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Research article

Organic farming practices increase weed density and diversity over conventional practices: A meta-analysis

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A R T I C L E I N F O

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A B S T R A C T

Population growth and climate change challenge our food and farming systems and provide arguments for an increased intensification of agriculture. Organic farming has been seen as a promising option due to its eco-friendly approaches during production. However, weeds are regarded as the major hindrance to effective crop production which varies depending on the type of crop and spacing. Their presence leads to reduced yield, increase in harvest cost and lower the qualities of some produce. Thus, weed management is a key priority for successful crop production. Therefore, we conducted a meta-analysis from published studies to quantify possible differences on weed density, diversity and evenness in organic and conventional farming systems and best intervention for weed management in organic farming system. Data included were obtained from 32 studies where 31 studies with 410 observations were obtained for weed density, 15 studies with 168 observations for diversity, and 5 studies with 104 observations for evenness. Standard deviation of mean was obtained from the studies, log transformed using natural logarithms and the effect size pooled using standardized mean difference (SMD). Publication bias was determined through funnel plot. Results showed that organic farming has significant higher weed density *($P < 0.01$)*, diversity *($P = 0.01$)*, and evenness *($P < 0.05$)* compared to conventional farming. Despite so, diversified crop rotation has been proved to reduce weed density in organic farming by up to 49 % while maize-bean intercropping decrease densities of *Amaranthus* ssp, *Cyperus* ssp and C*ammelina* ssp compared with monocropping. Use of mulch after one hand weeding was found to control up to 98 % of weeds and use of cover crop between 24 % and 85 % depending on the type of the cover crop. The study results show that organic farming encourages high weed density, diversity and evenness but use of the integrated approaches can help to maintain weed density at a manageable level.

1. Introduction

Unlike most agricultural pests, weeds are present all year around in agricultural field and require some degree of management for optimum crop yields and profitability [1,2]. Weeds not only compete for nutrients, light, and water but acts as an alternative host for

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crop pests and diseases (nematodes, insects, pathogens) [3]. Their impact results in reduced crop yields, quality and increase in harvest costs [3–5]. The magnitude of loss varies by crop, weed species, location, and farming system [6,7].

Weed management remains a key priority to produce health crop and high yields [8]. Herbicides are central to the conventional approach in weed management, and this has allowed growers to reduce management priority, time, effort, and cost of managing weeds [1]. Their use has at times come with a price such as herbicide-resistant weeds, environmental damage, reduced water quality, and loss of genetic diversity [9]. Since 1960s, there have been a raise in environmental awareness on the side effect of synthetic herbicide, pesticide, and fertilizer as well as consumers concern on food consumption with unacceptable levels of pesticide and herbicide [10]. As a result of this, demand for organic food to safeguard consumer health and the environment has risen [11].

Despite the high demand for organic products, conversion to organic farming is associated with challenges of weeds, pests, and disease management with no use of chemicals [12,13]. Weed management is a major barrier for conversion to organic farming by many farmers [14,15]. Organic farmers struggle to get the most effective, economic, and non-chemical weed control methods that they can embrace when dealing with weed management [16]. The management practice used should not compromise the standard requirements for organic produce [11].

Although growers use a combination of management practices to control weeds, differences between practices used in conventional farming compared to organic farming often vary widely in their implementation and relative importance [1]. Approaches to weed management within an organic system revolve around implementing a range of techniques, often consecutively over the course of the cropping season [17]. These management practices contribute to the variation of weed seeds in the soil which determines composition and density of the weeds [18]. Apart from the management practices, weed seed can get to the agricultural land by either wind, importation from other farms during ploughing or harrowing, use of irrigation water carrying weed seeds or use of animal manure containing weed seeds [16,19,20] (Fig. 1).

Composition of the weeds is highly influenced by the farming practices and activities carried out in the farm [21]. Unlike conventional farming systems that mostly rely on use of herbicide to control weed, organic farming systems rely on tillage, crop rotation, mulching, flaming and biological or mechanical weeding in weed management [13,22]. Organic farmers use animal manure, crop residues and organic fertilizers as their main fertility inputs [23,24]. Although organic fertilizer application aims at boosting crop growth, weeds also benefit from this application [25].

Reliance on non-chemical weed control methods in organic farming systems make it difficult to fully manage weeds [26]. It is always assumed that fields under organic farming systems have high weed density compared to those under conventional farming systems where there is use of herbicide that can almost clear any type of weed [27,28]. Even so, examining this in a wider geographical region can be more insightful with a review of the source of weeds into organic farming system explored. In this study, a meta-analysis to evaluate the proposition that organic farming generally results in an increase in weed density, diversity and evenness compared to conventional farming system will be used and the result linked to review on the management practices influencing weeds in organic farming systems.

A meta-analysis helps to analyze and synthesize the results of several independent studies in order to examine the question of concern [29–32]. The statistical procedure allows quantitative analyses of treatment effects, and accounts for the fact that all studies

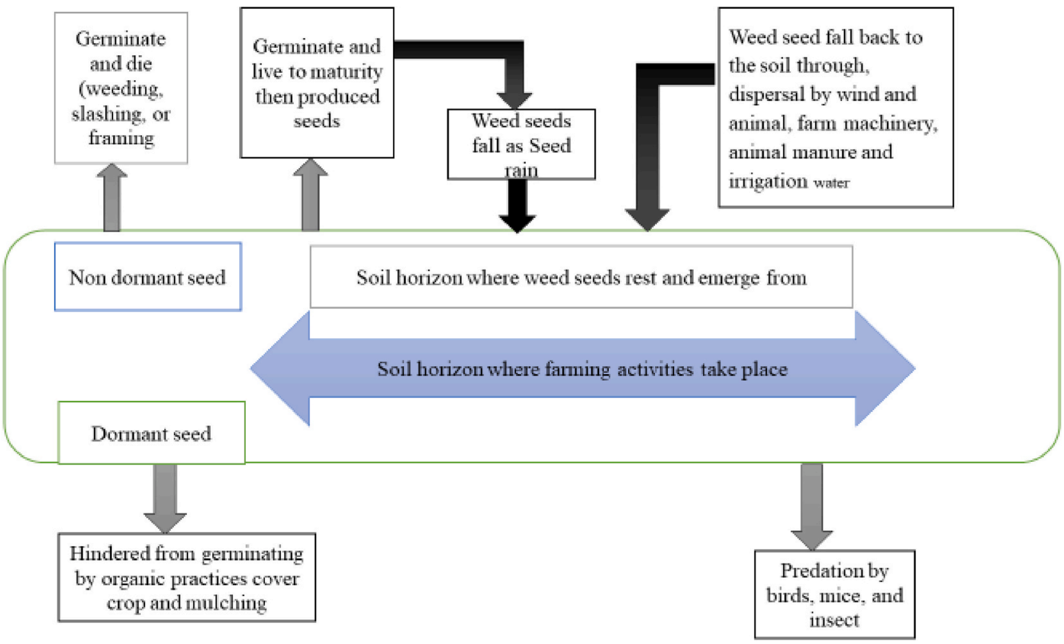

Fig. 1. A conceptual approach for the management practices and biotic and abiotic factors influencing weed seeds in organic farming system. Source (Author).

are not equally reliable. The objective of the study was to. i) Determine how organic farming practices influence weed density compared to conventional farming systems? ii) understand how organic farming practices influence weed diversity compared to conventional farming systems? iii) Find out how weed species evenness differ in organic and conventional farming system? In this case we hypothesized that organic farming systems have high weed density, weed diversity and evenness compared to conventional farming systems. From the meta-analysis we discussed practices that influence weeds in organic farming system.

2. Materials and methods

2.1. Material extraction

The meta-analysis focused on assessment of weed density, diversity and evenness in organic farming systems compared to conventional farming systems and the effective weed management practices that can be embraced by organic growers. Data compiled for the study had to show a comparison of weeds in organic and conventional farming systems. For organic farming, only those literatures where author defined as a farming system with no use of inorganic fertilizers, inorganic herbicides and pesticides were considered. Most of the articles used were those that showed more than 3 years' comparison of the two farming systems.

A comprehensive literature search was conducted to identify relevant studies. There was no restriction on the year of publication nor the geographical region for the literature. This was due to scarce literature on this type of comparison. To obtain the required literature information, the following search string was used in the web of science and google scholar: "(((((ALL=(organic farming)) OR ALL=(inorganic fertilizer, crop rotation, hand weeding, inter cropping, mulching, slashing, burning)) AND ALL=(conventional farming)) OR ALL= (synthetic fertilizer, mono cropping, mechanical weeding, herbicide)) AND ALL=(weeds)) OR ALL=(weed seedbank, density, diversity, composition)". The majority of publications retrieved from Google Scholar were consistent with those obtained from Web of Science, with the majority of publications originating from Web of Science.

The research was refined to the subject area's "agriculture", "plant sciences", "biodiversity conservation" and "environmental sciences & ecology". The document type was defined as "article". Search in the Web of Science resulted in 561 publications which were

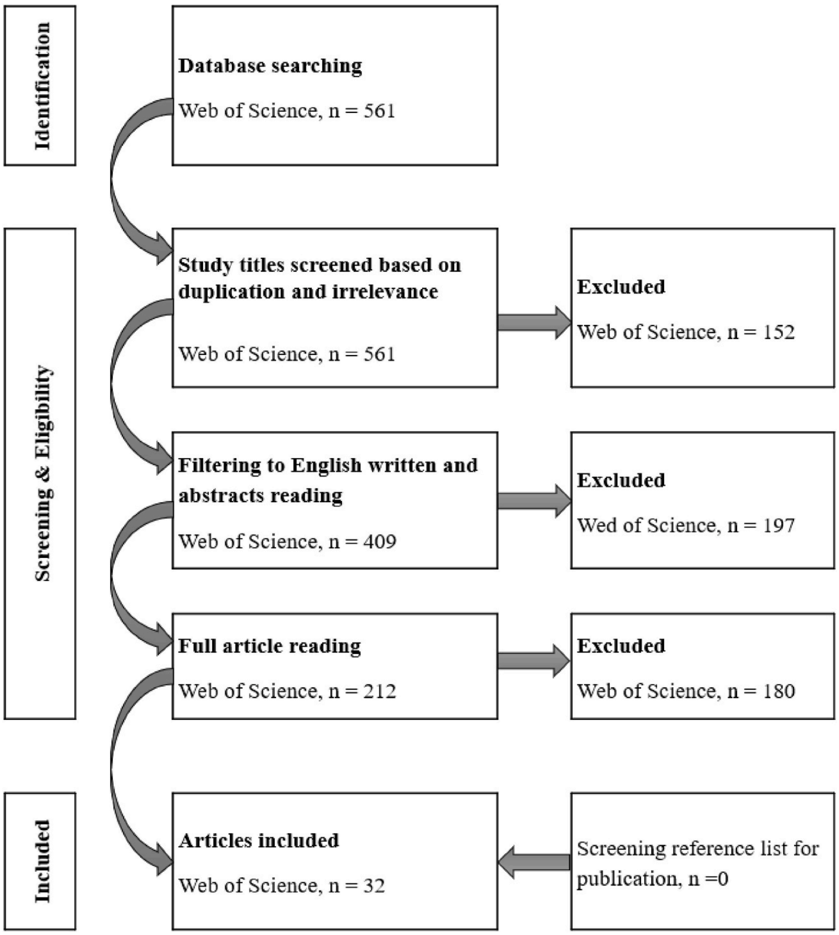

Fig. 2. PRISMA flowchart showing the systematic literature search and publication selection criteria.

reduced to 212 based on their titles and abstract relevance. Finally, the full papers were reviewed. The papers included in this study were selected based on the following criteria: i) the paper compared organic and conventional farming systems and provides a quantitative result at least in one of the following: weed density, weed diversity or evenness, ii) reported sample size and error iii) weed sampling done at the end of the cropping season and, iv) paper published in English. In the end, 32 publications comparing organic farming system verses conventional farming were obtained (Fig. 2).

The sample size *(n > 1)* was also tabulated from the information provided. These data were extracted directly from figures, tables or where values were reported within the text of the study. Data extracted as SE were converted into SDs using the following formulae $SE = SD/\sqrt{n}$.

2.1.1. PRISMA check list

This review adheres to the PRISMA guidelines.

2.2. Geographical distribution of the studies

There was no limitation on the geographical scope of the studies. Majority of the studies that met the inclusion and exclusion criteria were drawn from European nations, majorly from Germany, Poland and Finland with the list studies being carried out in Africa (Fig. 3). This agrees with [33]who also through a comparative meta-analysis for the biodiversity in organic farming verses conventional farming found that 80 % of the research work was done in Germany, 7 % in Asia, 6 % in North America, 5 % in Latin America and only less than 1 % in sub-Saharan Africa. This results from the high demand for organic produce in European nations, where one-quarter of the world's organic farmland is concentrated, and Germany stands as the largest market for organic produce [34].

2.3. Data analysis

From the 32 studies, the effect size of weed density, weed diversity and evenness were obtained. The difference between organic and conventional weed density, diversity and evenness was analyzed using RStudio where organic farming system was used as the main treatment and conventional farming system as a control. Before the analysis, the data were first standardized through natural log transformation.

To examine the publication bias, the funnel plot was generated using the package *meta* and function *funnel. meta*. Funnel plot assumes that studies with smaller sample size are more likely to be skewed, because they have lower statistical power. Studies in the top part of the plot (those with low standard errors), should lie closely together, and not far away from the pooled effect size. In the lower part of the plot, with increasing standard errors, the funnel "opens up," and effect sizes are expected to scatter more heavily to the left and right of the pooled effect.

Cochran's Q [35] and Higgins' I^2 were used to measure heterogeneity of the studies. Higgins' I^2 quantifies the percentage of heterogeneity [36] giving it a better interpretation. The significance of the Q statistics is based on the *p-value* of 0.1. If Q is significant, in between studies effect sizes is heterogeneous and differed among the included studies. Uncertainty in the study was quantified using 95 % confidence intervals (CI).

From the *"meta"* package, the function *"metacont"* which uses inverse variance method weighting on pooling effect size was used. The summary measure used to pool the effect size was standardized mean difference (SMD) [37,38]. Standardized mean difference and the standard deviation (SD) were used to measure the weight of the effect size. Restricted maximum-likelihood estimation (REML) method was used to estimate effects between study variance τ^2 (tau). This is represented by the variance of the distribution of the true study effects under assumption that the true effect size is normally distributed. The effect size of the sub-groups i.e., weed density, weed diversity and evenness was pooled separately.

In the forest plot, the central line signifies the null effect. A point on the negative side denotes a statistically significant negative

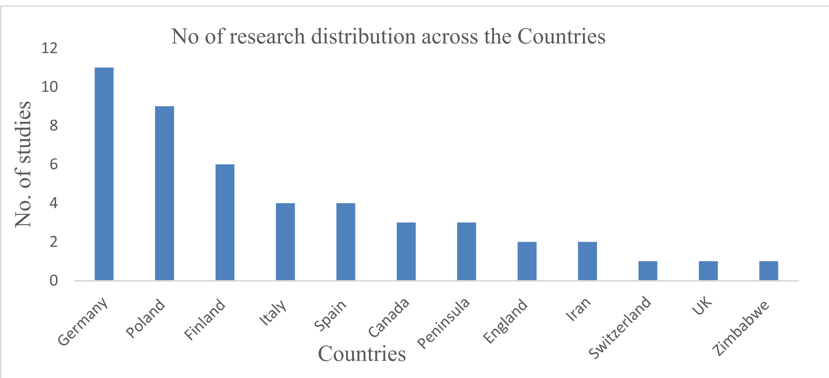

Fig. 3. Distribution of publications by Countries where comparative study on weed in organic and conventional farming systems has been carried out between 1992 and 2019.

effect, while a point on the positive side signifies a statistically significant positive effect. The dotted line corresponds to the mean of the combined effect, with a bullet marking the overall effect size. The grey box illustrates each study's contribution to the pooled effect size; a larger box indicates a greater contribution. Within each study, the horizontal line represents the 95 % confidence interval, with each end denoting the interval boundaries.

3. Results and discussion

3.1. Weed density

The overall analysis of weed density had 31 studies and 410 observations. In all the observations, organic farming system indicated a significant high weed density compared to conventional farming system (SMD = 0.208, 95 % CI 0.100–0.315, $P = 0.0004$) (Fig. 4). Test of heterogeneity in between study was not significant ($Q = 8.29$, $I^2 = 0.0$ %, $P = 1.0$). The studies used to pool the effect size of weed density showed no publication bias from the funnel plot (Fig. 5).

3.2. Diversity

The effect size on weed diversity was obtained from 15 studies and 168 observations. The pooled effect size indicated a significant high weed diversity in organic farming system compared to conventional farming system (SMD = 0.2688, 95 % CI 0.126–0.411, $P = 0.0015$) (Fig. 6). Heterogeneity between studies was not significant as the Cochran's *Q P- value* was more than 0.1 ($Q = 1.91$, $I^2 = 0.0$ %, P = 0.9995). From the funnel plot, there was no publication bias for the studies used to pool the effect size of weed diversity in organic and conventional farming (Fig. 7).

3.3. Shannon evenness

Composition of weeds within the organic and conventional farming systems did not only differ in density and diversity, but also showed a significant difference $P \leq 0.05$ in their evenness. Out of 5 studies and 104 observations made, organic farming system showed significantly higher weed species evenness compared to conventional farming system (SMD = 0.164, 95 % CI 0.003–0.325, P ≤ 0.05) (Fig. 8). Between study Heterogeneity was not significant ($Q = 0.35$, $I^2 = 0.0$ %, P = 0.986). From the funnel plot there was no publication bias within the studies (Fig. 9).

4. Discussion

From the meta-analysis, it's clear that organic farming systems lead to significant high weed density, diversity and evenness compared to conventional farming systems. This comes as a result of the management practices that differ within the two farming systems. Some of these management practices include the use/no-use of herbicides, the use/no-use of chemical fertilizer, and the use/

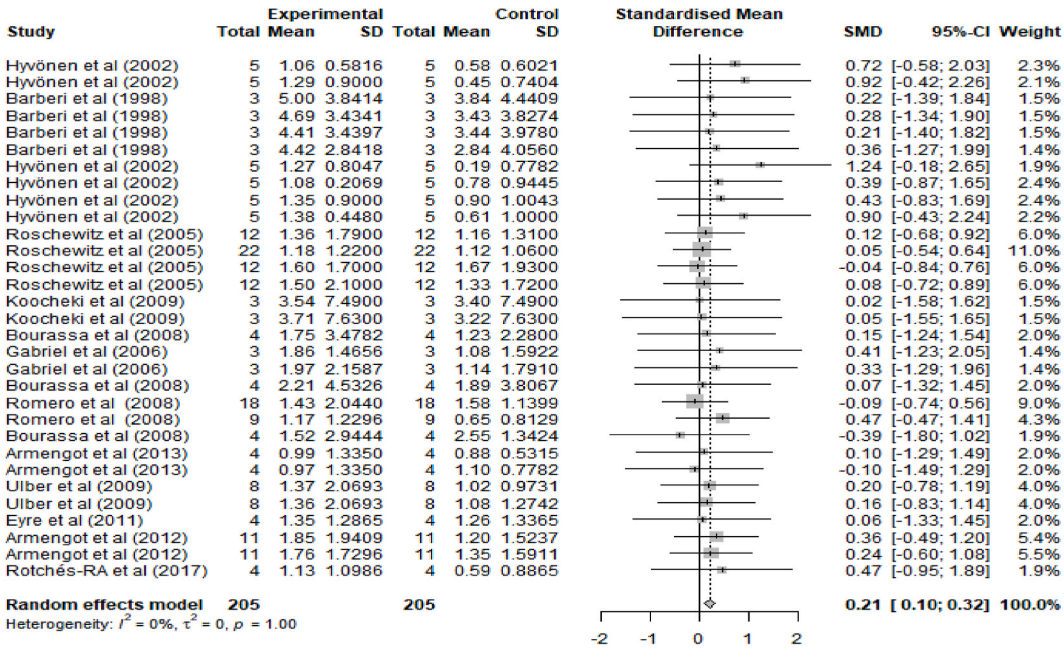

Fig. 4. Forest plot of the weed density in organic farming system verses conventional farming system.

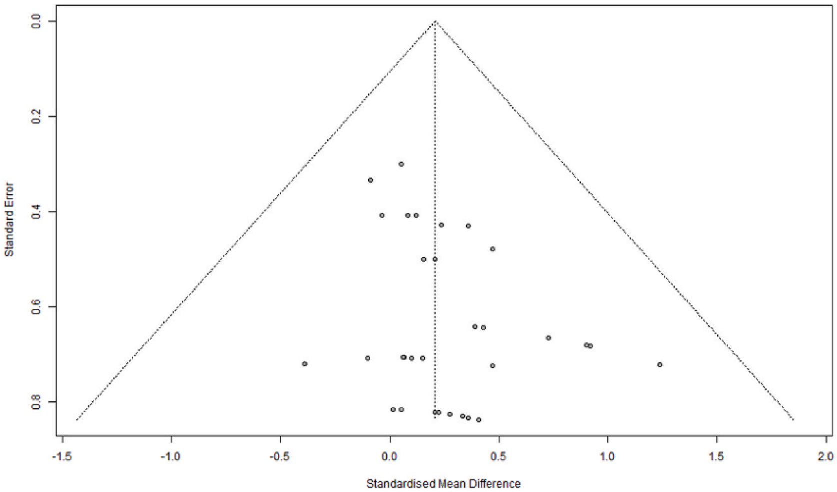

Fig. 5. Funnel plot of studies of weed density in organic farming system verses conventional farming systems.

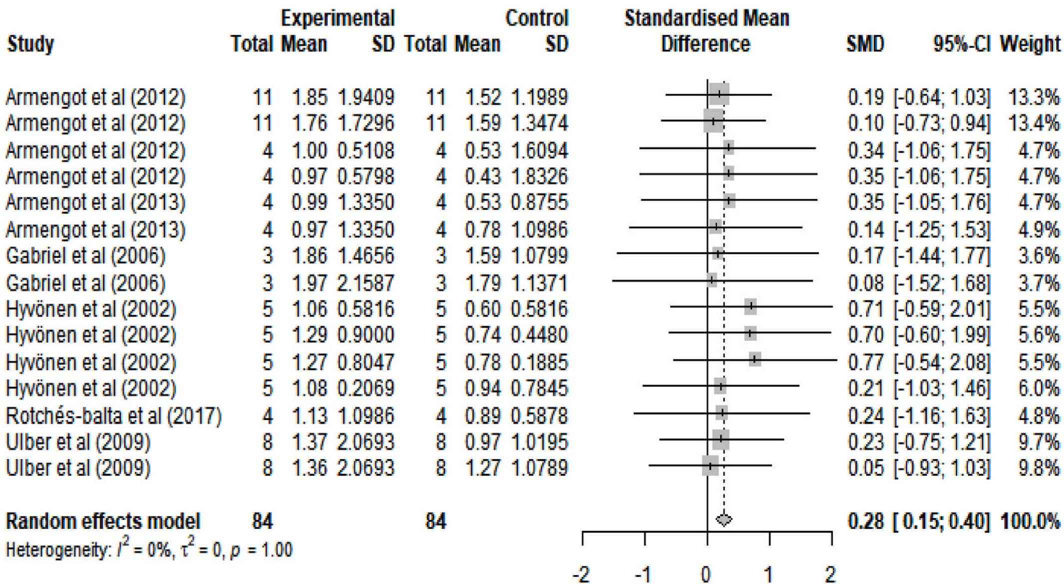

Fig. 6. Forest plot on weed diversity in organic farming system verses conventional farming system.

no-use of long varied crop rotation. Low weed density, diversity and evenness in conventional farming system has been highly contributed by the intensive use of herbicide that aims at complete eradication of weeds, while non-use has favored high weed density, diversity and evenness in organic farming. These results agreed with a meta-analysis done by Ref. [39] where they indicated that plant density was significantly higher on organic farms than conventional farms [40]. also indicated that species richness on organic farms is on average 34 % higher than conventional farms. Similar results were also observed by Ref. [41]who observed that organic farming methods have higher species richness and density compared with conventional farming methods.

4.1. Management practices that influence weeds in organic farming

Weed management remains one of the most challenging, frustrating, expensive, and time-consuming aspects in crop production faced by organic growers [42]. This challenge becomes more intense without the use of herbicide [43]. Weed management in organic farming entails a combination of management practices which includes, mechanical, biological, cultural, and preventive, these influences weed density, diversity and evenness [1,4]. Integration of this management practices, i.e., use of cultural control methods that relay on preventing weed build up through planned crop rotation, which incorporate weed management measures (e.g., cover crop, or high seed rate and intercropping) then backed up by direct means (usually mechanic or thermal), aims at weed control rather than weed eradication [13].

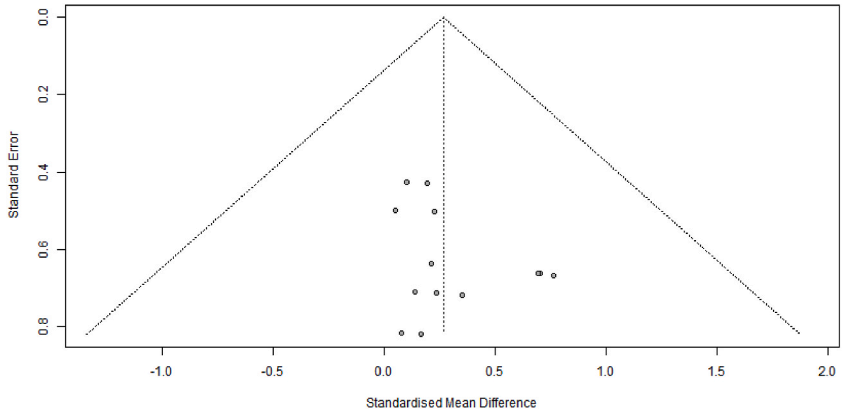

Fig. 7. Funnel plot of studies of weed diversity in organic farming system verses conventional farming systems.

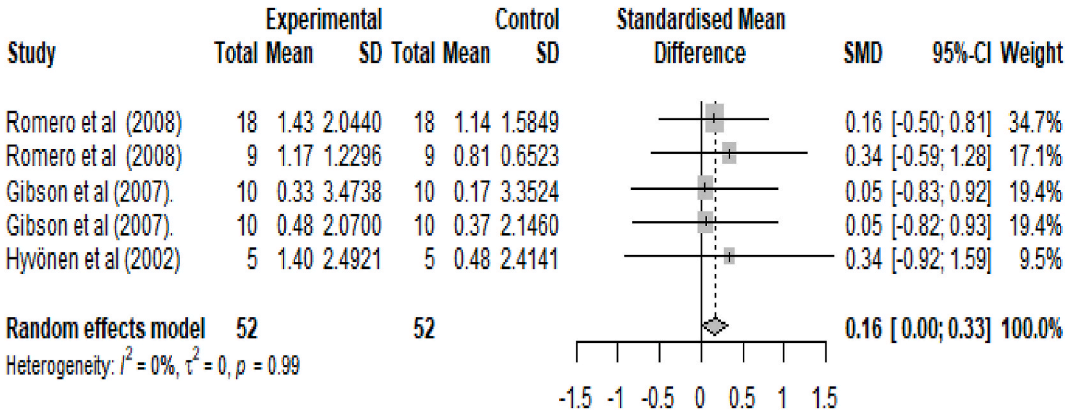

Fig. 8. Forest plot on Shannon diversity of weed in organic and conventional farming systems.

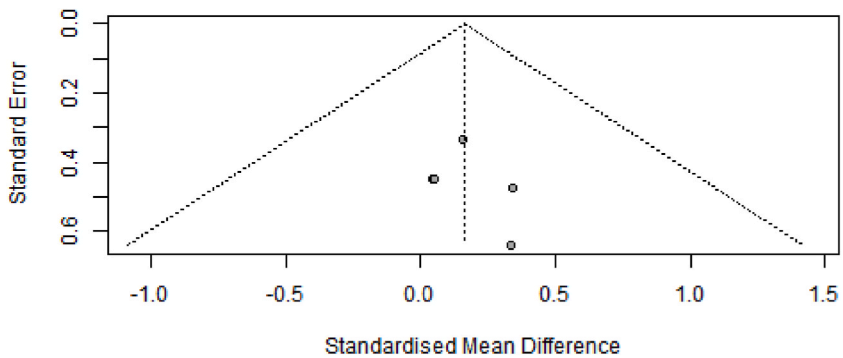

Fig. 9. Funnel plot of studies of weed species Shannon in organic farming system verses conventional farming systems.

Although such an integrated approach provides other additional benefits, organic farmers require an understanding of crop-weed ecology for a practical application and effective weed management [44]. For effective weed management, a thorough understanding of the biology and growth habit of the target weed species is very important [45]. Moreover, because organic weed management involves interaction of biological process with soil types and climate, a single approach is not feasible [46]. Rather, growers have to be guided on a set of approaches that are specifically suited to his/her cropping system, scale of production, existing weed composition, soil and climate in a way that is flexible enough to adapt to often severely fluctuating weather conditions [47]. Any management practice that will lead to maintenance of low densities of weeds, by enhancing the competitive advantage of the crop, increasing weed seed mortality or manipulation of the soil environment to reduce the probability of weed establishment should be encouraged [11].

4.2. Use of compost manure

Compost manure from animal and plant residues are the major source of soil nutrient used by organic farmers [48]. Preparations of compost manure require skills and understanding to prevent it serving as a source for weed seeds [49]. Many growers' lack this skill thus, end up using immature compost and fresh animal manure which leading to additional weeds seeds into their farm [16,50,51]. For example, raw cattle manure may contain viable weed seeds and may spread an otherwise isolated weed infestation more broadly across the farm or, if the manure is imported from outside the farm, introduce a weed problem that previously did not exist, leading to increased weed density under this farming system [52]. For organic farmers to use compost manure they require skills on how to prepare and handle it. This helps to eliminate weed seeds and other diseases and pathogenic vectors as a result of heat generated by microbial respirations and exposure to a range of biochemical [53].

4.3. Crop rotation

Organic farmers often use crop rotation to enhance soil fertility and economic diversity as well as a tool in weed management [54]. Despite crop rotation being used as a tool in weed management, it also results to increase in weed diversity over time [55]. Crop rotation entails use of different crops at different times on the same field [56]. Through long-term variations of crop species and planting times, rotation creates a changing environment that disrupts the regeneration niche of different weed species and prevents dominance of a particular weed species [53]. When a crop with a dense, closed canopy, such as potatoes, is grown prior to growing a crop that is less competitive with weeds, the dense crop reduces the development of weeds [57]. Research done on effectiveness of crop rotation has shown that weed density at the end of the research is always lower than that in the beginning of the rotation practice [8,58,59]. For example [60], reported that *Bromus tectorum* (L.) density remained relatively stable when winter wheat (*Triticum aestivum* L.) was rotated with oilseed rapes (*Brassica napus* L.), whereas the density of the weed increased rapidly when wheat was grown continuously. A meta-analysis by Ref. [56] showed that diverse crop rotations can lead to weed density decrease without decrease in weed diversity, compared to the fields where there is continuous cropping.

For better implementation, knowledge is required in order to target the most sensitive stage on weed life cycle and disrupt it [11]. A well-designed crop rotation, and mostly the sequence in which they have to follow, is of great importance for successful weed management [61]. Having crops with different life cycles during the rotational practices can help in disrupting weed associated with certain agricultural conditions [62]. Use of diversified crop species helps in controlling certain weeds from dominating crop field particularly weeds that are associated with certain crops species [63]. Moreover, evaluation of crop rotation should be done regularly to determine if problematic weeds are surviving crop rotation schemes and to determine what adjustments need to be made for more effective management [64].

4.4. Intercropping

Intercropping entails having more than two crops growing in the same piece of land at the same time where the growth of one crop does not interfere with the growth of the other [65]. Intercropping helps to increase diversity in the cropping system and enhance the utilization of resources such as light, heat and water and reduced chances of uncovered space in the farm that give room to emerging weeds [66]. This has been used as a weed management tool in organic farming system [67]. [68] noted that use of intercrop encourages high weed diversity and evenness. For better weed control in intercropping, the following factors have to be considered, plants composition, varieties, and density [69]. For example [70], found that a grain sorghum (*Sorghum bicolor (L.)* Moench.)/fodder cowpea (*Vigna unguiculata (L.) Walp.*) contained lower weed densities and less weed dry matter compared with sole-cropped sorghum. Also, intercropping maize and bean has been noted to reduce soil weed seedbank of some weed species such as *Amaranthus* ssp, *Cyperus* ssp and C*ammelina* ssp while favoring weed species such as bindweed (*Convolvulus arvensis*) and *Datura stramonium* when compared with monocropping [71].

4.5. Mulching

Covering or mulching the soil surface can reduce weed problems by preventing weed seed germination or by suppressing the growth of emerging seedlings [72,73]. [74] recorded that application of mulching under organic farming led to an apparent reduction in both the number of weed species and weed density when compared to the use of herbicides within a conventional farming system. Mulching smothers weeds by excluding light and providing a physical barrier to impede their emergence and through allelopathic effect [75]. There are different types of mulching materials majorly from organic matter and inorganic matter; the choice of the material depends on the cost and the availability of the mulching materials [76,77]. Plastic mulches have been developed that filter out photo synthetically active radiation but let through infrared light to warm the soil [78]. These infrared transmitting mulches have been shown to be effective at controlling weeds [79]. Use of black or white polyethylene sheets as a mulch after one hand weeding was found to control 98 % of weeds [80]. Crop residues create micro-environments that provide cover for animals that feed on the weed seeds [81]. Rye mulch effectively controlled weeds owing to its allelopathic characteristics while some of the organic mulching materials released phytotoxic chemicals which prevent weed seeds from germinating [82].

4.6. Use of cover crop

Organic farmers used cover crops for several benefits which includes, soil protection against erosion, improved soil structure, soil fertility enhancement, and weed suppression [83,84]. Cover crops are vigorous growing crops that are able to establish and cover the soil surface before the weeds emerge [85]. Their effectiveness mostly depends on the species of the cover crop used, its management and the targeted weed composition [86]. A cover crop helps to control weed through, prevention of weed seed emergency by hindering them from direct sunlight, out competing weeds in nutrient uptake, soil moisture and partly through allelopathic effects [66,87]. This results to a significant reduction of weeds density without reduction of diversity and evenness [88]. Prior to use of a cover crop as a tool in weed management strategies, a better understanding on the interaction effect among the cover crop features (species and growth pattern) and their management (timing and method of killing and incorporation in soil, position in the cropping sequence) in different soil, climate and weed flora conditions is important [89].

Research by Ref. [87] found that rye and red clover cover crops prior to soybean and corn, respectively, suppressed weeds by an average of 24 % relative to the no crop cover system [90]. found that residues of *Brassica napus* incorporated into field prior to planting potatoes resulted to reduced weed density and biomass [91]. reported that soil incorporation of *Brassica napus* residues also reduced weed density and biomass to the crop following incorporation compared to the field that had no cover crop before. Cover crops of wheat, barley, oats, rye, grain sorghum and Sudan grass do have allelopathic effect on weeds, thus can be used effectively to suppress broad leaf weeds species [82,92]. For this reason, organic farmers who have this knowledge opts to do a continuous cropping of rye for several seasons if weeds have presented a persistent problem in the past. However, highest allelopathic effects has been recorded on cover crops such as *Raphanus sativus*, *Fagopyrum esculentum* and *Avena strigosa* with the best target weed species being *Stellaria media* which is the most sensitive weed against allelopathic effects induced by all cover crops [93].

4.7. Thermal weed control

Thermal weed control is a weed control mechanism that involves the use of thermal flames to burn weeds in farms [94]. The main fuel used is liquidified petroleum gas (LPG), usually propane [95]. Weeds are killed when they come into contact with the intense wave of the heat. Fire causes the cell sap of plants to expand, rupturing the cell walls; this process occurs in most plant tissues at about 130 °F [78]. Weeds must have less than two true leaves for greatest efficiency of the burner [96]. This type of weed control method is usually cheaper compared to hand weeding, but the initial cost of the machine is very high [97]. Flame weeders can be used when the soil is too moist for mechanical weeding [98]. Before selection of thermal weeding knowledge on the type of crop is needed as they are not suitable with crops with shallow or sensitive root systems [99]. Despite flaming being an effective weed control method used by organic growers, it may also lead to increase in some weed species that their seed dormancy can be broken by the heat while as grasses may be harder to kill by flaming because their growing point is below the ground [100].

4.8. Hand and mechanical

Hand and mechanical weeding are also used to control weed by organic farmers. This is one of the most effective weed control methods [101]. In many parts of the world, majority of smallholders use hand hoe to control weed [102]. Despite being effective, it is also labor intensive and time consuming [103]. This has led to innovations on weeding mechanization using harrowing, torsion finger weeder and compressed air weeding in some European countries [104]. Tillage methods involves burring weeds into the soil, uprooting, and tearing them into pieces thus reducing density and destroying weeds seedbank [105].

4.9. Tillage

Tillage is one of the most common weed management practices done by organic farmers. Use of different tillage equipment influences soil weed seedbank size and composition [106] due to different depth distribution within the soil profile [107]. This affects weed emergency at different seasons and their population within the field [108]. [109] noted that weed emergency was greatest for seeds buried at 1 cm and decreased for seeds buried at 3 cm [110]. found that seedling emergence of common sowthistle (*Sonchus oleraceus* L.) was greatest from depths of 0 and 1 cm and no seedlings emerged from 5 to 10 cm depths. Tillage may increase germination of some seeds by mechanisms such as exposure of buried seed to light, aeration of soil, increased soil temperature, soil–seed contact and removal of plant canopy and release of soil-bound volatile inhibitors [111,112].

4.10. Benefits of organic farming systems

Despite weeds challenges in organic farming systems, this approach offers a multitude of benefits compared to organic farming system to the ecosystem. The main aim of organic production to ensure health food production without compromise to the biodiversity [113]. Organic farming helps to reduce environmental pollution emanating from agrochemical thus, safeguarding ecosystems and human health, while also fostering greater biodiversity, resulting to a healthy ecosystem [114,115]. Organic farming practices further enhance soil health through techniques like crop rotation and organic matter utilization, making soils more resilient to weed pressure [116]. Organic systems exhibit resilience to climate change due to improved soil health and biodiversity and promote local adaptation using regionally suited crop varieties and traditional practices [117,118].

5. Conclusion

From the meta-analysis it is clear that organic farming leads to an increase in weed density, diversity, and evenness. This is the major hindrance to slow adoption of organic farming by many farmers. Despite so, some organic farming practices may lead to reduction of weed density without necessary influencing diversity and evenness. But lack of proper skills and knowledge on the effective weed management tools to use by farmers has resulted in weeds being ever-present in organic farms. To achieve an effective weed management practice, the farmer must be well knowledgeable on the management practice he/she has to embrace. For this to be achieved, a combine effort from advisors and farmers is needed to come up with individual farm analyses to design site-specific solution may it be in crop rotation, intercropping, use of cover crop and other management practices that will lead to weed reduction. If the farmers can establish the best suite management practices based on knowledge of weed species characteristic and interception point this can help to reduce weed to a manageable level.

Data availability statement

Data are available on request.

CRediT authorship contribution statement

Obadiah Mwangi: Writing – original draft, Visualization, Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Monicah Mucheru-Muna:** Validation, Supervision. **Michael Kinyua:** Writing – review & editing, Methodology, Formal analysis. **Peter Bolo:** Writing – review & editing, Conceptualization. **Job Kihara:** Writing – review & editing, Validation, Formal analysis.

Declaration of competing interest

Authors have got no competing interest for the manuscript.

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