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Weed dynamic and community structure under different planting pattern and planting dates of cauliflower-lettuce intercropping system

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ABSTRACT

The aim of this work is to study the effect of intercropping cauliflowers (*Brassica oleracea var. Botrytis*) with lettuces (*Lactuca sativa L.*) on weed population and biomass, weed diversity and evenness. The experiment was carried out at two planting dates (date 1: the two crops were transplanted in the same day, date 2: lettuces were transplanted after two weeks of cauliflowers planting). Five patterns were designed for each date, P1: sole cauliflowers, P2: sole lettuces, P3: 50% cauliflowers, 50% lettuces, P4: 70% cauliflowers, 30% lettuces and P5: 30% cauliflowers, 70% lettuces. The weed population and dry weight were recorded at crop harvest and assessment was carried out with ecological indicators based on species richness, Shannon's diversity and evenness. Results have shown that minimum values of weed dry weight were noted at date 1, especially in patterns P3 (172.29 g/m^2) and P4 (193.86 g/m^2). In all planting patterns, species richness was greater in date 2 as compared with date1. Shannon's diversity and evenness were recorded to be better in intercropping patterns cropped in date1. Greatest values were obtained in planting pattern P3 for both years of experimentation. For weed smothering efficiency (WSE) and land equivalent ratio (LER), the highest values of WSE were obtained in planting pattern P3 (38.5%) followed by planting pattern P4 (31%) where lettuces were cropped simultaneously with cauliflowers (Date 1). P4 and P3 were more productive, values of LER were highest in P4 (1.38) followed by P3 (1.2) as compared with monocropping patterns and highest in date1 as compared with date 2. Results show that intercropping cauliflower and lettuce offer best reductions of weed density and biomass and preserve or ameliorate weed diversity, if they are cropped simultaneously in the same proportions or in patterns where cauliflowers have greater proportions than lettuces (70% cauliflowers and 30% lettuces).

Key words: *Brassica oleracea var.Botrytis.*, intercropping, weed smothering efficiency, species richness, Shannon's diversity and Shannon's evenness.

1. Introduction

The role of weeds in agro-ecosystems has been largely debated because of both their potential delivery of ecosystem goods and services and the competition between weeds and crops. Weeds are at the basis of the food web of agroecosystems. This notion implies numerous interactions with other organisms such as earthworms, arthropods, farmland birds and mammals [47]. In addition, arable weeds not only offer ecological and agronomical services, but they also have conservational and aesthetic values [16]. However, recent research has shown a severe decline in weed abundance and diversity as well as changes in weed species composition due to the intensification of agricultural practices of the last decades [15]. These intensified practices might negatively affect the food web interactions and, in turn, the ecosystem services. However, weeds are often recognized as a major constraint for crop production [36] because they use part of the resources that are essential for crop growth. In many situations, they lead to higher economical losses when compared to other pests, such as insects or fungi [43]. Therefore, weed control is considered as one of the crucial requisites for a successful production [20].

To date, weed management is primarily focused on curative control, as herbicides are highly effective and relatively cheap [41]. However, increasing concerns regarding the negative side effects of herbicides on the environment [9] and the growing interest in organic agriculture have, however, led to a growing demand for alternative weed control measures [5].

The negative side effects related to the use of chemical herbicides has led to stricter legislations and resulted in a decreased number of available herbicides. The intensive use of a limited number of herbicides creates a situation where herbicide resistance is more likely to develop [25] and has been identified as one of the main drivers of the current weed diversity decline in agroecosystems [32]. This is another reason why there is an increasing need for knowledge on the design and functioning of cropping systems that rely to a lesser extent on chemical inputs. Numerous studies have shown that to maintain a well functioning ecosystem, a sufficiently diverse system is needed ([11]; [57]). One method for enhancing species diversity is mixed cropping or the addition of a companion crop to the main crop. Mixed cropping or intercropping is widely practiced by small-scale farmers in developing countries for a variety of reasons. There are numerous examples that show the positive effect of intercropping on weed control ([6]; [46]; [51]), a reduced risk of complete crop failure, an increased yield level through a better exploitation of light, nutrients and water following from

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niche differentiation of the two crops ([37]; [39]) and an improved control of pests and diseases [61] are some of these reasons. Another alternative is a more systems-oriented approach, in which the design or the management of a cropping system is adjusted such that weed populations are kept at relatively low levels and the negative impact of weeds on crop production is minimized [3]. Accordingly, one of the current challenges that farmers face is the reduction of crop yield loss due to the weed–crop competition while preserving the weed flora. Here, we aimed to assess the effects of weed control on weed flora and on prevention of yield losses. Hence, the purpose of this experiment is to use a cauliflower-lettuce intercrop as a model system for examining how weed community structure changes with patterns of planting main crop (cauliflower) and intercrop (lettuce) and with the date of transplanting of intercrop. The composition of the weed flora in intercrops was compared with the weed flora of the respective sole crops. The research thus considered plant interactions and community ecology in the context of an agricultural crop system. Specifically, this experiment had three specific goals: (1) to determine if weed suppression was greater in intercropping compared with monocultures; (2) to investigate the community structure of the weeds in the different intercropping systems and to compare it with that in sole cropping; and (3) to determine if dates of transplanting intercrops affect the outcome of the interactions between weeds and crops.

2. Materials and methods

2.1 Experimental site

Field studies were conducted in 2012-2014 at the Higher Agronomic Institute of Chott-Mariem-Sousse (Latitude 35°55N, altitude 15 m). In the study area, the climate is typically Mediterranean with hot-dry summers and mild-rainy winters. According to long term weather data (1973-2006), maximum monthly temperatures ranged between 16 and 31 °C and minimum monthly temperature varied from 7 to 21 °C. Mean relative humidity varied from 69% to 71%. Monthly rainfall ranged between 2 and 58 mm [8]..

2.2. Field experiments and experimental design

A field test, conducted in row intercropping (alternate rows) between cauliflowers and lettuces, was followed to study the performance of sole and inter-crop of lettuces with cauliflowers in 1:1 (One row of cauliflowers and one row of lettuces), 2:1 (Two rows of cauliflowers and one row of lettuces) and 1:2 (One row of cauliflowers and two rows of lettuces) on weed dynamics

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and community structure. The experiment was carried out at two planting dates and five patterns during two consecutive years (2013 and 2014). It was set up as a split plot design with plots in factorial arrangement. The whole plots (12 m × 5 m) are the date of planting lettuces with two levels (date 1: lettuce transplanted at the same day of cauliflower planting and date 2: lettuces were transplanted after two weeks of cauliflower planting) and split plots (3 m × 2 m) are patterns of planting with five levels; P1: sole cauliflowers (100% cauliflowers) , P2: sole lettuce (100% lettuces), P3: one row of cauliflowers and one row of lettuces (50% cauliflowers and 50% lettuces), P4: Two rows of cauliflowers and one row of lettuces (70% cauliflowers and 30% lettuces), P5: One row of cauliflowers and two rows of lettuces (30% cauliflowers and 70% lettuces). The experiment occupied a total area of 450 m^2.

2.3. Cultural practices

Land preparation was carried out by tractor ploughing followed by harrowing. Planting of cauliflowers and lettuces seedlings (planted at the same day: date1) took place on 19 and 18 November 2012 and 2013, respectively. Transplanting of the rest of lettuces seedlings (date 2) took place on 04 and 03 December 2012 and 2013, respectively. The crops were raised with the recommended cultural practices and uniform plant stand was maintained, however, no chemical weed control procedure was used; only one hand weeding operation was done for all plots after one month from first planting date at both years of experimentation. Harvesting was done on 04 and 03 March 2013 and 2014, respectively

2.4. Indices to measure the weed community structure

2.4.1. Weed density and dry weight

Data pertaining to weed population and dry matter were recorded at crop harvest. Weeds were sampled from three 0.5 m^2 quadrate placed on the diagonal of each subplot. Aboveground weed biomass were collected, identified and counted, then oven-dried at 70 $^{\circ}$C temperature to a constant weight to record weed dry weight. Stem counts replaced plant counts for perennial monocots. Values obtained (means of three quadrates) were transformed per area unit for density (numbers/m^2) and for biomass (g/m^2).

2.4.2. Weed diversity

Species diversity consists of two related components viz., species richness (number of species present) and relative abundances of different species or equitability. A diversity index is a mathematical measure of species diversity in a community. Diversity indices provide more information about community composition than simply species richness. These indices reveal important information about rarity and commonness of species in a community [7].

Weed diversity was measured using weed species richness S, Shannon-Weiner diversity and evenness indices.

2.4.3. Species richness (S)

The species richness (S) is simply the number of species present in an ecosystem/community [31]. This index is the oldest and simplest measure of species diversity and makes no use of relative abundances.

2.4.4. Shannon-Weiner index (H')

A diversity index is a measure intended to understand the variety of individuals of a given population, thus allowing inferences about a particular plant community in terms of both the number of species found and the balance in the number of individuals per species [4] with a higher value of H' signifying greater diversity.

Shannon-Weiner diversity index H' is calculated for each sub-plot following [31] and [19]:

$$H' = -\text{Sum}\ PA_i\ (\ln PA_i) \quad (1)$$

Where PA_i is the proportional abundance of weed species i ($PA_i = n_i / n_{tot}$), n_i= the biomass of individuals of the i^{th} species and n_{tot} = the total biomass of individuals and S is the number of species by plot (species richness).

2.4.5. Evenness index (E)

Evenness index E, giving the distribution of individuals among the species [50], with greater value indicating greater uniformity between the species abundance, is reported by [18]:

$$E = H' / \ln S \quad (2)$$

Calculations of proportional abundance, Shannon's diversity and evenness were based on specific biomass data for each sampling quadrate, considering biomass as the most appropriate estimate of species abundance to make ecological inferences and interpretations about species evenness in plant communities [22].

2.4.6. Land equivalent ratio (LER)

It denotes relative land area under sole crop required to produce the same yield as obtained under a mixed or an intercropping system at the same level of management. It is the equivalent amount of land needed to produce the combined intercrop yield for crops grown in monoculture [34].

The land equivalent ratio (LER) was estimated through the following relationship [59]:

$$LER = (LERa + LERb) = (Y_{ab}/Y_{aa}) + (Y_{ba}/Y_{bb}) \qquad (3)$$

Where *LERa* and *LERb* are the partial LER of cauliflowers and lettuces, respectively, and

Y_{ab} = Yield of cauliflowers under intercropping conditions

Y_{ba} = Yield of lettuces under intercropping conditions

Y_{aa} = Yield of cauliflowers under sole crop conditions

Y_{bb} = Yield of lettuces under sole crop conditions

2.4.7. Weed smothering efficiency (WSE)

Weed smothering efficiency can be defined as follows [24]:

$$WSE = (W1 - W2) / W1 \times 100 \qquad (4)$$

Where,

W1: Weed population/biomass in sole cauliflowers

W2: Weed population/biomass in intercropping system

2.5. Statistical analysis

Data were analyzed by ANOVA (IBM SPSS Statistics version 20) for split-plot design. The analysis of the weed density, weed biomass, Shannon diversity and Shannon evenness data was performed separately for each date. The treatment and interaction at least significant differences (LSD) of the means were used to separate treatment means at 5% level of significance.

3. Results

3.1. Weed density and biomass

Weed density and biomass varied greatly over the year, it was higher in 2012-13 than 2013-14 in all planting patterns (Fig.1).

Monocropped cauliflower had significantly less weed density and dry matter as compared to monocropped lettuce (Fig. 1). In the first year of experimentation (2013), weed density and biomass in sole lettuce plots were higher about of 90 seedling/m^2 and 13g/m^2 in date 1 and 44 seedling/m^2 and 160g/m^2 in date 2 as compared to sole cauliflower plots. The corresponding values were 54 seedling/m^2 and 77g/m^2 in date 1 and 87seedling/m^2 and 119g/m^2 in date 2, respectively in the second year of experimentation (2014).

There was significant reduction of weed density and weed biomass under intercropping cauliflower-lettuce system at both planting dates as compared to monocropping of cauliflower or lettuce at both years of experimentation. Planting pattern P3 was recorded the best in reduction of weed density and weed biomass as compared to planting patterns P4 and P5. In 2013, lowest values of weed density (136 seedling/m^2) and weed dry weight (172g/m^2) were recorded in intercropped 50% cauliflowers and 50% lettuces (P3) cropped in the same day (date1). Same results were obtained in the second year; corresponding values were 112 seedling/m^2 and 171g/m^2. Whereas, highest weed density (296 seedling/m^2 and 216 seedling/m^2, respectively in 2013 and 2014) and weed dry weight (328g/m^2 and 270g/m^2) were recorded in planting pattern P5 (30% cauliflower and 70% lettuce) where lettuces were transplanted after 15 days of cauliflowers planting (date 2) (Fig. 1).

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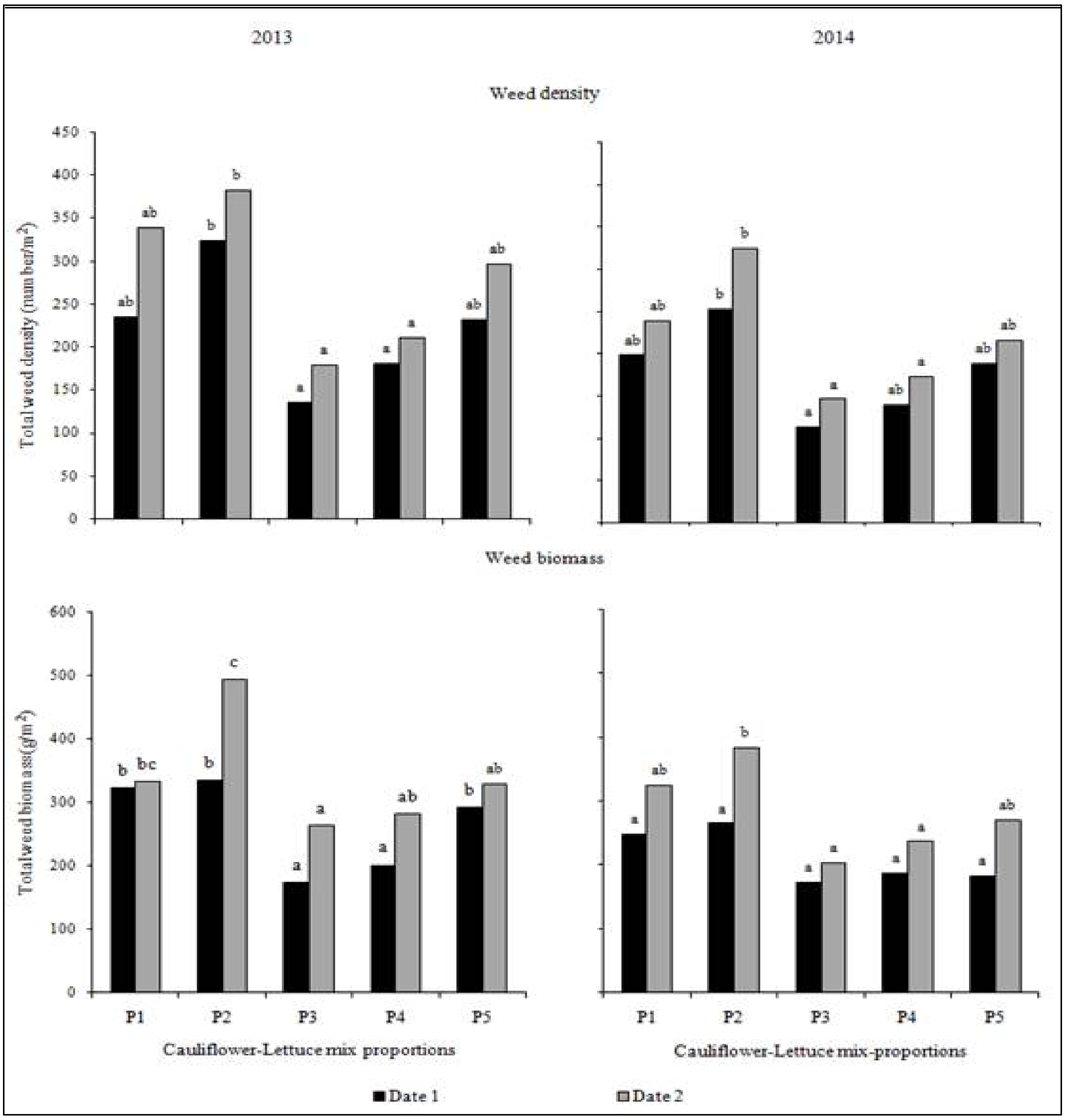

Figure 1: Weeds density and biomass for sole stands and intercrop of cauliflower with lettuce in three planting pattern and two planting dates in 2013 and 2014. *Date* 1: Cauliflower and lettuce planted in the same date, Date 2: Lettuce planted after two weeks of cauliflower planting, P1: sole cauliflower, P2: sole lettuce, P3: 50% cauliflower; 50% lettuce, P4: 70% cauliflower; 30% lettuce, P5: 30% cauliflower; 70% lettuce. Values (N=3±S.E.). Different letters on columns indicate significant differences among treatments at P<0.05 (LSD test).

For all intercropping planting patterns and for both years of experimentation, weed density and weed dry weight were proved higher in date 2 as compared with date 1. Means of increasing (means of two years) of weed density and weed dry weight in date 2 as comparing with date1 were (38 seedling/m^2 and 61 g/m^2), (32 seedling/m^2 and 65 g/m^2) and (45 seedling/m^2 and 63 g/m^2), respectively in P3, P4 and P5 (Fig. 1).

3.2. Weed diversity and evenness

The species richness (S), Shannon's diversity (H') and Shannon's evenness (E) varied between planting patterns and in all cases; they were greater in intercrops as compared with their sole crops (Fig.2).

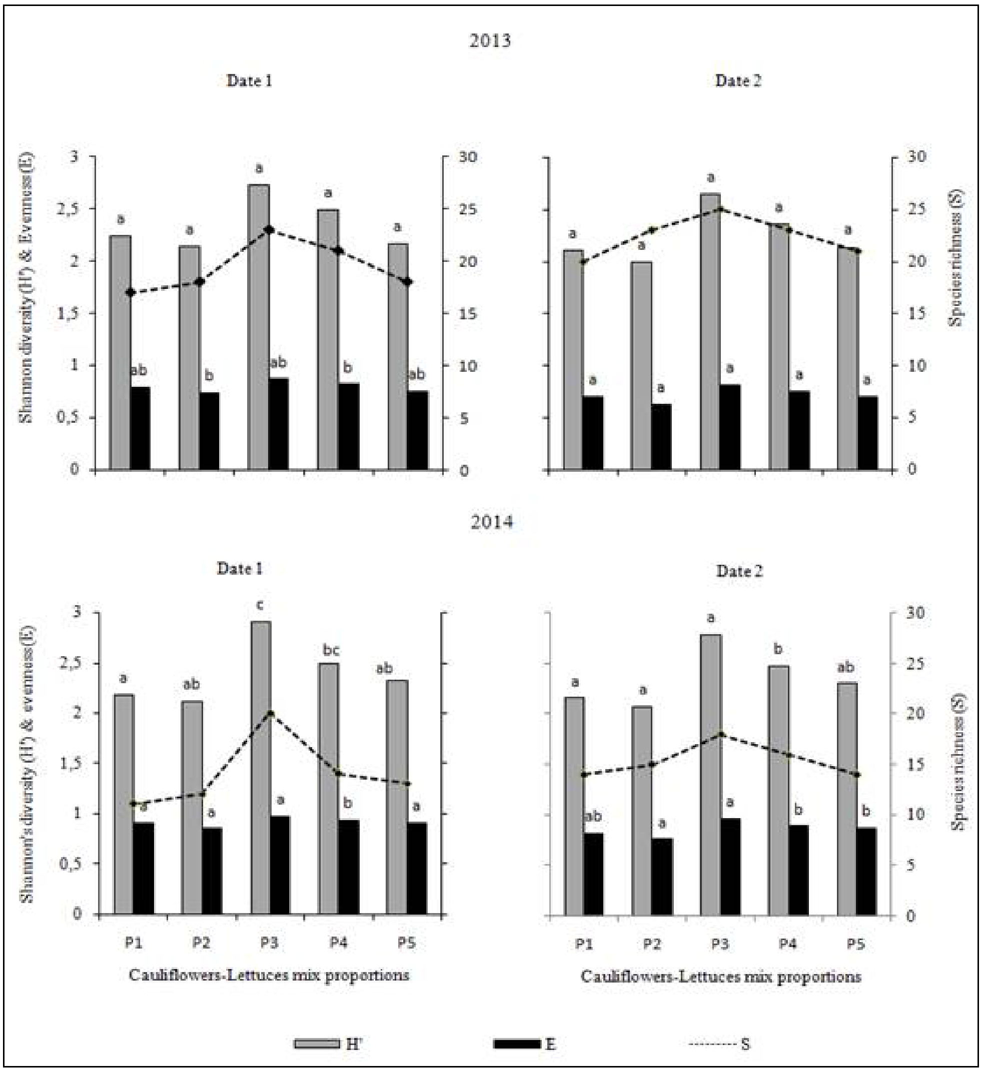

Figure 2: Richness (S), diversity (H') and evenness (E) for weed species present in sole stands and intercrop of cauliflower with lettuce in three planting patterns and two planting dates in 2013 and 2014. Date 1: Cauliflower and lettuce planted in the same date, Date 2: Lettuce planted after two weeks of cauliflower planting, P1: Sole cauliflower, P2: Sole lettuce, P3: 50% cauliflower; 50% lettuce, P4: 70% cauliflower; 30% lettuce, P5: 30% cauliflower; 70% lettuce. Values (N=3±S.E.). Different letters on columns indicate significant differences among treatments at $P<0.05$ (LSD test).

Highest values of species richness, Shannon's diversity and evenness were recorded in planting pattern P3 (Corresponding values were 23, 2.73 and 0.87, respectively in 2013 and 20, 2.91 and 0.97, respectively in 2014) followed by planting pattern P4 (Corresponding values were 21, 2.5 and 0.82, respectively in 2013 and 14, 2.49 and 0.94, respectively in 2014) in plots where cauliflowers and lettuces were cropped at the same date (date1).

When comparing Shannon's diversity (H') and evenness (E) between sole cauliflowers (P1) and sole lettuces (P2), generally for both dates and both years of experimentation, H' and E were greater in P1. In 2013, values of H' were 2.24 vs. 2.14 and those of evenness were 0.79 vs. 0.74, respectively in P1 and P2. Corresponding values recorded in 2014 were 2.18 vs. 2.12 for H' and 0.91 vs. 0.85 for E, respectively in P1 and P2 (Fig. 2).

Species richness recorded in monocropping (P1 and P2) plots and intercropping (P1, P2 and P3) plots cropped in date 2, were greater than species richness obtained in date 1 for both years of experimentation. Accordingly, values recorded in 2013 were 20 vz. 17 in P1, 23 vz. 18 in P2, 25 vz. 23 in P3, 23 vz. 21 in P4 and 21 vz. 18 in P5, respectively in date 2 and date1. Corresponding values obtained in 2014 were 14 vz. 11 in P1, 15 vz. 12 in P2, 20 vz. 18 in P3, 16 vz. 14 in P4 and 14 vz. 13 in P5 (Fig. 2).

3.3. Weed smothering efficiency

Values of weed smothering efficiency were under zero in planting pattern P2, indeed, weed density and biomass were greater in P2 than those in P1 (Table1).

Table1. Weed smothering efficiency (WSE) based on weed biomass and density over sole cauliflower in sole cauliflower and sole lettuce and intercropping cauliflower-lettuce in 2013 and 2014

	WSE(%) biomass				WSE(%) density			
	2013		2014		2013		2014	
	Date1	Date2	Date1	Date2	Date1	Date2	Date1	Date2
P1	0	0	0	0	0	0	0	0
P2	-3.77	-48.3	-7.13	-18.14	-38.07	-12.99	-27.6	-36.18
P3	46.31	21.03	30.46	37.3	42.04	47.25	43.1	38.83
P4	37.6	15.64	24.34	27.17	23.29	37.8	29.8	27.65
P5	9.26	1.25	26.19	16.65	1.13	12.6	4.88	9.49

Date 1: Cauliflower and lettuce planted in the same date, Date 2: Lettuce planted after two weeks of cauliflower planting, P1: Sole cauliflower, P2: Sole lettuce, P3: 50% cauliflower; 50% lettuce, P4: 70% cauliflower; 30% lettuce, P5: 30% cauliflower; 70% lettuce

Greatest weed smothering efficiency was obtained in planting pattern P3; mean values (means of years) of weed density declined by 42.57% and 43.04%, respectively in date1 and date2. Corresponding values of weed biomass were declined by 38.4% and 29.16%. P4 has demonstrated higher weed smothering efficiency compared to P5, mean values (means of years) of weed smothering efficiency based on weed density were 26.54% vs. 3% in date 1 and 30.97% vs. 17.72% in date 2, respectively in P4 and P5. Corresponding values of weed smothering efficiency based on weed biomass were 32.72% vs. 11% in date1 and 21.40% vs. 8.95% in date 2 (Table1).

3.4. Land-equivalent ratio

The land equivalent ratio values (Table 2) for all the intercropped patterns were greater than unity for both dates of plantation and for both years of experimentation. Maximum means (means of years) of land equivalent ratio (1.38 and 1.31) were recorded under cauliflowers-lettuces 70-30% mix proportions (P4), respectively in date1 and date 2 followed by cauliflowers-lettuces 50-50% mix proportions (1.2 in date1 and 1.11 in date2). This indicates that both systems as a whole were more productive, giving means (means of dates) of 34.5% and 15.5% of yield increase respectively in P4 and P3.

For all intercropping patterns, Land equivalent ratio was greater when cauliflowers and lettuces were cropped simultaneously (date 1) giving a means (means of years) of yield improvement about of 9.5%, 7% and 8%, respectively in P3, P4 and P5.

Table 2. Land equivalent ratio (LER) in sole cauliflower and sole lettuce and intercropping cauliflower-lettuce in 2013 and 2014

	2013		2014	
	Date 1	Date 2	Date 1	Date 2
P1 : Sole cauliflower	1	1	1	1
P2 : Sole lettuce	1	1	1	1
P3 : 50% cauliflower, 50% lettuce	1.19	1.11	1.21	1.1
P4 : 70% cauliflower, 30% lettuce	1.39	1.36	1.37	1.26
P5 : 30% cauliflower, 70% lettuce	1.18	1.15	1.16	1.03

Date 1: Cauliflower and lettuce planted in the same date, Date 2: Lettuce planted after two weeks of cauliflower planting

4. Discussion

4.1 Weed density and dry matter

For both years of experimentation, intercropping system (P3, P4 and P5) significantly reduced the weed population and biomass as compared to the monocropping for both dates of planting. Yih [60] and Liebman and Dyck [29] reported that weed density and dry weight decreased in intercropping system comparing to sole cropping and this may be due to the weed suppressing ability of intercropping over monocropping. They affirm also that intercrops may demonstrate advantages on weed control over sole crops both by producing greater crop yield and less weed growth through usurping resources from weeds and also by suppressing weed growth through allelopathy. Moreover, less weed biomass production and weed density under intercropping system is due to higher inter-specific competition combined with complementarity between intercrop species that improve the crop stand competitive ability towards weeds [42].

The lower weed density in sole cauliflower culture compared to sole lettuce culture, might be due (i) to the higher performance of cauliflower in the competition with weeds, in fact lettuces grow quickly from transplanting to harvest, but does not reach canopy closure across the whole planting bed due to the small size of the mature plants and planting densities commonly used [56] and are poor competitors and vulnerable to inundation by weeds or (ii) to better weed smothering efficiency of *Brassica* crops ([1], [44], [49]). In crops, the smothering effect of one plant on another is mainly due to interference i.e. competitive and allelopathic interactions. The crop competition may not provide complete weed control but minimizes the weed growth and density through the smothering effect. While on the other hand, allelopathy exerts considerable inhibitory effect on the germination and growth of weeds [58]. According to this affirmation and to the important reductions in weed biomass and density obtained with cauliflowers plots as compared with lettuces plots, the smothering effect should be due to allelopathic potential of these crops more than to competitive interactions. This findings were supported by [48]; [23]; [33] who affirm that *Brassica* species are promising cover crops in agricultural systems because, in addition to their general role as cover crops, they produce chemicals with activity on a broad range of soil-borne pests and diseases. Oleszek et al. [44] in their review have determined the smothering effect of three *Brassica* spp. viz. *B. juncea*, *B. napus* and *B. carinata* accession on the weed spp. and the genus *Brassica* was reported to have allelopathic properties that can affect germination, establishment and growth of other species in agroecosystems ([30]; [26]) throw the complex of glucosinolates and their derivatives common to this genus ([10]; [13]; [14]; [12]).

For sole and intercropping planting patterns, highest weed density and dry weight were achieved in date 2 (transplanting lettuce after 2 weeks of planting cauliflower), this might be to allowing weeds to have open niches for their growth. Liebman and Davis [28] affirmed that for most weeds of vegetables and other annual cropping systems, any space or time in which the soil has been recently disturbed or is open and uncovered by other vegetation constitutes a suitable niche for weed growth. Thus, a key step in ecological weed management is to reduce the number and size of these weeds niches in the cropping system.

4.2 Weed species richness, diversity and evenness

Species richness, diversity and evenness were found to be greater in intercropping planting patterns as compared with their sole patterns for both years of experimentation and both planting dates. These results are similar to those obtained by [53] who have studied the effect of intercropping baby corn with legumes on weed dynamics and community structure and have found that intercrops suppress weeds growth and population more than their respective sole crops, but weed diversity and evenness were higher in intercropping systems. These preliminary results allows us to confirm the hypothesis raised by [45] who have demonstrated, in an experimental agroecosystem, that the initial richness of crop species was positively related to the richness of weed species that eventually emerged. The authors speculated that the enhanced richness might be due to some complex interaction among crop species. Other authors ([17]; [21]; [27]) have also found that the initial richness and/or species combinations affect the nature and number of other species that colonize.

While, when comparing weed flora in different planting patterns based on relative proportion of cauliflowers we found that weeds in the cauliflower monoculture plots (Planting pattern P1) had a higher evenness index than when cauliflower was absent (lettuces plots: P2). Moreover, values of species richness, Shannon diversity and evenness obtained in planting patterns where cauliflowers proportions were equally or more presented than lettuces proportions (Planting patterns P3 and P4), were higher as compared with those obtained in planting patterns P5. So, increasing the proportion of cauliflowers increased weed diversity and evenness, while increasing the proportion of lettuces increased the dominance of a small number of weed species, and hence decreased species diversity. Accordingly, these observations suggest reduced vigor and competitive ability of the dominant weeds in the presence of cauliflowers. Same results were obtained by Shetty & Rao [54], who observed a change in the weed species composition in a groundnut pearlmillet intercrop that depended on the relative proportions of the two crop species. They also found that increasing the proportion of millet increased weed species richness, while increasing the proportion of groundnut increased the dominance of a small number of weed species, and hence decreased species diversity. These results strongly suggest that shifts in weed floristic due to intercropping might be predicted from knowledge of weed community composition in sole crops of the components. Mohler and Liebman [38] grew barley and pea sole crops and intercrops in two experiments and observed that as total crop seed production increased, there were decreases in both total weed biomass and the relative importance of the dominant weed species. The authors found that the relative abundances of the different weed species were most even in sole-cropped barley, intermediate in the intercrop, and least even in sole-cropped pea.

These researchers concluded that shifts in the composition of the weed community were dependent on the competitive dominance of the crop or crops planted not on the diversity of the cropping system (as supported by [45]).

Values of species richness obtained in date 2 were higher as compared with values recorded in date 1, in all planting patterns and for both years of experimentation, however, evenness values were unlike greater in date 1 than date 2. This might be explained by the elimination of less competitive weed species generated by the simultaneous presence of the main crops (cauliflowers) with intercrops (lettuces) in plots cropped in date 1. Less competitive weeds took advantages from the lag time, for which lettuces would be cropped after two weeks, to emerge and grow in opened niches and hence, evenness decreased ([21]).

4.3 Weed control efficiency

Weed-control efficiency of these intercropping systems (P3 and P4) was also higher as compared with other intercropping combinations (P5). This may be attributed to relatively less space available for the growth of the weeds from the early stage of crop growth and more shading effect due to lateral growth of cauliflowers plants between two rows of lettuces [55]. Maximum weed population and weed dry-biomass were recorded in all cauliflowers-lettuces planting patterns where lettuces transplanted after 15 days of planting cauliflowers seedlings (date 2). This might be due to slow initial growth of lettuces providing conductive conditions for growth of weeds.

4.4 Land Equivalent Ratio

The important reason to grow two or more crops together is the increase in productivity per unit of land [52]. Higher LER recorded in intercropping treatments indicated yield advantage over monocropping. In fact, intercrops may demonstrate advantages on weed control over sole crops both by producing greater crop yield due to better land utilization [35] and less weed growth through usurping resources from weeds [54] and also by suppressing weed growth through allelopathy [60]. Intercrops may also provide yield advantages without suppressing weed growth below levels observed in component monocrops by using resources that are not exploited by weeds and convert resources to harvestable materials more efficiently than monocrops [29]. In this case intercropping cauliflowers with lettuces has demonstrated better values of land equivalent ratio and better weed smothering efficiency as compared with their sole patterns.

Land equivalent ratio values obtained in plots where lettuces planted simultaneously with cauliflowers (date 1) were greater than those in plots were lettuces transplanted after 15 days of cauliflowers transplanting in date 2 for all intercropping planting patterns. These results agree with those obtained by [40] who found that planting cowpea simultaneously with maize gave better yield. Also, Amede and Nigatu [2] stated that simultaneously planting maize and sweet potato not influenced maize grain yields, whereas late planting of sweet potato negatively affects maize yield. This was possible due to greater temporal, spatial, and physiological complementarity in resource use among component crops which can lead intercrops to capture more nutrients, water, and light than sole crops [29].

5. Conclusion

Species diversity of weed community was directly related to crop relative proportions and planting date of companion crop. Species number and evenness increased in intercropping systems than their respective sole cropping systems. Evenness of weed communities was changed by the crop presence in two ways. Firstly, crop(s) reduced the abundance of the dominant weed species, which is shown by the difference among treatments. Secondly, presence of crop increased the equitability in the partitioning of the total biomass among the species in the community. Intercrop showed high reduction of dominant and rare weed species and biomass. Since, inter-specific competition coupled with complementarity increases crop stand ability to smother weeds, intercropping systems were found to be beneficial in terms of weed management and productivity. In the present work, intercropping of cauliflowers and lettuces cropped simultaneously in equally proportions (50% cauliflowers and 50% lettuces) or in patterns with best relative proportion for cauliflowers (70% cauliflowers and 30% lettuces) was found to be the most effective under experimental condition, for better land use efficiency, better smothering weeds and better weed diversity and evenness. Furthermore, it would be reasonable to expect that reduced abundance of some weed species by the suppressive effects of crop presence could also reduce their propagule production. Thus, the observed differences among treatments in their species diversity and seasonal composition may also be reflected, and even amplified, in the weed community structure of subsequent growing seasons. This could be used to define successional trajectories, by locally enhancing some species while excluding others. These findings have also interesting implications for developing cropping systems that are ecologically sound, especially when the aims are on reduction of agriculture pollution, as well as conservation and restoration of plant diversity. Thus, spatial and temporal design of cropping systems must be based on ecological and agronomical knowledge allowing suppressing weed growth and being the most cost-effective and environment-friendly methods for weed control.

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