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Weed Floral Dynamics in Maize as Influenced by Varying Herbicide Application Rates and Tillage Methods at Jalingo, Taraba State, Nigeria

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Abstract

This study examined how reduced rates of two pre-emergence herbicide mixtures and two tillage methods affected the weed flora of maize over two seasons (2008 and 2009) at the Teaching and Research Farm of the Taraba State College of Agriculture, Jalingo, Nigeria. A split-plot design in randomised complete blocks with three replicates was used, with tractor (TT) and manual (MT) tillage as main plots and ten weed-control treatments as sub-plots: atrazine + pendimethalin (2.0 + 2.0 kg a.i. ha^{-1}) and primextra (2.5 kg a.i. ha^{-1}), each at 100, 75, 50 and 25% of the recommended rate (AP4–AP1 and PX4–PX1), plus hand-weeded (C1) and unweeded (C2) controls. Weeds were sampled with quadrats. In 2008 the most abundant species under manual tillage were Dactyloctenium aegyptium (4.5), Cynodon dactylon (4.0) and Mitracarpus villosus (3.3), and under tractor tillage Andropogon gayanus (3.5), Rottboellia cochinchinensis and Leucas martinicensis (3.4 each); most had declined by 2009. In 2009, Hyptis lanceolata, absent in 2008, reached a frequency of 73.3% (MT) and 71.7% (TT) and led the weed population in most treatments, alongside Digitaria horizontalis, A. gayanus, Panicum maximum and Imperata cylindrica; the combined density of grasses rose from 16.2 to 46.6% (MT) and from 21.0 to 43.0% (TT). Grain yield was highest with hand weeding (3568.1 kg ha^{-1}) and lowest in the unweeded control (1550.9 kg ha^{-1}); 50% atrazine + pendimethalin (AP2) gave the highest yield among herbicide treatments (3203.2 kg ha^{-1}), comparable to hand weeding, and the tillage × herbicide interaction was significant. The results suggest that tillage and herbicide programme both shape weed succession in Guinea savanna maize, and they favour integrated, site-specific weed management over fixed herbicide regimes.

Keywords: *weed flora dynamics, herbicide mixtures, tillage systems, reduced herbicide rates, maize, savanna agroecology.*

1. Introduction

Maize (*Zea mays* L.) is among the most widely grown cereals in sub-Saharan Africa and supports food security, animal feed production and industrial supply chains [1]. Nigeria has greatly increased its maize output over the past two decades to meet demand from the poultry and food-processing industries, yet farm yields remain far below the attainable potential because soils are infertile, improved inputs are hard to obtain and weeds are poorly controlled [2,3]. Weeds are regarded as the most damaging biotic constraint on maize in the humid and sub-humid tropics, and uncontrolled infestation during crop establishment can cut grain yield by 30% to over 80% [4,5]. Similar losses are reported elsewhere: weed interference reduced maize yield by about 50% on average in North American trials [6], and weeds cause the largest share of the potential global crop loss attributed to pests [7].

Smallholders in the Nigerian Guinea savanna have traditionally controlled weeds by hoeing. Rising labour costs, seasonal labour shortages and the drudgery of hand weeding have, however, pushed many towards pre-emergence herbicides such as atrazine and pendimethalin and their mixtures [3,8]. Atrazine + pendimethalin mixtures, and ready-made formulations such as primextra (atrazine + metolachlor), are popular because a single application controls both broadleaf weeds and grasses [9]. The high price of imported agrochemicals, concern about residues and effects on soil organisms, and the risk that repeated, uniform herbicide use selects resistant biotypes [10,11] have revived interest in finding the lowest rate that still gives acceptable control [12,13]. In south-western Nigeria, stepwise reductions in atrazine dose gave weed control comparable to the full rate at lower cost and with less harm to soil organisms such as earthworms [12], which shows why rate-reduction trials are worth conducting.

Tillage is a second major influence on the make-up of weed communities. Cultivation moves seeds through the soil profile and exposes buried seeds to light and temperature fluctuations, thereby changing when, how densely and which species emerge [14–16]. Tractor ploughing generally buries seed more evenly and may favour early-emerging annual grasses and broadleaves, whereas hand-tilled or lightly disturbed soils tend to keep more seed near the surface and favour species with other life histories [17–20].

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Recent studies still show that tillage intensity restructures weed communities and diversity, although the direction and size of the response depend on soil, cropping history and climate [21–25]. Because soil disturbance, organic-matter distribution and moisture also alter how well herbicides work and how long they persist, tillage and herbicide programme can be expected to interact in determining which species dominate over successive seasons [26,27], in line with the long-standing view that weed succession is driven by the management regime [28].

Few studies in the Nigerian Guinea savanna have followed weed abundance, density, frequency and species dominance across successive seasons while varying both herbicide rate and tillage method. Earlier work on atrazine–pendimethalin and primextra in maize mostly addressed short-term control efficiency or yield [2,3,29] and did not describe the successional changes in the weed flora that reduced herbicide rates or different tillage intensities might cause. Such changes matter in practice because the decline of one dominant species is often followed by the rise of another that is harder to control, a process known as weed-flora shift under persistent selection by a narrow range of control measures [17,30].

This study therefore set out to (i) describe the abundance, density, frequency and percentage contribution of weed species in maize under four rates (100, 75, 50 and 25% of the recommended dose) of atrazine + pendimethalin and of primextra, compared with hand-weeded and unweeded controls; (ii) contrast the weed floral dynamics of tractor-tilled and manually tilled plots over two successive seasons (2008 and 2009); and (iii) relate the changes in weed composition to maize grain yield and 100-seed weight. We hypothesised that herbicide rate and tillage method would both influence weed species composition, and that rates below the recommendation would favour a shift towards grass-dominated weed floras over time. The results are intended to help select herbicide rates and tillage practices that give effective, affordable and ecologically sound weed control in maize-based systems of the Nigerian Guinea savanna.

2. Materials and Methods

2.1 Study site

The field experiments ran for two consecutive seasons (2008 and 2009) at the Teaching and Research Farm of the Taraba State College of Agriculture, Jalingo (8°50′ N, 11°50′ E), in the Northern Guinea savanna zone of Nigeria. The climate is tropical wet–dry, with a rainy season of about 150 days, annual rainfall of 700–1000 mm and a mean annual temperature near 28 °C.

2.2 Treatments and experimental design

The study tested four rates (100, 75, 50 and 25% of the recommended rate) of two pre-emergence herbicide mixtures, atrazine + pendimethalin and primextra, under two tillage methods (tractor, TT; manual, MT). The layout was a split-plot arrangement in a randomised complete block design with three replicates, with tillage as the main-plot factor and herbicide treatment as the sub-plot factor. The recommended rate of atrazine + pendimethalin was 2.0 + 2.0 kg a.i. ha^{-1} (AP4 = 100%, AP3 = 75%, AP2 = 50%, AP1 = 25%) and that of primextra was 2.5 kg a.i. ha^{-1} (PX4 = 100%, PX3 = 75%, PX2 = 50%, PX1 = 25%).

A hand-weeded control (weeded at 3 and 6 weeks after planting, WAP; C1) and an unweeded control (C2) brought the number of sub-plot treatments to ten (Table 1). Treatments stayed on the same main plots in both years.

Atrazine was applied as a 50% SC formulation (500 g L^{-1}; 6-chloro-N-ethyl-N′-(1-methylethyl)-1,3,5-triazine-2,4-diamine) and pendimethalin as a 500 EC formulation (N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine). Primextra Gold (660 g a.i. L^{-1}) is a ready-mix of atrazine (290 g L^{-1}) and metolachlor (370 g L^{-1}; 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide).

2.3 Planting and herbicide application

The open-pollinated, early-maturing maize variety 95-TZEE-W1, obtained from the International Institute of Tropical Agriculture (IITA), Ibadan, was sown on 30 June 2008 and 12 June 2009 at 25 cm × 100 cm, giving about 40,000 plants ha^{-1}. Herbicide solutions were prepared at the rate assigned to each treatment and sprayed within 48 hours of planting with a CP-15 knapsack sprayer calibrated to deliver 300 L ha^{-1}.

2.4 Trial management and harvesting

Hand-weeded plots were weeded at 3 and 6 WAP. All plots received nitrogen fertiliser at the recommended rate of 120 kg N ha^{-1}. Cobs were harvested at physiological maturity, 14–16 WAP.

2.5 Weed data collection

In total, 720 quadrats were sampled during the study. At each sampling (4 and 10 WAP and at crop harvest), a 0.5 m × 0.5 m quadrat was placed at random at two positions in every plot. Weeds within the quadrat were cut, grouped as broadleaves, grasses and sedges, and counted by species. Species were identified with the aid of a handbook of West African weeds [31]. Abundance, density and frequency of each species were calculated with standard phytosociological formulae [32]:

Abundance = total number of individuals of a species ÷ number of quadrats in which the species occurred.

Percentage density = (total number of individuals of a species ÷ total number of individuals of all species) × 100.

Percentage frequency = (number of quadrats in which a species occurred ÷ total number of quadrats sampled) × 100.

Frequency classes were assigned according to the system of life-form and frequency classification in [33]: V (c) = constant, 80–100% frequency; IV (ab) = abundant, 60–80%; III (f) = frequent, 40–60%; II (ac) = accessory, 20–40%; and I (r) = rare or accidental, 0–20%.

2.6 Statistical analysis

Grain yield and 100-seed weight were analysed by analysis of variance for a split-plot design, and treatment means were separated by Duncan's Multiple Range Test at $p = 0.05$. Weed abundance, density, frequency and percentage contribution are presented descriptively by tillage method, herbicide treatment and year, in keeping with the phytosociological approach used to assess the weed flora.

Table 1: Tillage and herbicide treatments evaluated in the experiment

No.	Tillage	Herbicide treatment	% of recommended rate
1	Manual	2.0 + 2.0 kg a.i./ha atrazine + pendimethalin (AP4)	100
2	"	1.5 + 1.5 kg a.i./ha atrazine + pendimethalin (AP3)	75
3	"	1.0 + 1.0 kg a.i./ha atrazine + pendimethalin (AP2)	50
4	"	0.5 + 0.5 kg a.i./ha atrazine + pendimethalin (AP1)	25
5	"	2.5 kg a.i./ha primextra (PX4)	100
6	"	1.875 kg a.i./ha primextra (PX3)	75
7	"	1.25 kg a.i./ha primextra (PX2)	50
8	"	0.625 kg a.i./ha primextra (PX1)	25
9	"	Hand-weeded control (C1)	3 + 6 WAP
10	"	Unweeded control (C2)	No weeding
11	Tractor	2.0 + 2.0 kg a.i./ha atrazine + pendimethalin (AP4)	100
12	"	1.5 + 1.5 kg a.i./ha atrazine + pendimethalin (AP3)	75
13	"	1.0 + 1.0 kg a.i./ha atrazine + pendimethalin (AP2)	50
14	"	0.5 + 0.5 kg a.i./ha atrazine + pendimethalin (AP1)	25
15	"	2.5 kg a.i./ha primextra (PX4)	100
16	"	1.875 kg a.i./ha primextra (PX3)	75
17	"	1.25 kg a.i./ha primextra (PX2)	50
18	"	0.625 kg a.i./ha primextra (PX1)	25
19	"	Hand-weeded control (C1)	3 + 6 WAP
20	"	Unweeded control (C2)	No weeding

AP = atrazine + pendimethalin; PX = primextra. C1 = hand-weeded control (3 + 6 WAP); C2 = unweeded control. The same treatments were applied to the same main plots in each of the two study years.

3. Results

3.1 Weed floral dynamics under manual tillage

Table 2 shows the abundance, density, frequency and frequency index of weed species under manual tillage. In 2008 the most abundant species were *Dactyloctenium aegyptium* (4.5), *Cynodon dactylon* (4.0), *Mitracarpus villosus* (3.3), *Leucas martinicensis* (3.2), and *Monechma ciliatum* and *Oldenlandia herbacea* (3.1 each); abundance of most of these fell sharply, or to zero, by 2009. *Tridax procumbens*, *Commelina benghalensis* and *Mucuna utilis* kept almost the same abundance in both years, whereas that of *Ageratum conyzoides* dropped from 2.4 to 1.5. Species that were absent in 2008 but conspicuous in 2009 included *Hyptis lanceolata*, *Digitaria horizontalis*, *Andropogon gayanus*, *Panicum maximum* and *Imperata cylindrica*. Summed over the grass species in Table 2, density rose from 16.2% of the weed population in 2008 to 46.6% in 2009. Together with the loss of many broadleaf species, this marks a succession from a broadleaf-rich flora towards one dominated by *H. lanceolata* and robust grasses under continuous manual tillage and herbicide use. Several species in the abundant class (frequency index IV) in 2008, such as *M. ciliatum*, *M. utilis* and *L. martinicensis*, had fallen to the rare class (I) in 2009, while *H. lanceolata* moved from absent (0% frequency) to abundant (index IV; 73.3% frequency).

Tables 3 and 4 give the percentage contribution of each species to the weed population in manually tilled plots in 2008 and 2009. In 2008 no species dominated consistently, and the leading species differed among treatments: *L. martinicensis* in AP4 (19.3%), PX4 (26.9%) and PX1 (20.7%); *M. ciliatum* in AP3 (24.1%), PX2 (30.7%) and C2 (16.7%); *A. conyzoides* in AP1 (25.3%); *Cynodon plectostachyum* in PX3 (18.6%); and *O. herbacea* in C1 (22.3%). *Mitracarpus villosus* and *M. ciliatum* tied in AP2 (13.3% each). *Leucas martinicensis* and *Mucuna utilis* occurred in every treatment, including both controls. By 2009 *H. lanceolata* made the largest contribution in seven of the ten treatments (22.6–46.2% in the herbicide plots and 45.0% in the unweeded control) and tied with *D. horizontalis* in PX4 (24.2% each), whereas *I. cylindrica* (26.3%) led in AP1 and *Aspilia bussei* (30.0%) in the hand-weeded control. *Digitaria horizontalis* and *A. gayanus* each occurred in seven of the eight herbicide treatments, consistent with the rise of grasses shown in Table 2.

Table 2: Effects of chemical weed-control treatments under manual tillage on individual weed abundance, density, frequency and frequency index in maize, 2008 and 2009.

Weed species	Abund. 2008	Abund. 2009	Density % 2008	Density % 2009	Freq. % 2008	Freq. % 2009	Index 2008	Index 2009
Broadleaf weeds								
Mitracarpus villosus (Sw.) DC	3.3	1.8	5.5	2.1	21.7	6.7	II (ac)	I (r)
Monechma ciliatum (Jacq.) Milne-Redhead	3.1	0.0	14.2	0.0	60.0	0.0	IV (ab)	I (r)
Oldenlandia herbacea L.	3.1	0.0	5.5	0.0	23.3	0.0	II (ac)	I (r)
Tridax procumbens L.	2.2	2.0	5.2	2.4	31.7	6.7	II (ac)	I (r)
Mucuna utilis	2.1	2.0	9.7	5.4	61.7	15.0	IV (ab)	I (r)
Leucas martinicensis (Jacq.) Ait. f.	3.2	2.0	15.7	0.6	63.3	1.7	IV (ab)	I (r)
Euphorbia hirta L.	2.0	0.0	0.5	0.0	3.3	0.0	I (r)	I (r)
Hyptis spicigera Lam.	1.6	0.0	1.0	0.0	8.3	0.0	I (r)	I (r)
Schwenckia americana L.	2.5	0.0	0.6	0.0	3.3	0.0	I (r)	I (r)
Vernonia ambigua Kotschy & Peyr.	2.2	0.0	1.4	0.0	8.3	0.0	I (r)	I (r)
Ageratum conyzoides L.	2.4	1.5	6.1	1.8	33.3	6.7	II (ac)	I (r)
Euphorbia heterophylla L.	2.4	0.0	3.3	0.0	18.3	0.0	I (r)	I (r)
Cleome viscosa L.	2.3	0.0	1.1	0.0	6.7	0.0	I (r)	I (r)
Vernonia cinerea (L.) Less.	2.1	0.0	3.2	0.0	20.0	0.0	II (ac)	I (r)
Evolvulus alsinoides (L.) L.	1.0	0.0	0.1	0.0	1.7	0.0	I (r)	I (r)
Indigofera hirsuta L.	1.0	0.0	0.1	0.0	1.7	0.0	I (r)	I (r)
Hyptis lanceolata Poir.	0.0	2.2	0.0	28.4	0.0	73.3	I (r)	IV (ab)
Aspilia bussei O. Hoffm. & Muschl.	0.0	1.6	0.0	5.4	0.0	18.3	I (r)	I (r)
Tephrosia linearis (Willd.) Pers.	0.0	2.0	0.0	1.2	0.0	3.3	I (r)	I (r)

Senna obtusifolia L.	1.0	0.0	0.1	0.0	1.7	0.0	I (r)	I (r)
Commelina benghalensis L.	1.8	1.9	5.4	4.5	38.3	13.3	II (ac)	I (r)
Sida acuta Burm. f.	1.8	0.0	4.6	0.0	33.3	0.0	II (ac)	I (r)
Desmodium scorpiurus (Sw) Desv.	2.0	0.0	0.3	0.0	1.7	0.0	I (r)	I (r)
Sida garckeana Polak	0.0	2.0	0.0	0.6	0.0	1.7	I (r)	I (r)
Aspilia africana (Pers.) C. D. Adams	0.0	2.0	0.0	1.2	0.0	3.3	I (r)	I (r)
Grasses								
Rhynchelytrum repens (Willd.) C.E. Hubbard	2.0	0.0	1.3	0.0	8.3	0.0	I (r)	I (r)
Rottboellia cochinchinensis (Lour.) Clayton	1.8	0.0	2.7	0.0	20.0	0.0	II (ac)	I (r)
Pennisetum pedicellatum Trin.	2.6	0.0	4.0	0.0	20.0	0.0	II (ac)	I (r)
Cynodon plectostachyum	2.9	0.0	4.5	0.0	20.0	0.0	II (ac)	I (r)
Dactyloctenium aegyptium (L.) P. Beauv.	4.5	0.0	1.1	0.0	3.3	0.0	I (r)	I (r)
Eragrostis tremula Hochst. ex Steud.	1.0	0.0	0.1	0.0	1.7	0.0	I (r)	I (r)
Digitaria horizontalis Willd.	0.0	2.2	0.0	14.9	0.0	38.3	I (r)	II (ac)
Setaria pumila (Poir.) Roem. & Schult.	0.0	2.0	0.0	1.2	0.0	3.3	I (r)	I (r)
Panicum laxum Sw.	0.0	2.0	0.0	0.6	0.0	1.7	I (r)	I (r)
Cynodon dactylon (L.) Pers.	4.0	0.0	1.0	0.0	3.3	0.0	I (r)	I (r)
Paspalum orbiculare Forst.	3.0	0.0	1.5	0.0	6.7	0.0	I (r)	I (r)
Andropogon gayanus Kunth var. gayanus	0.0	1.9	0.0	9.9	0.0	28.3	I (r)	II (ac)
Eragrostis atrovirens (Desf.) Trin. ex Steud.	0.0	1.7	0.0	1.5	0.0	5.0	I (r)	I (r)
Panicum maximum Jacq.	0.0	1.8	0.0	6.3	0.0	20.0	I (r)	II (ac)
Imperata cylindrica L.	0.0	2.6	0.0	12.2	0.0	26.7	I (r)	II (ac)

Frequency index classes [33]: IV (ab) = abundant (60–80% frequency); III (f) = frequent (40–60%); II (ac) = accessory (20–40%); I (r) = rare or accidental (0–20%).

Table 3: Percentage contribution of individual weed species to the weed population in maize as influenced by herbicide rate under manual tillage, 2008

Weed species	Family	AP4	AP3	AP2	AP1	PX4	PX3	PX2	PX1	C1	C2
Broadleaf weeds											
Mitracarpus villosus (Sw.) DC	Rubiaceae	0.0	14.5	13.3	0.0	3.8	0.0	0.0	0.0	18.4	0.0
Monechma ciliatum (Jacq.) Milne-Redhead	Acanthaceae	13.2	24.1	13.3	6.7	7.7	17.1	30.7	15.5	0.0	16.7
Oldenlandia herbacea L.	Rubiaceae	4.4	8.4	1.3	0.0	0.0	10.0	0.0	0.0	22.3	0.0
Tridax procumbens L.	Asteraceae	4.4	13.3	4.0	5.3	9.6	0.0	0.0	6.9	2.9	7.7
Mucuna utilis	Fabaceae	6.1	4.8	12.0	10.7	3.8	14.3	12.0	6.9	12.6	12.8
Leucas martinicensis (Jacq.) Ait. f.	Lamiaceae	19.3	16.9	8.0	18.7	26.9	14.3	14.7	20.7	12.6	9.0
Euphorbia hirta L.	Euphorbiaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1
Hyptis spicigera Lam.	Lamiaceae	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	2.6
Schwenckia americana L.	Solanaceae	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vernonia ambigua Kotschy & Peyr.	Asteraceae	3.5	0.0	6.7	0.0	0.0	0.0	0.0	0.0	1.9	0.0
Ageratum conyzoides L.	Asteraceae	0.0	6.0	5.3	25.3	11.5	0.0	6.7	5.2	2.9	3.8
Euphorbia heterophylla L.	Euphorbiaceae	11.4	0.0	0.0	0.0	0.0	5.7	2.7	12.1	0.0	0.0
Cleome viscosa L.	Cleomaceae	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1
Vernonia cinerea (L.) Less.	Asteraceae	1.8	0.0	4.0	0.0	11.5	1.4	4.0	0.0	5.8	5.1
Evolvulus alsinoides (L.) L.	Convolvulaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3
Indigofera hirsuta L.	Fabaceae	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sida acuta Burm. f.	Malvaceae	7.9	4.8	4.0	4.0	0.0	1.4	5.3	8.6	3.9	3.8
Commelina benghalensis L.	Commelinaceae	2.6	0.0	9.3	21.3	13.5	0.0	0.0	0.0	1.0	10.3
Desmodium scorpiurus (Sw.) Desv.	Fabaceae	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Senna obtusifolia L.	Fabaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Grasses											
Rhynchelytrum repens (Willd.) C. E. Hubbard	Poaceae	3.5	0.0	0.0	0.0	3.8	0.0	0.0	6.9	0.0	0.0
Rottboellia cochinchinensis	Poaceae	3.5	0.0	8.0	0.0	0.0	7.1	8.0	0.0	0.0	0.0
Pennisetum pedicellatum Trin.	Poaceae	3.5	0.0	0.0	6.7	0.0	10.0	6.7	0.0	4.9	6.4
Cynodon plectostachyum	Poaceae	6.1	0.0	4.0	0.0	7.7	18.6	0.0	0.0	0.0	10.3
Dactyloctenium aegyptium (L.) P. Beauv.	Poaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.5	0.0	0.0
Eragrostis tremula Hochst. ex Steud.	Poaceae	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0
Cynodon dactylon (L.) Pers.	Poaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.8	0.0
Paspalum orbiculare Forst.	Poaceae	0.0	0.0	6.7	0.0	0.0	0.0	9.3	0.0	0.0	0.0

AP4 = 2.0+2.0 kg a.i. ha^{-1} (100%), AP3 = 1.5+1.5 (75%), AP2 = 1.0+1.0 (50%), AP1 = 0.5+0.5 (25%) atrazine + pendimethalin. PX4 = 2.5 kg a.i. ha^{-1} (100%), PX3 = 1.875 (75%), PX2 = 1.25 (50%), PX1 = 0.625 (25%) primextra. C1 = hand-weeded control (3+6 WAP); C2 = unweeded control.

Table 4: Percentage contribution of individual weed species to the weed population in maize as influenced by herbicide rate under manual tillage, 2009

Weed species	Family	AP4	AP3	AP2	AP1	PX4	PX3	PX2	PX1	C1	C2
Broadleaf weeds											
Tridax procumbens L.	Asteraceae	0.0	0.0	0.0	0.0	6.1	0.0	4.2	11.1	0.0	0.0
Hyptis lanceolata Poir.	Lamiaceae	26.7	22.6	26.1	23.7	24.2	46.2	33.3	30.6	0.0	45.0
Aspilia bussei O. Hoffm. & Muschl.	Asteraceae	0.0	9.7	0.0	5.3	0.0	3.8	0.0	8.3	30.0	0.0
Mitracarpus villosus (Sw.) DC	Rubiaceae	0.0	0.0	0.0	0.0	0.0	0.0	4.2	8.3	6.7	0.0
Leucas martinicensis (Jacq.) Ait. f.	Lamiaceae	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0
Ageratum conyzoides L.	Asteraceae	0.0	0.0	13.0	0.0	9.1	0.0	0.0	0.0	0.0	0.0
Mucuna utilis	Fabaceae	13.3	6.5	8.7	0.0	0.0	0.0	12.5	0.0	13.3	0.0
Tephrosia linearis (Willd.) Pers.	Fabaceae	0.0	0.0	0.0	0.0	12.1	0.0	0.0	0.0	0.0	0.0
Commelina benghalensis L.	Commelinaceae	13.3	6.5	0.0	5.3	6.1	0.0	0.0	11.1	0.0	2.5
Sida garckeana Polak	Malvaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0
Aspilia africana (Pers.) C.D. Adams	Asteraceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
Grasses											
Digitaria horizontalis Willd.	Poaceae	13.3	9.7	0.0	23.7	24.2	26.9	29.2	11.1	3.3	0.0
Setaria pumila (Poir.) Roem. & Schult.	Poaceae	0.0	0.0	17.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Panicum laxum Sw.	Poaceae	0.0	0.0	0.0	0.0	0.0	7.7	0.0	0.0	0.0	0.0
Andropogon gayanus Kunth var. gayanus	Poaceae	13.3	12.9	17.4	10.5	0.0	15.4	8.3	19.4	6.7	0.0
Eragrostis atrovirens (Desf.) Trin. ex Steud.	Poaceae	6.7	0.0	0.0	0.0	9.1	0.0	0.0	0.0	0.0	0.0
Panicum maximum Jacq.	Poaceae	10.0	12.9	17.4	0.0	9.1	0.0	0.0	0.0	20.0	2.5
Imperata cylindrica L.	Poaceae	3.3	19.4	0.0	26.3	0.0	0.0	8.3	0.0	13.3	40.0

Treatment codes as in Table 3.

3.2 Weed floral dynamics under tractor tillage

Under tractor tillage (Table 5), *Andropogon gayanus* (3.5), *Rottboellia cochinchinensis* and *Leucas martinicensis* (3.4 each) were the most abundant weeds in 2008, and abundance of most species had fallen by 2009. In contrast, *Ageratum conyzoides* increased from 2.5 to 7.0, although its frequency fell from 25.0 to 3.3%, indicating a few dense patches rather than wide spread. *Tridax procumbens* (2.8 to 2.5), *Mucuna utilis* (2.3 to 2.1) and *Commelina benghalensis* (1.9 to 1.7) declined slightly, while *Hyptis lanceolata*, *Digitaria horizontalis* and *Imperata cylindrica* appeared in 2009. For density in 2008, *Monechma ciliatum* (14.7%), *M. utilis* (12.3%) and *Mitracarpus villosus* (11.6%) were highest, and the remaining species ranged from 0.2 to 9.8%. Summed over the grass species in Table 5, density rose from 21.0% in 2008 to 43.0% in 2009. Nearly all species that were abundant or frequent in 2008 had dropped to the rare class by 2009, the exception being *H. lanceolata*, which rose from absence to 71.7% frequency (index IV).

Tables 6 and 7 list the percentage contributions under tractor tillage in 2008 and 2009. In 2008 the leading species again varied with treatment: *M. villosus* and *Mucuna utilis* tied in AP4 (19.2% each); *Rottboellia cochinchinensis* led in AP3 (27.8%) and C1 (15.1%); *Cynodon plectostachyum* in AP2 (22.4%); *Leucas martinicensis* in AP1 (18.6%); *Monechma ciliatum* in PX4 (35.1%), PX1 (25.0%) and C2 (19.4%); *M. villosus* in PX3 (15.6%); and *M. utilis* in PX2 (17.6%). In 2009 *Hyptis lanceolata* contributed most in nine of the ten treatments (22.2–51.7%); the exception was the hand-weeded control, where *Digitaria horizontalis* led (33.3%). *Digitaria horizontalis* occurred in all ten treatments and *Panicum maximum* in seven of the eight herbicide treatments. These patterns confirm the move towards a community dominated by *H. lanceolata* and tall grasses under tractor tillage as well.

Table 5: Effects of chemical weed-control treatments under tractor tillage on individual weed abundance, density, frequency and frequency index in maize, 2008 and 2009

Weed species	Abund. 2008	Abund. 2009	Density % 2008	Density % 2009	Freq. % 2008	Freq. % 2009	Index 2008	Index 2009
Broadleaf weeds								
Mitracarpus villosus (Sw.) DC	2.7	1.8	11.6	2.1	46.7	6.7	III (f)	I (r)
Monechma ciliatum (Jacq.) Milne-Redhead	3.2	0.0	14.7	0.0	50.0	0.0	III (f)	I (r)
Laggera aurita (L.f.) Benth. ex C.B.Clarke	1.5	0.0	0.5	0.0	3.3	0.0	I (r)	I (r)
Oldenlandia herbacea L.	2.1	0.0	5.1	0.0	26.7	0.0	II (ac)	I (r)
Tridax procumbens L.	2.8	2.5	7.8	1.5	30.0	3.3	II (ac)	I (r)
Ageratum conyzoides L.	2.5	7.0	5.8	4.1	25.0	3.3	II (ac)	I (r)
Mucuna utilis	2.3	2.1	12.3	5.0	58.3	13.3	III (f)	I (r)
Leucas martinicensis (Jacq.) Ait. f.	3.4	0.0	9.8	0.0	31.7	0.0	II (ac)	I (r)
Euphorbia hirta L.	1.0	0.0	0.2	0.0	1.7	0.0	I (r)	I (r)
Schwenckia americana L.	1.0	0.0	0.2	0.0	1.7	0.0	I (r)	I (r)
Vernonia ambigua Kotschy & Peyr.	1.3	0.0	0.6	0.0	5.0	0.0	I (r)	I (r)
Ipomoea eriocarpa R.Br.	2.5	0.0	0.8	0.0	3.3	0.0	I (r)	I (r)
Striga hermonthica (Del.) Benth.	1.5	0.0	0.5	0.0	3.3	0.0	I (r)	I (r)

Stylosanthes hamata	1.0	0.0	0.3	0.0	3.3	0.0	I (r)	I (r)
Hyptis lanceolata Poir.	0.0	2.8	0.0	35.5	0.0	71.7	I (r)	IV (ab)
Aspilia bussei O. Hoffm. & Muschl.	0.0	1.7	0.0	4.4	0.0	15.0	I (r)	I (r)
Cleome viscosa L.	0.0	1.5	0.0	0.9	0.0	3.3	I (r)	I (r)
Euphorbia hyssopifolia L.	0.0	2.0	0.0	0.6	0.0	1.7	I (r)	I (r)
Commelina benghalensis L.	1.9	1.7	4.3	1.5	25.0	5.0	II (ac)	I (r)
Sida garckeana Polak	0.0	1.7	0.0	1.5	0.0	5.0	I (r)	I (r)
Zornia latifolia Sm.	1.5	0.0	0.9	0.0	6.7	0.0	I (r)	I (r)
Desmodium scorpiurus (Sw.) Desv.	1.0	0.0	0.2	0.0	1.7	0.0	I (r)	I (r)
Senna obtusifolia L.	1.5	0.0	0.5	0.0	3.3	0.0	I (r)	I (r)
Sida acuta Burm. f.	1.6	0.0	3.2	0.0	21.7	0.0	II (ac)	I (r)
Grasses								
Rhynchelytrum repens (Willd.) C. E. Hubbard	2.8	0.0	2.6	0.0	10.0	0.0	I (r)	I (r)
Rottboellia cochinchinensis (Lour.) Clayton	3.4	1.6	7.4	2.4	23.3	8.3	II (ac)	I (r)
Pennisetum pedicellatum Trin.	3.1	0.0	7.0	0.0	25.0	0.0	II (ac)	I (r)
Cynodon plectostachyum	1.4	0.0	2.6	0.0	20.0	0.0	II (ac)	I (r)
Digitaria horizontalis Willd.	0.0	2.3	0.0	18.9	0.0	46.7	I (r)	III (f)
Chloris pilosa Schumach.	0.0	2.0	0.0	1.2	0.0	3.3	I (r)	I (r)
Panicum laxum Sw.	0.0	2.0	0.0	0.6	0.0	1.7	I (r)	I (r)
Imperata cylindrica L.	0.0	2.3	0.0	4.7	0.0	11.7	I (r)	I (r)
Panicum maximum Jacq.	0.0	1.7	0.0	9.8	0.0	33.3	I (r)	II (ac)
Eragrostis atrovirens (Desf.) Trin. ex Steud.	0.0	1.5	0.0	0.9	0.0	3.3	I (r)	I (r)
Paspalum orbiculare Forst.	2.0	2.0	0.3	1.2	1.7	3.3	I (r)	I (r)
Andropogon gayanus Kunth var. gayanus	3.5	1.8	1.1	3.3	3.3	10.0	I (r)	I (r)

Frequency index classes [33]: IV (ab) = abundant (60–80% frequency); III (f) = frequent (40–60%); II (ac) = accessory (20–40%); I (r) = rare or accidental (0–20%).

Table 6: Percentage contribution of individual weed species to the weed population in maize as influenced by herbicide rate under tractor tillage, 2008

Weed species	Family	AP4	AP3	AP2	AP1	PX4	PX3	PX2	PX1	C1	C2
Broadleaf weeds											
Mitracarpus villosus (Sw.) DC	Rubiaceae	19.2	7.4	12.1	5.2	21.1	15.6	13.7	0.0	11.0	14.5
Monechma ciliatum (Jacq.) Milne-Redhead	Acanthaceae	9.6	0.0	19.0	17.5	35.1	10.9	11.8	25.0	0.0	19.4
Laggera aurita (L.f.) Benth. ex C.B.Clarke	Asteraceae	0.0	0.0	0.0	0.0	0.0	4.7	0.0	0.0	0.0	0.0
Oldenlandia herbacea L.	Rubiaceae	0.0	0.0	0.0	4.1	14.0	6.3	5.9	0.0	8.2	12.9
Tridax procumbens L.	Asteraceae	15.1	7.4	0.0	15.5	0.0	7.8	0.0	6.3	5.5	12.9
Ageratum conyzoides L.	Asteraceae	0.0	20.4	12.1	0.0	3.5	0.0	5.9	9.4	8.2	4.8
Mucuna utilis	Fabaceae	19.2	24.1	5.2	8.2	14.0	10.9	17.6	10.9	9.6	6.5
Leucas martinicensis (Jacq.) Ait. f.	Lamiaceae	8.2	0.0	19.0	18.6	0.0	9.4	0.0	10.9	8.2	16.1
Euphorbia hirta L.	Euphorbiaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0
Schwenckia americana L.	Solanaceae	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0
Vernonia ambigua Kotschy & Peyr.	Asteraceae	4.1	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0
Ipomoea eriocarpa R. Br.	Convolvulaceae	0.0	0.0	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0
Striga hermonthica (Del.) Benth.	Orobanchaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	0.0
Stylosanthes hamata	Fabaceae	0.0	0.0	0.0	0.0	1.8	1.6	0.0	0.0	0.0	0.0
Sida acuta Burm. f.	Malvaceae	0.0	0.0	5.2	0.0	0.0	7.8	0.0	10.9	8.2	0.0
Commelina benghalensis L.	Commelinaceae	5.5	7.4	5.2	3.1	0.0	10.9	3.9	7.8	0.0	0.0
Desmodium scorpiurus (Sw.) Desv.	Fabaceae	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Senna obtusifolia L.	Fabaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	1.4	0.0
Zornia latifolia Sm.	Fabaceae	0.0	0.0	0.0	4.1	0.0	0.0	0.0	1.6	0.0	1.6
Grasses											
Rhynchelytrum repens (Willd.) C. E. Hubbard	Poaceae	0.0	0.0	0.0	0.0	0.0	14.1	0.0	0.0	11.0	0.0
Rottboellia cochinchinensis (Lour.) Clayton	Poaceae	0.0	27.8	0.0	11.3	10.5	0.0	9.8	0.0	15.1	0.0
Pennisetum pedicellatum Trin.	Poaceae	17.8	1.9	0.0	7.2	0.0	0.0	13.7	7.8	8.2	11.3
Cynodon plectostachyum	Poaceae	0.0	0.0	22.4	0.0	0.0	0.0	0.0	6.3	0.0	0.0
Andropogon gayanus Kunth var. gayanus	Poaceae	0.0	0.0	0.0	0.0	0.0	0.0	13.7	0.0	0.0	0.0
Paspalum orbiculare Forst.	Poaceae	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Treatment codes as in Table 3.

Table 7: Percentage contribution of individual weed species to the weed population in maize as influenced by herbicide rate under tractor tillage, 2009

Weed species	Family	AP4	AP3	AP2	AP1	PX4	PX3	PX2	PX1	C1	C2
Broadleaf weeds											
Tridax procumbens L.	Asteraceae	0.0	18.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hyptis lanceolata Poir.	Lamiaceae	51.7	22.2	44.8	33.9	40.7	28.6	33.3	37.8	8.3	44.4
Aspilia bussei O. Hoffm. & Muschl.	Asteraceae	0.0	3.7	0.0	0.0	3.7	14.3	0.0	8.1	25.0	0.0
Mitracarpus villosus (Sw.) DC	Rubiaceae	0.0	7.4	0.0	0.0	0.0	0.0	0.0	0.0	20.8	0.0
Cleome viscosa L.	Cleomaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7
Ageratum conyzoides L.	Asteraceae	0.0	0.0	0.0	22.6	0.0	0.0	0.0	0.0	0.0	0.0
Euphorbia hyssopifolia L.	Euphorbiaceae	0.0	0.0	6.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mucuna utilis	Fabaceae	0.0	7.4	0.0	3.2	3.7	0.0	30.0	0.0	0.0	6.7
Commelina benghalensis L.	Commelinaceae	0.0	7.4	0.0	3.2	3.7	0.0	0.0	0.0	0.0	0.0
Sida garckeana Polak	Malvaceae	0.0	0.0	0.0	6.5	0.0	0.0	0.0	0.0	4.2	0.0
Grasses											
Digitaria horizontalis Willd.	Poaceae	13.8	7.4	27.6	17.7	7.4	7.1	26.7	18.9	33.3	26.7
Rottboellia cochinchinensis (Lour.) Clayton	Poaceae	10.3	0.0	0.0	0.0	0.0	10.7	0.0	5.4	0.0	0.0
Chloris pilosa Schumach.	Poaceae	0.0	14.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Panicum laxum Sw.	Poaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0
Andropogon gayanus Kunth var. gayanus	Poaceae	0.0	0.0	0.0	0.0	11.1	14.3	0.0	0.0	0.0	8.9
Eragrostis atrovirens (Desf.) Trin. ex Steud.	Poaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.1	0.0	0.0
Panicum maximum Jacq.	Poaceae	24.1	11.1	6.9	12.9	25.9	10.7	10.0	0.0	0.0	0.0
Paspalum orbiculare Forst.	Poaceae	0.0	0.0	13.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Imperata cylindrica L.	Poaceae	0.0	0.0	0.0	0.0	3.7	14.3	0.0	21.6	0.0	6.7

Treatment codes as in Table 3.

3.3 Effects of herbicide rate and tillage method on maize grain yield

Herbicide treatment and the tillage × herbicide interaction significantly affected mean grain yield and 100-seed weight (Tables 8 and 9). Hand weeding (C1) gave the highest grain yield (3568.1 kg ha^{-1}) and 100-seed weight (25.4 g), and the unweeded control (C2) the lowest (1550.9 kg ha^{-1} and 21.4 g). Among the herbicide treatments, 50% atrazine + pendimethalin (AP2) gave the highest grain yield (3203.2 kg ha^{-1}), which did not differ significantly from hand weeding, whereas the 25% rates (AP1 and PX1) were among the lowest-yielding chemical treatments. Tillage method alone did not significantly affect either trait, but the interaction was significant (Table 9). AP2 yielded well under both tillage systems (3304.1 kg ha^{-1} under TT and 3102.3 kg ha^{-1} under MT), whereas primextra responded less consistently: PX1, PX3 and PX4 yielded more under manual than tractor tillage, but PX2 showed the reverse.

Table 8: Main effects of herbicide treatment and tillage method on maize mean grain yield and 100-seed weight, 2008–2009

Treatment	Mean grain yield (kg ha^{-1})	100-seed weight (g)
AP4	2743.2bc	24.2
AP3	2792.3bc	23.5
AP2	3203.2ab	25.2
AP1	2370.3c	23.8
PX4	2601.7c	22.1
PX3	2346.8c	23.0
PX2	2564.8c	24.5
PX1	2253.0c	23.4
C1 (hand-weeded)	3568.1a	25.4
C2 (unweeded)	1550.9d	21.4
Tillage		
TT	2494.6a	23.8a
MT	2704.3a	23.4a

Means followed by the same letter within a column are not significantly different (DMRT, p = 0.05). TT = tractor tillage; MT = manual tillage.

Table 9: Tillage × herbicide interaction effect on maize mean grain yield and 100-seed weight, 2008–2009

Treatment	Mean GY – TT (kg ha^{-1})	Mean GY – MT (kg ha^{-1})	100 Seed Wt – TT (g)	100 Seed Wt – MT (g)
AP4	2555.6bcdefg	2930.9abcdef	23.4ab	24.7a
AP3	2577.9bcdefg	3006.8abcde	23.3ab	23.3ab
AP2	3304.1abc	3102.3abcd	25.9a	24.6a
AP1	2546.0bcdefg	2194.5efghi	23.7ab	23.9ab
PX4	2092.0fghi	3111.3abcd	21.4ab	22.8ab
PX3	2260.0defghi	2433.6cdefgh	21.5ab	24.6a
PX2	2671.6bcdefg	2458.0cdefgh	26.2a	22.8ab
PX1	1919.8ghi	2586.2bcdefg	24.1ab	22.8ab
C1 (hand-weeded)	3392.2ab	3744.0a	25.0a	25.7a
C2 (unweeded)	1626.6hi	1475.2i	23.4ab	19.3b

Means followed by the same letter within a column are not significantly different (DMRT, p = 0.05). TT = tractor tillage; MT = manual tillage.

4. Discussion

The species that came to dominate manually tilled plots, namely *Leucas martinicensis*, *Mucuna utilis*, *Hyptis lanceolata*, *Digitaria horizontalis*, *Panicum maximum*, *Imperata cylindrica* and *Andropogon gayanus*, share traits that favour rapid recolonisation of disturbed land: heavy seed output and, in *I. cylindrica* and *A. gayanus*, vegetative spread from rhizomes [5,34,35].

Under tractor tillage, the increase of *Ageratum conyzoides*, *H. lanceolata*, *P. maximum* and *I. cylindrica* fits the idea that mechanical disturbance redistributes a large seed bank and that species differ in how they germinate under the altered light and temperature of ploughed soil [14–16]. Recent phytosociological studies likewise identify tillage intensity, seed-bank position and residue cover as primary controls of weed community structure, with reduced tillage generally favouring species that germinate at the surface and conventional tillage favouring

those that are buried and later exposed [21,23–25]. This supports the view that the somewhat different successions under manual and tractor tillage reflect differences in seed-bank exposure as well as herbicide rate.

Atrazine + pendimethalin and primextra gave generally acceptable early-season control of many species, but some were poorly controlled whatever the tillage method or herbicide rate. *Euphorbia heterophylla*, *Commelina benghalensis* and *Imperata cylindrica* are listed among the most troublesome weeds of arable cropping in Nigeria [36], and the persistence, and in places the growing contribution, of *I. cylindrica* and other grasses at reduced rates in this study agrees with that record. It also agrees with evidence that atrazine-based pre-emergence programmes mainly suppress broadleaf weeds and leave several grasses, including *Digitaria* and *Rottboellia* species, less affected, especially as rates decline [3,12].

The change between 2008 and 2009 from a mixed flora of annual broadleaves and grasses towards one dominated by *H. lanceolata* and large grasses, seen under both tillage systems, is a typical sign of weed-flora shift under sustained, narrow-spectrum selection: repeated use of one mode of action removes susceptible species and frees space for tolerant ones [17,30]. Two caveats apply. The same treatments stayed on the same plots in both years, so the trend cannot be fully separated from year-to-year variation, and the shift was evident even at the full recommended rate (for example, *H. lanceolata* contributed 51.7% in AP4 under tractor tillage in 2009), so the present data do not show a clear dependence on herbicide rate. Similar shifts under continuous atrazine-based programmes have been reported from other maize-growing regions and have led to calls for herbicide rotation, or for adding other modes of action such as HPPD inhibitors or post-emergence graminicides, to slow the build-up of shifted or resistant populations [11,13,22]. Reliance on a single mode of action, even at the full rate, is generally recognised as a driver of long-term shift and resistance risk in maize [10,30]. The better yield of hand-weeded plots than of most herbicide plots, together with the competitive performance of 50% atrazine + pendimethalin (AP2), illustrates the cost–benefit trade-off of reduced-rate programmes: intermediate rates can keep yield statistically similar to full rates while lowering input costs and non-target effects, provided the critical early weed-free period is protected [12,37,38]. The significant tillage × herbicide interaction further shows that the rate needed for adequate suppression is not fixed but depends on the tillage system, consistent with reports that tillage modifies herbicide efficacy through soil–herbicide contact, weed emergence timing and seed-bank exposure [26,27].

These results suggest that weed management in maize in the Nigerian Guinea savanna should move beyond fixed-rate, single-herbicide programmes towards integrated strategies: moderate (50%) rates matched to the tillage system, periodic rotation of herbicide mode of action and, where feasible, supplementary hand weeding or mechanical cultivation aimed at the grasses that persist under continuous chemical use [2,3,30].

5. Conclusion

The weed flora of maize at Jalingo changed substantially between 2008 and 2009 under both tillage methods. Broadleaf species that were abundant and frequent in 2008, notably *Monechma ciliatum*, *Leucas martinicensis* and *Mitracarpus villosus*, declined sharply by 2009, while the broadleaf *Hyptis lanceolata* and the grasses *Digitaria horizontalis*, *Andropogon gayanus*, *Panicum maximum* and *Imperata cylindrica* became dominant. Grain yield and 100-seed weight were highest with hand weeding and lowest in the unweeded control, and 50% atrazine + pendimethalin (AP2) was the most consistent herbicide treatment across the two tillage systems. Because the weed data were analysed descriptively and the same treatments were repeated on the same plots, the specific contribution of herbicide rate to the floristic shift still needs formal testing. Reduced rates may lower costs, but the emergence of grass- and perennial-dominated communities means that sustainable weed management will require integrated approaches that combine appropriately rated herbicide mixtures, tillage-specific timing, and rotation or supplementation with other control measures to slow weed-flora shift and protect long-term productivity.

References

1. Food and Agriculture Organization of the United Nations. *FAOSTAT Statistical Database*; FAO: Rome, Italy, 2023.
2. Chikoye, D.; Schulz, S.; Ekeleme, F. Evaluation of integrated weed management practices for maize in the northern Guinea savanna of Nigeria. *Crop Prot.* 2004, 23(10), 895–900. https://doi.org/10.1016/j.cropro.2004.01.013
3. Imoloame, E. O. Evaluation of herbicide mixtures and manual weed control method in maize (*Zea mays* L.) production in the southern Guinea agro-ecology of Nigeria. *Cogent Food Agric.* 2017, 3(1), 1375378. https://doi.org/10.1080/23311932.2017.1375378
4. Akobundu, I. O. *Weed Science in the Tropics: Principles and Practices*; John Wiley & Sons: Chichester, UK, 1987.
5. Rodenburg, J.; Johnson, D. E. Weed management in rice-based cropping systems in Africa. *Adv. Agron.* 2009, 103, 149–218. https://doi.org/10.1016/S0065-2113(09)03004-1
6. Soltani, N.; Dille, J. A.; Burke, I. C.; Everman, W. J.; VanGessel, M. J.; Davis, V. M.; Sikkema, P. H. Potential corn yield losses from weeds in North America. *Weed Technol.* 2016, 30(4), 979–984. https://doi.org/10.1614/WT-D-16-00046.1
7. Oerke, E.-C. Crop losses to pests. *J. Agric. Sci.* 2006, 144(1), 31–43. https://doi.org/10.1017/S0021859605005708
8. Chikoye, D.; Ellis-Jones, J.; Riches, C.; Kanyomeka, L. Weed management in Africa: experiences, challenges and opportunities. In *Proceedings of the XVI International Plant Protection Congress*, Glasgow, UK, 2007; pp 652–653.
9. Gianessi, L. P. The increasing importance of herbicides in worldwide crop production. *Pest Manag. Sci.* 2013, 69(10), 1099–1105. https://doi.org/10.1002/ps.3598
10. Powles, S. B.; Yu, Q. Evolution in action: plants resistant to herbicides. *Annu. Rev. Plant Biol.* 2010, 61, 317–347. https://doi.org/10.1146/annurev-arplant-042809-112119
11. Heap, I. Global perspective of herbicide-resistant weeds. *Pest Manag. Sci.* 2014, 70(9), 1306–1315. https://doi.org/10.1002/ps.3696
12. Olabode, O.; Adesina, G.; Babajide, P. Weed control efficiency of reduced atrazine doses and its effect on soil organisms in maize (*Zea mays* L.) fields of south western Nigeria. *J. Trop. Agric.* 2010, 48(2), 52–54.
13. Karkanis, A.; Athanasiadou, D.; Giannoulis, K.; Karanasou, K.; Zografos, S.; Souipas, S.; Bartzialis, D.; Danalatos, N. Johnsongrass (*Sorghum halepense* (L.) Pers.) interference, control and recovery under different management practices, and its effects on the grain yield and quality of maize crop. *Agronomy* 2020, 10(2), 266. https://doi.org/10.3390/agronomy10020266
14. Chepil, W. S. Germination of weed seeds. I. Longevity, periodicity of germination, and vitality of seeds in cultivated soil. *Sci. Agric.* 1946, 26(7), 307–346.
15. Egley, G. H. Stimulation of weed seed germination in soil. *Rev. Weed Sci.* 1986, 2, 67–89.

16. Yenish, J. P.; Doll, J. D.; Buhler, D. D. Effects of tillage on vertical distribution and viability of weed seed in soil. *Weed Sci.* 1992, 40(3), 429–433.
17. Buhler, D. D. Influence of tillage systems on weed population dynamics and management in corn and soybean in the central USA. *Crop Sci.* 1995, 35(5), 1247–1258.
18. Zanin, G.; Otto, S.; Riello, L.; Borin, M. Ecological interpretation of weed flora dynamics under different tillage systems. *Agric. Ecosyst. Environ.* 1997, 66(3), 177–188. https://doi.org/10.1016/S0167-8809(97)00081-9
19. Clements, D. R.; Benoit, D. L.; Murphy, S. D.; Swanton, C. J. Tillage effects on weed seed return and seedbank composition. *Weed Sci.* 1996, 44(2), 314–322.
20. Cardina, J.; Herms, C. P.; Doohan, D. J. Crop rotation and tillage system effects on weed seedbanks. *Weed Sci.* 2002, 50(4), 448–460.
21. Feledyn-Szewczyk, B.; Smagacz, J.; Kwiatkowski, C. A.; Harasim, E.; Woźniak, A. Weed flora and soil seed bank composition as affected by tillage system in three-year crop rotation. *Agriculture* 2020, 10(5), 186. https://doi.org/10.3390/agriculture10050186
22. Ghosh, S.; Das, T. K.; Nath, C. P.; Bhatia, A.; Biswas, D. R.; Bandyopadhyay, K. K. Weed seedbank, above-ground weed community, and crop yields under conventional and conservation agriculture practices in maize–wheat–mungbean rotation. *Weed Res.* 2023, 63(4), 270–281. https://doi.org/10.1111/wre.12589
23. Allen, J.; Menalled, U. D.; Pelzer, C. J.; Jernigan, A. B.; Ryan, M. R. Fertility and tillage intensity affect weed community diversity and functional structure in long-term organic systems. *Ecol. Appl.* 2024, 34(7), e3029. https://doi.org/10.1002/eap.3029
24. Travlos, I. S.; Cheimona, N.; Roussis, I.; Bilalis, D. J. Weed-species abundance and diversity indices in relation to tillage systems and fertilization. *Front. Environ. Sci.* 2018, 6, 11. https://doi.org/10.3389/fenvs.2018.00011
25. Nichols, V.; Verhulst, N.; Cox, R.; Govaerts, B. Weed dynamics and conservation agriculture principles: a review. *Field Crops Res.* 2015, 183, 56–68. https://doi.org/10.1016/j.fcr.2015.07.012
26. Alagbo, O. O.; Saile, M.; Spaeth, M.; Schumacher, M.; Gerhards, R. Development and testing of a precision hoeing system for re-compacted ridge tillage in maize. *Heliyon* 2024, 10(23), e40527. https://doi.org/10.1016/j.heliyon.2024.e40527
27. Çiftçi Torun, Ü.; Gürsoy, S. Effects of different tillage and herbicide applications on weed control and yield in the double crop maize agriculture. *Middle East J. Appl. Sci. Technol.* 2024.
28. Swanton, C. J.; Clements, D. R.; Derksen, D. A. Weed succession under conservation tillage: a hierarchical framework for research and management. *Weed Technol.* 1993, 7(2), 286–297.
29. Salaudeen, M. T.; Daniya, E.; Olaniyi, O. M.; Folorunso, T. A.; Bala, J. A.; Abdullahi, I. M.; Nuhu, B. K.; Adedigba, A. P.; Oluwole, B. I.; Bankole, A. O.; Macarthy, O. M. Phytosociological survey of weeds in irrigated maize fields in a Southern Guinea Savanna of Nigeria. *Front. Agron.* 2022, 4, 985067. https://doi.org/10.3389/fagro.2022.985067
30. Kumar, S.; Rana, S. S.; Sharma, N. Long-term tillage and weed management effect on weed shifts, phytosociology and crop productivity. *Indian J. Weed Sci.* 2022, 54(2), 165–173.
31. Akobundu, I. O.; Agyakwa, C. W. *A Handbook of West African Weeds*; International Institute of Tropical Agriculture: Ibadan, Nigeria, 1987.
32. Misra, R. *Ecology Workbook*; Oxford & IBH Publishing: Calcutta, India, 1973.
33. Raunkiær, C. *The Life Forms of Plants and Statistical Plant Geography*; Clarendon Press: Oxford, UK, 1934.
34. Chikoye, D.; Ekeleme, F.; Udensi, U. E. Cogongrass suppression by intercropping cover crops in corn/cassava systems. *Weed Sci.* 2001, 49(5), 658–667. https://doi.org/10.1614/0043-1745(2001)049[0658:CSBICC]2.0.CO;2
35. Chauhan, B. S.; Johnson, D. E. The role of seed ecology in improving weed management strategies in the tropics. *Adv. Agron.* 2010, 105, 221–262. https://doi.org/10.1016/S0065-2113(10)05006-6
36. Ekeleme, F.; Atser, G.; Dixon, A.; Hauser, S.; Chikoye, D.; Olorunmaiye, P. M.; Sokoya, G.; Alfred, J.; Okwusi, M. C.; Korieocha, D. S.; Olojede, A. O.; Ayankanmi, T.; Lagoke, S. T. O. Assessment of weeds of cassava and farmers' management practices in Nigeria. *Tropicultura* 2019, 37(2), 1–12. https://doi.org/10.25518/2295-8010.586
37. Idziak, R.; Woźnica, Z. Efficacy of reduced rates of soil-applied dimethenamid-P and pendimethalin mixture followed by postemergence herbicides in maize. *Agriculture* 2020, 10(5), 163. https://doi.org/10.3390/agriculture10050163
38. Knezevic, S. Z.; Evans, S. P.; Blankenship, E. E.; Van Acker, R. C.; Lindquist, J. L. Critical period for weed control: the concept and data analysis. *Weed Sci.* 2002, 50(6), 773–786. https://doi.org/10.1614/0043-1745(2002)050[0773:CPFWCT]2.0.CO;2