Distribution and Abundance of Wild Sunflower (*Verbesina encelioides*) and its Impacts on Plant Biodiversity in The Central Rift Valley of Ethiopia

Amare Fufa[1], Taye Tessema[1], Zelalem Bekeko[2] and Tewodros Mesfin[1]
[1]Ethiopian Institute of Agricultural Research, Addis Ababa, P.o.box 2003, Ethiopia
[2]College of Agriculture and Environmental Science, Haramaya University, Dire Dawa, P.o.box 138, Ethiopia; Amare Fufa; email: amarefufa@gmail.com

Abstract

Wild sunflower (Verbesina encelioides) is a newly identified emerging invasive weed with adverse consequences that require management efforts. Surveys were conducted in the Central Rift Valley of Ethiopia during the main rainy season of the year 2020. The research aimed to determine the geographic distribution of wild sunflower, generate data on the quantitative measures, the threats posed by the weed to native plant biodiversity, and assess the influence of some environmental factors on wild sunflower. A total of 220 sampling points were assessed across 22 different sites. Ecological indices were used to assess the distribution and diversity of the weed species. The significance of nine key variables: rainfall, temperature, altitude, species abundance, richness, diversity, and the density, frequency, and dominance of wild sunflower, were assessed using principal component analysis. A total of 42 taxa that belong to 18 plant families were recorded. Wild sunflower was found in 68.64% of the total sampling points. The infestation was more prevalent at low altitudes, such as Fentale, Boset, and Adama. On the roadside, wild sunflower was the dominant weed species. It has also been observed in different crop fields, like common beans, onions, and tef. Principal component analysis showed that the first two of the nine principal components (largely wild sunflower density and frequency) accounted for 77% of the variation in the data set. Rainfall, altitude, and temperature were among the environmental factors that influenced wild sunflower distribution. The highest density of wild sunflower (54.19 plants m^{-2}) was observed to significantly reduce the diversity of other plant communities (H' = 2.47). Thus, practical and effective measures are required to prevent and control the spread of this exotic invasive weed to other parts of the country where it has not yet been introduced.

Keywords: Distribution; invasive species; land use types; principal component; *Verbesina encelioides*

Introduction

Ethiopia is endowed with a wide range of biological and ecological diversity. Its vast biological and ecological multiplicity is due to its diverse temperature, soil, altitude, and topography (EARO, 2004). However, abiotic and biotic factors are threatening the country's biological diversity. The biological invasion of invading alien species being the greatest threat to the native biota. Invasive alien plant species are one of the most serious ecological problems, as they cause a significant part of the extinction of native species (Pragya, 2017). They endanger biodiversity, habitat composition, ecosystem functioning, and human interests by displacing native species, resulting in a decline in native flora and fauna of biodiversity (Hulme, 2007; Crowl *et al*., 2008; Rezene, 2008; Taye *et al*., 2009; Rezene *et al*., 2012).

In Ethiopia, over 35 invasive alien weed species have been identified as established or potentially emerging invaders (Rezene *et al*., 2012). Parthenium weed (*Parthenium hysterophorus* L), Water hyacinth (*Eichhornia crassipes)*, and Mesquite (*Prosopis juliflora*) are the most prominent plant invaders in the country. They resulted in a significant reduction of crop yields, biodiversity, and economic losses in several parts of the country (Tamado, 2001; Firehun *et al*., 2007; Edward, 2013; Firehun *et al*., 2014; Ilukor *et al*., 2014). Besides the already established invasive alien weed problem, the problem of emerging invaders is becoming important due to a lack of comprehensive understanding of the invading weeds and the current shifting dynamics of weeds in crops, non-crops, and cropping systems, as well as environmental weeds (EIAR, 2016).

Wild sunflower (*Verbesina encelioides*(Cav.) Benth. & Hook. F. Ex A. Gray) is one of the recently identified emerging invasive weeds in Ethiopia. It is thought to have originated in Mexico and the United States, and is widely distributed in many parts of the world (Walther, 2004; Feenstra and Clements, 2008; Jain *et al*., 2008; Sayari *et al*., 2016). Though the source of the introduction is not exactly known, its rare presence was noted during the study of weed flora in agricultural fields in eastern Ethiopia as early as 1998 (Tamado and Milberg, 2000). Arne and Quentin (2017) reported that wild sunflower has been found in a number of Ethiopian localities with establishing dense stands, and that the weed's possible introduction pathway could be as an ornament and accidentally as a contaminant.

Wild sunflower is an aggressive weed that invades huge habitats like roadsides, farming fields, residential areas, and grazing lands, competes with native plants and reduces biodiversity (Sade *et al*., 2007; Taleb *et al*., 2011; Mohammad, 2014; Goyal *et al*., 2019). Its aggressiveness and fast growth capacity outcompetes native plants and prevent them from growing (Walther, 2004; Goyal *et al*., 2019). It competes with its neighbors through allelopathic interference; for example, it has a higher competitive ability than co-occurring species such as *Amaranthus viridis* and *Senna occidentalis* (Mehal *et al*., 2022). It is now a new and possibly emerging invader in Ethiopia having far-reaching consequences that necessitate efforts to contain the weed. However, knowledge about its ecological distribution and effects on plant biodiversity in Ethiopia, in general, and in Ethiopia's Central Rift Valley, in particular, is lacking. Therefore, the objectives of this study were to: (i) determine the abundance and distribution of wild sunflower; (ii) generate data on the threats posed by the weed to native plant biodiversity; and (iii) assess the influence of some environmental factors on wild sunflower distribution in the Central Rift Valley of Ethiopia.

Materials and Methods

Description of the Study Areas

The study was conducted in the Central Rift Valley of Ethiopia, which includes East Shewa and West Arsi. The East Shewa Zone is located from 38^o 03′ to 40^o 05′ E longitude and from 7^o 04' to 9^o 10' N latitude, covering a total area of about 13,766.5 km^2. Whereas, the West-Arsi Zone covers an area of approximately 12,938 km^2 and spans 38^o 0′ to 40^o 00′E longitude and 6^o 00′ to 7^o 35′N latitude. Based on the moisture index classification of climate, East Shewa is characterized by a semi-arid and sub-humid climate. Considering the long-term average seasonal rainfall, the area receives 458–718 mm of rain. According to the Food and Agriculture Organization (FAO) classification, Andosols, Vertisols, Rendzinas and Phaeozems, and Fluvisols are the dominant soil types found in the East Shewa Zone (Gizachew and Suryabhagavan, 2014). On the other hand, West Arsi receives 600 mm to 1400 mm of annual rainfall during the main rainy season. The average monthly temperature in the zone varies between 15 and 20°C. Orthicluvisol, Eutric Combilsols, and Vertisols are the dominant soils in West Arsi.

Sampling of the Species Occurrence and Environmental Data

The survey was conducted between August and October during the main season of 2020 when wild sunflower growth was at its peak. Initially, a preliminary field visit was conducted prior to the actual field assessment. A multistage sampling method was used to select eight districts based on the infestation level of the wild sunflower. Three sites were further selected from each district (except two districts where only two sites were examined in each) based on their accessibility to roads and wild sunflower occurrence along different land use types. In each site, ten quadrats (1m x 1m) were used for assessment. Thus, a total of 220 sampling points were examined from 22 sites. At each survey site, the occurrence of wild sunflower was noted and the geographic coordinates, latitude and longitude, as well as altitude, were also recorded by using a handheld Global Positioning System (Garmin GPS 60). Furthermore, the identity and quantity of other weed species in the quadrat was also recorded. Data recorded in all sites included altitude, species density, species richness, and wild sunflower density at different land use types. The long-term record of monthly rainfall and temperature of the study sites were obtained from National Metrology Agency. A summary of the description of the physical environment, and the aforementioned variables used in this study is given in Table 1.

Data analyses

Weed species distribution and abundance assessment

The data on weed species were summarized using: (1) frequency- the percentage of sampling plots in which a particular weed species is found. It explains how often a weed species occurs in the survey area, (2) abundance- the population density of a weed species expressed as the number of individuals of that species per unit area, and (3) dominance- the abundance of an individual weed species in relation to the total weed abundance. Wild sunflower density was calculated as the number of individuals of wild sunflower that occur per surface area of the sampling unit (plant per square meter). The formula used to calculate the frequency, abundance, and dominance of the species is described as follows:

$F = 100 * \frac{X}{N}$ where, F = frequency of particular weed species; X = number of samples in which a particular weed species occurs; N = total number of samples

$A = \frac{\sum W * 100}{N}$ where, A = abundance; $\sum W$ = sum of individuals of a particular weed species across all samples; N = total number of samples.

D = $A * \frac{100}{\sum A}$ where, D = dominance of a particular species; A = Abundance of the same species

$\sum A$ = total abundance of all weed species

Species diversity evaluation

Species diversity on the study sites was described by two parameters, richness and evenness, using the Shannon-Wiener Diversity Index. The formula is $H' = \sum[-Pi(lnPi)]$ where, H = Shannon-Wiener Diversity Index; Pi = proportional abundance of the i^{th} species. Then, using the calculated value of H, Evenness was calculated as: $E = \frac{H'}{lnS}$ where, E = Evenness; S=Species richness (the number of species in a community).

Principal component analyses

Principal component analysis was performed on the mean values obtained for each variable (Table 1) using R software, Version 4.05 (R Development Core Team, 2018). It was used to identify the main factors that influence the distribution and abundance of wild sunflower. ANOVA was applied to investigate the relationship between the mean abundance of wild sunflower and diversity variables against land use types.

Correlation and regression analysis

The mean density of wild sunflower was used as the independent variable and the density of broad-leaf and grass weeds as the response variables in the regression analysis.

Table 1. Description of variables used in principal component analysis

Variables	Variable code
Rainfall	Rainfall
Temperature	Temperature
Altitude	Altitude
Species abundance	Abundance
Mean density of wild sunflower	Density
Frequency of wild sunflower	Frequency
Dominance of wild sunflower	Dominance
Species richness	Richness
Shannon's diversity index	H'

Results and Discussion

Weed Species Community

A total of forty-two weed species from eighteen different families were identified (Appendix 1). The weed species communities were documented at twenty-two different sites along various land use types (roadsides, crop fields, fallow land, grazing land, and residential areas). The most diverse weed species were found on fallow land, followed by grazing land and residential areas (thirty-two, twenty-four, and twenty, respectively) (Table 2). The most important families, based on the number of taxa, were Astraceae (9), Poaceae (7), and Fabaceae (4). These three families were also the most important in eastern Ethiopia (Tamado and Milberg, 2000). Annual weed species were more common than perennials in the study areas, except on roadsides where perennial weed species were dominant (Table 2). Fallow land accounted for 76.19% of the total weed species recorded, of which 62.50% were annual.

Table 2. Number of weeds by their family, species, and growth form (annual and perennial) across land use types in the Central Rift Valley of Ethiopia

Land Use Types	Family	Weed Species	Annual	Perennial
Crop field	8	15	13	2
Fallow land	15	32	20	12
Grazing land	9	24	15	9
Residential area	8	20	8	12
Roadside	8	17	7	10

Distribution and Abundance of Wild sunflower

Wild sunflower was recorded in all districts of the twenty-two sites surveyed. It was recorded in 68.64% of the total sampling points, being more common in the Fentale, Boset, Adama, Lome, and Dugda districts than in Adamitulu, Shala, and Liben districts (Table 3). The majority of the districts are located along main roads and railway routes where massive infrastructure development and agricultural investment activities take place. Roadsides are vulnerable to the spread of non-native plant species because roads and road maintenance are vectors for their spread (Hulme, 2009). Although the wild sunflower current distribution in Lome and Dugda districts was relatively moderate, its invading potential in these districts was high due to large crop production area coverage, particularly horticultural crop production on a small and large scale under both rain-fed and irrigation conditions. It is common for producers in these areas to cover their crop harvest, such as onions and tomatoes, with various local materials, including invasive weeds, during transport to market. Moreover, continued agricultural activities may create a conducive environment for the invasive weed species. Such frequent movement of vehicles in and out of those areas along with continued and intensive farming practices could greatly contribute for the further expansion of invasive weed species in general and wild sunflower in particular.

On the other hand, the infestation of the weed was low in the Shala and Liben districts as compared to other surveyed districts. This might be due to the fact that these districts are relatively far from the main road, which is the main dispersal pathway of invasive weed species. Similarly, Wilson and colleagues (2009) reported that unintentional introductions of invasive species, such as those caused by mass dispersal, frequently involve the introduction of propagules into highly disturbed habitats, such as ports, roadsides, and commercial complexes, where the unaided establishment is more likely than in less disturbed habitats.

Table 3. Occurrence of wild sunflower in different districts in the Central Rift Valley of Ethiopia

Surveyed Districts	Number of sites	Total number of sampling points	Number of sampling points	
			Presence *	Absence
Adama	2(Site1&2)	20	15(75.00)	5
Adamitulu	3(Site3, 4&5)	30	19(63.33)	11
Boset	3(Site6, 7&8)	30	24(80.00)	6
Dugda	3(Site9, 10&11)	30	20(66.67)	10
Fentale	3(Site12, 13&14)	30	25(83.33)	5
Liban	2(Site15 &16)	20	9(45.00)	11
Lome	3(Site17, 18&19)	30	21(70.00)	9
Shala	3(Site20, 21&22)	30	18(60.00)	12
Total	22	220	151(68.64)	69

*values in parentheses are percentage presence out of total

With regard to the density of wild sunflower, it varied significantly across an altitude gradient. It was more abundant between 500 and 1500 m.a.s.l. than between 1500 and 2000 m.a.s.l (Figure 1). At an altitude ranging from 1500 to 2000 m.a.s.l., the mean density of wild sunflower was significantly lower, as compared to its density at lower altitudes, less than 1500 m.a.s.l. This indicates that the abundance of wild sunflower is greatly affected by altitude (Figure 1).

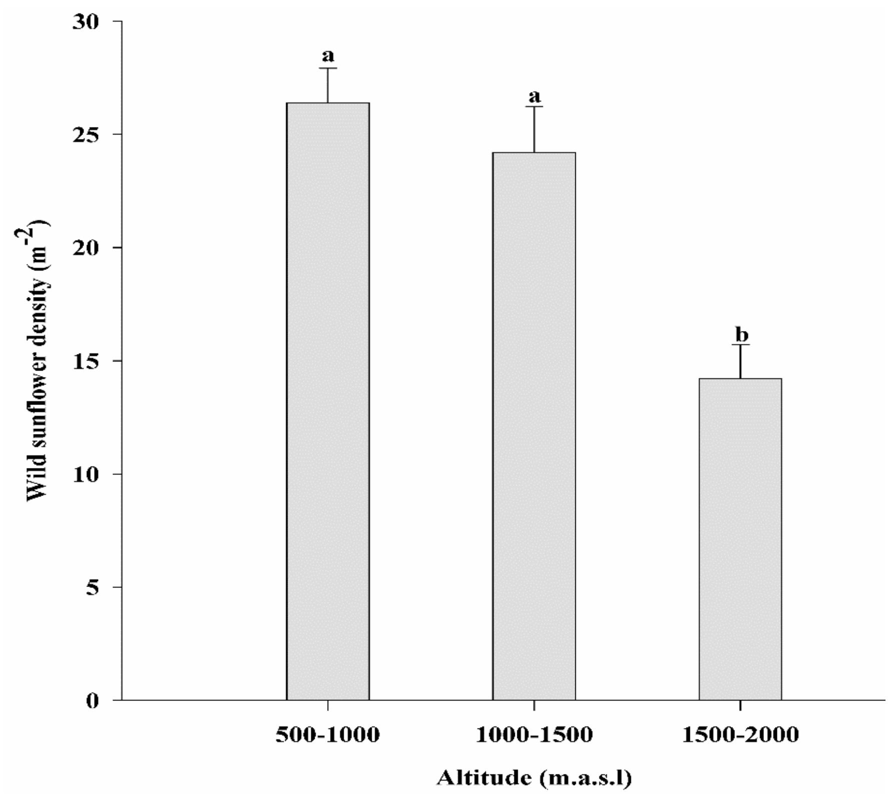

Figure 1. Distribution of wild sunflower along altitude gradient (LSD at $P\leq0.05=2.13$)

Because of anthropogenic disturbances such as uncontrolled grazing and large-scale commercial farms, the distribution and abundance of invasive plant species, including wild sunflower, were significant in the low and mid-altitudes (Figure 1). Likewise, Dai *et al*. (2020) reported a lower density of invasive plant species in the high-altitude region. The number of weed species was observed low at higher elevations, which accounts for less available space, limiting the growth of invasive species (Pathak *et al*., 2019).

Wild sunflower had the highest mean density (53.47 plant m^{-2}) on the roadside habitat, followed by the noxious invasive plant species, *Parthenium hysterophorus* (38.80 plant m^{-2}) (Appendix 1). This could be because wild sunflower is a potential emerging invader that has taken over roadside vegetation and has the potential to spread to other land use types or habitats. On the other hand, *P. hysterophorus* is already a well-established invasive plant species that is found beyond roadsides in a variety of habitats. For instance, the mean density of *P. hysterophorus* in a crop field was higher than wild sunflower by two-fold (Appendix 1).

Figure 2. Wild sunflower infestation in a) field after wheat, b) Common bean field c) Onion seedling, and d) Tef, in the Central Rift Valley of Ethiopia.

Wild sunflower is widely distributed in different habitats of the Central Rift Valley of Ethiopia, including crop fields where the weed has infested many crop fields (Figure 2). The crop fields heavily infested by the weed in the study area were common bean, onion, and tef fields (Figure 2b-d). Previous studies also showed that wild sunflower could be found in a variety of habitats, including crop fields, pasture land, roadsides, field borders, water course surrounds, and grasslands (Brunel *et al*., 2010; Goyal *et al*., 2019).

Factors Influencing the Distribution and Abundance of Wild sunflower

In order to better understand factors affecting the distribution and abundance of wild sunflower, a principal component analysis was computed. Table 4 shows a correlation matrix derived from principal component analysis. The mean density, frequency, and dominance of wild sunflower had a strong negative relationship with rainfall and altitude, on the other hand, they had a significant positive correlation with temperature (Table 4). The diversity and abundance of weed species were positively correlated with rainfall but inversely correlated with temperature. This might be due to the impact of high temperatures, which play a great role in contributing to climate change and favoring the dominance of a few invasive species, like wild sunflower. Climate change can have an immediate impact on weed distribution through variability in selective pressures on weed species as well as an indirect impact through changes in the abiotic and biotic factors in an ecosystem (Ziska *et al*., 2019). The abundance of weed species had a strong positive relationship with rainfall and a negative relationship with temperature. Moreover, species richness had a strong positive relationship with rainfall and a negative relationship with temperature and altitude. Walther *et al*. (2009), on the other hand, observed that climate change increases the abundance and distribution of some invasive species while decreasing or shifting the abundance and distribution of other native or invasive species, which may not result in changes in species richness.

Table 4. Correlation matrix of physical environment and species abundance and diversity indices

	Rainfall	Temperature	Altitude	Abundance	Density	Frequency	Dominance	Richness	Diversity
Rainfall	1.00								
Temperature	-0.63**	1.00							
Altitude	0.84***	-0.54**	1.00						
Abundance	0.56**	-0.65**	0.46*	1.00					
Density	-0.87***	0.62**	-0.91***	0.32	1.00				
Frequency	-0.84***	0.62**	-0.93***	0.32	0.97***	1.00			
Dominance	-0.78***	0.58**	-0.86***	0.14	0.93***	0.96***	1.00		
Richness	0.72***	-0.51*	-0.53*	0.25	0.29	0.29	0.22	1.00	
Diversity	0.52*	-0.52*	-0.10	0.11	0.38	0.38	0.42	0.58**	1.00

*significant at 0.05; ** significant at 0.01; ***significant at 0.001

With regard to principal component analysis, the first principal component accounts for 52.5% of the total variance, and the first two components explain around 77% of the total variance (Figure 3). As shown in Table 5, the variables most associated with the first principal component were the wild sunflower frequency (0.422), mean density (0.421), and dominance (0.407), indicating these three variables vary together. In other words, if one increases, the others tend to increase as well. In the first principal component, on the other hand, precipitation and altitude had almost parallel contrast with frequency, density and dominance. The second principal component was highly associated with that of species richness and Shannon's diversity index (Table 5).

Table 5. Eigen vector of the first two principal components of variables measured in different land use types of the Central Rift Valley of Ethiopia

	*Prin1	**Prin2
Rainfall	-0.409	0.121
Temperature	0.300	-0.199
Altitude	-0.394	-0.247
Species abundance	0.146	0.319
Mean density of wild sunflower	0.421	0.026
Frequency of wild sunflower	0.422	0.026
Dominance of wild sunflower	0.407	-0.049
Species richness	0.117	0.632
Shannon's diversity index	0.179	0.617

*Prin1-first principal component; **Prin2- second principal component

The principal factors for site clustering were wild sunflower density and frequency, as evidenced by the high positive load of these variables on the first principal component, which accounted for 52.5% of the variation of the data set (Table 5). Figure 3b depicts the survey sites' positions on the principal component dimensions. Sites on the right bottom (cluster 2) had an abundant distribution of wild sunflower. In contrast, sites on the right top (cluster 4) had a lower distribution of wild sunflower.

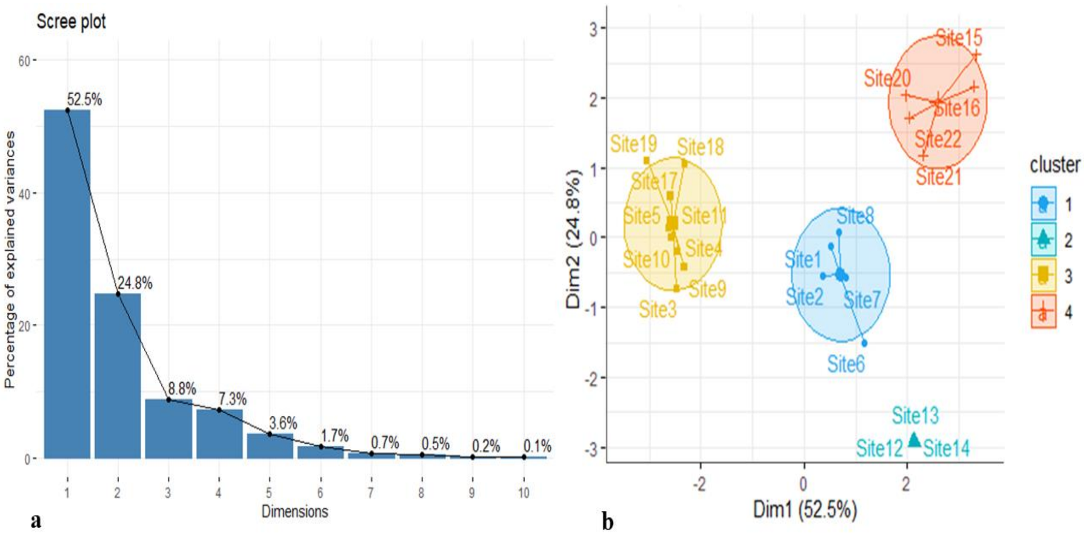

Figure 3. a) Scree plot b) Cluster plot of the 1st and 2nd axes from the PCA showing similarity of areas surveyed for the wild sunflower distribution in the Central Rift Valley of Ethiopia

Sites categorized in cluster 2 are those found in the Fentale district. The district is located in the lowland area of the Central Rift Valley of Ethiopia and it is one of the climate change-prone areas that have been affected by climate-induced shocks, and beneficial plant species have become endangered and have been replaced by unpalatable species as a result of declining rainfall, rising temperatures, and recurrent droughts (Mekuyie and Mulu, 2021). In general, climate-related variables are thought to be the dominant factors influencing species' presence or absence at spatial and temporal scales (Thuiller *et al*., 2007).

Impact of Wild Sunflower on Herbaceous Plant Biodiversity

The five land use types had a significant impact on the abundance of wild sunflower and species diversity. Species diversity indices on fallow land and grazing land were the highest, while those in crop fields and roadsides were the lowest (Table 6). Species richness, defined as the number of plant species present in an area, was significantly ($P<0.05$) influenced by land use types. Likewise, land use types had varying effects on the Shannon diversity index and species evenness. As a result, the species richness of fallow land, grazing land, and residential areas was significantly ($P < 0.05$) higher than that of roadsides and crop fields, respectively (Table 6). In fallow land, the highest species evenness was observed followed by grazing land and residential areas with 0.96, 0.94, and 0.91 respectively (Table 6). All of the diversity indices in crop fields were comparatively lower. This could be due to weed management practices in crop fields. On the other hand, the highest species richness in fallow land may be due to less soil disturbance than in other land use types. This is due to the fact that disturbed soil or land favors the dominance of invasive plant species over stable land.

Table 6. Mean abundance of wild sunflower, Species richness, Shannon's diversity index, and Evenness (mean ± standard deviation) of weed species at different land use types

Land use types	Mean abundance	Species richness	Shannon's Index	Evenness
Crop field	$13.47^{e} \pm 2.13$	$14.05^{e} \pm 2.81$	$2.47^{c} \pm 0.31$	$0.87^{b} \pm 0.08$
Fallow land	$25.21^{d} \pm 2.25$	$31.41^{a} \pm 2.16$	$3.25^{a} \pm 0.21$	$0.96^{a} \pm 0.11$
Grazing land	$34.14^{c} \pm 3.16$	$24.64^{b} \pm 1.74$	$3.00^{ab} \pm 0.28$	$0.94^{a} \pm 0.07$
Residential area	$42.23^{b} \pm 4.12$	$20.32^{c} \pm 2.18$	$2.79^{b} \pm 0.19$	$0.91^{ab} \pm 0.13$
Road side	$54.19^{a} \pm 5.64$	$17.23^{d} \pm 3.42$	$2.54^{bc} \pm 0.37$	$0.89^{b} \pm 0.09$

Note: Different letters within a column indicate that the values are significantly different at *p*-value ≤0.05.

The decrease in diversity indices, as wild sunflower mean abundance increased, indicated that the variation in weed species and community multiplicity decreased as wild sunflower infestation increased. Similarly, fallow land had a higher evenness index, indicating that weed species are more equitably distributed in low-disturbed habitats. When wild sunflower was present at its highest mean abundance (54.19 plants m^{-2}), the plant community's diversity was the lowest ($H' = 2.47$), and the highest ($H' = 3.25$) when wild sunflower was present at its lowest mean abundance (13.47 plants m^{-2}). Consequently, as the diversity of the plant community increases, the mean abundance of the wild sunflower decreases, and vice versa (Table 6). This suggests that wild sunflower significantly reduces the density and diversity of other plant species. Wild sunflower's aggressiveness and higher competitive ability prevent natural plants from growing (Walther, 2004; Goyal et *al.*, 2019). Due to allelopathic interference, wild sunflower competes with its co-occurring plant species (Mehal *et al*., 2022). According to Kaur *et al*. (2021), the presence of certain compounds in wild sunflower may be responsible for its dominance in areas where it occurs; i.e., this dominance may be related to the allelopathic impact of this weed. Wild sunflower infestation on the field after wheat revealed that it grows in dense populations with few or no other plants present, indicating its significant impact on plant biodiversity (Figure 2a).

The mean density of weed species along land use types was used to develop regression equations against the dependent variable of broad-leaf and grass weed density versus wild sunflower density. The result revealed a strong negative relationship between wild sunflower density and broad-leaf weeds (Figure 4a). Furthermore, wild sunflower was also negatively associated with grass weeds (Figure 4b). Figure 4 shows that the regression equation estimated by wild sunflower density explains 93.19 and 73.89% of the variability in broadleaf and grass weed populations per square meter, respectively.

When wild sunflower densities increased across land use types, there was a linear decrease in broad-leaf and grass weeds. Similarly, Million *et al.* (2021) also observed a negative association between the relative abundance of parthenium with species richness (R^2 = 85%) and the index of Shannon diversity (R^2 = 99%), respectively. The density of broad-leaf and grass weeds decreased linearly with each addition of wild sunflower plants m^{-2} by 0.78 and 1.20 plants m^{-2}, respectively (Figure 4a and b). Similarly, Taye *et al*. (2010) observed that as parthenium density increased, the density of broadleaf, grass, and sedges decreased.

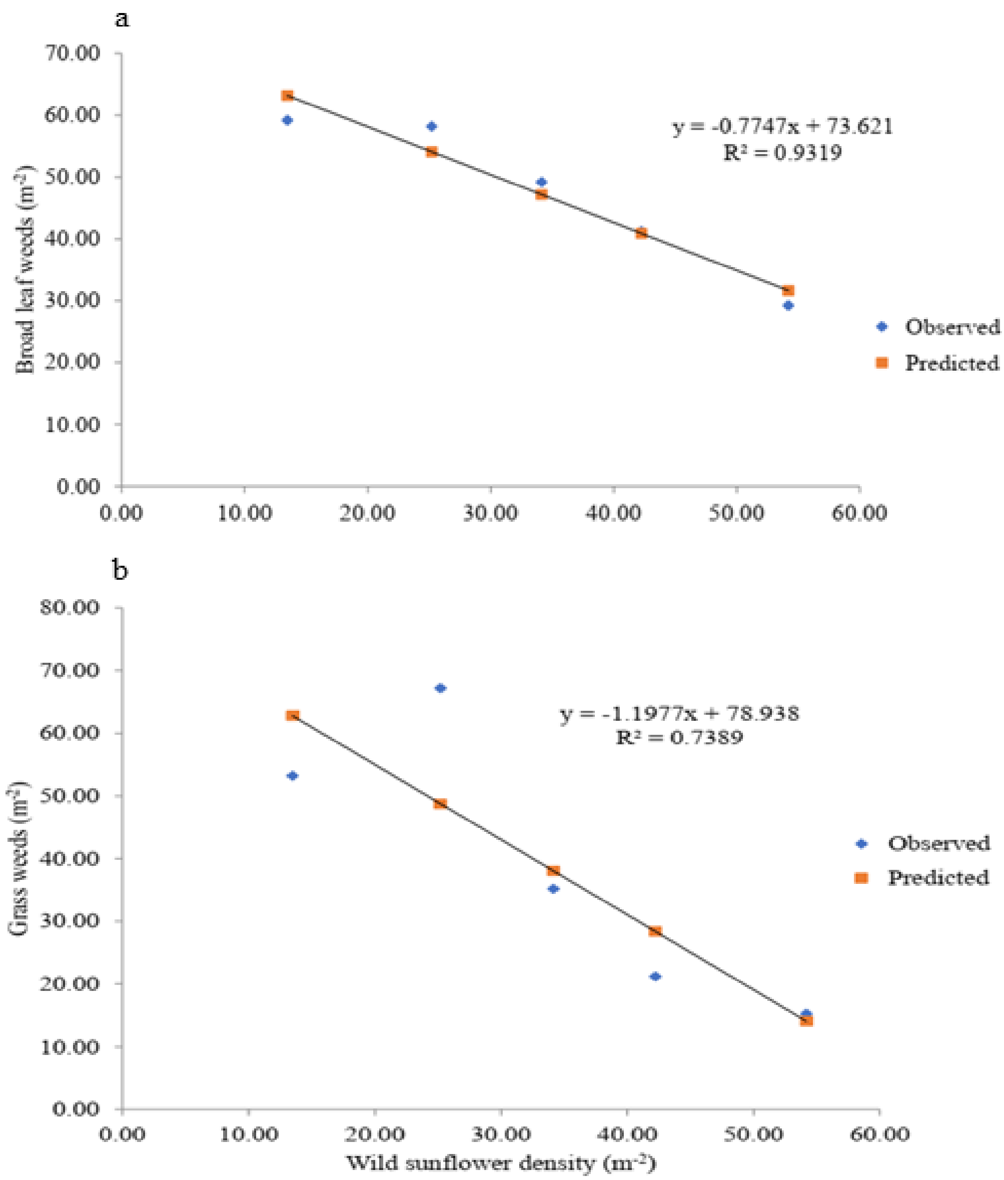

Figure 4. Regression of wild sunflower with a) broad-leaf weeds and b) grass weeds

Conclusion

This study described the distribution, abundance, and impact of wild sunflower in the Central Rift Valley of Ethiopia. It has documented the current distribution and abundance of the recently introduced wild sunflower, a species that has spread rapidly and has the potential to threaten different crop and non-crop environments. Accordingly, the occurrence of wild sunflower at twenty-two sites across land use types was documented. The most abundant weed species across land use types were also identified. On roadsides, for example, wild sunflower was the dominant weed species. Furthermore, it was widely distributed in different crop fields, like common bean, onion, and tef. The prevalence of the weed in farming fields indicated its potential to affect crop production. Rainfall, altitude, and temperature were among the environmental factors that influenced wild sunflower distribution. The study demonstrated that wild sunflower remarkably reduced the density and diversity of other plant species. Thus, if wild sunflower continues to grow unrestricted and unmanaged on an early note, it will have a significant impact on the country's agricultural and natural ecosystems. Given the current situation, it is critical that proper and effective measures for the prevention of this exotic invasive weed be implemented in order to control its spread from other areas of the country where it is not present at the moment.

Acknowledgments

The authors would like to acknowledge the Ethiopian Institute of Agricultural Research for providing funds and logistics.

References

Arne, W. and Quentin, L. (eds.). 2017. Guide to The Naturalized and Invasive Plants of Eastern Africa 1st edition. CABI, Nosworthy Way, Wallingford, Oxfordshire OX10 8DE, UK.

Brunel S., Schrader G., Brundu and Fried G. 2010. Emerging invasive alien plants in the Mediterranean Basin. G. *Bulletin* OEPP/EPPO Bulletin 40:219-238.

Crowl, T. A., Crist, T.O., Parmenter, R.R., Belovsky, G. and Lugo, A. E. 2008. The spread of invasive species and infectious diseases as drivers of ecosystem change. *Front. Ecol. Environ* 6: 238-246.

Dai, J., Roberts, D.A., Stow, D.A., An, L., Hall, S.J., Yabiku, S.T. and Kyriakidis, P.C. 2020. Mapping understory invasive plant species with field and remotely sensed data in Chitwan, Nepal. *Remote Sensing of Environment,* 250, 112037. https://doi.org/10.1016/j.rse.2020.112037

EARO. 2004. Biological impact assessments on selected invasive plant species in Ethiopia - A preliminary study. Reports submitted to the CABI Africa Regional Centre under the PDF-B phase of the UNEP/GEF Project: Removing Barriers to Invasive Plant Management in Africa. Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia.

Edward, R. 2013. Lake Tana Water Hyacinth Management Strategy 2016-2020. FAO, Addis Ababa.

EIAR. 2016. Plant Protection Research strategy. Ethiopian Institutes of Agricultural Research, EIAR, Addis Ababa.

Feenstra, K. R. and Clements, D. R. 2008. Biology and Impacts of Pacific Island Invasive Species. 4. *Verbesina encelioides*, Golden Crown beard (*Magnoliopsida: Asteraceae*). *Pac. Sci*. 62(2):161-176.

Firehun, Y., P.C. Struik, E.A. Lantinga, and Taye T. 2014. Water hyacinth in the Rift Valley water bodies of Ethiopia: Its distribution, socio-economic importance and management. *Int. J. Current Agri. Res*. 3:67-75.

Firehun, Y., Abera, T., Tariku, T. and Taye, T. 2007. Distribution, impact, and management of water hyacinth at Wonji-Shoa sugar factory. *Eth. J. Weed Management*. 1: 41-52.

Gizachew Legesse K.V. Suryabhagavan. 2014. Remote sensing and GIS based agricultural drought assessment in East Shewa Zone, Ethiopia. *Tropical Ecology* 55(3): 349-363.

Goyal, D., Kaur, N. and Chauhan, B. 2019. Effects of environmental factors and ageing on germination of golden crown beard (*Verbesina encelioides*)-A wide spread weed of Northern India. *Indian J. Weed Sc.* 51(4): 372-380.

Hulme, P.E., 2009. Trade, transport and trouble: managing invasive species pathways in an era of globalization. *Journal of applied ecology*, 46(1):10-18.

Hulme. 2007. Biological invasions in Europe: drivers, pressure, state, impacts, and response. *In*: Hester, R., Harrison, R.M. (Eds.), Biodiversity Under Threat Issues in Environmental Science and Technology, 25. Royal Society of Chemistry, Cambridge, pp. 56-80.

Ilukor, J., Regina, B. Mesfin, T. and Shimelis, G. 2014. Total Economic Value of *Prosopis juliflora* Invasion: A paper presented at Regional Conference on Management of *Propsopis juliflora* for better agro-pastoral livelihoods in the Horn of Africa. May 2014, Desalegn Hotel, Addis Ababa.

Jain, S. C., Jain, R., Singh, R. and Menghani, E. 2008. Perspective and potentials of a noxious weed: *Verbesina encelioides. Indian J. Tradit*. Know. 7(3): 511-513.

Kaur, K., Kaur, L., O. and Devi, P. 2021. Qualitative Phytochemical Analysis of a Recently emerging weed *Verbesina encelioides* in Punjab (India). *J. Phytol. Res.* 34 (2): 119-126.

Mekuyie, M. and Mulu, D. 2021. Perception of impacts of climate variability on pastoralists and their adaptation/coping strategies in Fentale district of Oromia region, Ethiopia. *Environmental Systems Research*. 10(1):1-10.

Mehal, K.K., Kaur, A., Singh, H.P. and Batish, D.R. 2022. Investigating the phytotoxic potential of *Verbesina encelioides*: Effect on growth and performance of co-occurring weed species. Protoplasma. pp.1-11. https://doi.org/10.1007/s00709-022-01761-2.

Million, D., Nigatu, L., Bekeko, Z. & Legesse, H. (2021). Integrated management of parthenium (*Parthenium hysterophorus* L.) and its effect on yield components and yield of maize (Zea mays L.) in West Gojjam Zone, Amhara National Regional State, Ethiopia. *Weed Biology and Management*, 21(2),1–13. https://doi.org/10.1111/wbm.12224

Mohammad, S. 2014. New records for two alien Asteraceae species in the United Arab Emirates. *J. New Biol.* Reports. 3(2): 115-119.

Pathak, H.N., Shrestha, B.B., Bhuju, D.R. and Subedi, D.S., 2021. Spatial distribution of invasive alien plants in Pokhara valley, Nepal. *Pak. J. Bot*, 53(3):1015-1024.

Pragya Sourabh. 2017. Modeling the potential invasion of alien species, *Verbesina encelioides* (Cav.) Benth. & Hook. Fil ex Gray in India. *An Int. J. Env. Biod*. 8(2): 124-129.
www.nebio.info I www.neceer.org.in.

R Core Team. 2018. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. https://www.R-project.org

Rezene, F., Taye, T., Firehun, Y. and Kassahun, Z. 2012. Invasive Alien Weed Species in Ethiopia: Status and Management. Pp. 76-112. *In:* Bayeh Mulatu (ed.). Invasive Plant Pests Threating Ethiopian Agriculture. Plant Protection Society of Ethiopia (PPSE). Proceedings of the 17th Annual Conference, November 26-27, 2010, Addis Ababa.

Rezene, F. 2008. Status of Invasive Alien Weeds in Ethiopia. Pp: 1-18. *In:* Rezene F., Aberra T., Kemal A., Mohammed D. and Seid A.(eds.). Alien Invasive Weeds and Insect Pests: Management and Control Options. *Proceedings of the Second National Workshop on Alien Invasive weeds and Insect Pests.* ARARI-EIAR, 6 - 8 June 2005, Bahr Dar, Ethiopia. EIAR, Addis Ababa.

Sade, R., Yaacoby, T. and Rubin B. 2007. Crownbeard (*Verbesina encelioides*), physiology, geographical distribution, and response to herbicides. Proceedings of the International Conference on 'Novel and sustainable weed management in arid and semi-arid ecosystems', Rehovot, IL, USA, pp 41.

Sayari, N., Mekki, M. and Taleb, A. 2016. Golden crown beard (*Verbesina encelioides*, Asteraceae), the first record of the Tunisian flora. *Flora Mediterrania*. 26: 19-24.

Taleb, A., Bouhache, M. and E.l. Mfadi, B. 2011. New species threatening the biodiversity in Morocco: *Verbesina encelioides* (Asteraceae). Proceedings of the 2nd International Workshop on Invasive Plants in the Mediterranean Regions of the World, Trabzon, Turkey, pp. 156-167.

Tamado, T. and Milberg, P. 2000. Weed flora in arable fields of eastern Ethiopia with emphasis on the occurrence of *Parthenium hysterophorus*. *Weed Research*. 40: 507-521.

Tamado, T. 2001. Biology and management of Parthenium hysterophorus L.) in Ethiopia. PhD thesis: Swedish University of Agricultural Sciences, Uppsala.

Taye Tessema, Rupschus C, Wiesner M, Rezene Fissahie., Firehun Yirefu, Ulrichs C, and Buttner C. 2010. Parthenium Weed (*Parthenium hysterophorus* L.) Research in Ethiopia: Impacts on Food Production, Plant Biodiversity and Human Health. *Ethiop. J. Agric. Sci*. 20:128-150.

Taye, T., Rezene, F., Firehun Y., Dereje T. and Tamado T. 2009. Review of Research on Invasive Alien Weed Species in Ethiopia. Pp. 381-407. *In:* Abraham Tadesse (ed.). Increasing Crop Production through Improved Plant Protection - Volume II. Plant Protection Society of Ethiopia (PPSE). PPSE, and EIAR, Addis Ababa, Ethiopia. 542 pp.

Thuiller, W., Albert, C., Araujo, M.B., Berry, P.M., Cabeza, M., Guisan, A., Hickler, T., Midgley, G.F., Paterson, J., Schurr, F.M. and Sykes, M.T. 2008. Predicting global change impacts on plant species' distributions: future challenges. Perspectives in plant ecology, evolution and systematics, 9(3-4):137-152.

Walther, M. 2004. A guide to Hawaii's coastal plants. Mutual Publishing, Honolulu, Hawai 'i.

Walther, G.R., Roques, A., Hulme, P.E., Sykes, M.T., Pysek, P., Kühn, I., Zobel, M., Bacher, S., Botta-Dukát, Z., Bugmann, H. and Czucz, B. 2009. Alien species in a warmer world: risks and opportunities. *Trends in ecology & evolution*, 24(12):686-693.

Wilson, J.R., Dormontt, E.E., Prentis, P.J., Lowe, A.J. and Richardson, D.M. 2009. Something in the way you move: dispersal pathways affect invasion success. Trends in ecology & evolution, 24(3):136-144.

Ziska, L.H., Blumenthal, D.M. and Franks, S.J., 2019. Understanding the nexus of rising CO2, climate change, and evolution in weed biology. Invasive Plant Science and Management. 12(2):79-88.

Appendix 1. Frequency, abundance and dominance of different weed species along land use system types in CRV of Ethiopia

Weed species	Family	Growth form	**Frequency**					**Abundance**					**Dominance**				
			RS	CF	FL	GL	RA	RS	CF	FL	GL	RA	RS	CF	FL	GL	RA
Achyranthes aspera	Amaranthaceae	Perennial	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alternanthera pungens	Amaranthaceae	Perennial	18.00	0.00	0.00	0.00	3.21	3.21	0.00	0.00	0.00	0.00	1.52	0.00	0.00	0.00	0.00
Amaranthus hybridus	Amaranthaceae	Annual	0.00	12.00	7.80	12.00	0.00	0.00	8.00	4.30	0.00	3.00	0.00	1.75	0.88	0.00	0.84
Amaranthus spinosus	Amaranthaceae	Annual	0.00	0.00	16.00	12.80	0.00	0.00	0.00	9.00	0.00	4.98	0.00	0.00	1.97	0.00	1.40
Anagalis arvensis	Primulaceae	Annual	0.00	0.00	8.00	0.00	0.00	0.00	0.00	6.00	0.00	0.00	0.00	0.00	1.31	0.00	0.00
Argemone auchroleuca	Papaveraceae	Annual	24.00	48.00	56.00	25.20	3.70	3.70	7.80	11.80	6.00	9.80	1.75	1.70	1.86	2.03	2.75
Bidens pilosa	Asteraceae	Annual	0.00	64.00	54.00	17.20	0.00	0.00	28.00	24.10	11.00	6.87	0.00	6.12	5.72	3.72	1.92
Calotropis_procera	Apocyanaceae	Perennial	12.00	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00	1.89	0.00	0.00	0.00	0.00
Chenopodium spp	Chenopodiaceae	Annual	0.00	65.00	32.00	0.00	0.00	0.00	8.00	20.86	0.00	0.00	0.00	1.75	5.28	0.00	0.00
Commelina benghalensis	Commelinaceae	Annual	0.00	0.00	35.00	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00	0.87	0.00	0.00
Convolvulus spp	Convolvulaceae	Perennial	0.00	0.00	15.00	0.00	0.00	0.00	0.00	6.00	0.00	0.00	0.00	0.00	1.31	0.00	0.00
Cynodon dactylon	Poaceae	Perennial	0.00	0.00	65.00	31.32	28.67	0.00	0.00	17.00	18.20	24.00	0.00	0.00	3.71	6.15	6.72
Cyperus esculentus	Cyperaceae	Perennial	0.00	40.00	84.00	30.52	32.35	0.00	22.00	41.00	15.00	24.54	0.00	4.81	10.38	5.07	6.88
Cyperus rotundus	Cyperaceae	Perennial	54.00	55.00	65.00	30.12	12.80	12.80	23.00	31.40	12.80	24.60	6.06	5.03	5.63	4.33	6.89
Cyperus sesquiflorus	Cyperaceae	Perennial	0.00	0.00	60.00	30.92	0.00	0.00	0.00	21.00	15.80	24.60	0.00	0.00	4.59	5.34	6.89
Datura stramonium	Solanaceae	Annual	0.00	0.00	15.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.44	0.00	0.00
Digitaria abyssinica	Poaceae	Perennial	32.00	0.00	56.00	32.00	11.00	11.00	0.00	37.00	22.80	25.00	5.21	0.00	9.37	7.71	7.00
Digitaria milanjiana	Poaceae	Perennial	40.00	0.00	48.00	32.00	7.00	7.00	0.00	32.00	22.40	9.80	3.31	0.00	8.10	7.57	2.75
Echinochloa colona	Poaceae	Perennial	0.00	0.00	45.33	0.00	0.00	0.00	0.00	8.00	0.00	0.00	0.00	0.00	1.75	0.00	0.00
Eleusine indica	Poaceae	Annual	34.00	65.00	60.00	26.52	13.00	13.00	11.00	10.00	19.23	2.00	6.15	2.40	2.53	6.50	0.56
Eragrostis cilianensis	Poaceae	Annual	0.00	0.00	35.00	0.00	0.00	0.00	0.00	6.00	0.00	0.00	0.00	0.00	1.31	0.00	0.00
Euphorbia heterophylla	Euphorbiaceae	Annual	0.00	0.00	0.00	12.00	0.00	0.00	0.00	0.00	3.00	2.43	0.00	0.00	0.00	1.01	0.68
Galinsoga parviflora	Asteraceae	Annual	42.00	90.00	60.00	42.12	12.00	12.00	38.00	33.20	13.00	13.80	5.68	8.30	7.94	4.39	3.87
Guizotia scabra	Asteraceae	Annual	0.00	95.00	72.00	43.8	52.00	0.00	33.00	43.12	12.80	14.86	0.00	7.21	7.51	3.75	4.16
Lantana camara	Verbenaceae	Perennial	36.00	0.00	0.00	0.00	44.00	4.60	0.00	0.00	0.00	7.00	2.18	0.00	0.00	0.00	1.96
Leucus mertinicensis	Lamiaceae	Annual	0.00	0.00	56.00	0.00	0.00	0.00	0.00	27.00	0.00	0.00	0.00	0.00	6.84	0.00	0.00
Medicago polymorpha	Fabaceae	Annual	24.00	0.00	0.00	9.20	2.17	2.17	0.00	0.00	2.12	3.20	1.03	0.00	0.00	0.72	0.90
Nicandra physalodes	Solanaceae	Annual	0.00	55.00	0.00	0.00	0.00	0.00	9.00	0.00	0.00	0.00	0.00	1.97	0.00	0.00	0.00

Note: RS-roadside; CF-crop field; FL-fallow land; GL-grazing land; RA-residential area; CRV-central rift valley

Appendix 1. Continued

Weed species	Family	Growth form	Frequency					Abundance					Dominance				
			RS	CF	FL	GL	RA	RS	CF	FL	GL	RA	RS	CF	FL	GL	RA
Parthenium hysterophorus	Asteraceae	Annual	86.00	45.00	62.00	52.00	38.80	38.80	27.00	44.80	33.80	20.60	18.37	5.90	11.34	11.42	5.77
Plantago leoncelata	Plantaginaceae	Perennial	0.00	0.00	65.00	0.00	0.00	0.00	0.00	7.60	0.00	0.00	0.00	0.00	1.66	0.00	0.00
Portulaca oleracea	Portulacaceae	Annual	0.00	45.00	38.00	28.00	0.00	0.00	21.00	22.00	5.00	4.30	0.00	4.59	5.57	1.69	1.20
Prosopis juliflora	Fabaceae	Perennial	12.00	0.00	0.00	0.00	4.00	4.00	0.00	0.00	0.00	0.00	1.89	0.00	0.00	0.00	0.00
Ricinus communis	Euphorbiaceae	Perennial	0.00	0.00	0.00	0.00	33.68	0.00	0.00	0.00	0.00	11.20	0.00	0.00	0.00	0.00	3.14
Rumex abvssinicus	Polygonaceae	Perennial	0.00	0.00	10.00	17.68	0.00	0.00	0.00	3.00	2.40	3.80	0.00	0.00	0.66	0.81	1.06
Senna didimobotriya	Fabaceae	Perennial	38.00	0.00	0.00	53.44	5.00	5.00	0.00	0.00	0.00	13.60	2.37	0.00	0.00	0.00	3.81
Senna ocidentalis	Fabaceae	Perennial	44.00	0.00	28.00	0.00	4.80	4.80	0.00	7.00	0.00	0.00	2.27	0.00	1.77	0.00	0.00
Setaria pumila	Poaceae	Annual	0.00	0.00	52.00	21.32	0.00	0.00	0.00	26.80	16.20	22.00	0.00	0.00	6.79	5.48	6.16
Setaria verticillata	Poaceae	Annual	0.00	0.00	56.00	12.00	0.00	0.00	0.00	25.40	16.00	23.20	0.00	0.00	6.43	5.41	6.50
Sorghum arundianaeeum	Poaceae	Annual	0.00	45.00	28.00	0.00	0.00	0.00	17.00	17.00	0.00	0.00	0.00	3.71	3.71	0.00	0.00
Verbesina encelioides	Asteraceae	Annual	92.00	23.56	64.00	92.00	53.47	53.47	14.13	25.49	34.20	43.12	25.52	2.77	16.32	14.37	13.60
Xanthium spinosum	Asteraceae	Perennial	36.00	0.00	64.00	54.56	12.24	12.24	0.00	14.67	1.80	2.43	5.79	0.00	3.71	0.61	0.68
Xanthium strumariam	Asteraceae	Annual	72.00	45.00	96.00	42.00	19.00	19.00	13.80	22.00	16.80	6.78	8.99	3.02	5.57	5.68	1.90

Note: RS-roadside; CF-crop field; FL-fallow land; GL-grazing land; RA-residential area