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WEEDS AND WEED CONTROL IN DRYLAND AGRICULTURE - A REVIEW

K. Ramamoorthy, A.C. Lourduraj, T.M. Thiyagarajan,
M. Prem Sekhar[1] and B.A. Stewart[2]

Directorate of Soil and Crop Management Studies,
TNAU, Coimbatore - 641 003, India

ABSTRACT

Most of the food and fibre production of the world is achieved under rainfed conditions. Among the various agronomic practices that could bring about immediate positive results in dryland areas, optimum and effective weed control is the first and foremost management practice. Hence, in this paper, an attempt has been made to review the weeds of dryland crops and cropping systems, factors influencing weed flora in dryland regions, critical period of crop weed competition, weed management in major dryland crops and cropping systems, tillage and weed management in dryland agriculture and future research priorities in the field of weed management in dryland agriculture.

Most of the World's food and fibre production is achieved under rainfed conditions. Drylands are of particular importance in South and West Asia, the Near East and North Africa. They are also major grain-producing areas in the United States, Australia and Canada (Whitman and Meyer, 1990). Dryland agriculture is a rainfed crop production system in which a major limitation is the deficiency of water. However, insects and diseases, weeds, high winds, hail and intensive rains are other hazards that can destroy crops in a matter of minutes. Many dryland areas also have severe soil problems. Consequently, dryland farming is, at best a risky enterprise (Parr *et al.*, 1990).

Among the various agronomic practices that could bring about immediate positive results in dryland areas, optimum and effective weed control is the first and foremost management practice. Weeds are no strangers to man. These have been present ever since crops began to be cultivated around 10,000 BC (Hay, 1974). When man first started to grow crops for food and fibre, he soon learned that yields were higher when weeds were removed. Thus, the concept of weed control is as old as agriculture itself. From the beginning of agriculture through the middle of the twentieth century, the plough and hoe have been the only widely employed means of weed control in agricultural crop lands.

Of the total losses caused by pests (insects, diseases, nematodes and weeds) in agriculture, weeds alone account for one-third of the loss, amounting to about 25 billion dollars and the estimated crop losses due to weeds in India amount to Rs. 16,500 millions in the year (Joshi, 1987). Misra (1962) opined that losses due to weeds in agricultural production are considerable and are sufficiently alarming as to warrant urgent attention worldwide. Parker and Enjer (1975) reported that about 10-15 per cent of the losses caused by weeds to the principal crops amount to approximately Rs.4200 million per annum.

Of the major pests of agricultural crops, weeds alone caused severe yield losses ranging from as low as 10 per cent to as high as 98 per cent of total crop failure in the dryland regions. It should be emphasised that yield losses caused by weeds could vary from crop to crop and from region to region for the same crops, in response to many factors that include : weed pressure, availability of weed control technology, cost of weed control and level of management practices (Rezene and Etagegnehu, 1994). The extent of yield

[1, 2] Present address: Dryland Agriculture Institute, West Texas, USA.

Table 1. Yield losses caused by uncontrolled weed growth

Crop	Yield (kg/ha)		Yield loss (%)	Source
	Weeded	Unweeded		
Maize	4239	1345	68	IAR (1985)
Sorghum	2779	967	65	Ahmed Sherif and Etagegnehu (1982)
Barley	2373	1964	17	IAR (1985)
Soybean	1323	59	96	IAR (1985)
Linseed	969	541	44	IAR (1985)
Tomato	8782	3266	63	IAR (1985)
Onion	10444	2078	80	IAR (1985)

reduction caused by uncontrolled weed growth in selected dryland crops are furnished in Table 1.

Dryland areas occupy extensive lands in all continents of the world. Approximately, 45 per cent of the World's land area is dryland and these areas contribute only 42 per cent of the total food grains production (FAO, 2000). The extent of drylands in various regions range from a low of 20 per cent in North Africa and Near East to 95 per cent in North Asia and East of Urals. It is also estimated that 38 per cent of the World's 6 billion people live in dryland areas. Kanemasu *et al.* (1990) estimated that the semi-arid tropics of the dryland alone contained 13% of the World's land area and were inhabited by 15% of the World's people but produced only11% of the World's food.

Immense potentiality exists for increasing productivity in dryland areas by adapting available improved weed control technology and by developing economically viable technology for managing troublesome/ noxious weeds in drylands (Ramakrishna and Tripathi, 1995). Hence, in this paper, an attempt is made to review the weed flora and available weed management technology for dryland crops and cropping systems as well as to identify future research priorities in the field of weed management in dryland agriculture.

I. Weeds of Dryland Crops and Cropping Systems

Weeds have become not only a nuisance in the tropical and sub-tropical agriculture but have a great menace in the arid and semi-arid regions of the world. Large number of weeds appear together or in succession during the rainy season when the rainfed crops are sown. Higher weed density is seen only in the rainy season due to ample presence of moisture in the soil. Also weeds react very quickly to alteration of their environment (Sen, 1990 a, b).

A large part of the loss in agricultural production is caused by few weed species. Sen and Kasera (1994) estimated that out of 3,00,000 plant species known in the world, about 30,000 are weeds. Earlier, Holm (1971) reported that of the 2,50,000 plant species that exist in the world, less than 250 species have become troublesome and more important in causing major losses to crop production. Based on life span, weed flora are classified into annuals, biennials and perennials. According to Rao (1983) majority of the weeds in the dryland regions are perennials; a smaller portion are annuals and biennials comprise only a small percentage.

Weed problem in dryland crop and cropping systems vary from one vegetation zone to another. Even within the same vegetation zone, variation in weed flora as well as intensity of weed infestation occurs because of differences in cropping systems, intensity of land use, rainfall, soil fertility and method of weed control used in individual crops. Differences in plant growth, architecture, morphology, growth cycle and canopy development influence what weed species will be most competitive in a given crop or cropping system particularly in the dryland zones (Ramakrishna and Tripathi, 1995).

Losses due to weeds are greater in rainy season crops than in post-rainy season crops because of limited field work days, and heavy labour requirements for irrigated crops in the rainy season. Repeated cultivations during the fallow period can efficiently control weeds in post-rainy reason crops grown after a rainy season fallow (Rao *et al.*, 1989).

Weed problems in the semi-arid regions are much more complex than in temperate zones because of heterogeneous soil conditions, erratic rainfall, small farm holdings, illiteracy and limited resources. Semi-arid regions has two predominant soil types, *Alfisols* and *Vertisols*. The first rains in semi-arid zones are accompanied by a flush of weeds dominated by several species live *Digitaria, Eleusine, Celosia, Cyperus, Tridax, Phyllanthus, Eragrostis, Euphhorbia, Trianthema, Brachiaria* and others especially in alfisols. The soils are sole cropped with sorghum, pearl millet - finger millet, castor and groundnut (Rao *et al.*, 1989).

In vertisols, there are two flushes of weeds dominated by *Commelina benghalensis, Cynotis cuculata* and *Euphorbia hirta* etc. Coinciding with two cropping seasons *viz.*, rainy and post-rainy season (ICRISAT, 1983).

Some perennial weeds like *Cyperus rotundus* L., *Cynodon dactylon* (L.) Pers; *Sorghum halepense* (L.) Pers. pose a serious problem because they are very competitive and difficult to control where routine crop husbandry practices are employed. The broad leaved perennials {*Convolvulus arvensis* (L.) and *Solanum elaegnifolium* Cav.} are also some of the most pernicious, ubiquitous weeds which are difficult to control (Ramakrishna and Tripathi, 1995). Weeds like *Asphodelus tenifolius* (L.) Cav. and *Ageratum conyzoides* L. are recently reported to be problem weeds in pearlmillet, maize and many other crops of dryland farming. A comprehensive list of major weeds in dryland crops is presented in Table 2.

Among the parasitic weeds, *Orabanche* spp, *Striga* spp. and *Cuscuta* spp. are fairly wide spread in semi-arid regions damaging a few crops including certain legumes, vegetables, tobacco, maize, sorghum, sudan grass, greengram and blackgram (Ramakrishna *et al.*, 1992).

In USA, Burcucumber (*Sieyos angulatus* L.) is an aggressive summer annual vine becoming a serious weed problem in maize, sorghum and wheat (Messersmith *et al.*, 2000). Cox *et al.* (1999) reported that there are several weed species in USA causing severe yield damage to crops like maize, soybean and sorghum. The most common weed species are *Abutilon theophrasti* Medik., *Setaria faberi* Herrm., *Agropyron repens* L., *Echinochloa crus-galli* (L.) P. Beauv. and *Chenpodium album* L. (Kransz *et al.*, 1995; Buhler *et al.*, 1995; Mulder and Doll, 1993; Gunsolus, 1990). Johnson *et al.* (1998) reported that *Setaria faberi* and *Ambrosia artemisiifolia* L. were the preponderant weed flora affecting the maize crop in dryland regions of USA.

II. Factors Influencing Weed Flora in Dryland Regions

Climatic, edaphic and biotic factors determine the distribution, prevalence, competing ability, behaviour, and survival of weeds. Man also plays an important role in changing the environment by crop husbandry practices (Hatfield, 1998).

1. Climatic factors: There are three primary factors that determine how well weed seeds germinate and grow in a crop canopy : availability of light, soil moisture and soil and air temperature (Egley, 1986). Light may be

Table 2. Major weeds of major dryland crops and cropping systems

Weeds	Cereals*	Millet	Oilseed crops **	Pulses ***	Fiber crop (cotton)
Ageratum conyzoides L.	X	X	-	X	-
Alysicarpus vaginalis (L.) DC.	X	X	-	-	-
Alysicarpus rugosus (Willd.) DC.	X	X	-	-	-
Amaranthus viridis L.	X	X	X	X	X
Amischophacelus axillaris (L.) Rolla Rao and Kamathy	X	X	-	-	X
Aristolochia bracteata (L.) Retz.	X	X	X	X	X
Asphodelus tenuifolius (L.) Cav.	-	-	-	-	X
Brachiaria ssp.	-	X	-	X	X
Celosia argentea L.	X	X	X	X	X
Convolvulus arvensis L.	X	-	-	X	X
Commelina benghalensis L.	X	X	X	-	X
Corchorus trilocularis L.	-	-	X	-	-
Cyanotis cucullata (L.) Kunth	X	X	X	X	X
Cynodon dactylon (L.) Pers.	X	X	X	X	X
Cyperus iria L.	X	X	X	X	X
Cyperus rotundus L.	X	X	X	X	X
Dactyloctenium aegyptim (L.) Willd	X	X	X	X	X
Desmodium dichtomium (Willd) DC.	X	-	X	-	X
Digera muricata (L.) Mart.	X	-	-	X	X
Digitaria ciliaris (Retz.) Koel.	X	-	X	X	X
Echinochloa crusgalli (L.) *P. Beauv.*	X	X	-	-	-
Echinochloa colona (L.) Link.	X	X	-	-	X
Eclipta prostrata (L.) L.	X	-	X	X	-
Eleusine indica (L.) Gaertn.	X	X	X	X	X
Eragrostis spp.	X	-	-	-	X
Euphorbia spp.	-	-	X	X	X
Hedyotis corymbosa (L.) Lam.	X	X	X	-	-
Mollugo pentaphylla L.	X	X	-	-	-
Panicum spp.	X	X	X	X	X
Pennisetum glaucum (L.) R.Br.	X	-	X	X	X
Rottboellia cochinchinensis (Lour) W.D.	X	-	-	-	-
Saccharum spontaneum L.	X	X	-	-	X
Sorghum halepense (L.) Pers.	X	X	X	X	X
Sonchus arvensis L.	-	-	X	X	X
Trianthema portulacasturum L.	X	X	X	-	X
Trichodesma indium (L.) R.Br.	X	X	X	X	X
Tridax procumbens L.	X	X	X	X	-
Vicia sativa L.	-	-	X	X	-
Xanthium strumarium L.	X	-	X	X	X

* Cereals represented by rice (up land), maize and sorghum
** Oilseed crops include groundnut, sunflower, safflower, castor, sesamum
*** Pulse crops comprise of soyabean, mungbean, blackgram, chickpea, pigeonpea
Cross (X) indicate the presence of weeds
Source : Annual Report, AICRPWC (1989) and Shetty *et al.* (1983)

necessary to induce germination and is required for photosynthesis in leaves of weed seedlings. Soil water availability is a necessary prerequisite for germination and growth, and a soil that dries quickly will not be able to support young seedling growth and development. A dry soil between crop rows and a moist soil under the canopy provide different environments for weed growth and development (Hatfield and Carlson, 1979).

Weed seed germination would be inhibited under dense canopy cover because of the fluctuations of solar radiation (Frankland, 1981). Seed germination and weed growth are functions of temperature. Temperature changes in soil and air also alters the weed seed germination and seedling growth (Luo *et al.*, 1992). Surface and near-surface soil temperature and water status influence the weed flora shift (Wiese and Binning, 1987). Soil moisture is a critical component of microclimate required for weed germination, emergence and growth (Globus and Gee, 1995).

According to Ramakrishna and Tripathi (1995), important climatic factors in the environment that affect weed flora are light, temperature, rainfall and humidity. Light intensity, quality and duration are important in influencing growth, reproduction, and distribution of weeds.

Tolerance to shading is a major adaptation that enable weeds to persist. Air and soil temperature affect the latitudinal and altitudinal distribution of weeds. Soil temperature affects seed germination and dormancy, which is a major survival mechanism of weeds (Rao, 1983).

2. Soil factors: Soil-water aeration, temperature, pH, fertility level and cropping systems influence the weed flora in dryland areas.

Some weeds are characteristically '*alkali*' plants known as 'basophiles' (pH range 7.4 to 8.5) and grow well in alkali soils. Alkaligrass (*Puccinella* spp.) and quackgrass (*Agropyron repens*) are the best examples of basophiles (Ramakrishna and Tripathi, 1995) and weeds like *Digitaria sanguinalis* and *Borreria* spp. inhabit only in acidic soils and are termed as '*acidophiles*', which have a pH range of 4.5 to 6.5.

Many weeds can adapt and grow well in soils having poor soil fertility status. For example, thatch grass (*Imperata cylindrica* Beauv.) grows well in low fertile soils and can also adapt well to soils of high fertility (Ramakrishna *et al.*, 1991a). Similarly, *Commelina benghalensis* L. thrives better in both moist and dry soil conditions (Ramakrishna *et al.*, 1991b).

3. Biotic factors: Plants and animals modify the weed flora in a variety of ways that affect weed persistence directly and indirectly. Cropping systems and agricultural practices associated with cultivation of a crop encourage or discourage the weeds growth and development (Ramakrishna and Tripathi, 1995). Sauer *et al.* (1996) reported that tillage operations will have a direct impact on the soil surface and thereby alters the weed seed germination and also weed flora shift.

III. Weed Shift in Dryland Regions

A very important dimension of agriculture in dryland regions of the world, which is undergoing a transition from extensive to intensive cultivation, is the shift in weed flora. In dryland regions of India, Ramakrishna and Tripathi (1995) found that 70% of the dryland areas are infested with the obnoxious weed known as '*baisure*' (*Pluchca lanceolata* Oliv.), Kandiari (*Carthamus oxyacantha* Bieb.), Prickly pear (*Opuntia* spp.) and Kans (*Saccharum spontaneum* L.). Variations in weed flora shift occurs from locality to locality, region to region and continent to continent. For example, weeds like mesquite (*Prosopis juliflora*), cedar, large crab grass and johnson grass were predominant in USA rangelands (Hatfield *et al.*, 1998), but these weeds are not severe in regions like Asia and Africa.

Primarily, weed flora shift can occur as a result of distribution of plants between regions and continents, use of continuous application of herbicides, frequent tillage operations and also change in cropping systems (Ramakrishna *et al.*, 1992; Sen, 1981).

Exotic weeds can become very aggressive in a new habitat if the ecological conditions are favourable. In a short period of time, they may become dominant in new areas, successfully replacing earlier established species of a plant community. *Eichhornia crassipes* (Mart.) Solns. (water hyacinth) is one of the most troublesome weed. It was introduced to India from South America around 1890, and has spread throughout India and have heavily infested deltaic regions of Ganga, Brahmaputra (Joshi, 1987). It blocks water bodies and irrigation systems besides interferes directly with rice growth and indirectly with the growth of a large number of crops because the water surfaces covered with this weed have much higher evapotranspiration rates than open water surfaces (Gopalakrishnan and Joy, 1977).

Mani *et al.* (1975) reported that *Parthenium hysterophorus* L. is mainly a wasteland weed and is considered a native of central and North America introduced to India in 1956 and had spread throughout India and now occupies more than 10 million ha of urban waste land and village grazing lands in addition to many dryland crop lands (Parihar and Kanodia, 1987). *Phalaris minor* L. is of Mediterranean origin and is reported to be a major weed in Mexico. Its presence has increased dramatically in areas cultivated to wheat and corn in recent decades in Northern India (Kundra, 1983).

Introduction of herbicides and their use is an important example of a change in agronomic practices that may cause serious changes in weed flora in an unfavourable direction. Ramakrishna and Tripathi (1995) reported that *Cyperus rotundus* became increasingly troublesome in recent years in most of the dryland areas. This weed is currently under control in mixed-plant communities since it is sensitive to shade and other weeds are stronger competitors. However, with the introduction of selective herbicides, more easily – controllable weeds were eliminated from the mixed plant community and have given ample scope for weed shifts. Ramamoorthy (1994) reported that continuous application of pre-emergence pendimethalin (stomp) in rainfed condition controlled all the total annual weeds and major weeds like *Echinochloa colona* L. and *Cleome viscosa* L. providing room for severe infestation of *Cyperus rotundus* in a rainfed rice-pulse cropping system.

The increased importance of annual grasses in reduced tillage systems has been reported frequently. Examples include that of giant foxtail (*Setaria faberi*), green and yellow foxtail (*S. viridis* and *S. glauca*), fall panicum (*Panicum dichotomiflorum*) and sandbur (*Cenchrus* spp). (Buhler and Oplinger, 1990; Wrucke and Arnold, 1985; Williams and Wicks, 1978; Forcella and Lindstrom, 1988).

Example of increased intensities of perennial weeds with reduced tillage operating include : quackgrass (*Agropyron repens*), canada thistle (*Cirsium arvense*) and foxtail barley (*Hordeum jubatum*) as reported by Merivani and Wyse (1984), Donald (1990 a,b). and Wrucke and Arnold (1985).

Intensity of large seeded broad leaf weeds such as *Xanthium strumarium*, Velvetleaf, (*Abutilon theophrasti*) sickle pod (*Cassia obtusifolia*) decreases as tillage is reduced (Buhler and Daniel, 1988; Buhler and Oplinger, 1990). But, small seeded broad leaf weeds like *Chenopodium album*, *Amaranthus retroflexus* were found to increase under no-tillage conditions (Putnam *et al.*, 1983; Buhler and Oplinger, 1990; Wrucke and Arnold, 1985).

Several factors contribute to unfavourable and unintentional shifts in weed flora composition due to changes in cropping systems. Changes in agronomic practices may also be conducive to creating opportunities for imported weed seeds to create major infestations (Ramakrishna and Tripathi, 1995). With the introduction of new high-yielding varieties of wheat in India, the wild oat (*Avena fatua* L.) problem has recently become acute. This weed has reduced the yield of new wheat varieties in large areas. Previously it was not considered a serious problem in traditional tall wheat varieties (Yaduraju and Mani, 1980). The change in the cropping system resulted in the shift of weed flora from dicots to grass (monocots) weeds (Hooda and Malik, 1980).

Rao (1983) reported that *Phalaris minor* L. was introduced to Asia during large scale import of wheat in the 1960's. It became a major weed of wheat in wheat growing regions of the world. Sen (1981) found that *Phalaris minor* infestation was maximum when rice - wheat rotation became common with the introduction of canal irrigation. Rapid spread of *P. minor* and *A. fatua* is because of their morphological similarity with the wheat plant upto flowering, their high reproductive potential, shedding of seeds two or three weeks before wheat harvest and seed dormancy (Ramakrishna and Tripathi, 1995).

IV. Critical Period of Crop Weed Competition

Most crops are sensitive to weed competition in the early stages of growth. In dryland regions, during the early stages of crop growth, weeds compete for nutrients. Later, competition for light and soil moisture becomes important, as weeds produce abundant foliage by then. Weeds absorb nutrients from the soil more rapidly and in relatively larger amount than does the crop.

NPK contents of common weeds and crops are furnished in Table 3. Lack of effective weed control during the first 20-30 days cause maximum yield losses in crops with a 100 day growth cycle. The late maturing crops like pigeonpea, castor etc. require a much longer weed free period. The extent of yield loss in rainy season crops can vary from 37% to as high as 80% depending on the severity of weed competition (Friesen and Korwar, 1982).

Late removal of weeds in a fingermillet crop resulted in a per hectare nutrient loss of 27 kg N, 3.2 kg P_2O_5, 76 kg K_2O, 15.9 kg Ca and 5 kg Mg. In another study Rao *et al.* (1989)

Table 3. Nutrient composition in different dryland crops and weed species

Plant species	Nutrients (on dry wt. basis) %		
	N	P_2O_5	K_2O
Crops			
Wheat	1.34	0.66	1.50
Maize	1.21	0.20	1.18
Sorghum	0.41	0.24	2.16
Pearlmillet	0.64	0.74	2.50
Pulses	1.24	0.54	1.31
Weeds			
Echinochloa colona	2.95	0.62	2.50
Amaranthus viridis	1.90	1.52	3.12
Xanthium strumarium	2.50	0.70	2.50
Chenopodium album	3.50	1.40	3.45
Commelina benghalensis	2.12	1.50	1.90
Phalaris minor	1.78	0.84	1.90
Cynodon dactylon	2.05	1.45	1.25
Cyperus rotundus	1.65	1.50	1.24

Source : Rao and Agarwal (1984)

reported that weeds removed 100% more Ca and N and 24% more K_2O than crop plants.

Weed competition for moisture usually occurs along with other forms of competition. It becomes critical with increasing soil moisture stress, as found in arid and semi-arid regions. Under dryland agricultural conditions, differential root development among weeds and crops ultimately determines the outcome of competition. Dryland crops that have the capacity for early and rapid root growth, relative to that of associated weeds, should maintain their competitive advantage for water throughout the growing season (Radosevich and Hott, 1984).

Black *et al.* (1989) listed water requirement of selected weed and crop species under dryland conditions (Table 4).

During moisture stress period, crops that make more efficient use of water will be expected to yield more than the less efficient crops. Similarly weeds that are more efficient in water use will have a competitive advantage over less competitive crops (Black *et al.*, 1989).

In general, for producing equal amounts of dry matter, weeds transpire more water than do most of crop plants. Therefore in dryland agriculture, the actual evapotranspiration from weedy crop fields is much more than evapotranspiration from a weed free crop field (Kanitkar *et al.*, 1960). Transpiration co-efficient of weeds ranged from 221 (*Tribulus terrestris*) to 1402 (*Tridax procumbens*) while that of maize and sorghum was 352 and 394 respectively (Kanitkar *et al.*, 1960).

Critical period of crop-weed competition is defined as a time span before and after which weed competition does not reduce the crop yield. Critical period vary from crop to crop depending upon competitiveness of weeds, environment, location, plant density, soil fertility and crop cultivar etc. In general 4 to 6 weeks period is more crucial from competition point of view in almost all the major dryland crops. The critical period of important dryland crops are given in Table 5.

Table 4. Water requirements of selected weed and crop species

Crop	Water requirement*	Weeds	Water requirement*
Efficient			
Maize	349	*Amaranthus retroflexus*	305
Millet	267	*Portulaca oleracea*	281
Sorghum	304	*Sorghum sudanense*	305
Non-efficient			
Cotton	568	*Bromus inermis*	977
Sunflower	623	*Chenopodium album*	658
Cowpea	569	*Polygonum aviculare*	678

* Grams of water required to produce 1 gm of dry matter

Table 5. Critical periods of competition and % yield reduction

Crop	Critical period	% yield reduction
Maize	15 - 40 DAS	40 - 60
Sorghum and millets	15 - 35 DAS	30 - 40
Cotton	30 - 60 DAS	45 - 85
Groundnut	25 - 55 DAS	55 - 70
Sunflower/safflower/castor	30 - 60 DAS	30 - 50
Soybean	20 - 45 DAS	25 - 35
Pigeonpea	25 - 60 DAS	40 - 60
Blackgram	25 - 35 DAS	45 - 60
Greengram	20 - 45 DAS	50 - 55

DAS - Days after sowing

Soure : Singh and Saraswat (1986)

V. Weed Control in Major Dryland Crops

The arid and semi-arid environment is ecologically fragile, and farmers in these regions generally have low resource-base. Weed control options should be those seeking to develop effective and economically viable weed management practices that will minimize drudging and be environmentally neutral or favourable. It is not only the method *per se* which affects the weed control but several others associated factors like timeliness and precision of operation. Irrespective of method of weeding, timeliness is considered to be more important than even number of operations involved. In dryland systems, for effective weed control, integration of mechanical/cultural, chemical and biological methods are most essential (Buhler *et al.*, 1992).

a) Mechanical and cultural weed control

Tillage immediately after harvest of crops helps

(i) Kill crop stubble and late-season weeds,
(ii) Conserve residual soil moisture, and
(iii) Form a rough cloddy surface that facilitates infiltration of the ensuing rains. Compared to traditional tillage practices on Alfisols of India, year round-tillage, with and without herbicides and interculturing, reduced weed infestation in the rainy season and led to increased sorghum yields (Friesen and Korwar, 1982).

Traditional methods of weed control include hand tools such as the sickle or animal-drown mechanical implements which is also used for line sowing and inter row cultivation e.g. blade harrows.. Many countries have developed effective and time-saving hand tools such as hand operated wheel-hoes, cultivators, and bullock drawn blade hoes for inter row cultivation in recent years (Rao *et al.*, 1989).

In rainfed fingermillet, newly designed agro-hoes and yake weeders were as effective as pre-emergence use of chloroxuron at 1 kg/ha (Rao *et al.*, 1989). In a weed control experiment on maize and sorghum, maximum weed growth was observed when the blade harrow was used without any other weeding. Whereas, weed growth was minimum after treatment with a hand-hoe. In general, the degree of weed control achieved by different mechanical weed control methods was less pronounced on sorghum yields than on maize yields (AICRPDA, 1978).

Messersmith *et al.* (2000) reported that Burcucumber density and control can be influenced by tillage system. Reduced density and weed dry weight were recorded under no till system as compared to mould board plough treatment in maize. Cox *et al.* (1999) found that mechanical weed management using mould board plough generally had lesser weed density and greater relative yield in soybean than chisel tillage. Rezene and Etagegnehu (1994) found that in dryland sorghum and millets, where *Striga* spp. is a problem, hand pulling of weeds is an important weed control method. They also reported that single or many hand weedings using hand hoes in sorghum, barley and linseed at early stage is essential for minimizing yield reduction and weed growth.

With increase in density of sorghum/pigeonpea system, there was rapid decrease in weed dry weights. The inclusion of additional '*smother*' crops like cowpea and mungbean minimized weed infestation in dryland regions. In the pearlmillet system, the row arrangement of one pearlmillet with three groundnuts resulted in optimum weed suppression and maximum intercrop advantage (Rezene and Etagegnehu, 1994).

Durutan (1982) found that one way to minimise the competition or interference effect of weeds on crops in drylands is proper fertilization. A balanced nutrient supply not only increases the water use efficiency of the crop directly, but indirectly affects it through increasing its ability to compete with weeds. The mean yield reduction under weedy conditions was 32% in unfertilized plots while it was 18% in fertilized ones as compared with fertilized and weed free plots. Another study showed the similar trend but of different magnitude, with yield reduction of 27% and 8% respectively (Durutan *et al.*, 1989).

Crop rotation is the best cultural method of weed control available because the different planting times and periods tend to keep the weed population down. Results indicated that continuous wheat created the most serious grassy weed problem since the competing plants are most alike in vegetative habits and demands upon resources. In a two-year cropping sequence, when winter and/or summer crops were alternated with wheat, weed growth levels in the subsequent wheat did not buildup (TARM, 1985-88).

b) Chemical weed control

Though, manual weeding or mechanical weeding and intercultural operations are common practices in dryland agriculture, but due to non-availability of labour at peak periods, high cost of weeding and drudging involved, many of the dryland farmers recently tend to use herbicides at optimum dose for controlling weeds in their fields. Modern agriculture relies much on herbicides to control weeds in both irrigated and rainfed agriculture.

Weed control achieved almost exclusively by chemical methods, for example, can lead to changes in weed flora composition and density over time (Johnson *et al.*, 1998). This has lead to renewed interest in the integration of weed control methods to prevent establishment of weed species that are highly adapted to a given management.

c) Integrated weed management (IWM)

Development and implementation of IWM strategies is becoming more important, considering recent environmental and social realities associated with traditional cropping systems. Better use of corn plant density and row spacing along with reduced dose of herbicide application may be one way to make crops more competitive with weed and better weed control efficiency in early crop growth stages (Swanton and Murphy, 1996; Teasdale, 1995). In another study, Messersmith *et al.* (2000) reported that combination of tillage systems and pre-and post emergence herbicide application had better weed control efficiency in controlling burcucumber (*Sicyos angulatus*) in maize under dryland conditions. They found that non-tillage with pre and post-emergence application of metalochlor at 2.2 kg ai./ha and glyphosate at 0.84 kg ai/ha controlled burcucumber consistently in corn.

Weed management practices in different crops under dry land farming are mentioned below:

Maize

Maize is very sensitive to weed competition during the first 20 - 30 days after sowing due to initial slow growth (Sandhu and Gill, 1973). Uncontrolled weed growth causes yield loss of 40 to 60 per cent. Some weeds like *Rottboellia cochinchinensis* and *Striga* spp., can cause total crop failure. The extent of infestation of different weeds varies from one zone to another (Ramakrishna and Tripathi, 1995).

Atrazine and EPTC (S-ethyl dipropylthiocarbamate) were used as pre-plant incorporated herbicides to get maximum weed control. These herbicides were highly toxic to weeds like Johnson grass and nutgrass (Roeth, 1973; Chenault and Wiese, 1979). Post-emergence herbicides that can be sprayed over corn are 2,4-D, dicamba, cyanazine and atrazine (Greez *et al.*, 1978). Atrazine must be sprayed with a surfactant or phytobland oil in the carrier to increase foliar uptake by weeds (Wiese, 1983).

Rao *et al.* (1989) reported that atrazine at 1.5 kg ai/ha plus alachlor at 0.5 kg ai/ha as blanket spray caused no damage to maize and effectively controled all the major weeds.

Messersmith *et al.* (2000) found that post-emergence application of atrazine plus dicamba at 1.8 and 0.56 kg ai/ha respectively at 4 weeks after sowing were more effective in controlling burcucumber and total weeds in corn compared to their pre-emergence application. Cox *et al.* (1999) reported that pre-emergence application of cyanazine and metolachlor at 2.5 and 2.2 kg ai/ha respectively had better weed control efficiency with increased yield and monetary returns in dryland maize.

Wheat

The major weed species that infest wheat crops are wild oats (*Avena fatua* L. and *A. barbata*), *Phalaris minor* and Pig weed (*Amaranthus retroflexus*).

Application of 2, 4-D at 1 kg ai/ha was found to be effective in controlling weeds in wheat crop when applied at full tillering stage to avoid crop injury (Wiese, 1983). Bromoxylin mixed with MCPA increased the spectrum of weed control when applied at the two to three-leaf stage (Pea body, 1976).

In Algeria, Zeghida *et al.* (1991) listed the following herbicides for better weed control efficiency in wheat.

Tribunil	-	High control of broad leaf weeds and moderate effect on wild oats, rye grass and *Phalaris* spp.
2, 4-D	-	Very efficient on broad leaf weeds only
Dieuran	-	40 to 60% effectiveness on wild oat, rye grass, *Phalaris* spp. and broad leaf weeds.
Suffix	-	Highly efficient on wild oats only.
Suffix + 2, 4-D	-	Total and 90% effectiveness on wild oats and broad/leaf weeds, respectively.
Dicolofop methyl	-	Effective on wild oats and rye grass

In heavily infested areas, the above herbicides significantly increased the yield of wheat. Application of Tribunil at 2.1 kg ai/ha as pre-emergence controlled weeds effectively and also improved the grain yield (Bahram *et al.*, 1991).

Sorghum

Sorghum is very susceptible to weed competition, as the seedlings starts off weak and frail under dry conditions (Ramakrishna *et al.*, 1991a). Sorghum is particularly vulnerable to damage by parasitic weeds like *Striga lutea*, *S. asiatica* and *S. hermonthica*. Two hand weedings are normally required, the first can be carried at thinning and another one at 35 to 45 day after sowing (Subbareddy *et al.*, 1976).

Burnside (1977) and Wiese (1983) reported that atrazine and propazine were found as effective pre-emergence herbicides to control grass weeds in dryland sorghum. Atrazine applied to sorghum grown in narrow 38 cm rows with high plant populations gave effective weed control and yield equal to hand weeding (Burnside, 1977).

In drylands of Asia, animal drawn blade harrow is normally used by farmers to control inter-row weeds in row-planted sorghum. The promissing herbicides for *Striga* control are 2, 4-D and MCPA. The best control of striga can be obtained with 2, 4-D at 2.0 kg ai/ha applied at 30 days after sowing without any crop injury (Korwar and Friesen, 1984). In addition to chemical weed control, crop rotation can also be practiced to suppress striga in dryland sorghum (Ramakrishna and Tripathi, 1995).

Pre-emergence application of isoproturon at 0.50 kg ai/ha had effective control of all the grass and broad leaved weeds in sorghum based cropping system (Ramamoorthy *et al.*, 1995).

Cotton

Cotton at early stage of growth period has been found to be severely affected by delayed or inadequate weeding. Wider row spacing and high nutrient requirement of high yielding varieties provide an ample scope for weeds to grow vigorously and rapidly and compete severely with cotton (Singh *et al.*, 1988). Cotton is particularly susceptible to weed competition when soil fertility and moisture are low in dryland regions. Weed competition causes 45 to 80 per cent reduction in yield as reported by Ramakrishna and Tripathi (1995).

Tiwana and Brar (1990) suggested that inter-row weeding about two weeks after cotton emergence and intra-row weeding one week later when the crop is thinned, provide adequate weed control in the beginning and 2 to 3 subsequent weedings would take care of remaining weeds till the crop flowers and produces good canopy cover.

Significant rainfall within 1 week after application of fluometuron, alachlor and prometryn gave best weed control when applied as pre-emergence spray. If it did not rain for 4 weeks after application, percentage of weed control dropped but was best with incorporation at 7.5 cm depth (Wiese and Smith, 1970). Wiese (1983) found that post-emergence application of diuron and prometryn at 0.55 kg/ha applied as directed sprays containing 0.5% surfactant, effectively controlled pigweed and large crab grass in cotton. Directed sprays of DSMA (disodium methane arsonate) and MSMA were highly toxic to perennial grass weed like Johnson grass in cotton and these could be used as directed sprays upto flowering without decreasing yield or increasing arsenic content of the seed (Wiese, 1983).

The effective pre-emergence, post-emergence and pre-plant incorporated herbicides for better weed control in maize, cotton, sorghum, pearlmillet, groundnut, sunflower, safflower, sesamum, castor, soybean, pigeonpea, greengram and blackgram under dryland conditions are listed in Table 6, which provide season long control of a wide spectrum

Table 6. Selective herbicides for weed control in major dryland crops (Ramakrishna and Tripathi, 1995)

Crops	Herbicides combination	Rate kg/ha	Time of application	Remarks
Rice (Upland)	Butachlor	1-1.5	PE (6-10 DAS)	Annual grasses and some broad leaved weeds
	Thiobencarb	1-1.5	PE (6-10 DAS)	
	Oxadiazon	0.5-1.0	PE	
	2, 4-D	1-1.5	POST-E	Broad leaved weeds Annual grasses
	Oxadiazon fb 1 HW	0.5	PE	
Maize	Atrazine	0.5-1.0	PE	Broad specturm control of brown leaved weed and annual weeds
	Pendimethalin	1-1.5	PE	
	Simazine	0.75-1.0	PE	
	Alachlor	1-2.0	PE	
	Atrazine+ Pendimethalin	0.5-0.5	PE	Many annuals including Rottboellia spp.
	Fluchloralin	0.75-1.0	PPI	

(Contd.

Crops	Herbicides combination	Rate kg/ha	Time of application	Remarks
Sorghum	Atrazine fb 1 HW	0.25-0.5	PE	Broad spectrum control of annual grassy and broad leaved weeds
	Simazine	0.5-1.0	PE	
	Alachlor	1-15	PE	
	Isoproturon	0.5-0.6	PE	
		0.2-0.5	PE	
		0.5-1.0	PE	
Millets	Atrazine	0.2-0.5	PE	Mainly grassy weeds
	2, 4 -D	0.75-1.0	POST-E	To control Striga spp.
Cotton	Fluchloralin	0.7-1.0	PPI	Broad spectrum control of annuals
	Pendimethalin	1-15	PE	
	Diuron	0.5	PE	
	Alachlor	1-1.5	PE	
	Oxadiazon	0.5-0.75	PE	
Groundnut	Alachlor	1-1.5	PE	Broad spectrum control of grassy and broad leaved weeds
	Simazine	1-1.5	PE	
	Fluchloralin	1-1.25	PPI	
	Pendimethalin	1-1.5	PE	
	Butachlor	1-1.5	PE	
Sunflower	Alachlor	1.0	PE	Broad spectrum control of annuals and grassy weeds
Safflower	Fluchloralin	0.75-1.0	PPI	
	Pendimethalin			
	Pendimethalin	1.0	PE	
Sesamum	Pendimethalin	1.0	PE	Control grassy and broad leave weeds
	Fluchloralin	0.75-1.0	PPI	
	Alachlor	1.0	PE	
Castor	Alachlor	1-1.5	PE	Broad spectrum control of annual and grassy weeds
	Fluchloralin	1.0	PPI	
	Pendimethalin	1-1.5	PE	
Soybean	Fluchloralin	0.75-1.0	PPI	Annual grassy and broad leave weeds
	Alachlor	1-1.5	PE	
	Pendimethalin	0.75-1.0	PE	
	Metribuzin	0.25-0.5	PE	
Pigeonpea	Alachlor	1.0	PE	Broad spectrum control of annuals
	Pendimethalin	1.0-1.5	PE	
	Fluchloralin	0.75-1.0	PPI	
Mungbean (Greengram)	Alachlor	0.75-1.0	PE	Broad spectrum control of annuals
	Pendimethalin	0.5-1.0	PE	
	Fluchloralin	0.75-1.0	PPI	
Blackgram	Pendimethalin	0.5-1.0	PE	Broad spectrum control of annuals
	Fluchloralin	0.5-1.0	PPI	
	Alachlor	0.75-1.0	PE	

PE = Pre-emergence;
POST E - POST - emergence;
PPI = Pre plant incorporated;
HW= Hand weeding ;
DAS = Days after sowing.,
f.b. = followed by.

of weeds. Integration of suitable herbicides with other cultural practices like hand weeding and hoeing, tillage, fertilizer, irrigation, crop rotation, intercropping etc. were more efficient in control of weeds than use of herbicides alone in dryland crop and cropping systems (Ramakrishna and Tripathi, 1995; Ramakrishna *et al.*, 1991b).

Oil seed crops like groundnut, sunflower, safflower, castor, soybean and sesamum are very sensitive to weed competition because of its initial slow growth, short stature and prostrate growth habit during the early stage of crop growth periods. Higher yield was obtained when weed-free condition is maintained for the first 20 days after sowing in sesamum, soybean and groundnut; upto 60 days after sowing in sunflower, safflower and castor etc. Generally hand weeding and inter row cultivation are done after the emergence of weeds in these dryland crops. However, integration of herbicides with other means of cultural/mechanical control methods provide season long weed control spectrum with increased yield and monetary returns (Naidu *et al.*, 1983; Singh and Singh, 1978; Muniappa *et al.*, 1986; Singh and Sharma, 1990; Kondap and Chandrasekhar, 1978).

In crops like pigeonpea, greengram, cowpea and blackgram the first 20-35 per cent of the life cycle is more critical for weed competition, but when crop is well developed, it will effectively suppress weeds (Masood Ali, 1991). Herbicides like pendimethalin, alachlor, fluchloralin etc. provide season long weed suppression and results in increased crop yield (Rao and Shetty, 1984; Kundra *et al.*, 1991).

VI. Weed Management in Cropping System

The best approach for increasing crop production/unit area is through cropping systems – the spatial and temporal combination of cultivars in any one plot in one year. Two major categories *viz.*, intercropping and sequential cropping are important in terms of weed management.

Intercropping

Control of weeds may be a greater menace in intercropping than when the component crops are grown alone. Mechanical weeding may be difficult or even impossible in certain spatial arrangements or when the row spacings of the component crops are very close to each other (Ramakrishna *et al.*, 1991a). It has been reported from several experiments at ICRISAT that intercrops are better than either or both of the component crops as sole crops in weed suppression. Shetty and Rao (1977) reported 50 to 70 per cent reduction in weed infestation by intercropping. The results obtained by Rao and Shetty (1976) in sorghum/cowpea and sorghum/mungbean intercropping systems indicated that one weeding would be sufficient to get yields equivalent to weed free control.

Most of the herbicides are more crop specific rather than weed specific. A herbicide that does not harm both the component crops usually does not control a large number of weeds. Herbicides for some crop combinations have been reported in Table 7.

Relay cropping of short duration crops, particularly grain legumes, either by broadcasting or row sowing into the main crop of cereals - maize, sorghum, pearlmillet before their harvest is a common practice. Weeds can be a major problem to relay planting. Weeds and crop stubbles may hinder relay crop establishment. Weeds can cause considerable damage to relay cropped chickpea or safflower due to frequent rains during the later part of monsoon in India (ICRISAT, 1979).

Sequential Cropping

Sequential cropping aims at growing two or more crops in sequence on the same field in a year. The problems of weed control in sequential cropping are different from those

Table 7. Herbicides identified for weed control in intercropping systems

Intercropping system	Herbicide	Source
Maize + mung bean	Butachlor	Bantilan *et al.* (1974)
Maize + cowpea	Butachlor	Pamplona and Imlan (1976)
Maize + cowpea or lab-lab	Alachlor	Damodaran and Sankaran (1974)
Sorghum + blackgram	Isoproturon	Ramamoorthy *et al.* (1995)
Sorghum + cowpea	Alachlor	Boopathi Babu (1978)
Sorghum + lab-lab	Dinitramine	Boopathi Babu (1978)
Maize + mungbean	Alachlor/Linuron	CIAT (1976)
Sorghum + pigeonpea	Ametryn. Prometryn Terbutryn	ICRISAT (1977)
Pigeonpea + groundnut	Pendimethalin Fluchloralin	Vijay Kumar *et al.* (1988)

Adapted from Ramakrishna and Tripathi (1995).

in intercropping. Continuous presence of crop cover, residual toxicity of herbicides applied to the previous crop and change in weed flora need a different approach in weed management (Ramakrishna and Tripathi, 1995). Apart from optimum weed control, agronomic management practices which would determine the success of sequential cropping include early crop establishment time and method of tillage, date and method of planting and harvesting, crop rotation and the length of the turn-around time (Moody, 1976).

Moody (1982) reported that frequent cultivation of the field is not possible because of the time factor and minimum and zero tillage techniques favour reduction in turn around time thereby, resulting in early crop establishment. Rangaiah (1981) observed a small increase in weed dry weight under minimum tillage (the land was tilled only once) compared to conventional tillage in a cotton – sorghum – finger millet system. Weeds were effectively controlled by pre-emergent herbicides followed by a late weeding.

By crop rotation, the possibility of build-up of certain weed flora is usually reduced. When an upland crop is rotated with a low-land crop, the total weed density is either lower than under continuous lowland or upland culture (Moody, 1977). Gill and Brar (1972) observed that when tall traditional wheat was grown as single crop *Phalaris minor*, a relatively minor weed, increased at alarming rates in an intensive rice-wheat crop rotation system.

The severity of weed problem in a crop sequence is determined by the weed control measures practiced in the component crops. Saraswat (1976) observed that in jute-oat rotation, the number of weeds growing in association with the oat crop was directly related to the weeds growing in the jute crop. The better the weed control in jute, the less were the weeds in the oat. Herbicide application is hazarduous in the sequential cropping especially if legumes are planted after cereal crop. Atrazine applied @ 0.5 kg/ha as pre-emergence gave better weed control efficiency in sorghum but the establishment of legumes like mungbean or groundnut which followed sorghum was poor, but following cotton was not affected (Palaniappan and Ramaswamy, 1976). However, atrazine, diuron and amiben applied to maize had no harmful effect on the succeeding soybean at lower doses but increased dosage reduced the emergence of soybean (Hugar and Hosmani, 1977). Singh and Mani (1981) reported that atrazine and alachlor each at 1.2 and 4 kg/ha as pre-emergence spray to maize gave better weed control and had no harmful effect on the succeeding peas, lentil and chickpea. Herbicides are seldom used in dryland agriculture because they are often unavailable, expensive, not adapted for use in multiple cropping systems and not effective enough in traditional cropping systems (Binswanger and Shetty, 1977).

Herbicides are important in double cropping technology, which were traditionally cropped only in the post rainy season. Soil-crop-weed management practice in dryland cropping systems like graded broad-bed and furrow system, soil preparation immediately after the harvest of post-rainy season crop, cropping system that utilise both the rainy and post rainy season, seeding crops in dry soil before the rains and improved implements for field operations are to be employed (ICRISAT, 1982). After dryseeding, weeds germinate along with crops, which means that the early flush of weeds can not be eliminated by mechanical means. Therefore, herbicides like tribunil, dinitremine, prefar and fluchloralin are highly promising herbicides for dryland crops and cropping systems (ICRISAT, 1978).

Fluchloralin was found to be most effective herbicide to control a number of weeds in sorghum/legume intercropping (Abraham and Singh, 1984). Blanket application of atrazine at 1.5 kg/ha and alachlor at 0.50 kg/ha with one hand weeding to control inter row weeds is the most efficient weed control method in maize sequential cropping (Rao *et al.*, 1989). Studies at ICRISAT (1983) showed that chickpea can be successfully planted without cultivation, following maize or sorghum by spraying paraquot @ 1.0 kg ai/ha to kill crop stubble and existing weeds and 0.75 kg ai/ha of prometryn to kill emerging weeds.

Large areas infested with certain perennial and problematic weeds such as *Cyperus rotundus, Cynodon dactylon, Solanum elaegnifolium, Ischemum rugosum, Sorghum halepense, Commelina benghalensis* and parasitic weeds like *Striga asiatica* and *Orabanche* etc. can be made more productive only by using suitable selective herbicides in dryland regions (Rao *et al.*, 1989).

VII. Tillage and Weed Management in Dryland Agriculture

Weeds present in crop production fields reflect management practices (Liebman and Dyck, 1993). Crop production practices in dryland regions exert selection pressure on weed communities and create niches that favour or disfavour various weed species. Since tillage has been an integral part of many dryland cropping systems, weeds that are present in fields have been greatly influenced by tillage for seed bed preparation and weed control (Buhler, 1998).

Tillage for seed bed preparation can greatly reduce densities of annual weed populations, especially if planting is delayed to allow weed seed germination prior to the final tillage operations (Gunsolus, 1990). Tillage buries crop residue and alters the characteristics of the surface soil, greatly influencing the germination environment of seeds by altering weed seed distribution in the soil (Buhler and Mester, 1991; Yenish *et al.*, 1992).

With less tillage and more plant residue on the soil surface, mechanical weed control operations may also become less effective (Springman *et al.*, 1989). Combining inter row cultivation with reduced herbicide use provided weed control similar to full-dose herbicide treatments in conservation tillage systems and reduced weed and other problems associated with herbicide dependence (Buhler *et al.*, 1995; Mulder and Doll, 1993). Plant residue on the soil surface in conservation tillage may alter the behaviour of soil-applied herbicides resulting better weed control (Johnson *et al.*, 1989).

In continuous corn production system, giant foxtail (*Setaria faberi* Herrm.) became more difficult to control with soil-applied herbicides as tillage was reduced (Buhler and Daniel, 1988). The effects of tillage systems on the control of broad leaf weed flora such as *Chenopodium album* L. and *Amaranthus retroflexus* L. varied by species and location

(Buhler, 1991; Buhler, 1992; Buhler and Oplinger, 1990).

Velvet leaf (*Abutilon theophrasti* Medik) in soybean with foliar applied bentazon or acifluorfen was not influenced by tillage systems (Freed *et al.*, 1987). In contrast, Buhler *et al.* (1990) reported that acifluorfen, bentazon or a combination of both was less effective in controlling velvet leaf in mouldboard plough than chiesel/plough or no-tillage. While foliar applied sethoxydim provided better control of *Setaria faberi* in mould board plough and chisel plough at both early and late application times (Buhler *et al.*, 1990).

The effect of tillage systems on weed control varied by weed species and herbicides. For example, control of annual grass weeds was often reduced as tillage was reduced, while velvet leaf control increased.

VIII. Summary and Conclusion

Very little work has been done on developing weed control strategies for cropping system as a whole and on a year round basis. Little information is available on the implications of weeds on cropping systems and vice-versa in dryland agriculture. Hence weed control in cropping systems needs to be considered on a different perspective from that in monoculture.

The effect of tillage systems viz., minimum or zero tillage and conservation tillage to control weeds varied by species and herbicide application. More particularly, choosing the appropriate herbicide and application timing is critical in conservation tillage system. Hence, knowledge on weed biology and ecology is essential to managing weeds in conservation tillage without increasing herbicide dosage that are environmentally and economically unacceptable.

Hence in dryland agriculture, the concept of integrated weed management aims at minimising losses due to weeds by combining improved agronomic management techniques, mechanical cultivation, and optimum use of herbicides and their combinations.

Good crop husbandry practices such as early post harvest land preparation, growing crops from the beginning of the rains as far as possible, intercropping with quick-growing, low canopy smother crops of grain legumes like cowpea, blackgram, greengram, soybean etc., these all contribute significantly to efficient weed management in dryland crops and cropping systems.

Future needs

The following few suggestions for weed control in dryland agriculture needs serious consideration.

a. Weeds must be considered as the first enemy to agriculture. In addition to use of hybrid variety of seeds, fertilizers, better irrigation, and mechanized farming systems, weeds eradication also should be kept in mind for maximising crop production.
b. For effective weed control in any habitat, one needs to know the complete life cycle of a particular weed, and if the weakest link in the life cycle is known, it is to be attacked at that particular stage.
c. Each herbicide should be evaluated separately with different crops and crop combinations to see their phytotoxic and persistence effects, before the recommendation for their wide agricultural use in that particular area is made.
d. Research in cropping systems requires the evaluation of several crops, not separately but as a package following a prescribed arrangement either in time or space.
e. There is an urgent need to evaluate specific weed management factors in a crop sequence as a whole. In addition, the evaluation needs to be done in both agronomic and economic terms.

f. Experiments on weed control in dryland agriculture should, therefore, be planned in such a way as to provide adequate agronomic and economic data.

g. For effective weed management strategy, we must learn more about the ecology of weeds and their association with the surrounding environment, their life cycle, morphology and physiology. Emphasis should be placed on developing weed control strategies for the farming systems as whole.

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