Weeds infesting crops must be controlled or they reduce crop yields, hinder harvest operations and contaminate produce. Herbicides offer excellent weed control in various crops and cropping systems. Over dependence on one or few herbicides has resulted in the development of herbicide resistance in many weeds. Selective herbicides like atrazine, alachlor, metolachlor and simazine are contaminating surface and ground water due to high residual soil activity. Under such situations non-selective herbicides offer excellent control of wide spectrum of weeds besides nil or very low soil residual activity. Exciting developments in plant biotechnology mark a new era in agriculture because herbicide-resistant crops (HRC's) are the first products of biotechnology to be grown on an economic scale. Worldwide spread of transgenic crops cultivation is 67.9 m. ha. In this 73% area (49.70 m. ha) is occupied by HRC'S. More than 40 HRC's are available for commercial cultivation in US, Canada, Australia, Europe, Brazil etc. Resistance in crops is available for different groups of herbicides like Sulfonylureas, Imidazolinones, Triazines, Glufosinates, Glyphosate etc. Roundup ready soybean, cotton and maize are popular in US. IWM approach is required to prolong the life of HRC's. Better weed control is obtained in HRC's when one or more of the practices are combined. Weed management in herbicide resistant crops should involve integrated weed management practices for retaining long-term potential of herbicides like glyphosate. Rotate HRC's with other crops, rotate herbicides, rotate HRC's that are tolerant to herbicide with different mode of action and other agronomic practices for effective weed control, better yields and prevention of herbicide resistance development.

Weeds are unwanted and undesirable plants that interfere with the utilization of land and water resources and this adversely affect crop production and human welfare. Weeds being well adopted, highly competitive with crop plants, interfere agricultural operation and ultimately reduce the economic produce. Yield losses are as high as 100% in some crops and they range from 12-72% under certain conditions and crops (Bhowmik, 1999).

In recent decades the predominant weed control method in many parts of the world is the use of effective and reliable chemical herbicides (Powles, et. al., 1997). Among pesticides sold world wide, herbicides occupy the major share of nearly 48%. North America consumes 42% Latin America-9%, East Asia-19, East Europe 3%, West Europe 23% and Rest of world uses 4% of the herbicides sold in the world (Powles, et. al., 1997).

The approximate cost of developing an agricultural chemical has increased over the years. The cost of development was around 1.2 million in 1956 and had risen to 20 million by 1984 (Lyon et. al., 1996). The cost of pesticide registration in 1993 was nearly $ 200 million. During this period, the probability of registering new products was decreasing. In 1956, about one of every 2000 chemicals synthesized for pesticides properties became a registered product. This rate declined to 1 in 18,000 by 1984 (Lyon et. al., 1996). In India approximately 55,000 tons of pesticides are used with herbicide share of 5,000 tons for 2003-04. The major concerns with the triazine herbicides like Atrazine, Simazine and Cyanazine is drinking water contamination and potential carcinogenicity.

There is an increased public concern with pesticide use because of their ability to contaminate drinking water and other resources. Apart from this, several weed species
have developed herbicide resistance to most of the herbicides. Herbicide resistant biotypes have been reported in over 100 weed species. Among the resistant weeds nearly 32% are resistant to triazine group, 18% weeds to ALS inhibitors and 15% to Bipyridiliums (Walia, 2003). Herbicide resistant population is more in USA (49 No.) because of greater selection pressure induced by large amount of herbicide usage.

Herbicide Resistant Crops

Rapid developments in the frontiers of Biotechnology have resulted in the development of Genetically Modified crops for various traits. The area under transgenic crops is 67.90 m ha with 42.8 m ha in USA alone (Raney, 2004). Argentina is in the second place with an area of 13.9 m ha. Seventy three percent of the transgenic crops area is under herbicide resistance trait (49.7 m ha) followed by 18% in insect resistance (12.20 m ha). Less than 1 m ha area is under other traits. Currently different herbicide resistant crops are available with resistance to different herbicide groups (Walia, 2003).

Benefits of Herbicide Resistant Crops

Some of the benefits of HRC’s, listed by Knezevic (2003) are as follows –
1. Broader spectrum of weeds controlled
2. Reduced crop injury
3. Price reduction of conventional herbicides
4. Environmental friendly
5. New mode of action for Resistance Management
6. Crop management flexibility and simplicity

Concerns in the Usage of HRC’s

A number of concerns should be considered when deciding whether to use HRC’s in weed management programme.
* Yield Performance
* Selection pressure and weed resistance
* Shift in weed Species
* Gene Escape

* Gene flow and contamination of organic crops

Non-selective herbicides are cheap, effective, safe and easy to use, are environmentally acceptable and enable less tillage. Use of varieties of HRC’s enables the use of non-selective herbicides in standing crop. Weeds have developed resistance to herbicides like glyphosate as well (Van Gessel, 2001). Hence, to prolong the life span such precious herbicides, there is a need to use the HRC’s carefully. In this background, varieties of HRC’s should be used as one of the components of integrated weed management practices. Regard less whether HRC’s or conventional crops are used, there are several things that can be done to give crops the advantage over weeds and to keep weeds “Off balance”. Such practices are as follows.

1. Time of Herbicide Application:

It is very important to achieve maximum control of weeds. This is more so with the standing crop where weeds are emerging continuously. Time of application of Glyphosate varied with the Glyphosate Resistant (GR) soybean (Glycine max) variety used for cultivation (Essah and Bishnoi, 2003). Glyphosate application ranged form 2 weeks after emergence (WAE) to 5 WAE or 4-5 WAE is cultivars H-6686, H-4994 and H-5164 respectively. Single application of glyphosate in GR soybean effectively controlled the weeds under favourable conditions. Complete weed free control throughout the crop period can be obtained by 2 application of glyphosate at 2 and 6 weeks after emergence.

In three of the 4 year, biomass of weeds emerging in maize after glyphosate application was greater when glyphosate was applied to 5 cm tall weeds than with other timings like 10 cm tall weeds, 15 cm tall, 23 cm tall and 30 cm tall (Dalley, et. al., 2004). Delaying glyphosate applications resulted in increased weed control and reduced weed biomass. Delaying glyphosate applications
beyond 15 cm weed height did not further reduce weed biomass. Similar findings were reported by Gower et al., (2002). Sequential glyphosate application was needed when initial application was applied 5 cm tall weeds. This resulted in weed control increase in some cases without any increase in the yields.

In contrast to the above example Carey and Kells (1995) reported 10 cm weed height for effective weed control and corn (Zea mays) yields for the application of nicosulfuron plus bromoxynil. Weed control was complete and corn height and grain yield were reduced when applications were delayed until weeds were 20 cm tall.

Late post application of imazethapyr @ 35 g/ha to 2-3 leaf imidazolinone tolerant rice (Oryza sativa) in absence of early post application resulted in significant rice yields (Otis et al., 2003). In absence of late post application, 18-35 g/ha of imazethapyr is required for early post applications.

Time of weed removal significantly affected herbicide tolerant canola yields in Canada. This significance was more with glyphosate than with imidazolinone and glufosinate. Canola (Brassica napus) seed yield was reduced when herbicide application were delayed from the four leaf stage to the six leaf stage of canola (Neil et al., 2004). Early weed removal is important in canola. Yields were greatest and weed management challenges were often least when herbicides were applied at the four-leaf stage as opposed to the two or six leaf stage.

Sequential glyphosate application significantly reduced the weed biomass in corn at 5 or 10 cm height of the weeds. Sequential application was not necessary when glyphosate was applied to 15 cm tall weeds (Dalley et al., 2004).

Glyphosate resistant and glufosinate resistant soybean varieties yielded significantly high with early post application at 3 weeks after planting over no herbicides treatment. Early post application performed equally with early post and late post application at 3 and 5 weeks after planting. These findings were reported by Reddy (2003). Significant reduction in weed dry weight and biomass was observed in HR cotton with pre and post application (Reddy, 2004). Weed management with post only program is feasible in the short term but involves risk in subsequent years.

2. Row Spacing of Crops

Planting of crops in different row spacing also affect the weed incidence and their subsequent effects on seed yield. Spacing determines the time of herbicide application.

Under highly competitive growing conditions (below normal rainfall and high weed density), corn yield was first reduced when weeds reached 10 and 15 cm in height with corn planted in 38 and 76 cm rows, respectively. Under similar conditions, soybean yield was first reduced when weeds reached 15 and 23 cm with soybean planted in 19 and 38 cm rows, respectively. Yield losses occurred only in the untreated control when soybean was planted in 76 cm rows (Dalley et al., 2004). Corn and soybean yields were higher when planted in narrow rows in 3 of 4 years but were more susceptible to early season weed interference than corn and soybean in wide rows.

Biomass of weeds emerging after glyphosate application was greater when soybean was planted in 76 cm than in 19 or 38 cm rows. However, weed biomass was generally similar in both row spacing of 38 or 76 cm in corn (Dally et al., 2004).

Weed density and weed dry biomass did not differ significantly for 3 years in ultra narrow (25 cm) and wide row (102 cm) in herbicide tolerant cotton (Gossypium hirsutum) (Reddy, 2004). However, significant increase
in the seed cotton yield was obtained with wide
cotton over ultra narrow cotton. Yield difference
could be a consequence of differences in
production practices like weed management,
cotton management and harvesting practices
in both the cottons.

Planting GR soybean in narrow rows
can improve weed control compared with wide
rows because of a faster closure of the soybean
canopy, which results in greater shading and
weed suppression (Nelson and Renner, 1999).
Narrow row planting of soybean has the
potential to reduce herbicide inputs and the
need for late post applications may be
eliminated because of weed suppression in
narrow row soybean (Mickelson and Renner,
1997).

3. Cover Crops

Cover crops have long been used to
reduce soil erosion and water runoff, and
improve water infiltration, soil moisture
retention, soil tilth, organic carbon and nitrogen.
Rye (Secale cereale) is often used as a cover
crop because of its winter hardiness and
production of abundant biomass, which
suppresses weeds by both physical and
chemical interference during weed
ermination and plant growth (Reddy, 2003).

Cultivating hairy vetch (Vicia villosa),
as cover crop in the fall season significantly
reduced the yellow nut sedge (Cyperus
esculentus) and prickly sida (Sida spinosa) at 7
weeks after planting in the summer planted GR
corn. (Reddy and Koger, 2004). However
density of barnyard grass (Echinochloa crusgalli)
and Johnson grass (Sorghum halepense) were
not affected by the cover crop cultivation. Entire
broadcast application of glyphosate to kill the
cover crop hairy vetch before corn planting is
found to be good to control all type of weeds.
However, band killing is sufficient to control
yellow nut sedge and Johnson grass.

Different cover crops like oats, rye and
wheat were raised in the winter season to test
their ability to suppress the weeds in the
subsequent summer grown GR corn along with
weed management by either pre or post
emergent herbicides (Jason, 2004). Weed
biomass was reduced by 84, 68 and 21% by
oats (Avena sativa), rye and wheat. Though
oats produced less biomass than rye, it had
allelopathic effect on the weeds. Highest corn
yields were obtained with rye as the cover crop,
which oats had some growth retardation effect
initially (Jason, 2004). Among weed
management systems, two sequential
applications of glyphosate @ 0.84 kg/ha to corn
was found to be good over pre emergent
applications of Atrazine (1.68 kg a.i./ha) + S-
metolachlor 1.08 kg a.i./ha) at corn planting
followed by 0.84 kg a.i./ha glyphosate.
Similarly gross profit earned in wheat and rye
as cover crops followed by 2 applications of
glyphosate to corn were comparable to no
cover crops. Reddy (2003) reported significant
effect of rye cover crop followed by no tillage
in reducing the weed biomass but this was not
sufficient to transform into increase in the
soybean yields. Because of additional cost, rye
cover crop-based soybean production was less
profitable compared with no cover crop based
production systems.

4. Tillage

Herbicide resistant crops offer greater
scope to adopt minimal or shallow tillage to
control weeds. Yield and net returns obtained
in GR and Non GR soybean cultivars in two
tillage treatments that are shallow and deep
tillage systems did not differ. However Johnson
ggrass control was ≤ 40% in non GR cultivars
regardless of fall tillage treatment. When GR
cultivars were used in either tillage environment,
control of Johnson grass was ≥ 93%. This
indicates that the extra expense incurred from
using deep tillage for perennial weed control is
not justified when GR cultivars are used (Larry et al., 2004).

Conventional tillage and no tillage were not efficient in reducing the weed dry biomass. The control was less in comparison to no tillage with rye as cover crop. However, the GR soybean yields were equal in both the tillage treatments. When herbicide resistant soybean is used additional cost can be saved by following no tillage (Reddy, 2003).

5. Varieties

In a crop, varieties with resistance to different herbicides are available for commercial cultivations. Reddy (2003) compared 3 varieties of soybean i.e. DP 5806 RR (Glyphosate resistant), A 5547 LL (Glufosinate resistant) and conventional DP 3588. Soybean yields were high in A 5547 LL and DP 3588 while, GR soybean yielded significantly less. However, weed control and net return among these soybean systems were similar.

Reddy (2004) studied the seed cotton yields of GR and bromoxynil resistant cotton varieties in Stoneville, US. Seed cotton yields of glyphosate resistant variety were consistently higher in a 3 year trial. However, growing of a variety with same herbicide resistance is no good from the point of weeds control. This may induce single selection pressure in weeds.

Soybean yield and net return were consistently higher in glyphosate resistant soybean cultivars irrespective of their duration over non glyphosate resistant varieties. This was due to better control of Johnson grass (Larry et al., 2004).

Herbicide resistant canola (Brassica napus) occupies approximately 80 % of the canola acreage in Western Canada. Neil et al., (2004) studied the Glyphosate resistant, Glufosinate resistant and Imidazolinone resistant canolas with other factors like herbicide dosage and time of application. Canola yields were similar among the three canola cultivar-herbicide systems. Use of herbicide resistant varieties may not always yield higher. Conventional corn variety Pioneer 33G26 yielded significantly lower than Imidazolinone, Glufosinate and Glyphosate resistant varieties of corn in 1999 while significantly higher in 2000 (Johnson et al., 2003). However, Johnson grass control was significantly high with glyphosate resistant corn.

In a study with bromoxynil resistant, glyphosate resistant and non-transgenic cotton cultivars in a no tillage environment were evaluated in North Carolina and Tennessee (Bailey et al., 2003). Non-transgenic cotton with pre emergent herbicides pendimethalin + flumeturon, pyrithiobac as post and cyanazine + MSMA as lay by application recorded significantly highest total lint yield and net returns.

6. Crop Rotations

Crop rotations are an effective tool for weed control. Continuous wheat production for 7 year became so infested with wild oats that yields were drastically reduced. By altering annual crops, production practices can be adjusted to control particular weed species (Tingle and Chandler, 2004). Crop rotation directly influences herbicide type and crop growth habit may further reduce weed competition. Crop or herbicide rotation, or both, may aid in the control of difficult-to-control weeds. For the control of Johnson grass in maize, cotton can be used in rotation. Low inputs or conventional herbicide treatments were sufficient in corn-cotton-corn and cotton-corn-cotton rotation to obtain identical yield of corn and cotton (Tingle and Chandler, 2004). However, to obtain high yields under transgenic cotton-cotton-cotton rotations high weedicide inputs were required. High input herbicides systems consisted of PRE applications of metolachlor and atrazine (1.07 and 1.4 kg a.i./ha respectively) followed by post glyphosate (0.56 kg a.i./ha) application at the 4 and 8 leaf stages.
Difficult to control weed like purple nut sedge (Cyperus rotundus) can be managed by rotating cotton with soybean or by using glyphosate based herbicide program in glyphosate-resistant cotton (Bryson et al., 2003). Cotton yields were significantly high in soybean-cotton-soybean-cotton rotation than continuous cotton.

Arranging four different crops in sequences of two cool season crops, followed by two warm season crops was the most beneficial for weed management (Anderson, 2004). Simulation study for a period of 12 years indicated that population of jointed goat grass (Aegilops cylindrica) was reduced when winter wheat was rotated with crops like corn and millet. Ecologically managing weeds will further reduce the weed populations.

7. Herbicide Rotations

Rotation of weedicides with different modes of action helps in delaying the development of resistance in weeds. Bromoxynil and glyphosate resistant cotton varieties are available for the growers. This offers the advantages of different mode of action for the growers (Reddy, 2004). Continuous use of BR cotton with broxynil weedicide was inefficient in controlling weeds like common purslane (Portulaca oleracia), sickle pod (Dichrostachys cinerea), smooth pigweed (Amaranthus hybridus) and yellow nut sedge (Cyperus esculentus). Use of glyphosate with GR cotton in the first year effectively controlled all the above-mentioned weeds (Reddy, 2004).

8. Salts of herbicides

Different salts of herbicides are available with different modes of action and with an ability to control different weeds effectively. Isopropyl amine, Trimethyl sulfonium, diammonium and amino methanamide dihydrogen tetraoxosulfate salts of glyphosate are available for application (Reddy and Robert, 2003). Salts differed in their ability to control barnyard grass and brown top millet with respect to time of application. Salts did not differ significantly within the same applications of glyphosate-Tms and glyphosate-Adt than with two application of glyphosphate regardless of formulations, with the exception of glyphosate – Ipa.

9. Herbicide Mixtures

Use of herbicide resistant crops is not a complete answer to the weed problem. Some weeds are not controlled effectively with these herbicides. Under such conditions herbicide mixtures have shown to be beneficial in controlling broader weed spectrums. Imazethapyr lacks activity in some broad-leaved weeds.

Control of alligator weed (Alternanthera philoxeroides) at 35 DAT was significantly improved when imazethapyr was combined with propanil, halosulfuron, cafentrazone, bentazon etc. (Kristie et al., 2004). However similar effect was not obtained either with weed control or maize yields, when imazapic was used in mixture with atrazine or bentazon at various rates in imidazohione resistant maize.

10. Volunteer Weeds

Use of herbicide resistant crops provides an unprecedented control of some troublesome weeds. These crops may turn to weeds in the next season due to seed shattering before harvest or residues of the failed crop due to moisture stress. Volunteer crop plants can reduce yields of the planted crop, reduce host insects or disease, interfere with harvest and reduce the quality of the harvested crop (Ogg and Parker, 2000). Control of herbicide resistant volunteer wheat and canola plants in the succeeding crops is very important because these cereals/weeds can act as a green bridge or host for numerous plant pathogens and insects between cropping season. Glyphosate
resistant wheat and canola can be easily controlled by the application of paraquat + diuron (Curtis et al., 2004). Glyphosate resistant cotton can be controlled easily in Glyphosate resistant soybean with the application of Imazaquin, metribuzin, metribuzin + chlorimuron or Fomesafen (York et al., 2004). Reduction in plant stand and fruit reduction with increased soybean yields were observed.

**Conclusion**

Herbicide resistant crops are one of the good alternatives available to control herbicide resistant weeds. However they have to be used with a caution to prolong their effective period. This can be achieved when they are used along with other control measures like cover crops, tillage, spacing, herbicide mixtures and other agronomic measures so that effective control of weeds is possible.

**Future Line of Work**

Presently HRC’s are not in use in India. However Monsanto is in the process of obtaining the permission from GEAC. Use of the conventional herbicides is not popular because of various reasons like lack of soil moisture on the soil at the time of sowing leading to their ineffectiveness; unpredictability of the success of the crop leading to no investment on the herbicides etc. Once farmer is assured of getting some returns from the crop he will invest. Another advantage with HRC’s is flexibility in the time of application, which the farmer needs. Hence in this background, research with HRC’s may be required in India, in the near future.

**REFERENCES**