STRATEGIES TO ENHANCE NAPIER GRASS (*PENNISETUM PURPUREUM*) PRODUCTION IN THE HUMID TROPICS

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ABSTRACT. The cost of livestock feed is considerably higher than any other variable-cost. Therefore, efforts are made to reduce the cost of feed using locally available pasture sources such as Napier grass. However, Napier yield is a major problem in tropical countries, especially for the small holder farmers. The choice of Napier grass varieties, techniques of planting with suitable plant density and distance, proper fertilizer management and irrigation, good seasonal or environmental condition, and proper cutting intervals influence the growth, yields, nutrient composition, and overall performance of Napier grass. Therefore, farmers need to understand the factors that affect the yield and quality of Napier grass to be able to formulate the most suitable protocol for management of the Napier grass in their respective farms. This review discusses the important issues regarding proper management of Napier grass for better yield.

***Keywords*:** Factors affecting production, Napier grass, tropical forage, yield

INTRODUCTION

Sustainable ruminant production in the humid tropics is extremely challenging due to the lack of quality forages and feed resources. Furthermore, feed cost is a major concern since it accounts for 50 % to 60 % of the total cost of ruminant production. Therefore, farmers in the tropics are most likely to offer feed with the lowest price tag but with variable nutrient content. However, formulating a cheap livestock feed that fulfills all requirements is a major challenge in ruminant production, especially in dairy cattle (Hazwan *et al.,* 2016) thus, resulting in poor production that leads to unsustainable venture. On top of that, the cost of feed is usually dependent on the availability of the materials within a country (Predith *et al.,* 2018).

Ruminants, especially dairy animals require quality grass, and Napier grass (*Pennisetum purpureum*) is the most common forage cultivated by farmers in the tropic as ruminant feed source. In fact, Napier grass with a botanical synonym name of *Cenchrus purpureus* is a multipurpose grass that can be harvested for fresh feeding or to be processed into silage or hay. It is generally cultivated for a cut-and-carry management system due to its high yield per unit area, with acceptable crude protein content and is able to withstand intermittent drought and repeated cutting without compromising its growth. It regenerates rapidly, forming tillers that produce palatable leafy shoots (Mustaffer *et al.,* 2023). Average price for fresh and chopped Napier grass in Malaysia ranges between RM100 (USD25) and RM160 (USD40) per ton while its silage is between RM250 (USD62) to RM300 (USD75) per ton (Hazwan *et al*., 2016). These prices are relatively lower than other locally available agriculture forage feedstuff used as ruminant feed (Table 1). However, the major concerns with Napier grass are the variable nutrient content and the difficulty to sustain optimal growth. This review attempts to highlight several strategies and actions that could be taken to enhance the production of Napier grass in the humid tropical countries.

Table 1. Nutrient composition and price per ton of locally available forage feedstuff in Malaysia

Feedstuff	**DM%**	**CP%**	**ME (MJ/kg)**	**CF%**	**TDN%**	**Ca%**	**Phos%**	**Price/ton DM (USD)**
Napier Grass (Fresh)	31.6 ±1.31	8.6 ±0.82	6.45 ±1.82	46.9 ±1.30	44.6 ±1.40	0.36 ±0.08	0.16 ±0.04	25 - 40
Napier Grass (Ensiled)	36.2 ±1.48	7.4 ±1.21	7.12 ±1.64	27.5 ±1.42	48.7 ±1.26	0.72 ±0.04	0.14 ±0.06	62 - 75
Corn Stover (Fresh)	24.5 ±1.82	6.8 ±0.86	7.50 ±0.87	29.6 ±1.64	51.0 ±0.84	0.16 ±0.08	1.72 ±0.12	30 - 45
Whole Corn (Ensiled)	29.5 ±1.25	9.7 ±1.08	7.00 ±1.02	29.6 ±0.80	47.9 ±1.23	0.32 ±0.12	0.21 ±0.24	64 - 87
Guinea grass (Fresh)	24.2 ±2.26	10.4 ±1.64	6.68 ±1.46	37.3 ±2.18	46.0 ±1.21	0.37 ±0.06	0.24 ±0.12	37 - 50
Oil Palm Frond	36.4 ±2.01	4.1 ±0.40	4.89 ±0.60	44.8 ±2.12	35.1 ±1.07	0.55 ±0.04	0.09 ±0.02	12 - 40
Paddy Straw	89.6 ±0.82	9.2 ±1.40	7.29 ±1.44	43.1 ±0.46	49.7 ±1.48	0.08 ±0.02	0.04 ±0.03	40 - 50
Sugarcane Baggase	45.9 ±1.25	2.0 ±0.87	6.93 ±1.47	31.2 ±0.61	47.5 ±1.35	0.10 ±0.04	0.03 ±0.06	50 - 70

*DM; Dry matter, CP; Crude protein, ME; Metabolisable energy, CF; Crude fiber, TDN; Total digestible energy, Ca; Calcium, Phos; Phosphorus.

CHARACTERISTICS OF NAPIER GRASS

Napier grass is a perennial C4 grass species belonging to the family Poaceae and the genus *Pennisetum*, originated from sub-Saharan Africa (Turano *et al*., 2016). It is widely distributed across most tropical and subtropical countries. Napier grass is highly adapted to most agro-climatic conditions and is able to grow on most types of soil. With proper management and irrigation, it grows best in areas where the annual rainfall is between 750 mm and 2,500 mm. It can tolerate intermittent drought as well as hot and humid conditions and therefore, could grow within the tropical and subtropical parts of Asia, Australia, the Middle East, Central and South America, and the Pacific islands. Today, it has been cross-bred with indigenous types of grass and crop plants that are available in many countries, producing cultivars with better yield and growth performance together with improved nutrient compositions.

Napier grass is commonly planted by vegetative cutting and tillers due to its limitations in producing enough seed for propagation. Indeed, the seeds that are produced are usually small, light, of poor quality and prone to shattering. Apart from that, the seedlings are highly heterozygous due to the pollinated crop, thus inappropriate to be propagated. Napier grass exhibits fast growing characteristics, perennial in nature, and able to produce an average dry matter (DM) yield of up to 40 tonnes/ha.

STRATEGIES TO ENHANCE NAPIER GRASS PRODUCTION

Low and inconsistent yield are among the major problems of growing Napier grass. It has been reported that tall Napier yield can produce more than 60 tonnes/ha while short Napier produce less than 60 tonnes/ha (Halim *et al.,* 2013), which is between 9 and 16 tonnes of dry matter/ha (Maleko *et al.,* 2019). However, Napier grass remains a socio-economically important tropical grass species in demand for the livestock and biofuel industries (Bangprasit *et al.,* 2017). It has also become one of the chosen grasses to be grown by farmers worldwide due to its yield production and easy to plant and manage (Figure 1).

To date, many attempts have been taken to improve the growth performance and to produce better yield and quality through many interventions. Common strategies implemented worldwide include the genetic modifications that improve the grass varieties (Premaratne *et al*., 2006), intercropping with other plants for mutual benefits (Indriani *et al*., 2019), proper rate of nitrogen fertilization (Snijders *et al*., 2011), implementation of suitable harvesting time and cutting interval (Jagadeesh *et al.,* 2017), proper planting density and distant (Wijitphan *et al*., 2009), and proper use of several planting methods to increase plant yield (Mustaffer, 2019). However, it is important to note that seasonal and agro-climatic conditions also influence Napier grass production (Orodho, 2006; Sandhu *et al*., 2015). The yield and quality of Napier grass have improved significantly through these interventions, but the main challenge remains at producing cultivars that are highly adaptable to agro-climatic conditions within each country.

Figure 1. Cultivated Napier grass in Malaysia at several planting stages: (A) 2-weeks old Napier grass, (B) 4-weeks old Napier grass, (C) Harvesting of Napier grass at 9 weeks old, (D) Collecting the harvested Napier grass. Pictures courtesy of MARDI Technology Bulletin Vol. 16 (2019)

GENETIC MODIFICATIONS AND IMPROVEMENT

The indigenous or native species of grass in any tropical country are most adaptable, leading to higher rate of survival but relatively low yield (Halim *et al.,* 2013). Grasses that are introduced from other countries such as Napier grass, require time to adapt to the local environmental conditions. For example, in Malaysia, common Napier grass is the native species that is widely distributed across the country and well propagated. However, it lacks uniformity and is quite hard to manage in a proper farming system. This is because common Napier grows well in certain areas such as riverbank, swamp, and areas with stagnant water, where it is difficult to harvest for ruminant feed. Therefore, several cultivars of Napier grass were introduced into Malaysia from East Africa in the 1920's and Napier is currently the most popular fodder grass used in dairy and feedlot industries in Malaysia. Taiwan Napier, Red Napier, Uganda Napier, Indian Napier, and Dwarf Napier were among the cultivars that had been introduced into Malaysia and in fact, into many countries around the world (Halim *et al*., 2013). Most of these new or improved cultivars were generated through genetic interventions either by crossbreeding or inbreeding.

Plant hybridization is actually the process of crossbreeding between genetically non-similar parent plants to produce a set of offspring plant that has the characteristics of both parents, known as hybrid plant. In fact, Napier grass species have been cross-bred with other species within the family of Poaceae and genus *Pennisetum*. For example, hybrid Napier var. CO-3 is an interspecific cross-bred between *Pennisetum purpureum* X *Pennisetum americanum* (Cumbu PT 1697) that was developed by the Tamil Nadu Agricultural University in 1997 and was introduced to Sri Lanka in 1999 as a resourceful fodder grass. Due to its improved tillering and regeneration capacity, the forage could yield between 250 and 350 tonnes/ha/year under local conditions in Sri Lanka, besides having high crude protein content and leaf to stem ratio, and quite resistant to pests and diseases (Premaratne *et al*., 2006). Later, the CO-4 hybrid variety was developed by interspecific crossing of *Pennisetum purpureum* (FD 461) X *Pennisetum glaucum* (Cumbu CO-8) or known as Bajra Fodder, producing more bio-mass at around 400 tonnes/ha/year than the CO-3 and other varieties of hybrid Napier grass (Kumar *et al.,* 2016).

King Grass, a hybrid of *Pennisetum purpureum* X *Pennisetum typhoides* was introduced into Malaysia in the early 1990's and has demonstrated faster growth rate but has lower crude protein and higher acid detergent fiber (ADF) contents. Due to its fast-growing characteristic, more nitrogen fertilization is required and it tends to become more fibrous at an earlier age (Halim *et al.,* 2013). A hybrid Napier grass, developed by the Department of Livestock Development in Pakchong, Nakhon Ratchasima province, Thailand is called Napier Pakchong 1. It is a cross between *Pennisetum purpureum* X *Pennisetum glaucum*, which results in high yield and fast growth that might reach over 3 meters tall in less than 2 months. It also has higher protein content (average 16 % to 18 %), wide range of adaptation, and longer lifespan of up to 8 years. However, Napier Pakchong 1 is ideally suited to a tropical climate of hot and humid such as Thailand, but may not perform its best potential in cold and dry lands such as the southern foothills of Bhutan (Wangchuk *et al.,* 2015). According to Rivashaa Agrotech Biopharma Private Limited, the newer hybrid of Napier grass is the Napier CO-5, an interspecific hybrid between *Pennisetum purpureum Schumach* (FD 437) X *Pennisetum glaucum* (Cumbu IP 20594). Yields of CO-5 ranged between 395 to 408 tonnes/ha/year. This CO-5 hybrid is produced to specifically target for use in the dairy industry as it has high nutritive value, succulent green leaves and shoots, drought resistant, and fast-growing characteristics.

There is no doubt that many newer hybrids or cultivars of Napier grass will be produced in different countries in the near future. However, these new cultivars need to be adapted well in the agro-climatic condition of the country in order to express their true potential. With proper management and irrigation of the pasture system, it is believed that every cultivar planted would produce their best along with their special characteristics.

INTERCROPPING WITH OTHER PLANTS

One of the strategies of enhancing Napier grass production and quality that is being widely studied is intercropping with other plants such as legumes and crop plants (Astuti *et al.,* 2019). Legumes such as *Desmodium* spp., *Stylosanthes* spp., *Macrotyloma* spp., *Leucaena* spp., *Gliricida* spp., *Hibiscus* spp., *Cajanus* spp., *Psopocarpus* spp., and *Centrosema* spp. are among the legume plants being intercropped with Napier grass. The main target of intercropping is to increase productivity while enhancing soil fertility and ensuring an efficient use of available nutrient resources through Nitrogen (N) fixation microorganism within the soil and able to reduce consumption of higher N-sourced fertilizers. This provides greater total yield stability as compared to single plant or monoculture. Crop plants such as maize and wheat are also being studied for synergistic effect with Napier grass. It has been shown that intercropping dwarf Napier grass with legume, *Centrosema pubescens* significantly affect the plant height, leaf area, tiller numbers, leaf and stem dry matters, and crude protein yield (Indriani *et al.,* 2019). This is because the nitrogen-producing legumes produce more nitrogen within the soil through the mutualistic bacterium, while the Rhizobium that is present in the root nodules acts as fertilizer in improving growth.

Formation of leaves, stems and roots require high N intake (Rahman *et al.,* 2016) thus, intercropping Napier grass with legumes ensures continuous supply of nitrogen within the soil. Therefore, intercropping Napier grass with legume enhances the grass quality due to the availability of nitrogen, which is generally more productive than single plant. The more nitrogen being supplied to the plant, the higher the crude protein content in the grass. Similarly, incorporating *Gliricidia* spp., *Psopocarpus* spp*.,* and *Hibiscus* spp. within alley at 5-meter distance in the Napier grass production system is the best model of intercropping Napier grass with a leguminous tree. The distance provides the best available nutrient to the Napier grass without impairing the leguminous rooting system and facilitates the soil sharing nutrient between the crops and at the same time, able to conserve the soil moisture. Increasing width of alley between intercropping plants resulted in decreased dry matter, crude protein, and crude fiber production for both plants (Sutarno *et al.,* 2017). A study revealed that plant height, leaf area, and dry matter weight yield of dwarf Napier grass cv Mott were increased to optimum level when being intercropped with Siratro legume (*Macroptilium atropurpureum*) at the rate of 30 % within a plot of 4 m x 4 m. Biological nitrogen fixation (BNF) that occurs within root nodule of leguminous plant such as *Macroptilium* spp. in symbiosis of nitrogen-fixing bacteria contributes significantly to the nitrogen requirement of the pasture to boost the growth and quality of the pasture.

On the other hand, Napier grass and *Desmodium* spp. were also planted together within lines of maize and wheat crops to protect the maize and wheat from large grain borer and spotted stem borer, as well as to prevent growth of Striga weed or witchweed. According to the International Centre of Insect Physiology and Ecology, headquartered in Nairobi, Kenya, stem borers are responsible for up to 40 % loss of cereal harvest. They lay their eggs while larvae feed on cobs, enhancing susceptibility of maize to storage mold. The molds are able to produce aflatoxin, which is hazardous for human consumption. Napier grass for instance, acts as a repellent plant by inhibiting the development of stem borer larvae from eggs thus, protecting the maize plant. Although this arrangement is not improving Napier grass yield, the intercropping provides both Napier grass and maize stalk to be utilized as fodder for ruminants. At the same time, intercropping the grass and legumes also discourages the abusive use of inorganic fertilizers.

It seems that the intercropping system not only benefits the pasture, but significantly benefits both plants. For example, incorporating dwarf Napier grass with jumbo grass (*Sorghum bicolor*), khesari (*Lathyrus sativus*), and *Splendida* spp. resulted in a significant increase in production and yield of all intercropping plants as compared to single culture of every plant (Rahman *et al.,* 2015). Napier grass recorded higher increase in yield when planted together with *Leucaena* spp., better than being grown solely or grown a distance away from each other. Maximum dry matter yield of 41.5 tonnes/ha of dwarf Napier grass was recorded when intercropped with *Leucaena* spp.*,* indicating that intercropping Napier grass with other plant provides a mutual benefit in terms of growth performance and yield for both plants (Tudsri *et al.,* 2002).

NITROGEN FERTILIZATION AND HARVESTING INTERVALS

There is no doubt that nitrogen fertilization resulted in higher yield for any grass. Nitrogen plays important roles for leafy plants to have better growth of leaf and stems. Therefore, supplying nitrogen fertilizer at an exact amount that a grass can tolerate, would result in optimal production (Astuti *et al*., 2019, 2020). Furthermore, for Napier grass, longer harvesting intervals would result in higher yield (Table 2). The yield of Napier grass is significantly increased by harvesting at longer intervals while providing the grass with 40 to 80 kg N/ha/harvest. Crude fiber percentage is significantly increased to 32.7 % when harvesting interval is more than 60 days. Similarly, crude protein and total ash contents per dry matter weight is decreased with longer harvesting intervals at 6.4 % and 14.6 %, respectively. These findings are supported by Lestari *et al*. (2018) who stated that defoliation intervals at longer duration significantly influenced the growth characteristic and quality of Napier grass in terms of height, numbers of leaf and tiller formation, leaf area, yield, and ADF content, while the crude protein would have decreased.

Longer harvesting intervals also provide opportunity for the grass to form more tillers as it aged, thus producing higher yield. This is due to the carbohydrate reserve that is translocated to the stem base or roots, and later used to form new tillers to sustain growth. Shorter harvesting intervals, on the other hand, resulted in lack of time for the grass to gather carbohydrate reserves for its growth activities. Therefore, farmers should consider the right harvest intervals without impairment to grass yield and nutrient composition. For example, the yield of green fodder and dry matter (DM) for Napier grass harvested at 30 to 60 days of growth ranged between 274.68 and 387.95 tonnes/ha and between 47.35 and 98.81 tonnes/ha, respectively whereas the crude protein ranged between 7.44 % and 11.45 % (Jagadeesh *et al.,* 2017). Taiwan Napier grass produces crude protein between 10.67 % and 6.31 % when harvested at 56-days and 84-days intervals, respectively (Budiman *et al.,* 2012). In contrast, Lestari *et al.* (2018) noted that the crude protein percentage of Taiwan Napier grass was 12.54 % and 13.27 % when harvested at 45 and 90 days, respectively. This might be attributed to the differences in the soil fertility and the climatic conditions of both experiments. In fact, Taiwan Napier grass is a high-quality forage, producing good yield with crude protein contents of 13 % to 15 % under a good pasture fodder production system.

Table 2. Dry matter yield (tonnes/ha) for various Pennisetum purpureum at different cutting age

Author	Country	Varieties / Cultivars	Harvesting Interval (d) / Biomass Production (DM tonne/ha)			
Man & Wiktorsson (2003)	Vietnam	P. purpureum	28d 3.98	42d 5.36	56d 7.76	70d 10.25
Budiman et al., (2012)	Indonesia	Taiwan King Mott	56d 1.10 0.98 0.06	84d 3.70 3.21 1.76		
Zailan et al., (2016)	Malaysia	Common Silver Red Dwarf	28d 0.79 0.94 1.06 0.80	42d 5.69 3.27 2.66 2.85	56d 6.00 3.89 6.09 3.87	
Haryani et al., (2018)	Malaysia	 3rd Generation India Kobe Red Taiwan Zanzibar	35d 3.73 2.96 3.62 2.90 3.43 3.31	42d 4.53 4.74 4.12 4.06 4.41 3.41		

*Adopted and extracted from various study by different authors regarding the relation of harvesting intervals on dry matter yield of Napier grass.

A 60-day harvesting interval under an optimum growing season was able to maintain high yield of Napier grass without compromising its nutrient composition (Wangchuk *et al.,* 2015). A study by Tudsri *et al*. (2002) on three grass species namely the Ruzi grass (*Brachiaria ruziziensis*), dwarf Napier (*Pennisetum purpureum* cv. Mott), and Taiwan A25 (*Pennisetum purpureum cv.* Taiwan) showed a marked increase in yield following longer cutting frequency, resulting in higher average dry matter yield. However, for a humid tropical country like Malaysia, harvesting of the various Napier grass at 35-day intervals proved most suitable in terms of yield and nutritive value (Haryani *et al*., 2018). It is important to note that maximum average yield is dependent on the weather, particularly on the rainfall distribution, temperature, and season on the irrigation system and on the optimum amount of fertilizer provided to the grass. In general, the trend of increasing yield with longer harvesting time is negatively correlated with dry period and cool season. This is mainly due to restrictions of water intake during the dry period and low sunlight during the cool season.

Nitrogen, supplied by both inorganic fertilizer and organic manure and from leguminous plant are necessary to ensure growth. A study by Snijders *et al*. (2011) concluded that incorporation of cattle manure together with applied fertilizer into the Napier grass production system improves nitrogen utilization, and integrating with *Desmodium intortum* provides better yield and higher protein content in Napier grass. On average, Napier grass with minimum supply of N fertilizer either by inorganic or organic fertilizer produces approximately 1 % or higher crude protein content as compared to Napier grass without the supply of N fertilizer. However, crude protein content and yield of the grass increased above average when manure or applied fertilizer N were incorporated within the soil as compared to surface application. This is due to the efficient uptake of N by the roots following in-soil rather than on-soil application. In addition, during the dry season, the availability of surface N fertilizer for the roots is much slower, affecting overall growth of the grass. A study by Umpuch *et al*. (2013) stated that a longer harvesting interval is needed to improve yield and fiber content. For example, in Thailand, tall Napier from Tifton cultivars was able to produce the highest annual biomass yield of 58.3 t/ha when left to grow until 3 months old.

SEASONAL VARIATION AND AGRO-CLIMATIC CONDITIONS

It is a well-known fact that seasons and climatic conditions have major effects on crop yield. In most instances, climatic conditions are believed to be beyond our control. For example, shortage of feed supply has been reported during dry season in Africa and during monsoon season in Southeast Asia that led to poor farming. Small holder farmers, in particular, need to set up their own intensive forage management system by efficient use of land for pasture and store animal feed to be used during adverse seasons (Wijitphan *et al*., 2009). To do this, they must have knowledge regarding the seasonal variations and agro-climatic conditions within their surrounding farms. According to Gezahagn *et al.* (2016), production and yield of Napier grass vary greatly depending on many factors including genotypic, environment and interactions between the two. Environmental conditions affect approximately 40.6 % of Napier grass production, making it critical for farmers to know when is the right time to start planting and later to harvest their grass. Most studies found that Napier grass performs better during wet or rainy season, resulting in higher yield, which could be attained with or without the supply of nitrogen fertilizer. However, during the dry season, the availability of good quality forage is limited when pastures such as Napier show stunted and slow growth with impaired nutrient compositions. Eventually, interventions such as proper irrigation to supply water could improve yields. Similarly, Napier grass is known to grow well on clay or sandy loam but yield of Napier grass varieties vary between seasons with the highest yield in wet season and lowest in the dry season (Umpuch *et al.,* 2013).

Needless to say, Napier grass grows best in the area with high and well-distributed rainfall of more than 1,000 mm per annum, with good soil fertility. However, it cannot tolerate flooding or waterlogging (Orodho, 2006; Sandhu *et al.,* 2015). Therefore, changes in temperature and rainfall distribution would have a significant impact on crop production and yield, even though improved grass varieties are being used. A special characteristic of Napier grass that is favored by most farmers is its ability to withstand moderate dry season for up to 4 months due to its deep rooting system. Napier grass grows well at altitudes below 2,100 meters above sea level. Higher altitude results in slow growth due to the low temperature since the optimal temperature for growth of Napier grass ranged between 25 ^{0}C and 40 ^{0}C, and it ceases to grow when temperatures fall below 10 ^{0}C. Furthermore, tall varieties of Napier grass could not withstand the frost compared to the shorter type or dwarf varieties. It is estimated that the productivity would decrease between 50 % and 65 % during dry season as compared to normal seasons (Sandhu *et al., 2015*). Thus, systematic workflow for Napier growth should be formulated by farmers not only to assess the adaptability of the Napier grass varieties to the local environment, but also to implement the necessary precautions to ensure productivity. It is strongly suggested that farmers identify the periods of high and low yield so that the harvests of the high-yield period of the rainy season could be stored either in the form of hay or silage for use during the low-yield period of dry season.

PLANT DENSITY AND METHOD OF PLANTING

Selection of good Napier variety and ensuring good soil fertility using N fertilizer are not enough to achieve optimum yield of Napier grass. Proper methods of planting, planting density, and planting distance are necessary to ensure optimum growth and yield of grass, and easy handling during harvesting time. Most smallholder farmers harvest Napier grass manually using a long knife or machete while others use brush cutter to cut and collect Napier grass. On the other hand, commercial dairy or feedlot farming harvest mechanically. Therefore, proper method of planting is needed to ensure easy machine planting, weeding, fertilizing, and later harvesting. There must be acceptable distance between ridges of Napier grass that could accommodate the machinery. A study by Wijitphan *et al.* (2009) on the effects of plant distance on total dry matter revealed that highest total dry matter yield of 70.84 tonnes/ha was obtained with a 50 cm x 40 cm planting configuration. However, plant spacing has no significant effect on overall nutritive value of Napier grass except for the Neutral Detergent Fiber (NDF), which ranged between 66.9 % and 68.2 %. This is due to the tendency for Napier grass to grow well in wider area that enables it to form broader leaf to get enough sunlight for photosynthesis and carbohydrate formation. In a large production system that uses machine harvester, farmers tend to use planting configuration of 1 meter between rows and 0.5 meter within rows, resulting in density of 20,000 planting stems per hectare land. This configuration is able to ease the machine harvesting and facilitates higher regeneration capacity and formation of new tiller.

There are several methods of planting Napier grass. Three conventional methods of planting have been described by Mustaffer (2019), which include line-furrow planting, clumps-in pit planting, and 45 ^{0} angle-planting (Figure 2). These planting techniques have been associated with growth performance and yield of the Napier grass and it was concluded that line-furrow planting is superior in enhancing the yield for up to 46 tonnes/ha. In line-furrow planting, Napier stems are embedding in lines for new tillers to grow from every node along the stems. The 45 ^{0} angle-planting allows the nodes to dry up and impairs tiller formation, resulting in slower growth rate while clumps in pit planting is a collection of 3 to 4 stems planted together in order to make the Napier grass grow in clumps. In countries with long drought seasons, the Tumbukiza method has successfully increased the yield of Napier grass and prolonged the survival rate of Napier grass. Tumbukiza method is the technique where planting of grass is performed in round or rectangular pits of 60 cm – 90 cm wide and 60 cm – 90 cm deep, filled with a mixture of topsoil and manure at the ratio of 1:2 (Orodho, 2006). This method enables the conservation of soil moisture within the pits for a longer period and the manure supplies nutrients for the Napier grass, resulting in higher forage survival and yield per unit area of land, even within areas with low rainfall distribution or dry land. Furthermore, the deep rooting system of Napier grass assists in the survival of the grass the whole year round and ensures the availability of feed supply to the animal during dry season.

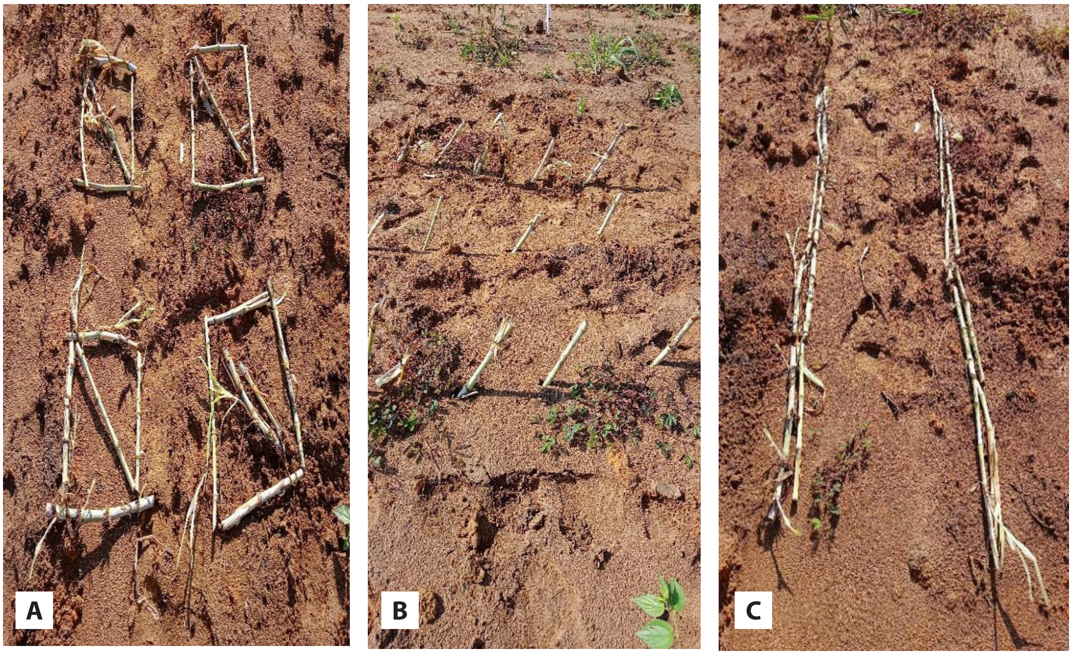

Figure 2. Planting methods of *Pennisetum purpureum*; (A) Line furrow planting, (B) 45° angle planting, (C) Clumps in pit

CONCLUSION

Overall performance and yield of Napier grass were determined mostly by proper management systems performed by farmers. Starting from selecting the Napier grass varieties to be planted to the techniques of planting being implanted together with suitable plant density and distance, good fertilizer management and irrigation, supported by good seasonal or environmental condition, and proper cutting intervals influence the growth, yields, nutrient composition, and long-term performance of Napier grass.

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