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Weed Ecology: Insights for Successful Management Strategies: A Review

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ABSTRACT

In crop ecosystems, the primary challenge in establishing a long-term weed management strategy arise from a lack of understanding regarding the nature of weediness and the factors that contribute to species dominance. To address this, farmers and researchers often rely on quick and efficient, yet temporary weed control methods, which can lead to long-term issues. To develop a more effective and sustainable weed management approach, it is crucial to gain a comprehensive understanding of both the biological characteristics and ecological behaviours of weeds. This can be achieved by incorporating preventive techniques, scientific knowledge and management skills, with the goal of enhancing crop production and benefiting farmers. While further information is needed in all aspects of weed management, the primary objective of weed science is to increase our knowledge of weed biology and ecology, thus fostering a better understanding of weediness. This understanding will facilitate the adoption of appropriate management strategies instead of relying solely on short-term solutions that may create or exacerbate long-term problems. The successful growth and reproduction of any species depend on a variety of conditions. In a given ecosystem, the species that can thrive more efficiently under the specific set of environmental conditions will produce the most viable offspring and become the most abundant organisms. Weed ecology, which examines the adaptive mechanisms that enable weeds to thrive in highly disturbed soil conditions, provides essential insights into the distribution and abundance of weeds in both natural and managed systems. The occurrence of a weed in a particular area is influenced by multiple factors, with climatic, soil-related (edaphic) and biotic factors being the most significant among them.

Key words: Species dominance, Weed abundance, Weed biology, Weed control, Weed ecology, Weed management.

Weeds exhibit dynamic spatial variations within and across fields, as well as temporal fluctuations during and between seasons. Weed establishment and the subsequent interactions with crops are governed by a range of ecological factors. Light, temperature, pH, moisture and even CO_2 concentration exert influence over the composition of weed communities. Consequently, it is crucial to enhance our comprehension of the effects of these factors and the underlying mechanisms through which they shape weed dynamics. Studying weeds in the context of their biology and ecology, particularly in relation to their environment, is undeniably vital for the progress of sustainable Integrated Weed Management (IWM) approaches. Based on the above mentioned arguments, a comprehensive review of literature has been done in order to understand the effect of climatic, edaphic and biotic factors on weed establishment.

Ecology based management

Weed ecology investigates the adaptive mechanisms that enable weeds to thrive under highly disturbed soil conditions. Each species has unique environmental requirements for optimal growth and reproduction. Among these requirements, the species that can adapt most effectively to the specific conditions of an ecosystem and its arrangement of environmental factors will produce the most viable offspring and become the dominant organisms. The appearance of weeds fluctuates depending on environmental factors, the makeup of the seed bank and agricultural techniques like soil cultivation, crop rotation and strategies for weed control (Narmadha *et al.*, 2023).

Light environment and implications for management

Light intensity, quality and duration have a profound impact on weed growth, reproduction and distribution. The spectral composition and irradiance of light, as well as the physiological state of the seeds and other environmental factors like temperature and water potential, can either stimulate or inhibit germination. Seed germination reactions to light are species specific. Seeds whose germination is influenced by light is called photoblastic seeds. In photoblastic seeds, weeds like *Avena fatua* and *Eleusine indica* germinates equally in presence and absence light, whereas certain weed germination is stimulated by light (*e.g.*

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Digitaria ciliaris, Echinochloa colona and Portulaca oleracea). Some species, for example, *Cyperus difformis, Digitaria longiflora* and *Eclipta prostrata* have an absolute light prerequisite for germination (Chauhan and Johnson, 2010a) and hence are considered as positively photoblastic, a response supposed to be controlled by a light-absorbing pigment within plants known as phytochrome.

How light affects the germination of photoblastic seeds

Exposure to light can induce a transformation in dormant phytochrome from the "red" form to the active "far-red" form. This conversion from phytochrome red (Pr) to phytochrome far-red (Pfr) played a role in controlling seed germination in phytochrome-regulated seeds. Far-red (FR) light inhibits seed germination by converting dynamic forms of phytochromes (Pfr) back into dormant structures (Pr). Conversely, red (R) light promoted the transformation of Pr into Pfr, thereby stimulating germination (Henning *et al*., 2002; Li *et al*., 2011). Pfr translocate to nucleus and initiates the transcription of Gibberellic acid and abscisic acid related genes for initiation of germination or breaking of dormancy (Yang *et al*., 2020).

Germination of seeds that require light occur only at the upper layer of soil where light penetrates and breaks dormancy, as minuscule amount of visible light can penetrate any soil beyond 2.5 mm depth (Jamil *et al.,* 2022). Species that thrive in open and bright habitats, such as sunny areas, are more likely to be absent or less abundant in dense forests and closed canopy environments. Tillage disrupts the soil, uncovering weed seeds to sudden light, prompting them to emerge from dormancy (Kumar *et al*., 2022). Light profoundly affected the emergence, growth and proliferation in *Chromolaena odorata*. The germination of *C.odorata* seeds was increased by red light and it was inhibited by canopy light (Ambika, 2002). Canopy light is known to be wealthy in the content of far red and this could be the explanation behind the absolute hindrance of germination under this condition. The germination of *Echinochloa glabrescens* was also affected by light conditions. (Opena *et al*., 2014). Very less seeds of *Chenopodium album* germinated under completely dark situation, however, germination increased as plants were provided with 12-hour photoperiod (Tang *et al*., 2022). Germination of weed seeds that light stimulated may pose severe challenge in no-till systems, due to a substantial portion of the weed seed bank remaining near the soil surface, where it is exposed to light. (Batlla and Benech-Arnold, 2014). Anjali *et al*. (2018a) reported that taller weedy rice morphotypes overshadowed and bent over the rice plants compared to dwarf morphotypes, diminishing the photosynthetic capacity of rice.

Chenopodium album had higher germination when seeds were at surface or very shallow depth (Tang *et al*., 2022) and thus even shallow tillage that would turn the soil and place the seeds at any soil depth more than 5 cm would inhibit germination. Seeds that require light for germination would remain dormant and, over time, may be subject to predation or decay if buried in the soil. A seed rate of 140 kg ha^{-1} in rice resulted in a high leaf area index, mainly due to the dense plant population per unit land area surpassing the optimum indicating abundance of leaves per unit area, leading to shading of lower leaves and consequently hindered photosynthesis of weedy rice (Anjali *et al*., 2018b). To manage such weeds, techniques such as mulching and planting cover crops can be employed. Mulching creates a physical barrier that prevents light from reaching the seeds, inhibiting their germination. Planting cover crops serves a similar purpose by shading the soil surface and reducing the availability of light for weed seed germination. These practices can effectively suppress the growth and emergence of light-dependent weed species. However, several other species do not have light as an absolute requirement for germination. Various cultivars exhibit distinct responses to shading stress, both in terms of morpho-physiological characteristics and yield outcomes (Pooja *et al*., 2021). For instance, *Leptochloa chinensis* showed 80% germination under 12-hour photoperiod treatment at 25/15°C and under complete dark condition 65 % germination was recorded (Sekhar, 2021).

Responses of weed seed germination to surface mulches

The proximity of crop residues and canopies has a substantial influence on the light spectrum that reaches the soil surface. Various factors, such as the characteristics of the weed species, the distribution and positioning of weed seeds in relation to the residue (whether they are above or below the residue) and the allelopathic properties of the residue, all contribute to the response of weed species to the presence of residue. When there is a significant accumulation of residue in the soil, it leads to a reduction in the number of weed seedlings and delays their emergence. This delay may occur due to a decrease in the temperature variation within the soil caused by the residue and the obstruction of light penetration by the residue layer.

The germination response of weeds under mulches varies with the quantity of mulches applied. Germination of *Chromolaena odorata, Echinochloa colona and Eleusine indica* was found to be decreased as the quantity of residue increased, whereas, germination of weeds such as *Melochia corchorifolia* and *Digitaria ciliaris* did not inhibit that much to the increased amount of residue mulch (Chauhan and Johnson, 2010a). Different mulch types *viz*., wheat straw and living mulches significantly reduced broad leaved weeds in coriander. Living much such as alfalfa and clover compete with weeds and may also have allelopathic effect, thus reducing weed growth (Vasilakoglou *et al.,* 2006). Wheat straw was found to more effective in weed control over living mulches, due to, shading effect on weed seeds inhibiting germination and elimination of competitive pressure from third species (living mulch) in crop-weed interaction (Mohammadi *et al.,* 2023). Ameena *et al*. (2013) illustrated that the weedy check plots exhibited the greatest rates of regrowth and viability in *C. rotundus*, suggesting that the newly developed tubers of purple nutsedge promptly germinated without seasonal dormancy.

In no-tillage cropping systems, the presence of cover crop residue can have an impact on weed population due to its proximity to the soil surface where seed germination occurs. Crop residue that remains on the soil surface not only helps conserve soil moisture and provide organic matter and nutrients during decomposition but also influences the germination, emergence, survival and growth of both weeds and crops.

Effect of temperature and implications for management

Temperature is the second most significant ecological prerequisite for germination of seeds (Derakhshan *et al*., 2014). Both above and below ground soil temperature are important which governs reproduction and establishment of weeds. The temperature controls the limit and pace of germination by influencing the seed torpidity (dormancy) status and the pace of the enzymatic activities (Bewley *et al*., 2013).

Temperature variations during different seasons are also a crucial factor in the process of seed germination. Temperature acts as a trigger for inactive seeds to transform into a viable state. Seeds that have either inherent or physiological dormancy, which means their germination is obstructed due to irregularities in physiological activities, can overcome this dormancy by being exposed to particular temperature conditions. This includes subjecting the seeds to high temperatures during summer (warm stratification) and/or low temperatures during winter (cold stratification), which can lead to the breaking of dormancy, depending on the species involved. The physiological dormancy (PD) occurs at three levels: non-deep, intermediate and deep. Seeds having non-deep and intermediate PD will break dormancy at certain temperature but will germinate at some other temperature. For example *Brassica napus* shows non-deep PD which breaks dormancy only at 15 and 20°C, after dormancy is broken germination may occur at higher and lower temperatures (Maleki *et al*., 2023). For deep PD, the germination generally occurs at the temperature at which dormancy breaks (Soltani *et al*., 2022).

Different weed species have different sensitivity levels to temperature during the germination stage, which dictates the growth habitat of the weed (Chauhan and Johnson, 2010a). Based on temperature requirement, weeds can be classified as rabi season weeds which germinates when temperature falls in between 10-20°C. *e.g. Phalaris minor, Chenopodium album* and *kharif* season weeds which shows germination only under high temperature condition when temperature exceeds 20°C *e.g. Echinochloa sp*., *Trianthema portulacastrum.* However, the seeds of some weeds like A*vena ludoviciana* do not lose their viability even if they remain under snow for a period of 3-4 months.

Response of weed seed germination to diurnal variation in temperature

Temperature plays a significant role in seed germination and can influence seasonality and the expansion of plant ranges. Certain seeds have the ability to germinate across a broad temperature range, while others have specific high temperature thresholds that they require for successful germination. *Chromolena odorata, Borreria ocymoides* and *Heliotropium indicum* can grow in a wide range of temperatures, therefore it is possible for these species to appear at low altitudes throughout the year in tropical regions. In contrary, germination of *Tridax procumbens* was hindered by suboptimal temperatures (Chauhan and Johnson, 2008 a,b).

Seeds of *Leptochloa chinensis* when exposed to alternating day/night temperatures germinated at all the temperature ranges that were tested. However, germination was observed to be higher (87.2%) at 25/15°C day/night temperature compared to 35/25°C (70.31%) (Sekhar*,* 2021). Controlling the germination of weed seeds that rely on ambient temperature can be achieved through various management techniques. These techniques include mulching, soil solarisation, fallowing and field burning. By implementing these methods, it becomes possible to manipulate the ambient temperature and regulate the germination of weed seeds. *Bidens pilosa* had higher germination at alternating diurnal temperatures of 25/15°C and 30/20°C compared to 35/25°C (Chauhan *et al.,* 2019).

Effect of high temperature on weed seed germination

In northern India, wheat farmers traditionally resort to burning their fields not only to manage crop residue but also to control the prevalence of *Phalaris minor*, a significant weed in wheat cultivation. Despite practicing burning annually, *Phalaris minor* continues to persist as a major weed. This suggests that burning does not effectively inhibit the germination of *Phalaris minor* seeds. In a study conducted in India, wheat straw was either removed from the fields or burned during combine harvesting. Soil samples were subsequently collected and carefully cleaned to separate the seeds of *Phalaris minor* and the germination of these seeds was evaluated. Burning of field straw reduced the germination of *P. minor* by 60% (Hari *et al*., 2003).

The introduction of high temperatures, which could be typical of vegetation burning, roused *Mimosa invisa* seeds from dormancy and boosted germination, increasing it from 4% prior to treatment to 94% after exposure to 120°C for 5 minutes (Silveira and Fernandes, 2006). Similarly, *Bidens Pilosa* showed more than 80% germination when exposed upto 120°C temperature for 5 minutes. The germination decreased with further increase in temperature showing 50% inhibition at 160°C and complete inhibition at 240°C (Chauhan *et al*., 2019). In a variety of hard-seeded species, fire has a significant impact on releasing physical dormancy. High temperatures have the potential to rupture the seed coat, allowing more absorption and germination. Additionally, fire opens up the earth, which could cause a large number of dormant seeds to be released, especially in hot and humid weather conditions.

Soil moisture and implications for management

Water is the most crucial factor for seed germination. The process of germination begins with the imbibition of water that activates the enzymes which in turn starts the essential metabolic processes. The presence of water significantly affects both the percentage and rate of seed germination. In arid regions, the unavailability of water prevents seeds from germinating prematurely, whereas in moist regions, dormancy mechanisms primarily regulate the timing of germination. Poor soil conditions such as insufficient soil moisture, waterlogging, salinity, pH imbalance, *etc*., can hinder the plant ability to absorb nutrients effectively (Pooja and Ameena, 2021). From one species to another, the threshold for seed germination in response to soil moisture content varies.

Effect of soil moisture on weed seed germination

Researchers have observed that the germination of *Borreria ocymoides* and *Heliotropium indicum* decreased as the osmotic potential of the environment declined (Chauhan and Johnson, 2008b). However, the germination of *Tridax procumbens* (Vanijajiva, 2014) remained unaffected by changes in osmotic potential. This suggests that the latter two species prefer a moist environment for germination and have the ability to stay dormant during dry periods until suitable moisture levels are available, which enhanced their chances of survival. To effectively manage weed seeds that require adequate soil moisture for germination, several practices can be employed, including crop rotation, fallowing, using competitive cultivars and implementing the stale seedbed technique. Ameena (2015) reported that stale seedbed followed by dry ploughing notably increased the presence of weedy rice by exposing additional seeds from the weed seed bank to the surface layer. The stale seedbed technique involves allowing weeds to emerge for at least two weeks before removing them, which has proven particularly effective in reducing the weed seed bank in the soil. A decrease in tuber viability (20-23.3%) and regeneration (6-8 sprouts per m^2) was observed when utilizing a stale seedbed in combination with pre-plant application, followed by targeted post-emergence glyphosate application for controlling *C. rotundus* (Ameena *et al*., 2006).

The germination of *Mimosa invisa*, a species commonly known as the Giant Delicate Plant, decreased from 97% to 64% as the osmotic potential declined from 0 to -0.8 MPa. Germination was completely inhibited at an osmotic potential of -1.2 MPa (Chauhan and Johnson, 2008d). However, there was 13% germination observed at -1.0 MPa, indicating that the seeds of this species can tolerate moderate water stress and still manage to develop. This suggests that both *Tridax procumbens* and *Mimosa invisa* are well adapted to dryland cropping systems, including no-till systems, where they are considered problematic. Soil solarization, which involves exposing the surface soil to solar heat, can be an effective method for managing such weeds. In the case of *Echinochloa glabrescens*, germination was highest at 0 MPa and decreased as the osmotic potential was reduced. Complete inhibition of germination occurred at -1.0 MPa (Opena *et al*., 2014). Similarly, in *Chenopodium album*, a decrease in germination from 94% to 5.5% was observed as the osmotic potential decreased from 0 to -1 MPa (Tang *et al*., 2022). These findings highlight the sensitivity of these species to reduced osmotic potential and indicate their preference for conditions with higher water availability for successful germination.

Influence of flooding on weed management

Flooding is a method employed for weed control and its effectiveness depends on the timing, duration and depth of flooding. Different weed species respond differently to flooding, leading to varying levels of growth inhibition. While flooding can effectively control certain weed species, others may be more challenging to manage due to their adaptability to waterlogged conditions.

When *Leptochloa chinensis* (Chinese sprangletop) was flooded for two days and seven days at a depth of two centimetres, the biomass production of the plant was significantly reduced by 73 and 99 percent, respectively (Chauhan and Johnson, 2008 b). The results showed that the growth of Chinese sprangletop can be drastically reduced with shallow and intermittent flooding. The growth of *Echinochloa crus-galli,* can be notably reduced by inundating fields within two days of sowing. This suggests that early flooding can be an effective method to suppress the growth of barnyard grass.

Deep flooding increased count of *Sphenoclea zeylanica, cyperus difformis* (Kent and Johnson, 2001) and *Monochoria vaginalis* (Juraimi *et al*., 2012). Increased flood depth increased count of *Sphenoclea zeylanica* yet flood duration had no huge impacts. *Cyperus difformis* was lowest in the no flood treatment, which was allowed to dry for five out of seven days. The shallow (2 cm) continual flooding treatment produced the highest biomass. It is important to understand that many rice farmers may have later faced water restrictions that limited their capacity to use continuous flooding as a weed control strategy. Flooding following herbicide application or hand weeding could significantly thwart the growth of this weed in the future and reduce the need for additional interventions.

Carbon dioxide and implications for management

The rising concentration of CO_2 and other greenhouse gases that interact with solar radiation is contributing to climate change. Changes in climatic parameters might bring a shift in the dynamics of crop weed competition towards favouring various weed species.

Plants utilizing the C3 photosynthetic pathway exhibit a stronger response to elevated CO_2 levels compared to those with the C4 pathway. Elevated CO_2 levels promoted biomass production by reducing water loss through stomata and stimulating root growth and structure (Li *et al*., 2020). Javaid *et al*. (2022) opined that increased CO_2 levels alleviated the adverse growth effects of drought, enhancing weed adaptation by improving water use efficiency. This implies that the weed has the potential to benefit from climate change, increasing its competitiveness with other plants in drought-prone areas and potentially expanding into new regions. Weedy rice demonstrated a more pronounced response to elevated CO_2 levels than cultivated rice, exhibiting stronger competitive abilities (Ziska *et al*., 2010). The changing climate not only affected the competitiveness between crops and weeds but also triggers early flowering, leading to multiple weed seed flushes and presenting significant challenges for weed control (Mahajan *et al*., 2014). Higher CO_2 conditions were associated with increased tillering, with weedy rice exhibiting higher tillering than cultivated rice species Jyothi and Uma under ambient conditions (Anjali *et al*., 2021).

Soil pH and implications for management

Soil pH plays a crucial role in determining the plant species that can thrive in a particular location. However, the effect of pH on weeds remains inconclusive. Weeds can be categorized based on soil pH as basophile weeds, such as *Agropyron repens* and *Dandelion*, can tolerate a pH range of 7.4-8.5. Acidophile weeds, including *Cynodon dactylon* and *Digitaria sanguinalis*, can tolerate pH levels ranging from 4.5 to 6.5. Neutrophile weeds like Shepherd's-purse, Prostrate knotweed and Common chickweed thrive in a pH range of 6.5-7.4. *Mimosa invisa* and *Tridax procumbens* (Vanijajiva, 2014) seeds have been found to germinate within a pH range of 4 to 10, but their germination rates were higher within the pH range of 6 to 7. This suggested that *T. procumbens* and *M. invisa* are tolerant to both acidic and alkaline conditions. The wide pH range for seed germination in these weeds indicated that soil pH is unlikely to be a limiting factor for their germination in most soil types.

Influence of soil pH on weed management

Attempts to raise soil pH have a dual impact on crop productivity. When agricultural crops are grown in soils with optimal pH levels, they tend to yield more and they possess a competitive advantage over weeds. A reduced weed population not only increases the effectiveness of herbicides used but also lowers the chances of weed seeds being added to the soil seed bank. In neutral or acidic soils, chemical breakdown of herbicides such as triazines and sulfonylureas occurs more rapidly. However, in alkaline soils, this process is significantly slower, which can limit crop options and expose late germinating weed seeds to lower, non-lethal doses of herbicides.

According to research on the effects of soil pH on the germination, growth and reproduction of *Ambrosia artemisiifolia* (common ragweed), a highly invasive allergenic species, plants grown at pH 7 were smaller and produced leaves at a slower pace than plants grown at pH 5 and pH 6; plants did not produce flowers or pollen at pH 7. According to the study, soil pH has a substantial impact on the growth and development of *A. artemisiifolia and* it may play a role in limiting the spread and threat of this plant (Gentili, 2018).

Salinity and implications for management

Soil salinity is another important environmental factor that has a major impact on the germination of seeds and seedling emergence in the field by reducing soil water potential and ionic toxicity (Al-Khateeb, 2006; Zhang *et al*., 2010). Different plant species react differently to rising salt concentrations. As salinity increased, seed germination of *Chromolaena odorata* and *Tridax procumbens* decreased. Germination of *Chromolaena odorata* was reduced by 50% at a NaCl concentration of 171.6 mM, but germination of *Tridax procumbens* was reduced by 50% at a concentration of 88.2 mM.

Seed germination, shoot and root biomass of *Echinochloa colona* and *Echinochloa crus-galli* were also decreased as the salinity increased (Chauhan *et al*., 2013) whereas, weeds such as *Heliotropium indicum*, *Cyperus rotundus* and *Trianthema portulacastrum* showed tolerance to salinity (Uddin *et al*., 2011). The response of these unwanted plants to high salt levels indicated that both saltiness and competition from weeds can limit the growth of cultivated crops.

In a study by Hakim *et al*. (2013), a survey was conducted to identify common weed species in coastal rice fields characterized by high salinity levels. The researchers found that the families Cyperaceae, Poaceae, Euphorbiaceae, Pontederiaceae, Scrophulariaceae and Rubiaceae were the most abundant. Among the surveyed species, the second most commonly found belonged to the family of Convolvulaceae, Capparidaceae, Asteraceae and Onagraceae. Regarding grass species, the three most prevalent were *Echinochloa crus-galli, Echinochloa colona and Leptochloa chinensis*. Within the Cyperaceae family, the most prevalent species were *Fimbristylis miliacaea*, *C. iria, C. difformis* and *Scirpus grossus*, while the most prevalent broadleaf weed species included *Jussiaea linifolia, Sphenoclea zeylanica, Monochoria hastata* and *Limnocharis flava*.

Impact of management practices on weed ecology

Role of tillage in weed seed emergence

Different tillage practices have a direct influence on the vertical distribution of weed seeds within the soil profile, which in turn affects the overall abundance of weed species in the field. This impact is observed through the effects on seed survival, the germination process and emergence. Tillage practices determine how seeds are dispersed and encapsulated both along and across the soil profile. The resilience of *C. rotundus* to various pressures originates from its strong subterranean tuber network, where each tuber produces multiple active buds on tillage, resulting in continuous expansion (Ameena *et al*., 2015). Skuodien (2020) reported that reduced soil tillage treatments had 1.6 times more weed seeds than conventional ploughing plots. Annual shallow plough less tillage resulted in significant soil contamination with weed seeds, with 72.3% of the total seed count found at depths ranging from 0 to 10 cm. Shallow ploughing contributed to 61.1% of the weed seeds at the same depth, while standard ploughing accounted for 43.7% of the total seed quantity. Ameena *et al*. (2014) found that controlling *C. rotundus* using cultural or mechanical approaches is challenging due to the persistent viability of its tubers and their ability to sprout repeatedly.

In situations where a significant accumulation of weed seeds occurs on the soil surface under continuous zero-tillage systems, deep tillage can be employed to bury the weed seeds at depths beyond their typical emergence range (Chauhan and Johnson, 2010a). Zhang *et al*. (2019) found that rotary tillage introduced newly shattered weedy rice seeds into the soil at various depths within the soil profile. Shallow tillage predominantly ploughed the weedy rice seeds into the shallow soil, while deep tillage buried some seeds at greater depths (Ameena, 2015). However, it is crucial to consider the persistence or longevity of weed seeds buried during previous deep-tillage events. If seeds buried during previous deep tillage operations remain viable, they have the potential to reinfest the field once they resurface in the soil.

Burial depth effect on germination and emergence

Tillage practices play a significant role in the dispersion of seeds within the soil profile in arable soils. The optimal burial depth refers to the depth at which the majority of sown seeds can successfully develop into established plants. Some species are capable of emerging at shallower burial depths, but their emergence is greatly inhibited when the seeds are buried deeper. For instance, *Ischaemum rugosum* (Lim *et al*., 2015), *Chromolaena odorata*, *Leptochloa chinensis* and *Echinochloa colona* (Chauhan and Johnson, 2010a) experienced complete inhibition of seedling emergence when buried at a depth of two cm or more. *Echinochloa colona* demonstrated 97% seedling emergence when sown on the surface, but this percentage dropped to 73%, 12% and 0% when buried at depths of 0.2 cm, 0.5 cm and 6 cm, respectively (Chauhan and Johnson, 2009). *Trianthema portulacastrum*, on the other hand, exhibited 96% seedling emergence when the seeds were placed on the soil surface (Vanijajiva, 2014). Weeds like *Melochia corchorifolia*, *Eleusine indica* and *Mimosa invisa*, have the ability to germinate even at depths greater than 6 cm (Chauhan and Johnson, 2010a). The fresh seeds of *Schoenoplectus juncoides* collected after physiological maturity failed to germinate under laboratory conditions. This could be attributed to seed dormancy exhibited by the weed (Umkhulzum *et al*., 2019). As considerable amount of the seed bank stays on the soil surface after crop planting, greater seedling emergence from seeds on or near the soil surface shows that no till farming practices may encourage the emergence of these small seeded species (Chauhan *et al*., 2006). The rise in chlorophyll content indicates an enhancement in PS II photochemistry, production of photosynthates and accumulation of dry matter (Pooja *et al*., 2023). According to Zhang *et al*. (2019) rate of emergence of seedling in weedy rice increased as the seed burial density decreased whereas the increase in seed burial depth decreased the rate of seedling emergence. The decrease in germination observed with increasing burial depth is attributed to inadequate light and gas exchange between the environment's surrounding the buried seeds.

CONCLUSION

Understanding weed ecology is crucial for effective weed management due to several factors. Firstly, there has been a shift towards weed species that are increasingly difficult to control, as some highly resistant weeds have replaced those susceptible to commonly used herbicides. Additionally, resistance to herbicides has emerged in many weed species and certain weeds show insensitivity to specific herbicides. Multiple resistance to herbicides from different chemical classes has also been observed. Moreover, current management approaches often fail to address weed challenges in monoculture agriculture and herbicides can have detrimental effects on the environment. Economic constraints have limited the development of alternative control methods. New weed issues are arising in reduced and minimum tillage systems. Given the diversity of weed communities, there is no one-size-fits-all solution for weed management. Ecological weed management focuses on creating an unfavourable environment for weed establishment, growth and reproduction, rather than relying solely on specific control measures. A deeper understanding of the underlying mechanisms that influence weed success or failure in agricultural ecosystems can facilitate the development and implementation of effective ecological weed management strategies for crops.

Conflict of interest

I declare that the authors do not have competing interest.

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