Effects of NPK Fertilizer application and plant density on forage yield and chemical composition of wild sunflower (*Tithonia diversifolia*)

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Abstract

A study was conducted in 2017 and 2018, in the Forest Zone of southwestern Nigeria, to evaluate the yield and chemical composition of wild sunflower (Tithonia diversifolia) fertilized with compound fertilizer (20N:10P_2O_5:10K_2O), under different planting densities. Seedlings of 20-day old Tithonia diversifolia were transplanted on a site, in a split plot arrangement, with fertilizer application at 0, 50, 100, 200 and 400kg/ha, using a planting density of 83.3 ×10^3, 166.7 ×10^3, 222 ×10^3, 333 ×10^3, 500 ×10^3, and 1000 ×10^3 plants/ha. After 114-116 days of growth, the plants were harvested and analyzed for proximate composition. The highest whole plant DM yield occurred at 400 kg/ha fertilizer level and a population density of 333×10^3 plants/ha. Leaf and inflorescence DM yields peaked at 400 kg/ha fertilizer application while the best leaf yield and inflorescence response to density resulted from 333 ×10^3 plants/ha, regardless of year under investigation. Overall fertilizer treatments and across densities, the leaf and inflorescence fractions recorded 16.88-22.92 % and 14.38-15.10% CP, 12.09-13.24 % and 21.25-23.60 % CF, 4.89-5.60 % and 3.67-4.72 % EE and 13.42-14.84 % and 6.27-7.53 % ash, respectively. Results obtained suggest that the high biomass yield of Tithonia diversifolia combined with its satisfactory nutrient levels, qualifies the plant as a potential suitable feed supplement source for ruminant livestock.

Keywords: application rate, inflorescence, inorganic fertilizer, plant density, seedlings, soil.

Running title: *Effect of NPK fertilizer on wild sunflower*

Effets de l'application d'engrais NPK et de la densité des plantes sur le rendement fourrager et la composition chimique du tournesol sauvage (*Tithonia diversifolia*)

Résumé

Une étude a été menée en 2017 et 2018, dans la zone forestière du sud-ouest du Nigéria, pour évaluer le rendement et la composition chimique du tournesol sauvage (Tithonia diversifolia) fertilisé avec un engrais composé (20N:10P2O5:10K2O), sous différentes densités de plantation. Des semis de Tithonia diversifolia âgés de 20 jours ont été transplantés sur un site, dans une disposition en parcelles divisées, avec une application d'engrais à 0, 50, 100, 200 et 400 kg/ha, en utilisant une densité de plantation de 83,3 × 103, 166,7 × 103, 222. ×103, 333 ×103, 500 ×103 et 1 000 ×103 plants/ha. Après 114 à 116 jours de croissance, les plantes ont été récoltées et analysées pour déterminer leur composition immédiate. Le rendement le plus élevé en matière sèche de plante entière a été obtenu avec un niveau d'engrais de 400 kg/ha et une densité de population de 333 × 103 plantes/ha. Les rendements en matière sèche des feuilles et des *inflorescences ont culminé à 400 kg/ha d'application d'engrais, tandis que le meilleur rendement foliaire et la meilleure réponse de l'inflorescence à la densité résultaient de 333 × 103 plantes/ha, quelle que soit l'année étudiée. Dans l'ensemble des traitements d'engrais et selon les densités, les fractions de feuilles et d'inflorescences ont enregistré 16,88-22,92 % et 14,38-15,10 % CP, 12,09-13,24 % et 21,25-23,60 % CF, 4,89-5,60 % et 3,67-4,72 % EE et 13,42-14,84 %. et 6,27 à 7,53 % de cendres, respectivement. Les résultats obtenus suggèrent que le rendement élevé en biomasse de Tithonia diversifolia, combiné à ses niveaux de nutriments satisfaisants, qualifie la plante comme une source potentielle de complément alimentaire appropriée pour le bétail des ruminants.*

Mots-clés : taux d'application, inflorescence, engrais inorganique, densité des plantes, semis, sol.

Introduction

Wild or Mexican sunflower, or marigold (*Tithonia diversifolia* [Hemsl.] A. Gray), is a tropical herbaceous or shrub-like annual, biennial or sub-perennial plant, depending on the habitat (Akinola *et al.,* 2000; Xu *et al.,* 2007; Odedire and Oloidi, 2011). It is native to North and Central America but naturalized in Africa, Australia and Asia (Duarte and Empinotti, 2012). The plant is an aggressive invader of fallow lands and grows luxuriantly on roadsides and abandoned sites, with reported claims of farmers deserting their lands due to control difficulties (Chukwuka *et al*., 2007). The aggressiveness and dominance over neighbouring vegetation have been attributed to the large biomass, extensive root system and allelopathic properties (Baruah *et al*., 1994; Oludare and Moughalu, 2014). *Tithonia diversifolia* averages 1-4 m in height (Mayara *et al*., 2016; Mauricio *et al*., 2017) but stands 5.3 m tall and up to 5.5 m in spread have been observed in southwestern Nigeria (Akinola, unpublished).

Notwithstanding its menace of invasiveness, *T. diversifolia* is used as green manure and a soil fertility improver (Olabode, 2007; Ndoli *et al.,* 2012) as well as a yield increaser of vegetable crops in general and maize in particular (Jama *et al*., 2000; Sangakkara *et al.,* 2002). Adesodun *et al*. (2010) reported its efficacy in remediating soils contaminated with zinc and lead. Tithonia has been described as pesticidal (John–Dewole and Oni, 2013; Omokhua *et al*., 2018). Ezeonwumelu *et al*. (2012), Tonia *et al*. (2016), Ajao and Moteetee (2017), Omokhua *et al*. (2018) and Souza-Silva *et al*. (2020) credited the plant with an array of formidable pharmacological properties, principal among which are anti-microbial, anti-inflammatory, anti -parasitic, anti-diabetic and anti-hyperglycemic. Nephro-and hepato-toxicity resulted from an overdose of the aqueous extract (Passoni *et al*., 2013) or a low dose of 70% ethanolic extract (Elufioye *et al*., 2009) of the aerial parts. There is a paucity of information in the literature on the agronomic and nutritive potential of *Tithonia diversifolia*. The objective of this study was to investigate the effects of a range of compound fertilizer NPK levels and plant population densities on its forage yield and proximate composition.

Materials and methods

Location

The trials were conducted during the 2017 and 2018 growing seasons. *Tithonia diversifolia* plots were established at a location, 4km from the Osun State College of Education, Ilesa ($7^0$36N, $4^0$42'E, 396 m asl) in the Forest Zone of southwestern Nigeria. There is no meteorological station at Ilesa but the Obafemi Awolowo University, Ile-Ife ($7^0$28'N, $4^0$38'E, 244m asl), 25km West of Ilesa, is characterized by a 1270-2500mm (mean 1684mm) annual rainfall with peaks in July and

September. The dry season lasts from December to February. Usual mean temperatures are 31.5^{0}C (max) and 21.5^{0}C (min) while the relative humidity averages 69%. The experimental site was, prior to the study, under fallow dominated by *Chromolaena odorata* and local *Panicum maximum* cultivar. Table 1 presents the physical and chemical properties of the soil taken from the top 0 -15cm layer before the trial.

Table 1: Properties of the top soil (0 – 15cm) samples from the experimental site before planting in 2017

Soil Property	Value
Clay (%)	18.3
Silt (%)	10.8
Sand (%)	70.9
pH (1:1, soil: water)	6.2
Organic Carbon	2.57
Total N (%)	0.15
Available P (Bray 1), ppm	8.57
K (cmol (+)/kg)	0.082
Ca (cmol (+)/kg)	1.77
Mg (cmol (+)/kg)	0.26

Experimental design and treatment

The land was prepared by ploughing twice and harrowing. The experiment was laid out in a split-plot design with three replications. The main plots were five compound fertilizer levels (0, 50, 100, 200 and 400 kg/ha of 20N:10P_2O_5:10K_2O) and the sub-plots, six spacings (60×20, 60×10, 45×10, 30×10, 20×10 and 10×10cm) to provide population densities of 83.3×10^3, 166.7×10^3, 222.3×10^3, 333.3×10^3, 500×10^3 and 1000×10^3 plants /ha, respectively). The sub-plots measured 4.8 x 3.6m and were separated by 2m paths. The fertilizer was hand broadcast and thoroughly raked into the soil. Twenty-day old (post emergence) *T. diversifolia* seedlings were carefully uprooted from a nearby field and transplanted according to the spacing required, from August 11-14 in 2017 and August 14-17 in 2018. Weeds were controlled by hand hoeing five weeks after transplanting.

Determination of forage yield and proximate composition

Forage dry matter yield was evaluated from the inner 1.20-1.35 × 2.4 m portion of each plot at about 50% first inflorescence opening. This equalled 116 and 114 days after transplanting in 2017 and 2018, respectively. At harvest, plants were cut with a sharp knife at ground level and weighed fresh. 500-600g sub-samples were taken and separated into the stem (inflorescence stalk inclusive), leaf (fresh and senesced) and inflorescence (capitulum) components, weighed, oven – dried at 80^{o}C for 48 hours and re-weighed for dry matter estimation. The dried plant fractions were ground and analyzed for nitrogen (AOAC, 2005), crude fibre, either extract and ash. Crude protein was calculated as N x 6.25.

Statistical analysis

Data obtained were analyzed using the General Linear Model of SAS (2008) and the Duncan New Multiple Range Test (Year?)was applied to test for significant differences among the treatment means.

Results

Dry matter yield

Table 2 shows that the effects of NPK fertilizer and plant density as well as those of fertilizer × density interactions for whole – plant DM yield in 2017 and 2018 were significant ($P < 0.05$). Highest yield was recorded at the highest fertilizer application level, 400 kg /ha, while 333×10^3 plants /ha resulted in the highest Leaf DM yield although this was not significantly different ($P>0.05$) from yields at either 222×10^3 or 500× 10^3 plants /ha. Generally, the lowest yields were observed from unfertilized plots and those grown at the highest and lowest densities in both experimental years (Table 3). Over all densities, 400 kg NPK / ha produced the highest yield and across all fertilizer rates, 222×10^3 and 333×10^3 plants /ha were the most productive. Inflorescence yield was highest at the highest fertilizer level and lowest without fertilizer (Table 4). The yield at 50kg/ha did not differ significantly from that without fertilizer in 2017 but surpassed it in 2018. At 400kg NPK /ha, yield levels were highest and similar for 222×10^3 and 333×10^3 /ha irrespective of year. The indications were that *T. diversifolia* might respond to still higher NPK rates but not densities beyond 222×10^3 and 333×10^3 plants /ha in this and similar environments.

Table 2: Whole plant dry matter yield (kg/ha) of *Tithonia diversifolia* grown at five NPK levels and six plant population densities in 2017 and 2018

Year	Fertilizer level	Density (Plants /ha × 10^3)						
		83.3	**166.7**	**222**	**333**	**500**	**1000**	**Mean**
	0	7849	7944	9363	8875	8115	7275	8237^g
	50	9210	10237	11481	11615	11030	9354	10488^g
	100	10788	11652	13725	15572	14123	11678	12923^h
	200	14116	16944	18176	19830	19249	17071	17564^i
2017	400	18103	21375	24417	24765	24003	22131	22466^j
	Mean	12013^a	13631^b	15433^{cd}	16131^d	15304^c	13502^{ab}	14336
	S.E.D. (F)	962.7						
	S.E.D. (D)	497.5						
	S.E. D. (F*D)	2167.1						
	0	7094	7698	8061	7133	6892	5869	7095^g
	50	8913	9727	10690	10550	9827	7752	9576^h
	100	10566	12043	15529	14983	13424	11639	13031^i
	200	13161	15627	18155	21439	20691	17842	17819^j
2018	400	17296	20481	24833	26528	26774	23001	23152^k
	Mean	11406^a	13115^b	15454^c	16127^c	15522^c	13185^b	14135
	S.E.D. (F)	1005.0						
	S.E. D. (D)	540.3						
	S.E.D. (F*D)	2267.2						

F= Fertilizer NPK; D= Population density; ^{a,b,c,d} Means across rows with different superscripts differ significantly (P<0.05); ^{g,h,i,j,k} Means within column with different superscripts differ significantly (P<0.05).

Table 3: Leaf dry matter yield (kg/ha) of *Tithonia diversifolia* grown at five NPK levels and six plant population densities in 2017 and 2018

Year	Fertilizer level	Density (Plants /ha × 10^3)						
		83.3	**166.7**	**222**	**333**	**500**	**1000**	**Mean**
	0	3124	2987	3511	3168	2694	2415	2983^g
	50	3408	3685	4168	4639	3518	2890	3718^h
	100	3808	3808	4667	5092	4308	3445	4225^i
	200	4249	4249	5380	5275	5255	4158	4903^j
2017	400	5105	5105	6568	6141	6049	4901	5753^k

	Mean	3939^{b}	4311^{c}	4859^{d}	4863^{d}	4365^{c}	3562^{a}	4316
	S.E.D. (F)	216.8						
	S.E.D. (D)	123.0						
	S.E. D. (F*D)	490.7						
2018	0	2809	2995	3031	2768	2488	1971	2677^{g}
	50	3476	3590	3603	3774	3282	2589	3386^{h}
	100	4014	4323	5264	5139	4416	3851	4501^{i}
	200	4027	5141	5507	6497	6023	5014	5368^{j}
	400	5120	6165	7127	7189	7256	5896	6459^{k}
	Mean	3889^{a}	4443^{b}	4906^{c}	5073^{d}	4693^{bc}	3865^{a}	4478
	S.E.D. (F)	222.7						
	S.E. D. (D)	161.0						
	S.E.D. (F*D)	513.7						

F= Fertilizer NPK; D= Population density; ^{a,b,c,d} Means across rows with different superscripts differ significantly (P<0.05); ^{g,h,i,j,k} Means within column with different superscripts differ significantly (P<0.05).

Table 4: Inflorescence dry matter yield (kg/ha) of *Tithonia diversifolia* grown at five NPK levels and six plant population densities in 2017 and 2018

Year	Fertilizer level	Density (Plants /ha × 10^3)						
		83.3	**166.7**	**222**	**333**	**500**	**1000**	**Mean**
2017	0	298.3	287.7	353.3	312.0	326.7	271.3	308.2^{g}
	50	314.7	332.0	373.3	384.0	359.0	296.3	343.2^{gh}
	100	345.7	374.3	434,3	500.7	414.3	349.3	403.1^{i}
	200	394.0	479.7	489.0	540.7	493.7	442.7	473.3^{i}
	400	495.3	555.3	605.3	615.0	578.3	537.3	564.4^{j}
	Mean	369.6^{a}	405.8^{bc}	451.1^{de}	470.5^{e}	434.4^{cd}	379.4^{ab}	418.5
	S.E.D. (F)	17.39						
	S.E.D. (D)	12.43						
	S.E. D. (F*D)	40.07						
2018	0	261.7	280.7	272.3	245.0	209.7	177.3	241.1^{g}
	50	331.3	342.0	354.7	345.7	299.3	241.0	319.0^{h}
	100	369.7	395.7	494.7	481.0	403.7	333.7	413.1^{i}
	200	433.0	485.7	506.3	631.7	596.3	498.3	525.2^{j}
	400	506.3	557.0	682.7	684.3	676.7	550.7	609.6^{k}
	Mean	380.4^{a}	412.2^{b}	462.1^{cd}	477.5^{d}	437.1^{bc}	360.2^{a}	421.6
	S.E.D. (F)	12.14						
	S.E. D. (D)	14.24						
	S.E.D. (F*D)	30.18						

F= Fertilizer NPK; D= Population density; ^{a,b,c,d,e} Means across rows with different superscripts differ significantly (P<0.05); ^{g,h,i,j,k} Means within column with different superscripts differ significantly (P<0.05).

Crude protein content

The effects of fertilizer, density and their interaction on leaf CP content were significant (P<0.05) for both years (Table 5). Mean values tended to increase as fertilizer rate rose although responses to 200 and 400 kg were not significantly different and to decrease with denser planting. The combination of 400kg NPK/ha (highest) and a population density of 83.3×10^3 plants /ha (lowest) resulted in the highest leaf CP contents (over 25%) while the densest population (1000×10^3 plants /ha) without fertilizer produced leaves with the lowest CP content (about 15%). Table 6 illustrates the non – significant (P>0.05) effect of fertilizer on inflorescence CP content in both 2017 and 2018 and that of density in 2018. In 2017, inflorescences contained significantly (P<0.05) higher CP at 83.3×10^3 and 166.7×10^3 plants /ha than at higher densities.

Table 5: Leaf crude protein content (% DM) of *Tithonia diversifolia* grown at five NPK levels and six plant population densities in 2017 and 2018

Year	Fertilizer level	Density (Plants /ha × 10^3)						
		83.3	166.7	222	333	500	1000	Mean
	0	17.80	17.27	17.70	16.53	16.17	15.83	16.88^{g}
	50	22.17	19.60	19.63	19.70	18.93	19.00	19.84^{h}
	100	24.00	24.20	22.90	19.90	20.17	18.87	21.67^{i}
	200	23.83	22.87	22.07	21.67	21.00	20.07	21.92^{j}
2017	400	25.10	24.37	23.90	21.93	21.33	20.90	22.92^{j}
	Mean	22.58^{c}	21.66^{b}	21.24^{bc}	19.95^{a}	19.52^{a}	18.93^{a}	20.65
	S.E.D. (F)	0.600						
	S.E.D. (D)	0.431						
	S.E. D. (F*D)	1.383						
	0	18.30	17.90	17.31	17.00	16.00	15.20	16.94^{g}
	50	20.90	20.90	20.21	20.01	18.30	18.60	19.80^{h}
	100	23.30	23.30	21.90	19.60	18.90	19.70	21.12^{i}
	200	23.30	23.00	22.70	21.30	20.50	19.30	21.67^{ij}
2018	400	24.80	24.20	23.00	21.30	21.00	20.20	22.41^{j}
	Mean	22.10^{b}	21.85^{b}	21.01^{b}	19.84^{ab}	18.93^{a}	18.60^{a}	20.39
	S.E.D. (F)	0.376						
	S.E. D. (D)	0.263						
	S.E.D. (F*D)	0.865						

F= Fertilizer NPK; D= Population density; ^{a,b,c,d,e} Means across rows with different superscripts differ significantly (P<0.05); ^{g,h,i,j,} Means within column with different superscripts differ significantly (P<0.05).

Table 6: Inflorescence crude protein content (% DM) of *Tithonia diversifolia* grown at five NPK levels and six plant population densities in 2017 and 2018

Year	Fertilizer level	Density (Plants /ha × 10^3)						
		83.3	166.7	222	333	500	1000	Mean
	0	14.700	14.900	14.600	15.033	14.000	14.300	14.589
	50	15.200	15.200	14.433	13.900	14.200	14.400	14.556
	100	14.300	15.200	14.600	14.333	14.200	14.900	14.589

	200	15.500	15.400	14.733	14.733	14.800	14.400	14.928
2017	400	15.800	15.633	14.933	14.933	14.600	14.400	15.050
	Mean	15.100[b]	15.267[b]	14.660[a]	14.587[a]	14.360[a]	14.480[a]	14.742
	S.E.D. (F)	0.2709						
	S.E.D. (D)	0.1732						
	S.E. D. (F*D)	0.6182						
	0	13.933	14.300	14.267	14.500	13.833	13.933	14.128
	50	14.200	14.500	14.333	13.933	14.033	13.900	14.150
	100	15.033	14.033	14.500	14.600	13.900	14.133	14.367
	200	14.833	14.500	14.100	14.600	14.233	14.600	14.478
2018	400	15.233	14.833	14.833	14.667	14.400	14.300	14.711
	Mean	14.647	14.433	14.407	14.460	14.080	14.173	14.367
	S.E.D. (F)	0.2184						
	S.E. D. (D)	0.2376						
	S.E.D. (F*D)	0.5343						

F= Fertilizer NPK; D= Population density; [a,b] Means across rows with different superscripts differ significantly (P<0.05).

Crude fibre content

Leaf CF concentration was not significantly (P>0.05) affected by either fertilizer level or plant density for any year, although values appeared to decrease as NPK rate increased in both years as plant population increased in 2017 only (Table 7). Table 8 demonstrates a significant (P<0.05) decline in inflorescence CF value as NPK level increased whereas it was similar for the densities explored.

Table 7: Leaf crude fibre content (% DM) of *Tithonia diversifolia* grown at five NPK levels and six plant population densities in 2017 and 2018

Year	Fertilizer level	Density (Plants /ha × 10³)						
		83.3	**166.7**	**222**	**333**	**500**	**1000**	**Mean**
	0	12.90	13.30	12.87	12.70	13.50	11.97	12.87
	50	13.07	12.77	13.20	12.73	11.90	12.00	12.61
	100	12.67	12.83	12.47	12.27	12.57	12.43	12.54
	200	12.93	12.43	12.50	11.90	11.73	11.70	12.18
2017	400	12.63	12.33	12.27	12.10	11.30	11.93	12.09
	Mean	12.82	12.73	12.66	12.34	12.20	12.01	12.46
	S.E.D. (F)	0.376						
	S.E.D. (D)	0.263						
	S.E. D. (F*D)	0.865						
	0	13.63	12.87	13.30	14.00	12.60	13.07	13.24
	50	12.03	13.50	13.13	12.90	13.03	13.57	13.03
	100	12.70	13.00	12.77	13.70	12.80	12.87	12.97
	200	13.30	12.83	13.00	12.87	11.40	11.87	12.54
2018	400	12.97	12.83	12.70	12.00	12.30	12.33	12.52
	Mean	12.93	13.01	12.98	13.09	12.43	12.74	12.86

	S.E.D. (F)	0.364
	S.E. D. (D)	0.308
	S.E.D. (F*D)	0.854

F= Fertilizer NPK; D= Population density

Table 8: Inflorescence crude fibre content (% DM) of *Tithonia diversifolia* grown at five NPK levels and six plant population densities in 2017 and 2018

Year	Fertilizer level	Density (Plants /ha × 10^3)						
		83.3	**166.7**	**222**	**333**	**500**	**1000**	**Mean**
	0	23.77	23.10	23.63	22.87	23.33	22.87	23.26^h
	50	22.00	22.13	20.67	21.50	21.50	22.87	21.78^g
	100	21.63	22.13	20.70	21.13	22.00	21.73	21.56^g
	200	21.57	20.87	21.63	21.17	20.83	21.67	21.29^g
2017	400	21.10	21.07	20.73	21.50	21.43	21.67	21.25^g
	Mean	22.01	21.86	21.47	21.63	21.82	22.16	21.83
	S.E.D. (F)	0.475						
	S.E.D. (D)	0.648						
	S.E. D. (F*D)	1.226						
	0	22.73	23.67	23.67	23.53	23.97	24.03	23.60^i
	50	23.03	23.73	21.90	22.03	21.87	22.13	22.45^{gh}
	100	23.03	22.87	21.87	22.03	22.53	23.33	22.61^h
	200	22.63	22.90	21.87	21.67	21.80	22.03	22.15^g
2018	400	22.00	21.73	21.00	21.70	20.80	22.17	21.57^g
	Mean	22.69	22.98	22.06	22.19	22.19	22.74	22.48
	S.E.D. (F)	0.498						
	S.E. D. (D)	0.556						
	S.E.D. (F*D)	1.225						

F= Fertilizer NPK; D= Population density; g,h,i Means within column with different superscripts differ significantly (P<0.05).

Ether extract content

In 2017, per cent leaf EE was significantly (P<0.05) reduced as fertilizer increased from 0 to 400kg NPK /ha (Table 9). For both years, the response to density was also significant (P<0.05), with 500×10^3 plants /ha demonstrating the highest EE content. Significant (P<0.05) reduction in inflorescence EE per cent occurred as fertilizer level and plant density increased (Table 10). Mean highest values of 4.772% and 4.556% and lowest of 3.928% and 3.778% were recorded for 2017 and 2018, respectively.

Table 9: Leaf ether extract content (% DM) of *Tithonia diversifolia* grown at five NPK levels and six plant population densities in 2017 and 2018

Year	Fertilizer level	Density (Plants /ha × 10^3)						
		83.3	**166.7**	**222**	**333**	**500**	**1000**	**Mean**
	0	5.600	5.400	5.867	5.433	5.833	5.500	5.606^i
	50	5.133	5.100	5.300	5.367	5.767	5.333	5.333^{hi}

2017	100	5.367	4.667	4.933	5.700	5.533	5.700	5.317[hi]
	200	5.400	5.033	5.200	5.033	5.200	5.800	5.278[gh]
	400	4.833	4.633	4.967	5.333	5.300	5.000	5.011[g]
	Mean	5.27[ab]	4.967[a]	5.253[ab]	5.373[b]	5.527[b]	5.467[b]	5.309
	S.E.D. (F)	0.1371						
	S.E.D. (D)	0.1293						
	S.E. D. (F*D)	0.3271						
2018	0	5.267	4.867	5.600	5.467	5.400	5.200	5.300
	50	5.333	5.533	5.700	5.467	5.533	4.833	5.400
	100	5.000	4.900	5.700	5.267	5.800	4.767	5.239
	200	5.200	4.867	4.900	5.033	5.733	5.000	5.122
	400	4.733	4.633	5.233	5.300	5.500	4.633	5.006
	Mean	5.107[ab]	4.960[a]	5.427[c]	5.307[b]	5.593[c]	4.887[a]	5.213
	S.E.D. (F)	0.1558						
	S.E. D. (D)	0.1380						
	S.E.D. (F*D)	0.3681						

F= Fertilizer NPK; D= Population density; [a,b,c,] Means across rows with different superscripts differ significantly (P<0.05); [g,h,i,] Means within column with different superscripts differ significantly (P<0.05).

Table 10: Inflorescence Ether extract (% DM) of *Tithonia diversifolia* grown at five NPK levels and six plant population densities in 2017 and 2018

Year	Fertilizer level	Density (Plants /ha × 10^3)						
		83.3	166.7	222	333	500	1000	Mean
2017	0	4.600	4.533	4.767	4.433	4.333	4.667	4.556[i]
	50	5.000	4.467	4.300	4.667	4.467	4.233	4.522[i]
	100	4.233	4.333	4.033	4.000	4.067	4.200	4.144[h]
	200	4.223	3.967	3.700	3.900	4.000	3.733	3.922[g]
	400	3.900	3.967	3.867	3.733	3.700	3.500	3.778[g]
	Mean	4.393[b]	4.253[ab]	4.133[ab]	4.147[ab]	4.113[ab]	4.067[a]	4.184
	S.E.D. (F)	0.1111						
	S.E.D. (D)	0.0723						
	S.E. D. (F*D)	0.2540						
2018	0	4.600	4.533	4.767	4.433	4.333	4.667	4.556[i]
	50	5.000	4.467	4.300	4.667	4.467	4.233	4.522[i]
	100	4.233	4.333	4.033	4.000	4.067	4.200	4.144[h]
	200	4.233	3.967	3.700	3.900	4.000	3.733	3.922[g]
	400	3.900	3.967	3.867	3.733	3.700	3.500	3.778[g]
	Mean	4.393[c]	4.253[bc]	4.133[ab]	4.147[ab]	4.113[ab]	4.067[a]	4.184
	S.E.D. (F)	0.1111						
	S.E. D. (D)	0.0723						
	S.E.D. (F*D)	0.2540						

F= Fertilizer NPK; D= Population density; [a,b,c,] Means across rows with different superscripts differ significantly (P<0.05); [g,h,i,] Means within column with different superscripts differ significantly (P<0.05).

Ash content

Leaf ash content was nearly uniform over the levels of fertilizer applied (14.51 – 13.42% in 2017 and 14.84 – 14.30% in 2018) for the 0 – 400kg /ha range (Table 11). Density effects were significant (P< 0.05) only in 2018 with mean values of 14.81% and 14.67% at 83.3 $\times 10^3$ and 1000×10^3 plants/ ha, respectively. Irrespective of year, inflorescence ash concentration fell gradually but significantly (P<0.05) as fertilizer level and plant density increased (Table 12). The mean lowest values of 6.627% and 6.683% for the highest fertilizer rate and highest of 7.147% and 7.38% for the lowest density were obtained in 2017 and 2018, respectively.

Table 11: Leaf ash content (% DM) of *Tithonia diversifolia* grown at five NPK levels and six plant population densities in 2017 and 2018

Year	Fertilizer level	Density (Plants /ha × 10^3)						
		83.3	**166.7**	**222**	**333**	**500**	**1000**	**Mean**
	0	14.80	14.30	13.80	14.60	15.33	14.23	14.51
	50	13.73	14.33	14.80	14.03	14.00	14.23	14.19
	100	14.03	13.93	12.93	13.20	14.60	13.70	13.73
	200	13.33	13.73	13.30	13.93	13.93	14.03	13.71
2017	400	14.43	14.20	12.43	13.03	13.00	13.43	13.42
	Mean	14.07	14.10	13.45	13.76	14.17	13.93	13.91
	S.E.D. (F)	0.429						
	S.E.D. (D)	0.414						
	S.E. D. (F*D)	1.028						
	0	15.00	14.80	14.30	15.00	14.93	15.00	14.84
	50	14.77	14.30	14.33	14.77	14.93	15.37	14.74
	100	15.33	14.63	13.90	14.80	14.40	14.87	14.66
	200	14.20	13.90	13.47	14.30	14.47	14.00	14.06
2018	400	14.77	13.93	14.30	14.50	14.20	14.10	14.30
	Mean	14.81[c]	14.31[ab]	14.06[a]	14.67[b]	14.59[b]	14.67[b]	14.52
	S.E.D. (F)	0.709						
	S.E. D. (D)	0.1732						
	S.E.D. (F*D)	0.6182						

F= Fertilizer NPK; D= Population density; [a,b,c,] Means across rows with different superscripts differ significantly (P<0.05).

Table 12: Inflorescence ash content (% DM) of *Tithonia diversifolia* grown at five NPK levels and six plant population densities in 2017 and 2018

Year	Fertilizer level	Density (Plants /ha × 10^3)						
		83.3	**166.7**	**222**	**333**	**500**	**1000**	**Mean**
	0	8.333	8.000	7.667	7.200	6.833	7.033	7.511[j]
	50	7.200	6.900	7.900	7.233	6.800	6.800	7.139[i]
	100	7.200	6.933	6.833	6.900	6.467	6.767	6.850[h]
	200	6.80	7.233	6.800	6.533	6.800	6.233	6.733[h]

2017	400	6.200	6.300	6.267	6.500	6.300	6.033	6.267^{g}
	Mean	7.147^{c}	7.073^{bc}	7.093^{c}	6.873^{b}	6.640^{a}	6.573^{a}	6.900
	S.E.D. (F)	0.1174						
	S.E.D. (D)	0.0973						
	S.E. D. (F*D)	0.2751						
2018	0	7.900	7.467	7.933	7.500	7.167	7.233	7.533^{i}
	50	7.467	7.900	7.233	6.633	7.233	7.033	7.250^{h}
	100	7.333	7.233	6.900	6.633	6.500	6.800	6.900^{g}
	200	6.900	7.333	7.033	6.633	6.500	6.567	6.828^{g}
	400	7.300	6.500	6.367	6.533	6.800	6.600	6.683^{g}
	Mean	7.380^{b}	7.287^{b}	7.093^{ab}	6.787^{a}	6.840^{b}	6.847^{a}	7.039
	S.E.D. (F)	0.1389						
	S.E. D. (D)	0.1717						
	S.E.D. (F*D)	0.3495						

F= Fertilizer NPK; D= Population density; ^{a,b,c,} Means across rows with different superscripts differ significantly ($P<0.05$); ^{g,h,i,j} Means within column with different superscripts differ significantly ($P<0.05$).

Year difference for dry matter yield and proximate composition

Significantly ($P<0.05$) higher whole plant but lower leaf DM yield occurred in 2017 than 2018 while the inflorescence yield was about the same for both years (Table 13). The leaf exceeded the inflorescence in CP, EE and ash concentrations but the reverse was true for CF. The leaf CP, CF and EE and the inflorescence EE contents did not vary between years. The inflorescence contained more CP but less CF and ash in the first experimental year.

Table 13: Year difference for dry matter yield and Proximate composition of components of *Tithonia diversifolia* grown at five NPK levels and six plant population densities in 2017 and 2018

Parameters	**Year**		
	2017	**2018**	**SED**
Whole plant yield (DM,kg/ha)	14336^{b}	14135^{a}	36.50
Leaf yield (DM, kg/ha)	4316^{a}	4478^{b}	10.60
Inflorescence yield (DM, kg/ha)	418.50	421.60	3.27
Leaf crude protein content (% DM)	20.65	20.39	0.30
Inflorescence crude protein content (% DM)	14.74^{b}	14.37^{a}	0.05
Leaf crude fibre content (% DM)	12.46	12.86	0.23
Inflorescence crude fibre content (% DM)	21.83^{a}	22.48^{b}	0.05
Leaf ether extract (% DM)	5.31	5.21	0.04
Inflorescence ether extract (% DM)	4.24	4.18	0.05
Leaf ash contents (% DM)	13.91^{a}	14.32^{b}	0.14
Inflorescence ash contents (% DM)	6.90^{a}	7.04^{b}	0.01

Discussion

The results suggest that *Tithonia diversifolia* may not be grown for optimum whole plant, leaf or inflorescence DM yields at densities in excess of 333-500 $\times 10^3$ plants /ha whereas higher yields of these components can still be achieved with compound fertilizer $20N:10P_2O_5:10K_2O$ levels above 400 kg/ ha. The highest whole-plant yield recorded in the present work exceeds the 7.43 tonnes/ ha reported by Farinu *et al.* (1999) for 136-day old *Tithonia diversifolia* grown at 333 $\times 10^3$ plants /ha at Ogbomoso, a relatively drier Derived Savanna zone of Nigeria and 10.96 tonnes/ ha by Paumier *et al.* (2020) in Cuba after 180 days' growth. It is however inferior to the 25 tonnes DM/ ha reported by Sao *et al*., (2010) in Vietnam for 12-month old plants. The differences may be ascribed to dissimilarities in plant maturity status (excluding the case of Farinu *et al.* (1999), environment and management practices. It can be inferred from our data that *Tithonia diversifolia* possesses the ability to furnish adequate material for composting or soil fertility improvement. The decline in leaf yield at densities above 222 $\times 10^3$ and 333 $\times 10^3$ plants /ha can be explained in terms of progressive reduction in the amount of light penetration from the plant top downwards as increasing leaf shedding and/ or leaf senescence occurred as plant population density increased. Even then, regardless of fertilizer rate and number of plants/ ha, the leaf DM yields observed surpass the 2.26 tonnes/ ha reported by Farinu *et al.* (1999). Paumier *et al.* (2020) indicated a leaf yield decline as plants age above 120 days. A survey of the data suggests leaf content and leaf – to – stem ratio fell with increasing fertilizer and denser planting, implying that stem growth was more favoured than leaf growth. It is clear from the results that *Tithonia diversifolia* can be deliberately cultivated to produce a sufficient volume of extractable foliage for medicinal purposes. It may be inferred from the inflorescence yield figures that *Tithonia diversifolia* can respond to still higher fertilizer rates than 400kg / ha but not densities in excess of 222 $\times 10^3$ or 333 $\times 10^3$ plants /ha. The 0.2 tonnes DM/ ha inflorescence yield (Farinu *et al*., 1999) is far lower than the mean values established in the present trial despite these authors' plants' more advanced flowering stage. The reduction in average contribution of inflorescence to whole – plant yield with increasing fertilizer (3.5-2.5%) and plant density (3.2-2.8%) is attributed to the impact of severe interplant competition. Although at the harvest stage, the immature seeds contributed little to the capitulum weight, the inflorescence weight reflected the mature seed yield potential.

Variations in *Tithonia diversifolia* leaf CP per cent would suggest its positive responsiveness to improved fertilizer and the reverse to closer spacing. The values obtained supersede those reported by Odedire and Oloidi (2011) and Olayinka *et al.* (2015), 18.06% and 14.43% respectively, but do not match the high figures of 26.72% and 27.69% of Cadena–Villegas *et al* (2020) and Omolola (2020), respectively. The lower inflorescence CP content of 10.79% reported by Farinu *et al.* (1999) than that found in this study may be accounted for, by the relatively older mature stage, 50-80% compared with 50% first inflorescence opening. In addition, the plants might have been faster growing at Ogbomoso, a hotter and lower-rainfall area than Ilesa. The combined leaf and inflorescence CP levels satisfy not only the 7.1% recommended by NRC (1985) as minimum requirement in forage-based diets for ruminants but also the 15-16% of Whiteman (1980) for a 550 kg dairy cow producing 20 kg milk daily. Odedire and Oloidi (2014) present one of the highest leaf CF figures in the literature, 18.25%, while 11.19% provided by Cadena–Villegas *et al*. (2020) ranks among the lowest and the 13.47% and 14.39% of Olayinka *et al*. (2015) and Omolola (2020), respectively, are in the range registered in this study. Our leaf and inflorescence mixture should provide CF values within the tolerable limit of 17% requirement for cattle (NRC, 2000). On the whole, the pooled proximate constituents of the leaf and inflorescence fractions would be adjudged to make *Tithonia diversifolia* forage an appropriate feed supplement source for ruminant and non – ruminant animals.

Conclusion

Tithonia diversifolia forage responds to NPK fertilizer up to the application rate of 400 kg /ha and a population density of 333×10^3 plants/ha gave the highest dry matter yield.

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