Indian Journal of Agricultural Sciences **88** (2): 181–96, February 2018/Review Article

Invasive noxious weed management research in India with special reference to *Cyperus rotundus*, *Eichhornia crassipes* and *Lantana camara*

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Received: 21 July 2017 ; Accepted: 15 September 2017

ABSTRACT

Weeds are eternal pest causing substantial losses of crop yields and quality, which are directly related to food security and safety, respectively. With existing crop protection measures, approximately one-third yield losses occur globally due to weeds, in which contribution of invasive/ noxious weeds is enormous. Invasive/noxious weeds have become a challenge in developing Asian countries, especially in India. These invasive/noxious weeds are widely distributed in all kinds of ecosystems. Invasive species cause losses of native biodiversity including species extinctions, and changes in hydrology and ecosystem function. The total annual cost of dealing with invasive species worldwide is estimated to be in the hundreds of billions of dollars, including costs of control, detrimental effects on human health and losses in agricultural production and ecosystem services. An estimated 20-30% of all introduced species worldwide cause a problem in a way or the other. The list of invasive alien weed species for India is well documented and available in public domain. There are 173 invasive alien species documented in India belonging to 117 genera and 44 families, which represents 1% of the total Indian flora. Tropical American region contributes to the maximum number (with 128 species or 74%) followed by tropical Africa (11%). Other regions, which contribute marginally, are Afghanistan, Australia, Brazil, East Indies, Europe, Madagascar, Mascarene Islands, Mediterranean, Mexico, Peru, Temperate South America, Tropical West Asia, West Indies and Western Europe. Different weed management practices are used for controlling these weeds both in cropped and non-cropped situations. Among these options, none is enough to completely control these weeds. Thus, integration of all these weed management tools is needed to be done. Considering the extent of yield losses caused by these noxious weeds, a comprehensive, effective and well adoptable technology is urgently needed to overcome these challenges. This review article is based upon the most striking management approach for the noxious weeds. It also emphasizes the relevance of future research aspects, such as early detection tool by adopting satellite based remote sensing, application of biotechnological tools like development of herbicide resistant crops, development of new herbicides molecules, enforcement of strong legislation and research on alternate approaches like weeds use for industry (making paper, herbal medicine and bio-fuel) to ensure higher income and livelihood security of farmers.

Key words: Biological control, Chemical control, *Cyperus rotundus*, *Eichhornia crassipes*, Handicraft, Invasive/Noxious weeds, *Lantana camara*, Weed control method

Weeds have been one of the major biotic constraints in achieving optimum production of crops. A sizeable quantity of crop harvests is lost each year, due to untimely and inadequate weed control. Weeds cause substantial losses in both crop yield and quality, and thus is a threat to both food security and safety. The extent of crop yield losses due to weeds, vary depending on the crop and associated agro-ecological factors. Even with existing crop protection measures, approximately one-third yield losses occur globally (Bruce 2012) and weeds contribute the most to these losses. Global estimated loss potential of weeds in rice, wheat and maize indicate that weeds account for 46.2 to 61.5% of potential losses and 27.3 to 33.7% of actual losses caused by all pests together (Oerke 2006). The crop losses of ₹ 900 billion (US$ 2 billion) per annum in India is caused due to insect pests, diseases and weeds (Singhal 2008). Zhang (2003) reported in China that, weeds are responsible for reduction in average crop yields of 12.3–16.5%. Invasive/noxious weeds cause a sizeable reduction in yield. In the initial years, some weed like parthenium (*Parthenium hysterophorus* L.) used to grow in the undisturbed wastelands/non-cropped areas, and not in the crop fields. However, it gradually encroached into agricultural lands with huge population in a number of crops

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including sorghum (Das, 2002). It has consistently higher growth rate and relative growth rate up to 90 DAS, when all other weeds reaches to almost maturity stage (Tadesse *et al*. 2010 a & b).It is an annual weed, having tendency to become perennial in the growing habitat.

According to habitats, weeds can be invasive or non-invasive, noxious or not noxious. International Union for Conservation of Nature and Natural Resources (IUCN) defines invasive species as an alien species, which becomes established in natural or semi-natural ecosystems/ habitat as an agent of change, and threatens native biological diversity. These invasive species are widely distributed in all kinds of ecosystems throughout the world. Many noxious weeds are invasive. Invasive plants include not only noxious weeds, but also other plants that are not native to this country or to the area where they are growing. The BLM (Bureau of Land Management, U.S.) considers plants invasive if they have been introduced into an environment where they did not evolve. As a result, they usually have no natural enemies to limit their reproduction and spread (Westbrooks 1998). Some invasive plants can produce significant changes to vegetation, composition, structure, or ecosystem function (Cronk and Fuller 1995). Some weeds are highly aggressive, cause invasion to a new area and in course of time establish them in that area. The threat to biodiversity due to invasive alien species is considered second only to that of habitat destruction. Invasive species cause loss of biodiversity including species extinctions, and changes in hydrology and ecosystem function. Differences between native and exotic plant species in their requirements and modes of resource utilization may cause a change in soil structure, its profile, decomposition, nutrient content of soil, moisture availability, etc. Invasive species are thus a serious hindrance to conservation and sustainable use of biodiversity, with significant undesirable impacts on the goods and services provided by ecosystems. Biological invasions now operate on a global scale and will undergo rapid increase in this century due to interaction with climate and other changes such as increasing globalization of markets, rise in global trade, travel and tourism. For effective management of these weeds, knowledge about their ecology, morphology, reproductive biology, physiology and bio-chemistry is essential.

Invasive species/weed

Organizations involved in research in invasive species have defined the invasive species/ weed by following ways:

According to National Invasive Species Council, 2001: “A species that is not native to the ecosystem under consideration whose introduction causes or is likely to cause economic or environmental harm or harm to human health”.

Convention on Biological Diversity (CBD): “Species, subspecies or lower taxon, introduced outside its natural past or present distribution; includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce”.

Global Invasive Species Programme (GISP): “Non-native organisms that cause, or have the potential to cause, harm to the environment, economies, or human health”.

International Union for Conservation of Nature and Natural Resources (IUCN): "Animals, plants or other organisms introduced by man into places out of their natural range of distribution, where they become established and disperse, generating a negative impact on the local ecosystem and species”.

Invasive Species Advisory Council (ISAC): “An alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health”.

Noxious weed

A noxious weed is an undesirable, troublesome and difficult to control weed. Noxiousness implies undesirability of a weed as well as the difficulty in controlling that weed. Noxious weeds have high rate of reproduction and dispersal capacity, besides they adopt tricky ways to defy man's efforts to get rid of them (Das 2008). Noxious weeds are known as ‘‘pernicious weeds’’ or ‘‘special problem weed”. Legally, a noxious weed is any plant designated by a country government as injurious to public health, agriculture, recreation, wildlife or property (Sheley *et al*. 1999). A noxious weed is also commonly defined as a plant that grows out of place and is "competitive, persistent, and pernicious’’ (James *et al*. 1991).

Consequences/losses due to invasive/noxious weeds

Invasion potential of species enables it to be successful invaders and colonizers of the novel environments, whether introduced deliberately or accidentally (Dogra *et al*. 2009). This rapid and increasing rate of invasive potential and its establishment have very little prospect of reversing (Sharma and Raghubanshi 2010). Developing regions are fast witnessing this change, which is particularly more evident in India. Losses caused by invasive weeds are thrashing of biodiversity from native ecosystem (Dogra *et al*. 2009), alteration in ecosystem, decline in abundance and richness of native flora, alteration in community structure, and many more. Risk is not only confined to loss in biodiversity, but it also extent to environment, economies, and humans health as well (Pimentel *et al*. 2001). The risk of introduction of alien invasive weeds has enhanced due to globalization (trade, tourism and travel). The total loss to the world economy as a result of invasive non-native species has been estimated at 5% of annual production (Pimentel *et al*. 2001). The total annual cost of dealing with invasive species worldwide is estimated to be in the hundreds of billions of dollars, including costs of control, detrimental effects on human health and losses in agricultural production and ecosystem services (Sastroutomo and Hong 2007). Most of estimates take in to account only the losses in yield. However, if the cost of weed management, reduced in input use efficiencies, losses in quality, disease and pest occurrences (weeds being the alternative hosts of many diseases and pests) are added into account, the figures could be quite high (Baki 2004). Pimentel *et al*. (2001) estimated that 20-30% of all introduced species worldwide cause a problem. Invasive weed species for different countries like Australia (DiTomaso 2012), India (Reddy 2008), Malaysia (Baki 2004), Indonesia (Tjitrosoedirdjo 2005), China (Xu *et al*. 2012), Tropics (Yaduraju and Kathiresan 2003), Pacific (Sherley 2000) and South and South East Asia (Pallewatta *et al*. 2003) were well documented and made available for public domain. Several recent studies have been undertaken to estimate the economic impact of INS (Invasive Non Native Species) in a number of countries, which indicate that the cost of INS to a country's economy can be very high, but the estimates vary widely (Yaduraju and Rao 2013).

Ziska and George (2004) studied the impact of climate change on invasive weeds and indicated that the invasive, noxious weeds on the whole have a larger growth in the projected increases in atmospheric CO_2 concentration in relation to other plant species; and also rising CO_2 can preferentially be suitable for invasive, noxious species within plant communities. Thus, the initial observations suggest that control of such weeds may be more difficult in the future. Yaduraju and Kathiresan (2003) have identified the number of potential invaders in some countries of the APR (Asia and Pacific region). Matsui *et al*. (2004) have developed an internet data base to facilitate sharing of information among countries in the Asian and Pacific region, and to easily accumulate and search data on various species existing in each country. Thus, the measures such as establishing early-warning mechanism, strengthening the management of invasive species, quarantine of alien species, and improving people awareness are necessary to control the invasion of non native weed species. Therefore, global efforts are very much important to manage/control these weeds. India is abode of indigenous species and well known for its biodiversity hotspots. A large majority of exotics plaguing the country are natives of American continent, followed by Eurasia, Europe, Asia, Africa and Australia. Although, a large number of exotics have reached naturalization in India; only a few have noticeably altered the ecosystem structure and functions.

Invasive alien species/ weeds of India and their distribution

There are 173 invasive alien species (Table 1) documented in India belonging to 117 genera and 44 families, which represents 1% of the Indian flora (Reddy 2008). Among these species Tropical America region contribute the maximum number/per cent (with 128 species or 74%) followed by tropical Africa (11%). The other regions, which contribute marginally, are Afghanistan, Australia, Brazil, East Indies, Europe, Madagascar, Mascarene Islands, Mediterranean, Mexico, Peru, Temperate South America, Tropical West Asia, West Indies and Western Europe.

Table 1 Invasive alien species/weeds of India (Reddy 2008; modified by authors)

Scientific name	Family	Native place	Distribution	Propagation
Acanthospermum hispidum	Asteraceae	Brazil	Throughout India	Seeds
Acacia farnesiana (L.) Willd.	Mimosaceae	Tropical South America	Throughout India	Seeds
Acacia mearnsii De Willd.	Mimosaceae	South East Australia	Western Ghats	Seeds
Acanthospermum hispidum DC.	Asteraceae	Brazil	Throughout India	Seeds
Aerva javanica (Burm.f.) Juss.ex Schult.	Amaranthaceae	Tropical America	Throughout India	Seeds
Aeschynomene americana	Papilionaceae	Tropical America	A.P, Bihar, W.B., Odisha, Kerala, TN	Seeds
Ageratina adenophora (Spreng.) King & Robinson	Asteraceae	Tropical America	Kerala, Tamil Nadu	Seeds
Ageratum conyzoides	Asteraceae	Tropical America	Throughout India	Seeds
Ageratum houstonianum Mill.	Asteraceae	Tropical America	Throughout India	Seeds
Alternanthera paronychioides A. St.Hil	Amaranthaceae	Tropical America	Throughout India	Seeds
Alternanthera philoxeroides	Amaranthaceae	Tropical America	Throughout India	Vegetative
Alternanthera pungens	Amaranthaceae	Tropical America	Throughout India	Seeds, Vegetative
Alternanthera tenella	Amaranthaceae	Tropical America	Throughout India	Seeds
Antigonon leptopus Hook. &Arn.	Polygonaceae	Tropical America	Throughout India	Seeds
Argemone mexicana	Papaveraceae	Tropical Central & South America	Throughout India	Seeds
Asclepias curassavica L.	Asclepiadaceae	Tropical America	Throughout India	Seeds
Asphodelus tenuifolius	Liliaceae	Tropical America	Throughout India	Seeds
Bidens pilosa	Asteraceae	Tropical America	Throughout India	Seeds

contd.

Table 1 (*Continued*)

Scientific name	Family	Native place	Distribution	Propagation
Blainvillea acmella	Asteraceae	Tropical America	Throughout India	Seeds
Blumea eriantha DC.	Asteraceae	Tropical America	Throughout India	Seeds
Blumea lacera (Burm. f.) DC.	Asteraceae	Tropical America	Throughout India	Seeds
Blumea obliqua	Asteraceae	Tropical America	Throughout India	Seeds
Borassus flabellifer L.	Arecaceae	Tropical Africa	Throughout India	Seeds
Calotropis gigantea	Asclepiadaceae	Tropical Africa	Throughout India	Seeds
Calotropis procera (Ait.) R. Br.	Asclepiadaceae	Tropical Africa	Throughout India	Seeds
Cardamine hirsuta L.	Brassicaceae	Tropical America	Himalaya, Western Ghats	Seeds
Cardamine trichocarpa Hochst.ex A. Rich.	Brassicaceae	Tropical America	Throughout India	Seeds
Cassia absus L.	Caesalpiniaceae	Tropical America	Throughout India	Seeds
Cassia alata L.	Caesalpiniaceae	West Indies	Throughout India	Seeds
Cassia hirsuta L.	Caesalpiniaceae	Tropical America	Throughout India	Seeds
Cassia obtusifolia L.	Caesalpiniaceae	Tropical America	Throughout India	Seeds
Cassia occidentalis L.	Caesalpiniaceae	Tropical South America	Throughout India	Seeds
Cassia pumila Lam.	Caesalpiniaceae	Tropical America	Throughout India	Seeds
Cassia rotundifolia Pers.	Caesalpiniaceae	Tropical South America	A.P., Pondicherry	Seeds
Cassia tora L.	Caesalpiniaceae	Tropical South America	Throughout India	Seeds
Cassia uniflora Mill.	Caesalpiniaceae	Tropical South America	A.P., Mah., Kar., T.N.	Seeds
Catharanthus pusillus(Murray) Don	Apocynaceae	Tropical America	Throughout India	Seeds
Celosia argentea	Amaranthaceae	Tropical Africa	Throughout India	Seeds
Chamaesyce hirta (L.) Millsp.	Euphorbiaceae	Tropical America	Throughout India	Seeds
Chamaesyce indica (Lam.) Croizat	Euphorbiaceae	Tropical South America	Throughout India	Seeds
Chloris barbata Sw.	Poaceae	Tropical America	Throughout India	Seeds
Chromolaena odorata	Asteraceae	Tropical America	Throughout India	Seeds
Chrozophora rottleri (Geis.)	Euphorbiaceae	Tropical Africa	Throughout India	Seeds
Cleome gynandra L.	Cleomaceae	Tropical America	Throughout India	Seeds
Cleome monophylla L.	Cleomaceae	Tropical Africa	Throughout India	Seeds
Cleome rutidosperma DC.	Cleomaceae	Tropical America	Throughout India	Seeds
Cleome viscosa L.	Cleomaceae	Tropical America	Throughout India	Seeds
Clidemia hirta (L.) D. Don	Melastomataceae	Tropical America	Himalaya, Western Ghats	Seeds
Conyza bipinnatifida Wall.	Asteraceae	Tropical America	Throughout India	Seeds
Corchorus aestuans L.	Tiliaceae	Tropical America	Throughout India	Seeds
Corchorus fascicularis Lam.	Tiliaceae	Tropical America	Peninsular India	Seeds
Corchorus tridens L.	Tiliaceae	Tropical Africa	Throughout India	Seeds
Corchorus trilocularis L.	Tiliaceae	Tropical Africa	Throughout India	Seeds
Crassocephalum crepidioides (Benth.) Moore	Asteraceae	Tropical America	Throughout India	Seeds
Crotalaria pallida Dryand	Papilionaceae	Tropical America	Throughout India	Seeds
Crotalaria retusa L.	Papilionaceae	Tropical America	Throughout India	Seeds
Croton bonplandianum	Euphorbiaceae	Temperate South America	Throughout India	Seeds
Cryptostegia grandiflora R.Br.	Asclepiadaceae	Madagascar	Throughout India	Seeds
Cuscuta chinensis	Cuscutaceae	Mediterranean	Throughout India	Seeds
Cuscuta reflexa	Cuscutaceae	Mediterranean	Throughout India	Seeds
Cyperus difformis	Cyperaceae	Tropical America	Throughout India	Seeds
Cyperus iria	Cyperaceae	Tropical America	Peninsular India	Seeds

contd.

Table 1 (*Continued*)

Scientific name	Family	Native place	Distribution	Propagation
Datura innoxia	Solanaceae	Tropical America	Throughout India	Seeds
Datura metel	Solanaceae	Tropical America	Throughout India	Seeds
Dicoma tomentosa Cass.	Asteraceae	Tropical Africa	Throughout India	Seeds
Digera muricata (L.) Mart.	Amaranthaceae	SouthWest Asia	Throughout India	Seeds
Dinebra retroflexa (Vahl) Panz.	Poaceae	Tropical America	Throughout India	Seeds
Echinochloa colona	Poaceae	Tropical South America	Throughout India	Seeds
Echinochloa crusgalli	Poaceae	Tropical South America	Throughout India	Seeds
Echinops echinatus Roxb.	Asteraceae	Afghanistan	Throughout India	Seeds
Eclipta prostrata	Asteraceae	Tropical America	Throughout India	Seeds
Eichhornia crassipes	Pontederiaceae	Tropical America	Throughout India	Vegetative
Emilia sonchifolia (L.) DC.	Asteraceae	Tropical America	Throughout India	Seeds
Euphorbia cyathophora Murray	Euphorbiaceae	Tropical America	Throughout India	Seeds
Euphorbia heterophylla L.	Euphorbiaceae	Tropical America	Throughout India	Seeds
Evolvulus nummularius (L.) L.	Convolvulaceae	Tropical America	Throughout India	Seeds
Flaveria trinervia (Spreng.) C. Mohr.	Asteraceae	Tropical Central America	Throughout India	Seeds
Fuirena ciliaris (L.) Roxb.	Cyperaceae	Tropical America	Throughout India	Seeds
Galinosoga parviflora Cav.	Asteraceae	Tropical America	Throughout India	Seeds
Glossocardia bosvallea (L.f.) DC.	Asteraceae	East Indies	Throughout India	Seeds
Gnaphalium coarctatum Willd.	Asteraceae	Tropical America	A.P.,H.P., T.N.	Seeds
Gnaphalium pensylvanicum Willd.	Asteraceae	Tropical America	Throughout India	Seeds
Gnaphalium polycaulon Pers.	Asteraceae	Tropical America	Throughout India	Seeds
Gomphrena serrata L.	Amaranthaceae	Tropical America	Throughout India	Seeds
Grangea maderaspatana (L.) Poir.	Asteraceae	Tropical South America	Throughout India	Seeds
Hyptis suaveolens (L.) Poit.	Lamiaceae	Tropical America	Throughout India	Seeds
Impatiens balsamina L.	Balsaminaceae	Tropical America	Throughout India	Seeds
Imperata cylindrica	Poaceae	Tropical America	Throughout India	Seeds
Indigofera astragalina	Papilionaceae	Tropical Africa	Throughout India	Seeds
Indigofera glandulosa Roxb. ex Willd	Papilionaceae	Tropical America	Throughout India	Seeds
Indigofera linifolia (L.f.) Retz.	Papilionaceae	Tropical South America	Throughout India	Seeds
Indigofera linnaei Ali	Papilionaceae	Tropical Africa	Throughout India	Seeds
Indigofera trita L.f.	Papilionaceae	Tropical Africa	Throughout India	Seeds
Ipomoea carnea	Convolvulaceae	Tropical America	Throughout India	Seeds
Ipomoea eriocarpa R.Br.	Convolvulaceae	Tropical Africa	Throughout India	Seeds
Ipomoea hederifolia L.	Convolvulaceae	Tropical America	Throughout India	Seeds
Ipomoea obscura (L.) Ker.-Gawl.	Convolvulaceae	Tropical Africa	Throughout India	Seeds
Ipomoea pestigridis L.	Convolvulaceae	Tropical East Africa	Throughout India	Seeds
Ipomoea quamoclit L.	Convolvulaceae	Tropical America	Throughout India	Seeds
Ipomoea staphylina Roem. & Schult.	Convolvulaceae	Tropical Africa	Throughout India	Seeds
Lagascea mollis Cav.	Asteraceae	Tropical Central America	Throughout India	Seeds
Lantana camara	Verbenaceae	Tropical America	Throughout India	Seeds
Leonotis nepetiifolia (L.) R.Br.	Lamiaceae	Tropical Africa	Throughout India	Seeds
Leucaena leucocephala (Lam.) de Wit	Mimosaceae	Tropical America	Throughout India	Seeds
Ludwigia adscendens (L.) Hara	Onagraceae	Tropical America	Throughout India	Seeds
Ludwigia octovalvis (Jacq.) Raven	Onagraceae	Tropical Africa	Throughout India	Seeds
Ludwigia perennis	Onagraceae	Tropical Africa	Throughout India	Seeds

contd.

Table 1 (*Continued*)

Scientific name	Family	Native place	Distribution	Propagation
Macroptilium atropurpureum (DC.) Urban	Papilionaceae	Tropical America	Throughout India	Seeds
Macroptilium lathyroides (L.) Urban	Papilionaceae	Tropical America	Throughout India	Seeds
Malachra capitata L.	Malvaceae	Tropical America	Throughout India	Seeds
Malvastrum coromandelianum (L.) Garcke	Malvaceae	Tropical America	Throughout India	Seeds
Martynia annua (Houstoun in Martyn) L.	Pedaliaceae	Tropical America	Throughout India	Seeds
Mecardonia procumbens	Scrophulariaceae	Tropical North America	Throughout India	Seeds
Melilotus alba	Papilionaceae	Europe	Throughout India	Seeds
Melochia corchorifolia L.	Sterculiaceae	Tropical America	Throughout India	Seeds
Merremia aegyptia (L.) Urban.	Convolvulaceae	Tropical America	Throughout India	Seeds
Mikania micrantha Kunth	Asteraceae	Tropical America	Throughout India	Seeds
Mimosa pigra L.	Mimosaceae	Tropical North America	Himalaya, Western Ghats	Seeds
Mimosa pudica	Mimosaceae	Brazil	Throughout India	Seeds
Mirabilis jalapa L.	Nyctaginaceae	Peru	Throughout India	Seeds
Monochoria vaginalis (Burm.f.) C. Presl.	Pontederiaceae	Tropical America	Throughout India	Seeds
Nicotiana plumbaginifolia Viv	Solanaceae	Tropical America	Throughout India	Seeds
Ocimum americanum	Lamiaceae	Tropical America	Throughout India	Seeds
Opuntia stricta Haw.	Cactaceae	Tropical America	Throughout India	Seeds
Oxalis corniculata	Oxalidaceae	Europe	Throughout India	Seeds
Parthenium hysterophorus	Asteraceae	Tropical North America	Throughout India	Seeds
Passiflora foetida L.	Passifloraceae	Tropical South America	Throughout India	Seeds
Pedalium murex L.	Pedaliaceae	Tropical America	Throughout India	Seeds
Pennisetum purpureum	Poaceae	Tropical America	Throughout India	Seeds
Peperomia pellucida (L.) Kunth	Piperaceae	Tropical South America	Throughout India	Seeds
Peristrophe paniculata (Forssk.) Brummitt	Acanthaceae	Tropical America	Throughout India	Seeds
Phyllanthus tenellus	Euphorbiaceae	Mascarene Islands	Throughout India	Seeds
Physalis angulata L.	Solanaceae	Tropical America	Throughout India	Seeds
Physalis pruinosa L.	Solanaceae	Tropical America	Delhi, Uttarakhand, A.P.	Seeds
Pilea microphylla (L.) Liebm.	Urticaceae	Tropical South America	Throughout India	Seeds
Pistia stratiotes L.	Araceae	Tropical America	Throughout India	Vegetative
Portulaca oleracea	Portulacaceae	Tropical Central America	Throughout India	Seeds
Portulaca quadrifida	Portulacaceae	Tropical South America	Throughout India	Seeds
Prosopis juliflora (Sw.) DC.	Mimosaceae	Mexico	Throughout India	Seeds
Rhynchelytrum repens (Willd.) C.E. Hubb.	Poaceae	Tropical America	Throughout India	Seeds
Rorippa dubia (Pers.) Hara	Brassicaceae	Tropical America	North India, A.P.	Seeds
Ruellia tuberosa L.	Acanthaceae	Tropical America	Throughout India	Seeds
Saccharum spontaneum	Poaceae	Tropical W. Asia	Throughout India	Seeds
Salvinia molesta	Salviniaceae	South Eastern Brazil	Throughout India	Vegetative
Scoparia dulcis L.	Scrophulariaceae	Tropical America	Throughout India	Seeds
Sesbania bispinosa (Jacq.) Wight	Papilionaceae	Tropical America	Throughout India	Seeds
Sida acuta Burm.f.	Malvaceae	Tropical America	Throughout India	Seeds
Solanum americanum	Solanaceae	Tropical America	Throughout India	Vegetative
Solanum seaforthianum Andre	Solanaceae	Brazil	Throughout India	Seeds
Solanum torvum Sw.	Solanaceae	West Indies	Throughout India	Seeds
Solanum viarum Dunal	Solanaceae	Tropical America	Throughout India	Seeds
Sonchus asper Hill	Asteraceae	Mediterranean	Throughout India	Seeds

contd.

Table 1 (*Concluded*)

Scientific name	Family	Native place	Distribution	Propagation
Sonchus oleraceus L.	Asteraceae	Mediterranean	Throughout India	Seeds
Spermacoce hispida L.	Rubiaceae	Tropical America	Throughout India	Seeds
Spilanthes radicans Jacq.	Asteraceae	Tropical South America	Throughout India	Seeds
Stachytarpheta jamaicensis (L.) Vahl	Verbenaceae	Tropical America	Throughout India	Seeds
Stachytarpheta urticaefolia(Salisb.)Sims	Verbenaceae	Tropical America	Throughout India	Seeds
Stylosanthes hamata (L.) Taub.	Papilionaceae	Tropical America	Peninsular India	Seeds
Synadenium grantii Hook. F.	Euphorbiaceae	Tropical America	Throughout India	Seeds
Synedrella nodiflora (L.) Gaertn.	Asteraceae	West Indies	Throughout India	Seeds
Torenia fournieri Linden ex E. Fournier	Scrophulariaceae	Australia	Throughout India	Seeds
Tribulus lanuginosus L.	Zygophyllaceae	Tropical America	Throughout India	Seeds
Tribulus terrestris	Zygophyllaceae	Tropical America	Throughout India	Seeds
Tridax procumbens	Asteraceae	Tropical Central America	Throughout India	Seeds
Triumfetta rhomboidea Jacq.	Tiliaceae	Tropical America	Throughout India	Seeds
Turnera subulata J.E. Smith	Turneraceae	Tropical America	Throughout India	Seeds
Turnera ulmifolia L.	Turneraceae	Tropical America	Throughout India	Seeds
Typha angustata	Typhaceae	Tropical America	Throughout India	Seeds
Ulex europaeus L.	Papilionaceae	Western Europe	Western Ghats	Seeds
Urena lobata L.	Malvaceae	Tropical Africa	Throughout India	Seeds
Waltheria indica L.	Sterculiaceae	Tropical America	Throughout India	Seeds
Xanthium strumarium	Asteraceae	Tropical America	Throughout India	Seeds
Youngia japonica (L.) DC.	Asteraceae	Tropical South America	Throughout India	Seeds

A P, United Andhra Pradesh; H P, Himachal Pradesh; Kar., Karnataka; Mah, Maharashtra; T N, Tamil Nadu; W B, West Bengal;

Invasive/ Noxious weed management

The first line of defence against invasion is prevention, which by and large depends on legislation backed up by inspection procedures. But, unfortunately this has not been put into practice in many countries with the exception of Australia and New Zealand (Yaduraju and Rao 2013). The developing countries in the Asia need to take helps from these two countries in effective weed risk analysis and their management. It has been reported from Australia, that every dollar spent on prevention activities, benefits between 25.60 to 38.30 $ are obtined (Sinden *et al*. 2004). Prevention, control and eradication were used to be three basic concepts of weed control earlier. However, management as another concept has been a fore-runner among weed control/management concepts in recent years and considered to be the most desired approach/ concept of weed control/management in modern era (Das 2008). Thus, weed management has several aspects such as mechanical and manual, cultural/ ecological/cropping and competition, biological, chemical and allelopathy. Biology and management methods for controlling of *Cyperus rotandus*, *Eichhornia crassipes* and *Lantana camara* are summarized as follows:

Cyperus rotundus L. (Purple Nutsedge; Family-Cyperaceae)

Biology: The genus *Cyperus* having a large number of annual and perennial species of sedges and belongs to a single botanical family Cyperaceae. *Cyperus iria*, *Cyperus difformis*, *Cyperus compactus, Cyperus compressus* are annual species and present lesser in number than the perennial ones. The perennial sedge species include *Cyperus rotundus*, *Cyperus esculentus*, *Cyperus blysmoides*, *C. bulbosus*, *C. rigidifolius*, *C. tuberosus*, etc. *Cyperus rotundus* (purple nutsedge, nutgrass, cocograss) is perennial in habit and difficult-to-control weed, it is prevalent in the tropics and sub-tropics (Das 2008). It multiplies rapidly through extensive network of under-ground tubers having strong apical dominance (Nelson and Renner 2002, Webster *et al*. 2008). It is considered as the world's worst weed (Holm *et al*. 1991). The tubers or bulbs are the main perennating structures of *Cyperus*, although it has rhizomes, corms or cormlets. The tuber or bulbs can remain dormant or inactive for a long period when buried deep, usually for at least 3 years. This cause a small percentage of the tuber/bulbs present in soil sprout in each season. Each tuber/bulb has several active buds on it and only 1-2 buds sprout at a time. Thus, if one shoot is destroyed by weeding or herbicide, the many tuber/bulb can re-sprout give birth of a new shoot. The sprouting can occur on an average of 4 times in one tuber/bulb. The tuber bulb dormancy can be broken by soil disturbance and suitable environmental conditions for germination. Under optimum conditions of temperature, day length and moisture, a tuber bud when sprouts, produces a rhizome, which reaches to the soil surface, differentiates in to a basal bulb from which leaves, roots, flowers, and other rhizomes originate. If the condition continues to be favourable, the rhizomes originating from basal bulb will produce their own basal bulbs and daughter shoots. From these daughter shoots again other daughter rhizomes, basal bulbs and shoots may originate and this continue if environment conditions permit. Drought stress, shorter day length or other unfavourable factors may induce the rhizomes to terminate into a tuber rather than producing a basal bulb. In *Cyperus rotundus*, a single tuber, however, produces vegetatively on an average 150 tubers in 3-5 months.

Management strategies/options

Cultural and physical method: Deep tillage without planking during summer months is useful to control *Cyperus* by exposing the perennating structures, e.g. tubers, bulb, rhizomes, corms and cormlets to hot sun. They get desiccated/dried up to a great extent and should be raked by forked hoes/onion hoes or harrowed and collected into piles after removed from the field. The tillage may be repeated at least once in every month depending on the level of control achieved. Exposing *Cyperus* plants to certain herbicides such as glyphosate, paraquat, diquat prior to tillage helps to break dormancy of the buds and enhance their sprouting. This improves *Cyperus* control efficiency to a great extent. Tillage cuts the tubers, bulbs, rhizomes etc. into smaller pieces, which may sprout due to breaking of apical dominance or dried up/desiccated.

The basic principle behind soil solarization is that light received from the sun is in the form of electro-magnetic short waves, which can easily pass through the transparent colourless polyethene films and reach to soil. As a result, earth/soil is heated up and emits long-wave terrestrial radiation, which, however, cannot pass through transparent polyethene films and results in build-up or trapping of heat (Katan *et al*. 1976; Yaduraju 1997). Soil solarisation, however is a costly affair, but is very effective for controlling *Cyperus*, if adopted before crop is sown. In the cropped situation, a thick layer of organic mulches (Crop/plant residues) or black polyethene sheet can be useful to suppress *Cyperus rotundus*. Kumar *et al*. (2012) reported that soil solarization followed by the application of glyphosate 1.0 kg/ha at 30 days caused inhibition in tuber germination by about 50% and reduced the starch content of tubers and density and dry weight of *C. rotundus*, which, consequently increased soybean and wheat yields, system productivity and gross returns. However, solarization *fb* the applications of glyphosate 1.0 kg/ha during summer and imazethapyr 0.075 kg/ha during the rainy-season in soybean gave better *C. rotundus* control and higher soybean-wheat system productivity. Yadav *et al*. (1997) used a black or white polyethylene sheets as a mulch after one hand weeding at 70 days after planting in ber orchard and he observed more than 98% control of *C. rotundus* and same time there was no regeneration of this weed.

Line sowing and intercropping facilitate better *Cyperus* management in crop fields. A live mulch, a forage/fodder intercrop, e.g. cowpea, sorghum, maize, or a green manuring crop like *Sesbania*, mungbean, in between the rows of a main crop may be quite useful to manage *Cyperus*. Niger and cowpea (Kumar et al., 2012) are highly competitive smother crops for perennial grasses and sedges like *Cynodon* and *Cyperus*. The effect is higher if the crop is broadcast. A competitive low-growing and easily destroyed cover crop during fallow or between crop rows can be grown to replace *Cyperus* in the crop fields. Among several crop husbandry practices adopted (Table 2) wheat straw incorporation during summer resulted in maximum suppression of *C. rotundus* followed by soil solarization in soybean under soybean-wheat (Das and Yaduraju 2008) and soybean-broccoli (Das and Yaduraju 2001) cropping systems.

Chemical method: There are many herbicides, which can control *Cyperus rotundus* with varying efficiency both in crop and non-crop situations (Table 3). In maize, the post-emergence application of 2,4-D di-methyl amine at 0.73 kg/ha was found more effective for controlling *C. rotundus* compared to other formulations (Singh *et al*. 2010). Susha *et al*. (2014) conducted experiment in maize at ICAR-IARI, New Delhi and reported that a tank-mix pre-emergence application of pendimethalin 0.75 kg/ha +imazethapyr 0.050 kg/ha with or without KNO_3 (6%) and application of 2,4-D for killing *Sesbania* sown with 10 kg seed/ha under brown manuring treatments resulted in significant suppression of *Cyperus rotundus* and caused a significant reduction in total weed population and dry weight. These tank-mixes were superior to other weed control treatments and resulted in higher weed control efficiency and weed control index. Shyam and Singh (2015) and Singh *et al*.

Table 2 Effect of crop husbandry practices adopted during summer season on the population of *Cyperus rotundus* in *kharif* soybean grown under soybean-wheat (Das and Yaduraju 2008) and soybean-broccoli (Das and Yaduraju 2001)

Crop husbandry practices	Soybean-wheat system	Soybean-broccoli system
	Cyperus rotundus population in soybean (no./m^2) at 20 DAS	*Cyperus rotundus* population in soybean (no./m^2) at 40 DAS
Control/farmers' practice	144	44
Repeated tillage without irrigation	86	44
Repeated tillage with irrigation	90	34
Soil solarization	72	60
Summer cowpea for fodder	80	60
Wheat straw incorporation	54	20
LSD (P=0.05)	32	15.7

Table 3 Chemical control of *Cyperus rotundus* under crops and non-crop situations

Herbicides/ combinations	Rate (kg a.i./ha)	Time of application (Pre/Post)	*Cyperus rotundus* control efficiency (%)	Crops/ non-crops situation	References
Brown manuring* + 2,4-D	0.750	Post	84.5	Maize	Susha *et al*. (2014)
2,4-D-dimethylamine	0.730	Post		Maize	Singh *et al*. (2010)
Cyhalofop-butyl + (chlorimuron + metsulfuron)	0.090 + 0.020	Post		DSR	Pratap *et al*. (2016)
Ethoxysulfuron	0.018	Post	80.4	PTR	Raj *et al*. (2016)
Ethoxysulfuron	0.060	Post	92.9	Sugarcane	Shyam and Singh (2015)
Ethoxysulfuron	0.060	Post	62.9	Sugarcane	Singh *et al*. (2014)
Glyphosate	1.250	Post	81.1	Non-crop	Das and Yaduraju (2002)
Glyphosate	2.460	Post		Non-crop	Sukhadia *et al*. (2000)
Glyphosate	0.840	Post	40-67	GR-corn	Reddy *et al*. (2009)
Glyphosate	0.840	Post	64-83	GR- Soybean	Reddy *et al*. (2009)
Glyphosate+2,4-D Na	1.5+2.5	Post		Non-crop	Ameena and George (2004)
Glyphosate+Ammonium sulphate	0.75+0.2 (%)	Post		Non-crop	Ahuja and Yaduraju (1995)
Halosulfuron methyl	0.060	Post	100.0	Sugarcane	Rathika *et al*.(2013)
Halosulfuron methyl	0.067	Post	97.8	Sugarcane	Chand *et al*. (2014)
Imazethapyr	0.075	Post	51.5	Soybean	Kumar *et al*. (2012)
Metribuzin (MTB)	0.500	Pre	85.9	Soybean	Tuti and Das (2011)
Metsulfuron +chlorimuron (commercial mixture)		Post	100.0	DSR	Singh *et al*. (2016)
Pendimethalin + imazethapyr (tank mixed)	0.750+0.050	Pre	89.7	Maize	Susha *et al*. (2014)
Pendimethalin +imazethapyr\	0.5+0.075	Pre		Soybean	Younesabadi *et al*. (2013)
Pyrazosulfuron *fb* fenoxaprop		Pre + Post		DSR	Singh *et al*. (2016)
Soil solarization for one month *fb* glyphosate during summer (before soybean sown)	1.000	Post	83.5	Soybean	Kumar *et al*. (2012)
Sulfentrazone + atrazine	1.0+2.0	Post		Sugarcane	Srivastava (2003)

*(Sesbania seed rate @ 10 kg/ha); PTR, puddled transplanted rice; DSR, direct-seeded rice; GR, glyphosate resistance.

(2014) conducted studies on effect of rates of ethoxysulfuron for the control of *Cyperus rotundus* and other weeds in sugarcane at Pantnagar, Uttarakhand. They have shown that the ethoxysulfuron at 0.060 kg/ha effectively reduced the density of *Cyperus rotundus* . Halosulfuron methyl (NC-319 75% WDG) at 0.060 kg/ha at 3-4 leaf stages of *Cyperus rotundus* was found most effective for controlling this weed in sugarcane at Tamil Nadu (Rathika *et al*. 2013). Post-emergence application of halosulfuron-methyl at 0.675 kg/ha was highly effective in lowering the population and dry weed weight of *C. rotundus* at 60 DAT in sugarcane with 97. 8 % *Cyperus* control efficiency (Chand *et al*. 2014). Pre-emergence application of metribuzin at 0.5 kg/ha in soybean resulted in more suppression of *Cyperus rotundus* in Delhi (Tuti and Das 2011). Tank-mix pre-emergence application of pendimethalin 0.50 kg/ha +imazethapyr 0.075 kg/ha could reduce *Cyperus* population in soybean (Younesabadi *et al*. 2013). Pratap *et al*. (2016) at Pantnagar reported the application of cyhalofop-butyl + ready mix of chlorimuron + metsulfuron at 0.060 + 0.020 kg/ha in direct-seeded rice (DSR) significantly reduced the density of *C. rotundus* at 30 DAS. Similarly, herbicide combination of metsulfuron and chlorimuron was also found effective in controlling *C. rotundus* in DSR (Singh *et al*. 2016). Chauhan and Bajwa (2015) conducted experiment on rice in both dry and wet season and reported that the maximum reduction (87%) in *C. rotundus* density was accrued from the pendimethalin 1.0 kg/ha followed by bentazon at 1.0 kg/ha +cyhalofop at 0.100 kg/ha during the dry season. But, in wet season, the application of oxadiazon (at 0.50 kg/ha) followed by bentazon (at 1.0 kg/ha)+cyhalofop (at 0.100 kg./ha) resulted in maximum reduction in *C. rotundus* density (90%). The applications of pretilachlor (Pre) and metsulfuron (Post) at 0.400 and 0.015 kg/ha in both aerobic direct-seeded rice and conventionally puddled transplanted rice reduced the density of sedges like *C. rotundus* and *C. iria* in NWPZ of India (Mahajan *et al*. 2009). An application of ethoxysulfuron (Post) at 0.018 kg/ha significantly reduced the density of this weed at 30 DAT of rice, however, the effect was nullified at 90 DAT (Raj *et al*. 2016). Reddy and Bryson (2009) at

Stoneville, USA determined the efficacy of in-crop and autumn applied glyphosate on purple nutsedge density and yield of no-till glyphosate-resistant (GR) corn and GR soybean. In GR corn, glyphosate (0.84 kg/ha) applied in the autumn reduced purple nutsedge density by 40 to 67% compared with no-glyphosate. In GR soybean, glyphosate applied in the autumn reduced purple nutsedge shoot density by 64 to 83% compared with no glyphosate.

Under non-crop conditions, the combined application of glyphosate (1.5 kg/ha) + 2,4-D (2.5 kg/ha) consistently prevented the sprouting of *Cyperus* tubers (Ameena and George 2004) and controlled *Cyperus* to the tune of 85-95% (Das 2008). Paraquat @ 1.0 kg/ha as post -emergence can control the top growth of *Cyperus* when it is at the actively growing stage, but not the under-ground vegetative organs. Thus, it gives temporary control of *Cyperus* and other perennial weeds. Das and Yaduraju (2002) reported that the post-emergence application of glyphosate proved highly effective in reducing the growth of *C. rotundus* at 40 days after spray under non-crop situation. Repeat application of glyphosate at 0.75 kg/ha was the best treatment with lowest number of *Cyperus* shoots. But the re-growth of *Cyperus* was significantly reduced with glyphosate applied in combination with ammonium sulphate at 2% (Ahuja and Yaduraju 1995).

Application of glyphosate at 1.0-2.0 kg/ha alone or combination with $(NH_4)\ SO_4$ (2%) or urea (2%) were also suggested by Das (2008) for controlling *Cyperus* in fallow land. Extract from mango leaves have an allelopathic chemical properties and it drastically suppressed the germination of *Cyperus rotundus* (48.3%). Pre-emergence application of *Mangifera indica* leaf extract at 30 % reduced the fresh weight and dry weight of *Cyperus rotundus* and observed higher *Cyperus* control efficiency (73.7) (Kumar *et al*. 2017).

Biological method: Ghorai *et al*. (2005) collected a pathogen from infected, C. *rotundus* plants from farmers' field at Kairapur, District 24 Parganas (N) and from CRIJAF main farm. The pathogen was identified as *Fusarium oxysporum* (Schlect) Snyder & Hansen. About two weeks after application of isolated fungus solution to *Cyperus*, the infection started. Initially the central leaf whorl of the sedges started yellowing, followed by wilting and they finally died. The pathogen was found to be more virulent on young seedlings emerging from tubers compared to older ones. Almost entire population were died within 40 days of inoculation. Das (2008) reported that *Bactra verutana* Zeller (Moth borer) controlled *Cyperus rotundus* in India, Pakistan and USA.

Eichhornia crassipes (Mart.) Solms. Laubach (Water Hyacinth; family - Pontederiaceae)

Biology: Water hyacinth is a perennial fastest-growing free living broad-leaved grass weed that persists in water bodies. It has established itself firmly wherever it has invaded and became naturalized over space and time, for example, in India. Water hyacinth is a rhizomatous and stoloniferous plant with long, pendant and adventitious roots. The leaves arise from the rhizome nodes and stand above the water. They are dark green, ovate and cordate at the base, borne on swollen bladder-like petioles. It can accumulate 100 -150 t/ha dry matter per year @ 800 kg dry matter/ha/day, which is much faster than even napier grass (106 t/ha), sugarcane (75-112 t/ha), *Eucalyptus* (39-54 t/ha), maize (24-37 t/ha) and lucerne (18-29 t/ha). Its solar energy conversion rate (2.0-3.1%) is also higher (Das 2008). A single inflorescence has 20 flowers and each flower produces 3000-4000 seeds. The seeds sink down to the bottom and remain viable at least for 20 years. This weed creates multiple hazards, e.g. ecological, economical, and social. It also jeopardizes biodiversity, cause eutrophication, shelter pests, clog fresh waterways, and affect agriculture and aquaculture, hamper shipping and recreational activities (Patel 2012). *Eichhornia* growth is maximum when average temperature ranges from 14 to 29°C, water *p*H remains about 7, low salinity, N, P, K-rich water under full sunlight and absence of physical disturbance or pests.

Management options

Eichhornia could be utilized alternatively for composting, green manuring, bio-gas production or mulching. It could also be used for phyto-remediation process for waste water and industrial effluents. *Eichhornia* can take up heavy metals like mercury, lead, iron, copper, silver, gold, zinc and tin from water and could be used in the phyto-remediation or bio-remediation process of industrial effluents (Malik 2007).

Mechanical and manual methods: Eichhornia can be removed by netting from the water surface or can be manually picked up and collected on a boat and removed from the water bodies. This could be best method of its control, which is less costly, economical and not degradative to water bodies and the environment. The collected biomass of *Eichhornia* could be utilized alternatively.

Chemical method: The effective control of water hyacinth depends upon the population and infestation level of water hyacinth and season of application. 2, 4-D has been widely used with varying rates from 1.0 – 8.0 kg/ha, however, its combinations with paraquat are the most effective ones, *viz*. 2, 4-DEE @ 1.0 kg/ha or 2,4-D-Na @ kg 2.0 kg/ha + paraquat @ 0.9 kg/ha + urea (1%) or 2,4-DEE @ 1.0 kg/ha or 2,4-D-Na @ kg 2.0 /ha + paraquat @ 0.9 kg/ha. These treatments (Table 4) resulted in complete control of water hyacinth after 28 days of spray and caused no detrimental effect to fish in the water bodies (Das 2008).

Yadav and Yadav (2010) conducted experiment at Karnal and reported 95-96% control of *Eichhornia crassipes* by the application of 2,4-D amine at 1.50 kg/ha followed by paraquat 2.00 kg/ha (93-96%), and 2,4-D ester 1.00 kg/ha (82-85%) at 30 days after spraying. Kannan and Kathiresan (2002) reported another herbicide for control of water hyacinth, which was the application of glyphosate @ 2.2 kg/ha. The application of diquat at 0.45 to 0.67 kg/ha have also been found effective to control of *Eichhornia*

Table 4 Chemical control of *Eichhornia crassipes*

Herbicides/ combinations	Rate (kg a.i./ ha)	Time of application (on the actively growing population)	Per cent control of *Eichhornia crassipes*	References
2, 4-D Amine	1.50	Post	95.0-99.0	Yadav and Yadav (2010)
2,4-DEE	1.0-1.5	Post		Das (2008)
2,4-DEE/ 2,4-D-Na + paraquat + urea (1%)	1.0/2.0+ 0.9+1(%)	Post		Das (2008)
Diquat	0.45 - 0.67	Post		Das (2008)
Glyphosate	2.20	Post		Kannan and Kathiresan (2002)
Paraquat	2.00	Post	93.3 - 99.3	Yadav and Yadav (2010); Das (2008)
Sodium chloride	0.030 kg/litre (~3% w/w)	Post	50 (at 15 DAS)	Kathiresan (2000)

crassipes (Das 2008). Application sodium chloride at 0.030 kg/litre reported 50 % killing of *Eichhornia crassipes* at 15 days after spray (Kathiresan2000).

Kathiresan (2000) conducted experiment on allelopathic potential of native plants against water hyacinth and observed the application of dried powder of the leaves of *Coleus amboinicus* L. at 0.040 kg/litre as a water suspension killed water hyacinth within 24 hr and reduced the fresh weight and the dry weight by 80.7% and 75.6% respectively, within one week.

Biological: Neochetina eichhorniae Warner larvae *tunnel* through the petioles and stems and thus open the way for soft-rotting bacteria. They are highly effective if *Eichhornia* is pre-treated with a growth retardant. In Tamil Nadu (India) 50 adults of *N. eichhorniae* in one square feet area were released and resulted in 50% damage of water hyacinth (Yasotha and Lekeshmanaswamy 2012). Other potential bio-agents are *Neochetina bruchii* (Hyacinth weevils), *Orthogalumha terebrantis* (Hyacinth mite), *Sameodes albiguttalis* (Hyacinth moth). All the above four bioagents are native to Argentina and these have been released and established in India and successfully used for controlling water hyacianth (Varshney *et al*. 2008). *Agasicles hydrophilla* (flea beetle) is also effective on water hyacinth. Among fungi bio-agents *Cercospora rodmanii* has been introduced for water hyacinth control in the water-ways of USA. It was developed to the level of a commercial product named "ABG 5003" long back. It causes leaf spot disease in water hyacinth whereas *Marasmiellus inoderma* causes thread blight and offers a promise to control *Eichhornia crassipes*. *Alternaria eichhorniae* also causes a disease on water hyacinth (Das 2008).

Lantana camara (Wild saga; Family- Verbenaceae)

Biology: Lantana camara, is a thorny multi-stem perennial shrub with an average height of 2 m (6 ft). It belongs to the class of Magnoliopsida, order Lamiales, family Verbenaceae and genus *Lantana*.

Stems are square shaped, covered with bristly hairs when green, often armed or with scattered small prickles. *Lantana camara* possesses a strong root system. The roots even after repeated cuttings give new flush of shoots. Leaves are opposite, simple, with long petioles, oval blades which are rough and hairy and have blunt toothed margins. The leaves of *Lantana camara* have a strong aroma. Its flowers are small, multi-colored, stalked, dense in flat-topped clusters with a corolla having narrow tube with four short spreading lobes. Their flowers undergo color change subsequent to anthesis. These flowers occurs in cluster which includes white-pink-lavendar or yellow-orange-red mix. The yellow coloration of the flower provides visual cue to pollinators and change in color is initiated on the act of pollination. Berries of *Lantana camara* are round, fleshy, 2-seeded drupe with initially green in color and turning purple and finally to blue-black color. However, the berries are very poisonous in nature though these are attractive to insects and birds (Priyanka and Joshi 2013). Seeds germination is easy and faster, large distribution of this weed is due to its wide ecological tolerance.

Lantana grows in varied habitats ranging from wastelands, rainforest edges, beachfronts (Thakur *et al.* 1992) to the disturbed areas such as roadside, railway tracks and canals (Sharma *et al*. 2005, Kohli *et al*. 2006, Dogra *et al*. 2009). A typical life cycle of *Lantana camara* commences with dispersal of seeds by various dispersal agents such as fruit-eating birds and few mammals. Pollination by insects such as butterflies, moths, bees and thrips are common. Besides these, vegetative mode of propagation includes, spread through layering, or reshooting. *Lantana camara*'s repetitive growth at base of stems confirms its

Table 5 Chemical control of *Lantana camara*

Herbicides/ combinations	Rate (kg or l a.i. /ha)	Time of application (Pre/post)	Per cent control of *Lantana camara*	References
Glyphosate	2.0	Post		Sharma (1988)
Glyphosate	0.8	Post	84.8	Khokhar *et al.* (2005)
Fluroxypyr	0.5 to 1 l / 100 l water	Post		Ferrell *et al.* (2011)
Glyphosate	0.75- 1.0(%)	Post		Gupta (2008)

tenacity. Various studies indicated that *Lantana* seed have viability ranging from 2-5 years. Anthropogenic disturbances (burning, slashing, clearing, construction activities) facilitate its germination and propagation. The growth of the plant occurs all year round but the peak is reached after summer rains. The species takes only few weeks to germinate. The dryness and open canopy promotes early germination. The mature thickets once established, continue to persist for long. The plant starts producing seeds after completing one season.

Management option

Mechanical/manual, chemical and biological methods have been used for the control of *Lantana* across the world including India. These control methods have been reviewed by different workers (Zalucki *et al*. 2007).

Mechanical and manual: The most common methods used in India for the control of *Lantana* in forests are: (i) hand pulling, (ii) slashing/chopping of the stems, (iii) burning and (iv)manual grubbing with substantial removal of the root system. Burning of *Lantana* clumps coupled with the use of herbicides or mechanical removals of *Lantana* have been used for control of large-scale infestations of *Lantana* in India (Love *et al*. 2009). A cut rootstock method is the new management strategy for control of lantana, has been suggested by Love *et al*. (2009) for *Lantana* control in forest area of India. As the name suggests, it involves cutting the main tap root of *Lantana* plant beneath the 'coppicing zone' (transition zone between stem base and rootstock). Control measure involving mechanical methods are having certain drawbacks such as problem of re-growth,which is imminent if the rootstock is not removed properly. Suitability of this method is for smaller areas only and not recommended in areas susceptible to erosion.

Chemical: Glyphosate is marginally effective as a foliar spray and re-growth is common. Fluroxypyr plus aminopyralid when applied twice within 6 months is effective, but costly (Table 5). Even, Fluroxypyr applied as a basal application is consistently effective (Priyanka and Joshi 2013). In India, eradication of *L. camara* from sub-watersheds in the Markanda catchment, Himachal Pradesh, was done by spraying glyphosate on four months cuts after regenerated growth and it was found effective and economical (Rana and Singh 1999). In Queensland, Dohn *et al*. (2013) suggested that foliar spraying with a glyphosate-based herbicide is the most efficient treatment for combating large infestations of *Lantana*. In Florida, Ferrell *et al*. (2011) reported that *Lantana* was effectively controlled by two applications of fluroxypyr, two applications of fluroxypyr+aminopyralid, or a single application of aminocyclopyrachlor. During the active growing period, use of fluroxypyr @ 0.5 to 1 l/ 100 l water, glyphosate @ 1 l/ 100 l water, triclopyr @ 1 l/ 60 l of water and Grazon DS (300 g/l triclopyr + 100 g/l picloram) @ of 350 ml/100 l water per ha is recommended (Invasive pest fact sheet, Asia - Pacific Forest Invasive Species Network). In India, the post emergence application of glyphosate (2 kg/ha) could provide good control (Sharma 1988). Applications should be done when there is good soil moisture and during the active growing period, either in the morning or late in the afternoon.

Biological: A number of biological control organisms have been studied in India for controlling *Lantana camara*. Among them no one was found solely effective to restrict invasion of this weed. Biological organisms for controlling *Lantana camara* include *Ophiomyia lantanae* (fruit-mining fly), *Calycomyza lantanae* (agromyzid seedfly), *Teleonemia elata* (leaf-sucking bug), *Teleonemia scrupulosa* (leaf-sucking bug) but mostly failed as they have several varieties or forms resulting in complicating the introduction and establishment of exotic insects. Several other host specific insects such as *Diastema tigris* (flower-mining moth), *Salbia haemorrhoidalis* (leaf-folding caterpillar), *Uroplata girardi* (leaf-mining beetle), *Octotoma scabripennis* (leaf-mining beetle) and *Epinotia lantanae* (flower-mining moth) have been introduced from time to time for the biological suppression of *Lantana camara* but have not been effective in controlling its infestation. The main reasons for failures being the extreme variability of the plants, the extensive climatic range it invades and high level of parasitism on the natural enemies. The failure of bio-control program directs to think on integrated management approach, which involves several control measures.

For better and sustainable management of *Lantana camara* a technique include mapping and modelling of *Lantana camara*, which would act as early detection tool for help in managing their invasion in current and new area. There are few empirical studies in India that look at *Lantana camara* for its ability to invade, despite it widespread distribution (Raghubanshi and Tripathi 2009). There is insufficient information of its distribution and the impact of its associated harm, which is critical for planning and management. There are a few studies that have demonstrated the application of remote sensing in studying *Lantana camara* (Prasad *et al*. 2006; Kandwal *et al*. 2009).However, for such accurate mapping of this weed, it is important to consider the phenological stage of species at the time of satellite image acquisition. A combination of remote sensing techniques, GIS and expert knowledge offer potential to detect understory invasion through development of models and risk maps. However, till date, no such attempts have been reported in this direction to develop invasion risk map of *Lantana camara*.

As discussed in previous sections, fully effective control techniques are not currently available for this notorious weed. In many areas, the sheer size of the infestations coupled with low land values makes conventional control not feasible. However, mechanical clearing and hand pulling are suitable for small areas and fire can be used over large areas. Also there are several chemicals, which are most effective when applied to re-growth following other treatments. Given the limited success of bio-control till date, it is therefore important for planners and managers to develop strategies aimed at best utilization of this species. This may include planning to use the species as means of generating livelihood opportunities through craft making, creating market for herbal medicine or serve as biofuel agents through involvement of community. These practices will not only curb the invasion but simultaneously make people aware of the consequences of plant invasion. Some of the potential commercial uses of *Lantana camara* are enlisted below.

Alternate uses: In the Male Madeshwara Hills in Karnataka, the project to control *Lantana camara* is an interesting mix of community involvement into conservation practices with payoffs for both (Aravind *et al*. 2006; Kannan *et al*. 2008). *Lantana camara* parts are being used effectively in making furniture, which is cheaper than cane and equally sturdy. The furniture lasts long and does not get easily eaten away by termites. Soligas, the tribal artisans of South India are ingeniously utilizing this weed, as a substitute for rattan and *W. tinctoria*, and converting it into value added products such as furniture, toys and articles of household utility (Kannan *et al*. 2008). Currently, nearly 50 replicas of cane furniture and 25 designs of toys produced by these artisans from *Lantana camara*. ATREE is helping the tribals in marketing and certification of *Lantana camara* products, marked *Lantana camara* crafts (LCC). This innovative idea won the Global Development Marketplace award in 2003. Through recent support from Rainforest Concern, the use of *Lantana camara* has been extended to additional communities in south India to develop their own administrative structures and formalize market linkages. Attempts are also being made to design and diversify the range of products. *Lantana camara* seemed to have overrun Lachhiwala village, 24 km from state capital Dehradun (Uttarakhand, India), occupying almost one lakh hectares of land. Lantana's reputation did not daunt the villagers as they have given it an economic value. They use *Lantana* and mud to make the walls of their houses as well as chicken coops. Stripped of the bark, the insect- and pest-resistant *Lantana* stems are put to varied use-the sturdier ones make good furniture, the pliant are fashioned into trays and baskets. The pungent *Lantana* leaves have been used to make excellent mosquito repellents and incense sticks. Such innovative use of the weed brings in ₹ 75000 a year for each of the families there. And it has earned the village a new name: *Lantana* village. The credit for the success of this experiment goes to the scientists of the Dehradun-based NGO Himalayan Environmental Studies and Conservation Organization (HESCO), which provides logistic and marketing support to the villagers. Experiments like that of *Lantana* village shows that innovation can uplift a weak economy.

Herbal medicine: Lantana camara has several therapeutic uses, mainly as herbal medicine (Sharma *et al*. 1988, Sharma *et al*. 1999). There has been much work conducted in India on the chemical constituents of *Lantana camara*; extracts from the leaves exhibit antimicrobial, fungicidal, insecticidal, nematicidal, biocidal activity (Begum *et al*. 2000, Sharma 2007). *Lantana* oil is used externally for leprosy and scabies. Plant extracts are used as medicine for the treatment of cancers, chicken pox, measles, asthma, ulcers, swellings, eczema, tumors, high blood pressure, bilious fevers, catarrhal infections, tetanus, rheumatism, malaria and atoxy of abdominal viscera (Begum *et al*. 2000).

Biofuel: Lantana camara twigs and stems serve as useful fuel for cooking and heating in many regions of India (Sharma *et al*. 1988), although it is less important than other fuel sources such as windrows, woodlots or natural bush (Varshney *et al*. 2006). Its use for fuel ethanol production is recommended in various research findings (Sharma *et al*. 1988, Varshney *et al*. 2006). Biofuels obtained from twigs and stems serve useful fuel for cooking and heating in many regions of India.

Kraft pulping: Lantana camara, having 75.03% hollo-cellulose, 18.21% lignin and 2.31% silica can be a good potential source of raw material for paper making (Ray and Puri 2006). Naithani and Pande (2009) and Bhatt *et al*. (2011) have demonstrated *Lantana camara* as potential source of raw material for paper making. Thus, it is important to develop a management framework keeping in benefits and limitations of various control techniques for sustainable management of *Lantana camara*.

FUTURE RESEARCH NEEDS

A huge loss are incurred in terms of quantity and quality of crop produce, degradation of native biodiversity, hazards on environment and human health owing to the invasive / noxious weed species. The several control measures adopted for the management of these species remains insufficient. The review highlights the need of an integrated, comprehensive and effective technology to cope up with these challenges. New research aspects such as early detection tool through satellite based remote sensing for mapping distribution of invasive species has started in various countries, which could also be initiated in the country like India. Integrated weed management approaches including physical, cultural, biological, and chemical and allelopathy needs to be strengthened. Application of biotechnological tool like development of herbicide resistant crops will be paramount approach to manage the invasive/noxious weeds in cropped situations. Development of new herbicides molecules and standardizing their doses for cropped and non-crop situations needs to be explored. Enforcement of strong legislation could also prevent introduction of invasive alien weeds in the country, besides conserving the rich biodiversity. A joint efforts, thus is needed collectively from all stakeholders including researchers, farmers, planners and policy makers for timely and effective weed management. Research on alternate approaches like use of invasive /noxious weeds for industry (paper making, pulp and bio-fuel) and herbal medicine needs to be focused to increase income and livelihood security of poor farmers.

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