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Original Article

The effect of nitrogen fertilizer on Napier grass (*Pennisetum purpureum*) productivity: a meta-analysis

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Abstract

Nitrogen fertilizer is the major nutrient required by grass for optimal growth and biomass production. The type and dosage of nitrogen fertilizer application influence plant productivity. This research used a meta-analysis approach aimed to assess how optimal N fertilizer dosage and types affect the productivity improvement of Napier grass *(Pennisetum purpureum*). Search done in Elsevier, Scopus, Science Direct, JSTOR, ProQuest, and Web of Science databases yielded 44 studies, of which 24 were suitable for the analysis. The dataset was collected between 1972 and 2022, and all experiments included a control treatment with no nitrogen fertilizer and a variety of forms (organic or inorganic) that were evaluated herein for the productivity and nutritional contents of Napier grass. The data were then subjected to meta-analysis using a mixed-effects model methodology, treating different doses or forms of nitrogen fertilizer as fixed effects and various studies as random effects, with the p-value used as the statistical model. The findings demonstrated that N fertilizer dosage influences ($P<0.05$) the total dry weight of forage, leaf weight, plant height, N, P, Na production, and dry matter digestibility. Furthermore, the type of inorganic fertilizer affects ($P<0.05$) the production of fresh Napier grass forage, leaf weight, and plant height but has no significant impact ($P>0.05$) on other production parameters. In conclusion, the productivity of Napier grass has the potential to increase effectively with higher doses of nitrogen fertilizer, with the optimal dosage at 1,493.31 kg N/ha/year. Both organic and inorganic types of N fertilizer show similar effects on most of the measured variables.

Keywords: Fertilizer, Napier grass, Nitrogen, Meta-analysis, Productivity fertilizer

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Introduction

The availability of forage is essential for farmers. Pastures and forages are the main feed for livestock. (Khanh et al., 2020). One of the forage crops is Napiergrass (*Pennisetum purpureum*) because of its high biomass production and good nutritional quality to meet storage capacity needs (Marafon et al., 2021). It is a C4 grass, clonally propagated, fast regenerating, high-quality leaves and stems, and palatability (Silva et al., 2019), bioethanol (Kongkeitkajorn et al., 2021), phytoremediation (Wu et al., 2023), and reclamation (Anda et al., 2022). Therefore, Napier grass is extensively cultivated in tropical and subtropical regions and is mainly used for livestock.

Napier grass management practices are more intensive than cereal crops, vegetables, fruit, and timber trees, for instance, annual quantities of fertilizers (200 kg N/ha/year). Generally, Napier grass receives a greater amount of fertilizer than other plants. In addition, Napier grass's cutting intensity (cutting biomass) and frequency (cutting periods) are generally greater than those of cereal crops and trees. Most previous research has concentrated on the effects of various management techniques on the productivity of Napier grass (Liang et al., 2013). Standard management practices of agricultural, horticultural, and forestry ecosystems include fertilization, harvest/cutting, irrigation, weeding, and insect control; one way to increase the productivity of Napier grass is by providing nitrogen fertilizer. Cultivation and management techniques influence the soil's hydraulic properties, particularly in the topsoil. Nitrogen fertilization influenced soil field saturated hydraulic conductivity (Kfs) more than cutting frequency and cutting intensity on Napier grass (Yang et al., 2016)

In another research, the hybrid Napier grass could tolerate high NH_4+ concentrations of up to 5 mM and grow under hypoxic conditions with a modest decrease in total nitrogen (Jampeetong and Muenrew, 2016; van Dung et al., 2023). In addition, we propose that moderate N fertilization (460 kg N/ha/year), moderate irrigation, and mowing will maintain soil health and provide substantial hybrid Napier grass yields. Ammonia volatilization losses were significant, amounting to an average of 49% of applied urea N, which is fivefold the IPCC default value (10%) and may indicate that indirect N_2O emissions are underestimated (de Morais et al., 2013), and biofertilizers can help increase crop yields, improve dryland conditions, and support long-term sustainable agriculture (Samijan et al., 2023).

Numerous studies of the dosage and form of nitrogen fertilizer in Napier grass have revealed several differentiating factors, including the research location, land, and climate conditions. Altogether, these variables may play a role in determining Napier grass's production and nutrient content. As a result, a systematic review is required to assess the linearity of the effect of dosage and form of nitrogen fertilizer in Napier grass's production and nutrient content. Meta-analysis is a powerful technique for analyzing numerous studies using consistent variables (Leandro and Gallus, 2005). Therefore, the objective of our study was to conduct a comprehensive meta-analysis of the effects of nitrogen fertilizer affects Napier grass's productivity and nutrient content.

Material and Methods

Development of database

This meta-analysis investigation adheres to the methodology outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines as documented by Selcuk (2019). The data employed in this study was obtained from published articles, which were subsequently documented within a database. The identification of said published articles was accomplished through the utilization of the keywords "*Pennisetum purpureum*" and "nitrogen fertilizer" to browse through various search engines for scientific articles, namely Elsevier, Scopus, Science Direct, JSTOR, Proquest, and Web of Science.

Criteria of inclusion/exclusion

The primary inclusion criteria consisted of the following: (1) A journal article in the English language that a reputable publisher published; (2) The experimental design adhered to the appropriate statistical principles; (3) The quantity of experimental and replicated material complied with the relevant statistical standards; (4) Specific experimental material was employed for *Pennisetum purpureum*; and (5) The number of replications utilized (n) fulfilled the necessary statistical requirements.

Data extraction

The data that was extracted from the chosen articles includes the names of the author(s), the year of publication, the name of the journal, the country, the climate, the type of soil, the pH of the soil, the temperature, the precipitation, the harvesting time, the replication, the observed parameters, the dose, the source of nitrogen fertilizer, the units for each parameter, the sampling technique, and the technique used to measure the parameters.

Initially, a total of 44 articles that described studies on the use of nitrogen fertilizer for *Pennisetum purpureum* were retrieved. However, only 32 articles met the inclusion criteria based on their title and abstract. The parameters that were included in the analysis were productivity (including total yield, plant height, leaf, stem, trash, ash, organic matter, crude protein, crude protein leaf, crude fiber, NDF, ADF, nitrogen, calcium, phosphorus, potassium, magnesium, sodium, copper, manganese, zinc, and iron), nutrient content (including dry matter, organic matter, crude protein, crude protein leaf, crude fiber, NDF, ADF, nitrogen, calcium, phosphorus, potassium, magnesium, sodium, copper, manganese, zinc, and iron), and in vitro nutrient digestibility.

After a thorough assessment, 24 articles were selected to be included in the database (see Table 1). The process of selecting and evaluating the articles is depicted in Figure 1.

Statistical analysis

The data underwent processing through a mixed-model procedure (Hidayat et al., 2020, 2021; Yanza et al., 2021). The analysis used the PROC MIXED procedure in SAS version 9.1 (SAS Institute Inc., Cary, NC, USA). The dosage of N fertilizer was designated as a fixed effect, while the various studies were identified as random effects (as stated in the RANDOM statement). The employed mathematical model was as follows:

$$Y_{ij} = \beta_0+\beta_1 \text{ Level}_{ij}+\text{Experiment}_i+\text{Experiment}_i \text{ Level}_{ij}+e_{ij} \quad (1)$$

$$Y_{ij} = \beta_0+\beta_1 \text{ Level}_{ij}+\beta 2 \text{ Level}_{ij}+\text{Experiment}_i+\text{Experiment}_1 \text{ Level}_{ij}+e_{ij} \quad (2)$$

Which: (1) Linear mixed model (LMM) mathematical model in the 1st order, (2) LMM mathematical model in the 2nd order, $\beta_0+\beta_1$ Level$_{ij}$ (1st order) and β0+β1 Levelij+β2 Levelij (2nd order)=fixed effect, Experiment$_i$ + Experiment$_i$ Level$_{ij}$ (1st and 2nd order), β_0 – overall intercept value across all experiments, β_1 – linear regression coefficient of the 1st order, β2 – linear regression coefficient of the 2nd order, Level$_{ij}$ – additional level on the random effect, experiment – experiment$_i$, and e_{ij} – unexplained residual errors.

When the respective quadratic regression model did not yield a significant result at a significance level of $p<0.05$, a linear regression model was employed instead. The assessment of model performance relied on evaluating p-values and the root mean square error. If a p-value of less than 0.05 was observed, the effect was deemed significant. Furthermore, if the p-value fell between 0.05 and 0.1, it indicated a tendency towards significance. All statistical analyses were conducted using SAS Software version 9.1. In instances where the quadratic regression yielded significant parameters, the optimal dosage of nitrogen fertilizer could be determined to maximize the parameters' performance. The differential method of the quadratic regression equation, as exemplified by the provided formula, can be utilized to derive the optimal dosage of nitrogen fertilizer.

$$Y = aX^2 + bx + c \quad (3)$$

$dy/dx = 2ax + b = 0$

$2ax+b = 0$

$X = -b/2a$

X = optimum dose of nitrogen fertilizer

Table-1. Studies included in the meta-analysis of nitrogen fertilizer on *Pennisetum purpureum*

No	Author	Dwarf/Non Dwarf	Country	Climate	Soil	Soil pH	Tempera-ture (ºC)	Precipitation (mm/year)	Nitrogen form	Nitrogen dosage (kg/ha/year)
1	(Bayble et al., 2007)	Non-dwarf	Ethiopia	Tropic	Ferralsol	n d	27.45	1,603.50	Diammonium hydrogen phosphate	171.09
2	(Capiel and Ashcroft, 1972)	Non-dwarf	Puerto Rico	Tropic	Luvisol	n d	25.00	1,600.00	Calcium nitrate	560 up to 1120
3	(Castillo et al., 2011)	Non-dwarf	United state	Sub tropic	Arenosol	6.30	22.50	1,392.00	Ammonium nitrate	350 up to 700
4	(Chew et al., 1982)	Non-dwarf	Malaysia	Tropic	n.d	4.50	n.d	n.d	Organic form (manure)	0 up to 1800
5	(Crespo and Álvarez, 2014)	Non-dwarf	Cuba	Tropic	Ferralsol		23.27	1,453.40	Carbonyl diamide	365,000
6	(Dokbua et al., 2021)	Non-dwarf	Thailand	Tropic	Acrisol	6.73	28.90	789.70	Ammonium. sulfate	0 up 1000
7	(Ebrahim et al., 2020)	Non-dwarf	Ethiopia	Tropic	Luvisol		21.00	650.00	Carbonyl diamide	0 up to 979
8	(Ferraris and Stewart, 1979)	Non-dwarf	Australia	Sub tropic	Fluvisol	6.05	23.71	3,827.28	Ammonium nitrate	0 up to 2000
9	(Flores et al., 2012)	Non-dwarf	Brazil	Tropic	n.d	5.75	n.d	n.d	Carbonyl diamide	0 up to 93.27
10	(Kaur et al., 2017)	Non-dwarf	India	Tropic	n.d	n.d	n.d	n.d	Carbonyl diamide, ammonium sulfate, calcium nitrate, ammonium.sulfate	50 up to 100
11	(Knoll et al., 2013)	Non-dwarf	United state	Sub tropic	Leptosol	6.10	6.20	464.59	Ammonium nitrate	0 up to 101
12	(Botero-Londoño et al., 2021)	Non-dwarf	Colombia	Tropic	Andosol	5.50	19.00	2,400.00	Calcium nitrate	802.40
13	(Manyawu et al., 2003)	Non-dwarf	Zimbabwe	Tropic	Cambisol	n.d	n.d	n.d	Ammonium nitrate	1,040.00
14	(Martha et al., 2004)	Non-dwarf	Brazil	Sub tropic	Kandiudalf	5.10	21.00	1,253.00	Carbonyl diamide, ammonium sulfate	500.00
15	(Meneses et al., 2018)	Non-dwarf	Brazil	Tropic	Fluvisol	7.10	27.78	185.00	Ammonium nitrate, organic form	0 up to 1620
16	(de Morais et al., 2013)	Non-dwarf	Brazil	Tropic	Acrisol	5.40	n.d	774.00	Carbonyl diamide	0 up to 297
17	(Neves et al., 2018)	Non-dwarf	Brazil	Tropic	n.d	n.d	n.d	n.d	Biosolid textile	0 up to 800
18	(Oliveira et al., 2022)	Non-dwarf	Brazil	Tropic	Arenosol	n.d	26.50	n.d	Carbonyl diamide and ammonium sulfate	0 up to 1123

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No	Author	Dwarf/Non Dwarf	Country	Climate	Soil	Soil pH	Tempera-ture (°C)	Precipitation (mm/year)	Nitrogen form	Nitrogen dosage (kg/ha/year)
19	(Pieterse and Rethman, 2002)	Non-dwarf	South Africa	Sub tropic	Loamy	6.50	n.d	750.00	Ammonium nitrate	0 up to 400
20	(Ra et al., 2012)	Non-dwarf	Japan	Sub tropic	n.d	n.d	n.d	n.d	Ammonium nitrate	72.00
21	(Rahman et al., 2008)	Dwarf	Japan	Sub tropic	n.d	n.d	n.d	n.d	Carbonyl diamide	0 up to 900
22	(Rahman et al., 2009)	Non-dwarf	Japan	Sub tropic	n.d	n.d	22.90	243.60	Ammonium nitrate	50 up to 300
23	(Ullah et al., 2010)	Non-dwarf	Pakistan	Sub tropic	Arenosol	8.40	40.00	722.64	Carbonyl diamide	0 up to 120
24	(Utamy et al., 2018)	Dwarf	Japan	Sub tropic	Andosol	6.60	16.20	2,610.00	Ammonium nitrate and organic form	184 up to 234

n.d = no available data

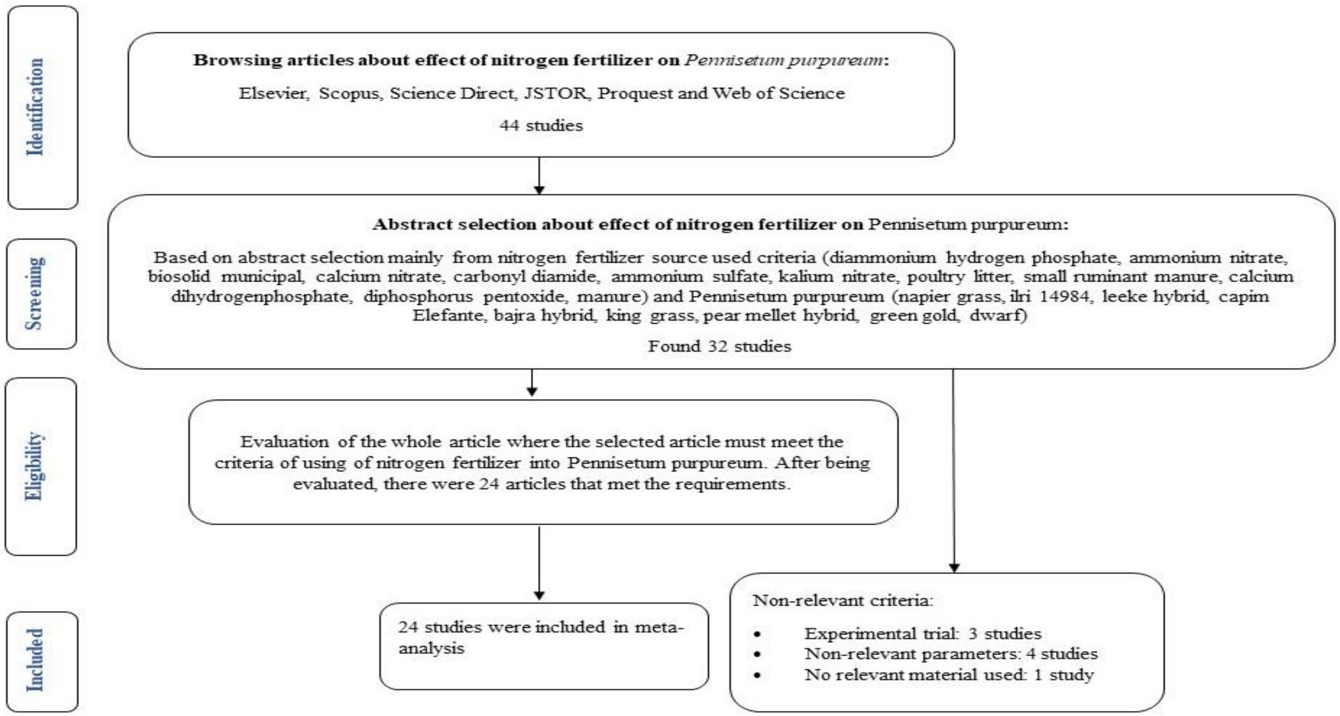

Figure-1. The selection of articles and evaluation process using PRISMA method. PRISMA=Preferred Reporting Items for Systematic Reviews and Meta-Analyses

Results

The effects of different doses and forms of nitrogen fertilizer on the productivity of Napier grass (*Pennisetum purpureum*) are shown in Table 2. A summary of the papers used for the various metanalyses is provided in Table 1. Using 24 papers are containing 44 trials with productivity, nutrient profile, and *in vitro* digestibility outcomes. The earliest article was published in 1972, and the most recent study was published in 2021. The cultivation conditions of Napier Grass (*Pennisetum purpureum*) in each paper, including nitrogen levels, forms, and abiotic conditions (climate, temperature, pH, and type of soil), are also reported in Table 1.

The dose of nitrogen form has a significant ($p > 0.05$) effect on total yield (ton/ha/year in DM). The nitrogen dose increased total yield (DM) following a quadratic pattern. The nitrogen fertilizer dose with the highest total yield was 1,493.31 kg N/ha/year in DM. Furthermore, the nitrogen dose also has a significant ($p>0.05$) effect on plant height (cm), leaf biomass (ton/ha/year in DM), ash biomass (ton/ha/year in DM), crude protein yield (ton/ha/year in DM), nitrogen yield (ton/ha/year in DM), phosphorus yield (ton/ha/year in DM), and potassium yield (ton/ha/year in DM). On the other hand, the form of nitrogen fertilizer has a significant effect on total yield (ton/ha/year in FM), plant height (cm), leaf biomass (ton/ha/year in DM), and potassium yield (ton/ha/year in DM).

Differences were not observed in the effects of dosage and form of nitrogen fertilizer on trash (ton/ha/year in DM), crude protein in leaves biomass (ton/ha/year in DM), crude fiber yield (ton/ha/year in DM), neutral detergent fiber/NDF yield (ton/ha/year in DM), acid detergent fiber/ ADF yield (ton/ha/year in DM), sodium yield (ton/ha/year in DM), cuprum yield (kg/ha/year in DM), manganese yield (kg/ha/year in DM), zinc yield (kg/ha/year in DM), or Ferrum yield (kg/ha/year in DM). However, the nitrogen dose tended to increase total yield in FM (ton/ha/year in FM) and other productivity parameters such as stem biomass (ton/ha/year in DM), organic matter, calcium, or magnesium yield (ton/ha/year in DM). The inorganic nitrogen fertilizer resulted in the highest total yield in FM (ton/ha/year in FM) compared to natural nitrogen fertilizer and without nitrogen fertilizer treatment.

As shown in Table 3, the form of nitrogen fertilizer did not significantly affect stem biomass, ash biomass, organic matter yield, crude protein yield, nitrogen yields, calcium yield, phosphorus yield, or magnesium yield (ton/ha/year in DM). Moreover, the nitrogen form tended to increase total yield in DM (ton/ha/year in DM) and other productivity parameters such as leaf biomass (ton/ha/year in DM), crude fiber biomass (ton/ha/year in DM), magnesium biomass (ton/ha/year in DM), and sodium yield (ton/ha/year in DM).

The effect of nitrogen fertilizer dosage on the nutrient content of Napier grass (*Pennisetum purpureum*) was presented in Table 4. Nitrogen fertilizer dosage has a significant impact ($p<0.05$) in increasing calcium content (% DM) but decreases potassium (% DM) and manganese content (mg/kg). Furthermore, following a quadratic pattern, the nitrogen dose decreased manganese content (mg/kg). The nitrogen fertilizer dosage that resulted in the lowest manganese content was 192.74 kg N/ha/year; however, it will increase when N fertilizer doses are higher (Figure 2b). Nitrogen fertilizer dosage did not have any effect ($p>0.05$) on the content of dry matter, organic matter, crude protein, crude protein in leaves, crude fiber, NDF, ADF, nitrogen, phosphorus, magnesium, sodium, copper, zinc, and Ferrum content. Furthermore, nitrogen fertilizer dosage tended to increase magnesium content (% DM).

Additionally, as demonstrated in Table 5, the nitrogen fertilizer form has a significant effect ($p<0.05$) on dry matter content but not on other nutrient content of Napier grass ($p>0.05$).

The effects of nitrogen fertilizer dosage and form on in vitro digestibility were presented in Table 6 and 7. The nitrogen fertilizer dosage has a significant impact ($p<0.05$) on the parameter of in vitro digestibility dry matter (IVDMD) of Napier grass, but nitrogen fertilizer form did not have a significant effect ($p>0.05$) on this parameter. In addition, the nitrogen dose decreased IVDMD by following a quadratic pattern. The nitrogen fertilizer dose that gave the lowest IVDMD was 452.17 kg N/ha/year in DM; however, it will increase when N fertilizer doses are higher (Figure 2c).

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Table-2. Regression equations on the influence of nitrogen fertilizer doses on productivity parameters

Parameter	Unit	Model	N	Parameter estimates				Model estimates	
				Intercept	SE Intercept	Slope	SE Slope	p-value	AIC
Total yield	ton/ha/year in DM	Quadratic	360	27.76	4.89	0.029	0.007101	0.0363	3052
						-0.00000971	0.00000462		
Total yield	ton/ha/year in FM	Linear	90	157.8	31.9891	0.04086	0.02178	0.0643	1048.3
Plant height	cm	Linear	148	158.71	22.4607	0.0743	0.01692	<.0001	1541.3
Leaf biomass	ton/ha/year in DM	Linear	38	6.6862	1.2886	0.004232	0.000905	<.0001	213.2
Stem biomass	ton/ha/year in DM	Linear	38	25.8143	3.5722	0.004978	0.002625	0.0664	283
Trash biomass	ton/ha/year in DM	Linear	34	3.3072	0.9943	0.000317	0.000666	0.6374	150.5
Ash biomass	ton/ha/year in DM	Linear	58	4.821	1.5595	0.004969	0.002462	0.0486	287.7
Organic matter yield	ton/ha/year in DM	Linear	12	51.3785	8.9092	0.03846	8.9092	0.0781	104.6
Crude protein yield	ton/ha/year in DM	Linear	106	2.644	1.6008	0.004629	0.001475	0.0023	508
Crude protein leaf yield	ton/ha/year in DM	Linear	12	2.283	0.626	-0.00153	0.002676	0.5797	21.3
Crude fiber yield	ton/ha/year in DM	Linear	42	11.0619	7.3754	-0.00223	0.03764	0.9532	293.1
NDF yield	ton/ha/year in DM	Linear	75	25.3346	10.9433	0.01917	0.01577	0.2285	664.2
ADF yield	ton/ha/year in DM	Linear	56	18.472	8.3733	0.007655	0.01	0.4476	441.9
Nitrogen yield	ton/ha/year in DM	Linear	130	0.4413	0.1656	0.000454	0.000173	0.01	242
Calcium yield	ton/ha/year in DM	Linear	27	0.02176	0.01883	0.000011	0.00000603	0.0728	-141.8
Phosphorus yield	ton/ha/year in DM	Linear	16	0.02462	0.006138	0.000016	0.0000058	0.0173	-95.4
K (potassium) yield	ton/ha/year in DM	Linear	35	0.3527	0.2936	0.000253	0.000098	0.0147	8.3
Mg (Magnesium) yield	ton/ha/year in DM	Linear	27	0.03137	0.03347	0.000016	0.0000089	0.093	-121.5
Na (Sodium) yield	ton/ha/year in DM	Linear	27	0.000752	0.000527	-0.0000013	0.0000013	0.3199	-221.8
Cu (Cuprum) yield	kg/ha/year in DM	Linear	12	0.1673	0.02182	0.000144	0.000095	0.1619	-15.1
Mn (Manganese) yield	kg/ha/year in DM	Linear	12	2.0767	0.4552	0.003224	0.001987	0.1357	45.7
Zn (Zinc) yield	kg/ha/year in DM	Linear	12	0.2253	0.02283	0.000108	0.0001	0.3054	-14.2
Fe (Ferrum) yield	kg/ha/year in DM	Linear	12	2.4727	0.2807	0.000718	0.001225	0.5707	36

NDF = Neutral Detergent Fiber, ADF = Acid Detergent Fiber

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Table-3. Influence of nitrogen fertilizer form on productivity parameters

Parameter	Unit	N	Nitrogen Form			p-value
			Control	Organic	Inorganic	
Total yield	ton/ha/year in DM	360	32.4235	34.8727	37.6592	0.076
Total yield	ton/ha/year in FM	90	125.98[a]	n.d	190.63[b]	0.0168
Plant height	cm	148	163.57[a]	192.03ab	198.7[b]	0.0167
Leaf biomass	ton/ha/year in DM	38	6.6736[a]	n.d	11.609[b]	0.0256
Stem biomass	ton/ha/year in DM	38	23.354	n.d	32.8607	0.0609
Trash biomass	ton/ha/year in DM	34	2.9	n.d	3.8475	0.4655
Ash biomass	ton/ha/year in DM	58	4.9657	7.9853	4.8092	0.207
Organic matter yield	ton/ha/year in DM	12	48.16	70.014	37.48	0.2285
Crude protein yield	ton/ha/year in DM	106	3.8657	5.167	4.0857	0.5576
Crude protein leaf yield	ton/ha/year in DM	12	n.d	1.9663	1.855	0.6107
Crude fiber yield	ton/ha/year in DM	42	11.2933	n.d	10.8559	0.9276
NDF yield	ton/ha/year in DM	75	25.1563	54.3347	27.798	0.0735
ADF yield	ton/ha/year in DM	56	21.6022	33.5192	18.5609	0.1694
Nitrogen yield	ton/ha/year in DM	130	0.5874	0.6842	0.5753	0.8856
Calcium yield	ton/ha/year in DM	27	0.02167	nd	0.02584	0.3142
Phosphorus yield	ton/ha/year in DM	16	0.02831	0.02836	0.03065	0.6537
K (potassium) yield	ton/ha/year in DM	35	0.3253[a]	nd	0.4703[b]	0.0489
Mg (Magnesium) yield	ton/ha/year in DM	27	0.03167	nd	0.03691	0.3933
Na (Sodium) yield	ton/ha/year in DM	27	0.001667	nd	0.0000064	0.0606
Cu (Cuprum) yield	kg/ha/year in DM	12	0.15	n.d	0.2067	0.1
Mn (Manganese) yield	kg/ha/year in DM	12	2.7867	n.d	2.5922	0.8033
Zn (Zinc) yield	kg/ha/year in DM	12	0.22	n.d	0.2522	0.3721
Fe (Ferrum) yield	kg/ha/year in DM	12	2.6467	n.d	2.5822	0.8825

NDF = Neutral Detergent Fiber, ADF = Acid Detergent Fiber, n.d = no available data

Table-4. Regression equations on the influence of nitrogen fertilizer doses on the nutritional content of Napier grass

Parameter	Unit	Model	N	Parameter estimates				Model estimates	
				Intercept	SE Intercept	Slope	SE Slope	p-value	AIC
Dry matter	Nutrient content of grass % FM	Linear	90	20.8047	2.4769	0.000957	0.000655	0.1481	442.4
Organic matter	% DM	Linier	12	84.2834	0.5397	0.000391	0.001187	0.7488	48.5
Crude protein	% DM	Linier	106	10.9312	1.7014	0.00345	0.002649	0.1959	650.8
Crude protein leaf	% DM	Linear	12	12.4872	1.7776	0.002141	0.007597	0.7839	42.2
Crude fiber	% DM	Linier	42	27.3362	3.3917	-0.02244	0.01334	0.1005	210.7
NDF	% DM	Linier	75	62.6906	5.4406	0.003206	0.004946	0.519	483.7

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Parameter	Unit	Model	N	Parameter estimates				Model estimates	
				Intercept	SE Intercept	Slope	SE Slope	p-value	AIC
ADF	% DM	Linier	56	40.6086	1.281	-0.00126	0.001732	0.4703	258.4
N (Nitrogen)	% DM	Linier	140	1.3446	0.3312	0.000328	0.000316	0.3025	431.2
Ca (Calcium)	% DM	Linier	35	0.2892	0.05005	0.000227	0.000072	0.0034	-25.8
P (Phosphorus)	% DM	Linier	28	0.1622	0.02276	0.000049	0.000036	0.1888	-82.6
K (Potassium)	% DM	Linier	43	2.8163	0.4942	-0.00076	0.000276	0.0088	90.2
Mg (Magnesium)	% DM	Linier	35	0.2533	0.09519	0.000088	0.000045	0.0584	-59.1
Na (Sodium)	% DM	Linier	35	0.04276	0.01668	0.000013	0.0000083	0.1372	-170
Cu (Cuprum)	mg/kg	Linier	39	9.6948	1.2381	-0.00042	0.00096	0.6629	175.2
Mn (Manganese)	mg/kg	Quadratic	12	208.14	25.99	-0.717 0.00186	0.33 0.00076	0.0376	133
Zn (Zinc)	mg/kg	Linear	12	17.7333	1.438	-0.00419	0.006276	0.5194	68.7
Fe (Ferrum)	mg/kg	Linier	12	196.6	17.8396	-0.08629	0.07786	0.2937	119.1

NDF = Neutral Detergent Fiber, ADF = Acid Detergent Fiber, n.d = no available data

Table 5. Influence of nitrogen fertilizer form on the nutritional content of Napier grass

Parameter	Unit	N	Nitrogen Form			p-value
			Control	Organic	Inorganic	
Dry matter	Nutrient content of grass % FM	90	19.8699[a]	nd	21.5981[b]	0.0295
Organic matter	% DM	12	83.47	84.571	83.94	0.5914
Crude protein	% DM	106	12.2959	10.9527	12.3364	0.7803
Crude protein leaf	% DM	12	n.d	12.9163	13.1125	0.7499
Crude fiber	% DM	42	26.2902	n.d	25.754	0.7613
NDF	% DM	75	60.5795	66.1836	63.619	0.3545
ADF	% DM	56	37.25	41.01	39.92	0.1805
N (Nitrogen)	% DM	140	1.3892	1.3516	1.5285	0.7417
Ca (Calcium)	% DM	35	0.3355	n.d.	0.3986	0.2834
P (Phosphorus)	% DM	28	0.1731	0.2088	0.1783	0.4013
K (Potassium)	% DM	43	2.7512	nd	2.4172	0.113
Mg (Magnesium)	% DM	35	0.2834	nd	0.2946	0.7177
Na (Sodium)	% DM	35	0.04603	nd	0.04897	0.5976
Cu (Cuprum)	mg/kg	39	8.944	nd	9.8603	0.1925
Mn (Manganese)	mg/kg	12	216.67	n.d	168.44	0.2055
Zinc	mg/kg	12	17	n.d	17	1
Zn (Zinc)	mg/kg	12	206.33	n.d	173.22	0.2343

NDF = Neutral Detergent Fiber, ADF = Acid Detergent Fiber, n.d = no available data

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Table-6. Regression equations on the influence of nitrogen fertilizer doses on *in vitro* digestibility of Napier grass

Parameter	Unit	Model	N	Parameter estimates				Model estimates	
				Intercept	SE Intercept	Slope	SE Slope	p-value	AIC
In vitro digestibility	% DM	quadratic	80	64.74	2.11	-0.0208	0.00922	0.0171	526
						0.000023	0.00000961		

Table-7. Influence of nitrogen fertilizer form on *in vitro* digestibility of Napier grass

Parameter	Unit	N	Nitrogen Form			p-value
			Control	Organic	Inorganic	
In vitro digestibility	% DM	80	65.8979	63.3009	63.4131	0.5442

Discussion

The increase in the production of dry matter forage (TDMY) in grass due to the higher dosage of N fertilizer has been reported by several studies (Alves et al., 2022; Lopes et al., 2020; Oliveira et al., 2022). Previous studies have shown variations in the optimum N dosage to improve TDMY, including N application at 224 kg N/ha (Jungers et al., 2015) and 269 kg N/ha (Haque et al., 2009). In contrast, Dokbua et al. (2021) study reported that N fertilization at a dose of 1000 kg N/ha did not lead to a decline in TDMY. The current meta-analysis study results indicate a quadratic curve between N dosage fertilizer and TDMY, in which the optimal N fertilizer dosage is 1493.30 kg N/ha/year (Figure 2). The contribution of N fertilizer to the increase in TDMY is due to the role of N in enhancing metabolic processes, providing assimilated materials, and transforming them into plant organs (Kakabouki et al., 2022). The increase in TDMY due to N fertilization can also be observed in Napier grass's increased leaf biomass from increased N doses (Table 2). The increase in TDMY due to N fertilization can also be observed in Napier grass's increased leaf biomass from increased N doses (Table 2). Nitrogen is one of the most important nutrients for plant growth and development, increasing leaf area and leaf number and directly impacting the vegetative and reproductive phases (Zhang et al., 2014). The increase in leaf biomass and leaf area can enhance TDMY in plants (Chowdhury et al., 2020; Fanindi et al., 2019). The increase in plant height due to N fertilizer is strongly related to plant development, as increasing N doses of fertilizer could stimulate stem growth and overall grass development (Dokbua et al., 2021). Furthermore, increased N fertilization can promote vegetative growth by enhancing N uptake and its role in photosynthesis and carbon dioxide assimilation (Barandozi et al., 2011).

The form of inorganic N fertilizer enhances fresh matter production, plant height, and leaf biomass, possibly due to the quicker availability of N inorganic fertilizers. Inorganic fertilizers are advantageous for fast-growing plants because their nutrients are already soluble in water. Therefore, their effects are usually immediate and rapid, containing all the necessary nutrients ready for use. Inorganic fertilizers have a relatively high nutrient content and require only a relatively small amount for productivity. The appropriate application of inorganic fertilizers can increase soil organic matter through increased root mass and crop residues (Han et al., 2016). Nevertheless, N fertilizer does not affect other productivity parameters, including dry matter production (TDMY). Including organic N fertilizer increased the organic matter production of Napier grass, which had higher organic matter production than control (46.5%) and inorganic N (31.4%). This indicates that the inclusion of organic N fertilizers in Napier grass cultivation didn't have significance on most of the parameters observed in one year because organic fertilizer has a long-term fertilization effect. Several researchers stated that organic nitrogen

fertilizer balances nutrient supply, including micronutrients
(Han et al., 2016; Kępka et al., 2016, 2017). They also increase nutrient availability through enhanced soil microbial activity, decomposing harmful elements, improving soil structure and root development, and increasing groundwater availability (Han et al., 2016). Other studies also demonstrated that utilizing organic N fertilizers has more significant long-term effects than inorganic fertilizers (Bhatt et al., 2019; Ma et al., 2023).

An increase in calcium (Ca) content with the rising N fertilizer dosage has been reported in various plants, such as grass (Cardoso et al., 2020), Napier grass (Pakwan et al., 2020), and rice (Shi et al., 2023). Increased mineral Ca may be due to greater extraction and higher nitrogen, calcium, and magnesium levels in the green leaves of livestock feed due to nitrogen fertilization, as described by Britz et al. (Britz et al., 2023). Furthermore, N fertilization enhances root growth, increasing plants' ability to acquire nutrients, including minerals (Zhen et al., 2020). The present study indicates decreased potassium (K) and manganese (Mn) content with increasing N fertilization. The lowest Mn content in Napier grass occurs at an N fertilization dose of 192.74 kg N/ha/year; however, it will expand when N fertilizer doses are higher (Figure 2b). This decrease is due to the competition of mineral elements related to absorption, function, and transportation within plants (Shi et al., 2023). For instance, increased Cu ions will reduce K in plant roots (Zhen et al., 2020). Likewise, research on tomato plants demonstrates a positive correlation between increased N and Ca, Fe, and Zn but a negative correlation with P; meanwhile, an increase in Mn in plants will decrease Ca, Mg, and K (Olaniyi and Ajibola, 2008). However, according to Caldelas et al. (Caldelas et al., 2023) was particular to the location, variations between environments, and varieties, which can lead to differing mineral content.

The results of this meta-analysis indicate that the use of organic and inorganic N fertilizer forms did not significantly affect Napier grass's productivity and nutrient content. This study also demonstrates that applying a single form of N fertilizer did not show optimal results. Since single forms of inorganic fertilizers do not always provide higher nutrient availability in the soil than organic fertilizers, the same things happen. This may be affected by the plant's growing environment, such as excessive rainfall, which causes the plants to lack N nutrients (Lin et al., 2023). Moreover, it caused the absence of a combination of N nutrients with other nutrients like potassium (K) (Dokbua et al., 2021) and phosphorus (Kebede et al., 2016). Even though, as Bhatt et al. (Bhatt et al., 2019) study, soils that are given both organic and inorganic fertilization will have better nutritional value than those that do not receive fertilization. Furthermore, it has been reported that soil type and fertility condition, as it is related to the availability of N, phosphorus, and organic matter in the soil, is a matter to determine the form of N fertilizers (Ma et al., 2023). Therefore, applying a combination of organic and inorganic N with the appropriate dosage is necessary to ensure nutrient availability in the soil for livestock without causing soil damage due to excessive chemical inputs.

The current meta-analysis study showed that N fertilizer dosage increases up to 452.17 kg N/ha/year could decrease the IVDMD rate; however, it increases when higher amounts of N fertilizer are applied (Figure 2c). Neves et al. (Neves et al., 2019) stated that 200 kg/ha of N fertilizer can increase the protein content and in vitro digestibility of dry matter in *Brachiaria brizantha* cv. Marandu due to the increased nutrient uptake efficiency by Brachiaria plants. Moreover, the increase in IVDMD indicates a tendency to decrease linearly crude fiber and ADF, which aligns with the findings of Ma et al. (2020). The authors reported that IVDMD was negatively correlated with ADF and NDF but positively correlated with CP (Ma et al., 2020). In forages, the ADF concentration indicates the ratio of cell wall components that comprise cellulose and lignin. Lignin, consisting of a structurally different, non-repeating hydrophobic aromatic unit, is considered a physical barrier for rumen microbes and their enzymes (Gharechahi et al., 2023). The increased lignin content in the forage will make it difficult to digest feed nutrients.

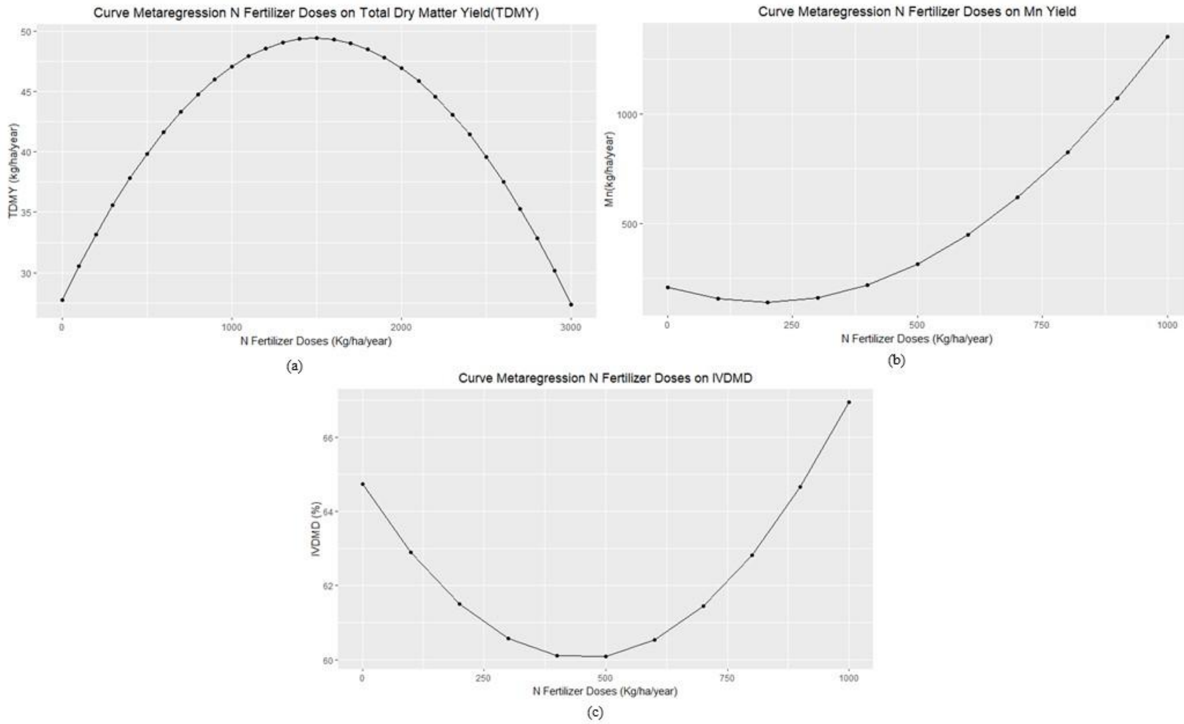

Figure-2. Curve Metaregression N Fertilizer Doses on (a) Total dry matter yield (TDMY); (b) Manganese (Mn) yield; (c) in vitro dry matter digestibility (IVDMD)

Conclusions

This present meta-analysis revealed the positive impact of the inclusion of nitrogen fertilizer and the nutrition content of Napier grass. The optimum N fertilizer dose that produces the best total yield dry matter was 1,493.31 kg N/ha/year. Meanwhile, the lowest Mn content and IVDMD occurred when doses of N fertilizer were 192.74 kg N/ha/year and 452.17 kg N/ha/year; however, it will increase when N fertilizer doses are higher. Both organic and inorganic N fertilizer forms almost did not significantly affect Napier grass's productivity and nutrient content, except for plant height. Since applying a single form of N fertilizer did not yield optimal results, it is recommended to use a combination of organic and inorganic N fertilizers with the appropriate dosage to ensure nutrient availability in the soil. The N fertilizer type and dosage selection should be made judiciously, considering specific objectives and environmental factors to optimize forage production and nutrient content.

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Contribution of Authors

Rahman R, Hidayat C, Krisnan R & Fanindi A: Designed research methodology, collected, analyzed and interpreted data, wrote original draft, reviewed and edited manuscript.

Kurniawan W, Bain A, Malesi L & Napirah A: Wrote and edited manuscript, project administration.

Sajimin S, Tresia GE, Harmini H & Sutedi E: Analysed and interpreted data, wrote original draft, reviewed and edited manuscript.

Pamungkas FA, Widodo S & Sholikin MM: Conceptualized, methodology and drafted the manuscript.

Herdiawan I, Isbandi I & Zulchi T: Wrote original draft, reviewed and edited manuscript, supervised the study and critically revised the manuscript for important intellectual content.
All authors have read and approved the final manuscript

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