Physiological and productivity evaluation of Napier grass (*Pennisetum purpureum* Schumach.) cultivars under variable water supply, temperature and carbon dioxide conditions

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Prologue

The main layout of this thesis follows the Style Guide of the University of New England

http://www.une.edu.au/__data/assets/pdf_file/0004/63229/Journal-Article-Format-for-PhD-Thesis-at-UNE-Guidlines.pdf. Formatting of the papers which constitute the major part of the thesis follows the editorial style of the relevant journal. For other chapters, the format adopted by Crop and Pasture Science journal was maintained. Figures and tables are located throughout the text.

Candidate's Certification

I certify that the work presented in this thesis has not been presented in any institution of higher learning for a degree or diploma award.

To the best of my knowledge and understanding this work has not been written by another author(s) except where due reference is made.

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Publications arising from this thesis

Journal articles

Mwendia S.W., I. Yunusa, R.D.B. Whalley, B. Sindel, D. Kenny and I. Kariuki (2013). Use of plant water relations to assess forage quality and growth of two cultivars of Napier grass (*Pennisetum purpureum*) subjected to different levels of soil water supply and temperature regimes. *Crop and Pasture Science*, **64,** 1008−1019. http://dx.doi.org/10.1071/CP1325

Conference proceedings/presentations

Mwendia S.W., I. Yunusa, B. Sindel, R.D.B. Whalley and I. Kariuki (2012). Water relations in two cultivars of Napier grass under variable water supply and temperature conditions. Proceedings of 16th Australian Society of Agronomy conference: Capturing Opportunities and Overcoming Obstacles in Australian Agronomy. 14—15th October 2012, University of New England, Armidale, NSW, Australia. http://www.regional.org.au/au/asa/2012/soil-water-management/8042_mwendiasw.htm

Mwendia S.W., I. Yunusa, I. Kariuki, R.D.B. Whalley and B. Sindel (2013). Performance of Napier grass under limited soil-water conditions. Proceeding of the 11th World Conference on Animal Production held on 15th—20th October 2013, Beijing International Convention Centre, Beijing China. http://www.chinaexhibition.com/trade_events/3935-WCAP2013The_11th_World_Conference on_Animal_Production.html

Mwendia S.W., I. Yunusa, I. Kariuki, B. Sindel and R.D.B. Whalley (2013). Performance of Napier grass in low rainfall environments. Agricultural Research Day 28th August 2013. Under Auspices of a Joint Conference of the Crawford Fund and Africa

Australia Research Forum: Theme: Mining Agriculture and development: Bread from stones? 25—28th August 2013. Perth, Western Australia. http://www.crawfordfund.org/wp-content/uploads/2014/02/CrawfordFund2013ConferenceProceedings.pdf

Mwendia S.W., I. Yunusa, B. Sindel, R.D.B. Whalley and I. Kariuki (2014). Responses in tissue water relations and growth in a C_4 and C_3 forage grasses to elevated ambient CO_2. Presented at: climate change adaptation 2014: Future Challenges 30th September–2nd October 2014, Gold Coast, Australia. http://www.nccarf.edu.au/conference2014/?page_id=4868

Abstract

Grasses have always been and will continue to be the most important resources for humans and their domestic animals. This study focused on one species of grass, Napier (*Pennisetum purpureum* Schumach.), that is valuable for fodder in both tropical and sub-tropical regions of the world. Napier grass cultivation is likely to increase, especially in east Africa, associated with the increase in human population coupled with a growing demand for livestock products. However, because the present arable land is fully committed, cultivation is expanding into marginal areas. These areas are usually characterised by high temperatures and reduced precipitation, likely to be adversely impacted by global warming associated with increased atmospheric CO_2 levels. This study was designed to increase understanding about how different Napier grass provenances respond to reduced water supply through rainfall and rising temperatures and their impacts on herbage productivity and quality. Such understanding would guide recommendations for farmers in these marginal areas to improve Napier grass management. Techiniques in tissue water status and gas exchange were applied to assess if they could be effective predictors of herbage yield and quality in Napier grass when subjected to water-stress and high temperature stress. The project was implemented in three phases: (1) a glasshouse study that tested the physiological techniques on two Australian cultivars, (2) field trials that tested the techniques on 10 acessions of Napier grass in two contrasting environments in Kenya, and (3) glasshouse study comparing Napier grass (C_4) with a common reed (C_3) subjected to water and heats tress and exposed to high atmospheric CO_2 concentrations.

The first phase of the study used two Napier grass cultivars grown under contrasting temperatures (15─25ºC and 25─35ºC) and soil-water supply conditions (25, 50 and 100% of field capacity) in a glasshouse at the University of New England, Armidale, Australia.

The trial aimed to address the hypothesis that Napier grass tissue water status is correlated with productivity performance. Tissue water status, stomatal attributes, water use, water use efficiency, biomass production and quality were quantified. Although leaf water potential (LWP), relative water content (RWC), stomatal conductance and gas exchange were all reduced with reduced soil-water supply and at high temperatures, there were only minimal differences in these response variables between the cultivars. These differences in response variables between the cultivars were not reflected in CO_2 assimilation rates, dry matter yields or water-use efficiency (WUE) within any watering regime and at 5─25ºC or 25─35ºC. Water use efficiency was generally higher under 15─25ºC (28.5─35.1 kg $ha^{-1}mm^{-1}$) compared with 25─35ºC regime (16.9─22.9 kg $ha^{-1}mm^{-1}$). However, dry matter increased as leaf area increased. It was concluded that any differences in the responses to water and heat stress between the two cultivars were not large enough to be detected in the physiological variables measured. It was then postulated that such techniques might be sensitive enough in discerning physiological responses amongst a much larger range of Napier grass accessions since the grass is known to differ widely in its growth vigour and productivity in the field, especially when water supply and temperatures fluctuate widely. Under such conditions any relationship between tissue water status and productivity would be revealed.

A study with 10 provenances of Napier grass was undertaken in semiarid lowland (Katumani) and a wet mesic highland (Muguga) over 8 growth cycles in tropical Kenya in 2011–2013. The 10 lines fell into 3 yield clusters: low yielding cluster (LYC), moderate yielding cluster (MYC) and high yielding cluster (HYC) based on dry matter yields, leaf yield, leaf to stem ratio and leaf area index. At both sites, biomass yield was mostly in the order HYC ≈ MYC > LYC and most yield reductions in LYC occurred during dry periods. Higher tissue water status at the wet site supported higher stomatal conductance and consequently higher biomass than at the dry site. Water use efficiency (kg $ha^{-1}mm^{-1}$) followed the order HYC (34.3) > MYC (32.6) > LYC (24.9). Neither relative water content nor leaf water potential was correlated with biomass accumulation, and so neither could be a reliable predictor of productivity in Napier grass except leaf area index. These results when taken along with those from phase 1 strongly suggest that this grass may be maintaining its tissue water-status and gas exchange at the leaf level within a narrow range; this range is tighter than that found in biomass accumulation, which is the sum of all the leaf area active in gas exchange and water-use. The grass thus possesses effective mechanisms for maintaining tissue water status within the narrow range observed that was not quite understood in this phase of the study. Future predictions of climatic scenarios arising from increased CO_2 concentration suggest atmospheric conditions that would be vastly different from those of the present and are likely to alter plant responses to water stress.

A third phase of the study was therefore undertaken to evaluate how exposure to elevated CO_2 (eCO_2) and temperature would influence responses to water-stress by Napier grass, especially when compared with common reed (*Phragmites australis*), a C_3 grass species. This phase was also used to identify key mechanisms for maintaining favourable tissue hydration in the two species when subjected to limited water supply under temperature regimes of either 15/25ºC or 17/30ºC over three successive growth circles. Physiological (LWP, osmotic adjustment) traits, stomatal morphology (density and distribution) and conductivity, along with dry matter accumulation were determined. Exposure to eCO_2 improved leaf water potential (LWP) in Napier grass at midday and in common reed at predawn when the plants were subjected to water stress. Exposure to eCO_2 increased the number of stomates in Napier grass under high temperature and reduced stomates in common reed under low temperature. The Napier grass generally maintained more favourable tissue hydration when subjected to water stress, and showed a more positive response to eCO_2 in increasing carbon assimilation and biomass accumulation at both temperature levels, than common reed. Favourable tissue moisture in Napier grass was achieved largely through both osmoregulation and stomatal control unlike in the common reed that had poor stomatal control and lower osmotic adjustment compared with Napier grass. Furthermore, there was no correlation between tissue water status and productivity of either of the grasses.

In conclusion, temperature and water stresses triggered stomatal regulation to conserve water in Napier grass and this appeared to be at the expense of carbon assimilation. The Napier grass also exhibited strong osmo-regulation, in addition to stomatal closure, in conserving favourable tissue water status but penalised carbon assimilation. Thus leaf level physiological traits proved to be unreliable predictors of productivity, which showed a strong correlation mostly with leaf area. Also high leaf to stem ratio was positively correlated with forage quality (digestibility). High degree of leafiness thus suggests a potential for high yielding herbage of top quality even under water- and heat-stress conditions.

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