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Procedia Engineering 18 (2011) 240 – 246

Procedia Engineering

www.elsevier.com/locate/procedia

The Second SREE Conference on Chemical Engineering

Review on Allelopathy of Exotic Invasive Plants

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Abstract

The characters of allelopathy, allelochemicals and allelopathy mechanism of exotic invasive plants were presented in this paper, which were toxic, pernicious or having negative impact on the local ecosystem. The invasion routes, transmission modes, reproductive characters and environmental adaptability of exotic invasive plants were reviewed, and then the development and application prospects of allelopathy of exotic invasive plants were analyzed.

Keywords: Invasive Plants; Invasion Mechanism; Allelopathy; Allelochemicals; Manifestation of Allelopathy

1. Introduction

In recent years, along with the development of traffic, the increasing of human activity and the strengthening of international trades, the communication between biological species of different habitats became more and more frequent. Some of these species had strong environment adapt ability and could grow and spread rapidly in the new environment, which caused a certain adverse effect on the economy, ecology and society of the local areas. At present, allelopathy has been considered to be the most important factor influencing the invasion and spread of exotic plants.

2. Characters of Exotic Invasive Plants

2.1Invasion.

There are two main invasion routes of exotic plants, introduced by hand and introduced by chance. According to the directory of the national exotic invasive species and other references, some of the introduced-by-hand plant species were introduced as vegetables or crops initially but now have became

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doi:10.1016/j.proeng.2011.11.038

pernicious weeds, such as *Cannabis sativa* Linn (Cannabaceae) and *Amaranthus retroflexus* L. (Amaranthaceous). Some of them were introduced as forage feed, while spreading rapidly or were found to be toxic, such as Eeichhornia crassipes and Melilotus albus. Some of them were introduced as flowers, for example, *Solidago canadensis* L. (Asteraceae) and *Lantana camara* L. (Verbenaceae). Some of them were introduced as officinal plants, such as *Saponaria officinalis* L. (Caryophyllaceae) and *Dature Stramonium* L. (Solanaceae), and some others were introduced as environment-improving species, such as *Spartina alterniflora* Loisel. and *Mikania micrantha* H.B.K. (Asteraceae) [1].

The ways of introduced-by-chance are as follows: natural spread, such as *Eupatorium adenophorum* Spreng and *Ambrosia artemisiifolia* Linn. (Asteraceae). Being brought in by vehicles. Entering with the other seeds, such as Lolium temulentum .Being brought in by immigration, such as *Amaranthus blitoides* S. (Amarantaceae). Being brought in by unkown way, such as *Convolvulus arvensis* L. (Convolvulaceae) [1].

2.2Invasion Characters of Exotic Plants

*2.2.1Reproductive Characters.*Those exotic plants which invaded successfully usually have strong reproductive capacity. Some exotic species can produce a lot of seeds and seedlings rapidly. Taking ragweed as an example, one ragweed can produce 2000 to 8000 seeds[2]. With high rate of seed germination, the seedlings grow rapidly and the juvenile stage is short, which the interval between its seeding and reproduction is short. Some have strong vegetative reproductive capacity, which can grow into a plant by plant debris or by underground rhizomes, such as Mikania micrantha [3].

*2.2.2Characters.*The exotic plants that invaded successfully usually have some propagation characters. Most of exotic invasive species' seeds are small and light with wings or pappus, which can help them travel long distance with the wind [4]. Some of them can be transmitted by the means of transport. For example, the closed angle at the top of the ragweed can pierce tires or other parts to achieve its goal of spread [5]. The North American plantain can be spread by colloids adhering to the vehicles. Several exotic invasive plants of genus *Amaranthus* are widely propagated by way of seeds in bird dropping [6].

*2.2.3Environmental Adaptability.*Many studies have shown that when the exotic species arrive in a new environment, their morphology, behavior and genetic characters may change rapidly, even the leap changes, to form the features which are beneficial to their survival and development. For example, some C3 plants will change into C4 plants through photosynthetic pathway when they enter into some arid areas where the temperature is very high [7], which will be beneficial to their survival and development, and achieving their successful invasion.

3. Invasion Mechanism

There are several hypotheses on the successful invasion of exotic plants, such as Kennedy's *diversity resistance hypothesis* [8], Keane and Crawley's *enemy release hypothesis*, ERH released in 2002 [9], Blossey & Notzold's *evolution of increased competitive ability hypothesis*, EICA [10] and so on. The most influential hypothsis is the *enemy release hypothesis* which states that plant species, on introduction to an exotic region, experience a decrease in regulation by other natural enemies, resulting in a rapid increase in distribution and abundance. Based on this hypothesis, the introduction of specific natural enemies from the origin country is an effective way to combat exotic invasive species. However, the successful cases of biological control have been very small so far. On the one hand, this shows the complexity of the mechanism behind biological invasion, on the other hand, it shows that *enemy release*

hypothesis may not be the main reason for the invasion of exotic species [11]. Based on *evolution of increased competitive ability hypothesis*, Yu-Long Feng and other researchers have proposed a relatively new theory—*hypothesis of evolution of nitrogen allocation*—to explain exotic plant invasions from physical perspective. The hypothesis considers that the essence of a successful invasion is that exotic invasive plants may decrease cell wall nitrogen allocations to defenses but increase allocations to photosynthesis to enhance photosynthesis, which will result in rapid growth of single-plant biomass to achieve their successful invasion [12, 13]. A lot of experiments have confirmed that allelopathy provides means of wide spread and mass expansion for their successful invasion [14].

4. Allelopathy

Allelopathy considered as a mechanism of invasion was proposed firstly by Molish in 1937. The definition of allelopathy is the biochemical interaction of inhibition and promotion within plants or micro-organisms [15].

4.1 The Characters of Allelopathy and Its Mechanism

There are three basic features of allelopathy: firstly, the object of interaction is the plants, while the interaction between plants and animals or the interaction between plants and organisms is not included. Secondly, the material of interaction is the secondary metabolites of plants, and must have the suitable way getting into the environment, but not the secondary metabolites had changes within plants. Thirdly, allelochemicals is used for influencing the growth and the development of its own or neighboring plants. If it is used in chemical communication of plants (such as giving an alarm) or for polluting environment (such as volatiles and NO of some trees forming the smog), we will also not see it as the scope of allelopathy. The key of allelopathy research is the release mechanism of allelochemicals, namely, why and under what conditions do the plants release allelochemicals[16].

4.2 Allelochemicals and Its Types

Allelochemicals, the secretions of plants, is the chemical substances which can affect the growth, behavior and population biology of other live beings [17], including chemical substances between plants, as well as plants and animals. In recent years, with the continuous exploration and the advances in science and technology, especially the development of the chemistry and biology, the study of allelochemicals has also been developed substantially. Currently, allelopathy research is focus on the interaction between higher plants and higher plants, between higher plants and microorganisms, between microbes and higher plants, and between microbes and microorganisms. Allelopathy has a broad application prospects in increasing crop production, forest tending, plant protection, biological control, etc. [18] The research and application of allelopathy have the great significance on the prevention of exotic invasive noxious weeds.

There are many known allelochemicals: water soluble organic acid, straight-chain alcohols, aliphatic series, aldehydes, ketones, simple unsaturated lactone, long-chain fatty acids, multi-alkyne, naphthoquinone, anthraquinone acid, quinone compound, simple phenols, benzoic acid and its derivatives, cinnamic acid and its derivatives, coumarin, flavonoids, tannins, terpenoids, steroids, amino acids, peptides, alkaloids, cyanohydrin, sulfide, glucosinolates, nucleotides. While phenolic acids and the terpenoid compounds are the more common types [19, 20].

4.3 Manifestation of Allelopathy

Allelopathy has two forms, self-toxicity and allelopathy. The studies have shown that rice, wheat, corn, sugar cane and other grasses, soybeans, broad beans and other legminosae, and planted forests and tea plantations have the obvious self-poisoning phenomenon. One of fully studied crops is the rice. Chon C H. and other researchers have found that rice stubble and straw can produce some toxic substances in the process of their decomposition, which will inhibit the growth of rice seedlings. Strongest inhibition happens at the temperature of 20-25 ℃, while when the temperature is ＞30 ℃， inhibition will decrease significantly over time. As a result, it will reduce the productive tillers, effective heads, 1000-seed weight and output of the rice [21]. This phenomenon has explained the obstacle of succession cropping, and a large number of experiments based on this theory have break the obstacle of succession cropping. Allelochemicals inhibits the mechanism of action of the growth of succession cucumber [22].

4.4 Examples for Allelopathy of Exotic Invasive Plants.

Ragweed (Compositae), originated in North America, were introduced into China at the end of 1930's, spreading rapidly in eastern China. It invaded crop fields (e.g. marijuana fields, corn fields, soybean fields, vegetable fields, etc.), orchards, nursery gardens pastures, and scenic tourist area, causing serious harm. Researchers found that allelochemicals released by ragweeds can bring inhibitory action to seed germination and seedling growth of the plants around them. The congeneric ambrosia trifida L. spread widely in the northeast region of China, releasing allelochemicals into surrounding by way of leaching to enhance their competitiveness in nature, which have bad impact on other plants [23].

Eupatorium adenophorum (Asteraceae) native to Mexico, Costa Rica and other countries in South America were introduced into southern Yunnan at early stage of 1950's from China-Burma border and China –Vietnam border, and now have widely distributed in the southwest of our country. It can crowd out the survive of other plants by way of growing in large scale with single developing priority and secreting toxins and hormones, so animals will fear them and the animal health will be in danger. The results show that the Eupatorium adenophorum have allelopathy on surrounding plants [24, 25]. The congeneric eupatorium odoratum, the harmful weeds native to the Americas, located in Hainan, Yunnan, and southern and southwestern regions of China, have also been confirmed the allelopathy [26].

Mikania micrantha, a perennial herbaceous vine, native to Central America and South America, have been widely distributed in Southeast Asia and the Pacific region, as well as Oceania and Australia. It entered into Guangdong coastal areas in late 80s and early 90s of 20th century with an alarming rate of spread speed, having cuased severe damage to National Nature Reserve of Ling Ting Island in Guangdong Province. Trees have been withering because of being covered by mikania micrantha (known as "plant killer ", the main harmful grass which will be harmful to crops and forest), and a large area of arbor and shrub forests have been degenerating into the underbrush. Hua Shao and other specialists have shown that the rapid growth of Mikania micrantha and its releasing of allelochemicals to the surrounding are closely related [27].

Phoenix eyes, also known as water hyacinth native to South American, were introduced as animal feed and ornamental plants into mainland China in 1930's, being widely planted as a water purification plant for its allelochemicals can inhibit the growth of aquatic plants and algae [28].

Lantana camara, native to the Americas, is located in Guangdong, Guangxi, Fujian and other provinces of South China, having become a violation of pasture, forest, tea plantations and orchards, and seriously damaging forest resources and ecosystems. At the same time, they are also the poisonous weeds. If the livestocks and people eat them carelessly, they will be poisoned. The research suggests that Lantana camara being with a strong allelopathy, can inhibit the growth of surrounding plants [29, 30].

Wedelia originates in Africa. Southern China uses them as the green manure. Wedelia in the south tend to grow in high-density and single-species. Rensen Zeng and other reseachers have confirmed by doing

lots of experiments that Wedelia have allelopathy on neighboring plants, so we can say that the allelopathy is the important reason for inhibiting the growth of other plants and the reproduction of themselves in vast stretches [31, 32]. The congeneric Wedelia trilobata, native to tropical America, entered into our country in 1990's. According to the study, allelopathy of Wedelia trilobata has seriously bad influence on the output of rice, peanut, and other crops [33].

Eucalyptus (Myrtaceae), native to the continent of Australia and the nearby islands, were introduced into a large number of countries due to its fast growth rate, adaptability, economic potential, etc. [34] China brought in them in 1890, and they have become an important reproducing tree species in southern China. However, with the development of eucalyptus plantations, the ecological problem has become more and more prominent [35]. The studies have shown that the ecological problems of its artificial forest are closely related to its strong allelopathic effects. Allelopathy of Eucalyptus makes the understory shrubs and herbs become scarce, and makes the decline of biodiversity in forests and simple community structure, which will directly cause the serious water losses and soil erosion [36].

Ageratum conyzoides L is the important weed in the south China. The study has suggested that its residual leaves and extract can restrain the growth of wheat, and the phenolic substances isolated from residual leaves is the source of its allelopathy [37].

Solidago canadensis (Canada golden-rod, Canada goldenrod) is a herbaceous perennial plant native to North America. It was introduced into China in 1970's as a flower, having been the common exotic wildflower in Southeast China. Fang Fang and other researchers measured the impact of Solidago canadensis' water extract on the germination and the growth of seeds of pepper, tomato, radish, cabbage and wheat, which showed that Solidago canadensis have the strong allelopathic effect on the tested crop seed germination, namely the strong allelopathy [39]. Zhou Kai showed that root aqueous extract and rhizosphere soil extract of Solidago canadensis can exhibit inhibition effects in terms of germination of Chinese cabbage seed and radish seed [40].

5 The Development and Utilization Prospects of Allelopathy of Exotic Invasive Plants

5.1 Eestablish a Rational System of Crop Intercropping.

Allelopathy is widely used in agricultural production. We must take into account the impact of allelopathy on either single-crop cultivation, or the cultivation of crop rotation, intercropping, relay intercropping, crop cover and continuous cropping [41].

5.2 Giving Full Play to Ecological Effects of Allelochemicals.

Pyrethrum is a perennial herb. Pyrethrin with terpenoids extracted from pyrethrum flowers has the contact toxicity and paralysis effects on insects, being one of the oldest pesticides. People have also synthesized a number of pyrethrin analogues, such as deltamethrin. [42]. Nematodes can be effectively suppressed by marigold plant, crotalaria mucronata, chaysanthemum, castor, casuarina, etc. Using chemical agents to kill nematodes will change physical and chemical properties of soil, influence microbial entiroment of soil, and disturb nutrient cycling. However, using the plants that can resist the nematode in intercropping or crop rotation can control nematodes and protect the environment [42].

5.3 Developing Resources by Using Allelochemicals.

Allelochemicals are mainly the active secondary metabolites. Scholars have been studying the allelopathic effects of exotic plants, and at the same time, some of them have proposed to develop pharmaceutical and botanical pesticides by using the allelochemicals of exotic plants. Yanbiao He reported that the fragrant eupatorium herb is rich in flavonoids which will make plutella xylostella keep away from the plants or eating the plants [26]. We must have a deep and objective understanding of exotic invasive plants, meanwhile, conduct in-depth study of allelopathy to understand its mechanism, and then make full use of allelopathy to eradicate exotic invasive plants to improve the environment and protect the ecology.

Acknowledgements

This research was supported by Special Fund for Agro-scientific Research in the Public Interest (No. 20110327)

References

[1] Li Z Y,Xie Y.Invasive alien species in China. Beijing: China Forestry Publishing House, 2002

[2] Zhao M. Integrated Control and Countermeasure of External Invasion Biology.

Agro-environment and Deveopment.2003, (5):pp38-39.

[3] Rejmanek M, Richardson D M, What attributes make some plant species more invasive? Ecology,1996, 77(6):pp1655-1661.

[4] Wan F H, Wang R. The biology and ecology characteristic of the malignancy harm grass Ambrosia artemisiifolia. Journal of weed science. 1990, 4(1):pp45-48.

[5] Guo S L. Study on the Origination, Spread and Bioecological Chracteristics of Exotic Weeds. Guihaia. 1995,15(1):pp89-95.

[6] Smith C M, Waiters L J. Fragmentation as a strate for Caulerpa species: fates of fragments and imlications for management of an invasive weed. Marine Ecology.1999, 20(33):pp307-319.

[7] Sage R F. The evolution of C4 photosynthesis. New Phytologist, 2004, 161:pp341-370.

[8] Kennedy T A, Naeem S, Howe K M, et al. Biodiversity as a barrier to ecological invasion. Nature, 2002, 417, pp. 636-638.

[9] Keane, R.M. and M.J. Crawley. Exotic plant invsions and the enemy release hypothesis. Trends in Ecology & Ecolution ,2002. 17(4), pp.164-169.

[10] Blossey B, Notzold R. Evolution of increased competitive ability in invasive nonindigenous plants:a hypothesis.Journal of Ecology, 1995,83: pp.887-889

[11] Feng Y L .Photosynthesis, nitrogen allocation and specific leaf area in invasive Eupatorium adenophorum and native Eupatorium japonicum grown at different irradiances. Physiol Plant 133 :pp.318–326.

[12] Feng Y L. Harald Auge, Susan K Oecologia.Invasive Buddleja davidii allocates more nitrogen to its photosynthetic machinery than five native woody species. Oecologia, 2007, 153(3):pp.501-510

[13] Feng Y L, Lei Y B, Wang R F, Ragan M. Callaway. Evolutionary tradeoffs for nitrogen allocation to photosynthesis versus cell walls in an invasive plant. PNAS.2009, 6,pp.1853–1856

[14] Callaway R M, Aschehoug E T.Invasive plants versus their new and old neighbors:a mechanism for exotic invasion. Science, 2000,290:pp.521-523.

[15] Molish Der Einfluss einer Pflanze aufdie andere. Allelopathie.Fisher,Jena.1937;pp.13-20.

[16] Kong C-H. Problems needed attention on plant allelopathy research.Chinese Journal of Appled Ecology,1998,9(3):pp.332-336.

[17] Whittaker RH,Feeny PP. Allelochemics: Chemical interactions between species. Science,1971, 39(37):pp.757-770.

[18] Yan F,Yan Z-M,Han L-M.Review on research methods for allelopathy and allelochemicals in plants. Acta Ecologica Sinica. 2000,20 (4) :pp.692-696.

[19] Song J. Allelopathy Among Plants. Chinese Journal of Ecology.1990, 9(6):pp.43-47.

[20] Sun W H,Yu S W. Allelopathy and Its Potential Application. Plant Physiology Communications. 1992,28(2),pp.81-87.

[21] Chon C H.Allelopathy in relation to agricultural productivity in Taiwan:problems and prospects.Allelopathy:Basic and Applied Aspects.London:Chapman and Hall，1992.pp.179-203.

[22] Lü W G,Zhang C L,Yuan F,et al. Mechanism of Allelochemicals Inhibiting Continuous Cropping Cucumber Growth..Scientia Agricultura Sinica , 2002, 35(1),pp.106-109.

[23] Wang D L,Zhu X R. Allelopathic Research of Ambrosia Trifid. Acta Phytoecologica Sinica, 1996, 20(4):pp.330-337.

[24] Qiang S. The History And Status of The Study on Crofton Weed (Eupatorium adenophorum) a Worst Worldwide Weed [J]. Wuhan Botanical Research, 1998，16(4):pp.366-372.

[25] Sharma G P, Singh J S, Raghubanshi A S. Plant invasions: Emerging trends and future implications.Current science, 2005, 88: pp.726-733.

[26] He Y B,Zhang M X,He T Y,et al.Studies on the Allelopathic Effects of Chromolaena odoratum. Journal of South China Agricultural University,2002,23(3):pp.60-62.

[27] Shao H,Peng S L,Wang J D,et al.The Potential Utilization and Exploitation of Mikania micrantha.Ecologic Science,,2005，22(5):pp.62-65.(in Chinese)

[28] Sun W-H,Yu Z-W. Inhibitory Effect of Eichhornia crassipes (Mart.) Solms on Algae. Acta Photophysiologica Sinica,1988,3:pp.294-300.(in Chinese)

[29] Liu S-Q,Jia Z-H. Biological activity of aqueous extract and volatile oil from the leaf of Lantana camara and its chemical constituents. Guihaia, 2002，22(2):pp.185-188. (in Chinese)

[30] Wang K-Z. Theory of Lantana.Plants,1999,(3):pp.10-11.

[31] Zeng-R-S,Lin X-L. Studies on The Allelopathic Effects of Wedelia chinensis Aqueous Extraction. Journal of South China Agricultural University, l994，15 (4):pp.26-304.

[32] Nie C-R, Zeng-R-S,Li H-S,et al. Physiological and Biochemical Mechanism of Allelopathy of Wedelia trilobata L. on Peanut. Peanut Science and Technology, 2002，31(3):pp.1-5.(in Chinese)

[33] Zhang Y-H,Liu M-F,Ling T-J,et al. Allelopathic Sesquiterpene Lactones from Wedelia trilobata. Journal of Tropical and Subtropical Botany,2004,12(6):pp.533-537.

[34] Liu X-X,Xie L-L,Chen Q-B,et al. A Review of Allelopathic Researches on Eucalyptus. Chinese Journal of Tropical Agriculture,2004,24(2):pp.54-61.

[35] Wang Z-H,Duan C-Q,Qi L-C,et al. A Preliminary Investigation of Ecological Issues Arising in the Man-made Forest of Eucalyptus in China. Chinese Journal of Ecology, 1995, 17(6):pp.64-68.

[36] Luo S M, Lin X L, Zeng-R-S,et al. Allelopathy of Typical Plants in Agroecosystemof South China. Ecologic Science,1995(2):pp.114-127.

[37] Kong C H,Hu F,Luo S M.Allelopathy of Ageratumcony Zoides L. on Crops. Scientia Agricultura Sinica,1997,30(5):pp.95.

[38] Guo S L, Mao Y R, Qiang S. Influences of temperature on peroxidase isozymograms of six exotic weeds.Guihaia,2002,22(6):pp.557-562.

[39] Fang F,Guo S L,Huang L B. Allelopathic Effects Of the Invasive Plant Solidago Canadensis. Ecologic Science.2004,23(4):pp.331-334.

[40] Zhou K,Guo W M. Allelopathic Effects of Aquatic Extracts from Solidago canadensis's Roots and Rhizospheric Soil on the Seed Germination and Early Seedling Growth of Chinese Cabbage and Radish. Acta Botanica Boreali-occidentalia Sinica,2005,25(1):pp.0174-0178.

[41] Norstad F A, Mccalla T M. Phytotoxic substance from a species of Penicillium. Science,1963,140:pp.410-411.

[42] Cai Q J, Luo W Z, Chen C X,et al. Study on Extraction and Killing Effect of Plant Nematodicide. Journal of Fujian College of Forestry,1998,18(4):pp.291-293.