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CONSERVATION AGRICULTURE: AN ECO-FRIENDLY SYSTEM OF WEED MANAGEMENT IN FIELD CROPS

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Abstract
Since the conservation agriculture (CA) is spreading across the globe, information on weed dynamics and their management under CA is needed. Here, an attempt has been made to summarize the recent research on weed dynamics and their management aspects in the CA systems. Changes in patterns of tillage, planting systems, and other management strategies can alter the soil environment and lead to shifts in weed populations. Weed patterns and populations are not always stable but vary with location, crop, and herbicides use. However, in many long-term conservation management studies, a general increase in perennial weeds and grass species has been observed. No tillage increased the weed population during first season and there after decreased. Residue has significantly reduced the number of weed species and population compared to conventional agriculture systems. The development of low-dose of non-selective pre and selective post emergence herbicides, and transgenic crops has greatly improved the feasibility of CA systems.
Keywords: Conservation agriculture, cover crops, crop rotation, tillage and weeds

Introduction

Declining soil fertility, increasing production cost and shortage of agricultural laborers have severely affected the productivity and sustainability of the conventional agriculture production systems in Nepal and across the globe. Greater part of the labor cost is incurred for land preparation and weed control. Weeds are the oldest problem in agriculture and since about 10,000 BC (Avery, 2006) have represented one of the main limiting factors in profitable crop production. The crop yield losses estimates due to weeds vary considerably world- wide depending on the weed species, intensity of weed population, competitive ability of the crop, duration of weed infestation, soil fertility, climatic conditions, edaphic and management factors (Ali *et al.*, 1984). Yield losses due to weeds in maize range between 20-

100% in the Philippines, Brazil, America, Gambia, Sierra Leone and Nigeria (Carson, 1987). In order to control the weeds, herbicides are being heavily used in the developed countries. Among the herbicides, glyphosate has more than doubled in use, from 85-90 million pounds in 2001 to 180-185 million pounds in 2007 (PAN, 2011). Herbicides are believed to present a bigger threat because they are highly concentrated in the water supply, due to runoff from agricultural use (Jackson, 2013).

Therefore, there is an urgent need to promote an alternative production system fitting in particular ecologies. Conservation agriculture being an alternative system aims to achieve sustainable and profitable agriculture and subsequently aims at improved livelihoods of farmers through the application of the three principles: continuous minimal mechanical soil disturbance, permanent organic soil cover, diversified crop rotations of annual crops and plant associations of perennial crops. CA holds tremendous potentiality for all sizes of farms and agro-ecological systems, but its adoption is perhaps most urgently required by smallholder farmers, especially those facing acute labor shortages (FAO, 2001).

Irrespective of tillage systems, herbicide application has been the basis for weed management in many developed and developing countries. Herbicides and improved mechanization enabled farmers to cultivate more land with less labor. Such technological advances are also being adopted by small scale farmers of developing countries. Conservation practices often enhance and utilize soil and crop micro-environments to inhibit germination, growth, and spread of weeds. However, use of conservation practices has not been considered as one of the major tools in weed management. Therefore, in this review, we discuss the various aspects of weed management practices in the context of conservation crop production. One goal of many conservation management systems is to increase accumulation of plant residue at the soil surface, i.e. a practice that leaves about 30% or more of crop residues on the soil surface at planting (Schertz and Becherer, 1995). Plant residue accumulation protects the soil from erosion, conserves soil moisture, and enhances soil tilth. Examples of conservation management practices that fit into a weed management program include reduced tillage, crop residue, crop rotation, variable row spacing, and timing of crop planting.

Reduced tillage

No-tillage, zero tillage, ridge tillage or strip tillage describe the types of reduced tillage practice. Before use of herbicides, hoeing and mechanical tillage (plowing, disking, or cultivation) were primary weed control methods. Herbicide use increased dramatically over the last fifty years, but there was no corresponding reduction in the use of mechanical tillage because it also was useful for preparing soil for planting, improving soil aeration, enhancing availability of soil nutrients, and post-planting weed control. Herbicides accounted for 45.4% of the pesticide market in the world. More than half of the world's pesticides are used in North America and Western Europe (Dinham, 2005).

Reducing tillage inhibit weed seed germination because of shading or cooler temperatures. When weeds are controlled, crop yield and net return in no-tillage systems are often equivalent or greater than corresponding conventional tillage systems (Heather *et al.*, 1994; Kapustaand Krausz, 1993). Inadequate weed management, however, can greatly reduce yields and net returns. Seed concentration in this surface soil layer is highly dependent on regular seed input and could be expected to be less in no-till than in tilled systems if few or no new weed seed were added to the system (Carter and Ivany, 2006). In spite of no active physical action from tillage implements in no-till systems, weed seeds may move in the soil profile (Westerman *et al.*, 2006). Weed seeds may be carried by water or subject to the passive action of gravity, freezing–thawing cycles, falling into cracks created by shrinking and swelling, particularly in heavy clay soils, or in burrows created by earthworms. Seed movement may also result from the active effects of invertebrates caching seed or feeding on seed, which are expelled in casts (Eriksen-Hamel *et al.*, 2009; Milcu *et al.*, 2006; *Regnier et al.*, 2008).

Crop residues

Crop residues are known to have a chemical (allelopathic) as well as a physical effect on the growth of subsequent crops and weeds. Many authors have discussed reductions in germination and growth of weeds and/or crops following crops with retained residues. The crop residue on the surface can suppress weeds by exhibiting allelopathic effects, compete for soil nutrients and light, and/or enhance conditions unfavorable for weed germination and establishment (Teasdale, 1998). Seed germination responses to light are species specific. Some species germinate equally in light and dark [e.g., *A. fatua*, *Eleusine indica* (L.) Gaertn. *Melochia concatenata* L., and *Mimosa invisa* Mart. ex Colla], whereas others [e.g., *D. ciliaris*, *Echinochloa colona* L. Link, and *Portulaca oleracea* L.] require light to stimulate germination. Some species have an absolute light requirement for germination [e.g., *Cyperus difformis L., Digitaria longiflora* Retz. Pers. and *Eclipta prostrata* L. and these are described as positively photoblastic, a response thought to be controlled by phytochrome, a light absorbing pigment within plants. In photoblastic seeds, light exposure may convert inactive-phytochrome ''red'' to active phytochrome ''far-red'' (Rollin, 1972). In an experiment of tillage systems (no-tillage and conventional tillage) and residue levels (residue removed and residue kept) under rice-maize system since 2010 (previously the field was cropped with rice and wheat) at Rampur, Chitwan, Nepal the weed pressure (species and density) significantly reduced in residue kept plot compared to removed in both the crops of rice and maize. No-till systems have proportionally more weed seeds at or near the soil surface (Conn, 2006; Mohler *et al.*, 2006), which may be in a better position for germination. However, these seeds are also exposed to a variety of potentially detrimental factors, including cooler and more humid environmental conditions associated with the presence of crop residues, and a greater concentration of microorganisms, granivorous arthropods, and surface-applied nutrients (Davis, 2007; Menalled *et al.*, 2007).

Cover crop

Adversely, cover crops may also compete with the crop of interest. Cover crops during early spring sometimes deplete soil moisture reserves (Munawar *et al.*, 1990). To avoid competition with a subsequent crop, cover crops are usually chemically desiccated prior to planting. Early desiccation of the cover crop in the spring may lengthen the duration of adequate soil moisture conditions during the growing season. Benefits in suppressing weeds, however, often are obtained if cover crop desiccation is delayed as long as possible (Teasdale and Shirley, 1998). Teasdale and Daughtry (1993) observed that a live winter cover of hairy vetch (Vicia villosa Roth) reduced total weed density and biomass, but when the vetch was desiccated, weed suppression benefits were not as evident as weed emergence and establishment increased. Sometimes weed suppression benefit from cover crops occurs early in the season. In no-tillage corn (*Zea mays* L.), hairy vetch suppressed weeds early in the growing season without herbicides, but for season-long control and optimum yields it was necessary to use herbicide (Teasdale, 1993). Elsewhere, Weston (1990) observed increasing crop biomass and growth over time following desiccation of grass cover crops under no-tillage management. Inadequate kill of a cover crop can adversely affect the yield of the subsequent crop. Some cover crops are difficult to kill and may require more than one herbicide application (Griffin and Dabney, 1990) or varying combinations of herbicides for sufficient desiccation (White and Worsham, 1990). Cover crop species vary in their suitability for certain cropping systems. Some cover crops cannot be used during winter because of herbicide carryover from the summer crop. Certain legumes such as clover (*Trifolium sp*.) and vetch (*Vicia sp*.) species can provide overwintering habitats for plant pathogens and insects. For example, crimson clover (*Trifolium incarnatum* L.) is an alternate host for Heliothis, which presents a problem for cotton (*Gossypium hirsutum* L.). It may sometimes be necessary to kill a cover crop earlier than is optimum for weed control benefits in order to minimize potential damage to seedlings from diseases, insects, or nutrient/moisture competition from the cover crop. From a farmer's perspective, use of cover crops must be justified economically by reduced herbicide input and/or increased yield. Although cover crops may suppress winter annual weed species during early spring and provide partial weed suppression during early season crop growth, cover crop residues often do not remain long enough to provide total weed control in summer crops (Teasdale, 1998). Therefore, eliminating herbicides in summer crops is not usually a viable option. In cover crop systems, there are added costs of seed, time and labor for planting and chemical desiccation.

Crop rotation

Crop rotation involves alternating crops over a series of growing seasons. Rotating crops aids in conservation by breaking cycles that may be detrimental to long-term management of a particular field. One of these cycles may be where one weed species or weed population has an advantage under a monoculture system. Rotating to another crop may increase weed diversity and prevent one particular weed community from becoming unmanageable. Regardless of tillage, crop rotation is an effective practice to use for weed control. Because of fewer selective herbicides available and the development of weed resistance to some herbicides, it may not be practical or economical to control certain weeds in a particular crop. Crop rotations affect weed communities by determining tillage frequency and through the effects of crop attributes and associated cropping practices (Smith and Gross, 2007). Monocultures repeatedly exert the same selection pressure, favoring the buildup of species with phenotypes and phenologies similar to that of the crop, e.g., grass weeds in cereals (Koocheki *et al.*, 2009). Some short row–crop rotations may result in effects similar to that of monocultures, because of the similarity in agronomic practices and life cycle among the crops included in the rotation (Teasdale *et al*., 2004). Including a perennial crop, even for a short period, or alternating winter and spring crops where possible, will disrupt the life cycle of certain weed species, in part by changing the timing and frequency of tillage and weed control (Sosnoskie *et al*., 2006). Multiple forage harvests or earlier grain harvest (e.g., a short season cereal crop vs. long-season corn) may compromise weed seed production, potentially reducing input to the seed bank. When crops are rotated, new herbicides and practices may control problem weeds. In addition to weed control, crop rotation often results in improved crop yields and soil properties. Our own data indicate that cotton yield following rotation with corn increased by 10% in the conventional cultivar and by 19% in the glyphosate-resistant cultivar compared to continuous cotton (Reddy *et al.*, 2002). Corn yield also increased by 12% in the conventional cultivar and by 5% in the glyphosate-resistant cultivar when rotated with cotton.

Weed population shifts

Shifts in weed populations and dynamics are a concern in conservation systems. The extent and direction of weed shifts due to conservation tillage practice are dependent upon a number of factors such as region, crop, and soil type, and extensive reviews are available that discuss the effects of agronomic management practices on the composition of weed flora. Modifications of agronomic practices such as herbicide use and crop rotation, together with altered soil characteristics can result in shifts in the density and composition of weed flora. Increased soil moisture improves germination conditions for weed seeds. Weed species more tolerant to shade or that are vigorous under wet, cool conditions would have an advantage. Arrowleaf sida (*Sida rhombifolia* L.) germinates at lower temperatures and from shallower soil depths than other closely related species (e.g. prickly sida) and have the potential to be more troublesome in reduced tillage systems (Bryson, 1993). Plant residues reduce herbicide efficacy in some cases, shifting the balance in favor of certain weed species. As a result of long-term evaluations of effects of management factors on weed populations, some pictures are emerging. However, more studies need to be initiated to confirm these trends in other regions and with various management combinations. Buhler *et al.* (1994) monitored perennial weed populations after 14 years of varying tillage and crop rotation (continuous corn *vs.* corn-soybean) in the Midwestern United States. Populations of perennial weeds tended to be greater and more diverse in the reduced tillage systems (no tillage, chisel plow, ridge-tillage *vs.* moldboard plow).Grass weed species such as green foxtail [*Setaria verifies* (L.) Beau.] and foxtail barley (*Hordeum jubatum* L.) were observed with more frequency in no-tillage than in conventional tillage after five years in a corn–soybean rotation system (Wrucke and Arnold, 1985). However, they observed fewer consistent tillage differences in populations of broadleaf species. Effect of tillage and wheat in rotation with other crops (continuous wheat, fallow, spring canola, or lentil) resulted in greater weed populations in no-tillage regardless of the rotation (Blackshaw *et al.,* 1994). No clear trend in a general population shift to predominantly annual or perennial species was observed, but rather the crop rotation sequences and particular herbicides used influenced the composition of weed populations. Trends associated with reduced tillage systems in corn, soybean and winter wheat were increased incidence of common lambsquarters (*Chenopodium album* L.) and green foxtail [*Setaria viridis* var. major (Gaudin) Pospichel] (Thomas and Frick, 1993). No-tillage fields had more redroot pigweed (*Amaranthus retroflexus* L.), crabgrass (*Digitaria* spp.) yellow foxtail, yellow nutsedge (*Cyperus esculentus* L.), dandelion (*Taraxacum officinale*), and velvet leaf (*Abutilon theophrasti* Medicus) than conventional tillage. Bryson and Hanks (2001) observed over a five-year period of reduced tillage cotton and soybean a general increase in perennial weeds, especially woody and viney species. There were more variable and higher weed populations in reduced tillage, but control was possible using post emergence herbicide applications. Swanton *et al.* (1999) did not observe consistent relationships between weed density and tillage system, but found differences in composition of weed populations between conventional and no tillage systems. For example, common lambsquarters and redroot pigweed were associated with conventional tillage and large crabgrass with no-tillage.

Weed seed bank

Soil disturbance strongly influences the size, profile distribution, density and species diversity of weed seed banks. Tillage prevents the repopulation of the weed seed bank by interrupting weed growth prior to seed development. Tillage may stimulate seed germination but subsequent cultivations or herbicide applications also prevent the weed from maturing and having the opportunity to replenish seed banks. Some weed species, including many winter annuals, require an undisrupted cycle to complete the reproduction process. If the soil is disturbed by tillage, the reproduction cycle is therefore interrupted. Timing of tillage may also be an important factor depending on whether it coincides with a critical stage in the reproduction cycle. During tillage, seeds may be transported to positions in the soil profile more or less favorable for germination. Egley and Williams (1990) evaluated the effects of tillage on weed seedling emergence and observed that in the first year of tillage, a greater number of velvetleaf, spurred anoda [*Anoda cristata* (L.) Schlecht], morning glory (*Ipomoea* spp.), and pigweed (*Amaranthus* spp.) seedlings emerged in untilled plots compared to tilled plots. They concluded that tillage may have buried seeds in lower depths of soil where conditions were unfavorable for germination and emergence. An exponential decline in the weed seed bank was measured over a five-year period. The rate of reduction was greatest in the untilled area because a greater percentage of the seeds germinated the first year, and the seeds which were left undisturbed in the soil surface may have lost viability due to exposure to extreme environmental conditions (such as wet/dry or hot/cold cycles). Buhler and Mester (1991) noted increased weed seedling emergence from shallow soil depths in no-tillage. They concluded that the most important factor was that absence of tillage reduced seed movement to greater soil depth. Other factors included greater moisture near the soil surface and protective effects of plant residue which contributed to favorable germination conditions. Reducing tillage limits redistribution of weed seeds and tends to concentrate weed seed accumulation at the soil surface. Schreiber (1992) reported that most seed of giant foxtail (*Setaria faberi* Herm.) was measured in the surface 2.5 cm of soil regardless of tillage or crop rotation.

Tillage differences were observed only in the 0–2.5 cm depth, and no-tillage soils contained greater numbers of weed seed than conventional. Similarly, Yenish *et al.* (1992) found over 60% of all weed seed in the surface 1 cm of soil in no-tillage corn plots and 30% in chisel plowed plots.

Conclusion

Conservation agriculture is an alternative production system to conventional agriculture of having higher cost of production due to intensive tillage for land preparation and intercultural operations, removal of crop residues from the field and no crop rotations are practiced. Where as in CA, tillage is omitted, residues are left on the soil surface and appropriate crop rotations are followed. Weed management is one of the major challenges of CA, where no till accelerates the germination of weed seeds left on the surface during the first season and crop residue do not allow the seeds to germinate and hence decreases the weed pressure in longer run. Crop rotations affect weed communities by determining tillage frequency and through the effects of crop attributes and associated cropping practices. No tillage along with crop residue and crop rotations interact and reduces the effect of weed pressure in the crop fields. In order to arrest the labor cost to prepare the land and control the weeds, restore the soil's fertility and make the system sustainable, CA is becoming an alternative system. It is particularly applicable in countries like Nepal, where the land is being degraded, cost of production is increasing and the labor shortage is everlasting.

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