International Journal on Food, Agriculture, and Natural Resources
Volume 7, Issue 2, Page 68-79
ISSN: 2722-4066
http://www.fanres.org

Original Paper

Optimizing Harvest Timing and Desmodium Intercropping to Enhance Napier Grass Productivity and Competitiveness

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Received: 08 April 2026; Revised: 29 June 2026; Accepted: 29 June 2026
DOI: *https://doi.org/10.46676/ij-fanres.v7i2.645*

Abstract*—The study was performed at two trial sites of Sirinka Agricultural Research Centre, Sirinka and Jari to evaluate the agronomic trait, herbage yield, and competitive indices potential of Napier grass (Pennisetum purpureum Schumach) intercropped with Desmodium species at different days of harvesting in the mid-land agro-ecology. A randomized complete block design was employed in the arrangement of a five × three factorial basis with treatments including pure stands of Napier grass, Desmodium uncinatum, Desmodium intortum, and their intercropping's, assessed at three harvesting days (60, 90, and 120 days). The collected data encompassed agronomic traits (height of the plant, leaf length, number of leaves and tillers per plant, leaf-to-stem ratio), yield related parameters and competitive indices measures. Results showed that all agronomic characteristics significantly differed ($p<0.05$) due to the effect of harvesting days and planting regimes, with most parameters improving as harvesting was delayed (120 days), except leaf-to-stem ratio. Intercropping Napier grass with Desmodium significantly increased dry matter yield and crude protein yield compared with sole Napier grass ($p<0.05$). Competitive indices, including partial land equivalent ratio, total land equivalent ratio, and area time equivalent ratio, were highest when Napier grass was intercropped with Desmodium intortum and harvested at 120 days. Harvesting at 60 days produced forage with higher crude protein concentration but lower biomass, limiting overall productivity. In contrast, harvesting at 120 days maximized biomass yield but reduced forage quality due to lower crude protein concentration, particularly in sole Napier grass and Napier grass intercropped with Desmodium uncinatum. Harvesting at 90 days provided the best balance between forage yield and nutritive value. Therefore, the study concludes that intercropping Napier grass with Desmodium intortum at 90 days of harvesting enhances growth performance, yield and competitive indices measures, making it a promising strategy for improving livestock feed availability in the region and suggested for the study area and comparable agro ecological regions.

Keywords*—Competitive indices, Dry matter yield, Days of harvesting, Napier grass, planting regimes

I. INTRODUCTION

Ethiopia has been an entry point for domestic animals from Asia to Africa and its varied ecosystems have facilitated the proliferation and diversification of these valuable resources. Regarding livestock population, Ethiopia stands first in Africa and fifth in globally [1]. Nevertheless, Sub-Saharan Africa's cattle industry, and Ethiopia's in particular, has a number of difficulties. Throughout the country, livestock productivity has been primarily impacted by inadequate availability and quality animal feed, particularly during the dry season. In systems that combine crops and livestock, one of the biggest obstacles to animal productivity is the availability and quality of feed [2], [3], [4].

In addition to decreasing ruminant energy utilization, the imbalance in dry matter and vital nutrients has led to decrease livestock output and an increase in methane emission from enteric fermentation, which also contributes to global warming [5]. The recognition of utilizing high-quality and climate-resilient forage species has gained significant attention as a solution to address this issue in tropical regions [6], including Ethiopia where integrating improved forage species at the household level in a sustainable way can improve the production of livestock [7], [8]. Additionally, to enhance the milk production and growth performance of animals, it is essential to incorporate and develop superior quality forages that have a significant output capability [9]. Furthermore, to address the yield constraints of existing feed resources, adopting strategies such as enhanced forage development through intercropping can be highly effective. Intercropping is a versatile forage production system that offers improved production outcomes compared to growing grasses in monoculture [10].

Napier grass is a preferred forage option not only in tropical regions but also globally, because of its favourable characteristics, including drought tolerance, adaptability to various soil types, and high efficiency in photosynthesis and water use [11]. This tall, deep-rooted perennial bunch grass is renowned for its substantial yield potential and is primarily utilized in cut-and-carry feeding systems [12]. It can be easily propagated through vegetative methods such as stem cuttings, root splits, or shoot tips [13], with propagation techniques often differing across agro-ecological zones [14]. Numerous studies showed that days of harvesting can affect both the

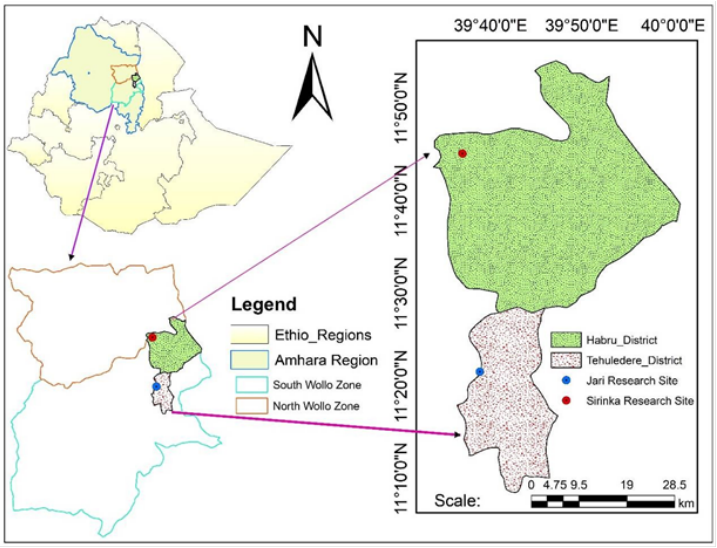


Fig. 1. Location map of the experimental areas

yield and nutritional quality of grass [15], [16], [17]. However, there is limited and debated scientific evidence regarding the ideal days of harvesting of Napier grass and the impact of legume intercropping such as Desmodium on the overall growth parameters, yield and competitive indices potential of this grass. Therefore, this research was focused to assess the influence of harvesting days on growth parameters, yield and competitive indices potential of Napier grass (Pennisetum purpureum Schumach) intercropped with Desmodium species and to suggest the ideal harvesting days and Desmodium forages that maximize growth characteristics and herbage yield for livestock producers.

II. Research Methods

A. Description of the Experimental Site and Climate Condition

The study was carried out during the main cropping season under rain-fed conditions (July to December 2023) at two experimental sites belonging to Sirinka Agricultural Research Center (SARC): Sirinka site in the vicinity of the center and Jari site located to the south in one of the sub-centers (Fig.1). Sirinka lies at an altitude of 1850 meters above sea level (masl) with 11˚45’00”N latitude and 39˚36’36”E longitude. The sub-center (Jari site) is located at an altitude of 1680 masl with situated at 11°21’00’’N latitude and 39°38’00’’E longitude. The farming system of the study areas is characterized by a combination of crop and livestock production system. The climate conditions in both locations during the experimental period are illustrated in Fig.2. Sirinka experience a mean annual rainfall of 931 mm. The area experiences a mid to warm climate, with average daily temperatures typically falling between 13.5 and 26.7oC. The sub centre Jari experiences a mean annual rainfall of 990 mm and has average daily temperature of ranges 13.4 to 28.3^{0}C.

B. Experimental Design, Treatments, and Planting

Napier grass variety (ILRI- 14984) was employed as test forage for this experiment during the main rainy season. The experiment was laid in a randomized complete block design (RCBD) with three replications in a factorial arrangement. The treatment combination consists of five level of planting regimes (sole Napier grass (sole NG), sole Desmodium uncinatum (sole DU), sole Desmodium intortum (sole DI), Napier grass intercropped with Desmodium uncinatum (NGDU), and Napier grass intercropped with Desmodium intortum (NGDI) and three level of harvesting days (60, 90, and 120 days of maturity after planting the forages). The experiment’s overall area, divided into three replications, was 15 m × 59 m (885 m2) at each trial site. The dimensions of each plot were 4 m × 3 m (12 m2). Thus, each replication had 15 treatment combinations laid per block on the 15 plots randomly, resulting in 45 total numbers of plots or observations for each parameter considered during the experimental period. The space among consecutive plots and replications (blocks) was 1 and 1.5 m, respectively. Napier grass root splits were planted in well-prepared soil under rain-fed conditions for introduction and the material was planted at an angle of about 30°-45° [18]. When planting forages in both pure and mixed stands, Napier grass was planted in plots consisting of 4 rows, with a spacing of 1 meter between consecutive rows and 0.5 meters between individual plants within each row. In the grass-legume mixed stand (intercropping), the Napier grass root split was first planted in each plot as described for the pure stand, followed by drilling either of the legumes between the Napier grass rows, which resulted in 7 rows per plot with 3 of the rows belonging to the legume and the space between rows of elephant grass and the intercropped legumes was 0.5 m. There were 24 plants planted on plots assigned for Napier grass in both planting regimes, with 6 plants per row. In both the mono and intercropped plots, each legume forage was manually drilled at a seed rate of 10 kg ha-1. Weeds were manually removed every two weeks leading up to the final harvest to prevent regrowth and encourage fodder regrowth by enhancing soil aeration through the removal of dry roots.

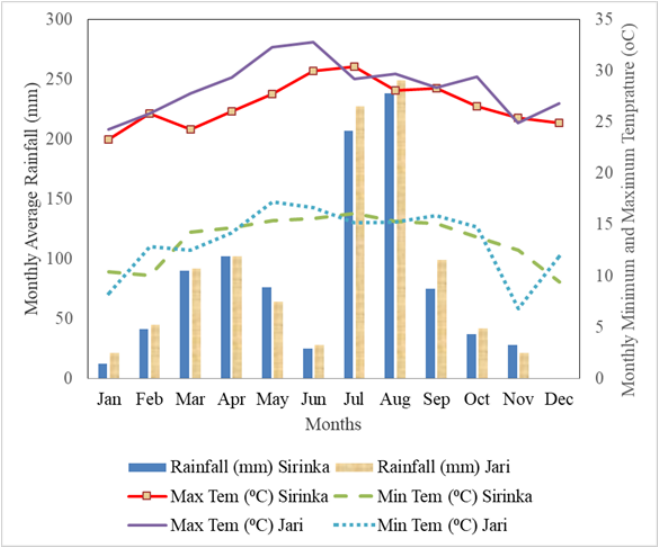


Fig. 2. The distribution of mean monthly rainfall, along with maximum and minimum temperatures, for the stud

III. Data Collection

A. Soil Sample Collection and Analysis

Composite soil samples were collected in an X-fashion pattern from 0-20 cm depth before planting from the entire experimental area. In addition, soil samples were collected after each harvest from each experimental plot at the same depth using an auger [19]. The collected soil samples were mixed at treatment based, air-dried, ground, and sieved with a 2 mm diameter screen to analyse soil pH, available phosphorus, and cation exchange capacity (CEC). In addition, soil samples were further passed in a 0.5 mm sieve to determine soil organic carbon (SOC) and total nitrogen (TN). The particle size distribution was analysed with the Hydrometer technique [20]. Soil pH was determined using a digital PHS-3E pH meter in 1:2.5 soil-water extract (Van Reeuwijk, 2002). Total nitrogen (TN) was analysed by micro-Kjeldahl method [21]. Soil organic carbon was determined using the wet digestion method [21]. Available phosphorus (AP) was analysed using the NaHCO3 extraction method [22]. Cation exchange capacity (CEC) was analysed by ammonium acetate.

B. Agronomic Parameters

Agronomic traits recorded at each harvest included plant height (PH), total number of leaves per plant (TNLPP), number of tillers per plant (NTPP), number of leaves per tiller (NLPT), leaf length per plant (LLPP), and leaf-to-stem ratio (LSR). For TNLPP, NTPP, and NLPT, data were obtained from ten randomly selected plants per plot, excluding border rows, and averaged for analysis. Plant height measurements were taken on 10 randomly selected plants just before biomass harvest at each day of harvesting. On the harvest date, it was measured as the distance from the soil surface to the highest point (tip) of each plant. The leaf length per plant of Napier grass was assessed from the base of the collar region to the tip of the leaf. This measurement was taken in ten randomly selected plants at each day of harvesting, and the average length was calculated. The biomass fractions of the stem and leaf (including the leaf blade and leaf sheath) were manually separated to calculate the leaf-to-stem ratio. Each leaf and stem sample was air-dried for three days until a constant weight was achieved, after which the leaf-to-stem ratio was calculated by dividing the dry weight of the leaves by the dry weight of the stems [23].

C. Soil Sample Collection and Analysis

Forage yield was determined by harvesting from the two central rows of each plot, cutting at 8 cm above ground level on the designated harvest dates. The fresh herbage weight of Napier grass was recorded immediately after harvest using a field spring balance. A 500 g subsample was then taken from each plot with a portable balance (accuracy ±0.01 g) to estimate dry matter yield. The subsamples were oven-dried at 65 °C for 72 hours and reweighed to determine dry matter content. Dry matter yield (DMY) was subsequently calculated according to the standard formula described in [24]:

$$DMY\left(\frac{t}{ha}\right) = 10\ x\ TFW\ x\ \left(\frac{DWss}{HA\ x\ FWss}\right) \quad (1)$$

Where, TFW represents the total fresh weight from the plots in kilograms; DWss represents dry weight of the sample in grams; FWss represents fresh weight of the sample in grams, HA represents harvest area in square meters, and 10 is a constant used to convert yields from kg/m² to t/ha. The total dry matter yield (TDMY) of intercropped Napier grass and Desmodium species was determined as the sum of the dry matter yields of Napier grass and Desmodium obtained from the intercropping system, while the dry matter yields of the respective sole-cropped treatments were considered constant reference values.

$$CPY\left(\frac{t}{ha}\right) = DMY\ Napier + DMY\ Desmodium \quad (2)$$

To determine the crude protein yield (CPY), the dry matter yield (DMY) was multiplied by % CP of the feed samples using the following formula:

$$CPY\ \left(\frac{t}{ha}\right) = DMY\ \left(\frac{t}{ha}\right)\ x\ \frac{\%CP}{100} \tag{3}$$

Where, DMY (t/ha) dry matter yield in tons per hectare and % CP crude protein content of the forages.

D. Soil Sample Collection and Analysis

The competitive indices of Napier grass intercropped with Desmodium species were assessed through land equivalent ratio (LER), land equivalent coefficient (LEC), area time equivalent ratio (ATER), and land use efficiency (LUE). The Land Equivalent Ratio (LER) for the intercropped plots is calculated for each forage component by summing the estimated totals of the two varieties, with the LER of the sole crop considered as one [25]. Generally, a LER value of 1.0 indicates no difference in herbage biomass yield whether the forages planted by intercropping or as sole/pure stand; a value >1.0 indicates a more herbage biomass yield advantage for the intercrop practice; and, a LER value <1.0 indicates a disadvantage for the intercrop. The land equivalent ratio (LER) was determined using the following formula [26], [27]:

$$LER = \frac{YGi}{YG} + \frac{YDi}{YD}\ or\ LER\ of\ grass\ (LERG) + LER\ of\ Desmodium\ (LERD) \tag{4}$$

Where, YGi and YDi are intercropped DMY, and YG and YD are sole DMY of grass and Desmodium, respectively.

$$LER = \frac{YGi}{YG}\ x\ \frac{YDi}{YD} \tag{5}$$

values > 0.25 indicate yield advantage [28]. For two-forage mixtures, the minimum expected productivity coefficient (PC) is 25% and a yield advantage is obtained if LEC exceeds 0.25.

ATER was used to compare the yield advantage of cultivated forages under intercropping to mono-cropping by taking into consideration the time taken by the component crops under intercropping systems in the field from planting to harvesting [29], [30].

$$ATER = \frac{((LERG\ x\ tg) + (LERD\ x\ td))}{T} \tag{6}$$

Where, tg and td are the number of days needed for grass and Desmodium species to develop from planting to maturity, respectively. T is the intercropping system's overall duration. The total area–time equivalent ratio (TATER) was calculated as the sum of the ATER values of Napier grass and Desmodium species in the intercrop, with sole-cropped treatments serving as constant references.

$$TATER = ATERG + ATERD \tag{7}$$

On the other hand, LUE was computed as indicated by [31] and [32].

$$LUE\ (\%) = \left(LER + \frac{ATER}{2}\right)\ x\ 100\% \tag{8}$$

IV. Statistical Analysis

Analysis of Variance (ANOVA) was performed on all data gathered throughout the experimental period, and Duncan's multiple range tests were used to differentiate the treatment means at a 5% level of significance using the statistical analysis system (SAS, version 9.1) software. Using the following mathematical model, the impact of every potential component was examined.

$$Yijk = \mu + Hi + Cj + Hi\ x\ Cj + Bk + eijk \tag{9}$$

Where, Yijk = dependent variable (plant agronomic parameters, yields and competitive indices potential) at each day of harvesting and planting regime, μ = overall mean, Hi= days of harvesting (i= 60, 90, and 120 days), Cj = planting regime effect (j = NG, NGDI, NGDU, DI, DU), Hi* Cj = the interaction effect of days of harvesting and planting regime, Bk = the kth block effect, eijk = residual error.

V. Statistical Analysis

A. Physicochemical Properties of Soil

The results of the soil physicochemical analysis conducted before planting and after harvesting Napier grass and Desmodium species are presented in Table 1. Although the variations observed in soil parameters such as pH, AP, TN, OC, and CEC were not statistically compared, but they provide valuable insight into the general nutrient status of the soil both before and after the forage crops were cultivated. The soil at the study site in Sirinka consisted of 26% sand, 35% silt, and 39% clay, while at Jari, the proportions were 29% sand, 31% silt, and 40% clay. Based on the soil texture classification the soils at both sites were classified as clay loam [33].

The pH levels of the composite soil samples taken before planting were 6.7 at the Sirinka site and 6.8 at the Jari site, indicating neutral soil conditions [34]. According to FAO (2010), the optimal pH range for highly productive soils is between 4.5 and 8. The pH levels measured in the composite soil samples from both experimental sites fall within this ideal range, indicating the soils are well-suited for productivity. After harvesting, the soil pH showed slight variations, either increasing or decreasing from the initial levels, depending on the specific treatment combinations applied. These minor fluctuations in pH may be due to the high organic matter content in the soil, which influences pH levels. In the current

study, the pH levels of all treatments fell within the neutral range [34].

The OC content of the composite soil samples before planting (CSBP) was 2.79% at Sirinka, and 2.66% at Jari site. This result indicated that the soil of the experimental site was medium in OC as rated by [35], and [34]. The OC content of the soil was higher for soil samples taken after harvesting as compared to the composite soil sample before planting at both experimental sites. The AP levels were measured at 8.65 ppm for the Sirinka experimental site and 9.28 ppm for the Jari site before the forages were planted, both of which are considered low based on the classification that categorizes a relative range of extractable phosphorous of 0.5 ppm, 6-10 ppm, 11-15 ppm, 16-20 ppm, and 21-25 ppm as very low, low, medium, high, and very high, respectively [36]. The AP content of the soil samples collected from all treatment plots after forage harvesting at both sites was classified as low to medium level based on the ratings made by [36]. The AP after harvesting was higher than the AP before planting, probably due to the decomposition of organic matter, which releases nutrients, including phosphorus, into the soil. The AP value of sole Desmodium species harvested at 120 days was higher, followed by intercropped treatments at the same stage of harvesting while a lower value was obtained in sole Napier grass at 60 days of harvesting. This might be due to Desmodium species generally having a vigorous growth rate and extensive root systems and at 120 days, they may have established significant biomass, leading to higher phosphorus availability through root exudation and organic matter contributions. In contrast, sole Napier grass may not reach similar phosphorus mobilization levels within the same timeframe. At 60 days of maturity, it may still be in its early growth stages, resulting in lower nutrient uptake and availability. The current result agreed with the result of [37], who reported that including legumes in crop rotation increases the phosphorus availability to the succeeding crop due to their deep roots.

The TN content of the soil before planting was 0.12% at Sirinka and 0.19% at Jari. According to [34], these values indicate that the soils at both experimental sites had moderate TN levels. Following harvesting, the TN content ranged from 0.12% to 0.23% at Sirinka and from 0.13% to 0.25% at Jari. Based on the same classification, these post-harvest TN values also fall within the medium range, suggesting that the intercropping treatments and harvesting stages maintained or slightly improved the soil nitrogen status.The TN content of the soil after harvest was higher than that of the pre-planting composite soil samples in all treatment groups except the sole Napier grass harvested at 60 days (T1). The observed increase in TN is likely associated with the contribution of the intercropped legume species through biological nitrogen fixation and the subsequent addition of nitrogen-rich plant residues to the soil. Similarly, [35] classified the soil total nitrogen content of less than 0.10% as low, 0.10-0.15% medium, 0.15-0.25% high, and greater than 0.25% very high. The CEC capacity of soil samples at each experimental site before forage planting and after forage harvesting was higher based on the ratings made by [38].

CS = Composite soil sample before planting, T1= Sole Napier grass harvested at 60 days, T2= Sole Napier grass harvested at 90 days, T3= Sole Napier grass harvested at 120 days, T4= Sole *Desmodium uncinatum* harvested at 60 days, T5= Sole *Desmodium uncinatum* harvested at 90 days, T6= Sole *Desmodium uncinatum* harvested at 120 days, T7= Sole *Desmodium intortum* harvested at 60 days, T8= Sole *Desmodium intortum* harvested at 90 days, T9= Sole *Desmodium intortum* harvested at 120 days, T10 = Napier grass intercropped with *Desmodium uncinatum* harvested at 60 days, T11= Napier grass intercropped with *Desmodium uncinatum* harvested at 90 days, T12= Napier grass intercropped with *Desmodium uncinatum* harvested at 120 days, T13= Napier grass intercropped with *Desmodium intortum* harvested at 60 days, T14= Napier grass intercropped with *Desmodium intortum* harvested at 90 days, T15= Napier grass intercropped with *Desmodium intortum* harvested at 120 days, PH= Power of Hydrogen, OC= Organic Carbon, Av.p= Available Phosphorus, TN= Total Nitrogen, CEC= Cation Exchange Capacity, ppm= Parts per million, g= gram, meq= milliequivalents

B. Physicochemical Properties of Soil

The combined ANOVA results for the effect of days of harvesting, planting regime, location and their interaction on the agronomic trait of Napier grass are summarized in Table 2. The results revealed that plant height (PH), total number of leaves per plant (TNLPP), number of tillers per plant (NTPP), number of leaves per tiller (NLPT), leaf length per plant (LLPP), and leaf-stem- ratio (LSR) were substantially influenced ($p<0.05$) by harvesting days, planting regime, and location. The interaction between harvesting days and planting regime significantly affects all the agronomic parameters ($p<0.05$). Additionally, the interaction effect between harvesting days and location significantly influenced growth parameters, except for NTPP and LLPP, which showed non-significant values ($p>0.05$). The relationship between planting regime and location was also significant ($p<0.05$), with the exception of NLPT, which was non-significant ($p>0.05$) variation. There were no noteworthy interactions among harvesting days, planting regime, and location for the measured agronomic variable. The influence of harvesting days and planting regime interaction was significant for the yield variables ($p<0.05$). Additionally, the relationship impact of planting regime and location significantly influenced the yield parameters. However, there were no significant interaction effects observed among harvesting days, planting regime, and location for the yield variable except the total crude protein yield (TCPY).

C. Agronomic Performance of Napier Grass and Desmodium Species

The interaction effect of harvesting days and planting regimes on the agronomic performance of Napier grass and desmodium species are presented in Table 3. A substantial variation ($p<0.05$) in plant height (PH) was observed with the highest PH (276.2 cm) for Napier grass intercropped with Desmodium intortum (NGDI) was recorded at 120 days of maturity, while the lowest (115.5 cm) occurred in sole Napier grass harvested at 60 days. PH increased progressively with

TABLE I. SOIL PHYSICOCHEMICAL PROPERTIES BEFORE PLANTING AND AFTER HARVESTING FORAGES AT SIRINKA AND JARI EXPERIMENTAL SITES

Treatment combinations	Sirinka					Jari				
	PH (1:2.5 H_20)	OC (%)	Av. P (ppm)	TN (%)	CEC (meq/100g soil)	PH (1:2.5 H_2O)	OC (%)	Av. P (ppm)	TN (%)	CEC (meq/100g soil)
CSBP	6.7	2.79	8.65	0.12	53.36	6.8	2.66	9.28	0.19	41.38
T1	6.5	2.87	6.11	0.12	64.38	6.5	2.67	10	0.13	60.84
T2	6.6	3.01	6.79	0. 13	63.33	6.6	2.68	10.03	0.18	42.21
T3	6.7	3.12	8.75	0.14	65.32	6.6	2.76	11.56	0.19	48.43
T4	6.6	4.34	10.87	0.18	66.56	6.8	2.91	11.75	0.19	64.64
T5	6.8	4.54	9.56	0.21	67.34	6.7	3.07	14.56	0.22	41.66
T6	6.9	4.62	12.56	0.23	62.54	7.3	3.93	14.78	0.25	62.61
T7	6.6	4.1	12.34	0.17	68.32	6.7	3.56	12.21	0.23	62.22
T8	6.5	4.21	11.67	0.21	67.12	6.8	4.08	13.67	0.24	48.91
T9	6.4	5.01	13.28	0.22	63.88	7.1	4.82	14.06	0.24	42.83
T10	6.5	4.19	9.64	0.14	50.72	6.8	2.92	11.97	0.19	62.62
T11	6.7	4.45	9.66	0.15	56.89	6.8	4.81	12.46	0.21	45.18
T12	6.6	4.51	10.78	0.17	60.84	6.9	4.93	14.89	0.22	47.12
T13	6.7	4.07	9.87	0.15	56.02	6.7	3.7	12.28	0.2	45.06
T14	6.9	4.24	9.56	0.16	55.72	6.9	4.64	13.74	0.21	52.04
T15	7.3	4.31	11.41	0.18	58.34	6.9	4.92	13.98	0.2	47.02

TABLE II. THE COMBINED MEAN SQUARE OF ANOVA FOR THE AGRONOMIC PARAMETERS AND YIELD OF NAPIER GRASS INTERCROPPED WITH DESMODIUM SPECIES AT DIFFERENT DAYS OF HARVESTING

Source of variation	DF	PH	TNLPP	NTPP	NLPT	LLPP	LSR	DMY	CPY	TDMY	TCPY
REP	2	1444.6^{ns}	968.7^{ns}	1.2^{ns}	0.28^{ns}	14.9^{ns}	0.1^{*}	3.9^{ns}	0.04^{ns}	3.35^{ns}	0.19^{ns}
HD	2	57013.4^{***}	149674^{***}	512.6^{***}	1648.3^{***}	507.8^{***}	1.8^{***}	183.9^{***}	0.9^{***}	231.9^{***}	1.46^{***}
PR	6	42226.1^{***}	74553.3^{***}	1153.7^{***}	230^{***}	10975.5^{***}	0.8^{***}	540.1^{***}	11.1^{***}	888^{***}	13.3^{***}
LO	1	3954.9^{**}	40906^{***}	557.7^{***}	2379.8^{***}	1296.6^{***}	2^{***}	27.6^{**}	0.79^{***}	126.4^{***}	8.7^{***}
HD*PR	12	3020.7^{***}	3935.9^{***}	16.9^{*}	33.7^{**}	106.2^{***}	0.2^{***}	23.5^{***}	0.13^{*}	33.6^{***}	0.12^{ns}
HD*LO	2	1853.1^{*}	31769.7^{***}	23.1^{ns}	315.4^{***}	4.6^{ns}	0.4^{***}	1.6^{ns}	0.17^{ns}	0.3^{ns}	0.31^{*}
PR*LO	6	4039.4^{***}	9356.1^{***}	45.8^{**}	17.8^{ns}	321.9^{***}	0.03^{ns}	21.3^{***}	2.7^{***}	34^{***}	2.87^{***}
HD*PR*LO	12	1258.6^{ns}	1486.2^{ns}	10.8^{ns}	25.3^{ns}	30^{ns}	0.1^{ns}	6.3^{ns}	0.11^{ns}	6.68^{ns}	0.14^{*}
Error	82	468.8	780.6	12.6	12.1	20.5	0.03	3.5	0.05	3.5	0.06

DF= Degree of freedom, PH = Plant height, TNLPP = Total number of leaves per plant, NTPP = Number of tillers per plant, NLPT = Number of leaves per tiller, LLPP = Leaf length per plant, LSR = Leaf to stem ratio, DMY = Dry matter yield, CPY = Crude protein yield, TDMY = Total dry matter yield, TCPY = Total crude protein yield, REP = Replication, HD = Harvesting days, PR = Planting regimes, LO = Location, ns = non-significant, *, **, and *** are statistically significant at probability levels of $p<0.05$, $p<0.01$ and $p<0.001$, respectively

maturity, likely due to enhanced root development and nutrient uptake over time. As plants mature, their roots might be grow deeper and spread out more extensively through the soil. This finding aligns with previous studies indicating that later harvesting results in taller PH of different grasses [39], [40], [41], [42] and [43]. The increase in height in the NGDI planting regime at 120 days may be attributed to Desmodium intortum's leafiness, deep rooting, nitrogen-fixing ability, and improving soil conditions. This was consistent with [44], which stated that higher Napier grasses were produced by the Pigeon Pea intercrop than by solitary Napier.

The TNLPP of Napier grass significantly ($p<0.05$) affected by the interaction effect of days of harvesting and planting regimes. The maximum TNLPP of Napier grass was recorded (389.7) when intercropped with Desmodium intortum at 120 days, followed by (338.3) with Desmodium uncinatum, and (302.9) for sole Napier grass. The increase in TNLPP with extended harvesting periods is linked to greater plant height, which promotes tiller and node development, leading to more leaves. This finding aligns with [45], who noted that higher TNLPP in Buffle grass was recorded at the later harvesting stages. Previous studies like [40], [46], [41], and [43], also reported an increase in leaf count with longer harvesting intervals. Napier grass intercropped with Desmodium species resulted in greater TNLPP than sole Napier grass. This can be explained by the synergistic effects of intercropping, where the combination of the two species enhances overall plant growth. The increased leaf production in intercropped Napier grass may be associated with the presence of Desmodium, which can improve soil fertility through biological nitrogen fixation and enhance nutrient availability, thereby promoting vegetative growth relative to sole Napier grass. The positive impact of intercropping with Desmodium species on Napier grass leaf production is further supported by [47].

There was a substantial interaction ($p<0.05$) between harvesting days and planting regime on the NTPP and NLPT of Napier grass. The highest NTPP values were recorded in the Napier with Desmodium uncinatum (NGDU) (33.1) and NGDI (31.9) regimes at 120 days, while the lowest NTPP were shown in sole Napier grass harvested in 60 days (13.5). Similarly, maximum NLPT was noted in NGDU (36.7) and NGDI (36) at 120 days. The rise in NTPP in the present finding with longer harvesting intervals agreed with [48], [49], [41] and [50]. The higher NTPP and NLPT in intercropped systems may be attributed to enhanced nitrogen fixation from legumes, promoting grass growth, consistent with [51], and [52].

The interaction between days of harvesting and planting regime had also a significant effect ($p<0.05$) on the LLPP

and LSR of Napier grass. The highest LLPP was recorded in Napier grass intercropped with Desmodium species and harvested at 120 days, whereas the lowest value was observed in sole Napier grass harvested at 60 days. According to [42], who observed that harvesting the grass late, after 135 days, resulted in longer LL, while harvesting early at 75 days led to shorter leaves, which aligns with the present study. Notably, Napier grass intercropped with Desmodium at 60 days of harvesting showed a higher LSR compared to sole Napier grass harvested at 90 and 120 days. The decline in LSR with plant age is attributed to leaf shedding and increased stem structural materials. Early in the plant's life, most of its energy goes into developing leaves because that's where the majority of photosynthesis happens. But as the plant matures, the focus shifts to strengthening its structural components, like the stem and roots, to support future reproductive growth (such as flowering or seed production). These findings are in line with earlier findings of [53], and [54], who noted a sharp decline in LSR with longer cutting intervals. Reference [52], also reported similar trends, highlighting higher LSR in intercropped treatments compared to pure stands.

The interaction between harvesting stage and planting regime significantly ($P<0.05$) affected the morphological characteristics of Desmodium species, except LLPP ($P>0.05$). Agronomic performance improved with increasing harvesting stage in sole-cropped Desmodium, whereas intercropped Desmodium exhibited reduced growth. The superior performance of sole-cropped Desmodium, particularly at later harvesting stages, may be attributed to the absence of interspecific competition, allowing the plants to achieve greater vegetative growth. The current finding aligns with [55], who found that sole Green leaf Desmodium outperformed than mixed plantings. Reference [56], also emphasized that shading effects in intercropping systems can influence plant morphology and physiology, ultimately affecting productivity.

PH, Plant height; TNLPP, Total number of leaves per plant; NTPP, Number of tiller per plant; NLPT, Number of leaves per tiller; LLPP, Leaf length per plant; LSR, Leaf to stem ratio; SNG = Sole Napier grass; SDU = Sole *Desmodium uncinatum*; SDI = Sole *Desmodium intortum*; NGDU, Napier with *Desmodium uncinatum*; NGDI, Napier with *Desmodium intortum*; SEM = Standard error of the mean; CV (%)= Coefficient of variation; HD, Harvesting day; PR, Planting regime; *; **; ***, are statistically different at probability values of $p<0.05$, $p<0.01$, and $p<0.001$, respectively, $^{a-k}$treatment means with the same superscript within a column are not statistically different at a 5% level of significance

D. Dry Matter and Crude Protein Yields of Napier Grass and Desmodium Species

The combined analysis of the influence of days of harvesting and planting regime interaction on the yields of Napier and Desmodium are illustrated in Table 4. The dry matter yield (DMY) and total dry matter yield (TDMY) of Napier grass were significantly influenced ($p<0.05$) by planting regime and harvesting days. At 120 days, the DMY for Napier grass intercropped with Desmodium intortum and Desmodium uncinatum was 21.2 t/ha and 19 t/ha, respectively, compared to 10.2 t/ha for sole Napier harvested at 60 days. The highest TDMY was observed in the NGDI system at 25.7 t/ha, followed by NGDU at 23.6 t/ha, both showing non-significant differences ($p>0.05$). Intercropped treatments at 90 days yielded 20.1 t/ha with Desmodium uncinatum and 18.3 t/ha with Desmodium intortum, also with non-significant variation between them. The increase in dry matter yield with longer harvesting periods is due to the result of a combination of cumulative plant growth and favourable environmental factors. Extended growth periods allow the plant to continue accumulating biomass through efficient photosynthesis, nutrient uptake, and root development. Together, these factors lead to higher dry matter yield, reflecting the plant's ability to grow, store energy, and mature fully over time. These findings align with [57] and [58], who reported significant differences in DMY based on harvesting days and intercropping of Desho grass with vetch. The current results also align with those of [59], who reported an increase in biomass yield as plants reached more advanced stages of maturity. The rise in dry matter yield of intercropped Napier grass with delayed harvesting in this study may be attributed to the capacity of Desmodium forages in nitrogen fixation, better resource utilization including light, water, and nutrients, enhanced photosynthesis due to increased light interception, and reduced weed competition through ground cover by Desmodium species than sole Napier grass. In agreement with this, reference [52] reported that intercropping elephant grass with vetch legumes resulted in higher dry matter yields than growing elephant grass alone.

The interaction between harvesting days and legume intercropping also significantly affect the crude protein yield (CPY) of Napier grass. In this study, the mean CPY of NGDI planting regime at 120 days were 1.5 t/ha, notably higher than sole Napier grass harvested at 60 days (0.4 t/ha). The higher CPY observed at later harvesting stages is likely due to increased biomass accumulation during plant maturation. As Napier grass continues to grow, greater dry matter production results in a higher total accumulation of crude protein. The increase in CPY of Napier grass, with the rise in days of harvesting in the current result agreed with the finding of [55]. Supporting this, reference [60] and [61], also noted that days of harvesting significantly influence CPY. The CPY observed in intercropped Napier grass at later harvesting stages was primarily attributable to the greater DMY produced by the Napier grass–Desmodium uncinatum and Napier grass–Desmodium intortum intercropping systems.

The interaction effect of the days of harvesting and planting regime was significant ($p<0.05$) on the CP contents of Napier grass. Higher mean CP (20.1 %) was recorded from intercropping Napier grass with Desmodium intortum at 60 days of harvesting, while lower CP (8.2 %) was obtained from sole Napier grass at 120 days of harvesting. The higher CP content of Napier grass obtained from the earlier harvesting in the current study in line with the reports of previous studies [42], [43], [62]. The increase in harvesting days of forages is related to the accumulation of a larger proportion of fiber matching plant growth [63], with a corresponding decline in CP content and the leaf-to-stem ratio [64]. The higher CP value of Napier grass intercropped with Desmodium intortum at 120

TABLE III. THE COMBINED MEAN VALUE OF THE INTERACTION EFFECT OF HARVESTING DAYS AND PLANTING REGIMES ON AGRONOMIC PERFORMANCE OF NAPIER GRASS AND DESMODIUM SPECIES

Harvesting stage	Planting regime	Forages	PH (cm)	TNLPP (count)	NTPP (count)	NLPT (count)	LLPP (cm)	LSR
60	SNG	NG	115.5^{e-h}	147.2^{e-g}	13.5^{e-g}	18.5^{e-h}	32^{d}	1.1^{cd}
	SDU	DU	67.4^{jk}	129.1^{f-h}	9.8^{g}	15.9^{gh}	5.2^{e}	1.4^{ab}
	SDI	DI	54.1^{k}	141.5^{f-h}	8.3^{g}	17.7^{f-h}	4.5^{e}	1.3^{a-c}
	NGDU	NG	100.3^{f-j}	195.7^{c-e}	21.3^{cd}	22.9^{c-g}	42.6^{c}	1.5^{a}
	DU		49.3^{k}	81.7^{h}	8.7^{g}	13.2^{h}	3.2^{e}	0.7^{d-f}
	NGDI	NG	128.9^{d-f}	200.3^{c-e}	23.7^{cd}	23.3^{c-g}	53.8^{b}	1.6^{a}
	DI		55.8^{k}	103.5^{h}	8.2^{g}	12.5^{h}	3.4^{e}	0.4^{g}
90	SNG	NG	144.1^{cd}	244.2^{c}	18.8^{d}	23.1^{c-g}	41.9^{c}	0.8^{d-f}
	SDU	DU	98.3^{f-j}	192.1^{c-e}	13.6^{fg}	21.7^{d-g}	4.9^{e}	0.9^{de}
	SDI	DI	84.3^{f-j}	202.8^{c-e}	8.1^{g}	22.4^{c-g}	5.1^{e}	1.0^{d}
	NGDU	NG	153.3^{cd}	318.2^{b}	26.2^{c}	25.4^{c-f}	55.2^{b}	0.8^{d-f}
	DU		78.1^{h-k}	153.7^{d-g}	11.3^{fg}	26.5^{c-e}	5.1^{e}	0.6^{fg}
	NGDI	NG	173.3^{bc}	300.5^{b}	29.1^{b}	30.8^{a-c}	54.1^{b}	1.0^{d}
	DI		72.3^{jk}	168.6^{d-f}	8.8^{g}	22.5^{c-g}	5.1^{e}	0.8^{d-f}
120	SNG	NG	198.2^{b}	302.9^{b}	23.4^{cd}	30.8^{a-c}	51.7^{b}	0.6^{fg}
	SDU	DU	117.1^{e-h}	238.3^{c}	15.9^{e}	27.9^{b-d}	5.2^{e}	0.8^{d-f}
	SDI	DI	117.5^{e-h}	214.3^{c}	12.9^{fg}	27.6^{b-d}	4.9^{e}	0.9^{de}
	NGDU	NG	206.8^{b}	338.3^{a}	33.1^{a}	36.7^{a}	58.3^{a}	0.7^{d-f}
	DU		76.6^{ijk}	153.5^{d-g}	12.7^{fg}	24.3^{c-g}	5.9e	0.7^{d-f}
	NGDI	NG	276.2^{a}	389.7^{a}	31.9^{a}	36.4^{a}	62.5^{a}	0.7^{d-f}
	DI		100.2^{f-j}	173.2^{d-f}	12.3^{fg}	28.2^{b-d}	5.2^{e}	0.5^{fg}
overall mean			117.2	209.4	16.7	24.2	24.3	0.9
SEM (±)			5.5	8.1	0.8	0.7	2.1	0.03
CV (%)			18.4	14.9	17	15.1	19.3	18.4
HD			***	***	***	***	***	***
PR			***	***	***	***	***	***
HD × PR			***	***	*	**	***	***

days of harvesting in the present study agreed with the finding of [65], who reported that the CP content of Napier grass increased as the proportions of Sesbania (Sesbania sesban) increased. Nevertheless, the current finding disagrees with the result of [66], who reported that the intercropping of herbaceous legumes such as Stylosanthes scarba and siratro (Macroptilium atropurpureum) with Napier grass was not significantly different from sole Napier grass in CP content in the semi-arid region of eastern Kenya. This difference might come from grass species differences, days of harvesting effect, differences in intercropped legumes, management practice, and soil fertility variation.

Harvesting stage and planting regime significantly (P<0.05) influenced the DMY and CPY of Desmodium species. Sole-cropped Desmodium produced higher DMY and CPY than intercropped treatments, likely due to the absence of interspecific competition for light, water, nutrients, and growing space. In contrast, when intercropped with Napier grass, the vigorous growth and taller canopy of the grass may have reduced resource availability for Desmodium, limiting biomass accumulation. According to [67], the greatest total DMY was obtained from sole Desmodium uncinatum, and the lower was observed in the intercropped Desmodium with Desho grass, which was agreed with the current finding. Additionally, the current results were consistent with the finding of, [68], who found that compared to intercropping treatments, sole-cropped legumes produced more dry matter, which might be explained by less habitat disturbances in the more uniform setting of single cropping. On the other hand, a significantly (p<0.05) higher value of CP content was recorded in sole-cropped Desmodium at 60 days of harvesting than intercropped Desmodium at 120 days of harvesting. A higher value of CP was recorded in sole cropped Desmodium at 60 days of harvesting than the intercropped Desmodium at 120 days of harvesting, which was due to differences in harvesting days.

DMY, Dry matter yield; CP (%), Crude protein in percent; CPY, Crude protein yield; TDMY, Total dry matter yield; TCPY, Total crude protein yield; SNG, Sole Napier gras; SDU, Sole *Desmodium uncinatu*; SDI, Sole *Desmodium intortum*; NGDU, Napier with *Desmodium uncinatum*; NGDI, Napier with *Desmodium intortum*; SEM = Standard error of the mean; CV (%) = Coefficient of variation; HD, Harvesting day; PR, Planting regime ; *; ***, are statistically different at probability values of *p<0.05, and p<0.001,* respectively; $^{a-h}$treatment means with the same superscript within a column are not substantially different at a 5% level of significance

E. Competitive Indices Potential of Napier Grass Intercropped With Desmodium Species at Various Days of Harvesting

The combined mean values of the effects of days of harvesting, planting regime, and their interaction on the competitive indices measures of Napier grass intercropped with Desmodium species are presented in Table 5. The interaction between harvesting stage and planting regime significantly affected the total area time equivalent ratio (TATER) (P<0.05), while other competitive indices showed non-significant differences (P>0.05). Harvesting stage had a significant effect on all competitive indices (P<0.05). The partial land equivalent ratio of Napier grass (LERN) was higher at late harvesting stages compared to earlier ones and was significantly greater in the NGDI planting regime than in NGDU (P<0.05). The land equivalent ratio of Desmodium

TABLE IV. THE COMBINED MEANS VALUES OF DRY MATTER AND CRUDE PROTEIN YIELDS OF NAPIER GRASS AND DESMODIUM SPECIES AS AFFECTED BY DAYS OF HARVESTINGS AND PLANTING REGIMES

Factors			Yield parameters				
Harvesting stage	**Planting regime**	**Type of forage**	**DMY (t/ha)**	**CP (%)**	**CPY (t/ha)**	**TDMY (t/ha)**	**TCPY (t/ha)**
60	SNG	NG	10.2^{d}	16.6^{jk}	0.4^{g}	10.2^{f}	0.4^{e}
	SDU	DU	5.4^{ef}	35.6^{a}	2.7^{b}	5.4^{gh}	2.7^{b}
	SDI	DI	4.9^{ef}	33.4^{ab}	2.4^{b}	4.9^{gh}	2.4^{c}
	NGDU	NG	9.9^{d}	19^{ij}	1^{fg}	12.6^{ef}	2.4^{c}
		DU	2.7^{f}	29.1^{cd}	1.4^{c-e}	2.7^{h}	1.4^{cd}
	NGDI	NG	12.1^{cd}	20.1^{h}	1.3^{f}	14.9^{de}	2.7^{b}
		DI	2.8^{f}	25.5^{c-f}	1.4^{c-e}	2.8^{gh}	1.4^{cd}
90	SNG	NG	12.6^{cd}	13.2^{kl}	0.9^{fg}	12.6^{ef}	0.9^{d}
	SDU	DU	5.8^{e}	29.1^{cd}	2.6^{b}	5.8^{gh}	2.6^{bc}
	SDI	DI	6^{d}	28.8^{cd}	2.5^{b}	6^{gh}	2.5^{bc}
	NGDU	NG	16.3^{b}	13^{kl}	1.2^{c-f}	20.1^{b}	2.7^{b}
		DU	3.8^{ef}	25.7^{c-f}	1.5^{cd}	3.8^{gh}	1.5^{cd}
	NGDI	NG	14.6^{bc}	15.5^{jk}	1.2^{c-f}	18.3^{bc}	2.7^{b}
		DI	3.7^{ef}	22.1^{f-h}	1.5^{cd}	3.7^{gh}	1.5^{cd}
120	SNG	NG	15.8^{b}	8.2^{m}	0.7^{fg}	15.8^{cd}	0.7^{d}
	SDU	DU	6^{d}	26.7^{c-e}	3.3^{a}	6^{gh}	3.3^{a}
	SDI	DI	6.2^{d}	24.9^{d-g}	2.9^{a}	6.2^{g}	2.9^{a}
	NGDU	NG	19^{a}	10.9^{lm}	1.2^{c-f}	23.6^{a}	2.9^{a}
		DU	4.6^{ef}	23.1^{e-h}	1.7^{c}	4.6^{gh}	1.7^{cd}
	NGDI	NG	21.2^{a}	12.4^{kl}	1.5^{cd}	25.7^{a}	3.1^{a}
		DI	4.5^{ef}	20.9^{g-i}	1.6^{cd}	4.5^{gh}	1.6^{cd}
Mean			9	21.6	1.7	10	2.1
SEM (±)			0.53	0.7	0.07	0.66	0.08
CV (%)			20.9	12.4	12.5	18.6	9.9
HD			***	***	***	***	***
PR			***	***	***	***	***
HD × PR			***	*	*	***	*

species (LERD) increased with delayed harvesting; however it was not significantly influenced by the planting regimes (P>0.05). The total land equivalent ratio (TLER) was significantly influenced by both harvesting stage and planting regime, with higher values at later harvesting stages and in the NGDI system as compared to NGDU planting regimes. The higher partial LER of the NGDI planting regime indicates that intercropping Napier grass with Desmodium intortum utilizes available resources such as light, water, nutrients, and growing space more efficiently than sole cropping. This suggests that the two species exhibit complementary resource use, reducing direct competition and enhancing the productivity of the dominant forage component. Although the partial LER of Desmodium was lower than expected because of its reduced dry matter yield under intercropping, its contribution to the total system productivity remained positive. The reduction in Desmodium yield is likely due to shading and competition from the vigorous growth of Napier grass, but this yield loss was more than compensated for by the increased productivity of the companion grass. Consequently, all intercropping systems recorded TLER values greater than 1, confirming a biological advantage over sole cropping. The TLER of 1.6 for the NGDI system indicates that 60% more land would be required under sole cropping to produce the same combined forage yield, while the TLER of 1.4 for the NGDU system reflects a 40% land-use advantage. These results are consistent with, [69], who found high TLER in intercropped Rhodes grass and alfalfa, and [70], who noted increased TLER in Panicum coloratum intercropped with Stylosanthes guianensis. Likewise, reference [71], reported greater herbage yields from grass–legume mixtures than from monocultures. Furthermore, reference [15], found TLER values between 1.09 and 1.58 for mixed proportion of Desho grass with vetch species, confirming that grass–legume intercropping enhances land-use efficiency and forage productivity.

The land equivalent coefficient (LEC) was significantly affected by harvesting stage (P<0.05), with the highest values recorded at 120 days. However, the effect of intercropping on LEC was not significant (P>0.05). Nevertheless, all intercropping systems produced LEC values greater than the critical threshold of 0.25, indicating a yield advantage over sole cropping. This suggests that the intercropping systems efficiently utilized available resources and achieved greater productivity per unit area of land than the corresponding monoculture systems. The TATER was highest at 120 days, intermediate at 90 days, and lowest at 60 days, with NGDI showing greater values than NGDU. Land use efficiency (LUE) was also significantly influenced by both factors, being highest at late harvesting stages and in the NGDI planting regime. The higher land use efficiency (LUE) observed in the intercropped system suggests that the combination of Napier grass with Desmodium intortum utilized land more effectively, resulting in a greater yield advantage. These findings are consistent with previous studies like [72] and [32], highlighting the benefits of intercropping in maximizing land use efficiency and productivity.

LERN, Land equivalent ratio of Napier; LERD, Land equivalent ratio of *Desmodium*; TLER, Total land equivalent ratio; LEC, Land equivalent coefficient; TATER, Total area time equivalent ratio; LUE, Land use efficiency; NGDI, Napier with *Desmodium intortum*;, NGDU, Napier with *Desmodium uncinatum*; SL, Significance level; CV (%), Coefficient of variation; HD, Harvesting day; PR, Planting regime; ns, non-significant; **; **; ****, are statistically different at probability values of *p<0.05, <0.01 and <0.001*, respectively, $^{a-c}$ treatment

TABLE V. THE COMBINED LEAST SQUARE MEANS AND STANDARD ERROR OF THE MEAN (LSM±SEM) OF THE COMPETITIVE INDICES MEASURES OF NAPIER GRASS WITH DESMODIUM SPECIES INTERCROPPING AT DIFFERENT HARVESTINGS DAYS

Factors	LERN	LERD	TLER	LEC	TATER	LUE (%)
HD						
60	0.8±0.07^{b}	0.3±0.02^{b}	1.2±0.07^{c}	0.3±0.04^{c}	0.7±0.06^{c}	158.5±11.02^{c}
90	1±0.07^{b}	0.4±0.02^{ab}	1.5±0.07^{b}	0.4±0.04^{b}	1.2±0.06^{b}	210.7±11.02^{b}
120	1.3±0.07^{a}	0.5±0.02^{a}	1.8±0.07^{a}	0.6±0.04^{a}	1.8±0.06^{a}	275.2±11.02^{a}
SL	***	**	***	***	***	***
PR						
NGDI	1.2±0.07^{a}	0.4±0.02	1.6±0.07^{a}	0.5±0.04	1.3±0.06^{a}	230.7±11.02^{a}
NGDU	0.9±0.07^{b}	0.5±0.02	1.4±0.07^{b}	0.4±0.04	1.1±0.06^{b}	198.8±11.02^{b}
SL	*	ns	*	ns	*	*
Overall mean	1.12	0.4	1.53	0.52	1.21	214.85
CV (%)	22.73	19.51	17.7	16.53	18.16	17.75
HD × PR	ns	ns	Ns	ns	*	ns

means with the same superscript within a column and a factor are not significantly different at a 5% level of significance

VI. CONCLUSION AND RECOMMENDATION

This study evaluated the effects of harvesting stage and intercropping Napier grass with different Desmodium species on agronomic performance, forage yield, and competitive indices. Harvesting stage and intercropping significantly influenced most agronomic, yield, and quality parameters. Most agronomic parameters, except leaf-to-stem ratio (LSR), were better in intercropped Napier grass at 120 days of harvesting. Competitive indices like partial land equivalent ratio, total land equivalent ratio and total area time ratio were also enhanced at 120 days of Napier with Desmodium intortum intercropping. At 60 days of harvesting, Napier grass had relatively high crude protein concentration but low biomass yield, resulting in reduced overall productivity of forages. Conversely, harvesting at 120 days substantially increased biomass production but reduced forage quality because of the decline in crude protein concentration, especially in sole Napier grass and Napier grass intercropped with Desmodium uncinatum. Harvesting at 90 days provided the best compromise between dry matter yield and nutritive value, producing forage with desirable biomass and balanced crude protein content. Among the intercropping systems, Napier grass intercropped with Desmodium intortum consistently produced superior crude protein concentration, crude protein yield, and competitive advantage over the other treatments. Therefore, intercropping Napier grass with Desmodium intortum and harvesting at 90 days is recommended as the optimum management practice for achieving a balanced combination of forage yield, protein quality, and land-use efficiency under the conditions of the study area. Future research should focus on evaluating the animal performance of forage produced under this intercropping system and assessing its economic feasibility to support wider adoption by smallholder farmers.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to the Amhara Agricultural Research Institute and Sirinka Agricultural Research Centre for their prompt provision of the research budget, which enabled the successful execution of this work.

References

[1] C. S. A. Livestock, "Livestock characteristics, agricultural sample survey. Addis Ababa, Ethiopia," Stat. Bull., vol. 2, no. 583, pp. 9–13, 2017.

[2] S. Gizaw, Sheep and goat production and marketing systems in Ethiopia: Characteristics and strategies for improvement, vol. 23. ILRI (aka ILCA and ILRAD), 2010.

[3] B. Duguma, Y. Kechero, and G. P. J. Janssens, "Analysis of constraints facing urban dairy farmers and gender responsibility in animal management in Jimma town," African J. Basic Appl. Sci., vol. 3, pp. 313–318, 2011.

[4] A. Hassen, A. Ebro, M. Kurtu, and A. C. Treydte, "Livestock feed resources utilization and management as influenced by altitude in the Central Highlands of Ethiopia," Livest. Res. Rural Dev., vol. 22, no. 229, 2010.

[5] S. M. Zewdu, "Stall feeding regimen for indigenous dairy cow production in northwestern Ethiopia," 2020.

[6] M. Ongadi, E. Mpolya, C. Gachuiri, F. Muyekho, and A. Lukuyu, "Effects of season variation on water, feed, milk yield and reproductive performance of dairy cows in smallholder farms in eastern Africa," J. Agric. Ecol. Res. Int., 2020.

[7] T. Mulualem and M. Molla, "Production constraints, farmers preferences and participatory on farm evaluation of improved forage technologies in selected Districts of southern Ethiopia," Greener J. Agric. Sci., vol. 3, no. 9, pp. 628–635, 2013.

[8] K. Yisehak, "Effect of seed proportions of Rhodes grass (Chloris gayana) and white sweet clover (Melilotus alba) at sowing on agronomic characteristics and nutritional quality," Livest. Res. Rural Dev., vol. 20, no. 2, p. 28, 2008.

[9] H. Hailesilassie, "The effect of improved fodder production on livestock productivity in Endamehoni District, southern Tigray Ethiopia," 2016, Mekelle University.

[10] M. A. Sanderson, G. Brink, R. Stout, and L. Ruth, "Grass–legume proportions in forage seed mixtures and effects on herbage yield and weed abundance," Agron. J., vol. 105, no. 5, pp. 1289–1297, 2013.

[11] W. F. Anderson, B. S. Dien, S. K. Brandon, and J. D. Peterson, "Assessment of bermudagrass and bunch grasses as feedstock for conversion to ethanol," in Biotechnology for Fuels and Chemicals: Proceedings of the Twenty-Ninth Symposium on Biotechnology for Fuels and Chemicals Held April 29–May 2, 2007, in Denver, Colorado, Springer, 2008, pp. 13–21.

[12] F. A. O. G. Index, "A searchable catalogue of grass and forage legumes. FAO, Rome, Italy, 2015."

[13] T. Zewdu, "Effect of plant density on morphological characteristics, yield and chemical composition of napier grass (Pennisetum purpureum (L.) Schumach)," East African J. Sci., vol. 2, no. 1, pp. 55–61, 2008.

[14] A. Getnet, K. Gezahagn, and F. Fekede, "Forage Seed Production and Quality in Ethiopia," FRG II Proj. Empower. Farmers' Innov. Ser., no. 3, 2012.

[15] M. Abera, A. Tolera, A. Nurfeta, and D. Geleti, "SPECIAL SECTION : DEVELOPING FODDER RESOURCES Herbage accumulation and nutritive value of mixtures of desho grass and Vicia spp . in southern Ethiopia," no. November 2021, pp. 165–172, 2022, doi: 10.1002/agj2.20891.

[16] M. D. Rambau, F. Fushai, and J. J. Baloyi, "Productivity, chemical composition and ruminal degradability of irrigated Napier grass leaves harvested at three stages of maturity," S. Afr. J. Anim. Sci., vol. 46, no. 4, pp. 398–408, 2016.

[17] Z. K. Tessema, J. Mihret, and M. Solomon, "Effect of defoliation frequency and cutting height on growth, dry-matter yield and nutritive value of Napier grass (Pennisetum purpureum (L.) Schumach)," Grass Forage Sci., vol. 65, no. 4, pp. 421–430, 2010, doi: 10.1111/j.1365-2494.2010.00761.x.

[18] T. Ansah, E. L. K. Osafo, and H. H. Hansen, "Herbage yield and chemical composition of four varieties of Napier (Pennisetum purpureum) grass harvested at three different days after planting," 2010.

[19] G. Estefan, R. Sommer, and J. Ryan, "Methods of soil, plant, and water analysis," A Man. West Asia North Africa Reg., vol. 3, pp. 65–119, 2013.

[20] G. J. Bouyoucos, "Hydrometer method improved for making particle size analyses of soils 1," Agron. J., vol. 54, no. 5, pp. 464–465, 1962.

[21] J. M. Bremner and R. D. Hauck, "Advances in methodology for research on nitrogen transformations in soils," Nitrogen Agric. soils, vol. 22, pp. 467–502, 1982.

[22] S. R. Olsen, F. S. Watanabe, H. R. Cosper, W. E. Larson, and L. B. Nelson, "Residual phosphorus availability in long-time rotations on calcareous soils," Soil Sci., vol. 78, no. 2, pp. 141–152, 1954.

[23] S. A. Nguku, D. N. Njarui, N. K. R. Musimba, D. Amwata, and E. M. Kaindi, "Primary production variables of Brachiaria grass cultivars in Kenya drylands," Trop. Subtrop. Agroecosystems, vol. 19, no. 1, pp. 29–39, 2016.

[24] S. A. Tarawali, Methods for the evaluation of forage legumes, grasses and fodder trees for use as livestock feed, vol. 1. ILRI (aka ILCA and ILRAD), 1995.

[25] H. I. Gitari, S. O. Nyawade, S. Kamau, C. K. K Gachene, N. N. Karanja, and E. Schulte-Geldermann, "Increasing potato equivalent yield increases returns to investment under potato-legume intercropping systems," Open Agric., vol. 4, no. 1, pp. 623–629, 2019.

[26] C. T. De Wit and J. P. Van den Bergh, "Competition between herbage plants," J. Agric. Sci., vol. 13, pp. 212–221, 1965.

[27] R. Willey, "Intercropping-its importance and its research needs. Part I. Competition and yield advantages," in Field Crop Abstr., 1979, pp. 1–10.

[28] P. O. Adetiloye, F. O. C. Ezedinma, and B. N. Okigbo, "A land equivalent coefficient (LEC) concept for the evaluation of competitive and productive interactions in simple to complex crop mixtures," Ecol. Modell., vol. 19, no. 1, pp. 27–39, 1983.

[29] C. K. Hiebsch and R. E. McCollum, "Area x time equivalency ratio-a method for evaluating the productivity of intercrops-REPLY," Agron. J., vol. 79, no. 5, pp. 945–946, 1987.

[30] B. T. S. Doubi, K. I. Kouassi, K. L. Kouakou, K. K. Koffi, J.-P. Baudoin, and B. I. A. Zoro, "Existing competitive indices in the intercropping system of Manihot esculenta Crantz and Lagenaria siceraria (Molina) Standley," J. Plant Interact., vol. 11, no. 1, pp. 178–185, 2016.

[31] R. Mead and R. Willey, "The concept of a 'land equivalent ratio'and advantages in yields from intercropping," Exp. Agric., vol. 16, no. 3, pp. 217–228, 1980.

[32] M. Yaseen, M. Singh, and D. Ram, "Growth, yield and economics of vetiver (Vetiveria zizanioides L. Nash) under intercropping system," Ind. Crops Prod., vol. 61, pp. 417–421, 2014.

[33] U. S. M. Level, "1, Module 3-USDA Textural Classification," Study Guid. United States Dep. Agric. Washington, DC, USA, pp. 1–48, 1987.

[34] T. Tadesse, I. Haque, and E. A. Aduayi, "Soil, plant, water, fertilizer, animal manure and compost analysis manual," 1991.

[35] H. F. Murphy, "A report on the fertility status and other data on some soils of Ethiopia," 1968.

[36] D. L. Waugh, R. B. Cate Jr, and L. A. Nelson, "Discontinuous models for rapid correlation, interpretation, and utilization of soil analysis and fertilizer response data," 1973.

[37] A. I. Hassen, F. L. Bopape, J. Habig, and S. C. Lamprecht, "Nodulation of rooibos (Aspalathus linearis Burm. f.), an indigenous South African legume, by members of both the α-Proteobacteria and β-Proteobacteria," Biol. Fertil. Soils, vol. 48, pp. 295–303, 2012.

[38] J. R. Landon, "A handbook for soil survey and agricultural evaluation in the tropics and subtropics," Booker Trop. soil Man., 1991.

[39] M. Abera, A. Tolera, A. Nurfeta, and D. Geleti, "Effect of Fertilizer Level and Harvesting Date on Yield and Nutritive Value of Desho Grass (Pennisetum pedicellatum) in Hula and Bule districts of the Southern Region of Ethiopia Description of the study area," vol. 20, no. 1, pp. 18–28, 2020.

[40] B. A. Bimrew Asmare, S. D. Solomon Demeke, T. T. Taye Tolemariam, F. T. Firew Tegegne, A. H. Aynalem Haile, and J. W. Jane Wamatu, "Effects of altitude and harvesting dates on morphological characteristics, yield and nutritive value of desho grass (Pennisetum pedicellatum Trin.) in Ethiopia.," 2017.

[41] A. Kefyalew, B. Alemu, and T. Alemu, "Effects of fertilization and harvesting age on yield and quality of desho (Pennisetum pedicellatum) grass under irrigation, in Dehana district, wag hemra zone, Ethiopia," Agric. For. Fish., vol. 9, no. 4, pp. 113–121, 2020.

[42] G. Tilahun, B. Asmare, and Y. Mekuriaw, "Effects of harvesting age and spacing on plant characteristics, chemical composition and yield of desho grass (Pennisetum pedicellatum Trin.) in the highlands of Ethiopia," Trop. Grasslands-Forrajes Trop., vol. 5, no. 2, pp. 77–84, 2017.

[43] M. Zemene, Y. Mekuriaw, and B. Asmare, "Effect of plant spacing and harvesting age on plant characteristics, yield and chemical composition of para grass (Brachiaria mutica) at Bahir Dar, Ethiopia," Sci. Pap. Anim. Sci. Biotechnol., vol. 53, no. 2, p. 137, 2020.

[44] E. A. Tenakwa, S. Cudjoe, and T. Ansah, "Biomass yield and fodder quality of Napier grass (Pennisetum purpureum) as affected by Pigeon pea (Cajanus cajan) intercrop and planting distance," Ghana J. Agric. Sci., vol. 54, no. 2, pp. 36–44, 2019.

[45] G. W. Yigzaw, "Effect of Harvesting Stage on Yield and Nutritive Value of Buffel Grass (Cenchrus ciliaris linn) Under Irrigation at Gewane District , North Eastern Ethiopia," vol. 8, no. 1, pp. 7–12, 2019.

[46] M. Demlew, B. Alemu, and A. Awuk, "Evaluation of agronomic performance and biomass yield of buffel grass and silver leaf Desmodium grown in pure stands and in mixture at different harvesting times in Gozamen district, east Gojjam Zone, Ethiopia," Greener J. Agric. Sci, vol. 9, pp. 396–404, 2019.

[47] M. A. Ullah, Forage production in panicum grass-legumes intercropping by combining geometrical configuration, inoculation and fertilizer under rainfed conditions. kassel university press GmbH, 2010.

[48] A. Bantihun, B. Asmare, and Y. Mekuriaw, "Comparative evaluation of selected grass species for agronomic performance, forage yield, and chemical composition in the highlands of Ethiopia," Adv. Agric., vol. 2022, 2022.

[49] B. A. Berhanu Alemu, S. M. Solomon Melaku, and N. K. Prasad, "Effects of varying seed proportions and harvesting stages on biological compatibility and forage yield of oats (Avena sativa L.) and vetch (Vicia villosa R.) mixtures.," 2007.

[50] T. Tolcha, "Effect of nitrogen fertilizer and harvesting days on yield and quality of Rhodes Grass (Chloris gayana) Under Irrigation at Gewane, North-Eastern, Ethiopia," 2017, MSc Thesis Haromaya University, Ethiopia.

[51] S. Ahmad, P. A. Khan, D. K. Verma, N. H. Mir, A. Sharma, and S. A. Wani, "Forage production and orchard floor management through grass/legume intercropping in apple based agroforestry systems," Int. J. Chem. Stud., vol. 6, no. 1, pp. 953–958, 2018.

[52] B. Gelayenew, B. Tamir, G. Assefa, and F. Feyissa, "Effects of spacing of elephant grass and vetch intercropping on agronomic performance and herbage yield of elephant grass," Ethiop. J. Agric. Sci., vol. 30, no. 2, pp. 13–30, 2020.

[53] N. Onjai-Uea et al., "Effect of cultivar, plant spacing and harvesting age on yield, characteristics, chemical composition, and anthocyanin

composition of purple Napier grass," Animals, vol. 13, no. 1, p. 10, 2022.

[54] K. Wangchuk, K. Rai, H. Nirola, C. Dendup, and D. Mongar, "Forage growth, yield and quality responses of Napier hybrid grass cultivars to three cutting intervals in the Himalayan foothills," Trop. Grasslands-Forrajes Trop., vol. 3, no. 3, pp. 142–150, 2015.

[55] M. Yegrem, B. Alemu, and A. Awuke, "Agronomic performance and dry matter yield of Desho (pennisetum pedicellatum) and Setaria (Setaria sphacelata) grasses mixed with greenleaf Desmodium (Desmodium intortum) at different harvesting time," Int. J. Res. Stud. Agric. Sci., vol. 5, no. 8, pp. 31–39, 2019.

[56] H. Hauggaard-Nielsen and E. S. Jensen, "Evaluating pea and barley cultivars for complementarity in intercropping at different levels of soil N availability," F. Crop. Res., vol. 72, no. 3, pp. 185–196, 2001.

[57] T. Tesfaye, B. Asmare, Y. Mekuriaw, and B. Hunegnaw, "Morphological characters, yield, and chemical composition potentials of desho grass (Pennisetum glaucifolium H.) intercropped with vetch species in the highlands of Ethiopia," Adv. Agric., vol. 2022, 2022.

[58] T. P. Liranso and T. Wolkaro, "Effect of vetch intercropping and harvesting stage on morphological characteristics, dry matter yield, and chemical composition of desho grass (Pennisetum glaucifolium)," 2023, Haramaya University.

[59] Z. K. Tessema and B. S. Feleke, "Yield, yield dynamics and nutritional quality of grass-legume mixed pasture.," JAPS J. Anim. Plant Sci., vol. 28, no. 1, 2018.

[60] S. Menbere, M. Dejene, and S. Abreha, "Dry matter yield and agronomic performance of herbaceous legumes intercropped with napier grass (Pennisetum purpureum) in the semi-arid areas of eastern amhara region," Wondo Genet Agric. Res. Cent. has been Work. a number Res. Act. to Adapt Dev. Technol. Knowl. Inf. mandate Commod. ie Aromat. Med. Bio fuel plants (AMBPs). Moreover, as a Collab., p. 217, 2015.

[61] W. A. Wassie, B. A. Tsegay, A. T. Wolde, and B. A. Limeneh, "Evaluation of morphological characteristics, yield and nutritive value of Brachiaria grass ecotypes in northwestern Ethiopia," Agric. Food Secur., vol. 7, pp. 1–10, 2018.

[62] B. L. Maass et al., "Homecoming of Brachiaria: Improved hybrids prove useful for African animal agriculture," East African Agric. For. J., vol. 81, no. 1, pp. 71–78, 2015.

[63] P. J. Van Soest, Nutritional ecology of the ruminant. Cornell university press, 1994.

[64] A. M. Salamone, A. A. AbuGhazaleh, and C. Stuemke, "The effects of maturity and preservation method on nutrient composition and digestibility of master graze," J. Anim. Res. Technol., vol. 1, no. 1, pp. 13–19, 2012.

[65] Z. Tessema and R. M. T. Baars, "Chemical composition, in vitro dry matter digestibility and ruminal degradation of Napier grass (Pennisetum purpureum (L.) Schumach.) mixed with different levels of Sesbania sesban (L.) Merr.," Anim. Feed Sci. Technol., vol. 117, no. 1–2, pp. 29–41, 2004.

[66] E. N. Njoka-Njiru, M. G. Njarui, S. A. Abdulrazak, and J. G. Mureithi, "Effect of intercropping herbaceous legumes with Napier grass on dry matter yield and nutritive value of the feedstuffs in semi-arid region of eastern Kenya," Agric Trop Subtrop, vol. 39, no. 4, pp. 255–267, 2006.

[67] W. Keba, "Determination of Optimum Level of Seeding Rate of Silver Leaf Desmodim Intercropping with Desho Grass for Dry Matter Yield and Yield-Related Components in Western Ethiopia," Adv. Agric., vol. 2023, 2023.

[68] U. Gulwa, N. Mgujulwa, and S. T. Beyene, "Effect of grass-legume intercropping on dry matter yield and nutritive value of pastures in the Eastern Cape Province, South Africa," Univers. J. Agric. Res, vol. 5, no. 6, pp. 355–362, 2017.

[69] S. Cınar and R. Hatıpoglu, "Forage yield and botanical composition of mixtures of some perennial warm season grasses with alfalfa (Medicago sativa L.) under Mediterranean conditions," Turkish J. F. Crop., vol. 19, no. 1, pp. 13–18, 2014.

[70] D. Diba and D. Geleti, "Effects of seed proportion and planting pattern on dry matter yield, compatibility and nutritive value of Panicum coloratum and Stylosanthes guianensis mixtures under Bako Condition, Western Oromia, Ethiopia," Sci. Technol. Arts Res. J., vol. 2, no. 4, pp. 56–61, 2013.

[71] K. Gebeyew, D. Diba, K. Beriso, S. Fikiru, and A. Omer, "Forage yield, compatibility and nutrient content of Panicum antidotale and Desmodium uncinatum mixed pasture under rainfed conditions in jigjiga district, Somali regional state Ethiopia," J. Agric. Environ. Sci, vol. 18, no. 5, pp. 239–245, 2018.

[72] S. A. John and C. Mini, "Biological efficiency of intercropping in okra (Abelmoschus esculentus (L.)," J. Trop. Agric., vol. 43, pp. 33–36, 2005.