The Pharma Innovation Journal 2022; 11(4): 463-466

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(4): 463-466

www.thepharmajournal.com
Received: 18-02-2022
Accepted: 24-03-2022

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Impact of soil properties on persistence of herbicides: A review

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Abstract
Use of herbicides in modern agriculture is increasing due to scarcity of labour, options in time of application of herbicides and reliable control of weeds. But their excessive and repetitive use may lead to Phyto-toxicity in crops, residual effect on succeeding crops and health hazards to human and livestock populations, due to accumulation of residues in soil, crop produce and groundwater. Therefore, there is a need to monitor herbicide residues in crop produce to assess build-up, bio-magnification and bio-accumulation to avoid their adverse effects. When a herbicide is applied to a soil, a number of processes immediately start to remove it. Its persistence, however, depends upon soil properties and climatic conditions. Among soil properties, pH, temperature, moisture, organic carbon content, microbes and texture play major role in degrading herbicides. The present review aims to provide a better insight on the effect of different soil properties on persistence of herbicides by examining the vast literature.

Keywords: Herbicide, persistence, degradation, soil properties

1. Introduction
Understanding herbicides degradation in soils is a key for assessing their persistence and risks of their transfer in the environment. Usually, degradation studies carried out in the field are considered relevant for their integrating of the effects of the entire uncontrolled phenomena causing degradation of the applied herbicides in soil. After application, the herbicide may dissipate through volatilization (Stranberg and Scott-Fordsmand, 2004) [40], photodecomposition (Sondhia, 2012) [33], leaching and runoff (Weber *et al.*, 2006; Kocarek *et al.*, 2016) [42, 16]. The amount of herbicide which has not volatilized and photodecomposed degrades physically, chemically or get metabolized in soil or subject to leaching (Lee *et al.*, 2000). Mineralisation is considered as the last step of pesticide degradation leading to its complete removal from the soil.
Under given climatic conditions, the persistence of herbicides in soil is affected by surface mulch, texture, organic matter content, pH, temperature, moisture, and types and abundance of microorganisms in soil.

2. Effect of soil properties on persistence of herbicides
The literature effect of soil properties and surface residues (mulch) on persistence of herbicides has been reviewed and presented under the following heads:

2.1 Surface mulch: The crop residues on soil surface led to interception of applied herbicides, particularly, apolar or low polarity herbicides like pendimethalin (Zablotowicz *et al.*, 2000) [43]. The interception may sometimes be negligible (Banks and Robinson, 1982) but more often ranges from 40 to 70% of the applied dose of pre-emergence herbicides depending on the amount and type of crop residues (Sadeghi and Isensee, 1997) [27]. Based on the nature of herbicide, this interception may generate photodegradation (Selim *et al.*, 2003) [28]. Crop residues may also limit soil aeration slowing down the activities of microorganisms involved in herbicide degradation (Sorenson *et al.*, 1991) [39]. Herbicide once intercepted by the mulch may be washed easily and reach the soil surface on first rainfall depending upon the intensity of rainfall (Alister *et al.*, 2009) [1]. Therefore, the timing between herbicide application and first rainfall event strongly influences the quantity of herbicides reaching the soil surface under CA systems (Isensee and Sadeghi, 1994) [12].

2.2 Texture: The soil texture largely influences organic matter, aeration, temperature, moisture and infiltration of soil.

The rate of degradation of herbicides decreases with increase in the fineness of soil texture (Dharumarajan *et al.*, 2008) [6]. Coarse-textured soils promote leaching of the applied herbicides to deeper depths as compared to medium or fine-textured depending upon the time and intensity of the rainfall received after their application (Sondhia, 2007) [34]. Freundlich and Langmuir adsorption isotherms found to describe the adsorption and desorption behaviour of pretilachlor in different textured soils (Kaur *et al.*, 2016) [14]. They reported adsorption in the order of clay loam>sandy loam>loamy sand while it was reversed in case of desorption. It was found that adsorption is mainly governed by the clay content whereas desorption is largely controlled by organic matter content in soils. Similar results were also reported by Sondhia (2014a) [37]. They reported higher persistence of cyhalofop-butyl in clayey than sandy clay loam soil. Some of the herbicides have also been reported to leach under irrigation or higher intensity rainfall just after the application of the herbicide (Sondhia, 2009) [36]. Heavier soil (clay loam) found to transmit metsulfuron to a deeper depth in the soil profile as compared to light textured soil (sandy loam) owing to better aggregation and consequently resulted in retention of applied herbicide for a longer period.

2.3 Organic carbon content: In general, adsorption of most of the herbicides in soil increases with increase in clay and organic carbon contents but at the same time the organic matter also influences the microbial population in soil which play a major role in degradation of herbicides in soil (Gomez *et al.*, 2014) [9]. The nature of organic matter fractions and their reactivity towards herbicides are influenced by the type of tillage (agricultural system) and nature of crop residues. Higher organic carbon in surface soil result in higher persistence of herbicides in surface as compared to lower depths in soil (Ulbrich *et al.*, 2005) [41]. Fuscaldo *et al.* (2016) [8] identified soil organic matter as a major contributor to persistence of herbicide as compared to other properties of soil. Positive correlation has been reported between the organic matter content and persistence of herbicides in soil (Maheswari and Ramesh, 2007; Janaki *et al.*, 2013; Rajasekharam and Ramesh 2015) [18, 13, 25]. However, addition of FYM at the rate of 10 t ha^{-1} decreased the half-lives of herbicides by 5.84 days (Sondhia, 2014b) [38].

2.4 Moisture content: Higher soil moisture content decreases the hydrophobicity of organic compounds and their access to sorption sites in soil resulting in decreased herbicide retention/ persistence (Ochsner *et al.*, 2006; Dharumarajan *et al.*, 2008; Sireesha, 2011) [20, 6, 32]. Higher moisture in soil has been reported to decrease the degradation of pendimethalin and oxyfluorfen in sandy loam soil of Chile (Alister *et al.*, 2009) [1]. Half-life of terbuthylazine found to decrease with increase in moisture to a certain level in mineral (50% of field capacity) as well as in organic soil (80% of field capacity) (Shahid and Teoh, 1994) [29]. Mobility and persistence of 2, 4-D was also found to be dependent on soil water content (Gupta *et al*. 2012). Faster degradation of herbicides was reported under flooded anaerobic conditions than aerobic (Singh and Kulshrestha, 1995; Goyal and Phogat, 2003) [30, 10].

2.5 Temperature: Persistence is, generally, inversely related to the soil temperature (Raut and Kulshrestha 1991) [26]. The degradation of pendimethalin found to increase with increase in soil temperature (Sireesha, 2011) [32]. Brar *et al.*, (2006) [4] reported that the persistence of sulfosulfuron herbicide applied to sandy loam soil decreased with increase in temperature from 15 to 35 ºC. Pahwa and Bajaj (1997) [21] also found positive correlation between temperature and persistence of pendimethalin and trifluralin in soil.

2.6 pH: There are controversial results on the effect of pH on persistence of herbicides. In some cases, higher pH was found to increase the persistence of herbicides. Brar *et al.* (2006) [4] reported higher persistence in sandy loam soil of Hisar having pH 8.1 as compared acid clay loam soil of Palampur (pH 5.1). Similarly, higher pH (>7.0) was found to slow down the degradation of sulfonylurea herbicides (Paporisch *et al.*, 2020) [22]. Singh and Kulshreshta (2006) [31] found the persistence of triasulfuron to be lower with increase in acidity of soil. The dissipation of metsulfuron-methyl was faster in acidic silty loam soil as compared to high pH soil (Paul *et al.*, 2009) [23]. In some other studies, the persistence of herbicides increased at lower pH values of the soil (Grey *et al.*, 1997) [11]. The persistence of imidazolionone herbicides was higher under pH<7.0 (Neina, 2019) [19]. In general, herbicides having pH close to the pH of soil are strongly retained, not subjected to leaching.

2.7 Soil microorganisms: A large portion of the applied herbicide accumulates in surface soil where most of the microbiological activities occur. The population of microorganisms (bacteria, fungi, actinomycetes) considered efficient in herbicide degradation, is also observed higher in the surface layer, particularly, under conservation agriculture systems than that under conventional agricultural systems, and their population increases as the degree of tillage is reduced (Kabir, 2005). Microorganisms degrade a variety of carbonaceous substances including the accumulated herbicides in soil and utilize them as a source of energy for metabolic activities and physiological processes (Bera *et al.*, 2013) [3], which inturn maximizes microbial population in rhizosphere. Some herbicides, like pendimethalin, serves as a good C and N source for soil microorganisms (Qiu *et al.*, 2009) [24]. Among microorganisms, actinomycetes have better ability to utilize pendimethalin under controlled conditions (Kocarek *et al.*, 2016) [16]. Kulshreshta and Singh (2006) [17] evaluated the role of soil microbes in degradation of pendimethalin under both aerobic and anaerobic conditions. They found relatively higher degradation by microbes ($t_{1/2}$: 33.4 days) under anaerobic conditions as compared to aerobic conditions ($t_{1/2}$: 52.2 days). Under sterilized conditions, the degradation of pendimethalin becomes slower under aerobic conditions than anaerobic. In a laboratory study, faster degradation of atrazine was reported in non-autoclaved soil than in the autoclaved (Ke-Bin *et al.*, 2008) [15].

3. Conclusion

The literature reviewed suggests that the persistence of herbicides is largely controlled by soil properties besides climatic factors. Among the soil properties, the degradation of herbicides decreases with increase in fineness of the texture and organic carbon content. Soil moisture and temperature play an important role. Higher moisture and temperature increase the degradation of the applied herbicides and hence decreases persistence. The soil pH may have both positive and negative effects on persistence depending upon the pH of the

herbicide. Most of the herbicides serve as substrate for microbial growth and hence are degraded or transformed into some other products by microorganisms present in the soil. In addition, the annual variability in climatic conditions may also cause variation in field studies hiding the effects governed by agricultural systems, and even lead to contradictory conclusions depending on the year. The literature emphasizes the importance of location specific field studies for better understanding of herbicide behavior and persistence in soil.

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