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Weed Community Dynamics under Conservation Agriculture

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India is an agrarian economy, where agriculture and the allied sectors contribute approximately 16% to the GDP, providing livelihood to 42% to 46% of the country's population. Every season, India loses a fifth to a third of its potential crop yield to weeds. This makes the weed management an important part of the intercultural practices. The adoption of conservation agricultural practices and its three interlinked principles – minimum soil disturbance, permanent soil cover and crop diversification, has changed the weed community diversity and its distribution in the soil. To effectively manage weeds in the long run under the conservation agricultural practices, it is of utmost importance to understand the shift in weed diversity in the initial and later years of CA adoption.

Introduction

With a growing world population, one of the major challenges of agriculture is to improve production while preserving the environment and the biodiversity present in agroecosystems (Robertson and Swinton, 2005). Among the different farming systems that can provide productive and sustainable agriculture, conservation agriculture (CA) has been identified as one of the most favourable options (Hobbs et al., 2008). Based on an objective of preserving agricultural soils, CA is characterized by the simultaneous and continuous application of three principles: minimum soil disturbance (no-tillage); residue cover on the soil surface (cover crops or dead mulch) and diverse crop successions and cover crop mixes (Reicosky, 2015). In India, the agriculture sector still loses a fifth to a third of its potential crop yield to weeds every season. This has made weed management agronomy's quiet battlefield. But with the adoption of conservation agriculture (CA) and its three principles across the Indo-Gangetic plains and the rainfed tracts of central and peninsular India, the weed community in the entire solum is changing shape. This has led farmers and researchers to dig deeper into the changing weed communities under the conservation agriculture for a better and more result-oriented solution.

The plough and Weed Flora

Under conventional tillage, the weeds seeds are buried deep and the germinating seedlings are killed by uprooting by the plough. It periodically resets the weed community by mixing and turning of the soil profile. By turning to conservation agriculture and practicing no-tillage, these effects of the plough on the weed seeds disappear. The result, according to a widely cited global review, is that CA "changes weed dynamics and communities and therefore necessitates adjusting weed control methods" (Nichols et al., 2015). The most consistent pattern documented worldwide is a shift away from small-seeded, shallow germinating broadleaf annuals — the weeds tillage used to bury and kill efficiently — toward grassy annuals and, over time, perennial weeds that tillage would otherwise have chopped up and destroyed (Nichols et al., 2015; Chauhan, Singh, & Mahajan, 2012). Grassy weeds are often closer relatives of cereal crops, making them harder to control selectively, and perennials regenerate from rhizomes and tubers that no herbicide reaches reliably.

In India, long term rainfed trials show the same dynamic with local characters. At the ICAR-Central Research Institute for Dryland Agriculture in Hyderabad, a seven-year study on pigeon pea-castor cropping system found that annual weed species dominated under conventional and reduced tillage, but a clear shift toward perennial weeds occurred under zero tillage; species richness, Shannon diversity, and evenness were all significantly higher in zero-till plots than in conventionally tilled ones (Pratibha et al., 2021).

The Seed bank dynamic from the surface to depth

To understand the process behind these community shifts, we have to look below the soil surface, in the weed seed bank which is the reservoir of dormant seeds. This determines every future flush of weeds. Under the conventional tillage, seeds are repeatedly redistributed through the plough layer. During this, a fraction of the weed seeds is buried deep enough to enter prolonged dormancy which can be for years. Whereas, under conservation and no-till system, there is no redistribution. The seeds shed by the present year's weeds simply accumulate at or near the surface, layer after layer. The accumulation of the weed seeds near the soil surface has two consequences, understanding both of which is imperative for proper weed management. On one hand, surface-dwelling seeds are exposed to far greater mortality risk — extremes of temperature and moisture, fungal attack, and predation by insects, birds, and rodents — so in the absence of fresh seed input, germinable seed banks under no-till can decline faster than under tillage (Nichols et al., 2015). On the other hand, surface weed seeds also get a more cohesive and favourable environment for germination by getting light, oxygen and temperature fluctuation. This results in an intense competition between weeds and crops in the early years just after switching to conservation agriculture. This weed seed bank dynamic was well recorded by a long-term rice-wheat-mungbean study at Patna, Bihar. Under a fully zero-till system across all three crops, the seed bank of *Trianthema portulacastrum* fell by 95%, and the total weed seed bank dropped by 62%, compared with a more tillage- and transplanting-intensive system, while roughly 70–90% of grass and broadleaf weed seeds were concentrated in just the top 15 cm of soil (Mishra et al., 2022). This study shows that under the conservation agriculture, the weed seed bank becomes shallower and not necessarily smaller in the short run which makes it really important for proper weed management practices in the first few years on adopting CA.

Persistence of *Phalaris minor* in Punjab

Phalaris minor, also called as littleseed canarygrass or *gulli danda* is a grass weed that has affected the rice–wheat belt of Punjab, Haryana, and western Uttar Pradesh. The continuous adoption of rice-wheat cropping system in wheat growing region of India has led to, the problem of *Phalaris minor*, causing yield reduction to the level of 30-80 (Walia, 2006). Introduced accidentally with wheat seed from Mexico in the 1960s, *P. minor* found the intensified, herbicide-dependent rice–wheat system of the Green Revolution heartland an ideal home. In this system, zero-till wheat, sown directly into rice residues without ploughing, was found to suppress Phalaris minor populations relative to conventionally tilled wheat, largely because early sowing (made possible by skipping tillage operations) let the wheat crop get a head start, and because seeds were not being redistributed into the surface layers where the weed germinates best (Chhokar, Sharma, Jat, Pundir, & Gathala, 2007; Erenstein & Laxmi, 2008). But this practice had an aftereffect. Since, zero-till wheat farmers still relied almost exclusively on a narrow set of herbicides to do the job tillage used to do, *P. minor* evolved resistance - first to isoproturon, and later to multiple herbicide groups, becoming one of the best-documented cases of multiple herbicide resistance in an Indian weed (Chhokar & Sharma, 2008).

Crop Residue and Weed dynamics

The second pillar of conservation agriculture is to maintain a permanent residue cover on the soil surface. This acts simultaneously as a physical barrier, a light filter, and when it decomposes, releases allelopathic compounds that can suppress weed germination. This practice can successfully lead to reduced weed germination especially of small seeded weed species that need light and warm, fluctuating surface temperatures to break dormancy. Further, studies conducted in India evidences the weed growth dynamic when crop residues are used as permanent soil cover. A study on weed control strategies under CA in soybean found that weed dynamics, crop productivity, and profitability all shifted with residue and tillage management, reinforcing that residue cannot be treated as a passive mulch but must be actively factored into the weed management plan (Sepat et al., 2017). In wheat–mungbean sequences under conservation tillage, weed infestation patterns and crop productivity likewise responded strongly to how nitrogen and residue were jointly managed (Nath et al., 2017). However, the positive effects of maintaining a permanent soil cover on the suppression of weeds is not uniform across all weed species. Large-seeded perennial weeds, having larger energy reserves, can often break through a residue cover favouring the grasses and perennial species of weeds that conservation agriculture already tends to promote.

The Long Arc of Weed Communities under CA

From long-running CA experiments, the findings concern the weed diversity dynamics not just in the first few seasons but over a long period of time. After adoption of conservation agricultural practices, the initial phase sees a more diverse and heterogenous weed community in the fields. But in the later stages, as the conservation agricultural practices mature and stabilize, the diversity tends to converge meaning the taxonomic and functional composition of weed communities across fields become more similar to each other. This puts the farming community in a state of caution as the weed diversity they see in the first one or two years of adoption will not be what they will have to encounter after ten or fifteen years. The weed management practices, hence, have to be continuously revised instead of following the same pattern over all the years.

Conclusion

Conservation agriculture in Indian conditions benefit soil health, water use efficiency and long-term productivity of crops. The weed management under CA, however, needs to be dealt with as an ecological issue rather than a spraying schedule. The three principles of conservation agriculture affect the weed community dynamics in the long term. The annual broadleaf weeds give ground to grasses, and eventually to perennials. The abundance of the weed seeds also shifts towards at or near the soil surface where the survival is riskier due to predation but germination is much easier as compared to when buried deep in the soil , as in conventional agriculture. Understanding of this dynamic of soil weed flora will lead to better weed management in fields under CA.

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