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Weed management in pigeonpea-based cropping systems

Ramanjit Kaur, Rishi Raj, T.K. Das, Kapila Shekhawat, Raj Singh and Anil K. Choudhary
Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi 110 012

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ABSTRACT

Pigeonpea (*Cajanus cajan* (L.) Millsp., syn. *Cajanus indicus* Spreng), also known as *arhar*, *tur*, redgram, congopea, no eye pea, is one of the most important pulse crop of India in terms of acreage and production. Worldwide, it is grown on an area of 4.75 million hectares with 3.68 million tonnes of production (FAO 2012). Its grains are highly nutritious and rich in protein (21.7%), carbohydrates, fibre and minerals that constitute the main source of dietary protein to all vegetarian people, especially in developing countries. Weed infestation in pigeonpea is severe at the initial period during first 6-8 weeks, when the crop requires to be kept free from weeds. Chemical weed control is most promising, although there are cultural options like intercropping, crop rotation, closer spacing, tillage, etc. which could reduce the weed infestation in pigeonpea and pigeonpea-based cropping systems. Intercropping of pigeonpea with soybean (2:4) had smothering effect on weeds and resulted in 32% more grain yield than in sole crop. In pigeonpea, pre-emergence applications of pendimethalin 1.25 kg/ha was found most effective with 21.4% higher grain yield. Integration of the components of production technologies enhanced the productivity of pigeonpea by 29.8% with 27.2% higher net returns. Therefore, an attempt has been made in this article to review works done on several aspects of weed management in pigeonpea-based systems.

Key words: Crop rotation, Herbicides, Pigeonpea, Weed flora, Weed management

In terms of both area and production of all important pulses grown during rainy season, India ranks first and contributes about 25% to the total pulse basket. During 1991-2007, area under pulses ranged between 20.35 and 24.66 million hectare while production and productivity ranged from 11.15 to 15.11 million tonnes and 533 to 635 kg/ha, respectively. On account of their importance as nutritious food, feed and forage, pulses remained an integral component of subsistence cropping system since time immemorial. In India, over a dozen of pulse crops are grown, the important ones being chickpea (45.6%), pigeonpea (16%), mungbean (10%), urdbean (9.7%) and lentil (5.7%). The productivity of pulses, however, continues to be low, as they are generally grown in rainfed areas under poor management condition and face various kinds of biotic and abiotic stresses. Less fertile and nutrient deficient soils, unfavourable weather, low availability of quality seeds, socio-economic factors, weed infestation, poor postharvest handling and inadequate market support are some major constraints in realizing the potential of available technologies. They can be grown as a sole crop, intercrop, catch crop, relay crop, cover crop and green manure crop, *etc*., under sequential/mono-cropping in different agro-ecological regions. In the cropping systems of dry regions, pulses are predominant due to their low input requirements and ability to tolerate drought and consequently perform relatively better than other crops in the fragile and harsh climate prevailing in the regions. Intercropping is commonly practised to obtain sustainable production even under adverse weather conditions. In North India, the development of short duration varieties of pigeonpea (*Cajanus cajan* (*L.)* Millsp., syn. *Cajanus indicus* Spreng), mungbean (*Vigna radiata* L) and urdbean (*Vigna mungo* L.) has paved way for crop diversification and intensification. On slopes of hilly regions, urdbean, mungbean, cowpea (*Vigna unguiculata*), ricebean (*Vigna umbellata*) and frenchbean (*Phaseolus vulgaris*) not only provide nutritious food and fodder but also act as an excellent cover crop. In these regions, pigeonpea, urdbean, mungbean, soybean (*Glycine max* L), *etc*. are also grown on rice bunds. In response to market opportunities and concern for systems sustainability, many new cropping systems involving pulses have replaced/ modified the traditional crop rotations. Some glaring examples are pigeonpea–wheat (*Triticum aestivum*), rice-urdbean/mungbean, soybean + pigeonpea, groundnut + pigeonpea, potato + rajmash, *etc*. In humid regions of North-East India and drier regions of central and coastal regions of South India, some of

***Corresponding author:** ramaan180103@yahoo.com

the pulses like urdbean, mungbean, lentil and lathyrus are grown as para crop (relay) which facilitates double cropping and sustainable production of the systems.

Pigeonpea (2n=22) is one of the important grain legume crop of tropical and sub-tropical regions of the world and globaly , it is grown on area of 4.75 mha with 3.68 mt of total production (FAO 2012). It is considered to be a crop of Indian origin and diversity (Van der Maesen 1980). About 1000 years ago, it was introduced in the African continent. Pigeonpea occurs throughout tropical and subtropical regions and in the warmer temperate regions from 30°N to 30°S. India, Malawi, Kenya, Myanmar Uganda and Tanzania are the major pigeonpea producing countries. During last 4 decades, pigeonpea has recorded a 72% increase in area (2.76 6 4.33 m ha) and 72% increase in production (2.14 to 3.8 million tonnes). To break the yield barrier in pigeonpea, ICRISAT and partners have developed a cytoplasmic male-sterility (CMS) based hybrid breeding technology in pigeonpea. CMS-based medium maturity hybrids, ICPH 2671 and ICPH 2740, produced 30-40% greater grain yields than the popular varieties across farmers' fields in India. This technology is also being transferred to China, Myanmar and to the ESA region.

Among the major countries growing pigeonpea, India ranks first with about 75% of the world area and 67% of production, covering about 3.53 mha, with average production and productivity of 2.89 mt and 741 kg/ha, respectively, accounts 91% of the global pigeonpea production (FAO 2012). The major pulse producing states in the country are Madhya Pradesh, Uttar Pradesh, Maharashtra, Rajasthan, Karnataka and Andhra Pradesh, which together contribute for 75% of the total pulses production in the country.

Benefits of growing pigeonpea in systems

Pigeonpea crop being deep rooted and drought tolerant grain legume and add significant amount of organic matter/nitrogen to the soil becomes an integral part of the dry land subsistence cropping system of the semi-arid tropics. It can be grown as a sole crop, mixed crop, intercrop or ratoon crop. With the development of short duration pigeonpea cultivars in recent years, its cultivation has now been introduced in irrigated areas under multiple cropping systems. The beneficial effect of pulse crops in improving soil health and sustaining productivity has long been realized. On account of biological nitrogen fixation, addition of considerable amount of organic matter through root biomass and leaf-fall, deep root systems, mobilization of nutrients, protection of soil against erosion and improving microbial biomass, they keep soil productive and alive by bringing qualitative changes in physical, chemical and biological properties (Dass and Sudhishri 2010). As a result of this, the productivity of cereals following a preceding grain legume often increases and corresponds to 40-60 kg N equivalent. Besides this, the cost of cultivation significantly decreases and returns per rupee investment increases. In the present scenario of degradation of natural resources, the value of pulses is far more important. It is, therefore, imperative that grain legumes are given a preference in cropping systems of both irrigated and dryland areas.

Three-year experiment on sandy loam soil of Kanpur, (IIPR 1984-87) reported significant improvement in productivity and N economy in wheat preceded by *Kharif* legumes. Cowpea was most beneficial followed by pigeonpea and pigeonpea + mungbean. Soybean–wheat system was most productive followed by pigeonpea – mungbean – wheat among *Kharif* pulse based cropping systems. The nitrogen economy due to preceding pigeonpea over sorghum was 51 kg N equivalent/ha. An overview of N economy of cereals and cropping systems in different agroclimatic zones under pulse based cropping system showed that N economy in different zones varied from 30-67 kg/ha.

Pigeonpea-based cropping systems

The major cropping systems involving pigeonpea are mixed cropping or intercropping and double-cropping. A large number of crops are grown together with pigeonpea in different proportion by mixing and broadcasting seeds of the component crops to cover the risk of crop failure. The intercropping system developed in vacant years aims at efficient use of production resources, enhanced productivity and providing greater stability in production system. In the pre-green revolution period, pulses found significant place in inter/mixed cropping with major and minor cereals.

Wheat was used to be generally grown with chickpea, lentil, mustard and other oilseed crops. Similarly, the coarse cereals were grown with short duration pulses like urdbean and mungbean in intercropping/mixed cropping systems. Cropping systems based approach of agricultural research, received little attention, except some considerations for utilizing the beneficial effects of growing crops of dissimilar nature in mixed/intercropping (Aiyer 1949) or sequential cropping and role of legumes in green manuring (Singh 1972). After introduction of high yielding varieties of wheat and rice in sixties, the entire agricultural systems of country witnessed a change. The low productive, risk prone legumes and oil seed crops were shifted towards marginal and fragile land of dry areas, whereas the cereal based multiple cropping systems covered irrigated areas in North. In Andhra Pradesh, Rajasthan, Gujarat, Karnataka, Maharashtra, Madhya Pradesh and Tamil Nadu states, area under pulses increased from 13.92 Mha in 1971-75 to 16.22 Mha in 2005-06, whereas Bihar, Haryana, Punjab, Uttar Pradesh, West Bengal and Orissa witnessed reverse trend, the area declining from 8.0 Mha to 4.6 Mha during the same period.

The adverse effect of continued cereal based cropping system in Northern India- the Green Revolution belt could be visualized only in the late nineties when compound production growth rate declined from 2.74% during 1981-90 to 1.66% during 1991-2000. Gradual decline in total factor productivity, deterioration in soil health and various other negative effects necessitated crop diversification and inclusion of pulses in the cereal-based system; in which pigeonpea based system plays an important role.

Availability of short duration varieties coupled with matching agro-technologies in eighties led to development of several remunerative and more productive cropping systems, which have either already shown their promise or have tremendous potential for expansion in new niches and diversification in the existing cropping systems (Ali 1994). Considerable increase in area under mungbean, urdbean, pigeonpea and lentil was observed in mid nineties and many new cropping systems emerged. In the irrigated areas of the northern and central India, pigeonpea-wheat has emerged as a promising system. Availability of short duration varieties such as *'UPAS 120', 'Manak', 'ICPL 151', 'Pusa 992'*, which takes about 120-160 days to mature has enabled their introduction in rice wheat systems in irrigated area of western U.P., Punjab and Haryana, Delhi and North-East Rajasthan. This has provided desired stability and sustainability to productivity of cereal based cropping system.

New niches for pigeonpea

An ideal cropping system should use natural resources efficiently and judiciously, provide sustainable, stable and high returns and do not damage the ecological balance. More than 250 double cropping systems of primary, secondary and tertiary importance in terms of their spread in the country have been listed. Out of which 30 are of primary importance (Yadav and Prasad 1997). Among top ten popular cropping systems in the country, only two, *viz.*, rice-chickpea and maize-chickpea contain a pulse crop with less than 6% of the total pulse area (Yadav 1996). The following are the important pigeonpea based cropping system in different agro-climatic zones and possible new niches for pigeonpea (Singh *et al.* 2009) (Table 1 and 2).

Table 1. Important pigeonpea-based cropping systems in different agro-climatic zones

Cropping system	Possible niches	Expected area (M ha)	Suitable varieties of pigeonpea
Pigeonpea-wheat	Haryana, Punjab, North-West U.P. and North Rajasthan	1.00	*UPAS 120, Manak, Pusa 33, AL 15, AL201*
Maize-*Rabi* pigeonpea	Central and Eastern U.P., North Bihar, West Bengal, Assam	0.30	*Pusa 9, Sharad*

Table 2. Possible new niches for pigeonpea

Agroclimatic zone	States represented	Annual rainfall (mm)	Cropping system
Western Himalayan region	Jammu & Kashmir, Himachal Pradesh,Uttar Pradesh	1650-2000	Pigeonpea-wheat
Eastern Himalayan region	Assam, West Bengal, Manipur, Meghalaya, Nagaland, Arunachal Pradesh	1840-3530	Maize-pigeonpea/ horse gram,
Central Plateau and hill region	Madhya Pradesh, Rajasthan,Uttar Pradesh	490-1570	Pearlmillet+pigeonpea-fallow, rice/maizechickpea/lentil/fieldpea,
Southern plateau and hill region	Andhra Pradesh, Tamil Nadu, Karnataka	680-1000	Maize-sorghum+pigeonpea mungbean-pigeonpea
East coast plains and hills Region	Orissa, Andhra, Pradesh, Tamil Nadu, Pondicherry	780-1290	Maize-horse gram/pigeonpea/chickpea
Gujarat, plains and hills region	Gujarat	340-1790	Pearlmillet/sorghum+ pigeonpea-chickpea

Weed flora

Because it is grown during rainy/*Kharif* season and slow initial growth and sowing at wider spacing, weed infestation in pigeonpea is as severe as in other pulses at the initial period of growth and the crop requires due care/attention towards weed control at that period, otherwise, the weed growth is very fast and weeds smother the crop and it causes reduction in yield to the tune of 55-60% (Kandasamy 1999). In some other instances, the yield losses have been reported to be 21-97% in pigeonpea. Weeds caused 79.93% reduction in pigeonpea grain yield if weeds were allowed to grow till harvest, however, grain yield losses were only 38.19% in pigeonpea + soybean intercropping system (Talnikar *et al.* 2008).

In rainy season, weeds come in 2-3 flushes and growth is very fast, therefore, they compete for light, nutrient and space ane are responsible for considerable reduction in yield. Some weed species commonly occurring in the *Kharif*/wet season pigeonpea are enlisted below. They all may neither be associated to a particular pulse/legume crop nor do all pulses and legumes have all these weeds distributed with them across states/regions of the country. However, this is an overall distribution of composite culture of weeds in the pigeonpea during *Kharif* season.

Annual grass weeds: *Acrachne racemosa, Commelina benghalensis/communis/subulata/ nudiflora, Eleusine africana/indica, Setaria viridis/ glauca/verticillata, Echinocloa colona/crusgalli, Rottboellia cochinchinensis (exaltata), Brachiaria* sp, *Panicum* sp, *Dactyloctenium aegyptium, Digitaria sanguinalis/adscendens.* Annual broad-leaved weeds: *Amaranthus graecizans/hybridus/ viridis/retroflexus, Ageratum conzoides, Bidens pilosa/biternata, Celosia argentea, Chorchorus* sp, *Capsella bursa-pastoris, Datura stramonium, Digera arvensis, Euphorbia hirta, Flaveria trinervia, Galinsoga parviflora, Galium aparine, Guizotia scabra, Heliotropium indicum, Leucas aspera, Malva prusila/parviflora, Nicandra physalodes, Physalis minima, Phyllanthus niruri, Parthenium hyster-ophorus, Scoparia dulcis, Solanum nigrum, Sonchus asper/aleraceous, Tagetes minuta, Trinthema portulacasttrum/monogyna, Tribulus terrestris, Xanthium strumarium.*

Perennial weeds: Grasses**:** *Cynodon dactylon, Plantago lanceolata* (simple perennial); Sedges: *Cyperus* sp (mainly *C. rotundus* and *C. esculentus*), Broad–leaved weeds: *Convolvulus arvensis, Launaea cornuta, Pluchea lanceolata* and *Oxalis latifolia* (simple perennial).

Critical period of crop-weed competition

The initial weed infestation depends mainly upon the extent of primary tillage, availability of soil moisture and the tilth of the seed bed. Weeds compete with the crop for resources such as moisture, nutrient, and light. Some major weeds: *Cyperus rotundus* and *Digera alternifalia,* for instance are known to have an allelopathic effect on pigeonpea. At present, weeds are controlled manually, mechanically or chemically. In India, where 90% of the world's pigeonpea is grown, manual and/or mechanical methods, weeds are more common. Weeds control methods vary greatly with the status of agriculture and the nature of the cropping system These practices have certain limitation like non-availability of labor at right time and economics. Pre emergence applications alone are not sufficient to curtail repeated flushes of weeds during rainy season, which highly necessitates a post-emergence application following pre-emergence one. Weeds do not cause harm to crops equally all through the growing period. There are certain stages in crop growth cycle when weeds are more damaging to crop growth and yield. Usually early season weed competition is most detrimental to crop and, therefore, early season weed control is indispensable, The critical period of weed competition may be defined as "the short time span in the life-cycle of a crop, when weed causes maximum reduction in its yield or in other words, when weed control measure if adopted may fetch near maximal or maximum acceptable crop yield (Das 2008)." It is the specific duration of weed-free situation of a crop resulting into near maximal yield, which is sufficiently close or equal to that obtained by the season-long weed-free situation. A "thumb rule" is that the first one-fourth ($1/4^{th}$) to one-third ($1/3^{rd}$) period of the total growing duration of a crop, irrespective of growth stages, weed species and environmental (climatic and soil) conditions may be assumed as "the critical period for weed competition." In pigeonpea, initial 6-8 weeks period is the critical period of the crop-weed competition.

Weed management strategies

Preventive and physical options

Clean cultivation, use of clean seeds, keeping the seed bed free from weeds, using well decomposed organic manures, keeping the bunds and irrigation channels free from weeds, keeping tools and farm machinery clean and control of weeds before they attain reproductive stage are some of the basic and free of cost practices to be followed for successful cultivation of any crop. In addition to these practices, destruction of weeds by cutting and removal through hand hoeing, hand pulling, tillage and flooding or desiccation and exhaustion of weeds through burning, soil sterilization and mulching can also be done. Hand hoeing is considered useful because it improves soil physical conditions in addition to the removal of weeds. Hand weeding loosens the soil surrounding the rhizosphere of crop plants and thereby enhances crop growth and yield. Hand pulling should be carried out in time and early in the crop growth. Weeds in pigeonpea can be controlled effectively with hand weeding to be done at 3 and 6 weeks after sowing (Anonymous 2014). However due to frequent rains it becomes difficult to do hand weeding at proper time, furthermore, non-availability of labour for hand weeding is another problem. So there is a need to find effective weed control techniques to keep the weed flora below economic threshold level (ETL). Further the practice of zero tillage along with residue has enough bearing towards weed suppression in cropped and non-cropped situations in addition to conserving the soil moisture by reducing evaporation. Mulching is very effective against most annual weeds and some perennial weeds such as *Cynodon dactylon* and *Sorghum halepense*.

In soil solarization, a good land preparation ensuring fine tilth and smooth and even surface of soil reduces air spaces between the polythene film and soil. Surface soil temperature may increase up to 55-60° C due to solarization during hot months, which kills weed seeds and vegetative propagules, insects, nematodes and disease pathogens and cause them to die. Solarization for a minimum period of two weeks during May and June is sufficient to control weeds. Summer ploughing significantly reduced the density and biomass of purple nutsedge (*Chenopodium album*) and increased rice yield to the tune of 58.2% as compared to control in rice – chickpea system. Under zero tillage, the density of purple nutsedge was found significantly higher in comparison to normal tillage in rice–lentil system.

Cultural options

Some cultural practices such as choice of crop species, crop cultivars, planting density, crop geometry, inter cropping, crop rotation, time of sowing, crop rotation, fertilizers and irrigation practices have profound effect on weed suppression. Normally weeds compete with crop plants more severely in early growth stages, therefore, crop planning should be done in such a way that it may boost the early growth and vigor of crop plants, which results into a better crop competition with weeds. To reduce the adverse effect of weeds in field crops, select long duration varieties as these varieties grow quickly and produce canopy early, resulting in shading and thus suppress the growth of weeds. If initial big flush of weeds germinating at one point of time is bypassed through manipulation of time of sowing of a crop, a little earlier or later than its normal time of sowing, the crop may germinate and have initial growth under almost weed-free or less weedy environment.Closer spacing (row to row) suppresses the germination and growth of weeds results in keeping the crops free from weeds as weeds get less space, light and nutrients for growth.

Crop rotation

Generally in pulses and particularly in pigeonpea and pigeonpea based cropping systems, crop rotation and intercropping plays a vital role in suppressing the weeds. The possibilities of certain weed species or a group of species occurring is greater if the same crop is grown year after year. In many instances, crop rotation can eliminate or at least reduce weed problems by changing microclimate in each field. The success of rotation systems for weed suppression appears to be based on the use of crop sequences that create varying patterns of resource competition, allelopathic interference, soil disturbance, and mechanical damage to provide an unstable and frequently inhospitable environment that prevents the proliferation of a particular weed species. Crop growth pattern, cultural practices, weed control techniques, type and intensity of tillage for different crops vary in crop rotation and this variation creates a barrier for further proliferation of crop-associated weeds. Crop rotation is highly effective against parasitic weeds such as *Striga hermonthica/asiatica, Orobanche ramosa, Cuscuta* spp. and crop associated weeds like *Echinochloa colona* in rice, *Phalaris minor* and *Avena* spp in wheat. Alfalfa/lucerne if replaced by cereal crops for 2-3 years, may control *Cuscuta* to some extent.

Results of a literature survey indicate that weed population density and biomass production may be markedly reduced using crop rotation (temporal diversification) and intercropping (spatial diversification) strategies. Crop rotation resulted in emerged weed densities in test crops that were lower in 21 cases, higher in 1 case, and equivalent in 5 cases in comparison to monoculture systems. In 12 cases where weed seed density was reported, seed density in crop rotation was lower in 9 cases and equivalent in 3 cases when compared to monocultures of the component crops. Significant advances in the design and improvement of weed-suppressive crop rotation and intercropping systems are most likely to occur if three important areas of research are addressed. First, there must be continued attention to the study of weed population dynamics and crop-weed interference in crop rotation and intercropping systems.

More information is needed concerning the effects of diversification of cropping systems on weed seed longevity, weed seedling emergence, weed seed production and dormancy, agents of weed mortality, differential resource consumption by crops and weeds, and allelopathic interactions. Second, there needs to be systematic manipulation of specific components of rotation and intercropping systems to isolate and improve those elements (*e.g.,* interrow cultivation, choice of crop genotype) or combinations of elements that may be especially important for weed control. Finally, the weed-related impacts of combining crop rotation and intercropping strategies should be assessed through careful study of extant, complex farming systems and the design and testing of new integrated approaches. Many aspects of crop rotation and intercropping are compatible with current farming practices and could become more accessible to farmers if government policies are restructured to reflect the true environmental costs of agricultural production (Liebman and Dyck 1993).

Intercropping

Intercrops may demonstrate weed control advantages over sole crops in two ways. First, greater crop yield and less weed growth may be achieved if intercrops are more effective than sole crops in usurping resources from weeds or suppressing weed growth through allelopathy. Alternatively, intercrops may provide yield advantages without suppressing weed growth below levels observed in component sole crops if intercrops use resources that are not exploitable by weeds or convert resources to harvestable material more efficiently than sole crops. The nature and magnitude of crop-weed competition differs considerably between sole and intercropping systems. Growing of crops in intercropping systems is found more productive particularly under rainfed conditions. More than 70% area of pulses in India is covered under intercropping systems. Pulses are intercropped with oilseeds, cereals, coarse grains and commercial crops. Pigeonpea is also inter/mixed cropped with short growing grain legumes. The crop species, population density, sowing geometry, duration, and growth rhythm of the component crops, the moisture and fertility status of soil, and tillage practices influence weed flora in intercropping systems. Ali (1988) reported that in pigeonpea-based intercropping, legumes (cowpea, urdbean and mungbean) suppress weed flora by 30 to 40% compared with 22% by sorghum. Studies on crop-weed competition revealed that the critical period for weed control in intercropping systems is slightly longer than that for sole crops.

Sole sorghum needs weed free conditions for the initial 4-5 weeks, whereas in sorghum/pigeonpea intercrops, this period has to be extended upto 7 weeks. Multilocational studies under AICPIP during 1984-87 revealed that in a short duration pigeonpea/ mungbean or urdbean intercropping, the initial 30 days is most critical for weed control. The uncontrolled weeds upto15, 30, 45, and 60 days of sowing caused yield loss of 13, 23, 31 and 35% respectively, over weed-free control. In a long duration pigeonpea/sorghum system, the critical period of crop-weed competition extended up to 8-9 weeks (Ali 1991).

In central and peninsular India, sorghum + pigeonpea has been found to be the most productive system on Vertisols whereas on Alfisols and Entisols, pearl millet + pigeonpea proved to be the ideal system (Ali and Singh 1997). Sowing of one row of sorghum followed by one row of pigeonpea gave additional yield of sorghum besides giving normal yield of pigeonpea. This system also reduced the wilt incidence in pigeonpea crop. The compact type varieties of pigeonpea are more suitable for intercropping systems than spreading varieties. For success of this system, choice of varieties having different plant growth habit, growth rhythm, maturity period and response to plant density are very important.

Pigeonpea + cereal intercropping systems are very common in central and western part of India. The short and early maturing cereals such as sorghum, maize and millets accumulated dry matter and utilized resources during the initial slow growth period of pigeonpea. As the reproductive growth of these intercrops does not coincide with pigeonpea, the yield of cereals is not affected adversely. After harvest of cereals, pigeonpea growth is compensated and additional pigeonpea yield is obtained. Experiment conducted at IIPR, Kanpur showed that in sorghum +

pigeonpea intercropping system, the highest pigeonpea grain yield (2.7 t/ha), pigeonpea equivalent yield (3.15t/ha), net returns (Rs. 43,303 kg/ha) and B: C ratio (3.6) was recorded with 2:1 row ratio on ridge and furrow planting system. Appropriate spatial arrangement not only helps in maintaining the required plant density but also minimizes competitions among the component crops in intercropping systems resulting in higher total productivity. In pigeonpea + sorghum intercropping system spatial arrangement of 2:1 row ratio on ridge planting system recorded higher pigeonpea equivalent yield and B:C ratio as compared to 1:1 and mixed planting system. For higher profitability, selection of high yielding pulses varieties having drought resistance and shade tolerant characteristics should be chosen (Reddy *et al.* 1990).

Intercropping enhances crop canopy and thus suppresses weeds. Short duration legumes, *viz*. urdbean, mungbean, soybean and cowpea when grown with pigeonpea under intercropping system suppressed weed flora considerably. Highest suppression ability was recorded with cowpea (45.8%) followed by urdbean (41.5%) and mungbean (38.2%). Talnikar (2008) found that weeds caused 79.93% reduction in pigeonpea grain yield if weeds were allowed to grow till harvest, however, grain yield losses were only 38.19% in pigeonpea + soybean intercropping system. Certain inter-croppings, *e.g.* pigeonpea + groundnut, sorghum + pigeonpea, perlmillet + pigeonpea *etc.* may be practised under rainfed condition in the subsistence type of farming, where there are low input investment and chance/risk of crop failure due to want of rains. This normally reduces weed competition wheather pigeonpea grown as main crop or intercrop. In intercropping systems where a main crop was sown with a 'smother' crop species, weed biomass in the intercrop was lower in 47 cases and higher in 4 cases than in the main crop grown alone (as a sole crop), a variable response was observed in 3 cases. When intercrops were composed of two or more main crops, weed biomass in the intercrop was lower than in all of the component sole crops in 12 cases, intermediate between component sole crops in 10 cases, and higher than all sole crops in 2 cases.

Manual weeding is the most common method of weed management in pigeonpea based intercrops. In broadcast sowing, weeding is also done by running a country plough at 40-50 cm spacing 4-6 weeks after sowing. However, this offers only partial control of weeds and also causes some damage to crops.

Chemical options

In any cropping system, chemical weed control should be done very carefully. While choosing a herbicide, care should be taken that a herbicide has less persistence or it remain active in the soil at least up to the critical period of weed competition in crop. A herbicide used in preceding crop should not have negative residual effect on the succeeding crop. Relatively little work has been done on herbicides for pigeonpea-based systems.Some of the recommended herbicides to be used in pigeonpea-based cropping systems are given (Table 4). In Inceptisols at Kanpur, pre-emergence application of pendimethalin (1.5 kg/ ha) proved quite effective in controlling weeds in a pigeonpea/sorghum intercropping system. In pigeonpea/short duration legumes, fluchloralin (0.5 to 0.75 kg/ha) and alachlor (2 kg/ha) have been reported to effectively control seasonal weeds (Venkateswarlu and Ahlawat 1986) and enhance productivity.

Among herbicides, pre-sowing incorporation of fluchloralin 0.5-1.0 kg/ha and oxadiazon 0.75 kg/ha were found most effective in controlling weeds in chickpea, lentil, mungbean, pigeonpea and urdbean. Pre-emergence application of pendimethalin 1.25-1.5 kg/ha was most effective in controlling broad leaved weeds in all the pulses and in pigeonpea+urdbean and chickpea + mustard intercropping systems. In French bean, pendimethalin 0.75–1.50 kg/ha or metachlor 0.50–1.0 kg/ha was found very effective.

Averaged across years, the most effective weed control among the chemical treatments was achieved with post-emergence imazapic 246 g/ha even though imazapic treatment caused temporary chlorosis and stunting (Bidlack *et al.* 2006). In terms of weed control, both of the pre-emergence, sulfentrazone + chlorimuron and metribuzin herbicides were effective in reducing the density of weeds, but those that escaped control grew large resulting in a total weed dry matter often similar to the untreated and sethoxydim grass herbicide treatments. Averaged across years there was a linear decrease in pigeon pea dry matter (g/m^2) as weed dry matter increased. Among treatments with similar total weed dry matter, pigeon pea dry matter accumulation was more adversely affected when there were many weeds (untreated and sethoxydim plots) as opposed to the metribuzin treatments resulting in fewer large weeds.

Dhonde *et al.* (2009) reported that weed intensity and weed dry matter of pigeonpea at harvest was significantly lower in weed free treatment followed by fluchloralin as pre-planting incorporation (PPl) 1.0 kg/ha plus glyphosate at 45 days after sowing (DAS). Weed control efficiency was higher (75.64%) and weed index was lower (14.06%) in pendimethalin PE 1.0 kg/ha plus glyphosate 1.0 kg/ha at 45 DAS as compared to other treatments except weed free treatment.

Integrated weed management

Dhonde *et al.* (2009) concluded that seed yield of pigeonpea (2.30 t/ha) and stick yield (6.50 t/ha) was maximum in weed free treatment followed by IWM treatment, *viz.* pendimethalin 1.0 kg/ha plus hand weeding at 45 DAS. Talnikar *et al.* (2008) reported that pre emergence application of alachlor 2 kg/ha with HW and hoeing at 6 weeks after sowing proved most effective and economical in controlling weeds and enhancing the grain yield in pigeonpea + soybean intercropping system.

Field experiments conducted from 1998 to 2004 on a loamy sand soil to study the effect of weed management on weeds, growth and grain yield of pigeonpea. In some years, weed dry matter was higher than in others, due to variation in rainfall received. Two hand weedings, pendimethalin in integration with hand weeding or ridging or both and paraquat in integration with hand weeding resulted in high weed control efficiency. Uncontrolled weeds caused 31.0 to 52.8% reduction in pigeonpea grain yield in different years. The sole application of pendimethalin as pre-emergence at 45 or 75 kg/ha was less effective in controlling weeds and improving grain yield than the above mentioned treatments as pigeonpea is a long duration (about 140 days) crop and weeds emerge in different flushes due to rainy season. Integration of pendimethalin 0.45 kg/ha + hand weeding 30 DAS + ridging 50 DAS provided the high weed control efficiency and produced the highest grain yields of pigeonpea in all the years of study (Singh and Sekhon 2013). Apart from two hand

Table 3. Herbicide recommendation for pigeonpea-based cropping systems

Pigeonpea-based cropping systems	Herbicide recommendation
Pigeonpea-wheat	
Pigeonpea	*Wheat*
Fluchloralin 1.0 kg/ha PPI*	Sulfosulfuron 0.025 kg/ha at 25-35DAS
Pendimethalin 1.0 kg/ha PE**	Clodinafop + carfentrazone 0.060 kg/ha +0.020 kg/ha at 25-35 DAS
Alachlor 1.0-2.0 kg/ha PE	Clodinafop + metsufuron 0.060 kg/ha +0.005 kg/ha at 25-35 DAS
Linuron 1.0-1.5 kg/ha PE	Sulfosulfuron + metsufuron 0.020 kg/ha + 0.004 kg/ha, 28-30 DAS
Clodinafop-propargyl 50-60 g/ha POE***	Metsufuron-methyl 0.004-0.008 kg/ha at 30-35 DAS
Quizalofop 125 g/ha POE	Carfentrazone 0.020 kg/ha at 25-35 DAS
Imazethapyr 100 g/ha POE	-
Pendimethalin 1.0 kg/ha PE *fb* imazethapyr 100 g/ha	-
Pendimethalin 1.0 kg/ha PE *fb* quizalofop 50 g/ha	-
Pigeonpea-onion	
Pigeonpea	*Onion*
As mentioned above	Oxadiazon 0.75-1.0 kg/ha within 2-3 days after transplanting
	Quizolofop-ethyl 0.037 kg /ha + oxyfluorfen 0.18 kg/ha at 21 DAT (POE) *fb* 1 HW at 45 DAT (Patel *et al.* 2011).
	Pendimethalin 1.0 kg/ha or 0.75 kg/ha *fb* one hoeing. Herbicide should be applied within a week after transplanting or after first irrigation.
	Pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha
	Pendimethalin 1.0 kg/ha PE *fb* oxyfluorfen 0.2 kg/ha POE
Pigeonpea-winter maize	
Pigeonpea	*Winter maize*
As mentioned above	Atrazine 1.0 kg/ha PE
	Atrazine 0.75 kg/ha POE (30-35 DAS)
	Tankmix of atrazine 0.75kg/ha + pendimethalin 0.75 kg/ha PE

PPI-Pre-plant incorporation, **PE-Pre- emergence,***POE-Post-emergence

Table 4. Some IWM options for controlling weeds in pigeonpea

Treatment	Seed yield (t/ha)	References
Pendimethalin 1.0 kg/ha PE + HW (45 DAS)	2.23	Dhonde *et al.* (2009)
Pendimethalin 0.75 kg/ha (PE) + paraquat 0.48 kg/ha (POE) 42 DAS	1.82	Padmaja *et al.* (2013)
Paraquat 0.48 kg/ha (25 DAS) + HW (50 DAS)	1.79	Singh and Sekhon (2013)
Pendimethalin 0.45 kg/ha (PE) + HW (30 DAS)	1.84	
Imazethapyr 246 g/ha POE	2.56	Bidlack *et al.* (2006)

weedings 30 + 50 DAS, weeds can also be effectively controlled with integrated use of pendimethalin 0.45 kg/ha with hand weeding 30 DAS or ridging 50 DAS or both and integrated use of paraquat 0.48 kg/ha, 25 DAS with hand weeding 50 DAS, which ultimately provide high grain yields of pigeonpea. Tomar *et al.* (2004) and Rao *et al.* (2003) concluded that in pigeonpea, effective weed control has been achieved with integrated use of pendimethalin and hand weeding.

Integration of pendimethalin with hand weeding 40 DAS is known to provide high WCE in pigeonpea. One hand weeding 30 DAS had low WCE, as after the hand weeding weeds appeared again. Similarly, sole application of pendimethalin had low WCE, as this herbicide was effective for initial 30-days only and later on as the effect of herbicide diminished weeds appeared again. Paraquat 0.48 kg/ha 25 DAS also had recorded low WCE as after initial killing of weeds, they started to grow again (Shinde *et al.* 2003). Post-emergence application of imazethapyr 75 g/ha at 15-20 DAS + paraquat 0.40 kg/ha at 8 WAS resulting in more effective control over all types of weed flora, remained at par with that of weed free treatment for various growth and yield parameters and recorded significantly higher net returns (Rs. 26,881/ha) and B:C ratio (1.8) (Sharma *et al.* 2014).

Therefore, good crop husbandry + recommended pre-planting or pre-emergence herbicides + one hand weeding to control late emerging annuals as well as perennial weeds, namely *Cynodon dactylon, Cyperus rotundus/esculentus* can be practised. Among the crop husbandary practices, time and date of sowing, tillage, variety, fertilization, crop rotation, intercropping, pests and diseases control measures may be taken care of.

Herbicide tolerant genotypes in pigeonpea

Total 1,561 germplasm lines of pigeonpea comprising of germplasm (1119), released varieties (69), Minicore (129), wild relatives (92) and derivatives of Indo-African derivatives (152) were screened against post-emergence herbicides. Foliar application of herbicides (Imazethapyr 4 ml/liter, followed by Glyphosate 5 ml/liter of water) was done with a gap of 45 days to identify herbicide tolerant lines. Only 20 genotypes exhibited some degree of tolerance, which are being rescreened to confirm their tolerance against post-emergence herbicides. Glyphosate was used for herbicide screening which affected plant at cell level irregular cell division was observed.

Weed infestation in pigeonpea is as severe as in other pulses at the initial period of growth and the crop requires to be kept free from weeds particularly during first 6-8 weeks. Intercropping enhances crop canopy and thus suppresses weeds. Short duration legumes, *viz.* urdbean, mungbean, soybean and cowpea when grown with pigeonpea under intercropping system suppressed weed flora considerably. In central and peninsular India, sorghum + pigeonpea intercropping system has been found to be the most productive system on the Vertisols. An application of pre-emergence pendimethalin 1.0 kg/ha *fb* post-emergence application of imazethapyr 0.10 kg/ha at 30-35 DAS has been found effective towards weed control in pigeonpea.

REFERENCES

Aiyer AKYN. 1949. Mixed cropping in India. *Indian Journal of Agricultural Sciences* **19**: 439-543.

Ali M. 1988. Efficacy of herbicides for weed control in winter French bean (*Phaseolus vulgaris*). *Indian Journal of Agricultural Sciences* **58**(2): 440-443.

Ali M. 1991. Weed management in pigeonpea under rainfed conditions in India. *Tropical Pest Management* **37:** 345-348.

Ali M. 1994. 25 years of research on pulse in India pp 19-22. In: *International Symposium on Pulses Rsearch* (Eds. Ali M *et al.*), 2-6 April, New Delhi, India.

Ali M. and Singh KK. 1997. Management of pulse crops under intercropping systems. In: *Recent Advances in Pulses Research* (Eds. AN Asthana and M Ali): Indian Society of Pulses Research and Development, IIPR, Kanpur. pp 489-508.

Anonymous. 2014. *Package of Practices for Kharif Crops of Punjab*. Punjab Agricultural University, Ludhiana, India.

Bidlack James E, Andy Middick, Delmar Shantz, Charles T MacKown, Robert D Williams and Srinivas C Rao. 2006. Weed control in a pigeon pea–wheat cropping system. *Field Crops Research* **96**: 63-70.

Das TK. 2008. Weed Science: Basics and Applications. Jain Brothers Pub. New Delhi. pp. 901.

Dass Anchal and Sudhishri S. 2010. Intercropping in fingermillet *(Eleusine coracana)* with pulses for enhanced productivity, resource conservation and soil fertility in uplands of Southern Orissa. *Indian Journal of Agronomy* **55**(2): 89-94

Dhonde MB, Kate SR, Pandure BS and Tambe AD. 2009. Integrated weed management in pigeonpea. *Indian Journal of Weed Science* **41**(1&2): 102-105.

FAO Stat. 2012. Food and Agricultural Organization Statistics. http://faostat.fao.org.

IIPR.1984. Annual Report, 1984-87. Indian Institute of Pulses Research, Kanpur.

Kandasamy OS.1999. Effect of herbicides with and without manual weeding on weeds and yield of rainfed pigeonpea (*Cajanus cajan* L. Millsp.). *Legume Res*earch **22**(3): 172-176.

Liebman Matt and Elizabeth Dyck. 1993. Crop rotation and intercropping strategies for weed management. *Ecological Applications* **3**(1): 92-122.

Padmaja B, Reddy Malla M and Reddy DV. 2013. Weed control efficiency of pre- and post-emergence herbicides in pigeonpea (*Cajanus cajan* L.). *Journal of Food Legumes* **26**(1&2): 44-45.

Patel TU, Patel CL, Patel DD Thanki JD, Patel PS and Ram A Jat. 2011. Effect of weed and fertilizer management on weed control and productivity of onion (*Allium cepa*). *Indian. Journal of Agronomy* **56**(3): 267-272.

Rao MM, Ramalakshmi D, Khan MM, Sree SP and Reddy MV. 2003. Effect of integrated weed management in post-rainy season pigeonpea + mungbean intercropping system in vertisols. *Indian Journal of Pulses Research* **16**(2): 112-115.

Reddy KC, Vander Ploeg J and Maga I. 1990. Genotype effects in millet/cowpea intercropping in the semi-arid tropics of Viger. *Experimental Agriculture* **26**: 387-396.

Sharma JC, Chandra Prakash, Shivran RK and Narolia RS. 2014. Integrated weed management in pigeonpea (*Cajanus Cajan* (L.) Millsp.) *International Journal of Advances in Applied Sciences* **2**(1-2): 69-74.

Shinde SH, Pawar VS, Suryawanshi GB, Ahire NR and Surve US. 2003. Integrated weed management management studies in pigeonpea + pearlmillet Walp) intercropping (2:2) system. *Indian Journal of Weed Science* **35**(1&2): 90-92.

Singh A. 1972. Conceptual and experimental basis of cropping patterns, pp 271-274. In: *Proceedings of Symposium on Cropping Patterns in India*. 27-31 January 1968, ICAR, New Delhi,.

Singh Guriqbal and Sekhon HS. 2013. Integrated weed management in pigeonpea [*Cajanus cajan* (L.) Millsp.] *World Journal of Agricultural Sciences* **9**(1): 86-91.

Singh KK, Ali M and Venkatesh MS. 2009. Pulses in cropping system. *Technical Bulletin,* IIPR, Kanpur.

Talnikar AS, Kadam GL, Karande DR and Jogdand PB. 2008. Integrated weed management in pigeonpea [*Cajanus cajan* (L.) Millsp.] *International Journal of Agricultural Sciences* **4**(1): 363-370

Tomar J, Singh HB, Vivek and Tripathi SS. 2004. Integrated weed management in intercropping of mungbean (*Vigna radiata*) and cowpea fodder (*Vigna unguiculata*) with pigeonpea (*Cajanus cajan*) under western U.P. conditions. *Indian Journal of Weed Science* **36**(1&2): 133-134.

Van der Maesen LJG.1980. India is the native home of the pigeonpea. *Miscellaneous Papers* **19**. Landbouwhoge School, Wageningen.

Venkateswarlu U and Ahlawat IPS. 1986. Studies on weed management in pigeonpea based intercropping systems. *Indian Journal of Agronomy* **31**: 184-187.

Yadav RL and Prasad K. 1997. Identifications of predominant cropping systems in different districts of India, pp.30-49. In:*NAnnual Report*, Project Directorate of Cropping Systems Research, Modipuram. .

Yadav RL. 1996. Cropping systems, pp 117-128. In: *50 Years of Crop Science Research in India* (Eds. R.S.Paroda and K.L.Chadha), ICAR, New Delhi.