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Effects of Organic and Inorganic Fertilizers on Weed Diversity and Population in Tobacco (*Nicotiana tabacum* L.) Farms in Migori County

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Abstract

Tobacco (Nicotiana tabacum L.) is a significant cash crop in Migori County, Kenya, and plays a vital role in the local economy. However, the cultivation of tobacco is not without its challenges, one of which is weed infestation. Weeds in tobacco farms can compete with the crop for essential resources, such as water, nutrients, and sunlight, leading to reduced crop yields and quality. Effective weed management is crucial to maintain the productivity and profitability of tobacco farming in the region. Therefore, the study objective was to analyze the effects of inorganic fertilizer (DAP fertilizer) and organic manure on population density of weed species, as well as the species diversity of the weed population under tobacco crop. A study was conducted in Migori county, employing a randomized complete block design, with four locations (Masaba, Mabera, Kakrao, and Bondo) and three different treatments, each of which was replicated three times. These treatments comprise of various types of fertilizers, including inorganic and organic variants, along with a control group receiving no fertilizer. The study's primary focus was on assessing weed population, leaf yield, and alterations in soil physico-chemical properties. During the second weeding phase, *Malva verticilate* was counted, with a mean value of 10.42, in both Mabera and Masaba. However, no instances of *Malva verticilate* were recorded in the other two sites. *Sida alba acuta* and *Richardia brasilium R. brasiliens* were counted in all four locations, with mean values of 6.22 and 28.21, respectively. The data obtained was subjected to statistical analysis using the General Linear Model (GLM) and analysis of variance (ANOVA) within the GENSTAT 12, 2012 statistical software package. To determine significant differences, means were separated using Tukey's test at a 5% level of significance. Results of the study showed that the dominant weed flora among monocot weeds were *Eleusine indica* L., *Cynodon dactylon* L., *Digitaria sanguinialis* L. and *Chloris barbata* L. Among dicot weeds, *Phyllanthus niruri* L., *Amaranthus viridis* L., *Euphorbia hirta* L., *Heliotropium indicum* L., *Gynandropsis pentaphylla* L., *Launaea nudicaulis* L. and *Oldenlandia umbellata* L. were found as major weeds. *Cyperus rotundus* L. was the only sedge found associated with tobacco crop across the four sites. This was common under inorganic fertilizer treatments, indicating that TF treatment suppressed growth and development of sedges. Results indicate that weed distribution and population under inorganic and organic fertilizer is related not only to the soil nutrient and physical content, but also to competition from the crop for water and light. Therefore, it is recommended to consider a combination of inorganic fertilizer and organic manures to optimize weed control and soil health in tobacco farming.

Keywords: Tobacco farming, weeds diversity, weeds management, soil nutrients, *Nicotiana tabacum*

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Introduction

Tobacco (*Nicotiana tabacum* L.) is the most widely grown commercial non-food crop in the world. It is an important commercial crop in view of revenue generation, export earnings and employment potential. Tobacco is grown over 0.46 million hectare (9.6% of world area) in Kenya having the production of 0.74 million tonnes with 1612 kg ha^{-1} average productivity in 2014-2015 (Magati *et al.,* 2016; GOK, 1994). Some of these tobacco growing zones include Busia, Bungoma, Meru, Migori, and Kuria (GOK, 1994). Today tobacco employs a large number of farmers and the number keeps on increasing yearly (Khisa, 2011). Tobacco growing has been embraced in Migori county due to the perceived advantages which are assumed to accrue from the growing of the crop. Tobacco farming faces a wide range of challenges including pests, diseases, weeds that reduce growth rate and production (yield), among others. Nevertheless, the effect of weeds population and management practices on tobacco production in Migori county has not been explored and is not very clear, leading to contradicting arguments which are not conclusive.

Weeds are an important variable in crop production, both economically and ecologically (Weisberger et al., 2019; Colbach et al., 2019; Odhiambo et al., 2015). There is a strong interest in developing alternative methods of physical weed control in organically grown crops, because weeds remain one of the most significant agronomic problems in the production of organic crops (Davies & Welsh, 2002). Cultural practices such as mulching, tillage, competitive cultivars, rotation, irrigation systems, and allelopathic crops and cultivars, influence weed density and distribution (Chauhan, 2012; Kumar et al., 2013; Nichols et al., 2015; Chauhan, 2012); Juraimi et al., 2013; Farooq et al., 2019).

A number of crop plants have been reported to acquire allelopathic potential that affects the growth of other species (Rehman et al., 2019; Shah et al., 2016; Khoshkharam et al., 2020). Allelopathic effect by crops grown in rotational sequence are helpful in reducing noxious weeds. However, the allelopathic effects of tobacco crops has not been investigated and reported in Migori County. Therefore, the aim of this study was to analyze the effects inorganic fertilizer (DAP fertilizer) and organic manure on population density of weed species, as well as the species diversity of the weed population under tobacco crop. The allelopathic effects of tobacco crops on specific weeds species was also investigated.

Materials and methods

The study was carried out in four localities in Migori county. These are Mabera, Bondo, Kakrao and Masaba sites.

The tobacco was grown using inorganic fertilizer (DAP and CAN) at a recommended rate of 60kg P/ha, and nitrogen at 30kg N/ha. The tobacco crop was grown using organic fertilizer (manure) at a recommended rate of 80kg P/ha and 30kg N/ha. Organic fertilizer/matter was applied as manure at a recommended rate of 4t/ha for tobacco crop. This was replicated three times.

The experiment involved planting of tobacco in a 10 m by 10 m square plots. The test crop was tobacco (T). This was grown using inorganic fertilizer (TF) and organic fertilizer/manure (TOM). The absolute control treatment (TO) was included. The experiment was laid out in a randomized complete block design (RCBD), with three replicates (figure1).

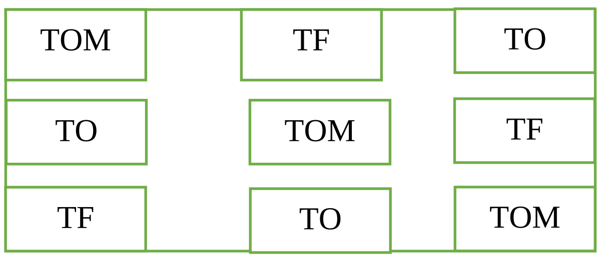


Figure 1: Field experimental layout

Land preparation was done by hand digging using a hoe to open up the 0-20cm layer. Certified tobacco variety 583V from British American Tobacco (BAT) was used in the four sites - Bondo, Kakrao, Mabera and Masaba. Normal agronomic management practices e.g., weeding, pest control was carried out on the experimental plots at appropriate stages of plant growth in the respective treatments.

Data was collected on number of weeds at vegetative stage prior to weeding. To characterize the vegetation under tobacco, a standard quadrant method and random sampling approach was followed. A quadrant size of 1m × 1m was used for the study to estimate vegetation. Vegetation maps and checklist were also used to provide the information on biodiversity. All agronomic practices were done every season in every site before first and second weeding, until tobacco had developed leaves that are able to be harvested. All individual weeds were counted to assess plant cover using a 2 m square frame placed at four random locations. All plants were identified and Shannon Diversity Index was calculated for weeds present in field. The Shannon Diversity Index (H') was calculated based on the formula developed by Magurran (1988)

$$H' = -\sum_{i=1}^{s}\left(\frac{N}{ni} x \log\frac{N}{ni}\right)$$

Where:

s = number of species present

ni = total number of individuals of the i^{th} species

N = total population of all species

Data obtained from the experimental variables was analyzed using General Linear Model (GLM) and subjected to analysis of variance (ANOVA) using GENSTAT 12, 2012 statistical package. Means were separated by Tukeys at 5% level of significance (Gomez and Gomez, 1984). Relationships between crop yields and the treatments were also drawn. Changes in the soil chemical properties and microorganisms' population counts over time under different treatments were also determined.

Results and discussion

Biological diversity of the weeds under different fertilizer types

Weed distribution was spatially heterogeneous in all fields at initial sampling. The commonly observed weeds species such as *Tagetes minuta, Richardia brasilium R. brasiliens, Schkhria pinnata, Galinsoga parviflora, Digitaria scalarum, Comellina Africana, Trianthema portulacastrum* were present in the experimental fields under different treatments across the four sites (Plate 1).

Species: *Richardia brasilium R. brasiliens*
Common name: Mexican-clover

Species: *Tagetes minuta*
Common name: African marigold

Species: *Trianthema portulacastrum*
Common name: Giant/Black Pigweed

Species: *Schkuhria pinnata*
Common name: dwarf Mexican marigold

Species: *Galinsoga parviflora*
Common name: gallant soldier

Species: *Digitaria scalarum*
Common name: fingergrass

Species: *Commelina africana*
Common name: common yellow commelina

Species: *Bidens palosa L.*
Common name: Black Jack

Plate 1: Common weeds under different treatments across the four sites

Biological diversity of the weeds in virgin land (VL), before and after harvesting stages

In the virgin land (VL) sampled across the four sites, *Digitaria scalarum* was numerous with a mean of 60.566 (total of 242.265 species counted). The highest number of *Digitaria scalarum counted was recorded in Bondo site.* This was followed by *Cyperus rotundus* species which were numerous with a mean of 23.711 (Table 1). Also, *Tagetes minuta* was recorded in large numbers across the four sites, with a mean of 17.209. The least number of species counted across sites were *Acanthospermum hispidum and Spilanthus mauritianum* with a total number of species counted across the four sites standing at 9.209 and 9.014 respectively (Table 1). The least number of *Spilanthus mauritianum* counted was in Bondo site at 2.109 (Table 1).

Among the sampled sites, Bondo had a high mean number of species at 8.400, followed by Masaba and Kakrao with 7.503 and 7.412 respectively. Mabera recorded the least mean number of species among the sites at 6.945.

Total number of counted species was high in Bondo and Masaba. The least total number of species counted was recorded in Mabera having 208.347 species count. This was evident in the lower diversity index from Bondo site at -1.118, followed by Masaba with 1.205. The diversity index of Kakrao and Mabera stood at -1.235 and -1.265 respectively. The highest diversity index was recorded in Bondo at -0.017(*Spilanthus mauritianum*), while the least diversity index was recorded in Bondo at -0.159 (*Digitaria scalarum*) (Table 1).

Before harvesting, *Acanthospermum hispidum* species with an overall mean of 0.472 were present in both Bondo and Kakrao, but were missing in Mabera and Masaba. TOM recorded a mean of 2.667 in Bondo. In Kakrao, a mean of 1.0 and 2.0 was recorded under TF and TOM treatments respectively, with TO recording none (Table 2a).

The *Cyperus rotundus* recorded a mean of 9.861, and this was counted in Bondo and Mabera. However, this weed was not present in Kakrao and Masaba (Table 2a). Also, *Corchorus olitorius* was present in only two sites, Mabera and Masaba with a mean of 1.028 before harvesting. Among the sites, *Centella asiatica, Chloris gayana, Asistasia schimperi* and *Amaranthus lividus* species was present only in Mabera, and this was under treatments TO and TOM (Table 2a).

Galinsoga parviflora species was common across the four sites, with the highest number recorded in Mabera. This was recorded under TF, TO and TOM treatments (Table 2b). *Emilia discifolia* was common under treatment TO in Bondo and Masaba. It was also common under treatment TOM in Kakrao and Masaba (Table 2b).

After harvest, *Ipomoea tenuirostris* was counted (5.330) under TO in Kakrao, with none recorded in other three sites (Table 3a). *Eragrostis tenuifolia* and *Eleusine indica* were only counted in Mabera (2.000 and 18.000 respectively) under TO and TF treatments respectively. *Euphorbia hirta (asthma plant)* was only present in Kakrao (16.333) (Table 3a).

After harvesting *Sonchus asper* was counted in Mabera (2.667) only under TOM treatment (Table 3a). Also, *Oxygonum double thorn* (3.667) *and Phillanthus fischeri* (3.000) were counted only in Masaba and Mabera respectively (Table 3a) after harvesting. This was under treatment TO in Masaba and TF in Mabera (Table 3a). *Schkuhria pinnata* was common in three sites- Bondo, Kakrao and Masaba- across all the treatments (Table 3a).

Species *Schkuhria pinnata* and *Tagetes minuta* was common across all the four sites and among the three tested treatments after harvest (Table 3b). At least every site recorded the species in all the plots, except for plots under TOM in Masaba (Table 3b). *Ageradum congzoidea* was recorded under TO treatments in Mabera site only (Table 3b). Similarly, species *Portulacea ouracea* was recorded only in Bondo under TF treatment, with *Thunbergia alata* being recorded only in Mabera under TOM (Table 3b).

In general, more weeds were counted under TO treatment as compared to TF and TOM treatments before harvesting. Masaba recorded the highest number of weeds, followed by Kakrao, Mabera and lastly Bondo, after harvesting (Tables 1 - 3b).

Table 1: Biological diversity of weeds in Virgin Land (VL) across sites

Site	Bondo	Kakrao	Mabera	Masaba	Total	Bondo	Kakrao	Mabera	Masaba
Acanthospermum hispidum	2.238	2.434	2.201	2.336	**9.209**	-0.018	-0.021	-0.021	-0.021
Amaranthus hybridus	6.493	6.454	5.703	5.893	**24.543**	-0.041	-0.045	-0.043	-0.041
Amaranthus lividus	2.877	3.098	2.671	2.795	**11.441**	-0.022	-0.026	-0.024	-0.024
Asistasia schimperi	3.993	3.433	3.101	3.482	**14.009**	-0.029	-0.028	-0.027	-0.028
Bidens Pilosa	3.322	3.458	3.339	3.296	**13.415**	-0.025	-0.028	-0.029	-0.027
Centella asiatica	4.009	3.601	4.101	3.879	**15.59**	-0.029	-0.029	-0.034	-0.030
Chloris gayana	31.085	30.102	24.005	24.281	**109.473**	-0.112	-0.118	-0.108	-0.104
Commelina africana	4.119	2.996	4.023	4.007	**15.145**	-0.029	-0.025	-0.033	-0.031
Corchorus olitorius	4.142	4.076	4.094	4.102	**16.414**	-0.029	-0.032	-0.034	-0.032
Cyperus rotundus	25.661	24.075	22.003	23.105	**94.844**	-0.101	-0.105	-0.103	-0.101
Digitaria scalarum	87.237	45.454	46.509	63.065	**242.265**	-0.159	-0.141	-0.145	-0.155
Eleusine indica	3.454	3.397	3.406	3.387	**13.644**	-0.026	-0.028	-0.029	-0.027
Emilia discifolia	3.092	3.902	3.495	3.504	**13.993**	-0.023	-0.031	-0.030	-0.028
Erlanfee cordifolia	3.333	3.405	3.429	3.403	**13.57**	-0.025	-0.028	-0.029	-0.028
Euphorbia heterophylla	3.002	3.104	2.265	2.208	**10.579**	-0.023	-0.026	-0.021	-0.020
Euphorbia hirta	3.028	3.329	3.006	3.009	**12.372**	-0.023	-0.027	-0.027	-0.025
Galinsoga parviflora	4.054	4.0107	4.037	4.111	**16.2127**	-0.029	-0.031	-0.033	-0.032
Eragrostis tenuifolia	2.309	2.239	3.005	3.19	**10.743**	-0.019	-0.020	-0.027	-0.026
Ipomoea tenuirostris	3.239	3.504	3.495	3.389	**13.627**	-0.024	-0.028	-0.030	-0.027
Kyllinga bulbosa	3.257	2.375	3.078	3.105	**11.815**	-0.024	-0.021	-0.027	-0.026
Malva verticilate	17.004	2.278	3.487	3.692	**26.461**	-0.079	-0.020	-0.030	-0.029
Oxalis latifolia	3.304	3.205	3.211	3.029	**12.749**	-0.025	-0.027	-0.028	-0.025
Oxygonum double thorn	4.045	4.033	3.95	3.694	**15.722**	-0.029	-0.032	-0.033	-0.029
Phillanthus fischeri	3.998	23.011	12.087	4.016	**43.112**	-0.029	-0.102	-0.072	-0.031
Schkuhria pinnata	3.209	12.843	12.287	4.887	**33.226**	-0.024	-0.072	-0.072	-0.036
Sida alba acuta	4.003	3.097	9.204	9.55	**25.854**	-0.029	-0.026	-0.060	-0.058
Sonchus asper	3.004	3.128	3.224	3.046	**12.402**	-0.023	-0.026	-0.028	-0.025
Sphacranthus shaveolence	3.408	6.409	3.985	4.021	**17.823**	-0.025	-0.044	-0.033	-0.031
Spilanthus mauritianum	2.109	2.118	2.384	2.403	**9.014**	-0.017	-0.019	-0.022	-0.021
Tagetes minuta	3.976	3.802	3.562	17.209	**28.549**	-0.028	-0.030	-0.030	-0.085
Total Sp. per site	**252.004**	**222.371**	**208.347**	**225.094**					
MEAN Sp. per site	**8.400**	**7.412**	**6.945**	**7.503**					
Diversity Index (H') per site						**-1.118**	**-1.235**	**-1.261**	**-1.205**

Table 2a: Biological diversity of weeds before harvesting under different treatments across sites

Site	Treatment (TRT)	*Acanthospermum hispidum*	*Amaranthus hybridus*	*Amaranthus lividus*	*Asistasia schimperi*	*Bidens Pilosa*	*Centella asiatica*	*Chloris gayana*	*Commelina africana*	*Corchorus olitorius*	*Cyperus rotundus*	*MEAN TRT*
Bondo	*VL*	*2.238*	*6.493*	*2.877*	*3.993*	*3.322*	*4.009*	*31.085*	*4.119*	*4.142*	*25.661*	***8.794***
	TF	-	-	-	-	-	-	-	-	-	2.000	**0.200**
	TO	-	-	-	-	-	-	-	-	-	-	-
	TOM	2.667	-	-	-	-	-	-	-	-	-	**0.267**
Kakrao	*VL*	*2.434*	*6.454*	*3.098*	*3.433*	*3.458*	*3.601*	*30.102*	*2.996*	*4.076*	*24.075*	***8.373***
	TF	1.000	-	-	-	-	-	-	2.670	-	-	**0.367**
	TO	-	-	-	-	2.667	-	-	-	-	-	**0.267**
	TOM	2.000	-	-	-	2.333	-	-	4.000	-	-	**0.833**
Mabera	*VL*	*2.201*	*5.703*	*2.671*	*3.101*	*3.339*	*4.101*	*24.005*	*4.023*	*4.094*	*22.003*	***7.524***
	TF	-	5.330	-	-	3.333	-	27.000	5.330	3.667	15.67	**6.033**
	TO	-	-	-	2.667	-	-	11.000	2.670	1.667	25.33	**4.333**
	TOM	-	-	7.000	-	-	6.000	42.333	12.000	-	75.33	**14.266**
Masaba	*VL*	*2.336*	*5.893*	*2.795*	*3.482*	*3.296*	*3.879*	*24.281*	*4.007*	*4.102*	*23.105*	***7.718***
	TF	-	4.330	-	-	61.000	-	-	7.670	-	-	**7.300**
	TO	-	14.670	-	-	23.000	-	-	4.670	2.333	-	**4.467**
	TOM	-	**3.000**	-	-	2.333	-	-	2.670	4.667	-	**1.267**
	Grand Mean	**0.472**	**2.278**	**0.583**	**0.222**	**7.889**	**0.500**	**6.694**	**3.473**	**1.028**	**9.861**	
	SE (SITE*TRT)	*0.1858****	*1.255****	*0.1667****	*0.0962****	*0.296****	*0.167****	*0.278****	*0.81****	*0.1716****	*0.419****	
	SED(SITE*TRT)	*0.2627*	*1.775*	*0.2357*	*0.1361*	*0.4184*	*0.2357*	*0.3936*	*1.145*	*0.2427*	*0.593*	
	LSD(SITE*TRT)	*0.5449*	*3.681*	*0.4888*	*0.2822*	*0.8678*	*0.4888*	*0.8162*	*2.375*	*0.5034*	*1.23*	
	%CV	27.0	31.1	14.3	21.7	12.4	16.7	3.8	19.2	16.9	10.3	

Treatments: *VL-Virgin Land, TO-Control, TF-DAP Fertilizer, TOM-Organic Fertilizer; *Significant at p≤0.05; **Significant at p≤0.01; ***Significant at p≤0.001; ns-Not Significant*

Table 2b: Biological diversity of weeds before harvesting under different treatments across sites

Site	Treatment (TRT)	*Digitaria scalarum*	*Eleusine indica*	*Emilia discifolia*	*Erlanfee cordifolia*	*Euphorbia heterophylla*	*Euphorbia hirta (asthma*	*Galinsoga parviflora*	*Eragrostis tenuifolia*	*Ipomoea tenuirostris*	*Kyllinga bulbosa*	*MEAN TRT*
	VL	87.237	3.454	3.092	3.333	3.002	3.028	4.054	2.309	3.239	3.257	11.601
Bondo	TF	26.330	-	-	-	-	-	-	-	-	-	2.633
	TO	147.670	-	3.000	-	-	-	10.670	-	-	-	16.134
	TOM	209.330	-	-	-	-	-	12.670	-	-	-	22.200
	VL	45.454	3.397	3.902	3.405	3.104	3.329	4.0107	2.239	3.504	2.375	7.472
Kakrao	TF	87.000	-	-	-	15.333	-	-	-	-	2.667	10.500
	TO	78.000	-	-	-	15.333	-	-	-	5.330	2.333	10.100
	TOM	123.670	-	3.000	2.000	-	16.333	4.330	-	-	-	14.933
	VL	46.509	3.406	3.495	3.429	2.265	3.006	4.037	3.005	3.495	3.078	7.573
Maber a	TF	-	18.000	-	-	-	-	125.330	-	-	-	14.333
	TO	-	-	-	-	-	-	113.330	2.000	-	-	11.533
	TOM	-	-	-	-	-	-	17.670	-	-	-	1.767
	VL	63.065	3.387	3.504	3.403	2.208	3.009	4.111	3.190	3.389	3.105	9.237
Masab a	TF	-	-	-	-	-	-	-	-	-	-	-
	TO	398.000	-	4.000	-	-	-	90.330	-	-	-	49.233
	TOM	-	-	3.667	-	-	-	42.000	-	-	-	4.567
	Grand Mean	**89.167**	**1.500**	**1.139**	**0.167**	**2.556**	**1.361**	**34.694**	**0.167**	**0.444**	**0.417**	
	$SE_{(SITE*TRT)}$	*0.622***	*0.1667***	*0.3001***	*0.167***	*0.139***	*0.193***	*0.401***	*0.1667***	*0.347***	*0.266***	
	$SED_{(SITE*TRT)}$	*0.879*	*0.2357*	*0.4244*	*0.236*	*0.1968*	*0.2722*	*0.567*	*0.2357*	*0.491*	*0.3761*	
	$LSD_{(SITE*TRT)}$	*1.823*	*0.4888*	*0.8802*	*0.489*	*0.4081*	*0.5644*	*1.176*	*0.4888*	*1.018*	*0.7799*	
	%CV	**10.4**	**19.2**	**29.6**	**25.1**	**9.4**	**24.5**	**11.2**	**25.1**	**39**	**14.1**	

Treatments: *TO-Control, TF-DAP Fertilizer, TOM-Organic Fertilizer; *Significant at p≤0.05; **Significant at p≤0.01; ***Significant at p≤0.001; ns-Not Significant*

Table 3a: Biological diversity of weeds after harvest under different treatments across sites

Site	Treatment	*Malva verticilate*	*Oxalis latifolia*	*Oxygonum double thorn*	*Phillanthus fischeri*	*Sida alba acuta*	*Sonchus asper*	*Sphacranthus shaveolence*	*Spilanthus mauritianum*	*MEAN TRT*
	VL	17.004	3.304	4.045	3.998	4.003	3.004	3.408	2.109	**5.109**
Bondo	TF	-	-	-	-	-	-	-	-	**-**
	TO	-	-	-	-	-	-	-	-	**-**
	TOM	-	-	-	-	-	-	-	-	**-**
	VL	2.278	3.205	4.033	23.011	3.097	3.128	6.409	2.118	**5.910**
Kakrao	TF	-	3.000	-	-	3.667	-	-	-	**0.833**
	TO	-	93.000	-	-	-	-	-	-	**11.625**
	TOM	-	-	-	-	-	-	-	-	**-**
	VL	3.487	3.211	3.950	12.087	9.204	3.224	3.985	2.384	**5.192**
Mabera	TF	17.000	-	-	3.000	3.000	-	3.000	1.667	**3.458**
	TO	2.000	-	-	-	3.000	-	6.000	-	**1.375**
	TOM	-	-	-	-	8.000	2.667	-	-	**1.333**
	VL	3.692	3.029	3.694	4.016	9.550	3.046	4.021	2.403	**4.181**
Masaba	TF	18.667	-	-	-	-	-	-	-	**2.333**
	TO	-	-	3.667	-	3.000	-	-	-	**0.833**
	TOM	4.000	-	-	-	-	-	-	-	**0.500**
	Grand Mean	**3.472**	**8.000**	**0.306**	**0.250**	**1.722**	**0.222**	**0.750**	**0.139**	
	$SE_{(SITE*TRT)}$	*0.274****	*0.230****	*0.0962****	*0.1667****	*0.3282****	*0.2546****	*0.2303****	*0.096****	
	$SED_{(SITE*TRT)}$	*0.3871*	*0.3257*	*0.1361*	*0.2357*	*0.4642*	*0.36*	*0.3257*	*0.1361*	
	$LSD_{(SITE*TRT)}$	*0.8028*	*0.675*	*0.2822*	*0.4888*	*0.9627*	*0.7467*	*0.6754*	*0.2822*	
	%CV	7.7	11.8	15.7	23.3	14.8	27.3	19.2	34.6	

Treatments: *TO-Control, TF-DAP Fertilizer, TOM-Organic Fertilizer; *Significant at p≤0.05; **Significant at p≤0.01; ***Significant at p≤0.001; ns-Not Significant*

Table 3b: Biological diversity of flora after harvest under different treatments across sites

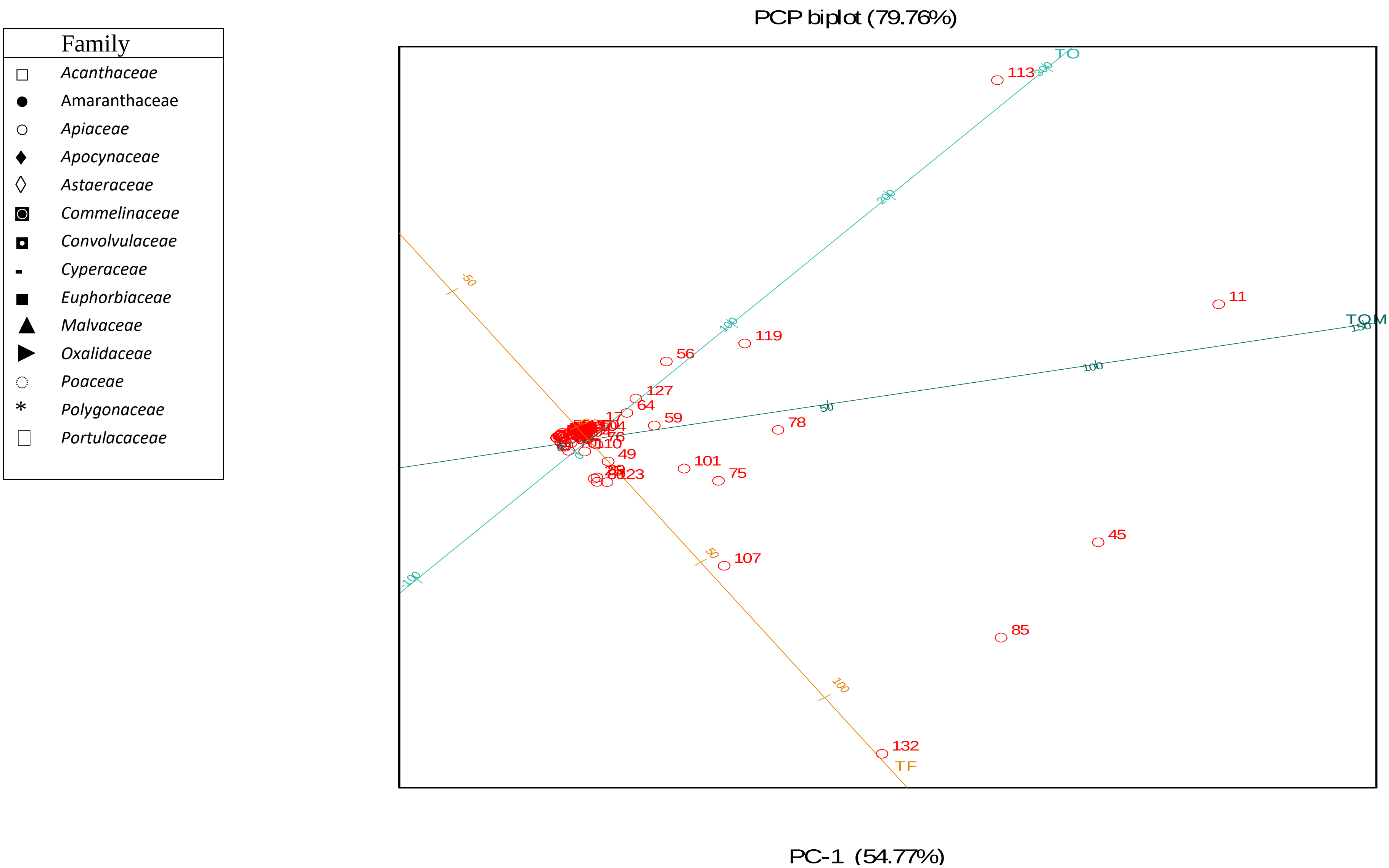
Site	Treatment	*Thunbergia alata*	*Ageradum congzoidea*	*Cynodon dactylon*	*Portulacea ouracea*	*Malva verticilate*	*Oxalis latifolia*	*Schkuhria pinnata*	*Tagetes minuta*	*Portulacea ouracea*	*Richardia brasilium R. brasiliens*	*MEAN TRT*
Bondo	TF	-	-	-	2.003	-	-	6.667	17.000	-	4.667	**3.033**
	TO	-	-	-	-	-	-	2.667	21.000	-	11.667	**3.533**
	TOM	-	-	-	-	-	-	1.667	15.000	1.667	9.667	**2.800**
Kakrao	TF	-	-	-	-	-	82.670	-	2.670	-	-	**8.534**
	TO	-	-	-	-	4.001	95.000	5.333	6.670	-	-	**11.100**
	TOM	-	-	13.010	-	-	53.67	4.667	1.670	-	-	**7.301**
Mabera	TF	-	-	21.333	-	-	-	6.667	15.67	-	4.667	**4.834**
	TO	-	1.667	13.012	-	-	-	2.667	21.33	-	11.667	**5.033**
	TOM	2.333	-	31.000	-	-	-	1.667	14.67	2.000	11.000	**6.267**
Masaba	TF	-	-	-	-	7.000	-	-	5.67	2.333	-	**1.500**
	TO	-	-	-	-	32.33	-	2.667	13.67	2.667	-	**5.133**
	TOM	-	-	-	-	16.33	-	-	-	-	-	**1.633**
	Grand Mean	**0.194**	**0.139**	**6.528**	**0.167**	**4.972**	**19.278**	**2.889**	**11.252**	**0.722**	**4.445**	
	SE$_{(SITE*TRT)}$	*0.1925****	*0.0962****	*0.3282****	*0.1667****	*0.696****	*0.804****	*0.193****	*0.514****	*0.308****	*0.343****	
	SED$_{(SITE*TRT)}$	*0.2722*	*0.1361*	*0.4642*	*0.2357*	*0.984*	*1.136*	*0.2722*	*0.721*	*0.4362*	*0.4855*	
	LSD$_{(SITE*TRT)}$	*0.5644*	*0.2822*	*0.9627*	*0.4888*	*2.04*	*2.357*	*0.5644*	*1.496*	*0.9045*	*1.0068*	
	%CV	49.5	34.6	13.9	50	12.6	13.8	16.7	5.2	37.1	5.7	

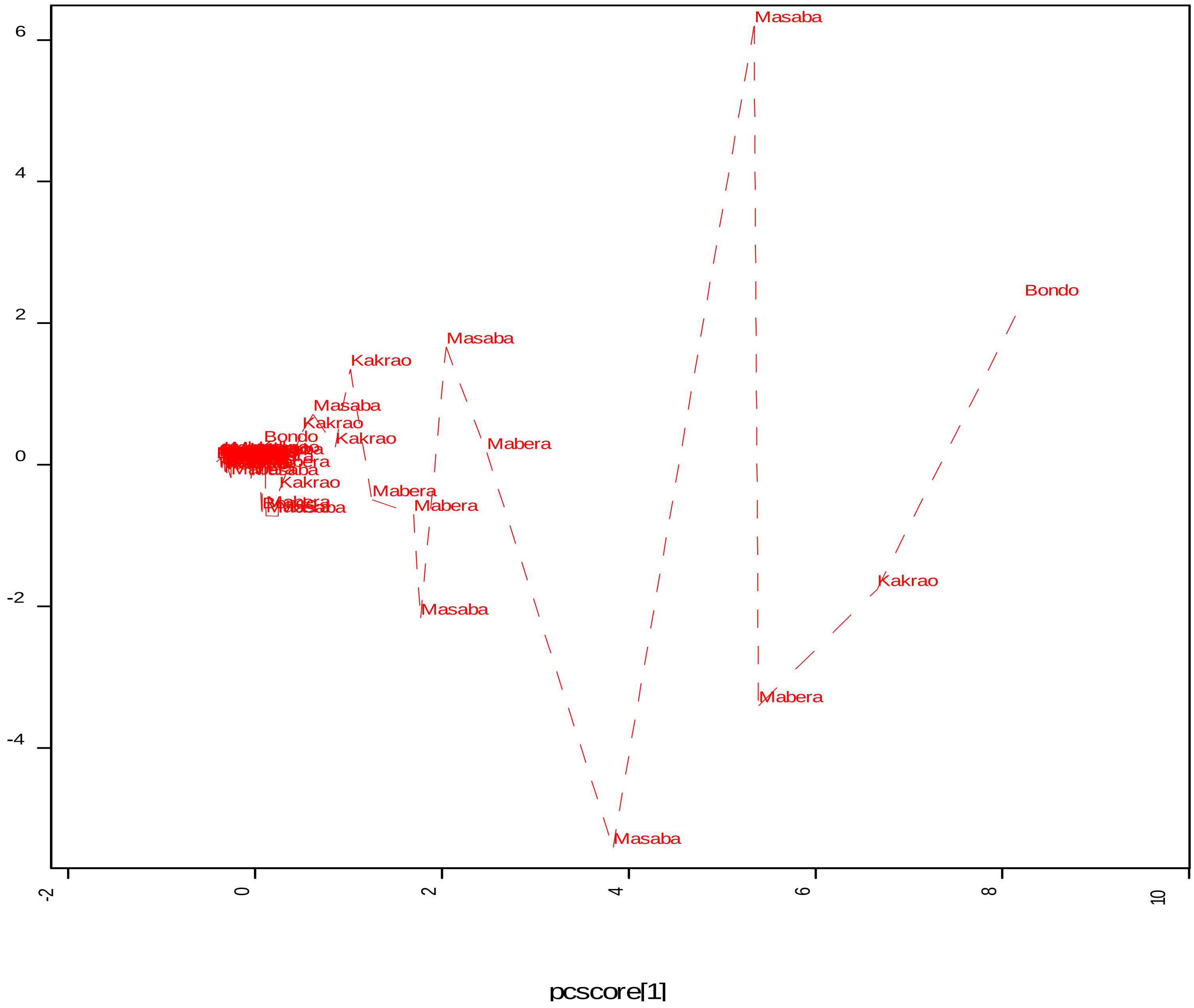
Treatments: *TO-Control, TF-DAP Fertilizer, TOM-Organic Fertilizer; *Significant at p≤0.05; **Significant at p≤0.01; ***Significant at p≤0.001; ns-Not Significant*

Table 4: Weed Diversity Index – All Treatments

Family	Weed Species	Types	Life Span	TF		TO		TOM	
				No. of *Sp.*	Pi*lnPi	No. of *Sp.*	Pi*lnPi	No. of *Sp.*	Pi*lnPi
Acanthaceae	*Asistasia schimperi*	*Herb*	*A*	1.000	-0.004	0.000	0.000	4.667	-0.014
	Thunbergia alata	*Shrub*	*P*	9.660	-0.027	14.670	-0.023	3.000	-0.010
Amaranthaceae	*Amaranthus hybridus*	*Herbs*	*A*	0.000	0.000	0.000	0.000	7.000	-0.020
	Amaranthus lividus	*Herbs*	*A*	0.000	0.000	2.667	-0.006	0.000	0.000
Apiaceae	*Centella asiatica*	*Herb*	*A*	64.333	-0.099	25.667	-0.036	4.666	-0.014
Apocynaceae	*Sphacranthus shaveolence*	*Shrub*	*A*	0.000	0.000	0.000	0.000	6.000	-0.017
Astaeraceae	*Acanthospermum hispidum*	*Herbs*	*A*	27.000	-0.057	11.000	-0.019	42.333	-0.073
	Bidens pilosa	*Herb*	*A*	15.670	-0.039	7.340	-0.013	18.670	-0.041
	Emilia discifolia	*Herb*	*A*	3.667	-0.013	4.000	-0.008	4.667	-0.014
	Ageradum congzoidea	*Grass*	*P*	17.670	-0.042	25.330	-0.035	75.330	-0.103
	Galinsoga parviflora	*Herb*	*A*	113.330	-0.132	623.670	-0.148	333.000	-0.154
	Schkhria pinnata	*Herb*	*A*	18.000	-0.043	0.000	0.000	0.000	0.000
	Sonchus asper	*Herb*	*A*	0.000	0.000	7.000	-0.013	6.667	-0.019
	Spilanthus mauritianum	*Shrub*	*P*	0.000	0.000	0.000	0.000	2.000	-0.007
	Tagetes minuta	*Herb*	*A*	15.333	-0.038	15.333	-0.024	0.000	0.000
Commelinaceae	*Comellina africana*	*Herb*	*P*	0.000	0.000	0.000	0.000	16.333	-0.038
Convolvulaceae	*Ipomoea tenuirostris*	*Shrub*	*P*	125.330	-0.137	214.330	-0.133	76.670	-0.104
Cyperaceae	*Cyperus rotundus*	*Sledge*	*P*	0.000	0.000	2.000	-0.005	0.000	0.000
	Kyllinga bulbosa	*Sledge*	*A*	0.000	0.000	5.330	-0.010	0.000	0.000
Euphorbiaceae	*Euphorbia heterophylla*	*Herb*	*A*	2.667	-0.010	2.333	-0.005	0.000	0.000
	Euphorbia hirta (asthma plant)	*Herb*	*A*	35.667	-0.069	2.000	-0.005	4.000	-0.013
	Phillanthus fischeri	*Herb*	*A*	3.000	-0.011	93.000	-0.086	0.000	0.000
Malvaceae	*Corchorus olitorius*	*Herb*	*A*	0.000	0.000	3.667	-0.008	0.000	0.000
	Erlanfee cordifolia	*Shrub*	*P*	3.000	-0.011	0.000	0.000	0.000	0.000
	Malva verticilata	*Herb*	*A*	27.340	-0.058	74.660	-0.075	33.330	-0.062
	Sida alba acuta	*Grass*	*A*	6.667	-0.020	6.000	-0.011	8.000	-0.022
Oxalidaceae	*Oxalis latifolia*	*Herb*	*P*	0.000	0.000	0.000	0.000	2.667	-0.009
Poaceae	*Chloris gayana*	*Grass*	*A*	3.000	-0.011	6.000	-0.011	0.000	0.000
	Cynodon dactylon	*Grass*	*P*	1.667	-0.007	0.000	0.000	0.000	0.000
	Digitaria scalarum	*Grass*	*A*	138.000	-0.142	46.666	-0.055	18.333	-0.041
	Eleusine indica	*Grass*	*A*	0.000	0.000	0.000	0.000	2.333	-0.008
	Eragrostis tenuifolia	*Grass*	*P*	0.000	0.000	1.667	-0.004	0.000	0.000
Polygonaceae	*Oxygonum sinuatum*	*Herb*	*A*	21.333	-0.048	13.000	-0.021	44.000	-0.075
Portulacaceae	*Portulacea ouracea*	*Grass*	*A*	2.000	-0.008	0.000	0.000	0.000	0.000
Total *Sp.*				655.334		1207.330		713.666	
Diversity (*H'*)					-1.025		-0.754		-0.859

Treatments: *TO-Control, TF-DAP Fertilizer, TOM-Organic Fertilizer*


Family
Acanthaceae
Amaranthaceae
Apiaceae
Apocynaceae
Astaeraceae
Commelinaceae
Convolvulaceae
Cyperaceae
Euphorbiaceae
Malvaceae
Oxalidaceae
Poaceae
Polygonaceae
Portulacaceae
PCP biplot (79.76%)
TO
TOM
TF
113
11
119
56
127
64
59
78
101
75
49
107
45
85
132
PC-1 (54.77%)


Masaba
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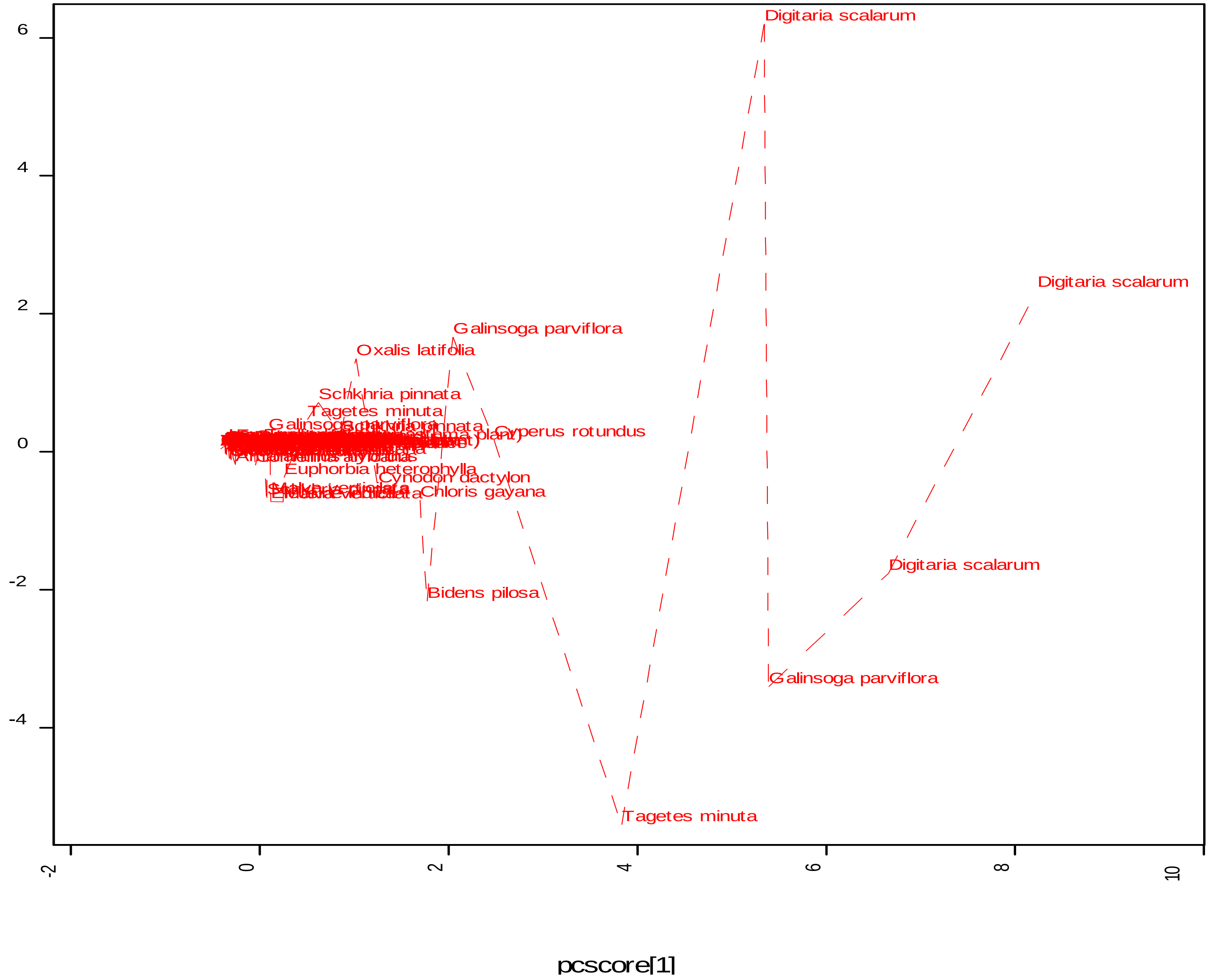
pcscore[1]


Digitaria scalarum
Digitaria scalarum
Digitaria scalarum
Galinsoga parviflora
Galinsoga parviflora
Oxalis latifolia
Schkhria pinnata
Tagetes minuta
Tagetes minuta
Cyperus rotundus
Euphorbia heterophylla
Cynodon dactylon
Chloris gayana
Bidens pilosa
6
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pcscore[1]

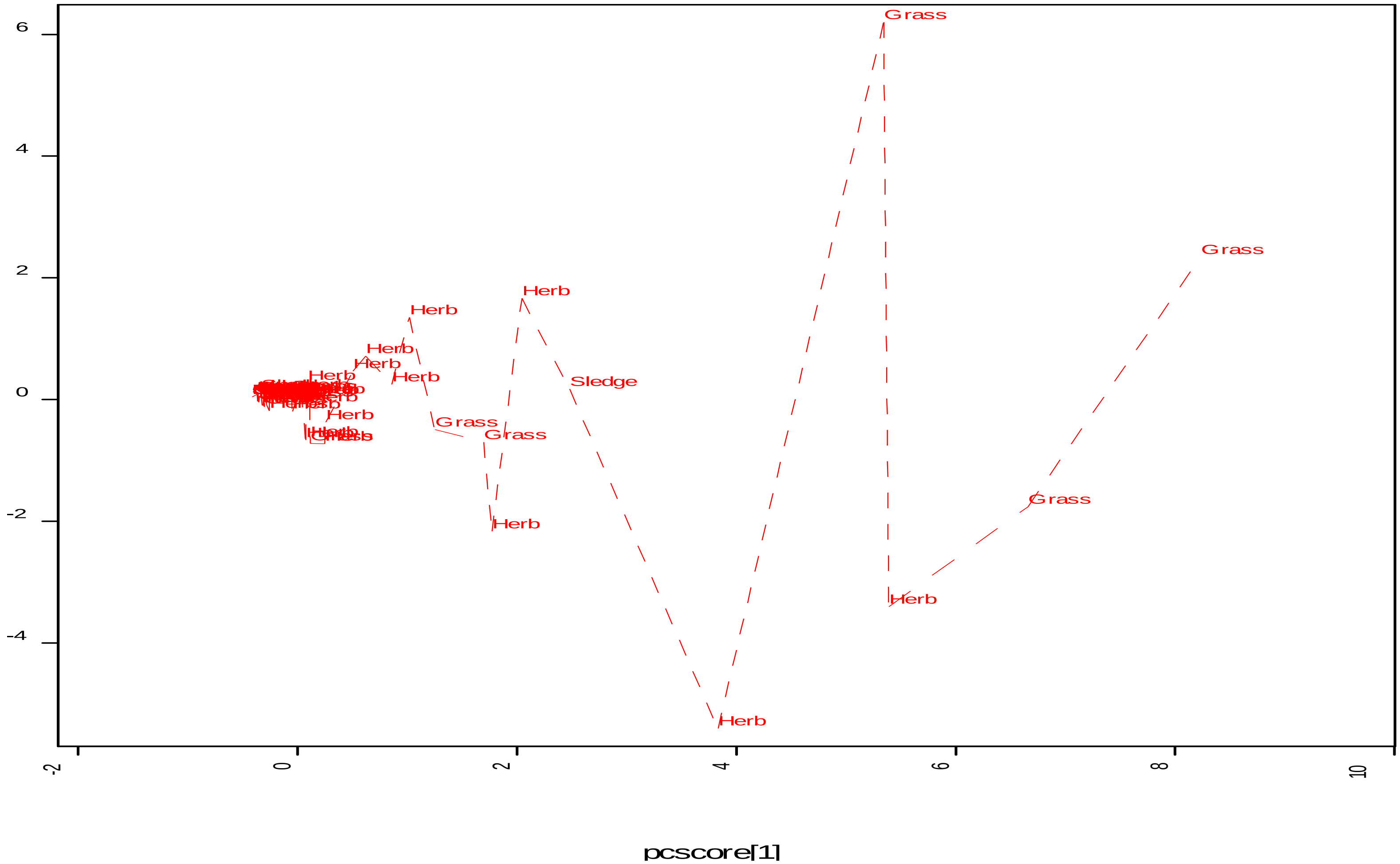

Figure 1: Principal components analysis (PCA) of weed species

Diversity of weed species under different treatments

Diversity of the weed species was calculated using Shannon index (*H'*);

$$H' = -\Sigma\, p_i (\ln p_i)$$

Where, ***H'***= diversity

Σ= Summation,

p*i* = N*i*/N total,

ln = natural logarithm,

N*i*= number of individuals of species *i*

N total = Total number of individuals in all species

Digitaria scalarum (grass) recorded the highest number of weed species counted under treatment TF, giving 138.000 weeds. This was followed by *Ipomoea tenuirostris* (Shrub) and *Galinsoga parviflora* (herb) were dominant under treatment TF. With 623.670 species of *Galinsoga parviflora* (herb) being counted under TO, this was the highest number recorded under this treatment. Also, *Ipomoea tenuirostris* (Shrub) and *Phillanthus fischeri* (herb) were dominant under treatment TO. *Galinsoga parviflora* (herb) realized the highest count at 333.000 weeds under TOM. This was followed by *Ipomoea tenuirostris* (Shrub) and *Ageradum congzoidea (grass)* which were dominant under treatment TOM (Table 4).

Total number of species was highest under TO (control) with a total of 1207.330. This was followed by treatment TOM (organic fertilizer) and TF (inorganic fertilizer) having 713.666 and 655.334 weed species respectively (Table 4). This reflected into small weed diversity index under TF treatment with -1.025, as compared to TOM (-0.859) and TO (-0.754) (Table 4).

Principal components analysis (PCA) of weed species and the three different fertilizer treatments – TO, TOM and TF- showed some of the sampled weed species were significantly predominant. Weed species *Ageradum congzoidea, Galinsoga parviflora, Ipomoea tenuirostris, Phillanthus fischeri* and *Digitaria scalarum* realized a significant amount of colonization. Species with low frequencies of occurrence (<5%) are not shown.

Standardized principal component analysis of the variation of eight functional families in seven weed species, measured at the individual level within tobacco field showed that contribution of families to the first and second principal components.

Discussion

The weed distribution across the sites is related not only to the soil surface but also to competition from the tobacco crop for canopy and nutrients. Similar results were also obtained by Grattan *et al.,* (1990). Moreover, density and number of perennial weeds (*Bidens pilosa*, *Convolvulus arvensis* and *Cyperus rotundus*) was influenced by the type of fertilizer, with more weeds being counted under inorganic fertilizer (TF). On the other hand, Grattan *et al.,* (1990) found that growth of *Convolvulus arvensis* was not influenced by the time of weeding and fertilizer application time.

The dominant weed flora among monocot weeds were *Eleusine indica* L., *Cynodon dactylon* L., *Digitaria sanguinialis* L. and *Chloris barbata* L. Among dicot weeds, *Phyllanthus niruri* L., *Amaranthus viridis* L., *Euphorbia hirta* L., *Heliotropium indicum* L., *Gynandropsis pentaphylla* L., *Launaea nudicaulis* L. and *Oldenlandia umbellata* L. were found as major weeds. *Cyperus rotundus* L. was the only sedge found associated with tobacco crop across the four sites. This was common under inorganic fertilizer treatments, indicating that TF treatment suppressed growth and development of sedges. This could be attributed to inorganic fertilizers containing some elements that inhibits both cell division and cell elongation in susceptible weed species. These results were in agreement to those obtained by Amin *et al*., (2015) using different types of inorganic fertilizers at different application times.

Reduction in weed density were more pronounced under inorganic fertilizer application. In contrast, weaker weed population responses to organic fertilizer (TOM) were also observed by Mandumbu *et al.,* (2012). Gopal *et al.,* (2010) and Odhiambo *et al.,* (2015) observed higher weed density following more frequent tillage in rice production and maize production respectively. Generally, treatment TF resulted in weed cover declines. Transitioning to organic manure for tobacco production did not affect weed cover except for grass cover increase at Mabera. Decline in the abundance of the four most dominant weed species in tobacco planted under TOM however, was statistically significant, but of much smaller magnitude than changes due to use of inorganic fertilizer. This observation further indicated that is too early to see the response of organic manure on weed population. More long-term research on organic manure application using dose response approaches could help farmers manage multiple benefits associated with organic manure (TOM).

These research results however, demonstrated the reduction in weed density and population diversity as early as two years into the transition without any negative impacts on tobacco yield and growth. It is therefore, an important starting point that can guide local research and extension during transition (Panell *et al.,* 2014). Such analyses are important to determine robust recommendations designed for specific agro-ecological and socio-economic conditions (Nyamangara *et al.,* 2014).

The changes in soil properties may occur within hours to a period of decades with respect to response level of soil properties (Carter, 1996). However, the limits to which dynamic soil properties can change are dictated by inherent properties (Norfleet *et al.,* 2003). The inherent soil properties are influenced by pedogenic processes and the changes are more pronounced in tropical climate due to physical and chemical weathering enhanced by high temperature and precipitation (Larsen and Pierce, 2019). In general, soil quality assessment was based on selecting a set of soil properties which are considered as indicators of soil quality that are sensitive to soil quality indicators (Aparicio and Costa, 2007; Dumanski and Pieri, 2000)

Species richness, an indicator of plant diversity, is a useful metric for landscape health as it can influence ecosystem multifunctionality and stability (Symstad *et al.,* 2011; Zavaleta *et al.,* 2010; Allan *et al.,* 2015). The consistent correlation between species number and plant community dynamics index and EHI suggest that EHI could be an effective assessment of tobacco growing land ecological health. In this study, mean Plant Species Number was positively correlated with EHI across both sites.

Conclusion and recommendation

In conclusion, the use of inorganic fertilizer (TF) effectively reduced weed populations in Mabera, Kakrao, Masaba, and Bondo soils, while the application of organic manures (TOM) significantly enhanced Soil Quality Index (SQI) and Ecological Health Index (EHI). This approach enhances soil quality, ultimately promoting the cultivation of healthy soils for tobacco crop production. Therefore, it is recommended to consider a combination of inorganic fertilizer and organic manures to optimize weed control and soil health in tobacco farming.

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