



ISSN Print: 2617-4693
 ISSN Online: 2617-4707
 IJABR 2025; SP-9(2): 565-573
www.biochemjournal.com
 Received: 15-11-2024
 Accepted: 20-12-2024

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Allelopathic approaches for weed management

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DOI: <https://doi.org/10.33545/26174693.2025.v9.i2Sh.3839>

Abstract

Weed management sustainably become mandatory due to the yield losses caused by weeds, especially in low-input agricultural systems and environmental pollution caused by the excessive use of synthetic herbicides. To deal with these issues, allelopathy is gaining popularity which is a biochemical phenomenon having the chemical interactions between plants by the release of secondary metabolites into the environment. Many important crops are recognized for the potential of allelopathy, farmers are still not aware to use such knowledge practical use. Therefore, it is important to assist advisors and farmers in assessing whether allelopathy can be effectively implemented to manage the weed eco-friendly. Here, we aim to give a broad and efficient review on the herbicidal potential of allelopathy. Allelochemicals have the potential to be used as a herbicide. Allelopathy may help in weed management through the inhibition of weed seed germination and seedling growth. Weed-suppressing ability in several crops is either due to the exudation of allelochemical compounds released from living plant parts or from decomposing residue. As these are free from all the problems associated with present herbicides, they could be used directly as herbicides, and their chemistry can also be used to develop new herbicides. A lot of secondary compounds are produced by plants and microorganisms, and many of these are phytotoxic to weeds, thus having the potential to be used as herbicides. This review shows how important the role of allelopathy for sustainable weed management is and, at the same time, indicates the need for field experiments, mainly under an integrated approach.

Keywords: Allelopathy, secondary metabolites, eco friendly, sustainable weed management

Introduction

The most important biotic constraint for crop production are weeds having the loss of yield ranging from 45-95 percent which depends upon the environmental conditions and agronomical practices (Oerke, 2006) [46]. Herbicides usage in high volume causes many changes in plant growth viz., growth inhibition, leaf chlorosis, albinism and necrosis (Rao and Madhulety, 2005) [85]

Weeds are presently managed by many conservative and recent approaches. The reason behind the use of common use of synthetic herbicide is quick response and accessibility (Santos, 2009) [65]. Allelopathy produced by the plants having enough support and capability for sustainable management of weed. Development of herbicides from the plants will be safe to use and they are also biodegradable which proves that allelochemicals of plant derivatives having potential for selective weed management biologically. The occurrence of allelopathy refers to chemical interactions between plants of all types. Under this process the leachates or chemical exudates releases from parts of the plants viz. stem, roots, leaf of a plant can inhibit the growth of a neighbor plants (Scrivanti *et al.*, 2011) [69].

The allelopathy term was given by plant physiologist Molisch (1937), University of Vienna, Austria constitute two Greek words, allelon meaning 'mutual' and pathos meaning 'to suffer', harmful effects on each other (Chon & Nelson, 2012) [12] and therefore can be used both positive and negative interactions. Allelopathy of one plant effects directly or indirectly on the on the germination, growth or development of surrounding plants (Dhanpal *et al.*, 2019) [18]. We can also say that it is a biological process through which an organism developed one or more biochemical that affects the survival, germination, growth and reproduction of other organisms.

Studies on the potential use of the allelopathic process in agriculture have been gaining thrust among the scientists all over the world, since the seventies (Singh *et al.*, 2001) [74, 76]. The recent focus of research is more concentrated on weed management practices which are safe

for humans along with quality of eco-friendliness (Bhadoria, 2011) [7]. The allelopathic phenomenon which is having positive influence upon the yield of agriculture should take into the consideration for the planning of agricultural activities like growing of cover crops, replanting and rotational cropping (Chon *et al.*, 2006) [13]. Therefore, allelopathic potential of plants are consider as alternative for the direct or indirect control of weed growth and to overcome the problems which arises from the high use of pesticides (Appiah *et al.*, 2015a) [3]. The most useful alternative for the chemical traditional control is allelopathy (Macias *et al.*, 2007) [42] in several forms of delivery, including the deployment of allelopathic crops, cover crops, bioherbicides which is derived from plant material, mulches or intercrops (Scavo & Mauromicale, 2021) [68]. Regardless of its extensive history, allelopathy remains underutilized for the management of weed (Willis, 2007) [98]; behind this less adoption is continuing uncertainty over the stability and applicability of allelopathy, depends upon the inherent complexity of proving the interaction, and prevailing limitations in experimental practices.

Allelopathins (Dorota *et al.*, 2013) [19] are the produce of the secondary metabolism and also primary metabolites which is non-nutritional (Weir *et al.*, 2004 and Iqbal & Fry, 2012) [94, 26]. These compounds belong to several to several chemical groups involving: terpenes, flavonoids, strigolactones, fatty acids, coumarins, benzoquinones, tannins, lignin and nonprotein amino acids. These wider range of biochemicals are synthesized through the shikimate pathway (Hussain and Reigosa 2011) [25] or in the case of essential oils, from the sopenoid pathway. Allelochemicals can be categorized into 10 groups (Li *et al.*, 2010) [40] on the basis of their different properties and structures:

1. Water-soluble organic acids, straight-chain alcohols, aliphatic aldehydes and ketones
2. Simple lactones
3. Long-chain fatty acids and polyacetylenes
4. Quinines (benzoquinone, anthraquinone and complex quinines)
5. Phenolics

6. Cinnamic acid and its derivatives
7. Coumarins
8. Flavonoids
9. Tannins
10. Steroids and terpenoids (sesquiterpene lactones, diterpenes and triterpenoids).

Crop Allelopathy

An allelopathic crop should have the (i) vegetation patterns in its surrounding, (ii) influence the growth of other crops or the same crop growth if grown in succession, (iii) causing the problems of soil sickness due to the allelochemicals build-up in the soil, (iv) produce and release the bioactive allelochemicals into the environment. Among the large number of plant species which are recognized to have allelopathic properties, mainly are weeds. The latest assessment found ~240 allelopathic weeds (Qasem *et al.*, 2001) [53], but from the past 20 years several other weed species were recognized to show allelopathic effects. Along with the weeds, many woody crops and herbaceous crops shows the allelopathic traits both on other crops and weeds (Tesio, *et al.* 2010) [88]. One of the important allelopathic crop is sorghum, the activity of the allelopathy in sorghum varies across the environmental conditions, cultivars and plant growth stages. Phenolics, hydrophobic p-benzoquinone (sorgoleone) and cyanogenic glycoside (dhurrin) are the important allelochemicals (Weston *et al.*, 2013) [95]. The most potent allelochemical of sorghum which is exuded from its roots is sorgoleone. The responsible part of the plant for the exudation of sorgoleone is root hair cells (Weston *et al.*, 2012) [97]. The manipulation in the allelopathic activity of sorghum can be done by using sorghum residues as mulch, as cover crop and intercrop or inclusion of sorghum cultivars in a crop rotation. The most important allelopathic crop under consideration is sunflower. Numerous species of weed have also been founded to be suppressed by sunflower allelopathy. Alsaadawi *et al.*, 2012 [12] evaluated the potential of allelopathy in sunflower cultivars.

Table 1: Important crops showing allelopathic properties with corresponding allelochemicals involved.

Crops	Scientific name	Allelochemicals	References
Rice	<i>Oryza sativa</i> L.	Phenolic acids	Rimando <i>et al.</i> , 2001 [60]
Wheat	<i>Triticum aestivum</i>	Hydroxamic acids	Niemeyer, 1988
Black Mustard	<i>Brassica nigra</i> L.	Allyl isothiocyanate	Weston, 1996 [96]
Sweet clover	<i>Melilotus</i>	Phenolics	Weston, 1996 [96]
Oat	<i>Avena sativa</i> L.	Phenolic acids and Scopoletin	Weston, 1996 [96]

Approximately more than 3200 species belongs to Brassicaceae family, of which the Brassica genus involves numerous highly allelopathic crops like cabbage (*B. oleracea*), Indian mustard (*B. juncea*), canola (*Brassica napus* L.), cabbage (*B. oleracea*) and black mustard (*B. nigra*). Rehman *et al.* 2018 reviewed the Brassica allelopathy use for management of weed and also documented that glucosinolates (mainly nitriles and isothiocyanates) and the endogenous steroidal compounds brassinosteroids (e.g. 28-homobrassinolide, brassinolide and 24-epibrassinolide) are responsible for their phytotoxicity. In some leguminous crops significant evidence of allelopathic effects has been reported. The most important example is alfalfa (*Medicago sativa* L.) which is most commonly used as dead or living mulch in management of

weeds and broadly studied also as a model plant in autoallelopathy (Chon *et al.*, 2002 and chon *et al* 2006) [11, 13, 14]. Other examples of allelopathic Fabaceae plants are the peanut (*Arachis hypogaea* L.), common bean (*Phaseolus vulgaris* L.), faba bean (*Vicia faba* L.) and recently, liquorice (*Glycyrrhiza uralensis* Fisch.) (Li *et al.*, 2014, Ren *et al.*, 2017 and Asaduzzaman *et al.*, 2012) [41, 58, 4]. The phenolic acid is responsible in Fabaceae allelopathy such as caffeic, coumaric, p-hydroxybenzoic, vanillic, salicylic, benzoic, salicylic etc. The Solanaceae family is gaining in interest for the potential of allelopathy traits in tomato (*Solanum lycopersicum* L.) and the major identified its major root allelochemicals as the alkaloid-tomatine, the steroid stigmaterol, the furocoumarin bergapten and orobanchol, the strigolactones solanacol and strigol, etc.

Important phytochemical advances were also made in the discovery and identification of tobacco (*Nicotiana tabacum* L.) (Baek *et al.* 2017) ^[5] and red pepper (*Capsicum annuum* L.) allelochemicals (Sun *et al.*, 2015) ^[86].

Allelopathic interaction

Allelopathic interactions between crops and weeds in agro ecosystems can be of four types as describes below:

Table 2: Weed on crops (Seema *et al.*, 2017) ^[70]

Weeds	Effect on	Cause/source	Effect
Wild oat (<i>Avena fatua</i>)	Wheat, barley (<i>Hordeum vulgare</i>), oat (<i>Avena sativa</i>)	Root exudates	Growth of leaves and roots of wheat
Bermuda grass (<i>Cynodon dactylon</i>)	Barley	Decayed grass residues	Seed germination, root and crop growth
Johnson grass (<i>Sorghum halepense</i>)	Sugarcane (<i>Saccharum officinarum</i>), maize, soybean	Root exudates and decaying residues	Root and shoot growth
Field bind weed (<i>Convolvulus arvensis</i>), Canada Thistle (<i>Cirsium arvense</i>)	Cabbage (<i>Brassica oleracea</i> var. <i>capitata</i>), carrot (<i>Daucus carota</i> subsp. <i>sativus</i>), tomato	Root exudates	Seedling growth
Cogon grass (<i>Imperata cylindrica</i>)	Tomato (<i>Solanum lycopersicum</i>) and cucumber (<i>Cucumis sativus</i>)	Root exudates	Inhibit growth

Table 3: Weed on another weed (Seema *et al.*, 2017) ^[70]

Weeds	Effect o	Cause/source	Effect
Cogon grass	Button weed (<i>Borreria hispida</i>)	Exudates of inhibitory substances through rhizomes	Inhibits the emergence and growth
Johnson grass	Giant foxtail (<i>Setaria faberi</i>), Large crabgrass (<i>D. sanguinalis</i>)	Living and decaying rhizomes and leaves	Inhibit growth

Some rice genotypes have already been known which also having the allelopathic effects on weeds. Allelopathic effect

of crops and weeds on other weeds may be used to get natural herbicide.

Table 4: Crop on weed (Seema *et al.*, 2017) ^[70]

Weeds	Effect on	Cause/source	Effect
Coffee (<i>Coffea Arabica</i>)	Spiny amaranth (<i>Amaranthus spinosus</i>)	1,3,7-trimethylxanthin	Inhibit germination
Maize	Associated weeds	Increased Catalase and Peroxidase activity by root extract	Inhibit growth
Oat, wheat, pea (<i>Setaria faberi</i>)	Lams quarter (<i>Chenopodium album</i>)	Root exudates	Suppress growth

Crop on another crop

The compounds released from the top of chickpea, soybean and beans lessen the uptake of P by the corn plants.

Allelopathic effects also seen of pear millet on the germination and seedling growth of lentil, wheat, barley etc. and aqueous root extract of soybean on rape and mustard.

Table 5: Mechanism of Action of Allelochemicals (T.K. Das, 2015) ^[15]

Mechanism of action	Allelochemicals involved
Cell division and cell elongation inhibition and production of ultrastructure of cells	Cinnamic and coumarin
Inhibition of gibberellic acid (GA) or indole acetic acid (IAA) induced growth	Polyphenols
Inhibition of photosynthesis	Polyphenols, quinones
Inhibition of protein synthesis and organic acid metabolism	Cinnamic acid and ferulic acid
Changes in membrane permeability to ions, water, certain biomolecules etc	Salicylic acid, benzoic acid and cinnamic acid
Inhibition of mineral nutrient uptake	All phenolic acids
Effect of corking and clogging of xylem element and internal water relations	Phenol, salicylic and cinnamic acid

Allelopathic Approach in weed management

Allelochemicals as bio herbicides

The natural products of biological origin are generally defined as Bioherbicides derived from living organisms or their secondary metabolites to lessen smother the population of target weed without affecting the environment (Hoagland *et al.*, 2007) ^[24]. The mode of action of allelochemicals and herbicides are similar (Soltys *et al.*, 2013) ^[81]. The majority of the allelochemicals are partially or completely water soluble. Therefore its application becomes easy without addition of surfactants (Dayan *et al.*, 2009) ^[17]. To fulfill the

purpose of this review allelochemicals which are derived from plants are considered. The allelochemicals derived from plant called bioherbicides are gaining the popularity with the aim of overcoming weed-resistance phenomena, reducing synthetic herbicides use and minimizing herbicidal environmental impact having the many advantages: eco-friendly chemical structure (absence of 'unnatural' rings, sp³-hybridized carbon molecules, high number of oxygen and low amounts of 'heavy atoms'), opportunity of new molecular targets in weeds, high degradability in water and soil and social public acceptability (Dayan *et al.*, 2012) ^[16].

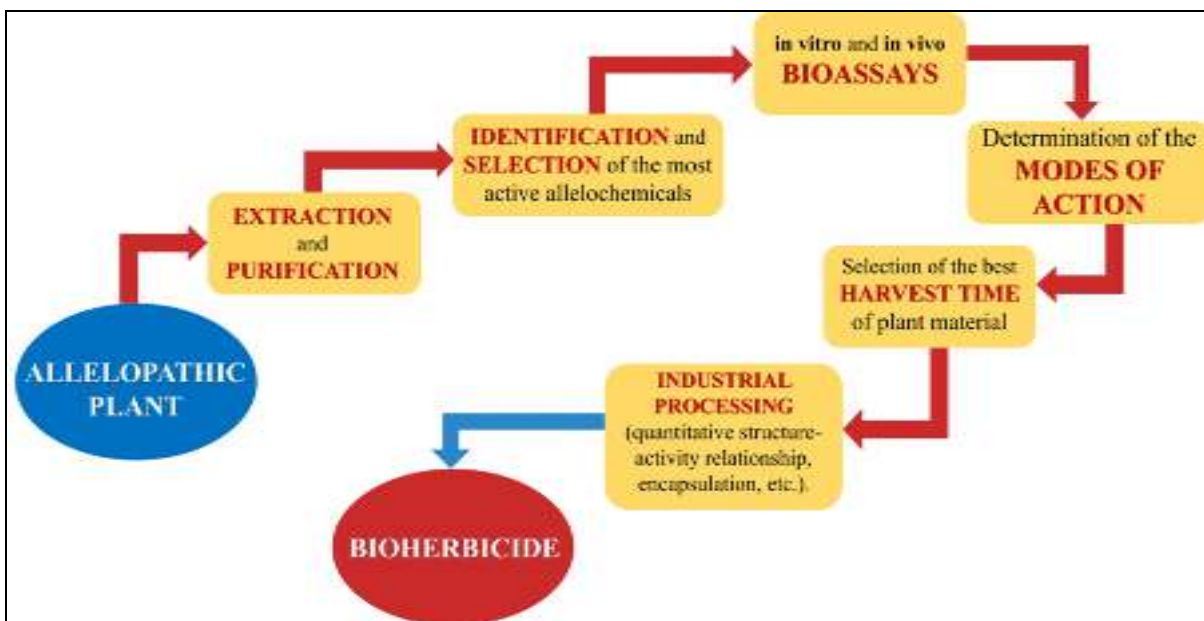


Fig 1: Commercial bioherbicide production steps

The best genotype selected after the establishment of allelopathy potential, and then there is need of extraction of allelochemicals after that purification and identification. Then there is requirement to check the both *in vitro* and in field conditions on a broad range of different weeds. Once the choice of the harvest time (i.e., maximum concentration of allelochemicals in plant tissues) has been made, a number of industrial processes such as quantitative structure-activity relationship (QSAR), chemical stabilization, encapsulation, etc., complete the whole process. (Scavo *et al.*, 2021) ^[68]

Allelopathic plants as cover crops

Cover crops are the plant species which are introduced in cropping especially when the soil is fallow and this cover crops are not the main crop. Additionally it can also be used in non cultivated areas to conserve the soil moisture, prevent the erosion and for the conservation of nutrients in the soil (Gallandt *et al.*, 1999) ^[23]. Cover crops also show their importance in the rotational cropping system due to rapid growth and form a cover over the surface of the soil and prevent the germination and growth of weed species (Singh *et al.*, 2001) ^[74, 76]. Fujii, 2003 ^[22] suggested the allelopathic cover crops use to inhibit the other plants growth as one of the important ways in the integration of the allelopathic concept in weed control. The test of 53 species of plant cover crops has been done by Fujii, 2001 ^[21] using the plant box method. The study shows that certain cover crops having the capacity to be used to weed control. These lower crops are *Vicia villosa*, *Hordeum vulgare*, *Mucuna pruriens*, *Avena sativ* and *Secale cereal*. During the summer season, when the fields were dry, *Vicia villosa* was able to control weeds in the paddy fields by forming a thick cover on the paddy soil surface (Fujii, 2001) ^[21]. Cover crops can also help to reduce the weed seed bank in conservation till systems. The reduction of seed banks (30-70 percent) of weeds in the upper layers of soil like *Digitaria sanguinalis* (L.) Scop., *E. indica*, *Datura stramonium* L. and *Amaranthus retroflexus* L. can be done by some cover crops such as oat and Hairy vetch (Dube *et al.*, 2012) ^[20]. Eventually, a variety of allelopathic cover crops can reduce the weed infestation in field crops.

Allelopathic Plant Residues

Plant residues which are allelopathic which have been left in the field deliberately or accidentally shows their suppressing behavior. In the same way, residues of maize also found to reduces the weed biomass in the next crop (broccoli) by 22-47 percent in an organically farmed maize broccoli rotation (Bajgai *et al.*, 2013) ^[6]. The mulches are gained more success than the control treatment to suppress the weeds (35-80 percent) in terms of biomass and density and oat is one of the most efficient of the mulches in suppressing weeds. On the other hand, oat had a detrimental impact on yield of tomato but hairy vetch produced considerable raise in yield over the control. Oat and hairy vetch residue mulch effectively reduced weed density in black pepper (*Polygonum oleracea*, *A. retroflexus*, *C. album* and *Polygonum aviculare* L.) in a comparable study (Campiglia *et al.*, 2012) ^[10].

Dead Mulching

The preventive weed control identified as surface-applied mulches to control the weed by affecting the soil weed seed bank, weeds establishment and weed emergence (Scavo *et al.* 2020) ^[67]. Sturm *et al.*, 2016 ^[84] evaluated ten different cover crop mulches and mixtures in sugar beet cultivation and get different results relevant to cover crop type and target weed. Particularly, there is observation of reduction of weed density by all cover crops as compare to untreated control, with the highest reduction caused by cover crop mixtures because of synergistic effect of allelochemicals. In comparison to the incorporating plant residues into the soil, dead mulching is mostly less efficient because of the more release rate mediated by soil microorganisms and to the longer persistence of released allelochemicals (Lemessa *et al.*, 2014) ^[39].

Allelopathy Intercrop: Intercropping with Cultivars Possessing Allelopathic Potential

Kandhro *et al.* 2014 ^[30] studied the two allelopathic crops intercropping i.e. sunflower and sorghum for management of weed in cotton. They observed that both intercrops increase the seed cotton yield by 17 to 22 percent by

suppressing the weeds by 60 to 22 percent in cotton. Sorghum and sunflower harvesting also leads to increase in crop yield, land productivity and economic benefits. Weed intensity lower down by crops having potential of allelopathy and therefore, increases output in agriculture when intercropped with other crop plants. As an example, maize intercropped with cowpea on alternate ridges helped to suppress weed *Echinochloa colona* (L.) Link., *Chorchorus olitorius* L., *Portulaca oleracea* L. and *Dactyloctenium aegyptium* (L.) Willd. Intensity by ~50 percent and also improved land use efficiency (Saady, 2015) [66].

Green Manuring

Masilionyte *et al.*, 2017 [44] reported that white mustard (*S. alba*), particularly when combined with buckwheat (*F. esculentum*), showed a higher reduction in the weeds number and biomass of weed than narrow-leafed lupine (*Lupinus angustifolius* L.) in a mixture with oil radish (*Raphanus sativus* L.), because of its biomass production and release of allelochemicals into the soil. Alonso-Ayuso *et al.*, 2018 [1] studied barley vetch (*V. sativa*) and (*H. vulgare*) green manure in a long-term field experiment involving two cash crops: sunflower and corn. As a whole, replacement of a winter fallow by cover crops had good effects on weed

density, soil seedbank and diversity, with both cover crops showing a weed density reduction of 51-63% in spring, where as barley green manure smothers winter weeds more efficiently than vetch. Although, there was no effect on weed seed bank even after 10 years of cover cropping. Additionally, only during 1 year did the weed control efficacy increase as the cover crop termination date was delayed.

Limitation of Using Allelopathy Effect

There are numerous limitations in adapting allelopathy potential as a tool for the management of weed because of plant itself produces allelochemicals and the environmental conditions also. The phytotoxic levels of allelochemicals are influenced by both biotic and abiotic factors like temperature, plant age, temperature and soil conditions, nutritional status, microflora and treatment of herbicide effects the production as well as release of allelochemicals, whereas allelopathy is also considered under the genetically influenced factor. When allelochemicals enters into the soil, it undergoes numerous transformation due to many factors regarding soil environment (chemical, Physical and biological), it may be toxified or detoxified due to effect of allelochemicals.

Table 6: Biotic and Abiotic Factors affecting Plant Allelopathy (Zixiang *et al.*, 2023) [102]

Biotic Factors		
Factor	Target Plant	Description
Plant competition	Rice (<i>O. sativa</i>)	Barley grass may emit signaling chemicals such as (-)-loliolide from their roots to stimulate the generation of protective metabolites such as momilactone B and tricin in rice against competitors.
Animals	Rice	Herbivore feeding enhances the Chemo sensory effect of rice.
Insects	Maize	When the beet moth feeds on corn, the corn releases volatile terpene molecules into the air, triggering a chemical defense mechanism that attracts the moth's natural enemies.

Abiotic Factors:		
Factor	Target Plant	Description
Light	<i>O. Sativa</i>	Increases the concentration of momilactone B in the shoots and roots of rice seedling
Temperature	<i>O. Sativa</i>	Extracts of roots and shoots had the highest amount of phenolic and flavanoid substances
Drought	<i>P. sativum</i>	Bioaccumulation of bioactive chemicals terpenes and phenols
Carbon dioxide	<i>B. Napus</i>	Volatile terpenoid emissions
Nutrient deficiency	<i>O. sativa</i>	Allelochemicals produce in nitrogen and phosphate limited conditions

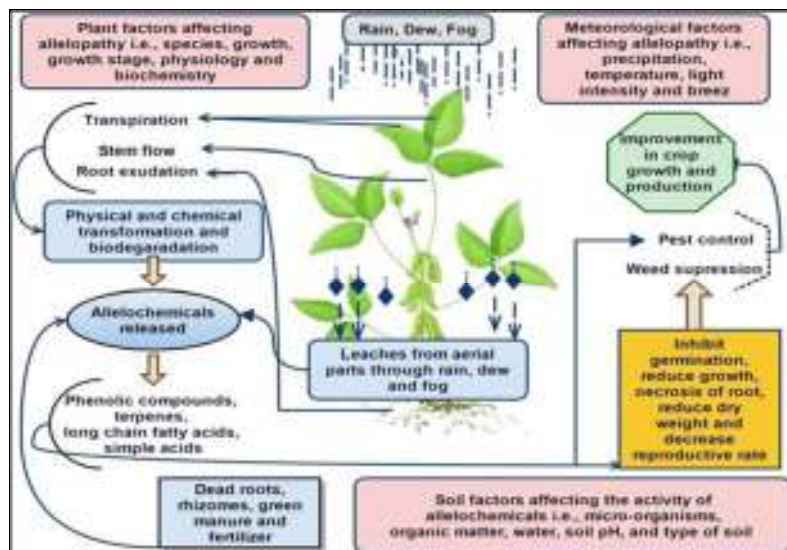


Fig 2: Complete process of allelopathy and factors affecting allelopathy (Compiled: Shah *et al.* 2016) [71]

Conclusion

In this review, we have introduced the allelopathy as a new tool to make weed management more sustainable. More rigorous testing's are required for the agronomic performances of allelopathic cover cropping, crop rotation and application through bioherbicides and need to focus on the field trials setup with the knowledge of biotic and abiotic factors, with the dual aim of considering both direct, indirect and synergistic allelopathic effects and having a broad overview of these will help to increase the allelopathy efficiency as an eco-friendly tool for weed management in agroecosystems, increase its spreading among farmers and stakeholders and decreasing the use of synthetic herbicides and thus the development of weed-resistant ecotypes.

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