

ROLE OF CUTTING TYPE AND PLANTING DENSITY FOR THE PRODUCTION OF BIOMASS FROM NAPIER GRASS (*Pennisetum purpureum* SCHUMACH.)

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Abstract

Climate change is going to impact agriculture, so that biofuel production from crops like Napier grass will be produced under more restricted environment's conditions in the upcoming years. This field experiment was conducted to determine the importance of the size of cane-section cuttings establishment and performance on the field under minimal farming management in the Nakhon Ratchasima Province/Thailand. The effects of initial cutting length, planting method (vertical or horizontal) or initiation density of setts (a short cane-section cutting that contains at least two nodes) were compared as to propagation success, plant survival, tiller formation and dry matter yield (DMY) under rainfed conditions in randomized block design. An early harvest, tested on horizontally buried setts, did not affect an increase of tiller formation, but the tiller increased with maturation instead. The planting method, horizontal or vertical, of setts did not affect the plant architecture like tiller formation for DMY production in the end. In the drier 2012/13 period, an increasing density of setts tended to produce more DMY, a trend, that was lost during the wetter 2013/14 period. Though longer canes produced absolutely more DMY than the compared smaller sections but a significantly better performance or DMY could not been found. From our results, we conclude that the rate of successfully propagated cuttings or plant architecture is not equivalent for DMY. Attributes like planting density or length of cane-section did not affect the later-produced biomass under restricted farming conditions.

Keywords: Production; propagation; biomass; *Pennisetum purpureum*; density; cutting

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Introduction

To fight global warming, it has been declared an international goal to reduce the greenhouse-gas emissions such as carbon dioxide (CO₂). Many countries, as well as the Thai government, have joined the Kyoto Protocol of the United Nations Framework Convention on Climate Change which stipulates that the emissions have to be cut to limit global warming. In contrast to fossil energy sources, biomass is not included in the CO₂ balance of the Kyoto Protocol as the carbon cycle of biomass is neutral and the CO₂ emissions of biomass are not larger than the quantity fixed by photosynthesis (Stöcker, 2008). In 2013, the Thai government introduced the Alternative Energy Development Plan which promotes the climate and site-tolerant Napier grass (*Pennisetum purpureum* Schumach.) as head crop to produce biomass for conversion into bio-energy, and to claim the reduction of CO₂ emissions (Ministry of Energy, Department of Alternative Energy Development and Efficiency, 2014).

Besides, a wide range of site adaptability, Napier grass is also a tall-growing stem-forming plant, which prefers warm climates as found almost throughout Thailand. It can be easily propagated directly in the field by all vegetative parts: from root splits, canes or even terminal cuttings (Haegele and Arjharn, 2017). Under a heavy fertilization and additional irrigation regime, it can produce up to a maximum of 60 t dry matter (DM) ha⁻¹ yr⁻¹ on Thailand's fields (Rengsirikul *et al.*, 2011). The ministry of energy assumed Napier grass's dry biomass has an overall potential to yield about 27 to 58 t ha⁻¹ yr⁻¹ on Thailand's fields without describing the effort of farmer's care taking.

However, such ideal cultivation is often limited in Thailand, particularly at sites with marginal agricultural land (Vangnai, 1981). As a matter of fact, rainfed is the dominant land-use system in Thailand especially in the Nakhon Ratchasima Province (Wijnhoud *et al.*, 2003) where Thailand's largest agriculturally used field site is located, very often managed under less-than-ideal practices by smallholders. Under such restricted conditions, it has been

found that yield from Napier grass can decrease to 0.96 Mg DM ha⁻¹ letting prefer farmers leave valuable farm land lie fallow due to the massively resulting yield gap (Haegele and Arjharn, 2017).

With the traditional propagation-method of Napier grass, cane-section cuttings, which contain two nodes and referred to as a sett, are inserted vertically with one node in the ground and the other one above. The organogenesis of Napier is quite similar to that of sugarcane (*Saccharum officinarum* L.) as every phytomer contains a single bud, which completes organogenesis within eight weeks after planting. As young sprout emerges, it develops its own competent root system. After eight weeks, the mother cutting dies off and the seedling assimilates photosynthates as an independent plantlet (Bakker, 1999). Under less-than-ideal conditions, the bud and cutting often dies off and the propagation failed. To compensate unsuccessful propagation in the field, farmers from the Nakhon Ratchasima district reported of propagating full canes in the field more successfully than setts.

The propagation of full stems is similar to the practice in Short Rotation Coppice systems (SRC), which is used to grow woody plant species for bio-energy purposes in the Northern hemisphere. In SRC, typically fast-growing species such as willow or poplar can adapt to a wide range of environmental condition, are planted in high density using long cane-section cuttings, and left to grow for one or two years before harvesting. The importance and role of initial cutting length for propagation, vegetative establishment and aerial biomass development have been reported for woody species for SRC, since the vigor of seedlings is stronger with increasing cutting length (Vigl and Rewald, 2014). Moreover, we have learned that plantations of perennial woody plants bear several environmental advantages such as higher retention of nitrogen, positive impacts on soil ecology, biodiversity and the potential to sequester meaningful amounts of carbon above and below ground (Rowe *et al.*, 2013). Interestingly, it has been reported that Napier

grass contains chemical composition and physical structure suitable for the conversion into bio-energy. The benefit from its maturation can be obtained by lignocellulose in less frequent cutting intervals (Rengsirikul *et al.*, 2011).

In face of climate change and the current situation for farmer who must grow Napier grass under less-than-ideal conditions, strategies for successful in-field propagation will become important. One part of the objective of this field experiment was to clarify if the initial cutting length or the planting method of small setts, suitable to be inserted vertically or buried horizontally in the field, influences the establishment and performance of Napier grass under minimum farm management as it is reported from farmers or from SRCs. Furthermore, we investigated if the planting density of setts and an early harvest showed an effect on initiation and stand development as a part of a new strategy for farming under restricted conditions. The propagation success, tiller formation and dry-matter yield (DMY) were compared for performance under rainfed conditions during a single cropping season, consisting of the rainy and the dry season in Nakhon Ratchasima Province.

Materials and Methods

Site Description

Field studies were conducted from 2012 to 2014 on the farm yard of the campus of Suranaree University of Technology (SUT), Nakhon Ratchasima Province, Thailand. As the current results were part of a comprehensive experiment, the same site and equipment were used as previously described in Haegele and Arjhan (2017).

Experimental Design and Cultivation Method

For propagules, matured canes of Napier grass were collected from a two-year-old stand from a neighboring field. The genotype of tested Napier grass is a cultivar which is inclined to form tall canes (Haegele *et al.*, 2017). Cleared of dry leaves, whole stalks

were randomly sized to propagules before propagated directly in the field which had been ploughed. Setts, which contained a minimum of two nodes, small canes (approx. 60 cm), and full canes (approx. 100 to 120 cm) were used as propagules in this field experiment from 2012 to 2013 (abbr. 2012/13), and repeated from 2013 until 2014 (abbr. 2013/14). All cuttings planted by the horizontal method were buried in almost 5 cm-deep furrows, but the vertically inserted setts were stuck without an angle, with one node in the ground and the other one exposed. Before plots were initiated, nodes of randomly chosen samples ($n = 100$) of all tested cutting types were counted and averaged to determine the number of nodes in the ground for each specific treatment (2012/13: setts 2.42 nodes, small cane 6.87 nodes and full cane 13.08 nodes; 2013/14: setts 2.02 nodes, small cane 5.50 nodes and full cane 6.74 nodes).

The experimental design comprised following treatments to test:

- Three different cutting types (sett, small cane and full cane) and the planting method of setts (horizontal or vertical) with harvesting interval. The plots containing setts were planted with nine cuttings m^{-2} , those ones containing long cane-sections were planted with three cuttings m^{-2} . The treatments were referred to as sett (horiz), sett (vert), small cane and full cane.

- Horizontally buried setts (nine m^{-2}) without harvesting interval.

- Planting density of six, nine, ten and twelve horizontally buried setts m^{-2} without harvesting interval.

The plots, each measuring 6×14 m, were spaced 1 m apart and arranged in a randomized block design with three replications for each treatment. Both experiments were initiated in mid-May, and plots were harvested 150 days after planting (DAP) with a brush cutter 10 cm above ground by the ratooning method, which leaves the stubble in the ground for regrowth. A further 180 days after harvest (DAH), or 330 DAP, respectively, all plots were finally harvested as shown in the cultivation scheme in Figure 1. Due to flooded fields after heavy rain during September 2013, plots were

harvested almost two months later than planned in the second experiment. No fertilizer or irrigation was applied at any time during the experiment, plant protection or weeding was also omitted in both years.

Plant Sampling and Data Analysis

For the harvest of the net plot (2×6 m) and the determination of dry matter (DM) for analysis of variance (ANOVA), the method and the equation for conversion into t DM ha⁻¹ was used as described in Haegele *et al.* (2017). The dry matter yields (DMY) in Table 3 and 4 from the 2012/13 period, have been previously used for comparisons in Haegele *et al.* (2017). Plantlets that appeared viable, referred to as emerged nodes, were counted for every net plot and divided by the number of total planted nodes (the number of cuttings m⁻² was multiplied with av. number of nodes per cutting type and the net plot area) and converted into percent 150 DAP. Additionally, all tillers, primary and secondary, were counted in the net plot and divided by the specifically counted number of net plots' plantlets, and expressed as average tiller plant⁻¹.

Statistical Analysis

All data were subjected to the ANOVA, performed using the IBM SPSS Statistics for Windows, Version 23.0 (IBM Corp., 2015). For the performance 'DM yield' was treated as dependent variable and 'treatment' as factor. The LSD-test was used as post-hoc-test to determine significant differences among treatments. Significant differences among treatments were compared with the critical difference at 0.05 levels of probability for significance.

Results and Discussion

Climatic Conditions

Precipitation in both years mirrored the course of Thailand's two seasons with rainfall from May to November (the rainy season), and almost no rainfall from November to April (the dry season), as shown in Figure 1. Higher rainfall was recorded for the replication experiment in 2013/14 (total 1,351.70 mm) and exceeded that of the first experiment in 2012/13 (total 811.40 mm). During both experiments, the average temperature ranged between 20°C and 30°C.

Effect of Cutting Regime on Field Performance

In the experimental period 2012/13, 150 days after planting (DAP) between 11.25 and 13.90% of nodes plot⁻¹ of horizontally buried setts emerged, referred to as propagation

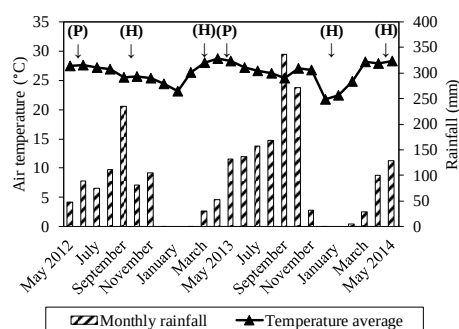


Figure 1. Monthly precipitation and average air temperature on the farm yard of the campus of SUT in 2012-2014; modified from Haegele and Arjarn (2017). P = Planting, H = Harvesting

Table 1. Measurements of emerged nodes and tillers for Napier grass plots from horizontally buried setts to test for the effect of harvest interval on crop development

	Without harvest interval		With harvest interval		CV
	150 DAP	330 DAP	150 DAP	180 DAH (330 DAP)	
2012/13					
Emerged nodes (%)	11.25 A	11.59 A	13.90 A	7.65 A	0.64
Total tiller plant ⁻¹	1.09 B	1.98 AB	1.05 B	2.73 A	0.46
2013/14					
Emerged nodes (%)	17.74 A	5.78 A	14.97 A	7.64 A	0.58
Total tiller plant ⁻¹	1.59 A	2.38 A	1.71 A	1.93 A	0.32

Means followed by the same uppercase letter within a row are not significantly different at $P < 0.05$. DAP = Days after planting; DAH = Days after harvest; CV = Coefficient of variation.

Table 2. Results of ANOVA to test for the effect of emerging nodes and tiller formation for four different cutting types of Napier grass in the years 2012-2014

Cutting type	Emergent nodes (%)		Total tiller plant ⁻¹	
	150 DAP	180 DAH (330 DAP)	150 DAP	180 DAH (330 DAP)
Experimental season 2012/13				
Sett (horiz)	13.90 a	7.65 a	1.05 a	2.73 a
Sett (vert)	13.27 a	4.94 a	1.32 a	5.89 a
Small cane	8.22 a	2.02 a	1.64 a	2.53 a
Full cane	2.48 a	2.69 a	1.65 a	6.15 a
CV	0.81	1.03	0.28	0.55
Experimental season 2013/14				
Sett (horiz)	14.97 a	7.64 a	1.71 a	1.93 a
Sett (vert)	21.91 a	11.73 a	2.00 a	4.35 a
Small cane	19.70 a	11.95 a	1.80 a	3.05 a
Full cane	23.77 a	9.62 a	2.00 a	2.44 a
CV	0.31	0.42	0.22	0.41

Means followed by the same lowercase letter within a column and experimental season are not significantly different at $P < 0.05$. DAP = Days after planting; DAH = Days after harvest; CV = Coefficient of variation.

Table 3. Effect of cutting types and planting method of setts on dry matter yield (t DM ha⁻¹) of Napier grass

Cutting type	Produced biomass (t DM ha ⁻¹)			
	Experimental season			
	2012/13		2013/14	
	150 DAP	180 DAH (330 DAP)	150 DAP	180 DAH (330 DAP)
Sett (horiz)	1.01 b, A	0.31 b, A	2.78 a, A	1.02 a, A
Sett (vert)	0.54 b, AB	0.10 b, B	1.97 a, A	1.44 a, AB
Small cane	1.22 b, B	0.04 b, B	4.06 a, A	3.80 a, A
Full cane	2.60 b, A	1.14 b, A	4.13 a, A	1.66 a, A
CV	0.88	2.06	0.49	0.74

Means followed by the same lowercase letter within a column and the same uppercase letter within a row are not significantly different at $P < 0.05$. DAP = Days after planting; DAH = Days after harvest; CV = Coefficient of variation.

Table 4. Effect of various sett densities on produced dry matter yield (t DM ha⁻¹) of Napier grass in the years 2012-2014

Density (setts m ⁻²)	Produced biomass (t DM ha ⁻¹)	
	Experimental period	
	2012/13	2013/14
6	0.68 a, B	4.16 a, A
9	0.96 a, A	2.34 a, A
10	1.66 a, A	2.34 a, A
12	2.09 a, A	3.53 a, A

Means followed by the same lowercase letter within a column and the same uppercase letter within a row are not significantly different at $P < 0.05$.

success (Table 1). The propagation success was found to be more successful with 17.74 and 14.97% in the wetter experimental period 2013/14 than in the previous period. With or without harvest interval, the number of emerged nodes of all treatments decreased consistently, when the dry seasons continued from 180 days after harvest (DAH) until 330 DAP, except one treatment where additional nodes emerged (11.59%). The number of formed tillers plant⁻¹ increased continuously

with maturation during both experimental periods. Only in the period 2012/13, the counted number of tillers plant⁻¹ increased significantly from 1.05 to 2.73 tiller plant⁻¹ (Table 1). Taken together, a significant effect between treatments or year could not be found. However, Rengsirikul *et al.* (2011), found the tiller density m⁻² started to increase significantly on a monthly harvest interval, an effect that did not appear for less-frequent harvests, for three different cultivars. Due to the absence of a clear significance or

pattern, it appears that a less-frequent harvesting regime could not affect the tiller formation, but maturation did instead of what agrees with literature.

Effect of Cane-section Cutting Length and Planting Method of Setts on Field Performance

The nodes of the propagated cane sections of various length emerged on a range of 2.48 to 13.90% nodes plot⁻¹ in the experimental period 2012/13, whereas, the propagation success decreased with the length of cane sections (Table 2). A reversed trend was observed when 23.77% of nodes plot⁻¹ containing full canes, sprouted the maximum of the experiment in 2013/14. In both experiments, massive losses of viable plants appeared 180 DAH, except for the plots containing full canes for which even additional emerged nodes were observed (2.69%). The lack of significance is due to the big variance with in the replications which resulted from the inhomogeneous germination.

Literature reports, that the environment impairs strongly the propagation success of cuttings with the best rates under ideal fertile conditions and increasing failures under less-than-ideal conditions (Beyl and Trigiano, 2016). In a study under greenhouse management, germination rates of 57.5 to 100% for horizontally planted setts, and 85 to 97.5% for vertically inserted setts, respectively, were demonstrated (Knoll and Anderson, 2012). Particularly cane-section cuttings of Napier grass rooted reliably under fertile conditions, e.g. nitrogen supply and availability of water (Woodard and Prine, 1990; Hanna *et al.*, 2004). As so, the reduced germination of propagules for Napier grass was found under deficit circumstances (Rusland *et al.*, 1993). The propagation success of the present study, which ranged between 2.48 and 23.77% at 150 DAP for all tested cutting types were attributed by the procedure of minimum management in the experiment.

A range of 1.05 to 1.65 tiller plant⁻¹ was observed for all plots, 150 DAP in 2012/13, but more tiller plant⁻¹ were counted in 2013/14 (1.71 to 2.00, Table 2). Apparently more tiller plant⁻¹ was formed from plots containing

vertically planted setts than from those plots which contained horizontally buried setts in both years. In 2013/14, horizontally buried setts formed the fewest tiller plant⁻¹ again and vertically inserted setts the most of all different cutting types. In both years, full canes formed more tiller per plant than the small canes. Consequently, full canes formed the most tiller per plant of all plots. Three hundred and thirty DAP, more tiller plant⁻¹ were formed from vertically planted setts and full canes in 2012/13. Interestingly, only sett (vert) formed more tiller (4.35) in 2013/14 again but full canes did not differ in this year. On the whole, both types of canes formed many tiller plant⁻¹ 150 DAP after planting but sett (vert) formed finally the most tiller plant⁻¹ in both years (Table 2).

The DMY of plots did not vary significantly among treatments at each harvest, but more DMY was measured in the 2013/14 period. In both experimental periods, treatments produced apparently more biomass during the first period 150 DAP (0.54 to 4.13 t DM ha⁻¹) than during the period of 180 DAH (0.04 to 3.80 t DM ha⁻¹), shown in Table 3. Though the number of emerging nodes of horizontally buried and vertically inserted setts did not very much (13.90 and 13.27%, Table 2), the latter formed more tiller plant⁻¹ (1.05 and 1.32 tiller plant⁻¹, Table 2), but almost twice as much biomass was produced from the plots containing horizontally buried setts than from the vertically inserted ones in 2012/13 (1.01 and 0.54 t DM ha⁻¹, Table 3). This was even more apparent in 2013/14 when less biomass was produced from the plots which contained vertically inserted setts (1.97 t DM ha⁻¹), though many more nodes emerged and more tillers were formed than from those containing horizontally buried setts (2.78 t DM ha⁻¹), shown in Table 3. For woody species grown in Short Rotation Coppice systems (SRC), the planting method of small cane-sections was described for general importance, with an advantage for conventional cuttings (20 cm lengths planted vertically) than the planting method of billets (10 cm lengths planted horizontally), on growth of two *Salix* spp. genotypes (McCracken *et al.*, 2010). According to literature, we assume

Napier grass owns also vigorousness as it is described that the initial length of cuttings being for a general importance since the vigor of seedlings is stronger with increasing cutting length (Vigl and Rewald, 2014).

However, in Tifton/United States, a greenhouse experiment demonstrated a similar effect for canes of Napier grass when vertically planted cuttings thrived significantly with more total shoots cutting⁻¹, and the authors concluded that vertical planting will result in higher establishment than horizontal planting (Knoll and Anderson, 2012). The present study agrees with the earlier results on the better establishment of vertical inserted setts, when setts planted by the vertical method produced more tiller plant⁻¹ than plots containing horizontally buried ones. In the present investigation, horizontally buried setts produced higher DMY, even though the vertical planting method owned a better plant architecture for high DMY by more tiller plant⁻¹. For this reason, we conclude that the vertical planting method of setts is more advantageous due to their easier handling on the field. The plant architecture of vertically inserted setts is superior, if plots are able to thrive and catch up DMY as it seems to be possible under wetter conditions. Failing this, the method of horizontal burial is more suitable for less-than-ideal conditions.

It was expected that at least a similar or even higher number of nodes would emerge from the longer cane-section cuttings than from setts. Interestingly, plots containing long canes produced more biomass than setts, even though those plots were propagated less successfully (Table 2). In contrast to the expectations, the opposite effect was found in our trial, highlighting that more buds will not necessarily emerge from longer cuttings. Until 330 DAP, the plots containing longer cuttings grew more vigorously than setts, compensated the germination rate, and consequently, produced higher DMY (Table 3). Thus, the amount of emerged nodes was not consequently the equivalent for produced biomass. The length of woody cuttings is a significant factor in establishing plantations for perennial woody crops in SRC (Burgess *et al.*, 1990). Hardwood

cuttings depend on the hydrolysis and availability of carbohydrates stored within the cane tissues, which increase with cutting length (Leakey, 2004). Buds of longer cuttings can benefit more from storage in the cane tissue. Hence, seedlings develop a competent root system faster after planting, and are able to maintain access to water and nutrients for photosynthesis more quickly than those from smaller cuttings (Jansen *et al.*, 1998). In conclusion, the results of the present study are in accordance with earlier trials on *Salicaceae* which demonstrated that long cuttings also produce more above-ground biomass as developed plantlets improve in growth, respectively (Vigl and Rewald, 2014). Therefore, it seems as if cane-section cuttings of Napier grass perform similarly to hardwood cuttings and their emerging nodes grow vigorously.

It occurred, that treatments produced apparently more biomass during the first period 150 DAP (0.54 to 4.13 t DM ha⁻¹) than during the period of 180 DAH (0.04 to 3.80 t DM ha⁻¹), shown in Table 3. With the decreasing number of viable plants during the dry season (180 DAH), the produced biomass declined massively although the number of formed tillers per viable plant still increased in that period (Table 2). Previous studies found correlations between DMY, tiller number, plant height and maturation (Ferraris and Sinclair, 1980; Jørgensen *et al.*, 2010). The minimum farming practice, resulted in unfavorable climatic conditions, and only light precipitation (Figure 1) as well as the massive losses of plants could not have been compensated by the tiller formation, and consequently, less biomass was produced during the period of 180 DAH. Thus, precipitation and available crop water appeared to have an effect on produced biomass. Apparently, all plots and small canes, produced more biomass in the wetter 2013/14 trial than in 2012/13 (Table 3). Under rainfed conditions, with an initial fertilization rate of 24 kg nitrogen ha⁻¹ and further 32 kg nitrogen ha⁻¹ applications every 30 days, an earlier work attained between 30.6 to 48.4 t ha⁻¹ yr⁻¹ for the varieties 'Muaklek' and 'Common' Napier grass' at Suwanvajokkasikit Research Station that located in Nakhon

Ratchasima Province (Rengsirikul *et al.*, 2011). However, investigations for DMY potential of Napier grass under more restricted farming conditions are lacking for Thailand. But such one, that investigated the effects of organic production methods and irrigation on the genotype 'Taiwan' in Khon Kaen University for a full year from April to April, found that no application of manure (plots without manure yielded 1,300 kg DM ha⁻¹) affected DMY more than any other treatment (plots with manure yielded between 1,807 to 6,943 kg DM ha⁻¹) (Pholsen *et al.*, 2014). The produced biomass in the present investigation that omitted additional fertilizer and irrigation was generally consistent with those DMY from Khon Kaen University. In our study, the minimum (0.64 t DM ha⁻¹) was attained from sett (vert) in 2012/13, and the maximum (7.86 t DM ha⁻¹) by small cane in 2013/14, (Table 3).

Effect of Planted Sett Density on Biomass Production

In the present experiment, a density of six to twelve planted setts m⁻² produced between 0.68 and 4.16 t DM ha⁻¹. But taken together, an absent significance between dry matter yields showed no effect (Table 4). The smallest DMY was measured for densities of six and nine setts m⁻². But, as the density of planted setts increased, also more biomass was produced in the 2012/13 period. An ambiguous pattern was found in the period 2013/14 when sparser plots produced more biomass than denser ones. For instance, six setts m⁻² produced more biomass (4.16 t DM ha⁻¹) than twelve setts m⁻² (3.53 t DM ha⁻¹).

In earlier field experiments, the effects of increasing plant densities on produced DMY were described with ambiguous results for several locations and conditions. Under an intensive nitrogen fertilization and irrigation regime in Japan, when the narrowest planted plots of Napier grass (plots were arranged in rows of 50, 75, 100, or 125 cm apart with 50 cm between), produced significantly more DMY than the wider ones (Miyagi, 1980). A study conducted in Ethiopia described ambivalent results for Napier grass populations with densities between 8,888.9 plants ha⁻¹ and

80,000 plants ha⁻¹ when wider spacing produced repeatedly similar or even more biomass than closer spacing under rainfed conditions and additional fertilization (e.g. in 2004: a population of 26,666 plants ha⁻¹ produced 6.1 t ha⁻¹, which yielded more than the 5.9 t ha⁻¹ from the population of 40,000 plants ha⁻¹; in 2005: a population of 13,333.3 plants ha⁻¹ yielded 40.0 t DM ha⁻¹ and the highest DMY of all tested treatments). Nevertheless, the author maintained that increasing populations also would increase the DMY (Tessema, 2008). In another study in Ethiopia, conducted under rainfed conditions and without additional fertilization, the absence of significance in DMY was described by increasing Napier grass's populations from 20,000 plants ha⁻¹, 26,666.7 plants ha⁻¹ to 40,000 plants ha⁻¹, even though yields (6.37 t ha⁻¹, 7.05 t ha⁻¹ and 9.24 t ha⁻¹) tended to increase with density (Mohammed *et al.*, 2016). In the present study, insignificant differences among DMY were produced from diverse densities (6, 9, 10, or 12 setts m⁻²). Along with these contradicting reports, our results agreed with literature, the more similar the environmental conditions were, and disagreed the more it differed.

This hypothesis of a yield increase until maximum yield saturation is achieved is collaborated for intensely managed farms (Miyagi, 1980). Nutrient underuse, on the other hand, leads to yield gaps. The lesser nutrient and water management is done the bigger this gap gets (Mueller *et al.*, 2012). In the case of minimum farming, as done in the present investigation, a doubling of cuttings density did not show such an effect as it is described for best management.

Although the produced biomass increased directly with density in the 2012/13 period, a reversed pattern was observed when the thinnest density of six setts m⁻² produced the highest DMY (4.16 t ha⁻¹) in 2013/14 when more rainfall was measured than in the experimental period before (Table 4, Figure 1). Tilahun *et al.* (2017), observed that individual plants counteracted to some extent the greater number of tillers plant⁻¹ at wider spacing. The productivity of Napier grass is attributed to the leaf area index (LAI) which changes with

successive lateral expansion and plant architecture from planophile to erectophile as the light extinction coefficient (K) reduces by shade. Under poor light exposure, e.g. by interplant competition due to narrow spacing or competitive weeds, Napier grass etiolates and its morphology changes (i.e. reduced LAI, weaker stalks) which results in a poor photosynthetic output (Kubota *et al.*, 1994). These are attributes that were not met in our investigation as weeding, additional fertilizer application or irrigation was omitted. We observed that the Napier grass stands were still able to outgrow competitive weeds, but the conditions were not fertile enough, e.g. available water for vigorous morphological development. In consequence, the insignificant effect of planted density and DMY was measured, as in the studies in Ethiopia, under restricted environmental conditions.

On the other hand, Napier grass forms a competent root system that can reach down to 2.6 m, deeper than many competitive weeds, into deep soil layers and tap nutrient reserves (Sekiya *et al.*, 2013). As the thinnest stand of six setts m⁻² yielded the highest (4.16 t DM ha⁻¹) in 2013/14. We conclude that those plots grew stronger than denser stands, which is in accordance with Sekiya *et al.*, as fewer plants had access to more nutrients that are more supportive to plant development.

Conclusions

Based on the results of our investigation, a recommendation for best planting method could not been identified due to a missing significance. The farmer's report, that longer cane-sections grow better under restricted environmental conditions, could not be confirmed. Though not more or less buds thrived from long cane-sections than from small sections and setts, the absolute higher DMY must have been grown from vigorously thriving plantlets. A harvest before the dry season starts is possible. Neither the whole plant architecture, like formed tiller, nor the number of thriving buds showed an effect on the stand establishment and performance in the

field. On the other hand, the vertical insertion should be favored only under the aspect of their easier handling on the field. Besides that, horizontally buried setts are not the first recommended option, and plots should be initiated with the lowest density, which was six setts m⁻² in the present field experiment.

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