranging from 50–100% of maximum emergence as soils cooled to about 23 °C. Emergence then declined linearly, ceasing when soil temperatures were ≤12 °C (Figure 2A).

There was no emergence of digit grass in either warming or cooling soils when temperatures were ≤14 °C (Figure 2B). Emergence of digit grass was linear in warming and cooling soils, with maximum emergence occurring in January across all sites.

There was no emergence of Makarikari grass seedlings when soil temperatures were <12 °C. Rate of emergence increased as soil temperature increased (Figure 2C). In cooling soils, decline in emergence of Makarikari grass was linear with emergence ceasing when temperatures were ≤15 °C.

There was no emergence of panic grass seedlings when soil temperatures were <14 °C and seedling emergence response in warming soils was linear (Figure 2D). The change in slope when soil temperatures were 18–20 °C corresponded with highly variable emergence across the sites ranging from 10–100% of maximum. The response in cooling soils, was also linear, with emergence ceasing when temperatures were below 15 °C.

Due to the limited number of data points and being sown at only 1 site, emergence responses for kikuyu grass, paspalum, *Urochloa* hybrid and desmanthus were less instructive (Figure 2). Kikuyu grass did not emerge when average temperatures were ≤14 °C, however 70% of maximum emergence occurred when soil temperatures had increased to 20 °C. Emergence was high (>90%) in cooling soils when soil temperatures were >21 °C but declined rapidly below this temperature (Figure 2E).

Highly variable emergence (5–45% of maximum) was observed for paspalum when soil temperatures were ~20 °C at Trangie. Emergence peaked when soil temperatures were ~27 °C, declining rapidly in cooling soils. Emergence was low when soil temperatures had fallen to 19 °C and ceased when soil temperatures were 15 °C (Figure 2F).

No seedlings of the *Urochloa* hybrid emerged when soil temperatures were below 15 °C. In warming soils, emergence was variable when soil temperatures were ~22 °C ranging from 55–100% of maximum. In cooling soils, emergence declined rapidly as temperatures fell below 25 °C. The limited data points when soil temperature was 15–20 °C resulted in large standard errors for emergence at low temperatures in cooling soils. Nil emergence was observed when soil temperatures were below 19 °C, compared to ~10% modelled by the response curve (Figure 2G).

Pooled data for desmanthus cultivars provided more data points but are from only 1 site (Figure 2H). No seedling emergence of desmanthus was observed in warming soils when temperatures were 11 °C, and minimal emergence (2%) occurred when temperatures were 15 °C. However, emergence was greater than 60% of maximum emergence when temperatures were ≥22 °C. At this temperature (October–December), emergence of the 5 entries was variable, ranging from 65–100%. There was also significant variation in emergence in cooling soils when soil temperatures ranged from 19–25 °C. In cooling soils, emergence ceased when temperatures reached 13 °C.

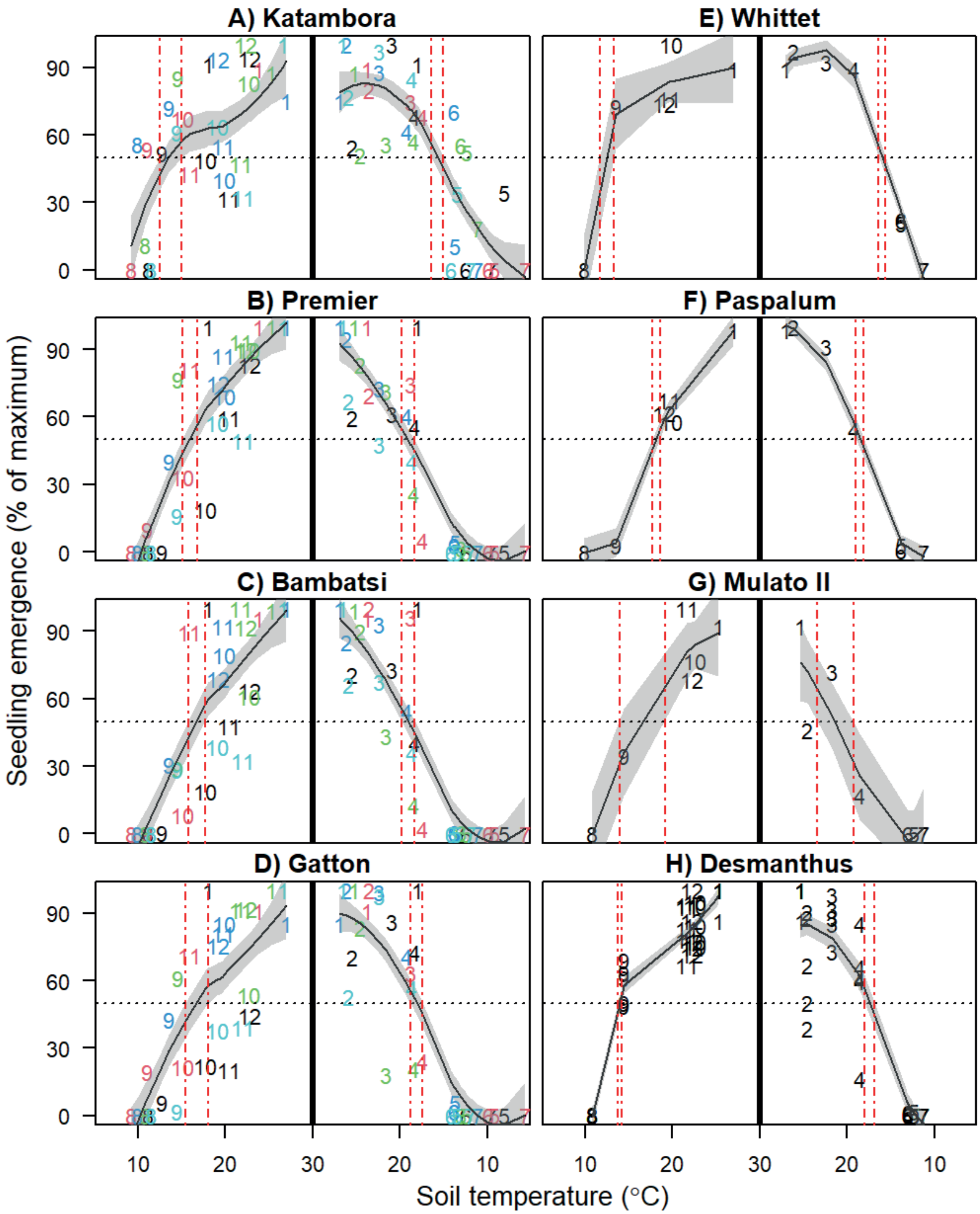

Figure 2. Smoothed mean seedling emergence response to soil temperature for 12 months from August to January as soil temperatures increased (left panel of each subfigure) and January to July (right panel) as temperatures decreased for (A) Rhodes grass cultivar 'Katambora', (B) digit grass cultivar 'Premier', (C) Makarikari grass cultivar 'Bambatsi', (D) panic grass cultivar 'Gatton', (E) kikuyu grass cultivar 'Whittet', (F) paspalum, (G) *Urochloa* hybrid cultivar 'Mulato II' and (H) desmanthus cultivars 'JCU2', 'JCU4', 'JCU7', 'JCU9' and 'Marc'. Sites for pooled figures (A-D) are: Cowra (■), Orange (■), Tamworth (■), Trangie (■) and Wagga Wagga (■). Numbers on each figure indicate the month of the year, (1=January to 12=December). Grey shading represents the standard error of the mean. The black dotted horizontal line represents 50% of maximum seedling emergence while the red lines indicate the upper and lower temperature ± standard error to achieve 50% maximum emergence.

Soil temperatures to achieve 50% maximum seedling emergence

Rhodes grass required the lowest temperature to achieve 50% emergence in warming soils (17 °C), followed by digit grass, Makarikari grass and panic grass (19–20 °C) (Table 3). Of the additional species assessed at Trangie, the 50% emergence temperature for kikuyu grass was similar to Rhodes grass (18 °C). Paspalum required the highest temperature of the tested species and reached 50% emergence at 22 °C. Species ranking for temperatures to achieve 50% of maximum seedling emergence in cooling soils was slightly different to warming soils (Table 3), with Rhodes grass and kikuyu grass having the lowest temperature requirement (17 °C) followed by desmanthus (19 °C). Panic grass, Makarikari grass and digit grass were intermediate (20–22 °C). Paspalum and the *Urochloa* hybrid had the highest temperature requirement (23 °C) to achieve 50% of maximum seedling emergence. The temperature range from warming to cooling soil temperatures, an indicative 'window' for effective emergence, was widest for Rhodes grass, then kikuyu grass. Desmanthus was intermediate. The effective emergence window for digit grass, Makarikari grass and panic grass was relatively narrower, but not as short as paspalum which required soil temperatures to be >22–23 °C in both warming and cooling soils.

Table 3. Predicted soil temperatures (°C) for 50% of maximum emergence for the pasture species tested in warming and cooling soils.

Species	Warming soil temperature (°C)	Cooling soil temperature (°C)
Rhodes grass	17.1±1.5	16.6±0.5
Digit grass	19.7±0.6	22.0±0.5
Makarikari grass	20.5±0.9	21.2±0.7
Panic grass	20.1±1.4	20.1±0.8
Kikuyu grass[1]	17.8±0.7	17.4±0.5
Paspalum[1]	21.9±2.1	22.5±1.1
Urochloa hybrid[1]	19.2±1.8	22.7±1.3
Desmanthus[1,2]	19.3±0.3	18.5±0.7

[1]Values are based on emergence at 1 site.
[2]Values are based on pooled data for the 5 cultivars.

Discussion

This study is the first to quantify emergence of tropical perennial species across multiple locations representing a range of temperatures at temperate latitudes and therefore increasing the applicability of results to other temperate regions of the world where tropical pasture plants are increasingly being used. The species tested differed in their emergence response in warming and cooling soils. Their temperature requirements to achieve 50% maximum emergence also varied which is useful information to develop sowing time recommendations.

Maximum emergence for each species recorded at all sites occurred at Tamworth, the site with the most northern latitude while the slowest emergence tended to occur at the 3 most southern latitude sites (Orange, Cowra, Wagga Wagga). All species included in this study are known to persist in frost prone northern NSW, except for the *Urochloa* hybrid cultivar 'Mulato II' which has not been tested in inland NSW to our knowledge, although it is reported as suited to high rainfall tropical/lowland subtropical environments (Cook et al. 2020; Hare at al. 2007). Each of the 4 core grasses persisted to varying degrees in central and/or southern NSW for 2–3 years, with digit grass and Makarikari grass consistently persistent at all sites (Newell et al. unpublished). Despite their cold tolerance as mature plants, the species had varied emergence responses to temperature.

Rhodes grass, kikuyu grass and paspalum have a wide geographical distribution and are sown and/or naturalised in many locations across the world (Cook et al. 2020). Kikuyu grass and paspalum were early introductions to southern Australia and were evaluated for their potential as pasture species (Reed 2014). Kikuyu grass is now widely sown and naturalised across large areas of eastern Australia and south-west Western Australia (Morris 2009; Moore and Barrett-Lennard 2006). Paspalum has long been recognised as a persistent pasture species in cooler climates and while it is naturalised in many areas, it is not widely sown (Reed 2014).

Urochloa hybrid had the slowest emergence of the species tested and a narrower emergence temperature range than the other grasses sown at Tamworth. This may be due to 'Mulato II' being suited to high rainfall tropical and lowland subtropical environments

(Pizarro et al. 2013; Cook et al. 2020). The temperature, humidity and soil moisture regime at the site would have been suboptimal. Additionally, as there was no information whether any seed treatments had been applied, it may be that seed was dormant. This would also account for the low emergence of this grass compared with the other species tested. The common practice is for seed to be acid-scarified for successful germination (Hare et al. 2007; Pizarro et al. 2013). 'Mulato II' was included in the study at Tamworth because it was an opportunity to gather some fundamental information on emergence response in a temperate, summer dominant rainfall environment.

Emergence temperatures for the tropical species determined from the current study were 3–6 °C higher than previously reported. Based on the 50% emergence method using growth cabinet emergence data, Egan et al. (2017) suggested Rhodes grass could begin to be sown when temperatures were 12 °C and increasing, while McDonald and Bowman (2002) suggested 14 °C; 3–5 °C lower than the temperature recommended from this study. Similarly, for Makarikari grass, previous studies have suggested 17 °C (McDonald and Bowman 2002) and 18 °C (Egan et al. 2017); 2–3 °C lower than the temperature recommended from this study. Both of those studies were conducted in controlled environments. In other field studies average soil temperatures >22 °C have been recommended for sowing tropical pastures (Lodge and Harden 2009) which aligns with the current study. Germination has been reported to be similar under constant and alternating temperatures when the temperatures are within the optimum range for the species. However, when either the minimum and/or maximum temperatures were outside this optimum range, the rate of germination and total gemination achieved are reduced (McDonald and Bowman 2002). This helps to explain the higher temperature recommendations in both field studies. Additionally, this study was conducted under conditions where daily temperature fluctuations were inconsistent, which may have influenced emergence. Other environmental factors, such as wind, could also have influenced emergence, especially at the southern sites that are at latitudes considered marginal for the growth of tropical species. In this study, maintaining a moist soil surface for emergence was difficult during windy periods, which can adversely impact germination and emergence. Maintaining the required moist soil surface over several days, let alone for extended periods like 10 days during summer, is challenging. Summer rainfall commonly falls in high intensity storms, hence management practices that leave organic matter on the soil surface should maintain conditions suitable for germination over a longer period. The cover reduces maximum soil temperature on hot days and holds moisture nearer the soil surface for longer, thereby assisting germination and emergence (Ward 1993; Unger 1978).

The 50% emergence threshold in warming and cooling soils provides a theoretical 'time window' to develop recommendations for soil temperatures for sowing. Warming soil temperatures for 50% emergence can be used as an indicator for the earliest time to sow. Temperatures in cooling soils are more problematic to estimate because the rate of plant development following establishment and the ability of immature plants to survive the coming winter varies (Lodge et al. 2010).

Based on the current study it is suggested tropical grasses be sown in spring when soil temperatures are rising and when the 3-day average soil temperature at 10 mm depth is at least 17 °C for Rhodes grass, 18 °C for kikuyu grass, 19 °C for *Urochloa* hybrid and desmanthus, 20 °C for digit grass, panic grass and Makarikari grass and 22 °C for paspalum. Autumn sowing should be opportunistic, and only considered when there is a very high likelihood of good rainfall over a period of about 4 days and soil temperatures are several degrees above the 50% maximum emergence temperature for cooling soils. Additionally, it is suggested sowing should be at least 2 months before frost to allow the seedlings to establish. It is also recommended that only species with known ability to overwinter are sown in autumn (kikuyu grass, digit grass or Rhodes grass) and not Makarikari grass. This follows the recommendation by Lodge and Harden (2009) where sowing in autumn should not be conducted in northern inland NSW because insufficient autumn rainfall has the potential to result in poor emergence, which is confounded by potentially low winter survival if seedlings are small and weakened due to weed competition (Descheemaeker et al. 2014). Poor persistence and subsequent low productivity have been reported for autumn-sown Makarikari grass (Jones 1969; Lodge et al. 2010), although neither digit grass nor Rhodes grass were affected (Lodge et al. 2010). Small plant size and low foliage cover due to defoliation at the onset of frosts/winter have been suggested as reasons for the poor overwintering ability of some grasses (Jones 1969). A study in northern NSW also noted that plants sown in autumn were smaller (<0.1 m) and vegetative compared to those sown in the previous spring and summer (>0.5 m and flowering) at the time of the first frost (late May, 75 days after autumn sowing) (Lodge et al. 2010).

Central and southern NSW also receive summer rainfall, albeit with even greater variability and less reliability than northern NSW. Based on rainfall data from Wagga Wagga for the period 1990–2022, the occurrence of more than 25 mm falling over a 7-day period in any single month from December to March averaged 55% (range 48–61%). However, by sowing early in the emergence window, for example by sowing on 1 December, the likelihood of receiving 25 mm over a 7-day period increased to 94% of years (31 of 32 years) compared to 52% if the pasture was sown on 1 February (17 of 32 years) (climateapp.net.au).

Peak seedling emergence in this study tended to occur in summer with high emergence continuing into early autumn in some species. Other studies have also reported this (Lodge and Harden 2009; Lodge et al. 2010) and suggested it was due to average temperatures masking the large variation between minimum and maximum temperatures that occurred at this time (Lodge and Harden 2009). These results support this suggestion because the range in daily air and soil temperatures was greater in spring than autumn. For example, average soil temperatures at Wagga Wagga in October and March were similar, both being ~20 °C, however, October average minimum and maximum temperatures were 10 °C and 38 °C (range 28 °C) while in March temperatures were 12 °C and 33 °C (range 21 °C). This variation also helps explain the highly variable germination of panic grass and Rhodes grass between October to December when average 3-day soil temperatures ranged from 17–22 °C.

Desmanthus virgatus is the most widely sown species of the desmanthus genus with several cultivars commercially available, although several other species have also been commercialised in Australia (Gardiner 2016). These can be blended to provide regionally specific mixes (Gardiner 2016), therefore a single sowing temperature recommendation has merit. There was variation between the entries tested which might represent species differences, but further testing would be required to confirm this because desmanthus cultivars were only studied at Tamworth. Further regional studies investigating different sowing times in different soils with and without cover in central and southern NSW will refine localised recommendations.

Conclusions

Results support the recommendation to sow tropical perennial species in spring when soils are warming, beginning at a minimum temperature of 17 °C for Rhodes grass, 18 °C for kikuyu grass, 19 °C for both *Urochloa* hybrid and desmanthus, 20 °C for digit grass, panic grass and Makarikari grass and 22 °C for paspalum. Sowing at these times provides more opportunities for suitable rainfall to achieve successful establishment and sufficient time for establishing plants to mature to survive the following winter. Although the rate of emergence and total emergence were often higher in late summer–early autumn than spring, the likelihood of receiving adequate rainfall to promote emergence is lower and the timeframe for plant development is shorter, with increased risk of establishment failure. Sowing in late summer–early autumn may be an option if sowing can occur before a rainfall event that has a high probability of delivering significant rainfall over multiple days. Species with superior cold tolerance, such as Rhodes grass and digit grass, could be sown in autumn, while sowing those with lower tolerance, such as Makarikari grass, should be avoided.

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(Note of the editors: All hyperlinks were verified 1 September 2023).

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Artículo Científico

Producción de forraje en híbridos de *Urochloa* bajo condiciones de sol y sombra de *Melia azedarach* L.

Forage production in Urochloa *hybrids under sun and shade conditions of* Melia azedarach *L.*

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Resumen

Se evaluaron los híbridos de *Urochloa* CIAT BR02/1752 y CIAT BR02/1794, bajo condiciones de sol y sombra de árboles en una plantación de *M. azedarach* (1,000 árboles/ha). El estudio se desarrolló en Tlapacoyan (Veracruz, México), a 847 msnm, en un clima (A)C(m)w′(f), con temperatura media anual >18 °C, y precipitación de 1,991 mm/año. Las gramíneas se establecieron en marzo del 2019 usando material vegetativo, a una distancia de 0.5 × 0.5 m, en parcelas de 2.5 × 5 m, en un diseño de bloques completos al azar con tres repeticiones y un arreglo de parcelas divididas con la condición (sombra y pleno sol) en parcelas, los híbridos en subparcelas, las fechas de muestreo en sub-subparcelas y la edad de rebrote en sub-sub-subparcelas. Se midió la producción de materia seca (MS) por hijato y por macolla, así como también el rendimiento de MS total y de sus componentes, cortando a las 8 y 12 semanas de rebrote una muestra de un 1 m^2 en el centro de cada sub-sub-subparcela. El material cosechado se separó en hojas y tallos y se secó a 55 °C durante 72 h. La MS/hijato fue afectada por la Edad ($P<0.0001$) y Grupo × Edad ($P<0.0003$); con el Grupo definido como la combinación de Condición × Híbrido. El rendimiento de MS/ha fue afectado ($P<0.01$) por la Condición, Edad, Condición × Edad y otras interacciones (con Híbridos, Fechas y Edades de muestreo). La MS/hijato fue más afectada por la condición de sombrío que por los híbridos. La producción de forraje fue mayor a pleno sol (1026.8±72.6 kg de MS/ha) que bajo sombra (505.3±72.5 kg de MS/ha), y lo mismo sucedió para hojas y tallos. El híbrido 1752 se comportó mejor que el 1794 (1026.9±72.7 and 695.3±72.7 kg DM/ha, respectivamente). Así mismo, el rendimiento se incrementó con la edad de rebrote.

Palabras clave: Componentes, pasturas bajo plantaciones forestales, rendimiento biomasa total, sistemas silvopastoriles, trópico húmedo.

Abstract

Urochloa hybrids CIAT BR02/1752 and CIAT BR02/1794 were evaluated under full sun and shade in a *Melia azedarach* L. plantation (1,000 trees/ha). The study was carried in Tlapacoyan (Veracruz, Mexico), at 847 masl, in an (A)C(m)w′(f) climate, with a mean annual temperature >18 °C, and 1,991 mm of rain/year. The grasses were established in March 2019, using vegetative material planted at 0.5 × 0.5 m, in 2.5 × 5 m plots. The experimental design was a split-split-split plot in three complete randomized blocks, with full sun or shade conditions as main plots, the hybrids as sub-plots, the harvest date as sub-sub plots and age of regrowth as sub-sub-sub plots. Dry matter (DM) yields per tiller, plant and hectare were measured at 8 and 12 weeks of regrowth, harvesting a 1 m^2 sample located in the middle of each sub-sub-subplot. Fresh material harvested was separated into leaves and stems, and dried at 55 °C for 72 h. The DM/tiller was affected by Age

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(P<0.0001) and Group × Age (P<0.0003); with Group defined by the combination of Condition × Hybrids. DM yield/ha was affected by Condition, Age, Condition × Age, and other interactions (with Hybrids, Date and Age of Harvest). DM yield/tiller was more affected by Condition than by Hybrids. Total DM/ha yield was higher under full sun (1026.8±72.6 kg DM/ha) than shade (505.3±72.5 kg DM/ha), and the same happened for leaf and stem yields. Hybrid 1752 outyielded 1794 (1026.9 ±72.7 and 695.3±72.7 kg DM/ha, respectively). DM yield/ha also increased with age of regrowth.

Keywords: Biomass components, humid tropics, pastures under tree plantations, silvopastoral systems, total biomass.

Introducción

La ganadería es la actividad agropecuaria que ocupa la mayor superficie, cubre el 70% del área agrícola y alrededor del 26% de la superficie terrestre (Steinfeld et al. 2006; Phelps y Kaplan 2017). Pero en las últimas décadas, con frecuencia se ha asociado la ganadería con la deforestación y el calentamiento global producto de la emisión de gases de efecto invernadero, tales como dióxido de carbono, metano y óxido nitroso (Mauricio et al. 2019).

Por lo tanto, urge un cambio substancial en la forma que se practica la ganadería, transformándola hacia sistemas de producción animal sostenibles y resilientes (Sánchez-Mendoza 2020), que incrementen la eficiencia productiva y económica, la rentabilidad y que mantengan un equilibrio natural con el entorno (López-Vigoa et al. 2017). El reto es aumentar la producción animal con el uso eficiente de los recursos naturales, como estrategia para la mitigación y adaptación de los efectos al cambio climático. Por ello los sistemas silvopastoriles (SSP) se consideran una opción clave para lograrlo (Buitrago-Guillen 2018).

En los SSP, las plantas forrajeras dependen del microambiente generado por la presencia de leñosas y de la fotosíntesis para la producción de energía de mantenimiento y crecimiento y, por ello, debe pensarse en una estructura que permita una adecuada intercepción de la radiación solar (Fedrigo et al. 2018). En un SSP, la sombra y la altura del dosel influyen en las características estructurales y de producción del pasto (Oliveira et al. 2020). Sin embargo, para comprender los principios del crecimiento y la utilización de los pastos en estos sistemas es fundamental tomar en cuenta que los componentes cosechables, principalmente hojas, son los mismos que intervienen en la fotosíntesis (Parsons et al. 2010).

En sistemas manejados bajo pastoreo, la duración del periodo de descanso y la cantidad de forraje residual después de la defoliación, determinan la producción de biomasa vegetal en el rebrote (Ramírez-Reynoso et al. 2010). El pastoreo tiene un efecto directo en la producción forrajera, tanto en cantidad como en calidad nutritiva, pero también puede incidir en la fijación de carbono en el suelo (Van Den Pol-Van Dasselaar 2017).

Muchos de los SSP incluyen especies forrajeras exóticas cuya persistencia obedece a su nivel de adaptación al clima y a la sombra de los árboles (Soares et al. 2009). *Melia azederach* L., conocida localmente como "piocho", es un árbol multipropósito con potencial maderable, caducifolio, de rápido crecimiento, que puede alcanzar hasta 15 m de altura (Sánchez 2011), y que por las características de su dosel tiene potencial para formar parte de SSP.

La incorporación de *M. azederach* L. en SSP puede ser un medio para diversificar la producción en fincas ganaderas, permitiendo que los pastos crezcan durante los primeros años de vida de los árboles y luego, cuando la cobertura de copa se hace muy alta, se retiran los animales y las pasturas se dejan exclusivamente para la producción de madera en el mediano y largo plazo (Santiago-Hernández et al. 2016).

El microclima que generan los árboles en SSP afecta la cantidad y calidad del forraje producido (Gobbi et al. 2009), pues la competencia por una menor radiación que llega al estrato herbáceo incide en el desarrollo de las plantas (Pompeu et al. 2009; Fragoso et al. 2016), y si esto no es bien manejado puede afectar eventualmente su persistencia (Araujo et al. 2015).

Antes de seleccionar una especie forrajera para cualquier sistema de producción, se requiere conocer su comportamiento productivo (Maass et al. 2015). En ese sentido, el género *Brachiaria* (ahora *Urochloa*) posee un buen número de especies con cualidades de mayor producción y mejor calidad nutritiva (Mwendia et al. 2021). Sin embargo, la producción de cualquier pasto no solo es función de la genética (Miles 2006), sino también de la edad de la planta y las condiciones de clima a lo largo del año bajo las cuales éstas crecen (Lara et al. 2010, Garay-Martínez et al. 2017); así como, el efecto del manejo agronómico sobre las características morfológicas y estructurales de la planta (Cruz-Hernández et al. 2017). También es importante conocer la influencia de la estacionalidad en el crecimiento y producción de las especies forrajeras, para con base en ello definir estrategias de manejo que conlleven a maximizar la producción animal (Avellaneda-Cevallos et al. 2008).

Con base en lo anterior, el objetivo del presente estudio fue evaluar la producción (MS) de forraje total y de sus componentes en los híbridos de *Urochloa* CIAT BR02/1752 y CIAT BR02/1794, en función de la edad de rebrote, bajo condiciones de pleno sol y sombra de *Melia azedarach* L., como base para la intensificación y diversificación de la ganadería en la región tropical húmeda de México.

Materiales y Métodos

El experimento se llevó a cabo en Tlapacoyan, Veracruz (México), localizada entre 19°56´ 26´´ y 19°56´ 48´´ latitud Norte, y entre 97°15´ 55´´ y 97°15´ 34´´ longitud Oeste, a 847 msnm. El clima que prevalece es (A)C(m) w´(f), semicálido húmedo regular con lluvias todo el año (García 1981), con una temperatura media anual superior a los 18 °C, con una media de 16 °C en el mes más frío y de 22 °C en el mes más caliente. La precipitación media anual es de 1977 mm, con mayores registros entre junio y octubre, pero prácticamente en todos los meses llueve al menos 100 mm (CONAGUA 2023; Figura 1). Aproximadamente, el 24% de las precipitaciones caen entre diciembre y enero, temporada de "Nortes", que es cuando se hicieron las evaluaciones en esta investigación, y en ese período la temperatura fue de 17.2±1.28 °C.

El área experimental está ubicada en una zona montañosa con pendientes, con suelos franco-arenosos, que corresponden al Orden Andosol, de tipo lúvico, con pH entre 5.1 y 5.2, y contenidos de MO de 5.5 y 6.6%, en las áreas a pleno sol y bajo la copa de los árboles, respectivamente.

Tratamientos y diseño experimental

Las gramíneas se establecieron en marzo de 2019 bajo condiciones de sol y de sombra en una plantación de *M. azedarach* (1,000 árboles/ha; distancia 2.5 m entre árboles y 4 m entre hileras) que había sido establecida en 2003, y al comienzo del experimento el diámetro del árbol a la altura del pecho era de 20.0 cm. Para la evaluación de las gramíneas sin árboles se utilizó un área ubicada a 20 m de la plantación de *M. azedarach*. En un estudio previo (Santiago-Hernández et al. 2016) se describió la actividad fotosintéticamente activa y la eficiencia fotosintética que ocurría bajo las condiciones sol y sombra en las mismas áreas en que se desarrolló el presente experimento.

En ambas condiciones (pleno sol y bajo la sombra de *M. azaderach* L.) se establecieron parcelas de 2.5 m de ancho × 5 m de largo (con el lado más largo a favor de la pendiente), en las que se plantaron macollas de pasto a un distanciamiento de 50 × 50 cm, en un diseño de bloques completos al azar en dirección perpendicular a la pendiente (aprox. 25%) en un arreglo de parcelas sub-sub-subdivididas, con tres repeticiones. Las parcelas grandes correspondieron a las condiciones de sol o sombra; las subparcelas a los híbridos; las sub-subparcelas a las fechas de muestreo y las sub-sub-subparcelas a las

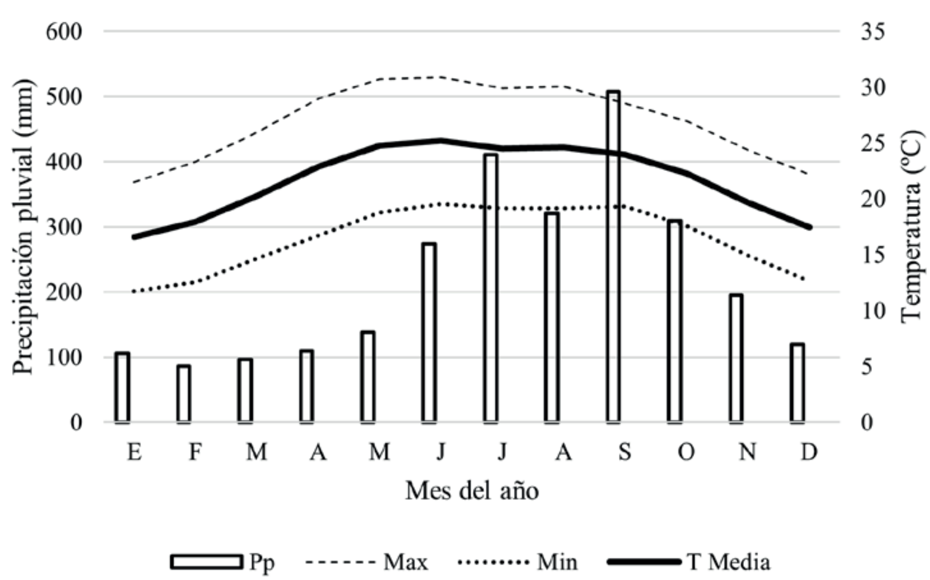

Figura 1. Temperatura (°C) media, máxima, mínima y Precipitación pluvial (Pp; mm) durante el año 2019, en Platanozapan, Tlapacoyan, Veracruz.

edades de rebrote. Los híbridos de *Urochloa* estudiados fueron BR02/1794 (un trihíbrido de *U. ruziziensis* (R. Germ. & Evrard) Crins 9 × *U. decumbens* (Stapf) RD Webster × *U. brizantha* (Hochst. ex A. Rich.) RD Webster), y CIAT BR02/1752 (*U. brizantha* CIAT 16320 × híbrido del cuarto ciclo de reproducción sexual).

Todas las evaluaciones se realizaron durante la época de invierno ("Nortes"), con cortes de uniformización el 26 de setiembre y 19 de diciembre del 2019, para los dos períodos de muestreo; y a partir de ellos se efectuaron evaluaciones de los rebrotes a las 4, 8 y 12 semanas.

En el área de estudio no se aplicaron fertilizantes ni se permitió que pastaran los animales.

Variables medidas y procedimiento de muestreo

Para la determinación del rendimiento de biomasa seca (MS) total, de hoja, de tallo y la producción por macolla, se cortó a 10 cm sobre la superficie de suelo, un área efectiva de un 1 m^2 (cuatro macollas) en el centro de cada parcela, a las 4, 8 y 12 semanas de rebrote. El material fresco cosechado se separó en hojas y tallos, las cuales se pesaron individualmente. Para la determinación de la MS, todas las muestras se secaron en un horno de aire forzado a 55 °C durante 72 h.

Análisis estadístico de los resultados

En el caso de la variable producción de MS del hijato y de hojas por hijato, se eliminó la edad de rebrote de 4 semanas debido a datos faltantes, por lo que para ese propósito al final solo se consideraron las edades de 8 y 12 semanas de rebrote.

Para propósitos de análisis de varianza (ANDEVA), con los datos de la variable producción de materia seca, se agruparon los tratamientos de sol y sombra con los híbridos 1794 y 1752, creando la variable GRUPO, con cuatro niveles: G1, Sol-1794; G2, Sol-1752; G3, Sombra-1794; y G4, Sombra-1752, de manera que se trabajó con el siguiente modelo mixto:

$$Y_{ijklm} = \mu + GRUPO + BLOQUE(GRUPO) + EDAD + GRUPO \times EDAD + FECHA + FECHA \times EDAD + FECHA \times GRUPO \times EDAD + \xi$$

donde: μ=media general y ξ=error residual

Para el análisis se usó el factor Bloque(Grupo) como efecto aleatorio para probar el efecto de Grupo, y el residual para probar el resto de los efectos fijos, y la Fecha como medición repetida. El tipo de covarianza utilizado fue el de Componentes de Varianza (VC por sus siglas en inglés), pues fue el único que permitió la convergencia del modelo. Las medias se compararon entre sí mediante contrastes ortogonales. Además, para el análisis del peso de MS por hijato y hoja por hijato se utilizaron contrastes ortogonales, tomando la condición sol y sombra entre los dos híbridos y las tres edades de rebrote.

Para las variables producción de MS por macolla, rendimiento de MS total y de hoja, se usó el factor Grupo (Condición × Híbrido) como efecto aleatorio para probar el efecto de Híbrido × Fecha de Muestreo, y por diferencia, el residual para probar el resto de los efectos fijos y la Fecha de Muestreo como medición repetida. El tipo de análisis de covarianza utilizado fue la autoregresiva, pues fue la única que permitió la convergencia. Las medias se compararon entre sí mediante contrastes ortogonales. Para todos los análisis se usó el procedimiento PROC MIXED de SAS (SAS 2013).

Resultados

Producción de materia seca por hijato (g MS/hijato)

La producción de materia seca por hijato aumentó con la edad de rebrote, con 0.07±0.008 y 0.16±0.008 g a las 8 y 12 semanas, respectivamente. La cantidad de biomasa por hijato a las 4 semanas resultó imposible de medir de manera confiable, por lo que para propósitos de análisis se desechó esa edad. En el Cuadro 1 se observa que se detectó significancia para los efectos de la Edad de Rebrote (P<0.0001) y de la interacción Grupo × Edad de Rebrote (P<0.0003); en cambio, no se detectaron diferencias significativas (P>0.05) debidas a Grupos en el peso promedio de MS por hijato y de hoja por hijato, siendo el promedio general de peso por hijato de 3.0±1.4 g MS. Si bien no se detectó diferencia entre Grupos para el peso de hojas (P=0.09), ésta mostró una tendencia a mayor producción bajo sombra (0.13±0.009 y 0.13±0.009 g MS, para los grupos 3 y 4, respectivamente) que bajo condiciones de sol (0.09±0.009 y 0.10±0.009 g MS, para los grupos 1 y 2, respectivamente).

Cuadro 1. Prueba tipo 3 de efectos fijos para el rendimiento de materia seca por hijato y de hoja del hijato en los híbridos 1752 y 1794, bajo condiciones de sol y sombra.

Efectos	Grados de libertad		P>F[1]	
	Num.	Den.	Hijato	Hoja
Grupo	3	8	0.1008	0.0963
Edad	2	16	<0.0001	<0.0001
Grupo × Edad	6	16	0.0009	0.0003

[1]P>F es la probabilidad de encontrar un valor mayor a la F calculada por el análisis de varianza (significancia de la prueba de F).

En el Cuadro 2, se presenta un análisis de tendencias con base en la interacción Condición × Híbrido como efecto aleatorio para probar el efecto de Híbrido × Edad, indicando que el efecto de la edad sobre el peso de los hijatos fue lineal ascendente (P<0.0001).

En el análisis de tendencias del Cuadro 2, al considerar la interacción Condición × Híbrido como efecto aleatorio para probar el efecto de Híbrido × Edad, se observó que el efecto de la edad sobre el peso de materia seca de hoja por hijato fue lineal ascendente (P<0.0001).

Producción de materia seca por héctarea (KgMS/ha)

La condición sol o sombra, los híbridos y la edad de rebrote afectaron significativamente la producción de biomasa por hectárea (Cuadro 3). También se detectó significancia para las interacciones dobles Condición × Híbrido, Condición × Edad, Híbrido × Edad, Fecha × Condición, Fecha × híbrido y Fecha × Edad. Por otro lado, en los Cuadros 4 y 5 se presentan las fuentes de variación que resultaron significativas en los análisis de varianza del rendimiento de hojas y de tallos, respectivamente.

Cuadro 2. Pesos en materia seca (g MS/hijato) de hijato y hoja por hijato: análisis de tendencias, con base en el factor Bloque (Condición × Híbrido) como efecto aleatorio para probar el efecto de Híbrido × Edad.

Contraste	Estimador	Error estándar	Grados de libertad	Valor de t	Pr>|t|
Peso de hijato (g MS)					
Edad, lineal	0.1336	0.01238	16	10.79	<0.0001
Sol vs Sombra	-0.2882	0.04953	16	-5.82	<0.0001
1794 Sol vs 1794 Sombra	-0.1099	0.03502	16	-3.14	0.0063
1752 Sol vs 1752 Sombra	-0.1783	0.03502	16	-5.09	0.0001
1794 Sol vs 1752 Sombra	-0.1279	0.03502	16	-3.65	0.0022
1752 Sol vs 1794 Sombra	-0.1603	0.03502	16	-4.58	0.0003
Peso de hoja (g MS/hijato)					
Edad, lineal	0.09846	0.00938	16	10.49	<0.0001
Sol vs Sombra	-0.2421	0.03753	16	-6.45	<0.0001
1794 Sol vs 1794 Sombra	-0.09807	0.02654	16	-3.70	0.0020
1752 Sol vs 1752 Sombra	-0.1440	0.02654	16	-5.43	<0.0001
1794 Sol vs 1752 Sombra	-0.1130	0.02654	16	-4.26	0.0006
1752 Sol vs 1794 Sombra	-0.1290	0.02654	16	-4.86	0.0002

Pr>|t| es la probabilidad de encontrar un valor de t mayor a la estimada por la prueba de contrastes ortogonales.

Cuadro 3. Prueba tipo 3 para los efectos fijos sobre la producción biomasa total (kg MS/ha) en función de la condición (sol o sombra), híbridos, fecha de muestreo, edad de rebrote y las interacciones que alcanzaron significancia.

Fuente de Variación	Grados de libertad		Valor de F	Pr>F[1]
	Numerador	Denominador		
Condición	1	4	87.88	0.0007
Híbrido	1	4	19.10	0.012
Condición × Híbrido	1	4	6.96	0.0577
Edad	2	16	67.75	<.0001
Condición × Edad	2	16	11.54	0.0008
Híbrido × Edad	2	16	7.17	0.006
Fecha × Híbrido	1	24	46.28	<.0001
Fecha × Edad	2	24	37.29	<.0001
Fecha × Condición	1	24	179.97	<.0001

[1]Pr>F es la probabilidad de encontrar un valor mayor a la F calculada por el análisis de varianza (significancia de la prueba de F).

El rendimiento de forraje bajo la sombra de árboles fue en promedio un 41.5% menor que a pleno sol (505.3±56.0 y 1216.8±121.1 kg de MS/ha, respectivamente). El efecto de la sombra en la disminución del rendimiento de biomasa total fue mayor en el híbrido 1752 que en el 1794 (Figura 2). En el caso de la producción de hojas, la disminución en el rendimiento fue de 36.9 y 42.8% para los híbridos 1794 y 1752, respectivamente. Además, bajo condiciones de sol, el rendimiento de biomasa total y sus componentes fue mayor en el híbrido 1794, pero bajo condiciones de sombra no se detectaron diferencias entre los híbridos.

Cuadro 4. Prueba tipo 3 para efectos fijos sobre la producción de hojas (Kg de MS/ha) en función de la condición (sol o sombra), fecha de muestreo, edad de rebrote y las interacciones que alcanzaron significancia.

Fuente de Variación	Grados de libertad		Valor de F	Pr>F[1]
	Numerador	Denominador		
Condición	1	4	67.99	0.0012
Edad	2	16	54.09	<.0001
Condición × Edad	2	16	6.99	0.0066
Fecha × Híbrido	1	24	5.79	0.0241
Fecha × Edad	2	24	16.19	<.0001
Fecha × Condición	1	24	129.90	<.0001

[1]Pr>F es la probabilidad de encontrar un valor mayor a la F calculada por el análisis de varianza (significancia de la prueba de F).

Cuadro 5. Prueba tipo 3 para efectos fijos sobre la producción de tallos (Kg de MS/ha) en función de la condición (sol o sombra), híbridos, fecha de muestreo, edad de rebrote y las interacciones que alcanzaron significancia.

Fuente de Variación	Grados de libertad		Valor de F	Pr>F[1]
	Numerador	Denominador		
Híbrido	1	4	7.51	0.0519
Edad	2	16	9.42	0.0020
Condición × Edad	2	16	5.20	0.0182
Fecha × Híbrido	1	24	7.26	0.0127
Fecha × Edad	2	24	4.41	0.0233
Fecha × Condición	1	24	16.29	0.0005

[1]Pr>F es la probabilidad de encontrar un valor mayor a la F calculada por el análisis de varianza (significancia de la prueba de F).

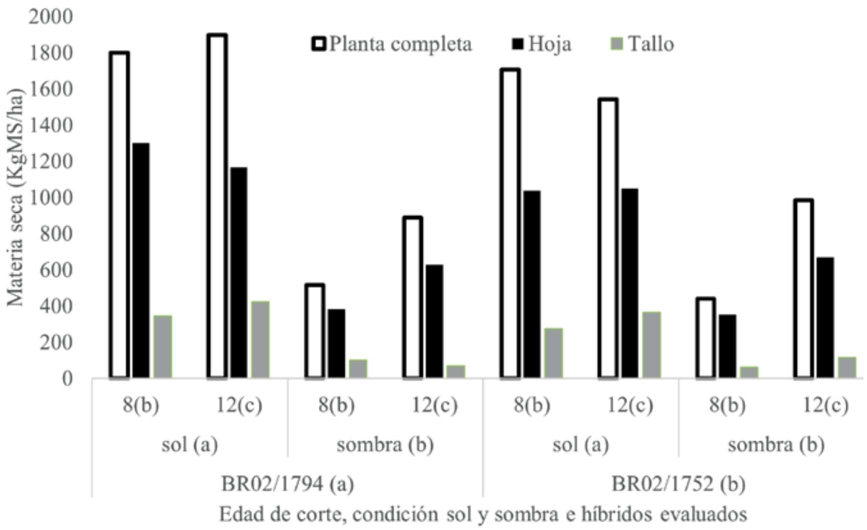

Figura 2. Producción de materia seca (MS) total, hoja y tallo por hectárea en función de la condición sol o sombra, híbridos y edad de rebrotes. Literales diferentes indican diferencia estadística significativa (P<0.05).

Discusión

La capacidad productiva de cualquier especie forrajera es el resultado del genotipo (Miles 2006), la edad de la planta, las condiciones climáticas que se presentan a través del año (Lara et al. 2010; Garay-Martínez et al. 2017) y el manejo agronómico al que están sometidos (Cruz-Hernández et al. 2017).

La tolerancia a la sombra es una condición necesaria para aprovechar las ventajas de integrar pasturas con árboles. Dicha tolerancia varía en función de la especie de leñosa y la densidad en que se presentan estas (Alonso et al. 2006). *Melia azaderach* es una especie arbórea que presenta poco follaje y es decidua, lo que ayuda a que con una densidad relativamente alta (1,000 árboles/ha) las gramíneas sean capaces de presentar una respuesta productiva similar a la obtenida con arbóreas que poseen una copa más densa sembradas a menor densidad.

En el caso del género *Urochloa*, se reconoce que está entre las gramíneas tropicales (C_4) que poseen una buena capacidad de adaptación a la sombra y que por tanto puede usarse como componente en sistemas silvopastoriles que involucran plantaciones forestales (Santiago-Hernández et al. 2016; Oliveira et al. 2022; Santos et al. 2023). Sin embargo, el que se adapte a la sombra no previene que su rendimiento se vea afectado, sino que dicho efecto es menos marcado que en especies no tolerantes, tal como fue observado por Santiago-Hernández et al. (2016) en híbridos de *Urochloa* y las variedades Tanzania y Mombasa de *Megathyrsus maximus* producidos bajo la sombra de una especie de uso forestal, y por Jácome-Gómez et al. (2021) para *Megathyrsus maximus* cv Mombasa que crecía en plantaciones de cítricos. Los datos presentados en la Figura 2 confirman que el rendimiento de biomasa total y de sus componentes en los dos híbridos de *Urochloa* fueron afectados por la sombra de *Melia azedarach* L.

El incremento en la producción de biomasa de forrajes a medida aumenta la edad de rebrote está ampliamente reportado en la literatura (Garay-Martínez et al. 2018; Martínez et al. 2020). En el caso de pasto Mulato (*Urochloa* híbrido 36061), Cruz-Hernández (2010) observó que la disponibilidad de forraje total se incrementó al alargar el intervalo de pastoreo de 14 a 28 días, pero la tasa de crecimiento foliar tendió a disminuir con la edad de rebrote. Sin embargo, cuando se alcanza temperaturas críticas para el crecimiento de los forrajes tropicales (12–15 °C), no se pueden detectar diferencias debidas a la edad de rebrote, pues bajo esas condiciones se detiene el crecimiento (Jaime et al. 2019).

La disminución del 28% en la producción de biomasa que mostraron los dos híbridos de *Urochloa* en el período de "Nortes", coincide con lo observado por Cruz-Hernández (2010), quien atribuyó los menores rendimientos a la combinación de alta nubosidad y baja temperatura que caracterizan a este período, y que crean condiciones sub-óptimas para el crecimiento de gramíneas C_4 (Moreno et al. 2014; Martínez et al. 2020; Santos et al. 2022).

En este estudio se utilizó 28 días (4 semanas) como la edad de rebrote más corta, la cual puede ser adecuada para estos híbridos cuando crecen en la época de lluvias y con temperatura cálida (Torres Salado et al. 2020); sin embargo, bajo condiciones de bajas temperaturas como las que se presentan en la época de "Nortes", parece se requiere al menos 8 semanas de recuperación para obtener el mismo rendimiento (Garay-Martínez et al. 2017).

Cuando se analizó el rendimiento en los diferentes muestreos se observó que este fue mayor en los de noviembre-diciembre que en los de enero-febrero; en el primero, no solo la temperatura promedio fue mayor (18.5±1.01 vs. 17.2±1.17 ºC), sino que además hubo una mayor disponibilidad de humedad. Martínez et al. (2020) observaron un comportamiento similar en otra área de Veracruz (México) trabajando con *Urochloa humidicola*, así como por Muñoz-González et al. (2016) trabajando en Chiapas (México) con *Paspalum notatum*, *U. humidicola*, *U. brizantha* y un híbrido de *Urochloa*.

Sin embargo, este no es el único factor que puede haber incidido en las diferencias observadas en producción de biomasa, pues también puede ser resultado de la menor radiación solar incidente y del área foliar presente para captar dicha radiación (Obispo et al. 2013). Respecto a esto último debe anotarse que en los muestreos de enero-febrero se presentó una menor producción de hojas, y ésta fue aún menor bajo la sombra de los árboles de *M. azaderach*, lo cual ayuda a explicar el porqué de la menor producción de biomasa bajo esas condiciones. Este efecto también ha sido observado en sistemas silvopastoriles similares al del presente estudio, pero con otras especies de pastos y leñosas, como por ejemplo *Megathryrsus maximus* asociado con *Leucaena leucocephala* (Alonso et al. 2006) y *Urochloa decumbens* asociado con *Eucalyptus urograndis* (*E. urophylla* × *E. grandis*) (Machado et al. 2020).

Alonso et al. (2006) citan que la producción de biomasa de las gramíneas manejadas en sistemas silvopastoriles depende del nivel de radiación que alcance al componente herbáceo, el cual debe variar en función de las especies leñosas involucradas. En el caso de *U. decumbens*, la leñosa debe generar un 43% de sombra para que se logre un 95% de intercepción de luz en el estrato pastura. Sin embargo, este objetivo requiere se maneje la densidad de copa de las leñosas (Machado et al. 2020).

Pero, la menor radiación incidente en el estrato herbáceo afecta también el número de hijatos y el peso de las raíces, todo lo cual redunda en una menor producción de biomasa aérea (Moscat Faria et al. 2018), e incluso se puede afectar la persistencia del pasto, si no se toman medidas para ajustar la carga animal.

El peso de hojas por hijato obtenido en este estudio para los híbridos BR02/1752 y BR02/1794 creciendo bajo sombra es similar a lo encontrado por Flores-Morales et al. (2023) para los mismos híbridos (0.13±0.009 y 0.12±0.01 g, respectivamente) a las dos semanas de edad, creciendo bajo sol y en época de lluvias.

Conclusiones

Cualquiera de los híbridos evaluados (*Urochloa* CIAT BR02/1752 y CIAT BR02/1794) se puede asociar con *M. azederach* en un sistema silvopastoril de plantación forestal; sin embargo, debe reconocerse que durante la época de "Nortes" la productividad de las gramíneas va a reducirse por la menor temperatura y luminosidad que caracterizan ese período.

Se recomienda evaluar el sistema silvopastoril *M. azederach* + *Urochloa* CIAT BR02/1752 bajo pastoreo, para ver la respuesta de dicha gramínea en términos de la disponibilidad de biomasa y calidad nutritiva de la misma, cuando está sometida a la defoliación y el pisoteo ejercidos por los animales.

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Artículo Científico

Indicadores químicos de la salud del suelo en sistemas silvopastoriles, bosque de restauración y cultivo de maíz en un bosque seco tropical

Chemical indicators of soil health in silvopastoral systems, restoration forest, and maize cultivation in a tropical dry forest.

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Resumen

Los cultivos agrícolas y pasturas en monocultivo frecuentemente comprometen servicios ecosistémicos por la pérdida de suelos y biodiversidad. Como alternativa en la producción ganadera se han propuesto los sistemas silvopastoriles (SSP); sin embargo, hay pocos estudios que demuestren los beneficios de estos sobre la salud del suelo. Este estudio tuvo como propósito evaluar el efecto de diferentes usos de la tierra sobre la salud del suelo medida a través de indicadores químicos. Para tal fin, se usaron parcelas con al menos 19 años bajo los siguientes usos: (i) cultivo intensivo de maíz (*Zea mays*), (ii) pastura mixta de gramíneas (*Megathyrsus maximus* + *Dichantium aristatum*), (iii) SSP con pastos + arbustos (*Cresentia cujete* y *Leucaena leucocephala*), (iv) SSP multiestrato con los mismos pastos + leñosas de uso forrajero (*Cassia grandis*, *Albizia saman* y *Guazuma ulmifolia*) y (v) bosque secundario de restauración como referencia. Las evaluaciones se hicieron en épocas contrastantes (seca y lluviosa), en suelos del Valle medio del rio Sinú (Colombia), con gradiente de drenaje. En general, los suelos de los SSP presentaron los más altos indicadores químicos: MOS, N total, Mg, B, N-NO_3 y CICE; la pastura de solo gramíneas presentó los mayores valores en micronutrientes: Mn, Fe, Cu, Zn y S, y NH_4 y valores más bajos de pH, P, y NO_3 y más altos de Al. El bosque secundario presentó valores intermedios para todos los indicadores, mientras que los suelos con maíz presentaron los indicadores químicos más pobres. Se concluye que los SSP mejoran los indicadores químicos de salud del suelo en comparación a la pastura de solo gramíneas y el monocultivo de maíz.

Palabras clave: Especies leñosas, fertilidad, gramíneas, sostenibilidad, usos del suelo.

Abstract

Annual crops and pastures in monoculture frequently have negative effects on ecosystem services due to soil and biodiversity losses. Silvopastoral systems (SSP) have been proposed as an alternative for livestock production systems; however, there are few studies that demonstrate their benefits on soil health. For that reason, this study was established to evaluate the effect of different land uses on soil health measured through chemical indicators. For this purpose, the following land uses managed for at least 19 years were evaluated: (i) intensive maize (*Zea mays*) production, (ii) a guinea (*Megathyrsus maximus*) and angleton (*Dichantium aristatum*) mixed pasture, (iii) SSP with grasses and shrubs of totumo (*Cresentia cujete*) and leucaena (*Leucaena leucocephala*), (iv) a multistrata SSP with the same grasses and shrubs plus tree fodder species: (*Cassia grandis, Albizia saman* and *Guazuma ulmifolia*); and (v) a secondary forest used as a reference. The evaluations were made in contrasting seasons (dry and rainy), in soils of the Middle Sinú river valley (Colombia), with a drainage gradient. In general, the soils of the SPS presented the

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highest values for MOS, total N, Mg, B, N-NO_3 and CICE, the grass alone pasture presented the highest values in micronutrients: Mn, Fe, Cu, Zn and S and NH_4, and lower values for pH, P and NO_3, and the highest for Al; whereas, intermediate values for all chemical indicators were obtained in the secondary forest. In contrast, soils cultivated with corn presented the poorest chemical indicators. It is concluded that SSP improve the chemical indicators of soil health as compared to the grass alone pasture and corn monoculture.

Keywords: Grasses, land uses, soil fertility, sustainability, woody perennials.

Introducción

La degradación de tierras afecta por lo menos 500 millones de hectáreas (Lamb et al. 2005), amenazando los servicios ecosistémicos y la seguridad alimentaria en los países en desarrollo. Los agricultores con sistemas mixtos (cultivos-ganadería) producen cerca de la mitad de los alimentos del mundo, y tienen del reto de aumentar la producción de alimentos de origen animal (Herrero et al. 2010) para contribuir a la seguridad alimentaria de una población que se espera alcance los 9,500 millones en el 2050 (Van Dijk et al. 2021).

Los sistemas ganaderos de la región Caribe de Colombia, caracterizada por tener una zona de vida de Bosque seco Tropical (Bs-T), presentan problemas de sostenibilidad pues tienen más del 80% de sus pasturas con problemas de erosión, compactación y baja disponibilidad de nutrientes en el suelo (McAlpine et al. 2009; Cajas-Girón et al. 2002; Obalum et al. 2012; Martínez 2013). Una de las causas de estos problemas es el uso de prácticas de manejo inadecuadas, como el tener pasturas de gramíneas en monocultivo, con poca diversidad de plantas, el uso inadecuado de fertilización y la ausencia de prácticas de conservación del suelo (Mejía-Kerguelén et al. 2020; Cajas-Girón et al. 2002). Por lo anterior, estos suelos exhiben compactación (>1.5 MPa) y baja disponibilidad de nutrientes para las plantas cultivadas (e.g., <10 mg/kg fósforo Bray-II; <0.10 $cmol_c$/kg de P en Fluoruro-Amonio), lo cual restringe la capacidad para producir forraje en cantidad y calidad suficientes, particularmente en la larga estación seca (Cajas-Girón et al. 2002; Martínez 2013). En consecuencia, la capacidad de carga animal de las pasturas es muy baja (<1 animal/ha), los animales presentan baja ganancia de peso (<300 g/día), edad tardía para el sacrificio (30–36 meses) y altos costos de producción (US$ 0.80/kg) (Martínez 2013; Martínez et al. 2014).

La salud del suelo o la capacidad de este para funcionar adecuadamente es crítica para la sobrevivencia humana, por lo que su cuantificación ayudará a entender las funciones del suelo, con el fin de aumentar la productividad agrícola (Moebius-Clune et al. 2016). Esto incorpora la idea de que el suelo es un ecosistema vivo que necesita un manejo cuidadoso para recuperar y mantener su habilidad para funcionar óptimamente (Doran y Parkin 1994). Entre los indicadores químicos de la salud del suelo están la concentración de nutrientes y el pH (Moebius-Clune et al. 2016).

Aunque se reconoce la importancia de la sostenibilidad del suelo en varios aspectos como el mantenimiento del crecimiento forestal y los servicios ecosistémicos (Brevik et al. 2018), aún falta mucho por hacer. Por eso, uno de los retos que enfrenta la ganadería es desarrollar un componente de cultivos forrajeros viable, sostenible y con mínima degradación del suelo, gracias a la gestión cuidadosa de los insumos (fertilizantes, agua) y recursos alimenticios para minimizar los residuos y el consecuente impacto ambiental (Sadeghian et al. 1998; Herrero et al. 2010).

Ballesteros-Correa et al. (2019) sugieren que la conversión de ganadería extensiva hacia SSP dotados de fragmentos residuales del Bs-T puede ampliar la cobertura vegetal e incrementar la conectividad funcional, posibilitando la supervivencia de las especies sensibles a la deforestación y consecuente pérdida de hábitat. Los SSP pueden mejorar la fertilidad del suelo a través del almacenamiento, reciclaje y transporte de nutrientes, desde el subsuelo hasta la copa; así como la acumulación de materia orgánica superficial (Gamarra-Lezcano et al. 2018; Martínez 2013).

Los arreglos silvopastoriles multiestrato han sido poco estudiados en términos de sus propiedades químicas (Martínez 2013) y se desconoce el impacto real de estos sistemas en la salud del suelo. Se requiere indicadores de medición que valoren la disponibilidad de nutrientes, lo que ayudará en la toma de decisiones enfocadas en la conservación, sostenibilidad y productividad del suelo.

La hipótesis de este estudio fue que la disponibilidad de nutrientes medida por medio de indicadores químicos puede ser mejorada mediante el establecimiento de SSP multiestrato, en comparación a lo que ocurre en otros sistemas tales como el monocultivo de maíz y las pasturas de solo gramíneas. Por lo anterior, el objetivo del presente estudio fue evaluar el efecto de diferentes formas de uso del suelo sobre indicadores químicos de la salud del mismo.

Materiales y Métodos

Localización

El estudio se realizó en el Centro de Investigación-Turipaná (AGROSAVIA), ubicado a 08°51′N, 75°49′O, a una altitud de 18 msnm, en el municipio de Cereté (Córdoba, Colombia). La zona tiene un clima cálido seco, con un período de lluvias de mayo a noviembre. La precipitación media anual es de 1,380 mm, la temperatura promedio de 28°C, humedad relativa del 81% y la evapotranspiración potencial de 1,240 mm/año (Estación Climatológica AGROSAVIA-C.I. Turipaná). Según Holdridge (1971) la zona se clasifica ecológicamente como Bosque seco Tropical (Bs-T). Los suelos son moderadamente profundos, con textura de fina a media, susceptibles de inundación, con drenaje de imperfecto a moderadamente natural y fertilidad de moderada a alta. Los usos agropecuarios más comunes son la siembra de arroz, maíz, y banano), y ganadería semi-intensiva (IGAC 2009). Esta investigación se llevó a cabo en el año 2018, cubriendo las estaciones lluviosa y seca.

Sistemas de uso de la tierra estudiados

Los tratamientos consistieron en cinco arreglos: (i) cultivo de maíz (*Zea mays*) solo (M); (ii) pastura mixta de pasto guinea (*Megathyrsus maximus*) cv. Mombasa y Angleton (*Dichantium aristatum*) (P); (iii) arreglo de SSP compuesto por los mismos pastos + totumo (*Crescentia cujete*) + leucaena (*Leucaena leucocephala*) (P+a); (iv) arreglo de SSP multiestrato compuesto por los mismos pastos y arbustos forrajeros + arboles de guácimo (*Guazuma ulmifolia*), caña fistula (*Cassia grandis*) y campano (*Albizia saman*) (P+a+A); y (v) Bosque secundario (Bs) de restauración natural.

Las parcelas de maíz solo (M) tuvieron un manejo tradicional durante 25 años, con una preparación del suelo previo a la siembra el cual consistió en dos pasadas de laboreo convencional y una pasada de rastra ligera, y aplicaciones de 200, 100 y 100 kg de urea, $(NH_4)_2HPO_4$ y KCl/ha, respectivamente.

Durante el período en que se realizó el estudio las parcelas con pastos sin (P) y con leñosas (P+a y P+a+A) se manejaron bajo pastoreo rotacional, con dos días de ocupación y veintiocho días de descanso, y hubo un control manual de malezas después del pastoreo. Estas parcelas no fueron fertilizadas durante el tiempo que duro el estudio, pues esto alteraría el efecto comparativo de la disponibilidad de nutrientes en cada uno de ellos.

Los SSP (P+a y P+a+A) tuvieron 600 arbustos/ha (300 de cada especie arbustiva), a un distanciamiento de 4 × 4 m, y en el tratamiento con árboles (P+a+A) se tuvo además 39 árboles/ha (13 de cada especie arbórea), sembrados a 16 × 16 m. Las leñosas fueron sembradas en 1998 para contribuir a la sostenibilidad, tal como informaron Cajas-Girón y Sinclair (2001). Las parcelas de bosque secundario (Bs) que se dejaron para regeneración natural con fines de conservación del suelo, no recibieron fertilización ni riego, y en ellas no ha habido intervención humana por 20 años.

El total del área donde se desarrolló el estudio fue de 30 ha, pero por un efecto diferencial de drenaje esta se dividió en tres sectores identificados como bloques con drenaje pobre, moderado y bueno. En cada bloque se estableció una réplica de los tratamientos evaluados en un área de 2 ha (100 m de ancho por 200 m de largo) c/u, para un total de tres réplicas por tratamiento y 15 parcelas (Figura 1).

Muestreo

En todos los tratamientos, en cada uno de los períodos de muestreo, se tomaron muestras de suelo en el horizonte A (0–10 cm). En los tratamientos M, P y Bs, se tomaron 20 submuestras al azar de 50 g de suelo c/u. En el arreglo SSP P+a se tomaron al azar 20 submuestras (50 g c/u) de la pastura y por separado se escogieron al azar 20 arbustos y alrededor de ellos (a 30–40 cm de la base del tallo) se tomaron 50 g de suelo en cada sitio. En el SSP P+a+A se hizo lo mismo que en el SSP P+a y adicionalmente se escogieron al azar 20 árboles y se tomaron 50 g por sitio (a 1–2 m de la base del tallo). En cada caso, las submuestras se mezclaron, homogenizaron y se tomó finalmente 1 kg de suelo para análisis. Se efectuaron dos muestreos en el período seco y dos en el período lluvioso, siguiendo la propuesta de Martínez (2013) para estos sistemas.

Variables evaluadas

Para la determinación de los indicadores fisicoquímicos del suelo se enviaron las muestras al Laboratorio de Suelos de la Universidad Nacional de Colombia, Sede Medellín. Ahí las muestras se secaron en un horno a 60°C por 48 h y luego se pasaron por una malla de 2 mm. Los índices medidos fueron: contenido de arena, limo, arcilla (Bouyoucos; %), textura, pH (agua, 1:1), contenido de materia orgánica (MO; Walkley y Black, %), Al, Ca, Mg y K (acetato de amonio 1 M, $cmol_c$/kg), CICE (suma de cationes de intercambio, $cmol_c$/kg), P (Bray II, mg/kg), S (fosfato de calcio 0.008 M, mg/kg); Fe, Mn, Cu y Zn (Olsen-EDTA, mg/kg), B (agua caliente, mg/kg) y N total (Kjeldahl, %). Detalles de los métodos están descritos en Soil Survey Laboratory (Burt 2004).

Análisis estadísticos

El muestreo se realizó bajo un diseño de bloques al azar con repeticiones en el tiempo, desbalanceado, asimétrico, y con efectos fijos. Se consideraron como factores de muestreo el arreglo o sistema de uso del suelo (M, P, P+a, P+a+A y Bs), los cuales constituyeron los cinco tratamientos. Estos se replicaron en los tres bloques definidos por la condición de drenaje (D) con tres niveles (bueno, regular, pobre), excepto por los tratamientos M y Bs, que solo se encontraron en terrenos con buen drenaje.

El estudio se desarrolló en dos épocas (E), con dos muestreos por época (seca y lluviosa), para un total de 96 unidades experimentales (Cuadro 1). Los residuales del modelo se sometieron a un diagnóstico de homogeneidad de la varianza, independencia del error y distribución normal. Los datos fueron sometidos a análisis de varianza y a la prueba de comparación de medias de Tukey. En ambos casos se empleó un nivel de significancia (P≤0.05). Los análisis se realizaron con el software libre R y R Studio versión 4.2.3 (R Core Team 2023).

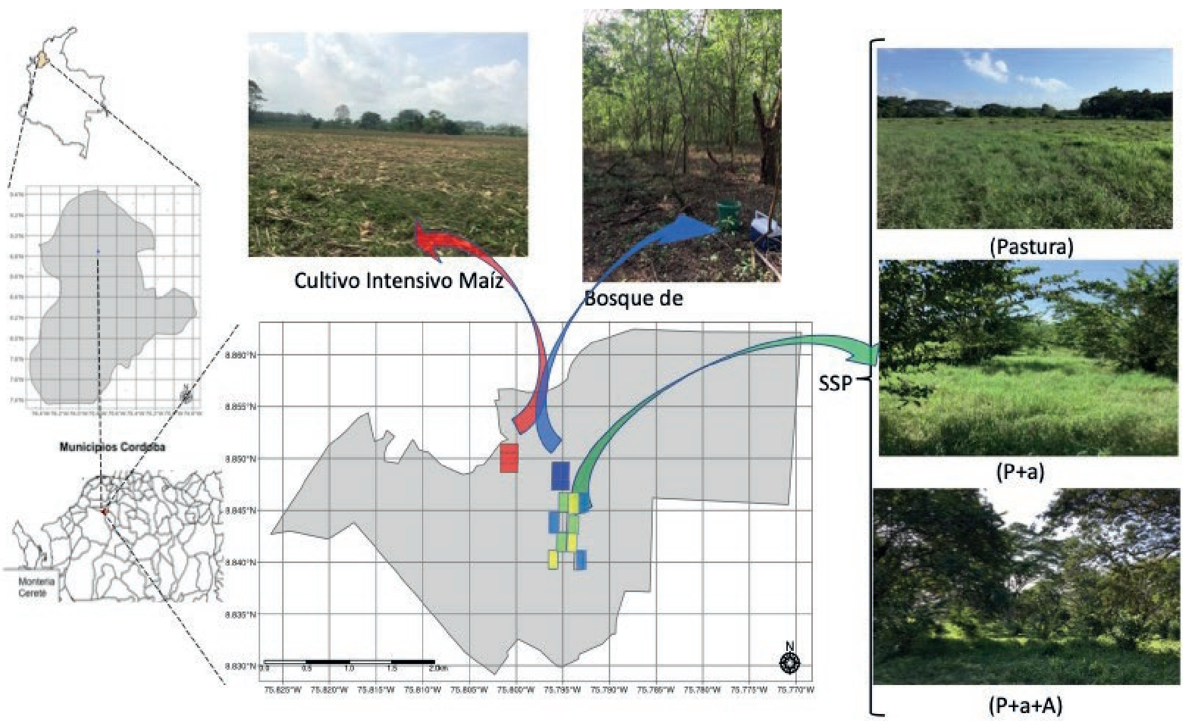

Figura 1. Localización del estudio. Arreglos: sistema agrícola cultivo de maíz (M), sistema pastura (P), SSP pastura + arbustos (P+a), SSP pastura + arbusto + árboles (P+a+A) y sistema forestal de bosque secundario (Bs), en el C.I. Turipaná (Agrosavia). Rojo: Maíz, Azul oscuro: bosque de restauración Azul: Pastura, Amarillo: P+a y Verde: P+a+A. Fuente: Elaboración propia.

Cuadro 1. Número de muestras colectadas en cada una de las combinaciones de arreglos y drenajes en cada período de muestreo.

Drenaje	Arreglos				
	M*	P	P+a	P+a+A	Bs*
Bueno	3	1	2	3	3
Moderado	0	1	2	3	0
Pobre	0	1	2	3	0

*Solo hubo muestreo para los arreglos M y Bs en el drenaje Bueno. No se encontraron esos usos del suelo en áreas de drenaje Moderado y Pobre.

Resultados

El análisis de varianza del efecto de los factores arreglo (A), época (E), drenaje (D) y sus interacciones sobre los indicadores químicos del suelo permitió evidenciar que los arreglos tuvieron un efecto significativo en todas las variables. Mientras que los factores tiempo y drenaje solo tuvieron efecto para algunas, y que solo se detectó significancia para la interacción triple A × E × D en el caso de la CICE. Es necesario anotar que como el diseño experimental fue desbalanceado, el modelo era incompleto para las interacciones A × D.

Acidez del suelo

Los resultados muestran que hubo diferencias ($P \leq 0.001$) en el valor del pH en función de los diferentes usos. El valor del pH mostró el siguiente orden decreciente: Bs (7.02, neutro); P+a+A y M (6.07 y 6.18, ambos ligeramente ácidos); P+a (5.86, moderadamente ácido) y P (5.47, fuertemente ácido). Por otro lado, el pH presentó diferencias ($P \leq 0.05$) en función de la época del año (6.20 y 6.04 para las épocas lluviosa y seca, respectivamente) (Figura 2a).

La concentración de aluminio (Figura 2b) fue afectada significativamente por los arreglos; pero, este elemento solo fue detectable en los suelos con los arreglos pastura sola (P) y P+a, con valores de 0.12 y 0.02 cmol$_c$/kg, respectivamente, siendo significativamente mayor el primero. La concentración de aluminio no fue detectable (0.0 cmol$_c$/kg) para los tratamientos M, P+a, P+a+A y Bs, y no resultaron diferentes ($P \geq 0.05$) del valor obtenido (0.2 cmol$_c$/kg) para la pastura sola (P).

Materia orgánica del suelo (MOS)

El contenido de MOS fue afectado ($P \leq 0.001$) por los arreglos. Los valores de MOS (%) en orden decreciente fueron: P+a (11.19); P+a+A (10.82); P (10.01); Bs (6.62) y M (2.83) (Figura 3).

Capacidad de Intercambio Catiónico (CICE)

El valor de la CICE en el suelo fue afectado por los arreglos ($P \leq 0.001$) y por la triple interacción A × E × D ($P \leq 0.05$). El arreglo de maíz solo (M) presentó los menores valores de la CICE en ambas estaciones (16.3 y 16.7 cmol$_c$/kg, para lluviosa y seca, respectivamente), el arreglo forestal Bs presentó valores intermedios (27.2 y 29.4 cmol$_c$/kg, para época seca y lluviosa, respectivamente), pero sin mostrar diferencias ($P > 0.05$) debidas a época de muestreo (Figura 4).

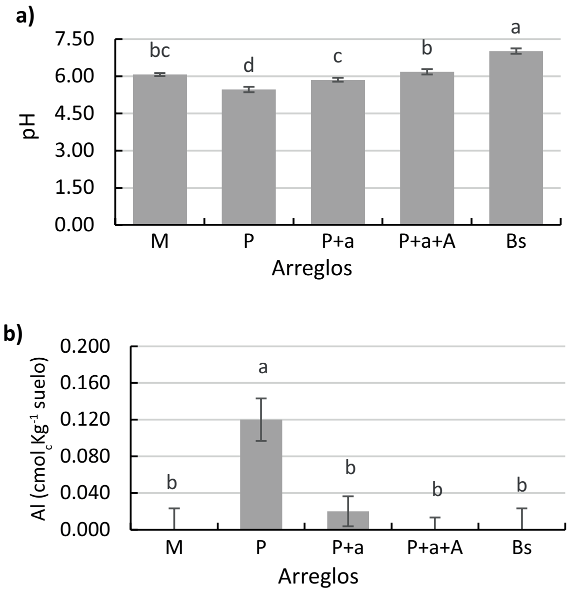

Figura 2. Acidez del suelo en función de los diferentes usos del suelo: (a) pH; (b) Concentración de aluminio (cmol$_c$/kg). Cada valor representa el promedio de tres réplicas y las barras el error estándar. Promedios con diferente letra minúscula difieren ($P \leq 0.05$) según la prueba de Tukey.

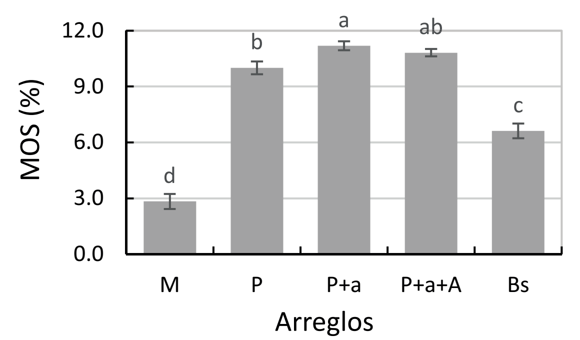

Figura 3. Contenido de MOS (%) en función de los diferentes usos del suelo. Cada valor representa el promedio de tres replicas. Las barras indican el error estándar. Promedios con letras minúsculas diferentes son diferentes ($P \leq 0.05$) según la prueba de Tukey.

En la época seca, en las parcelas bien drenadas (D1), el arreglo silvopastoril P+a+A presentó un mayor valor de CICE que en Bs y P (35.6 vs. 27.2 y 24.3 cmol$_c$/kg, respectivamente), pero no fue diferente del SSP P+a (28.1 cmol$_c$/kg); en cambio, no se presentaron diferencias significativas entre P, P+a y P+a+A (valores entre 28.1 y 30.0 cmol$_c$/kg) en las parcelas moderadamente drenadas (D2). Por otro lado, en las parcelas pobremente drenadas (D3) se presentó un comportamiento similar a las bien drenadas, con diferencias entre el sistema silvopastoril P+a+A y la P (33.9 vs. 24.1 cmol$_c$/kg), pero no con el sistema silvopastoril P+a (27.9 cmol$_c$/kg).

En contraste, en la época lluviosa, en las parcelas bien drenadas (D1) no se detectaron diferencias (P≤0.05) entre arreglos para la CICE (entre 29.6–30.3 $cmol_c$/kg), excepto para el sistema de maíz solo (M). En las parcelas moderadamente drenadas (D2) de nuevo se presentaron diferencias (P≤0.05) entre el sistema silvopastoril P+a+A y la P (33.2 y 26.4 $cmol_c$/kg, respectivamente), pero no con el sistema silvopastoril P+a (29.5 $cmol_c$/kg). De igual manera, en las parcelas pobremente drenadas (D3) hubo diferencias (P≤0.05) entre el tratamiento P+a+A y la P (35.9 vs. 20.9 $cmol_c$/kg), pero no con el P+a (28.6 $cmol_c$/kg), tal como ocurrió en la época seca.

Bases intercambiables

Los arreglos afectaron (P≤0.001) el contenido de calcio, el cual en orden decreciente fue: Bs, P+a+A, P+a, P y M, con valores de 19.21, 18.80, 15.00, 12.78 y 9.18 $cmol_c$/kg, respectivamente (Figura 5a). El nivel de potasio en el suelo fue afectado por los arreglos (P<0.05), pero solo se observó diferencias entre el sistema silvopastoril P+a+A y el arreglo M (1.319 y 0.887 $cmol_c$/kg, respectivamente) (Figura 5b).

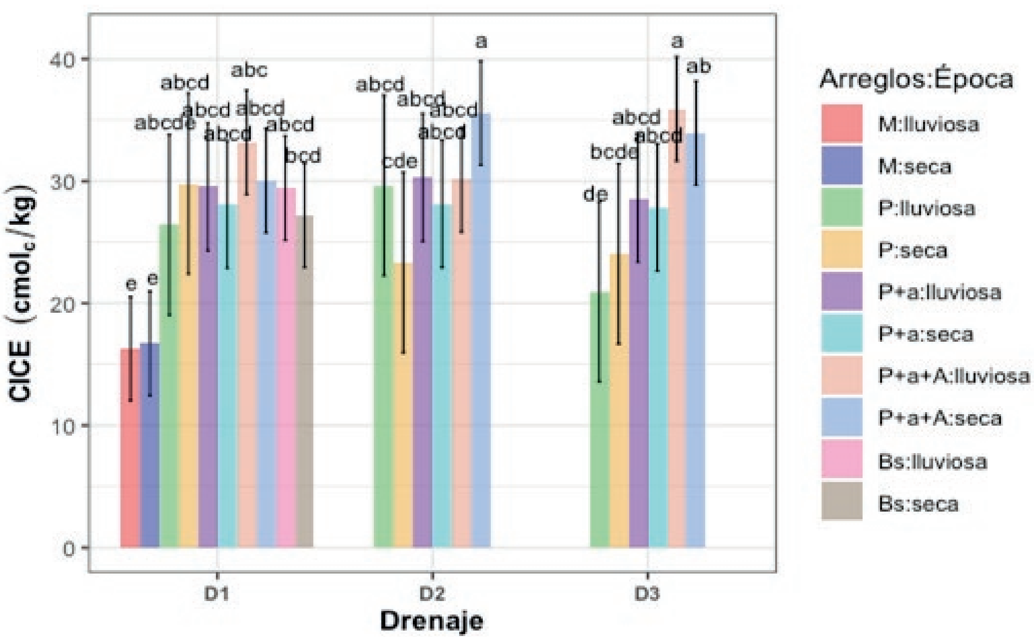

Figura 4. CICE ($cmol_c$/kg) en el suelo en función de la interacción arreglos × drenaje × época (A × D × E). Cada valor representa el promedio de tres replicas y dos épocas (lluviosa y seca) Las barras indican el error estándar. Promedios con letras minúsculas diferentes son diferentes (P≤0.05) según la prueba de Tukey. D1, D2 y D3 corresponde a drenaje bueno, regular y malo, respectivamente.

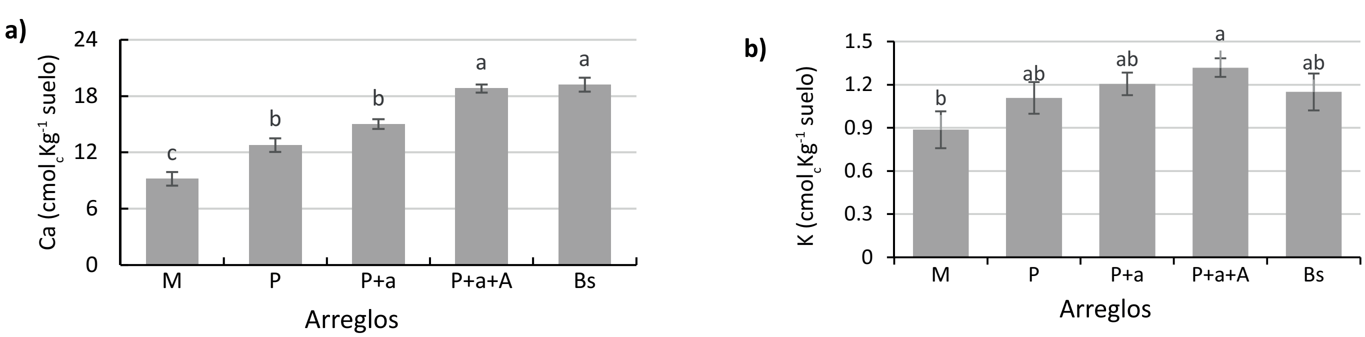

Figura 5. Contenidos de calcio ($cmol_c$/kg) (a) y de potasio ($cmol_c$/kg) (b) en el suelo, en función de los usos del suelo. Cada valor representa el promedio de tres replicas. Las barras indican el error estándar. Promedios con letras minúsculas diferentes son diferentes (P≤0.05) según la prueba de Tukey.

Nitrógeno total e inorgánico

Los arreglos afectaron ($P \leq 0.001$) el contenido de nitrógeno total (Nt) en el suelo, y estos se ordenaron de manera decreciente como: P+a+A, P+a, P, Bs y M, con valores de 0.637, 0.621, 0.578, 0.435 y 0.233%, respectivamente. Los tres primeros valores no difirieron ($P \leq 0.05$) entre sí (Figura 6).

La respuesta del contenido de amonio (NH_4^+) en el suelo en función de los arreglos fue afectado ($P \leq 0.05$) por la época del año; así, en el arreglo SSP P+a+A el contenido de NH_4^+ fue mayor en la época lluviosa que en la seca (21.9 vs. 16.7 mg/kg), pero no se presentaron diferencias debidas a época para el resto de los arreglos (Figura 7a); además, la interacción A × E alcanzó significancia ($P \leq 0.001$). Por otro lado, también se detectaron diferencias ($P \leq 0.05$) debidas a la época para el contenido de nitratos (NO_3^-) en el suelo. Los valores de este elemento fueron mayores para los SSP P+a y P+a+A en la época lluviosa; mientras que en la época seca los valores más altos correspondieron al tratamiento de maíz solo (Figura 7b).

Fósforo y azufre

El nivel de fósforo en el suelo fue afectado ($P<0.001$) por los arreglos (Figura 8a). El valor más alto de fósforo se presentó en el arreglo Bs (42.8 mg/kg), el cual fue diferente al resto de los arreglos, excepto del sistema silvopastoril P+a+A (34.8 mg/kg); éste fue a su vez diferente a los arreglos M y P, pero no al P+a (26.5 mg/kg). En los arreglos M y P se presentaron los valores más bajos (22.8 y 20.2 mg/kg, respectivamente).

El contenido de azufre en el suelo (Figura 8b) se vio afectado ($P \leq 0.05$) por el arreglo y la interacción arreglo × drenaje (A × D). En las parcelas bien drenadas (D1), la concentración de S difirió ($P \leq 0.05$) entre los arreglos P y M (24.25 y 7.58 mg/kg, respectivamente). Los otros arreglos presentaron valores intermedios y no fueron diferentes de los anteriores (11.08 y 18.62 mg/kg, para Bs y P+a, respectivamente). En las parcelas con drenaje moderado (D2) no se presentaron diferencias entre los arreglos en cuanto al contenido de azufre; mientras que en las parcelas con mal drenaje (D3) la concentración de S en el suelo fue mayor ($P \leq 0.05$) en el sistema P (37.25[a] mg kg^{-1}) que en los sistemas silvopastoriles P+a+A y P+a (15.33 y 18.62 mg/kg, respectivamente), pero no hubo diferencia entre estos últimos.

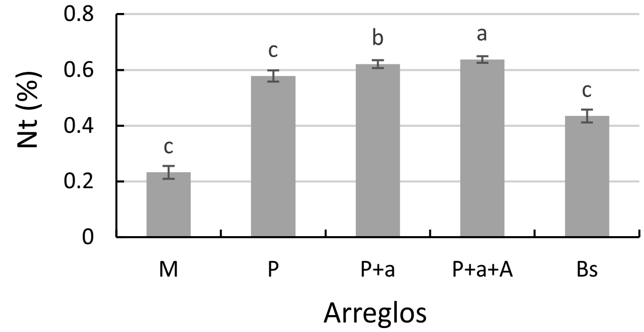

Figura 6. Contenido de nitrógeno total (%) en el suelo en función de los diferentes arreglos. Cada valor representa el promedio de tres replicas. Las barras indican el error estándar. Promedios con letras minúsculas diferentes son diferentes ($P \leq 0.05$) según la prueba de Tukey.

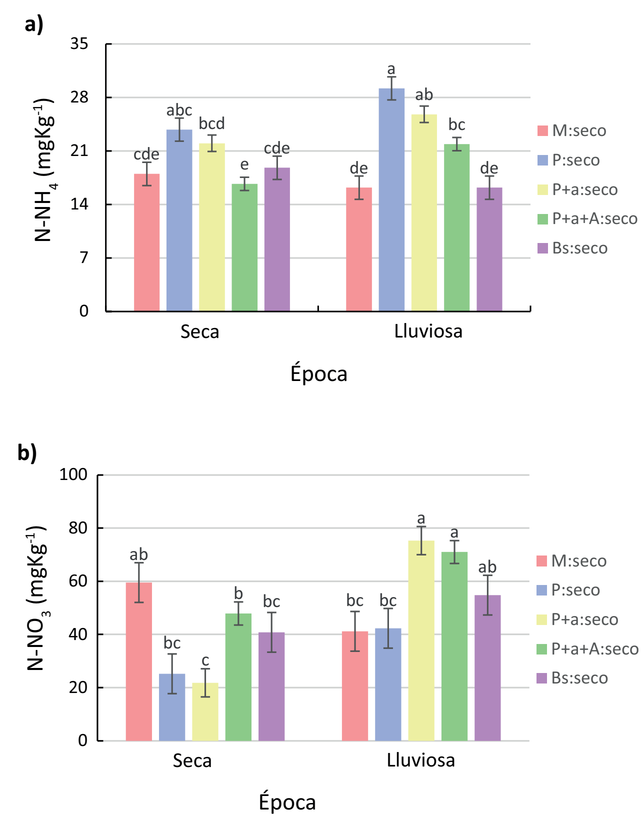

Figura 7. Contenidos de amonio (N-NH_4 mg/kg) (a) y de nitratos (N-NO_3 mg/kg) (b) en el suelo en función de la interacción arreglos × época (A ×E). Cada valor representa el promedio de tres replicas y dos épocas (lluviosa y seca). Las barras indican el error estándar. Promedios con letras minúsculas diferentes son diferentes ($P \leq 0.05$) según la prueba de Tukey.

Micronutrientes

El factor arreglo y la interacción A × D tuvieron un efecto significativo (P≤0.001) sobre el contenido de hierro en el suelo (Figura 9a). En las parcelas bien drenadas (D1) hubo diferencias (P≤0.05) en la concentración de hierro en el suelo entre los arreglos P y P+a (301.0 y 215.8 mg/kg, respectivamente); y los valores más bajos correspondieron al arreglo maíz solo (49.0 mg/kg). Por otro lado, en las parcelas con drenaje moderado (D2) no se presentaron diferencias entre los arreglos, con valores que oscilaron entre 173.3 y 219.0 mg/kg. En cambio, en las parcelas con drenaje pobre (D3) el arreglo de solo pasturas (P) presentó el valor más alto de hierro (626.5 mg/kg; P≤0.05), mientras que los valores para los arreglos silvopastoriles P+a y P+a+A (300.6 y 172.4 mg/kg, respectivamente) no difirieron entre sí.

La concentración de Mn en el suelo (Figura 9b) fue afectada por el factor arreglo (P≤0.001), con el mayor valor para el arreglo solo pasturas (P) (10.08 mg/kg), mientras que para los otros tratamientos no se detectaron diferencias, con valores que fluctuaron entre 5.17 y 7.04 mg/kg, para P+a y P+a+A, respectivamente. La concentración de cobre en el suelo (Figura 9c) fue afectada por el tipo de arreglo (P≤0.001) y por la época del año (P≤0.05). En orden decreciente, los contenidos de cobre fueron: 9.00, 6.88, 5.92, 4.08 y 3.67 mg/kg para P, P+a, P+a+A, Bs y M, respectivamente.

La concentración de zinc en el suelo (Figura 9d) se vio afectada (P≤0.001) por el factor arreglo. Los valores de zinc en orden decreciente fueron: 7.75, 7.33, 4.69, 2.28 y 1.53 mg/kg para P+a, P, P+a+A, Bs y M, respectivamente. En el caso de la concentración de boro en el suelo (Figura 9e) está también fue afectada (P<0.001) por el factor arreglo. La concentración más alta se halló en el uso forestal Bs (2.1 mg/kg), seguido por el P+a+A y el P+a (1.71 y 1.59 mg/kg, respectivamente). Los contenidos más bajos de zinc en el suelo (P≤0.05) correspondieron a la pastura sola y a la siembra de maíz en monocultivo, con valores de 0.85 y 0.98 mg/kg, respectivamente.

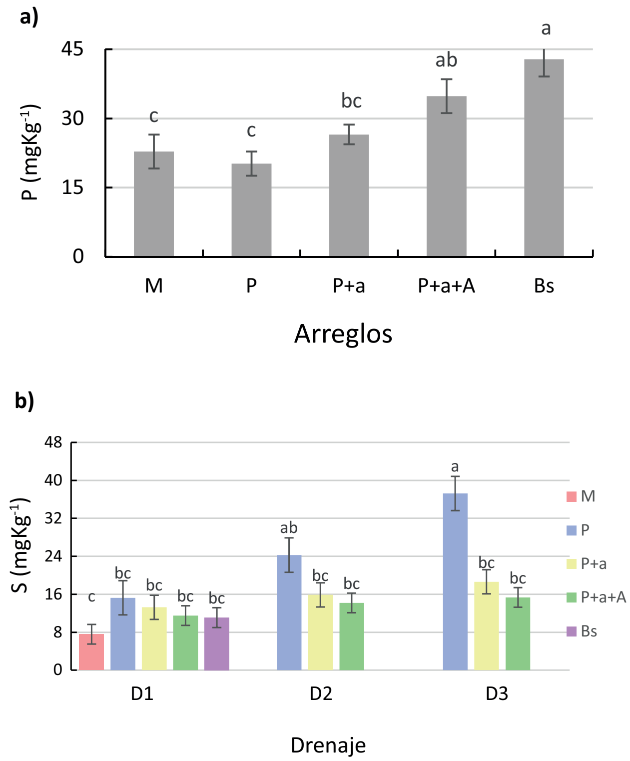

Figura 8. (a) Niveles de fósforo (mg/kg) en el suelo en función de los arreglos. (b) Concentración de azufre (mg/ kg) en el suelo en función de la interacción arreglos × drenaje (A × D). Cada valor representa el promedio de tres replicas y dos estaciones (lluviosa y seca) que no fueron significativos. Las barras indican el error estándar. Promedios con letras minúsculas diferentes son diferentes (P≤0.05)según la prueba de Tukey.

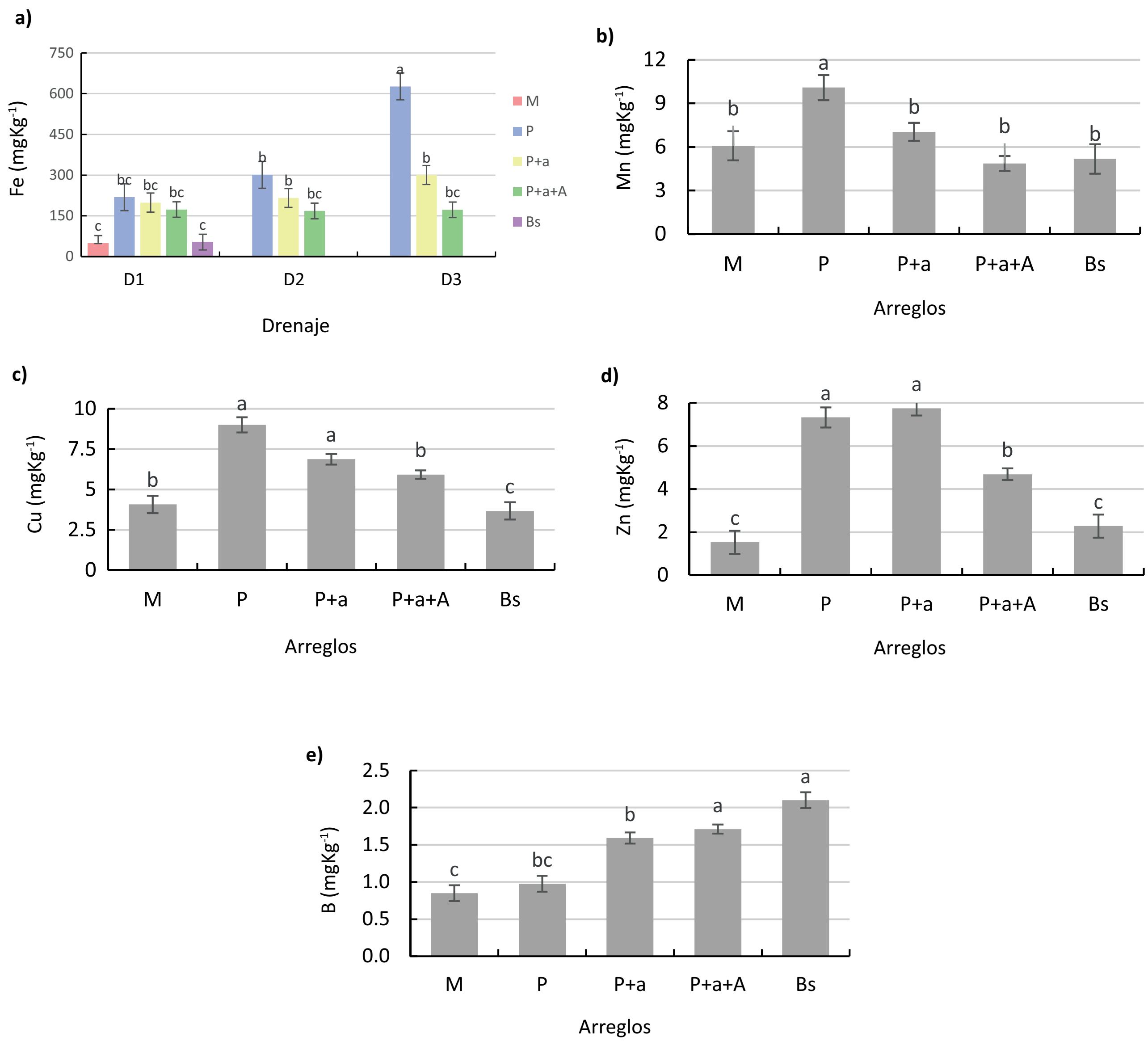

Figura 9.(a) Concentración de hierro (mg/kg) en el suelo en función de la interacción arreglos × drenaje (A × D); y (b) concentración de manganeso (mg/kg); (c) de cobre (mg/kg); (d) de zinc (mg/kg) y (e) de boro (mg/kg) en función de los diferentes arreglos. Cada valor representa el promedio de tres réplicas y dos épocas (lluviosa y seca) que no fueron significativos. Las barras indican el error estándar. Promedios con letras minúsculas diferentes, difirieron (P≤0.05) según la prueba de Tukey.

Discusión

Los suelos de los arreglos silvopastoriles presentaron los mayores contenidos de MOS, N total, N-NO_3, Mg, B y CICE. Los incrementos en estos indicadores pueden estar asociados al mayor aporte de hojarasca que generan estos sistemas y el reciclaje asociado a la descomposición de dicho material. Martínez (2013) reportó aportes anuales de hojarasca de 2,877 kg/ha/año en sistemas silvopastoriles multiestrato similares a los de este estudio, lo cual indica que estos sistemas son una fuente importante de nutrientes depositados en el suelo.

Los sistemas silvopastoriles tienen como ventaja que tanto los árboles como los arbustos actúan como agentes de fertilización (Bordron et al. 2019), los cuales absorben nutrientes en estratos profundos del suelo, los llevan a su dosel y cuando cae la hojarasca (hojas, flores, frutos), aportan materia orgánica y los nutrientes contenidos en ella (Zhu Xiai et al. 2021). Lo anterior se comprueba al comparar los contenidos de MOS en los diferentes arreglos estudiados (Figura 3), en los cuales los SSP tienen valores 3.8–4.0 veces más altos que lo que lo observado en el sistema maíz y un 8–12% (en términos relativos) mayor que la MOS del sistema pastura.

La velocidad de descomposición de la hojarasca en los ecosistemas de bosque seco tropical en general es bastante rápida, lo que permite que muchos de los nutrientes sean liberados en menos de un año (Sierra y Nygren 2006); sin embargo, la presencia de metabolitos secundarios (como los taninos) en las raíces y en la hojarasca hacen que el proceso de descomposición sea más lento (Castellanos-Barliza y León-Peláez 2011; Chomel et al. 2016). Además, estos autores argumentan que la influencia de los metabolitos secundarios se da a través de la interacción con la cadena alimenticia trófica del suelo.

Asimismo, los SSP presentaron en promedio 2.7 veces más Nt en el suelo que en las parcelas de maíz solo (M), pero los valores encontrados en M no difirieron de los que presentaron los terrenos con solo pastura (P). Estas diferencias se asocian a que en los SSP había presencia de arbustos y arboles leguminosos capaces de fijar altas cantidades de N atmosférico (Bryan 2000). En contraste, el cultivo de maíz solo y sus prácticas asociadas producen una disminución de los contenidos de MOS y el Nt, los cuales no son siempre recuperados o nivelados con los aportes de nitrógeno vía fertilizantes (Sellan et al. 2020).

Este comportamiento también se detectó en la concentración de NO_3 y NH_4 del suelo. Es bien conocido que los microorganismos del suelo realizan los procesos de amonificación y nitrificación; la amonificación por medio de hongos, bacterias y arqueas (Balume et al. 2022), mientras que la nitrificación ocurre por acción bacteriana, liberándose NH_4 y NO_3, respectivamente. Es posible que al tener la pastura un pH más bajo (5.47) y mayor presencia de aluminio, ocurra más amonificación y se limite la nitrificación. Por el contrario, en los SSP con pH de 5.9–6.2, y sin presencia de aluminio, ambos procesos no se ven limitados (Norton y Ouyang 2019).

Por otro lado, durante la época lluviosa, los SSP presentaron contenidos de nitratos más altos (71.0 y 75.3 mg/kg) que los arreglos de maíz y pastura de solo gramíneas (41.2 y 42.3 mg/kg), quizás porque los SSP fueron capaces de mantener más humedad en el suelo, lo cual afectó la tasa de nitrificación, la disponibilidad del sustrato amonio y del oxígeno por difusión; en contraste a los arreglos de pastura sola y maíz, en los cuales se pueden presentar más situaciones de estrés hídrico (Yang Xioyan et al. 2019) por no tener cobertura de leñosas.

Los contenidos de fósforo, calcio, potasio y boro en el suelo presentaron un comportamiento similar entre ellos. En general, el arreglo silvopastoril (P+a+A) y el Bs presentaron valores más altos para estos elementos que en los otros arreglos, siendo menor en el sistema de maíz solo, mientras que el silvopastoril P+a y solo pasturas (P) presentaron valores intermedios. En el caso del fosfato, en este estudio se encontró que los SSP multiestrato fueron superiores a los de maíz y pasturas solas en un 53 y 73%, respectivamente. En general se sabe que la MOS es una fuente de fosfato y de los otros nutrientes del suelo, y como en los sistemas silvopastoriles y el bosuqe seco existe una mayor diversidad de especies vegetales incluyendo leñosas, se espera que haya una mayor oportunidad para que las raíces de los árboles extraigan nutrientes de zonas más profundas del perfil del suelo (Bordron et al. 2019), los lleven al dosel y posteriormente lo aporten al suelo como hojarasca, y que finalmente se liberen nutrientes como producto de la descomposición de MO por acción microbiana.

Cajas-Girón (2002) plantea que la escogencia de especies arbóreas para establecer SSP se debe hacer considerando aquellas que poseen las características deseadas en términos de la interacción planta-suelo. En ese contexto, Casanova et al. (2007) destacan la importancia que las especies arbóreas elegidas posean raíces agresivas con relación a los sistemas radiculares del cultivo asociado, y que manifiesten un crecimiento lateral profundo o posean una alta plasticidad.

En el caso particular del P inorgánico, éste es liberado por acción de las fosfatasas de los microorganismos (Osorio 2014). Los resultados obtenidos en este estudio para el SSP multiestrato (P+a+A) son comparables a los reportados por varios autores (Martínez et al. 2014; Yang Xioyan et al. 2019; Sayer et al. 2020). En cuanto al boro, Chetelat et al. (2021) sostienen que el reciclaje de este elemento vía vegetación puede ocasionar una concentración relativamente alta en la solución del suelo, tal como se encontró en el presente estudio; en cambio, en los arreglos M y P se presentan raíces menos profundas y es mucho menor el reciclaje a través de la hojarasca (Jia Qianmin et al. 2020).

También es de destacar que en el sistema de maíz solo las concentraciones de nutrientes tienden a ser más bajas, a pesar de las aplicaciones de fertilizante fosfórico y enmiendas orgánicas, lo cual demuestra la baja sostenibilidad de este sistema, asociado a la calidad/salud de suelo, y por extensión se puede sugerir que en algún grado puede ocurrir algo similar en el sistema de solo pastos. Además, es necesario resaltar que en el arreglo de solo pastos se presentó un mayor contenido de aluminio (Figura 2b) lo cual podría haber interferido con la disponibilidad del P inorgánico (Penn y Camberato 2019; Chavarro-Bermeo et al. 2022).

En el caso de los micronutrientes Fe, Mn, Cu y Zn se encontró una menor disponibilidad en el suelo de los arreglos maíz solo (M) y Bosque secundario (Bs). En el caso del maíz solo, esto era de esperar debido no solo a la continua remoción de nutrientes a través de los granos cosechados (Miner et al. 2018), sino también por los bajos aportes de MO a través de los residuos del cultivo, lo que restringe las posibilidades de reciclaje. En el caso del Bs, por el contrario, hay un aporte de MO y un reciclaje activo, pero el pH del suelo es más alto (pH 7.02), lo cual puede haber contribuido a la insolubilización de estos micronutrientes y su precipitación como hidróxidos (Acevedo-Sandoval et al. 2004).

En contraste, en el arreglo pasturas (P) el pH fue más bajo (pH 5.47), lo cual favorece la solubilización de esos micronutrientes (Dhaliwal et al. 2019; Mao Qinggong et al. 2017). Adicionalmente, los estudios de Sayer et al. (2020) evaluando por más de 15 años el ciclo de nutrientes en el bosque seco tropical, sugirieron que micronutrientes tales como el Zn y el Mn están más influenciado por procesos biológicos como la descomposición de hojarasca por acción fúngica, que por procesos químicos o físicos.

Por otro lado, se sabe que cuando hay mayor disponibilidad de P, tal como ocurrió en los tratamientos P+a+A y Bs, disminuye la disponibilidad de micronutrientes (Roshinus et al. 2021). Queda aún por explicar por qué en los suelos con SSP (P+a y P+a+A) fue menor la disponibilidad de micronutrientes, pero lo que sí está claro es que estos no limitaron el crecimiento vegetal; aunque en estudios de descomposición de hojarasca se ha visto que hay una tendencia a la inmovilización de los micronutrientes, al quedar estos atrapados en la materia orgánica (Dhaliwal et al. 2019).

Los SSP tienden a generar una mayor concentración de nutrientes en el suelo comparado con lo que hace la pastura y muy particularmente cuando se compara con el cultivo de maíz en monocultivo. En los SSP sobresalen los contenidos de MOS, Nt, P, K, B, Mg, Ca y los niveles de CICE. Esto puede ser el resultado del mayor reciclaje de biomasa senescente que ocurre en los SSP, donde las leñosas con un sistema radicular pivotante son capaces de extraer nutrientes de mayor profundidad y eventualmente reciclarlos vía caída de hojarasca (Casanova et al. 2007), la cual se descompone por acción de microrganismos del suelo, dejando el suelo con una mejor biodisponibilidad de nutrientes para ser absorbidos por las plantas. Esto es favorecido aun más si las leñosas son de tipo leguminoso, que están en relación simbiótica con bacterias fijadoras de nitrógeno asociadas a su raíz, lo cual permite la captura de N atmosférico, el cual recircula entre las plantas, animales y el componente biorgánico del suelo (Bryan 2000).

Conclusiones

Los resultados de este estudio confirman que los indicadores químicos de salud del suelo pueden mejorarse con el establecimiento de SSP, en comparación a lo que ocurre en sistemas tradicionales más simples, como el maíz en monocultivo o pasturas de solo gramíneas; sin embargo, tal efecto está condicionado por la época del año y las condiciones de drenaje del suelo. Además, los SSP involucran la presencia de animales en pastoreo, lo cual permite el reciclaje de nutrientes a través de las excretas, aumentando su disponibilidad de estos en el suelo.

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Short Communication

Nitrogen fertilization effects on forage production and nutritive value of 4 tropical grasses on alkaline soils in Argentina

Efectos de la fertilización nitrogenada sobre la producción forrajera y el valor nutritivo de 4 pastos tropicales en suelos alcalinos en Argentina

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Abstract

This study evaluated effects of nitrogen (N) fertilization and gypsum application and their interactions on total pasture forage production and nutritive values of *Chloris gayana* cultivars 'Santana' and 'Finecut' and *Panicum coloratum* cultivars 'Klein' and 'Bambatsi' growing in a moderately sodic soil (Typic Natracualf) in northcentral Santa Fe Province of Argentina over 3 years. Sown pasture forage production differed among cultivars. *C. gayana* cultivar 'Finecut' produced more forage biomass than the other 3 cultivars. *P. coloratum* cultivars were superior to *C. gayana* cultivars for nutritive value, showing lower NDF and ADF. N fertilization strongly increased forage production, total biomass and sown pasture biomass with improved crude protein content and improvement in plant N status. Addition of gypsum did not affect forage production and nutritive value. This research showed the feasibility to improve production and nutritive value of tropical pastures in subtropical areas by species/cultivar selection and N fertilization.

Keywords: C4 species, *Chloris gayana*, nitrogen nutrition index, *Panicum coloratum*.

Resumen

Los objetivos de este trabajo fueron evaluar los efectos de la fertilización nitrogenada, el encalado y su interacción sobre la producción total de forraje y el valor nutritivo de cultivares de *Chloris gayana* 'Santana' y 'Finecut' y de cultivares de *Panicum coloratum* 'Klein' y 'Bambatsi' creciendo en un suelo sódico moderado (Natracualf típico) de la región centro-norte de la provincia de Santa Fe de Argentina durante tres años. Los cultivares difirieron en producción de forraje, siendo esta mayor en *C. gayana* 'Finecut' que en los otros tres cultivares. Los cultivares de *P. coloratum* fueron superiores en valor nutritivo a los de *C. gayana* por menores contenidos de FDN y de FDA. La fertilización nitrogenada aumentó fuertemente la producción total y de la pastura sembrada y mejoró el contenido de proteína y el estatus de nitrógeno en la planta. El encalado no afectó la producción forrajera ni el valor nutritivo. Esta investigación demostró la posibilidad de mejorar la producción y el valor nutritivo del forraje en áreas subtropicales mediante la selección de la especie/cultivar y la fertilización nitrogenada.

Palabras clave: *Chloris gayana*, índice nutrición nitrogenada, megatérmicas; *Panicum coloratum*.

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Introduction

Extensive grazing on both natural grasslands and cultivated pastures is the predominant livestock production system in Argentina. Grazing in marginal areas with salinity, alkalinity and frequent flooding has become common in recent years as cropping expands (Manuel-Navarrete et al. 2009) in areas of central Argentina with mesothermal climate (Mosconi et al. 1981) and high temperatures. C4 tropical forage grasses adapted to salinity (Pittaro et al. 2015), waterlogging (Imaz et al. 2015) and their combined stress (Lifschitz et al. 2022) have proved to be adapted to environmental conditions in the area (Romero and Mattera 2013; Mattera et al. 2015; Tomás et al. 2018).

Nitrogen (N) fertilization increased forage production and nutritive value in Rhodes grass (*Chloris gayana* Kunth.) in a sodic soil in a subtropical region (Bruno et al. 1982) and was very responsive to N application associated with adequate rainfall (Boschma et al. 2014). Increases in forage production due to N application have been reported in *C. gayana* and *Panicum coloratum* L. (Pesqueira et al. 2016). Gypsum provides soluble calcium to the soil solution and replaces sodium, resulting in improved soil conditions (Qadir et al. 2007). The relationship between nitrogen and gypsum to improve forage production in these species is unknown. The aims of this study were to evaluate effects of N fertilization and gypsum application and their interactions on total pasture forage production and nutritive values of *C. gayana* cultivars 'Santana' and 'Finecut' and *P. coloratum* cultivars 'Klein' and 'Bambatsi' in a moderately sodic soil (Typic Natracualf) in northcentral Santa Fe Province of Argentina over 3 years.

Materials and Methods

The experiment was carried out at La Palmira Ranch, San Cristóbal Department, Santa Fe Province, Argentina (29°46'36'' S, 61°14'43'' W; 66 masl) from 2014–2016. The soil was Natracualf with soil capability VI_{ws} (Klingebiel and Montgomery 1961). Soil analysis of the 0–20 cm horizon before sowing showed the following parameters: Organic matter 3.6%, extractable phosphorus 22.7 ppm, pH 7.6, electrical conductivity 1.1 mmhos/cm, exchangeable sodium (ESP) 22%, and sodium to calcium ratio 0.66. Average annual precipitation at the site in the last 50 years was 1,103 mm and average temperature was 21 °C with a frost-free period from October to March. Precipitation during the experiment was above the historical average in the 3 years of the experiment (Table 1).

The experiment was carried out in an area of natural vegetation with the grasses *C. gayana*, *Chloris halophila* Parodi and *Distichlis scoparia* (Kunth) Arechav. without previous grazing and fertilization. The experiment included combinations of 3 factors: Cultivar (*C. gayana* cultivars 'Santana' and 'Finecut'; *P. coloratum* var. *coloratum* cultivar 'Klein' and *P. coloratum* var. *makarikariense* cultivar 'Bambatsi'), N fertilization (unfertilised and N applied as urea as a single dose of 100 kg N/ha/year) and gypsum amendment (unamended and 0.5 t gypsum/ha/year in the first year and 1 t gypsum/ ha/year in following years). A randomized complete block design was used with split plot arrangement and 3 replicates. The main plot was the cultivar (40 m^2/plot) and subplots were the factorial combination of N fertilization and gypsum amendment (10 m^2/plot).

Thousand seed weight of *C. gayana* was 0.86±0.02 g and 1.00±0.02 g with a germination percentage of 44±6% and 51±11% for cultivars 'Santana' and 'Finecut', respectively. *P. coloratum* 1,000 seed weight was 1.36±0.08 g and 2.63±0.17 g with a germination percentage of 22 ± 13% and 36 ± 6% for cultivars 'Klein' and 'Bambatsi', respectively. Seeds of cultivar 'Bambatsi' were coated with calcium carbonate to increase seed size while the remainder were uncoated and no treatments or inoculations were given. The seedbed was prepared by disc and tine harrows and the experiment seeded in rows at a sowing depth of 1 cm with row spacing of 16 cm on 22 January 2014. Seeding densities were high with the aim to obtain 250 seedlings/m^2, ranging from 7 kg/ha (*C. gayana cultivars*), 23 kg/ha (*P. coloratum* cultivar 'Klein') and 26 kg/ha (*P. coloratum* cultivar 'Bambatsi'). N fertilization and gypsum amendment were performed

Table 1. Rainfall (mm) at La Palmira Ranch during 2014–2016.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2014	193	186	112	42	62	6	38	1	62	97	113	278	1,190
2015	222	117	158	40	8	18	0	89	5	142	224	112	1,135
2016	68	179	46	510	5	25	0	20	20	126	136	198	1,333

on the same day at sowing in the first growing season (22 January 2014) and in spring in the second and third growing seasons (14 October 2014 and 20 November 2015, respectively).

Data collection

For forage evaluation, both total forage production in the plot from sown and unsown grass and other species (total pasture) and biomass production of the sown species only (sown pasture) were measured. Evaluation was carried out at several regrowth periods of different lengths according to phenological stage, with harvesting at beginning of reproductive development during 3 growing seasons (Table 2). The first evaluation, corresponding to the establishment period, was the time between sowing and first harvest. The second and third growing seasons covered 3 evaluations (regrowths after cleaning cut) each from spring to autumn. At each harvest an area of 5 m^2, avoiding the borders of each plot, was harvested at 5 cm cutting height above ground level. Fresh material was weighed after each regrowth period in the field and 2 forage sub-samples were taken from each plot (200 g); the first sample was used to estimate dry matter content and the second to estimate the proportion of sown pasture compared to the total after it was separated from natural vegetation. The harvested forage was dried to constant weight in an air-forced oven at 60 °C.

Forage samples of sown pasture were taken to the laboratory from the first regrowth period for 2 growing seasons (2014 and 2014–15) for nutritional analysis. Analyses were performed at INTA Rafaela Forage Laboratory assessing crude protein (CP) (AOAC 1995), neutral detergent fiber (NDF) (Ankom 2005) and acid detergent fiber (ADF) (Ankom 2005). Additionally, nitrogen nutrition index (NNI) was estimated as an indicator of N plant status, calculated as:

NNI=Observed nitrogen content/Expected critical nitrogen content

Expected critical nitrogen content was estimated according to the reference curve for C4 grasses:

Critical nitrogen (%)=3.6 × $\text{Biomass}^{-3.4}$ (Duru et al. 1997)

Biomass was considered as the forage production of the sown pasture only for the estimation. In the second growing season (2014–15), *P. coloratum* cultivar 'Bambatsi' was excluded from analysis because forage biomass was very limited in plots under natural conditions and it was impossible to obtain a representative sample.

Table 2. Forage evaluation harvesting dates over 3 growing seasons (2014–16).

Growing season	Start date	Harvesting date
2014	Sowing: 22 Jan 2014	15 Apr 2014
2014–15	Cleaning cut: 14 Oct 2014	5 Dec 2014
		27 Jan 2015
		17 Mar 2015
2016	Cleaning cut: 20 Nov 2015	5 Jan 2016
		3 Mar 2016
		18 May 2016

Statistical analysis

Total and sown pasture forage production were analyzed as a split plot design and factorial arrangement of fertilization and gypsum amendment. Repeated measures with R Core Team (2021) lme4 package (Bates et al. 2015) were used to evaluate the 3 growing seasons together. Additionally, independent ANOVAs were performed for each individual growing season. Normality and variance heteroscedasticity were checked and means compared with Fisher's least significant difference (LSD) to detect differences between treatments (P<0.05) using INFOSTAT software (Di Rienzo et al. 2017). For nutritive value variables and NNI, the same R package was used for the unbalance due to missing values for *P. coloratum* cultivar 'Bambatsi' in the second growing season.

Results

Forage production

No differences in total forage production (P>0.05; Figure 1, blue columns) were detected among cultivars. However, sown pasture forage production differed among cultivars with *C. gayana* cultivar 'Finecut' (Figure 1, green columns) showing significantly higher yields in all 3 growing seasons.

N fertilization had a significant positive effect on both total and sown pasture forage production (Figure 2). Increments were higher for the third growing season, followed by the second growing season (nitrogen × growing season interaction; P<0.05). *P. coloratum* showed a higher responsiveness to N fertilization for sown pasture forage production (cultivar × nitrogen interaction; P<0.05). Gypsum amendment did not affect forage production for any growing seasons and did not interact with the other factors (P>0.05).

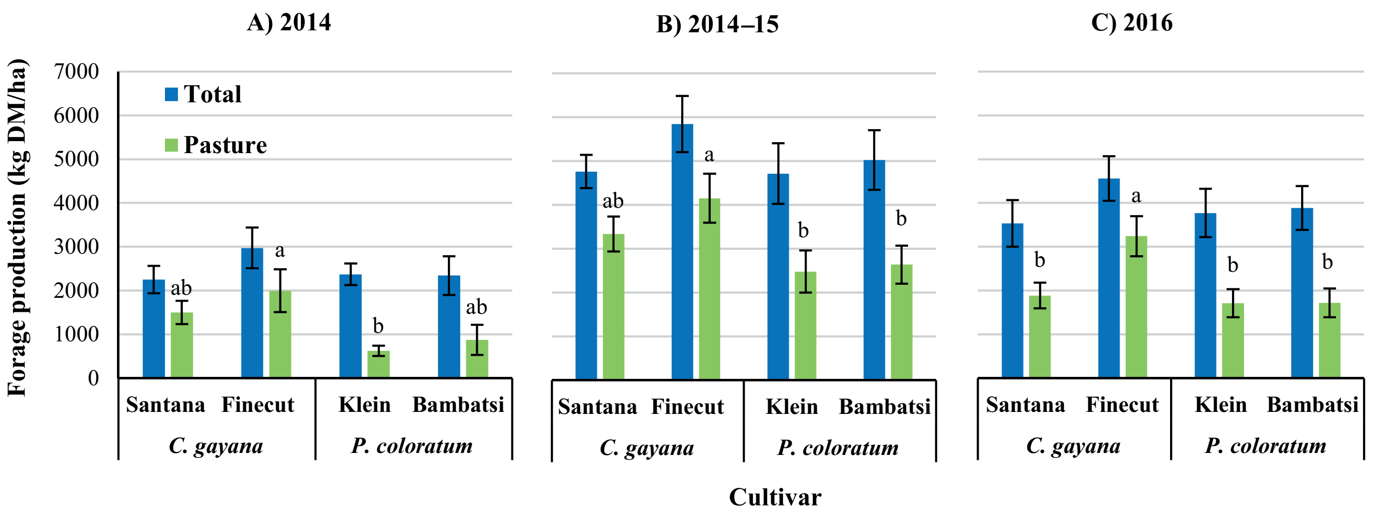

Figure 1. Total forage production (blue columns) and sown pasture forage production (green columns) of tropical grass cultivars (*C. gayana* cultivars 'Santana' and 'Finecut', *P. coloratum* cultivars 'Klein' and 'Bambatsi') in 3 growing seasons. Different lower-case letters indicate significant differences for total and sown pasture forage production, respectively (P<0.05). Bars represent standard errors.

Nitrogen plant status

Although NNI was below the reference curve, N fertilization improved NNI in both growing seasons (P<0.05) (Table 3), with a more pronounced increment in the second growing season (nitrogen × growing season interaction; P<0.05). *P. coloratum* had lower NNI than *C. gayana* in the first growing season (P<0.05).

Nutritive value

ADF differed between cultivars (P<0.05) with *P. coloratum* cultivar 'Bambatsi' having the lowest ADF (Table 4). In the second growing season (2014–15), *P. coloratum* cultivar Klein had a significantly lower ADF and NDF than *C. gayana* cultivars. N fertilization increased forage CP (P<0.05) whereas gypsum amendment did not affect nutritive value in any growing season (P>0.05). No significant interactions were detected between factors for forage nutritive value.

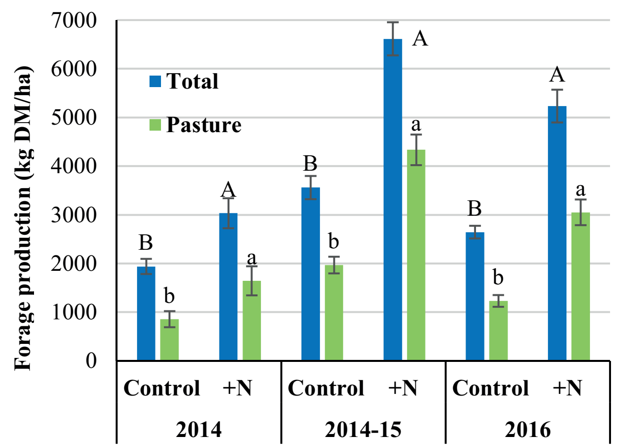

Figure 2. Total forage production (blue columns) and sown pasture forage production (green columns) of tropical grass cultivars (*C. gayana* cultivars 'Santana' and 'Finecut', *P. coloratum* cultivars 'Klein' and 'Bambatsi') in 3 growing seasons for different nitrogen fertilization. Different upper case and lower case letters indicate significant differences for total and sown pasture forage production, respectively (P<0.05). Bars represent standard errors.

Table 3. Nitrogen fertilization and gypsum amendment effects on nitrogen nutrition index (NNI) of tropical grass cultivars (*C. gayana* cultivars 'Santana' and 'Finecut', *P. coloratum* cultivars 'Klein' and 'Bambatsi') in a Natracualf soil according to the growing season.

		NNI 2014	NNI 2014–15
Cultivar	Klein	0.25 b	0.42
	Bambatsi	0.27 b	-
	Finecut	0.41 a	0.47
	Santana	0.41 a	0.48
Nitrogen fertilization	Natural condition	0.30 b	0.31 b
	Nitrogen	0.37 a	0.60 a
Gypsum amendment	Natural condition	0.33	0.44
	Gypsum	0.34	0.46
CV (%)		19.61	20.54

*Different letters between levels of each factor indicate significant differences (P<0.05)

Table 4. Nitrogen fertilization and gypsum amendment effects on nutritive value of tropical grass cultivars (*C. gayana* cultivars 'Santana' and 'Finecut', *P. coloratum* cultivars 'Klein' and 'Bambatsi') in a Natracualf soil according to the growing season.

		2014			2014–15		
		CP (%)*	NDF (%)	ADF (%)	CP (%)	NDF (%)	ADF (%)
Cultivar	Klein	7.09	67.85	34.96 ab**	10.77	64.74 b	28.72 b
	Bambatsi	7.42	65.25	32.39 c	s.d.***	s.d.	s.d.
	Finecut	7.90	66.26	35.58 a	9.07	67.49 a	33.60 a
	Santana	8.53	65.83	33.11 bc	9.75	66.86 a	33.33 a
Nitrogen fertilization	Natural condition	7.84	65.65	33.80	9.16 b	66.93	31.52
	Nitrogen	7.63	66.64	34.22	10.57 a	65.80	32.25
Gypsum amendment	Natural condition	7.71	66.69	34.20	9.86	66.13	31.63
	Gypsum	7.76	65.61	33.82	9.87	66.59	32.14
CV (%)		11.08	3.53	6.70	12.07	2.69	3.61

*CP=crude protein; NDF=neutral detergent fiber; ADF=acid detergent fiber. **Different letters between percentages of each factor indicate significant differences (P<0.05). ***No analysis due to scarce biomass of *P. coloratum* cultivar 'Bambatsi' in 2014–2015.

Discussion

This study confirms previous reports that showed good adaptation of *C. gayana* in northcentral Santa Fe Province (Bruno et al. 1982; Romero and Mattera 2013; Mattera et al. 2015). Forage production of *P. coloratum* was lower than *C. gayana*, mainly due to a lower percentage of plant biomass in plots. This lower production of *P. coloratum* in sub-tropical environments, despite persistence and good tillering capacity, is in line with results reported by Pesqueira et al. (2016). *C. gayana* was recognized as a weed in *P. coloratum* plots, probably from the seed soil bank as *C. gayana* is naturalized in the area (Pisani et al. 2009).

High exchangeable sodium limits forage productivity and can be alleviated with application of gypsum due to replacement of sodium by calcium in the soil solution (Qadir et al. 2007). In this study, neither forage production nor nutritive value were significantly improved by addition of gypsum with low impact on soil pH and electrical conductivity (data not shown). Leaching of salt would be required to decrease exchangeable sodium from the soil profile (Qadir et al. 2007) but was probably prevented by poor drainage and a fluctuating water table (Hein and Hein 1986).

N fertilization influenced forage production, corroborating previous studies that showed N responsiveness of these grasses in subtropical and temperate environments (Bruno et al. 1982; Boschma et al. 2014; Pesqueira et al. 2016). A moderate single annual dose of N (100 kg N/ha) increased forage production between 70% and 147%. Although sown pasture forage production increased in all cultivars with N fertilization, the increment was particularly important in *P. coloratum* as an important strategy to improve pasture establishment and subsequent production. Improved plant status of N increased plant growth and forage production and was reflected in increase in NNI value, which is a good indicator of plant response to nitrogen (Lemaire et al. 2008). In this study, a higher relative increase in NNI was recorded in the second growing season, probably associated with well-established adult plants with well-developed root systems. NNI values were below the reference curve, indicating N-fertilized pastures were deficient in N, allowing a response in forage production. Future studies to assess nitrogen recovery and nitrogen use efficiency would add to the understanding of N dynamics in pastures because it was not possible to determine N absorption in this study.

Although forage nutritive value was higher in *P. coloratum* than *C. gayana*, impact on overall feed value may be low due to lower percentage of the species in total forage. As expected, crude protein content increased with N fertilization, coincident with increased forage production and NNI improvement.

Conclusions

C. gayana cultivar 'Finecut' was the most productive of the 4 cultivars of tropical grasses tested in the study in a subtropical area. *P. coloratum* cultivars had higher nutritive value but were few in the pasture. Nitrogen fertilization increased forage production and crude protein content through improving N status in fertilized plots. During the evaluation period, addition of gypsum had no effect on forage production nor forage nutritive value of the 4 cultivars tested.

Acknowledgments

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(Note of the editors: All hyperlinks were verified 8 September 2023).

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Obituary

Mauricio Álvarez de León

We regret to inform that on May 24 of this year, M.Sc. Mauricio Álvarez de León passed away. He had been a researcher at the Colombian Agricultural Research Corporation (Agrosavia) for 25 years and worked at the La Libertad Research Center, which supports agricultural activities in the Colombian Orinoco region.

Álvarez de León was an Animal Scientist, with a M.Sc. degree in Animal Production with emphasis on Agricultural Ecology. He has been recognized for his contributions in the use of remote sensing for analyzing information from Unmanned Aerial Vehicles (UAVs) or satellite remote sensors as a tool for rural territory characterization. This included aspects such as land use planning, monitoring of cultivated areas with annual crops such as corn, soybeans, and rice, as well as pastoral areas for beef and dairy cattle production, which are the most important productive activities in the Colombian Orinoco.

Throughout his career, he demonstrated leadership, enthusiasm for training young professionals, and willingness to promote teamwork not only within Agrosavia but also with strategic institutional partners. This approach was instrumental in achieving high-performance results in research and development projects in the Orinoco and other regions of the country. His dedication and passion for research and the use of new remote sensing technologies paved the way for innovation in the agricultural sector of the Orinoco, leaving behind a lasting legacy.

In this Journal you can find articles in which M.Sc. Mauricio Álvarez de León participated as a co-author, as well as a research article in which he contributed and that will be published soon.

* * *

Con gran pesar informamos que el 24 de mayo de este año falleció el MSc Mauricio Álvarez de León, quien por 25 años fue Investigador de la Corporación Colombiana de Investigación Agropecuaria (Agrosavia), y estuvo trabajando en el Centro de Investigación La Libertad, el cual apoya las actividades agropecuarias en la Orinoquía Colombiana.

Álvarez de León era Médico Veterinario Zootecnista y Magíster en Producción Animal con énfasis en Ecología Agropecuaria. Él ha sido reconocido por sus contribuciones en el área del uso de la teledetección para el análisis de la información proveniente de sensores remotos aerotransportados o satelitales, como herramienta para la caracterización del territorio rural, en aspectos tales como el ordenamiento territorial, seguimiento de superficies cultivadas con cultivos transitorios maíz, soya y arroz y de áreas pastoriles para la producción animal con bovinos de carne y de doble propósito, las que constituyen las actividades productivas más importantes en la Orinoquia Colombiana.

A lo largo de su carrera demostró su capacidad de liderazgo, su apertura entusiasmo en la formación de profesionales jóvenes, su voluntad para a fomentar el trabajo en equipo no solo dentro de Agrosavia, sino también con aliados institucionales estratégicos, como medio para el logro de resultados de alto desempeño en proyectos de investigación y desarrollo en la Orinoquia y otras regiones del país. Su dedicación y pasión por la investigación y el uso de nuevas tecnologías de sensoramiento remoto han abierto el camino a la innovación en el sector agropecuario de la Orinoquia, dejando un legado que perdurará en el tiempo.

En esta revista se encuentran artículos en los cuales el MSc Mauricio Álvarez de León participó como co-autor, así como un artículo científico en el cual contribuyó y que será publicado pronto de manera póstuma.

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