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Production Systems

# Diversity and composition of weed species in a continuously grown maize field treated with selected pre-emergence herbicides

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***Abstract.*** *This study analyses the floristic composition of field weeds recorded at the University of Ilorin Teaching and Research Farm (008˚ 27' 23.9'N and 004˚ 39' 42.9'E) in the southern Guinea savannah of Nigeria during the 2019 - 2021 growing seasons. The area is characterized by a bimodal rainfall pattern with an average annual rainfall of 1227.85 mm and sandy loam soil (plinthustaffs). The experiment was set up as a randomized complete block design and repeated three times in a field that had been continuously maize-cropped for 10 years. Treatments were pre-emergence applications of atrazine, metolachlor, and primextra at the rate of 1.5, 2.5, and 3.5 kg a.i.ha$^{-1}$ and Weedy Check. Maize was sown and maintained using the recommended agronomic practices for ecology. Weed species composition was estimated using four continuous sample quadrats (0.5 m$^2$) at 3, 6, 9, and 12 weeks after sowing. The weed flora consisted of 48% broadleaves, grasses 45%, and 7% sedges. Between 2019 and 2021 there was a gradual shift from the predominant annual broadleaves to induced annual grasses and a reduction in the floristic composition of the weed community by approximately 2 - 28%. Fifteen (15) weed species were predominant and the most stable weed species were Richardia scabra, Digitaria horizontalis and Digitaria sanguinalis. This requires finding an ideal weed control option that controls the negative impact of agricultural weeds on crop after yield while maintaining a diverse weed community.*

**Keywords:** biodiversity, floristic, weed families, pre-emergence application, herbicide, arable field, maize

## Introduction

Weeds are among the major biotic constraints on efficient crop production in sub-Saharan Africa (SSA) and are an important component of biodiversity in agricultural systems around the world (Gerasimova and Mitova, 2020). Weed problems account for between 20-60% of production costs depending on ecology and crop. Meanwhile, poor weed control can cause up to 35-60% yield losses in crops at harvest (Onyibe and Shebayan, 2013).

Weed control is very labour intensive and reliance on human labour could be expensive and delays farming operations in SSA. Mahadi et al. (2013) reported that 309 manpower is needed to hand weed one hectare of maize field compared with 91 manpower/ha required for herbicide application. Herbicides were therefore adopted as the most efficient and cost-effective means of weed control that eliminate the associated risk of a decline in crop yield.

Efforts to minimize the threat of weeds in successful crop production have led to rapid changes in recent agricultural practices that involve continuous cultivation with intensive chemical fertilization and herbicide application (Štefanić et al., 2019). The above advantages

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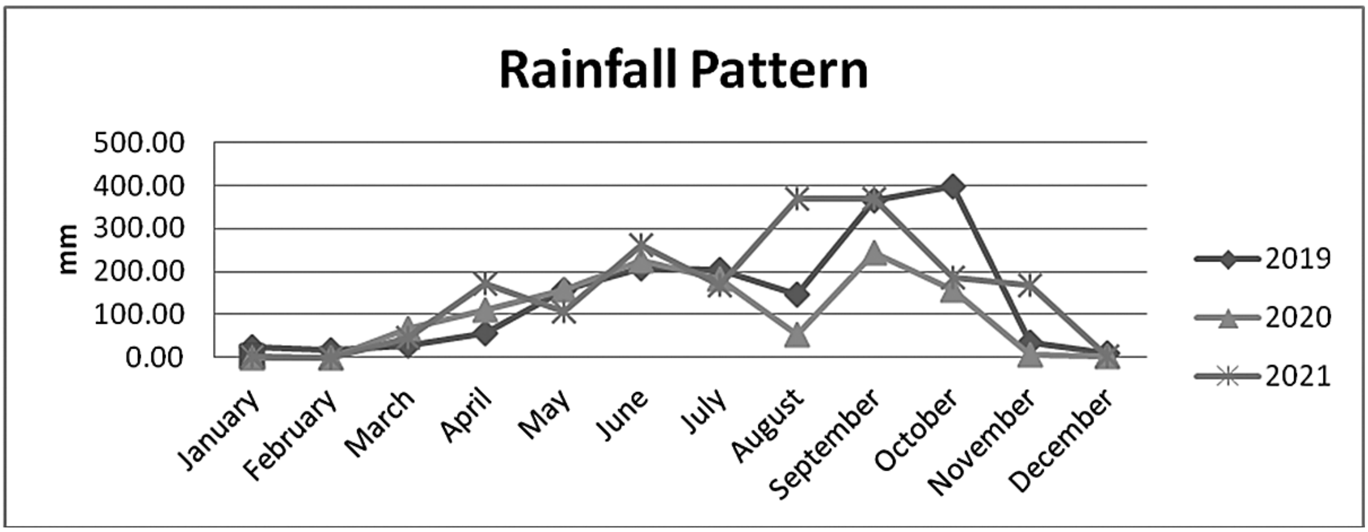
have a significant impact on the numbers and abundance of arable weeds, leading to a huge decline in weed biodiversity (Barancok and Barancokova, 2016). Štefanić et al. (2019) encountered 143 weed species in 2005 and 97 species in 2017, although they discovered 33 new weeds not found in the 2005 season. Therefore, the need for frequent phytosociological survey and characterization of weeds to determine efficient weed management (Melo et al., 2019), to check weed biodiversity (Perrings and Halkos, 2015) and the proportion of herbicide-tolerant or resistant weed species (Edesi et al., 2012).

Therefore, the aim of this trial is to investigate the influence of application rates of three commonly used pre-emergence herbicides on weed species diversity in a continuously managed maize field.

## Material and methods

The study was conducted from 2019 to 2021 growing seasons at the University of Ilorin Teaching and Research Farm located at 08˚ 27' 23.9'N and 004˚ 39' 42.9'E in the southern Guinea savanna of Nigeria with an altitude of 307 m above sea level. The area is characterized by a bimodal rainfall pattern with peaks between June-July and September with an average annual rainfall of the area 1204.72 mm – 1850.98 mm and mean maximum temperature range of 30.22-31.48˚C (Table 1, Figure 1). The soil was sandy loam and classified as a plinthustaffs. The field had been on continuous maize cultivation between 2010 and 2019. Weed control measures adopted during previous cultivation of maize were the use of pre-emergence application of either atrazine (6-chloro-N-ethyl-N'-(1-methyl ethyl)-1,3,5-triazine 2,4-diamine), and/or in combination with metolachlor [2-chloro-N-(ethyl-6-ethy(phenyl)-N-(2-methoxyl-1-methyl ethyl acetamide] or primextra [a proprietary mixture of metolachlor (290 g/L) and atrazine (370 g/L)] and later a supplementary hoe weeding at 5 or 6 weeks after application.



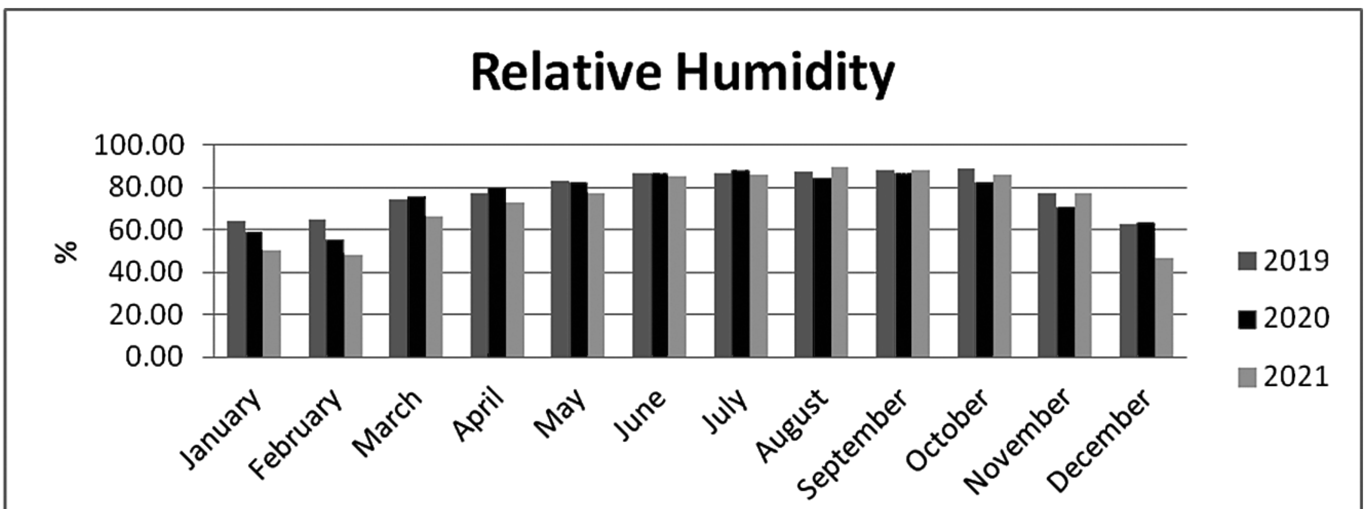




**Figure 1.** Rainfall and Relative humidity pattern of the study area from 2019-2021

**Table 1.** Maximum and minimum temperature ($^{o}c$) of the study area from 2019-2021

| Month | 2019 Temperature (Maximum) | 2019 Temperature (Minimum) | 2020 Temperature (Maximum) | 2020 Temperature (Minimum) | 2021 Temperature (Maximum) | 2021 Temperature (Minimum) |
|---|---|---|---|---|---|---|
| January | 31.86 | 18.86 | 30.77 | 16.09 | 34.04 | 18.96 |
| February | 31.87 | 20.16 | 32.74 | 18.12 | 35.35 | 21.00 |
| March | 32.57 | 22.87 | 32.74 | 23.22 | 33.88 | 22.97 |
| April | 32.48 | 23.68 | 31.43 | 23.12 | 33.18 | 23.28 |
| May | 30.78 | 23.09 | 31.03 | 23.16 | 32.42 | 23.28 |
| June | 29.18 | 22.51 | 28.87 | 22.30 | 29.29 | 22.25 |
| July | 28.46 | 21.88 | 27.79 | 21.48 | 28.55 | 21.54 |
| August | 28.00 | 21.64 | 28.49 | 20.48 | 27.39 | 21.60 |
| September | 28.24 | 22.01 | 28.30 | 21.40 | 28.11 | 21.52 |
| October | 28.03 | 21.70 | 29.84 | 21.34 | 29.45 | 22.10 |
| November | 30.54 | 21.28 | 31.75 | 20.77 | 30.19 | 21.31 |
| December | 30.61 | 17.24 | 33.37 | 20.16 | 35.94 | 20.89 |

The experiment was laid as a randomized complete block design and replicated three times. The treatments were pre-emergence applications of atrazine, metolachlor, and primextra at the rate of 1.5, 2.5, and 3.5 kg a.i.$ha^{-1}$ and weedy check. The field (720 $m^2$) was mechanically ploughed, harrowed, and ridged. A plot comprised of 5 ridges, 5 m long and 1.2 m crest to crest. Maize was sown at two seeds per hole at a spacing of 25 cm within a row. NPK fertilizer (20:10:10) was applied two weeks after sowing (WAS) and urea (46%) at 50% tasselling while Methomyl 90% SP (80 g/ha) was applied to control fall armyworm (*Spodoptera frugiperda*) at 2, 3 and 4 WAS.

Weed species composition, as well as weed density and dry matter, were estimated using four continuous sample quadrats (0.5 $m^2$) per plot at 3, 6, 9, and 12 WAS. The weed seedlings were pulled, counted and identified to species level using the Weed Identification Manual of Akobundu et al. (2016).

Importance Value Index (IVI), which is the arithmetic mean of the values of relative density (DE = I/T*100, where DE is the relative density (%), I is the number of individuals of the species x in the area, and TI is the total number of individuals in the area.); relative frequency (FR =Q/TQ*100, where FR is the relative frequency (%), Q is the number of samples evaluated in the area where the species x is present, and TQ is the total number of samples in the area.); and relative dominance (DO =DM/TDM *100, where DO is the relative dominance (%), DM is the dry matter of individuals of species x in the area, and TDM is the total dry matter of weeds in the area.). Therefore, IVI = $(DE + FR. + DO)^{-3}$.

Shannon index of biodiversity (H') and Simpson dominance index were applied for weed community assessment. The Sorensen similarity index (qualitative) was used for comparison of the weed community's similarity in the maize field between 2019 and 2021. Weed biodiversity within the communities was estimated and compared based on: species richness (S) is a number of species in the community; Shannon-Wiener diversity index (H'): H' = Σpi (Ln pi), where Ln-natural logarithm and pi –relative abundance of the i-th species in the community, Simpson's Diversity (dominance) index: D = Σni(ni-1)/N(N-1), where ni is the number of individuals of species i, N is the total number of individuals in the sample. Thereafter, Simpson's index of Diversity (1-D) and Simpson's Reciprocal Index (1/D) were computed. Lastly, Sorensen similarity qualitative index was calculated as SSI = [2D $(A + B+C)^{-}1$]*100, where D – is the number of the common to each community species and A + B +C is the sum of the total number of species in each community. GGE Biplot was used to analyze the weed community composition. Only weed species that occurred frequently enough to have normal error distributions were analyzed (Swanton et al., 1999). Densities of weed species in three replicates of each rate and herbicide type during 2019–2021 were used for the analysis. Data were analyzed using analysis of variance (ANOVA), and means were compared based on the Least Significant Difference at 0.05 probability level.

## Results

*Weed Composition*

In the study period 2019 - 2021, a total of 85 weed species from 22 families within 67 genera were identified in the field. Broadleaf weed species were heavily dominant at 47.67%, grasses and sedges accounted for 45.35% and 6.98% of the weed community, respectively. The weed spectrum comprised 54.65% annuals, 40.69% perennials and 4.66% were classified as annuals/perennials. In the primextra-treated plots, the highest weed species richness was 32 in the 2019 season, 30 species in the 2020 season and 23 species in the 2021 season belonging to either 13 or 11 families, respectively (Table 2).

**Table 2.** Importance value index of weed species encountered on primextra treated field

| Family | Weed Species | ML | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| Amaranthaceae | *Gompherena celosioides Mart* | *BP* | 8.82 | 8.60 | 3.79 |
| Asteraceae | *Ambrosia trifida* L. | BA | 5.66 | 4.91 | 2.21 |
| | *Tridax procumbens* L. | *BA* | 7.32 | 7.09 | 5.18 |
| Caryophyllaceae | *Sagina apetala* Ard | BA | 5.91 | 3.07 | |
| Cleomaceae | *Cleome viscosa* L. | *BA* | 2.20 | 2.05 | 2.07 |
| Cyperaceae | *Cyperus eragrostis* Lam | *SP* | 4.63 | 1.96 | 1.79 |
| | *C. rotundus* L. | *SP* | 1.64 | | |
| Euphorbiaceae | *Astaea lobata (*L.) Klotzsch | BAP | | 2.80 | 1.69 |
| | *Euphorbia hypericifolia* L. | *BP* | 2.84 | 1.97 | 1.71 |
| | *Phyllanthus amarus* Schumach & Thonn | *BA* | 1.01 | | |
| Fabaceae | *Cassia tora* (L.) Roxb | *BA* | 0.12 | 1.47 | |
| | *Chamaecrista rotundifolia* (Pers.) Greene | BAP | 6.80 | 5.92 | 2.11 |
| | *Lotus edulis* L. | BA | 3.44 | 0.84 | |
| | *Pillostigma thonningii* (Schun) Milne. Redh | *BA* | 6.81 | 8.57 | 5.72 |
| | *Tephrosia villosa* (L.) Pers | BAP | 8.72 | 6.20 | 3.44 |
| Lamiceae | *Hyptis suaveolens* (L.) Poit | *BA* | 7.44 | 7.29 | 8.19 |
| | *Leucas aspera* Willd | BA | 1.23 | 0.82 | |
| Malvaceae | *Corchorus trilocularis* L. | BA | 2.07 | | |
| | *Sida acuta* Burm. F | *BP* | 5.43 | 4.26 | 2.15 |
| Nyctaginaceae | *Boerhavia erecta* L. | *BA* | 9.24 | 7.52 | 1.69 |
| Plantaginaceae | *Misopates orontium* L. | BA | 4.23 | 2.87 | 1.23 |
| Poaceae | *Arthroxon hispidus* (Thunb) | GA | 4.00 | 1.44 | 1.15 |
| | *Cenchrus purpureus* Schumach | GP | 1.04 | 1.21 | |
| | *Dactylocterium aegyptium* (L.) Willd | *GA* | 2.75 | 2.52 | 1.90 |
| | *Digitaria sanguinalis* L. Scop | *GP* | 9.77 | 8.13 | 5.36 |
| | *D. horizontalia* Willd. | *GA* | 3.06 | 3.21 | 1.84 |
| | *Echinochloa crusgalli* (L.) Beauv | *GA* | 1.06 | | |
| | *Eleocharis vivipara* Link | *GA* | 4.51 | 1.33 | |
| | *Eleusine indica (*L.) Gartn | *GA* | 10.68 | 9.04 | 8.28 |
| | *Eragrostis minor* (L.) Wolf | *GA* | 3.44 | 3.67 | 2.30 |
| | *Eragrostis pilosa* L.P.Beauv | *GA* | 2.54 | 0.43 | 1.89 |
| | *Pennisetum polystachion* (L.) Schult | *GP* | 0.92 | 1.84 | 1.26 |
| | *Seteria verticillate* (L.) P. Beauv | *GA* | | 2.05 | |
| Rubiaceae | *Richardia scabra* L. | *BA* | 18.64 | 18.43 | 16.60 |

ML= morphology, L= life cycle, A= annuals, B= broadleaf, G= grass, P= perennial, S= sedge

Atrazine-treated plots had 44 species in 2019 and 43 species each in 2020 and 2021, both belonging to 13 families (Table 3), while 50, 48 and 46 species belonging to 19, 18, and 17 families, respectively, were found in metolachlor-treated plots over the three years (Table 4). The most representative families in terms of species richness were Poaceae, Fabaceae and Cyperaceae (Figure 2).

**Table 3.** Importance value index of weed species encountered on atrazine treated field

| Family | Weed Species | ML | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| Asteraceae | *Ageratum conyzoides* L. | BA | | | 0.07 |
| | *Chromolaena odorata* (L.) R.M.King & Robin*son* | BP | 0.03 | 0.06 | 0.08 |
| | *Tridax procumbens* L. | BA | 5.27 | 13.76 | 15.37 |
| Boraginaceae | *Trichodesma indicum* (L.) Sm. | BA | 8.96 | 0.10 | 0.09 |
| Caryophyllaceae | *Sagina apetala* Ard | BA | 0.07 | 0.07 | 3.41 |
| Cleomaceae | *Cleome viscosa* L. | BA | 0.02 | 1.78 | 1.76 |
| Commelinaceae | *Commelina benghalensis* L | BP | 0.05 | 0.03 | 0.04 |
| Cyperaceae | *Cyperus compressus* L. | SA | 10.30 | 12.03 | 10.30 |
| | *C. eragrostis* Lam | SP | 5.20 | 8.62 | 13.67 |
| | *C. haspan* L. | SAP | 0.16 | 0.07 | 0.02 |
| | *C. rotundus* L. | SP | 10.21 | 0.14 | 0.07 |
| | *Fimbristylis littoralis* Gaudich. | SA | 44.11 | 57.55 | 50.81 |
| Euphorbiaceae | *Acalypha indica* L. | BA | | | 0.10 |
| | *Phyllanthus amarus* Schumach & Thonn | BA | 0.06 | 0.06 | 10.15 |
| Fabaceae | *Cassia tora* (L.) Roxb | BA | 3.41 | 0.12 | 0.17 |
| | *Chamaecrista rotundifolia* (Pers.) Greene | BAP | 0.00 | 0.02 | 0.13 |
| Lamiceae | *Hyptis suaveolens* (L.) Poit | BA | 6.87 | 5.70 | 9.02 |
| Malvaceae | *Corchorus trilocularis* L. | BP | 1.00 | | |
| | *Sida acuta* Burm. F | BP | 10.05 | 4.54 | 2.28 |
| Nyctaginaceae | *Boerhavia diffusa* L. | BP | 1.23 | 2.35 | 2.33 |
| | *B. erecta* L. | BA | 0.02 | 0.01 | 0.05 |
| Poaceae | *Axonopus compressus* (SW) P. Beauv | GP | 70.70 | 71.40 | 41.32 |
| | *Brachiaria deflexa* (Schumach) C. E. Hubbard | GA | 29.45 | 18.17 | 20.62 |
| | *B. erusiformis* (Sm) Griseb | GA | 0.15 | 0.06 | 0.09 |
| | *B. ramosa* (L.) stap F | GA | 0.11 | 0.13 | 0.21 |
| | *Cynodon dactylon* (L.) Pers | GP | 95.06 | 80.61 | 69.49 |
| | *Dactyloctenium aegyptium* (L.) Willd. | GA | 15.31 | 18.82 | 18.91 |
| | *Digitaria horizintalis* Willd. | GA | 219.18 | 165.41 | 158.88 |
| | *Echinochloa crusgalli* (L.) Beauv | GA | 10.16 | 15.23 | 6.78 |
| | *Eleusine indica* (L.) Gaertn | GA | 70.79 | 101.01 | 85.17 |
| | *Eragrostis mexicana* L. | GA | 0.20 | 0.25 | 0.28 |
| | *E. minor* (L.) Wolf | GA | 30.39 | 25.40 | 35.58 |
| | *Heteropogon contortus* (L) P. Beauv ex Rome & Schult | GP | 10.30 | 6.87 | 0.16 |
| | *Imperata cylindrica* (L.) P. Beauv | GB | 0.17 | 0.07 | 0.17 |
| | *Panicum repens* L. | GP | 0.17 | 0.15 | 0.05 |
| | *Paspalium scrobiculatum* L. | GA | 17.15 | 3.70 | 27.29 |
| | *Pennisetum polystachion* (L.) Schult | GP | 62.50 | 71.54 | 18.13 |
| | *P. purpureum* (Schumach.) Morrone | GP | 10.09 | 26.91 | 6.73 |
| | *Phalaris minor* Retz | GA | 20.18 | 47.09 | 6.78 |
| | *Rottbeollia cochinchinensis* (Lour.) Clayton | GA | 10.37 | 17.01 | 13.71 |
| | *Setaria pumila* (Poir.) Roem. & Schult | GA | 0.02 | 0.01 | |
| | *S. viridis* (L.) P. Beauv | GA | 0.10 | 0.15 | 0.15 |
| | *S. verticillata* (L.) P. Beauv | GA | 44.85 | 63.88 | 44.29 |
| | *Sporobolus diander* (L.) (Retz) Beauv | GAP | 10.09 | 10.09 | |
| | *S. indicus* (L.) (Retz) Beauv | GP | 11.02 | 7.15 | 0.22 |
| Rubiaceae | *Richardia scabra* L. | BA | 195.14 | 220.50 | 239.09 |

ML= morphology, L= life cycle, A= annuals, B= broadleaf, G= grass, P= perennial, S= sedge

**Table 4.** Importance value index of weed species encountered on metolachlor treated field

| Family | Weed Species | ML | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| Asparagaceae | *Chlorophytum comosum* (Thunb.) Jacques | *BP* | 0.84 | 0.39 | 0.24 |
| Asteraceae | *Ageratum conyzoides* L. | *BA* | 0.39 | 0.29 | 0.20 |
| | *Tridax procumbens* L. | *BA* | 5.22 | 3.04 | 1.95 |
| Boraginaceae | *Trichodesma indicium* R.Br | *BA* | 0.16 | | |
| Bromeliaceae | *Tillandsia filifolia* Schltdl & Cham | *BP* | 0.20 | 0.10 | 0.10 |
| Caprifoliaceae | *Centranthus ruber* (L.) DC | *BP* | 0.70 | 0.72 | 0.41 |
| Caryophyllaceae | *Silene latifolia* Poir | *BP* | 0.29 | 0.29 | 0.20 |
| | *Stelleria longifolia* Muhl.ex Willd. | *BP* | 0.08 | 0.10 | 0.13 |
| Cleomaceae | *Cleome viscosa* L. | *BA* | 5.46 | 3.85 | 1.61 |
| Convolvulaceae | *Dichondra micrantha* J.R.Forst | *BP* | 1.01 | 0.21 | |
| Cyperaceae | *Cyperus strigosus* L. | *SP* | 6.00 | 2.13 | 1.14 |
| Euphorbiaceae | *Euphorbia hypericifolia* L. | *BP* | 1.68 | 0.37 | |
| | *Phyllanthus amarus* (Schumach.& Thonn). | *BA* | 0.26 | 0.33 | 0.26 |
| Fabaceae | *Cassia tora* L. Roxb | *BP* | 0.33 | 0.14 | 0.11 |
| | *Chamaecrista rotundifolia* (Pers). Gereene. | *BP* | 2.09 | 1.57 | 1.04 |
| | *Medicago denticulata* L.H.S Irwin & Barneby | *BA* | 6.00 | 3.56 | 1.25 |
| | *Pillostigma thonningii* (Schun) Milne.Redh. | *GA* | 0.20 | 0.10 | 0.07 |
| | *Senna obtusifolia* (L.)H.S. Irwin & Barneby | *BA* | 3.04 | 2.88 | 1.72 |
| | *Tephrosia villosa* L. | *BP* | 0.95 | 0.63 | 0.37 |
| | *Trifolium obtusiflorum* Hook.f | *BA* | 3.23 | 1.49 | 0.50 |
| | *T. subterraneum* L. | *BA* | 3.35 | 2.36 | 1.24 |
| Lamiceae | *Hyptis suaveolens* L. Kuntze | *BP* | 4.96 | 1.24 | 1.09 |
| Malvaceae | *Sida acuta* Burm. f. | *BA* | 6.95 | 3.85 | 1.74 |
| Nyctaginaceae | *Boerhavia diffusa* L. | *BP* | 4.23 | 2.70 | 2.61 |
| | *B. erecta* L. | *BP* | 0.10 | 0.16 | 0.08 |
| Poaceae | *Arthraxon hispidus* (Thumb) Makino. | *BP* | 0.59 | 0.78 | 0.49 |
| | *Axonopus compressus* (Sw).P.Beauv | *GP* | 4.96 | 2.23 | 0.74 |
| | *Cenchrus ciliuris* L. | *GP* | 0.27 | 0.07 | 0.01 |
| | *Chloris cucullata* Bisch | *GA* | 0.17 | 0.13 | 0.11 |
| | *Dactyloctenium aegyptium* L. Willd | *GP* | 2.48 | 1.24 | 0.74 |
| | *Digitaria cilliaris* (Retz) Koeler | *GA* | 0.18 | | |
| | *D. sanguinalis* L.Scop | *GP* | 7.28 | 6.60 | 4.86 |
| | *Ehrharta erecta* Lam. | *GP* | 3.21 | 1.95 | 0.95 |
| | *Eleusine indica* L. Gartn | *GA* | 4.71 | 4.37 | 2.36 |
| | *Elymus canisius* L. | *GA* | 4.13 | 2.50 | 1.57 |
| | *Eragrostis mexicana* Honem. | *GA* | 0.16 | 0.11 | 0.06 |
| | *Eragrostis pilosa* L.P.Beauv | *GA* | 0.13 | 0.06 | 0.04 |
| | *Glyceria striata* (Lam.) Hitchc | *GP* | 3.97 | 1.49 | 0.25 |
| | *Heteropogan contortus* L.P.Beauv ex Roem. & Schult | *GP* | 0.13 | 0.19 | 0.15 |
| | *Panicum clandestinum* L.Gould | *GP* | 3.07 | 2.17 | 1.27 |
| | *Paspalum distichum* L. | *GA* | 0.51 | 0.16 | 0.05 |
| | *Setaria parviflora* (Poir) Kerguecen | *GP* | 0.21 | 0.26 | 0.04 |
| | *S. viridis* L.P.Beauv | *GP* | 0.58 | 0.37 | 0.16 |
| | *S. glauca* L.P.Beauv | *GP* | 2.98 | 2.23 | 0.74 |
| Polygonaceae | *Polygonum aviculave* | *BA* | 4.96 | 2.73 | 1.99 |
| Primulaceae | *Lysimanchia nummularia* L. | *BP* | 0.09 | 0.19 | 0.43 |
| Rubiaceae | *Gallium boreale* L. | *BP* | 0.11 | 0.13 | 0.25 |
| | *Mitracarpus hirtus* L. | *BA* | 0.13 | 0.21 | 0.27 |
| | *Richardia scabra* L. | *BP* | 8.44 | 5.03 | 3.48 |
| Solanaceae | *Physalis heterophylla* Nees. | *BP* | 0.09 | 0.20 | 0.10 |

ML= morphology, L= life cycle, A= annuals, B= broadleaf, G= grass, P= perennial, S= sedge

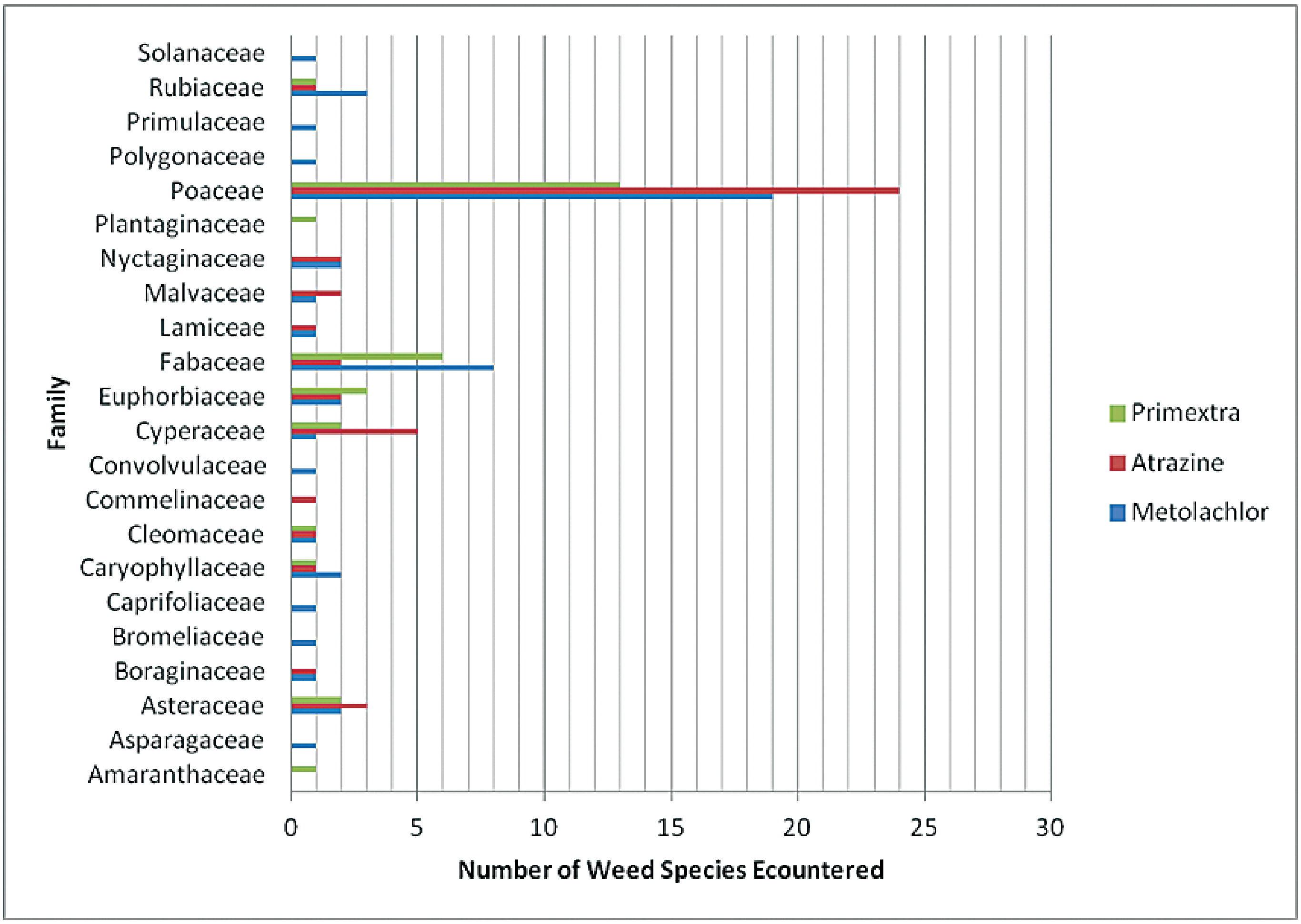



**Figure 2.** The Pattern of family distribution and weed species identified across treated plots

The weed flora changed in the course of the growing season depending on the type and amount of herbicide applied. Atrazine-treated plots were dominated by grass weed species (24 species), metalochlor (19), while primextra-treated plots had 12 species. Metalochlor-treated plots had 9 dominant members of Fabaceae, 6 were identified in primextra plots, and 3 in atrazine-treated plots. Conversely, members of Cyperaceae in atrazine-treated plots (5 species) were higher than 2 and 1 species identified in primextra and metolachlor-treated plots, respectively. Table 5 shows Simpson, Shannon-Wiener and other related indices of weed flora diversity. Plots treated with atrazine and metolachlor were more diversified in weed species compared to plots treated with primextra with inverse Simpson diversity indices of 3.049, 3.039 and 2.825, respectively. The Shannon-Weiner Index (H) value ranged from 0.473 to 0.552. In contrast to the Simpson index, H was the highest in the metolachlor (0.552) treated plots. The similarity of weed species treated with atrazine-treated plots for three consecutive seasons was 63.08%, primextra 51.76%, while plots treated with metolachlor were 63.89%. The similarity index of the weed species identified on the herbicide-treated plots during the three-year study was 15.38% (Figure 3).

**Table 5.** Similarity and diversity indices of the field, 2019 - 2021

| Indices | Primextra | Atrazine | Metolachlor |
|---|---|---|---|
| Simpson Dominance (D) | 0.328 | 0.354 | 0.329 |
| Gini-Simpson (1-D) | 0.672 | 0.646 | 0.671 |
| Simpson Diversity (1/D) | 3.049 | 2.825 | 3.039 |
| Shannon diversity (H') | 0.477 | 0.473 | 0.552 |
| Sorenson Similarity | 63.08% | 51.76% | 63.89% |

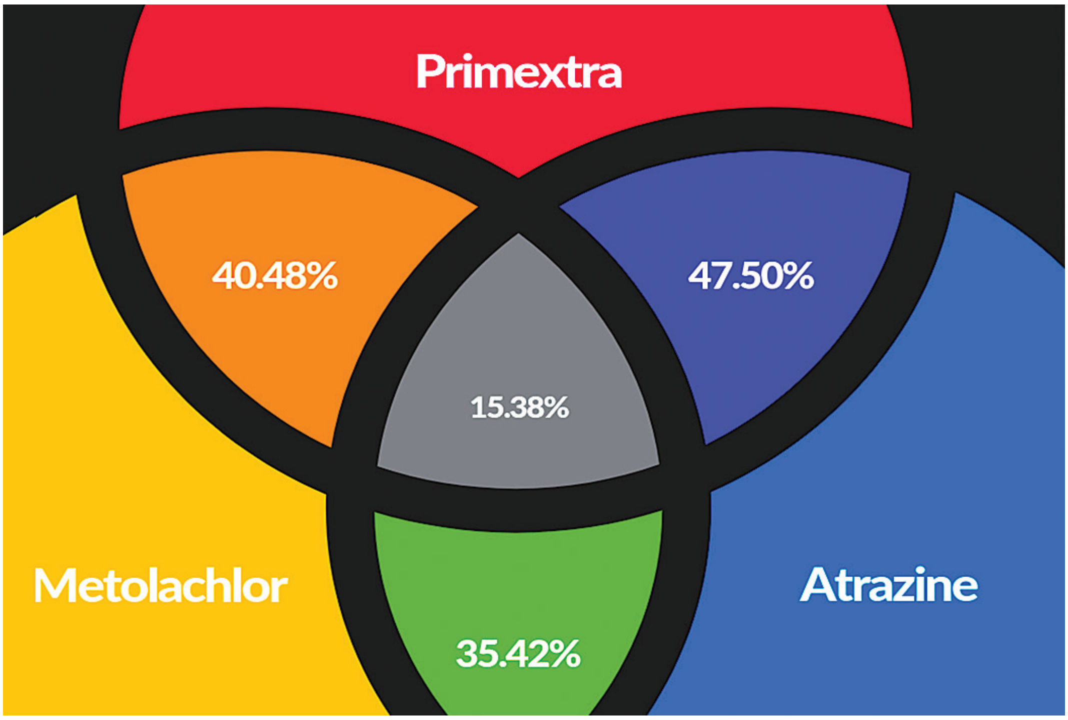



**Figure 3.** Similarity Indices between herbicide treated plots across three seasons

*Pattern of Emergence*

The pattern of family distribution differed across periods (Figure 4). The number of families in atrazine-treated plots gradually increased, peaking at 9 WAP and declining, while metolachlor-treated plots had the same number of families between 3 and 9 WAP and declining at 12 WAP.

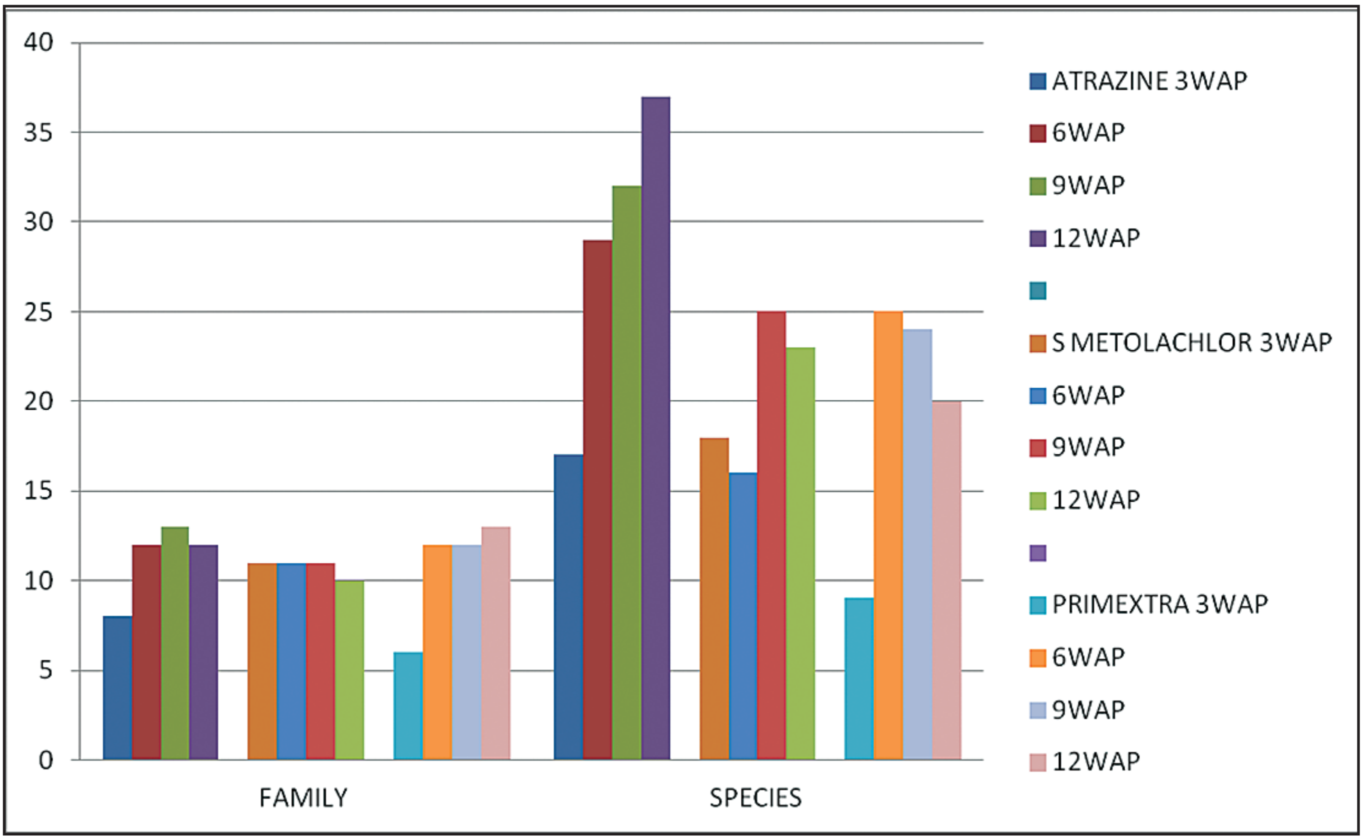



**Figure 4.** Pattern of family and species distribution across weeks of assessment and similarity indices

Plots treated with primextra had a gradual increase between 3 and 6 WAP, stabilized between 6 and 9 WAP and decreased at 12 WAP. The weed species distribution pattern shows a continuous increase in the number of species over sampling periods in atrazine-treated plots. Meanwhile, peaks at 3 and 9 WAP in metolachlor-treated plots and a peak at 6 WAP in primextra-treated plots were observed. Weed species density differed significantly across herbicide application rates and sampling time (Table 6). Weed density in plots treated with metolachlor and primextra peaked at 9 WAP with the exception of plots treated with 3.5 kg a.i /ha which peaked at 12 WAP. Atrazine applied at 1.5 kg a.i /ha peaked weed density at 3 WAP and gradually decreased thereafter. The weedy check plots had at least 1000 species/m$^2$ with peaks emergence at 6, 9 or 12 WAP. Similar trends were observed in fresh weed biomass.

**Table 6.** Effect of herbicide rate of application on average weed density (number of seedlings/m$^2$) and fresh weed biomass (g/m$^2$) across weeks after application (WAA) on maize field in 2019-2021

| Herbicide | | 1.5kg a.i./ha | | 2.5kg a.i./ha | | 3.5kg a.i./ha | | Weedy check | |
|---|---|---|---|---|---|---|---|---|---|
| | WAA | No/m$^2$ | g/m$^2$ | No/m$^2$ | g/m$^2$ | No/m$^2$ | g/m$^2$ | No/m$^2$ | g/m$^2$ |
| Metolachlor | 3 | 53 | 5.02 | 43 | 3.04 | 32 | 1.22 | 1917 | 61.74 |
| | 6 | 66 | 10.24 | 41 | 8.26 | 31 | 6.11 | 1097 | 84.23 |
| | 9 | 962 | 52.17 | 552 | 31.34 | 299 | 22.82 | 1383 | 104.66 |
| | 12 | 254 | 17.34 | 440 | 23.16 | 613 | 37.63 | 2165 | 163.07 |
| Atrazine | 3 | 537 | 37.41 | 494 | 29.18 | 369 | 24.07 | 1924 | 77.10 |
| | 6 | 495 | 86.81 | 576 | 66.91 | 535 | 57.22 | 1950 | 92.34 |
| | 9 | 400 | 42.83 | 421 | 37.16 | 483 | 28.72 | 1631 | 109.22 |
| | 12 | 394 | 34.03 | 437 | 31.84 | 529 | 26.60 | 1499 | 98.08 |
| Primextra | 3 | 10 | 0.19 | 6 | 0.08 | 2 | 0.03 | 1412 | 78.36 |
| | 6 | 45 | 2.33 | 47 | 2.11 | 52 | 1.92 | 1595 | 92.21 |
| | 9 | 596 | 47.61 | 457 | 31.44, | 409 | 26.21 | 1853 | 106.18 |
| | 12 | 536 | 30.83 | 422 | 26.88 | 442 | 31.63 | 1732 | 97.11 |
| LSD (0.05) | | 186.58 | 16.94 | 154.03 | 24.53 | 168.93 | 15.69 | NS | NS |

*Prevalent Weed Species*

The variations in occurrence (density) of weed species in 2019 and 2021 as determined by biplot analysis are shown below (Figures 5-10). Only fifteen (15) weed species with the highest density were reported and these 15 weed species were identified and thereafter designated as dominant (prevalent) weed species. *Gompherena celosiodes, Hyptis suaveolens, Boerhevia erecta, Digitaria sanguinalis, Eleusine indica* and *Richardia scabra* were identified on the primextra-treated plots (Figure 5).

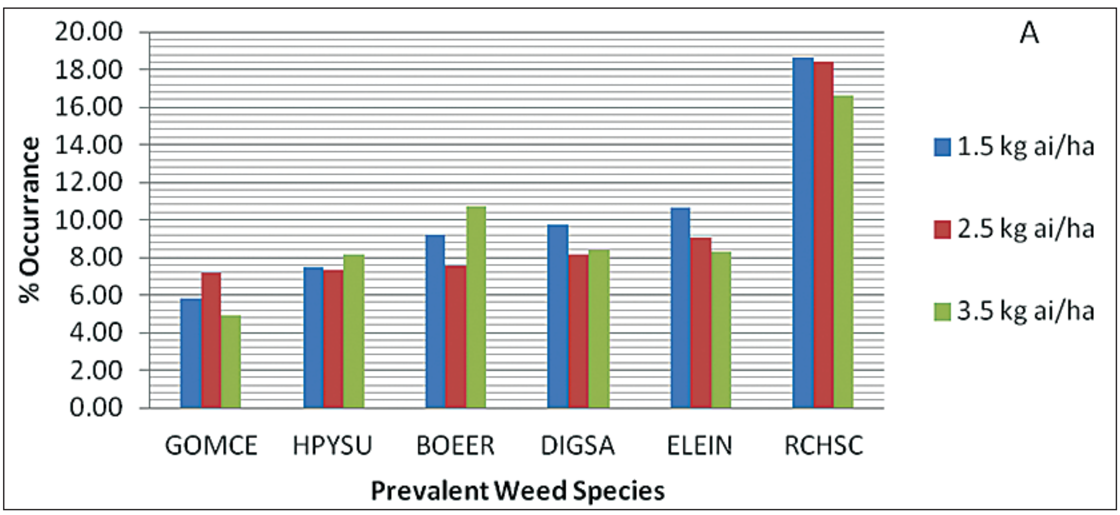



**Figure 5.** The polygon view of biplot showing which weed species won in which primextra-treated field
GOMCE= *Gompherena celosiodes*, HPYSU= *Hyptis suaveolens*, BOEER= *Boerhavia erecta*, DIGSA=*Digitaria sanguinalis*, ELEIN = *Eleusine indica*, RCHSC = *Richardia scabra*

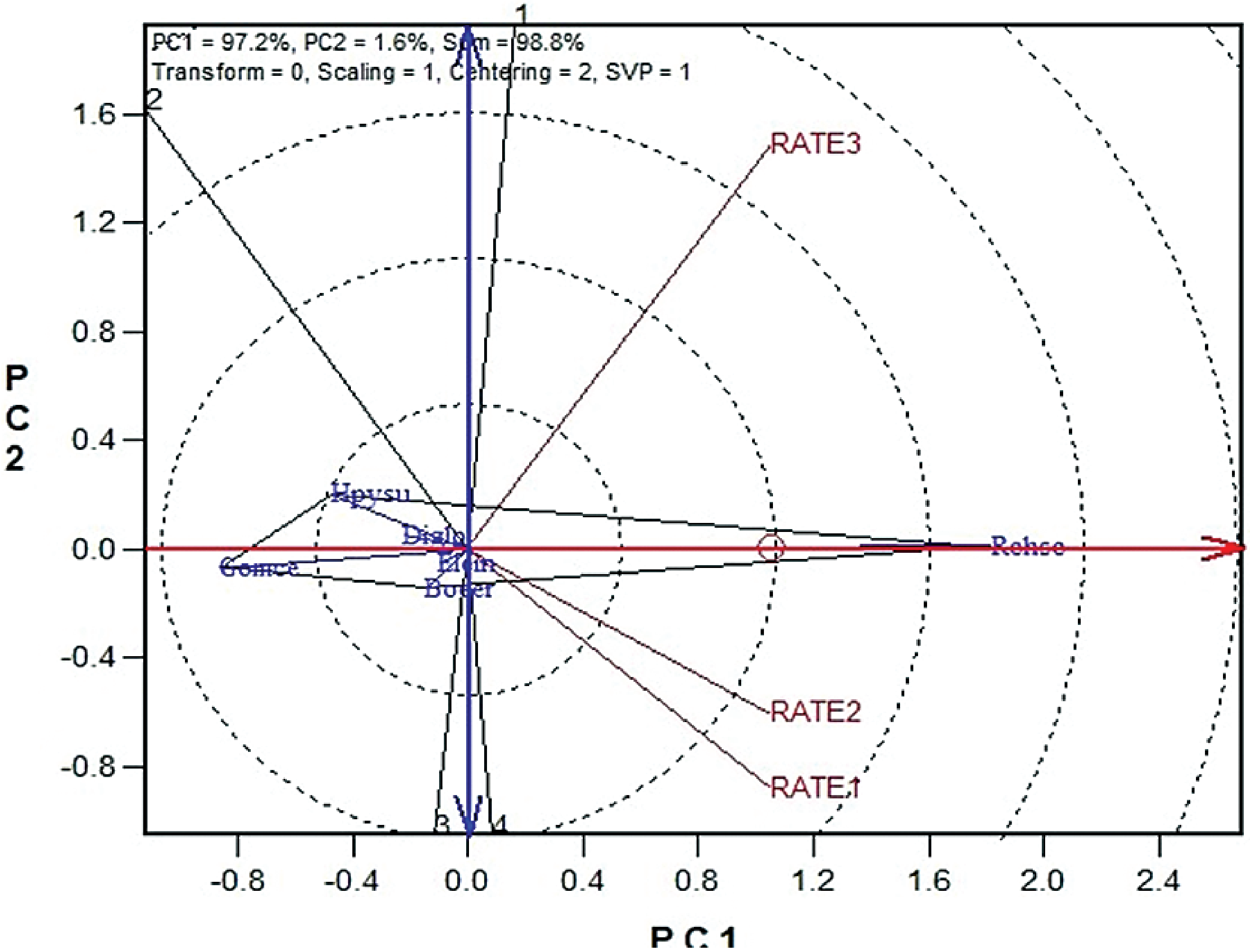



**Figure 6.** Prevalent weed species encountered on Primextra treated field
GOMCE= *Gompherena celosiodes*, HPYSU= *Hyptis suaveolens*, BOEER= *Boerhavia erecta*, DIGSA=*Digitaria sanguinalis*, ELEIN = *Eleusine indica*, RCHSC = *Richardia scabra*

The above six species had a similar mean abundance percentage across primextra application rates in each growing season. The ideal weed species with a relatively high and stable density was *Richardia scabra* (RCHSC), while others had relatively low densities and were unstable across application rates (Figure 6). Seven predominant weed species were identified in the atrazine-treated plots and these were: *Axonopus compressus, Digitaria horizontalis, Eleusine indica, Fimbristylis littoralis, Pennisetum polystachion, Richardia scabra and Seteria verticillata* (Figure 7). The mean incidence percentage showed no significant trend over rates of atrazine use except in *A. compressus* and *P. polystachion* where there was significantly lower percentage incidence with a higher dose of atrazine use. *Richardia scabra* (RCHSC) and *Digitaria horizontalis* (DIGHO) were the most stable weed species in all atrazine-treated plots (Figure 8). Also, *Boerhevia diffusa, Cleome viscose, Digitaria sanguinalis, Eleusine indica, Medicago denticulate, Richardia scabra* and *Tridax procumbens* were enumerated as prevalent weed species in s-metolachlor-treated plots (Figure 9). The percentage mean occurrence showed a significantly lower weed species population with higher dose of atrazine application, while *Richardia scabra* (RCHSC) and *Digitaria sanguinalis* (DIGSA were the most stable weed species across metolachlor-treated plots (Figure 10).

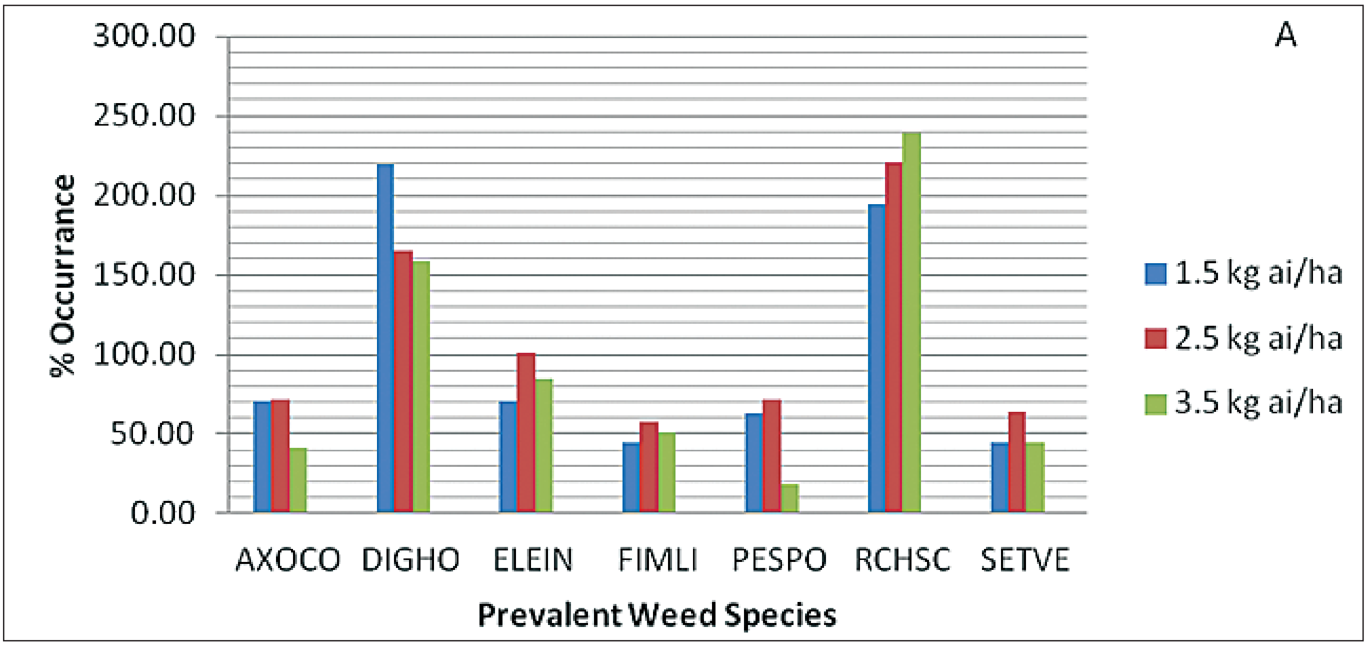



**Figure 7.** Prevalent weed species encountered on atrazine-treated field
AXOCO= *Axonopus compressus*, DIGHO=*Digitaria horizontalis*, ELEIN=*Eleusine indica,* FIMLI= *Fimbristylis littoralis*, PESPO= *Pennisetum polystachion*, RCHSC=*Richardia scabra*, SETVE = *Seteria verticillata*

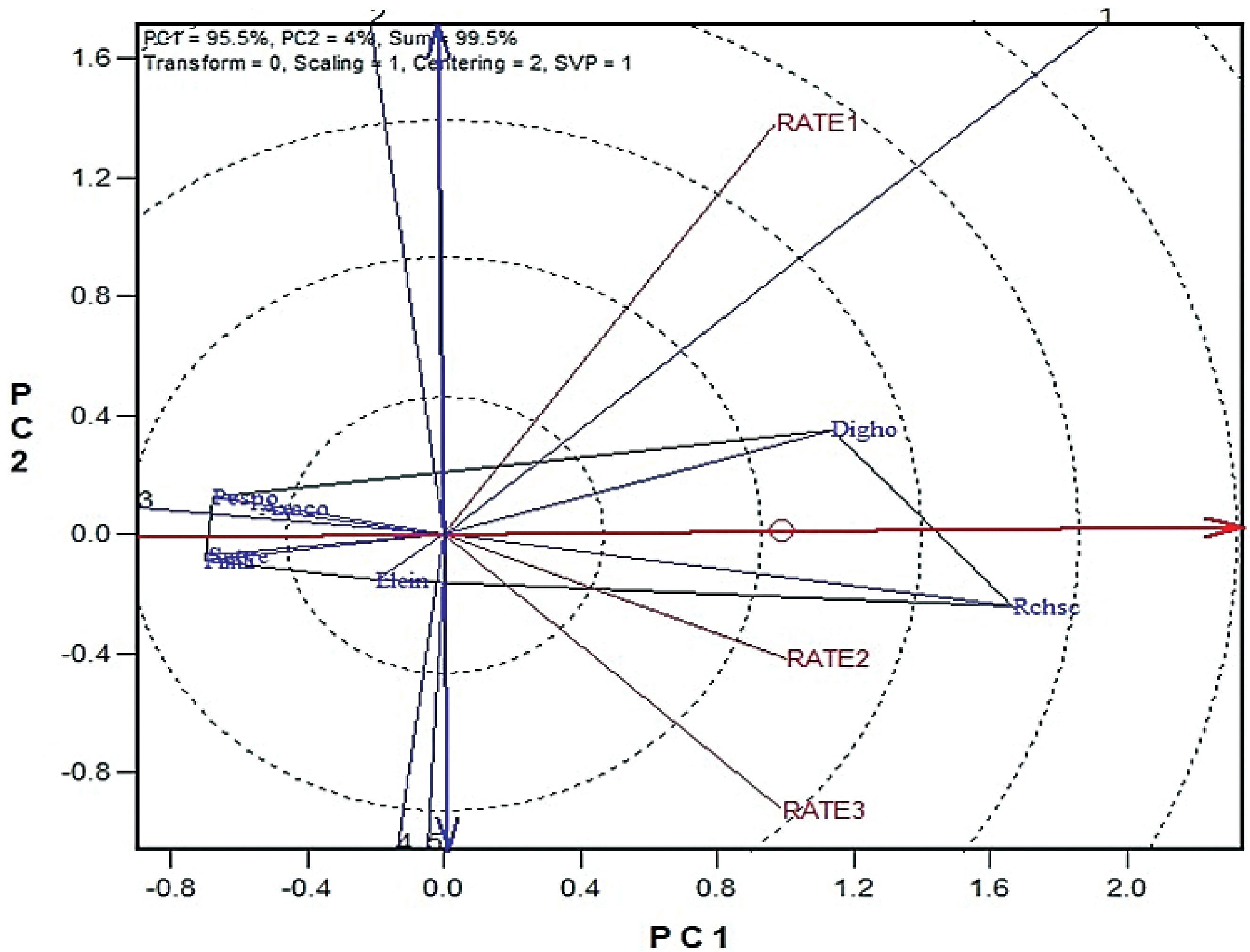



**Figure 8.** The polygon view of biplot showing which weed species won in which atrazine-treated field
AXOCO= *Axonopus compressus*, DIGHO=*Digitaria horizontalis*, ELEIN=*Eleusine indica,* FIMLI= *Fimbristylis littoralis*, PESPO= *Pennisetum polystachion*, RCHSC=*Richardia scabra*, SETVE = *Seteria verticillata*

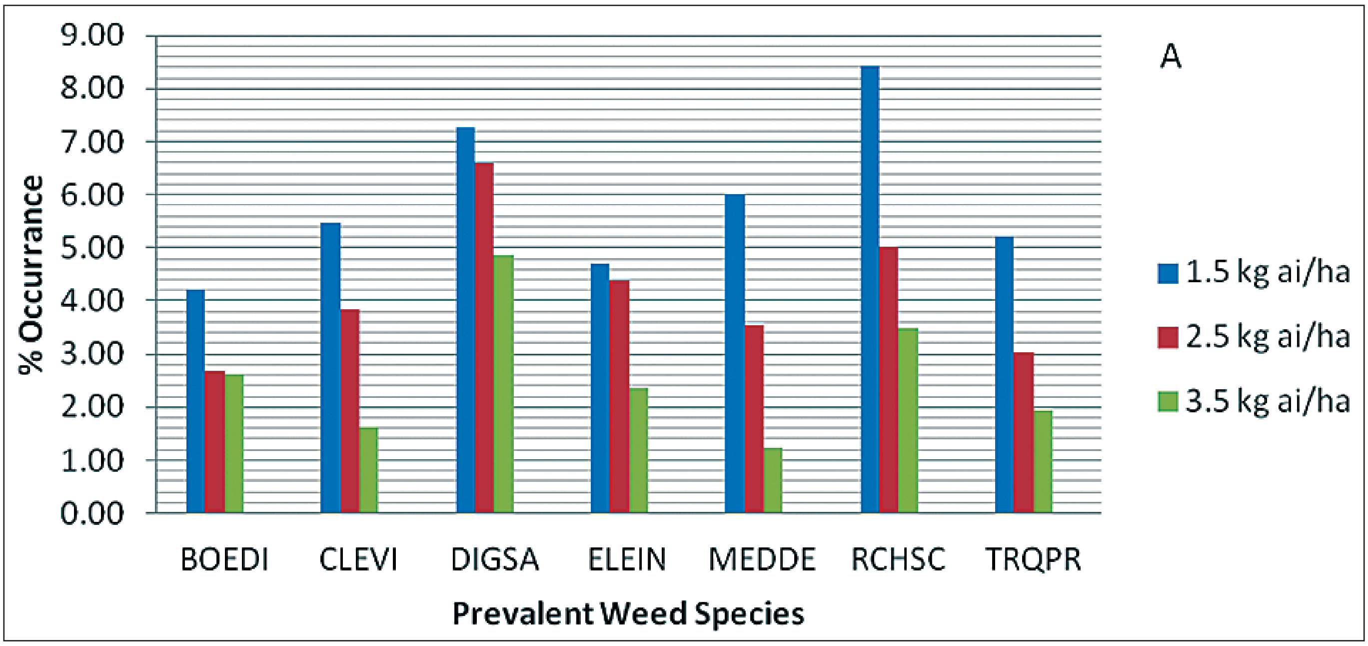



**Figure 9.** Prevalent weed species encountered on metolachlor treated field
BOEDI= *Boerhavia diffusa*, CLEVI= *Cleome viscose,* DIGSA=*Digitaria sanguinalis*, ELEIN=*Eleusine indica,* MEDDE= *Medicago denticulata*, RCHSC=*Richardia scabra*, TRQPR = *Tridax procumbens*

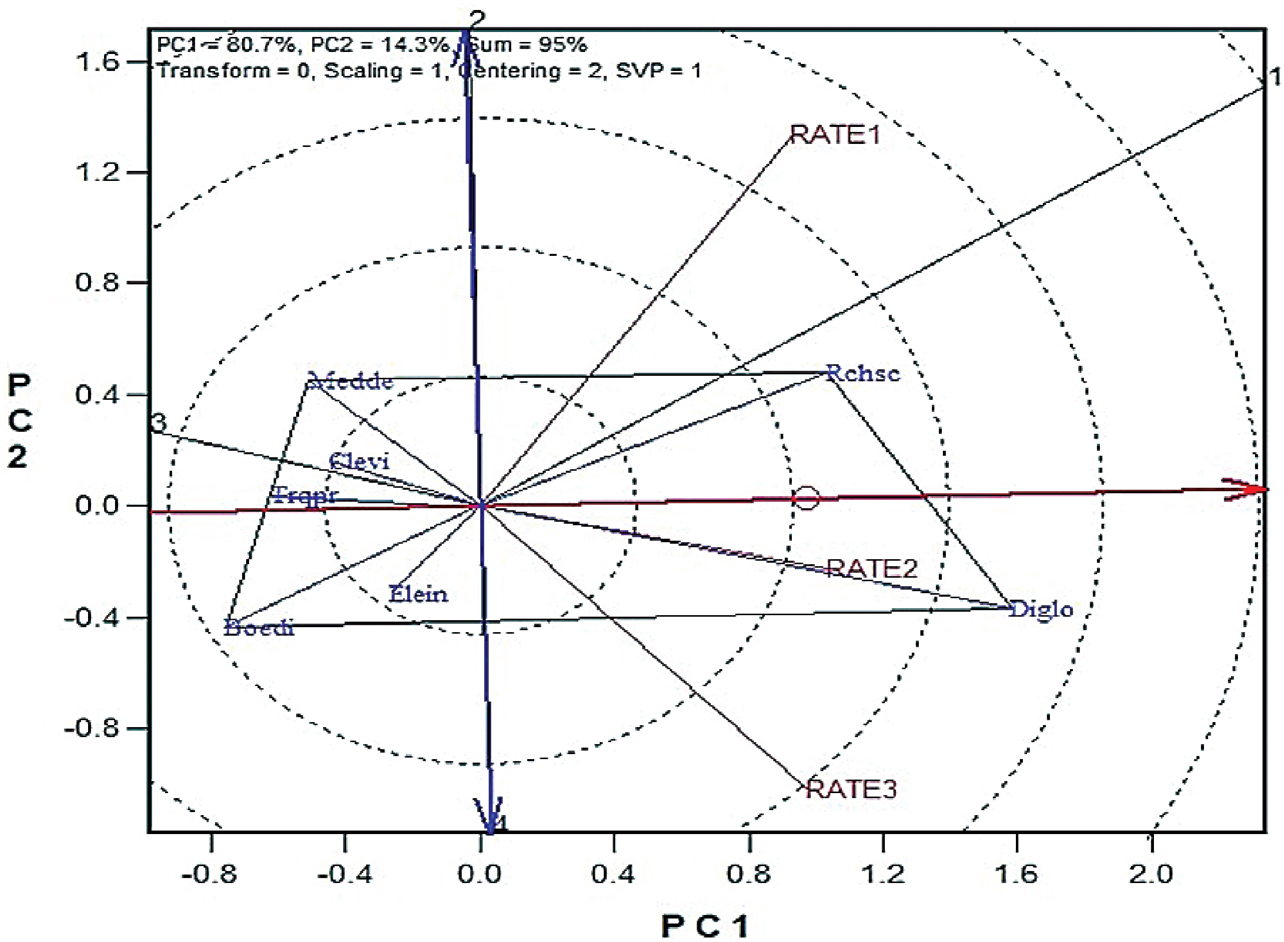



**Figure 10.** The polygon view of biplot showing which weed species won in which metolachlor-treated field
BOEDI= *Boerhavia diffusa*, CLEVI= *Cleome viscose,* DIGSA=*Digitaria sanguinalis*, ELEIN=*Eleusine indica,* MEDDE= *Medicago denticulata*, RCHSC=*Richardia scabra*, TRQPR = *Tridax procumbens*

## Discussion

This study showed that the weed flora consists of broadleaves and grasses in a relatively similar proportion, although members of the Poaceae dominated the maize weed community, followed by Fabaceae and Cyperaceae. This was consistent with Takim and Amodu (2013) who reported high diversity of broadleaves species with dominant grasses in a sugarcane field located approximately 2-3 km from the present study. Similarly, Williams and Lagoke (2018) reported predominant broadleaved weeds compared with grasses and sedges in the fields studied in forest ecology.

The weed community of the study area comprised 55% annuals, 40% perennials and 5% unclassified, and there is a gradual shift from the predominant annual broadleaves to induced annual grasses. This contradicts Takim and Amodu (2013) who reported a gradual shift from dominant annual broadleaves to an induced vegetation of perennial grasses in a long monoculture sugarcane field. While Lososova et al. (2004) observed a predominantly annual plant community with significantly higher temporal dynamics than other vegetation types in Central Europe. Štefanić et al. (2019) on the *Istrian Peninsula* indicated a shift in weed population, specifically a decline in some species and an increase in the richness and abundance of others.

Derksen et al. (1995) and Rassam et al. (2011) highlighted how herbicide use can alter the composition and the structure of the weed community. Continued use of herbicides in maize production reduces the abundance of herbicide-susceptible broadleaf species and supports the abundance of grass species (Hyvonen and Salonen, 2002).

The floristic composition of the weed community in this study showed an approximately 28% reduction of weed species in primextra-treated plots, 8% and 2% for metolachlor and atrazine-treated fields, respectively, between 2019 and 2021. Across Europe, Richner et al. (2015) recorded a 20% decrease between 1939 and 2012, Štefanić et al. (2019) observed significant decrease in ruderal weed community richness from 85 in 2005 to 31 weed species in 2017. The changes in weed species composition could be due to the use of similar herbicides in a continuous monoculture resulting in a reduction of weed species susceptible to the herbicides applied or a shift to weed species associated with the crop being grown. Lossova et al. (2014) associate weed migration with increasing altitude, precipitation, decreasing temperature and soil condition, Fried et al. (2008) considered the variations to be genetic similarity between weed species and crop type while Pinke et al. (2011) explained the fluctuations in terms of the seasonal aspect. The similarity and diversity indices obtained in this study showed that atrazine-treated fields had the lowest indices over the three growing seasons, while other treated fields had relatively similar indices with the exception of Simpson Dominance (D), which was higher in the atrazine-treated fields (0.35) compared to 0.33 obtained for other herbicide-treated fields. The treated fields had consistent environmental conditions, as shown by higher Similarity index values, although the atrazine field showed slight differences that could be due to the frequent use of atrazine-related products in previous seasons.

In this study, 15 weed species were predominant, 7 weed species consisting of 5 grasses and 2 broadleaves were prevalent in atrazine-treated fields, and the most stable weed species were *Richardia scabra* and *Digitaria horizontalis*. Similarly, 7 (2 grasses and 5 broadleaved) species of the 15 predominant weed species were dominant in the metolachlor-treated field with *Richardia scabra* and *Digitaria sanguinalis* being the most stable weed species in the field over the three seasons. Three broadleaf weed species and 3 grasses were predominant in primextra applied field with *Richardia scabra* being the most stable weed species.

## Conclusion

The weed community of the study area consisted of 55% annuals, 40% perennials, and 5% unclassified plants, and there was a gradual shift from the predominant annual broadleaves to induced annual grasses. There was a 2 to 28% reduction in the floristic composition of the weed community. Fifteen (15) weed species were predominant and the most stable weed species were *Richardia scabra, Digitaria horizontalis and Digitaria sanguinalis.* A search for an ideal weed management option that controls the negative impacts of weeds on crop yield in arable farms while maintaining a diverse weed community is required.

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