Review Article

"Weed management indices and its relevance in weed science research"

ABSTRACT

Weeds are one of the most important biotic factors cause significant loss in crop productivity. Of the total loss caused by various pests in agriculture, weeds accounts for 37% followed by insects 29%, diseases 22% and others 12 %. Weed competes with crops for various resources, resulting in severe yield loss, although it largely depends on the management strategies adopted. For the effective management of weeds, various management strategies are adopted *viz;* cultural, mechanical, chemical and biological. All these approaches are used based on their performance. Henceforth, it is imperative to evaluate the efficacy of suitable management strategies. To evaluate the performance many weed indices are being used. Understanding of these indices is still vital. Weed indices provides a standardized way to quantify the impact of weed presence on crop yield. Allowing researchers to directly compare different weed management approaches, assess their effectiveness, and identify the most efficient methods for managing weeds in a given agricultural setting.

Key words: Weeds, weed management, weed indices, herbicides efficiency, weed persistence.

Introduction

Weeds are the major problem in agricultural production systems, acting at same tropic level as the crop. Weeds capture a part of the available resources that are essential for plant growth (**Oerke, 2006; Ryan *et al.,* 2009; Smith *et al.,* 2010**). Diverse climatic conditions in India favor the most adopted weeds to prevail and cause severe crop yield losses. Weeds also degrade quality of the produce, raise cost of production; harbor and serve as alternate hosts to several insect pests and diseases (**Rao *etal.,* 2020**). Among the pests, weeds cause maximum yield losses (34%), although it largely depends on the management strategies adopted. The problem of weeds is exacerbated by modern farming practices, such as monoculture, faulty fertilizer use, and the use of heavy machinery, which creates ideal conditions for weed growth and spread (**Gaweda *et al.,* 2020**). Inevitably, leaving weeds uncontrolled will sooner or later lead to considerable reductions in crop yield and increase production cost (**Sharma, 2014**). Weed competes with crops for light, water, space and nutrients, thereby reduce crop yield and quality and lead to billions of dollars in worldwide crop losses annually (**Kaur *et al.,* 2024; Kumar *et al.,* 2019**).The concept of competition refers to the struggle for survival and existence (**Korav*et al.,* 2018**). Competition occurs between at least two plant for limited resources (**Ekwealor, *et al.,* 2019**). Resource limitations may be due to the unavailability, improper supply, or proximity to neighboring plants, which ultimately can aggravate an already insufficient resource or create a deficiency where ample resource was available for a single individual.

Weeds persist and spread through the reproduction and dispersal of dormant seeds/ vegetative propagules, for this reason weeds are virtually impossible to eliminate from any given field (**Singh 2014; Sharma 2014**). Persistence refers to adaptive potential of a weed that enables it to grow in any environment. In the presence of weeds, any attempt to improve the crop production and productivity is futile until not taken the action to control weeds. In modern agriculture, for the effective management of weeds, various methods are adopted *viz;* cultural, mechanical, chemical and biological methods. Traditional weed control methods include hand weeding and hands hoeing etc are effective, but these are labour intensive and increasingly impractical on a large scale of the farming (**Rastogi *et al.,* 2024**). In response, chemical (herbicide) weed control method has gained a traction as a practical and cost effective remedy. Although, herbicides are effective, but the regular use of same type of herbicide lead to shift in weed flora and development of herbicide resistant weed species. For instance, in several research studies, it is evident that the weed *Phalaris minor* is emerging as highly resistant to Isoproturon. This has promoted the requirement of more sustainable solutions, leading to increasing recognition of weed management (IWM) strategies. IWM employs a combination of two or more suitable technologies to manage weeds throughout the growing season. All these methods are used based on their performance. Continuous monitoring and refinement in management strategies is essential for alleviating adverse effects of weeds on agricultural productivity and environmental health **(Rao and Nagmani, 2013)**. Chemical methods are used to control weeds in crop as pre or post emergence application of herbicides which reduces the population of weeds significantly. Sometimes, the herbicides apart from harming target species, affect the non target living being also like micro flora or fauna or biochemical reaction in soil and plants. These chemical means may sometimes enhance yield (Phytotonic effect) or sometimes produce detrimental effect (phytotoxic) on plant. Under changing climatic scenario, it is needful to conserve ecosystem and biodiversity along with sustained production (**Kumar *et al.*, 2019)**. To quantify weed persistence, crop resistance and phytotonic as well as phytotoxic effect of herbicidal treatments, mathematical formula based on plant growth characters may be used. These mathematical formulas are termed as indices. Various indices are in vogue include weed Index, weed control efficiency (WCE), and smothering efficiency, etc. These indices play a crucial role in agricultural production by providing metrics to evaluate the impact of weeds on crop yield and the effectiveness of various weed control measures. Weed indices provides a logistic support in impact assessment, interpretations and drawing appropriate conclusions in weed management research (**Thesiya *et al.,* 2024; Esposito *et al.,* 2021; Mac Laren *et al.,* 2019**).These indices provide a standardized way to quantify the impact of weed presence on crop yield, allowing researchers to directly compare different weed control treatments, and identify the most efficient methods for managing weeds in a given agricultural setting. By application of these indices, farmers may make well-informed decisions to increase crop yield and decrease weed-related losses, which will eventually improve the sustainability and profitability of agriculture. Therefore, in this paper weed management indices and their relevance in weed science research has been reviewed.

1. Weed Control Efficiency (WCE): Mani *et al*. (1973) suggested weed control efficiency as a derived parameter out of weed population/density per unit area for studying treatments' performance in weed control researches. Weed control efficiency usually indicates the percentage reduction in weed population or dry weight of weeds under different methods/ treatments of weed control compare to untreated plot (Das 2008). Although weed density may not be a reliable estimate of weed competition/ control in crops, the trend in methods'/treatments' efficiency may be visualized in terms of their superiority or inferiority.

$$\boldsymbol{WCE}\ (\%) = \frac{\boldsymbol{WDC - WDT}}{\boldsymbol{WDC}} \times \mathbf{100}$$

Where, WD_C: Weed density (number/m^2) in control (un-weeded) plot, WD_T: Weed density (number/m^2) in treated plot. (Unit of the WD_C and WD_T should be same or uniform).

Normally the value of weed control efficiency ranges from zero to hundred. Its value in weedy check or un-weeded plots will be 0 (zero) and in case of weed free plots it will be 100 (hundred). Therefore, the higher value of weed control efficiency of a treatment indicates that this treatment is highly effective in control of weeds. However, in certain cases WCE can also be negative (-ve) for a treatment which is worse than the weedy check. It happens in the field experimentation. It could be worked out for both sole and intercropping situations.

In a crop/season, WCE of a treatment particularly herbicide normally decreases over time or as the date of observation advances. For example, upon application of an herbicide, WCE obtained at 30 or 40 DAS is usually the highest and then it decreases gradually as the crop growth advances towards maturity and becomes the lowest in maturity stage. This all happens due to weed population normally goes on decreasing over time under weedy/un-weeded situation (control plots) and, on the contrary, it likely increases under herbicide-treated plot at the later period of crop growth since herbicide loses its activity. If plots are not periodically weeded out or put some treatments superimposed with the former in a sequential manner, WCE decreases across growth stages of a crop.

2. Weed Control Index: Mishra and Tosh (1979) replaced weed density in **Mani *et al*. (1973)** formula by dry weight to calculate weed control index. It is also a derived parameter which compares different treatments of weed control on the basis of weed dry weight across them. It is more reliable estimate of weed competition/control in crops than weed control efficiency.

$$\boldsymbol{WCI} = \frac{\textbf{WDMC}-\textbf{WDMT}}{\textbf{WDMC}} \times \textbf{100}$$

Where, WDM_C: Weed dry weight (unit/m^2) in control plot, WDM_T: Weed dry weight (unit/ m^2) in treated plot. The unit of both WDM_C and WDM_T should be same.

The value of WCI normally ranges from 0 (zero) to 100 and, on principle, weedy check always has zero (0) WCI value and weed-free treatment has 100. Therefore, higher the value of WCI of a treatment, greater is the weed control by that treatment. However, in certain cases WCI can also be negative (-ve) for a treatment which is worse than the weedy check. It happens in the field experimentation. It could be worked out for both sole and intercropping situations.

In a crop/season, WCI of a treatment particularly herbicide normally decreases over time or as the date of observation advances. For example, upon application of an herbicide, WCI obtained initially at 30 or 40 DAS is usually the highest and then it decreases gradually as the crop growth advances towards maturity and becomes the lowest in maturity. This all happens due to weed dry weight normally goes on decreasing over time under un-weeded situation (control plots) and, on the contrary, it likely increases under herbicide-treated plot at the later period of crop growth since herbicide loses its activity. If plots are not periodically weeded out or put some treatments superimposed with the former in a sequential manner, WCI decreases across growth stages of a crop (Das 2008).

3. Weed index (WI)/ Weed competition Index (WCI): Gill and Kumar, (1969) suggested weed index as a derived parameter from the crop yields obtained across the treatments of weed control researches. It is nothing but a measure of the crop yield loss accrued across treatments in comparison to a weed free plot or in certain cases the minimum weed- infested plot like two or three hand weeding (as good as weed free check) adopted in an experiment. It is the ultimate parameter towards appraisal of the superiority or inferiority of several treatments and is worked out in almost all weed control researches.

$$\boldsymbol{WI} = \frac{\textbf{YWF} - \textbf{YT}}{\textbf{YWF}} \times \textbf{100}$$

Where, Y_{WF}: Crop yield in weed free plot, Y_T: Crop yield in treated plot. The unit of both Y_{WF} and Y_T should be same.

The value of WI generally does not have a definite range. Weedy check will have the highest value since its yield is likely to be the lowest. However, sometimes certain treatments appearing as poor as weedy-check, may have similar lower values. In an extreme situation of the weedy check when there is no yield obtained, WI becomes 100. Weed-free check, however, will have 0 (zero) value. Certain treatments particularly some herbicide (eg; pendimethalin, atrazine) yielding higher than that obtained under season- long weed-free situation, may have WI values negative (-ve), which indicates superiority of that treatment than even weed free check. WI could be worked out for both sole and intercropping situations over different treatments employed.

4. Relative dry weight (RDw): In the above two formulae (WCE and WC), the composite culture of weed species is taken into consideration and the effect of a single weed species is ignored or hardly evaluated. Therefore, the relative dry weight can be chosen as a parameter of study just to evaluate, in terms of dry weight accumulated, the effect of a particular weed species to the overall total effect of composite weed community. Accumulation of dry matter will reflect to a great extent the vigour and competitive ability of weed species individually.

$$RDW = \frac{\text{Dry weight of weed species per unit area}}{\text{total dry weight of composite weed in that unit area}} \times 100$$

5. **Weed Smothering Efficiency (WSE):** Weed smothering efficiency (WSE) is a modification of **Mani *et al.* (1973)** formula and suits best under an intercropping situation. Intercrops are chosen generally for their weed smothering action. Thus, WSE may be a good indicator of weed smothering abilities of different intercrops adopted in certain crops of prime interest. There is no scope for working out WSE under sole cropping. To have more accuracy, observation may be collected from 2-3 spots within a plot or treatment per replication and averaged out.

$$WSE = \frac{\text{Mdw} - \text{Idw}}{\text{Mdw}} \times 100$$

Where, **Mdw:** Average dry weight of weeds in main/ sole crop, **Idw**: Average dry weight of weeds in intercropping situation.

6. Weed persistence index (WPI): Mishra and Misra, (1997) has suggested WPI recently which got enough relevance to study the aspect of weed management on comparative basis/scale. WPI indicates relative dry matter accumulation of weeds per count in comparison to control. Weed persistence index, which demonstrates the resistance of escaped weed against the particular weed control measure, reflected variability.

$$WPI = \left(\frac{Weed\ population\ in\ control\ plot}{Weed\ population\ in\ treated\ plot}\right) \times \left(\frac{Weed\ dry\ weight\ in\ \ treated\ plot}{weed\ dry\ weight\ in\ control\ plot}\right)$$

7. Crop resistance index (CRI): It refers to the relationship between a proportionate increase in crop biomass and a proportionate decrease in weed biomass in the treated plots (**Mishra and Mishra, 1997)**. In other hands we can say, the crop resistance index indicates increased vigor of crop plant due to weed management measures.

$$\boldsymbol{CRI = \left(\frac{Crop\ dry\ weight\ in\ treated\ plot}{Crop\ dry\ weight\ in\ control\ plot}\right) \times \left(\frac{Weed\ dry\ weight\ in\ control\ plot}{Weed\ dry\ weight\ intreated\ plot}\right)}$$

8. Weed management index (WMI): This index indicates the yield increase with respect to control because of weed management options taken and percent control of weeds by the respective treatment. It can be calculate by the formula that suggested by **Mishra and Mishra (1997).**

$$\boldsymbol{WMI = \left(\frac{Percent\ crop\ yield\ over\ control}{Percent\ control\ of\ weeds}\right)}$$

9. Agronomic management index (AMI): It combines yield and weed control effects, similar to WMI. It also considers the change in weed dry weight in relation to the control plot. These indices provide valuable insights into the effectiveness of herbicide treatments and their impact on both crop yield and weed management strategies. To calculate the AMI **Mishra and Mishra (1997)** suggested a formula:

$$\boldsymbol{AMI = \left(\frac{(Percent\ crop\ yield\ over\ control) - (Percent\ control\ of\ weeds)}{Percent\ control\ of\ weeds}\right)}$$

10. Integrated weed management index (IWMI): It is a composite indicator that combines the **Weed Management Index (WMI)** and the **Agronomic Management Index (AMI)** to provide a comprehensive assessment of the effectiveness of weed control measures alongside agronomic practices. This index of weed management suggested by **Mishra and Mishra (1997),** it has got popularity in current weed management approaches. The lowest values of IWMI indicate better weed control and the higher value of IWMI indicates opposite. It is calculated as the arithmetic mean of the two indices, represented mathematically as:

$$IWMI = \frac{\text{WMI}+\text{AMI}}{2}$$

Where, WMI: Weed management index, AMI: Agronomic management index

11. Herbicide efficiency index (HEI): The Herbicide efficiency index (HEI) is useful to assess the potential of an herbicide treatment in killing weeds while considering its impact on the crop. To calculate this index **Krishnamurthy *et al*., (1975)** derived a formula:

$$HEI = \frac{\frac{(YT-YC)}{YT} \times 100}{\frac{WDMT}{WDMC} \times 100}$$

Where, Y_T: crop yield from treated plot, Y_C: crop yield from control plot, WDM_T: weed dry matter weight in treated plot, WDM_C: Weed dry matter weight in weedy check plot.

12. Weed intensity (WIn): Rana and Kumar (2014) suggested weed intensity indices that refers to the proportion of weeds in relation to the total plant population (weeds + crops) in a given area, expressed as a percentage.

$$WIn = \frac{Weed\ density}{density\ of\ weed + crop} \times 100$$

In present day research, related to weed management indices are being used to compare the management strategies and draw a valid conclusion before recommending to the farming community. Different impact indices, viz. weed persistence index (WPI), weed management index (WMI), agronomic management index (AMI) and integrated weed management index (IWMI) were worked out by **Sen *et al*., (2020)** in his study.

CONCLUSION

From the literature, it may be concluded that these indices indicate the potential of herbicides adopted under chemical method of weed management as well as weed management strategies/approaches to manage weeds and their phytotoxicity effect on the crop. They are also helping in determining economic threshold level, weed persistence, effect of herbicides on environment and their impact on both crop yield and weed management strategies. To quantify weed persistence, crop resistance and phytotonic or phytotoxic effect of herbicidal treatments by using mathematical formula can be easily identified, and may be taken into consideration for further studies.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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