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Role of allelopathy in sustainable agriculture: Use of allelochemicals as naturally occurring bio-agrochemicals

C.H. CHOU

Research Center for Biodiversity and Graduate Institute of Ecology and Evolutionary Biology
China Medical University, Taichung 40402, Taiwan
E. Mail: choumasa@mail.cmu.edu.tw

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CONTENTS

ABSTRACT

Alleopathy is the process whereby plant releases toxic compounds into environment, resulting in a detrimental effect on neighbouring plants or its own sharing the same habitat. The toxic metabolites are released into environment through volatilization, leaching, decomposition of plant residues in soil and root exudation. The phenomenon was earlier found in agricultural practice by Theophrastus (372 to 285 BC), who reported the inhibitory effect of pigweed on alfalfa. In 1832, De Candolle suggested that the soil sickness problem in agriculture might be due to exudates of crop plants. Since then, many scientists had reported the significance of toxic effects of plant residues decomposing in soil, leading to the reduction in crop productivity. The productivity of many crops (*Sorghum bicolor*, *Medicago sativa*, *Oryza sativa*, *Asparagus officinalis*, *Phaseolus radiatus*, *Saccharum sinensis*, etc.) was reduced significantly after a continuous monoculture. The crop productivity declines due to (i). crops produces phytotoxic substances in soil and (ii). the accumulation of phytotoxins causes the imbalance of microbial population, such as *Fusarium oxysporum* in soil. These harmful allelopathic effects could be reduced through crop rotation or improving soil drainage in field. In a unique example of pasture and forest intercropping system was demonstrated by the author that an aggressive kikuyu grass (*Pennisetum clandestinum*), was introduced into the deforested conifer land. The kikuyu grass suppressed the growth of weeds significantly, but was not harmful to the regeneration growth of conifer plants or seeding growth of other hardwood trees. The pasture-forest intercropping system, indeed, benefited the forest management by reducing the use of herbicide, saving expensive manpower, and enhancing forage material for livestock. Finally, the author in recent years have developed a unique system of using the plant parts, leaves, twigs, or roots, of allelopathic plants to make a cocktail of agrochemicals to replace conventional herbicides, fungicides, or insecticides, resulting in avoiding the residual effects of agrochemicals and reducing the environmental deterioration. Using advanced biotechnology, the allelopathic genes can be introduced into crops which possess the allelopathic potential to suppress its competitive weeds in the field. Thus, allelopathy has played important roles in sustainable agriculture.

Keywords: Alkaloids, allelochemicals, allelopathy, flavonoids, phenolics, phytotoxins, soil-borne pathogen, terpenoids

1. INTRODUCTION

Since World War II, industrialization has developed extensively, leading to migration of people from villages to cities and thus causing the shortage of labour in agriculture. Consequently, the agricultural practices have changed from conventional tillage to modern farming (heavy use of fertilizer and agrochemicals). Superficially, the crop productivity of modern agriculture seems to be increasing by using agrochemicals; however, the application of agrochemicals for a certain period of time may obviously cause a tremendous environmental deterioration, resulting in chemical pollution in soil and reducing the soil fertility. Thus in the long run, our earth would be deteriorated and crop productivity would reduce. For the sake of healthy earth ecosystem and sustainability of human being, conventional agriculture has to be improved by reducing the use of synthetic fertilizers or agrochemicals (herbicides, fungicides and pesticides). In Earth Summit held in Rio de Janeiro in 1992, *Sustainable Development* and *Agenda 21* were declared. Meanwhile, a concept of sustainable agriculture has been adopted by many industrial countries, such as Japan, EU countries and USA.

The 6th International Federation of Organic Agriculture Movements (IFOAM) (1986) Santa Cruz, California declared the term sustainable agriculture (SA). It means that a minimum amount of fertilizers and/or synthetic agrochemical should be avoided in an agriculture system. In other words, an alternative, biodynamics, regenerated, low-energy input, and resource-conserving ways of agriculture practice were suggested (1,10,24). SA gradually becomes common in most advanced agriculture countries. Particularly, organic farming is popular in Japan and EU countries and organic foods have been appreciated by public. To replace synthetic fertilizer and agrochemicals, compost and allelochemicals are increasingly being used in the field and playing an important role in sustainable agriculture.

Allelochemical was defined as the metabolite released from the organisms into environment may stimulate, inhibit, attract, nourish, repel or poison other organisms sharing the same habitat (19). The allelochemical was derived from the term *Allelopathy* which was coined by Molisch (39), using two Greek words "allelon" and "pathos" meaning "mutual harm". In early literature, Theophrastus reported an example of inhibitory effect of pig weed on alfalfa (33). De Candolle, a Swiss botanist, suggested that the soil sickness problem in agriculture might be due to exude of crop plant (22). Hoy and Stickney (30) reported harmful effects of black walnut on the growth of neighbouring plants. Putnam and Duke (45) indicated that Molisch's use of term allelopathy was technically erroneous. Muller (40) rather preferred using "interference" to describe plant-plant interaction, which involves both Competition and Allelopathy. Rice (46) extended the meaning of allelopathy and defined as both stimulatory and inhibitory effects among the organisms. In agriculture, tremendous publications related to allelopathy were released (2,5,10,19,31,47,48,52). In addition, autointoxication, another phase of allelopathy phenomenon occurred in many crops, particularly, the fact was found in a continuous monoculture of crops, such as rice (17), mungbean (20), asparagus (57), sugarcane (54) and in trees replanting problems, such as apple (7) and peach (28,43,44). Muller (41) further concluded that the allelopathy plays an important role in the mechanism of plant dominance, plant succession, climax vegetation formation, and crop productivity. Chou (10) further emphasized that allelopathy also plays an important role in plant biodiversity in regulating plant population and evolutionary strategy of the plants. Regarding the roles of allelopathy in sustainable agriculture, great number of articles have been published by various scientists all over the world (3,9,10,26,34,39,48,49).

2. PHYTOTOXICITY OF DECOMPOSING PLANT RESIDUES TO CROP YIELDS

In early 20th century, allelopathy research was done on crops (6,7,23,44). Particularly, phytotoxic substances produced during the decomposing crop residues in soil may reduce the yields. Several unique examples are given below.

2.1. Rice yield reduction in second crop in Taiwan

Since last century in Taiwan, two rice crops are grown per year i.e. in spring and fall. The first crop in spring season is grown from late February to June (about 130 days), while the second crop in fall season is grown from July to November (about 110 days). There is a 2-3 weeks fallow period between these crops and the farmers always submerge the rice stubbles in the fields during the fallow period. Thus, organic acids are produced during the decomposition of stubbles in soil. For nearly a century, the yield of the second rice crop was generally 25 % lower than first crop. Chou and Lin (17) conducted a series of experiments to elucidate the mechanism of yield reduction. They showed that when rice straw was incorporated into soil (1:10 / straw: soil) that allowed to decompose for 1, 2, 4, and 8 weeks, the aqueous extracts of straw-soil mixture was phytotoxic to rice seedlings (17). The phytotoxicity lasted for 16-weeks, indicating that the phytotoxins were retained in the soil mixture. The phytotoxins were: *trans*-*p*-coumaric, *cis*-*p*-coumaric, vanillic, *p*-hydroxybenzoic, ferulic, and *o*-hydroxyphenylacetic acids and some short chain fatty acids (17). The *o*-hydroxyphenylacetic acid was first reported as phytotoxin at a concentration below 10^{-4} M. Chou *et al.* (12) further conducted experiments by incorporating enriched ^{15}N-ammomum sulfate in soil-straw mixture, which were incubated at various temperatures (15 °C to 33 °C) for different times. After 6-weeks incubation, it was found that the phytotoxicity reached maximum peak at temperatures between 25 °C to 35 °C, indicating that the residue decomposition in soil was rapid and thus released higher amounts of phytotoxins during the summer fallowing period. It was concluded that the yield reduction of rice in second crop was primarily due to the phytotoxins produced during the decomposition of rice straw in soil.

2.2. Sugarcane yield reduction

The sugarcane yield in a continuous monoculture has declined in many fields in Taiwan and other countries, involving several causes (56). Wang *et al.* (53) conducted field and laboratory experiments and showed that phytotoxicity of decomposing sugarcane stubbles in soil was a major factor. Four phytotoxic phenolics [ferulic, *p*-hydroxybenzoic, *p*-coumaric, and vanillic acids] and 6 short chain fatty acids [acetic, butyric, oxalic, malonic, tartaric and malic acids] were found in decomposing sugarcane leaves in water-logged soil. Wu *et al.* (56) found that the population of *Fusarium oxysporum* in the rhizosphere soil of poor growing ratoon cane roots was much greater than the better growing ratoon roots. They also found fusaric acid, a metabolite of *F. oxysporum*, was toxic to the growth of young sugarcane plants at 10 ppm, by using Murashige and Skoog's medium. The leaves of sugarcane became wilted and chlorotic (56).

2.3. Asparagus plants yield reduction

The yield reduction and poor quality of *A. officinalis* occurs in a continuous monoculture soil in Taiwan and Russia (32,57). Young (57) conducted experiments to find the cause of the poor asparagus plantation in Taiwan, by using three asparagus varieties: Mary Washington, California 309, and California 711. He found that the root exudates of asparagus drastically suppressed (80 %) the shoot growth of asparagus plants than control, besides 40-60 % reduction in root growth. However, the inhibition was not significantly different among three varieties. The responsible phytotoxin isolated and identified was methylenedioxycinnamic acid, which significantly inhibited curly cress root and shoot growth at concentration of 25 ppm. Several phenolic compounds were also identified (57).

2.4. Synergistic effects of phytotoxicity and pathogenicity in mungbean monoculture

After a continuous monoculture of mungbean (Fig. 1) in the Asian Vegetable Research and Development Center, Tainan, Taiwan, the growth of mungbean was severely reduced. Exceedingly poor growth of mungbean plants occurred after continuous monoculture (Fig. 1, right) as compared to the plant without monoculture (Fig. 1, left). After many studies, Chou *et al.* (20) concluded that at least 25 % growth reduction in successive crops of mungbean plants was due to the phytotoxic effects. Several phytotoxic phenolics, including *p*-coumaric acid and soyasaponin 1 were present in mungbean leaves. It was assumed that after deglycosidation of soyasaponin 1, the aglycone moiety might exhibit phytotoxic effect pronouncedly. However, the findings of further studies showed that soil-borne pathogens, such as *Pythium* and *Fusarium* spp. played a significant role of pathogenicity in mungbean plantation. Thus, the poor growth and yield reduction of mungbeans might possibly due to the synergistic effect of both phytotoxicity and pathogenicity.

Figure 1. The growth of mungbean plant without monoculture (left) and continuing monoculture (right).

2.5. Improving the productivity of autotoxic crops

To increase the productivity of monoculture crops, there may be several agricultural approaches: crop rotation, water drainage, fire and modification of soil. Crop rotation is most important for management of soil sickness (31). Patrick (44) reported that a crop rotation of tobacco/ryegrass/cone system was effective in reducing the severity of tobacco root rot caused by *Thielaviopsis basicola*. In crop rotation of rye grass, it may release phytotoxins during the decomposition of rye grass residues in soil (18) and suppress the growth of *T. basicola*. Even more, a large amount of phytotoxic substances may also be produced during the decomposing of corn residues in soil. Chou and Patrick (18) identified more than 10 organic compounds in the corn decomposing residues, which suppressed the growth of soil-borne pathogen and weeds. It is concluded that phytotoxins play an important role in controlling pathogen population, enhancing the balance of soil microbial population. A unique long-term crop experiment (1959 to 2000) was conducted at the Kitami Agricultural Experiment Station, Hokkaido, Japan (31). The experiment was designed to compare a system of continuous monoculture of bean plants with a 6-year rotation system in a sequence of potato/sugar beet/oat/bean/winter wheat and red clover. The findings revealed that the average yield of monoculture bean was 970 kg/ha/yr as compared to without monoculture 2380 kg/ha/yr (Fig. 2). The improvement in bean productivity was simply due to the control of damping-off of bean caused by *Pythium* spp. Perhaps, the control mechanism was due to the allelopathic effects on *Pythium* spp. Many excellent examples of enhancing crop productivity by rotation have been reported in many countries (1,29,37,38,48).

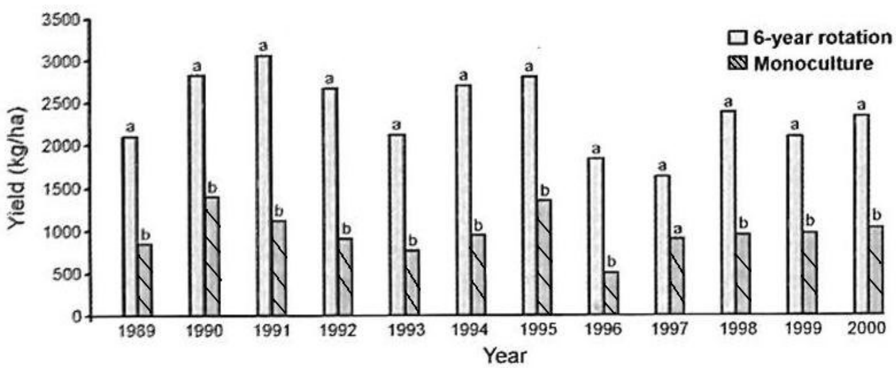

Figure 2. During 1989-2000, seed yield of bean was high in the 6-year rotation but was low in the continuous bean monoculture (31)

3. ALLELOPATHY IN INTERCROPPING SYSTEMS

3.1. Cruciferous plants as intermediate crop

Cruciferous crops are important crops in temperate zones for forage production and resource for biofuel. Most cruciferous plants had exhibited allelopathic activity. For example, *Brassica nigra* invaded into California annual grasslands and soon established as dominant vegetation (4). However, Yurchak *et al.* (58) found the plant exhibited lower allelopathic activity. The aqueous extracts of inflorescence, stalk, and leaves exhibited significant inhibition in seed germination and growth of tested species as compared to control. However, seed germination and subsequent seedling growth was slightly stimulated in wheat and was significantly promoted in maize (26). When ground rape roots were added to soil, it enhanced the wheat root growth (26). In rape roots, β-phenyl mustard oil was identified but the compound was soon decomposed into non-toxic phenylethylamine. Rape is commonly used to control couch grass [*Agropyrum repens* (L)] weed (26). Regarding the allelopathic compounds, 14 native brassinosteroids have been found in crucifers, however, their role in agriculture has not been fully investigated.

Regarding the weed control by cruciferous plants, Uteush (51) reported that when winter rape was used as intermediate crop, 40 % weed population was reduced. It exhibited a similar result (48.7 % reduction in weed population), when rape was grown in spring. Furthermore when rape was planted after corn harvest, 90 % weeds growth was reduced. It was concluded that crucifers are effective intermediate crops that provide biological control of weeds, pests and unwanted microflora. Thus, in crop rotation, cruciferous plants could be beneficial for the productivity of successive crops.

3.2. Beneficial effects of corn-soybean intercropping

The beneficial effects of corn-soybean intercropping or crop rotation are well-known to farmers. The corn-soybean intercropping or rotation system is indeed a unique example for sustainable agriculture. Legume plants would provide nitrogen to soil thus reduced nitrogen fertilizer in the field. In addition, several additional benefits to agriculture are; improving soil physical properties, reduced soil erosion, suppressing weeds through allelopathic effects and insects and disease control. A unique example of corn-soybean system was conducted in Urbana, Illinois from 1969 to 1981. Odell *et al.* (42) showed that the corn production after soybean yield 17 % more than continuous corn (49). The corn plant intercropped with other cereals also showed allelopathic effect. For example, Guenzi *et al.* (27) reported that corn and sorghum residues released toxic material at harvest and required decomposition for 22-28 weeks to allow disappearance of toxic substances. Chou and Patrick (18) indicated that during the decomposition of corn residues in soil, more than 10 phytotoxic phenolics were released, to suppress the growth of weeds or successive crop. Allelopathy certainly plays a significant role in regulating weed population or weeds growth and is beneficial to productivity of plant growth. In conclusion, allelopathy plays an appreciable role in agriculture cropping system, involving a stimulatory role of soybean-corn system. However, allelochemical isolation and identification in a complex systems of corn-soybean or soybean-other crop were not successful, further investigation should be carried on.

3.3. Introduction of kikuyu grass after deforestation

Weed control after deforestation is necessary and important to allow re-establishment of young seedlings or regeneration of forest. Using herbicides to control weed population has long been employed, however, it causes environmental deterioration when the herbicides leach out to river or water reservoir. On the other hand, removal of weeds by labour is ecologically safe but is expensive in most developed countries. The ideal way is to introduce a dominant forage grass to the deforested land, allowing the grass to establish soon after deforestation. However, the grass should possess a high competition against weed growth. It would be even better if the forage grass exhibits high allelopathic potential to suppress the weed growth. The author had introduced an ideal forage grass, called kikuyu grass (*P. clandestinum*) into a deforested land of Chinese fir (*Cunninghamia lanceolata*) in 1980s. Our experiments were conducted at the Hoshe Forestry Experiment Station Farm, National Taiwan University (1300 m elevation). The fir was grown there for many decades and a portion of mature plantation was harvested in October 1983. The detailed field experimental setting was described by Chou *et al.* (11,15). Four treatments were: (A). Surface fir litter removed and nothing planted, (B). Surface fir litter left and nothing planted, (C). Surface fir litter removed and kikuyu grass planted and (D). Surface fir litter left and kikuyu grass planted. Stolon cuttings of kikuyu grass were planted. The area was well protected and very little mammal activity occurred during the study (8). The measurement of relative coverage of weed, kikuyu grass and Chinese fir was taken on 4 consecutive dates 6 months after treatments (8). The results of measurement indicated that the % coverage of weed in treatments A and B (without kikuyu grass planting) was significantly high at the first three harvested dates but decreased to nearly zero at the last measurement 20-months after treatment. On the other hand, in treatments C and D, where kikuyu grass was planted, the % coverage of weed was significantly low from 32 % and 57 %, respectively. Regarding the % coverage of kikuyu grass was much low in treatments A and B, but was increasingly high in treatments C and D. In particular, the kikuyu grass established almost entire plot a year after planting and even invade into the plots of A and B. Nevertheless, the reseedings of Chinese fir were not significantly different among 4 treatments although the fir seedlings were gradually re-established (Fig. 3). The findings indicated that the kikuyu grass suppressed the weed growth but was not harmful to the growth of Chinese fir (15).

Figure 3. Regeneration of *C. lanceolata* after kikuyu grass was introduced into the deforested *C. lanceolata* land. The photo was taken one year after deforestation.

Extensive studies were further conducted by introducing kikuyu grass into 3 other hardwood forests, namely *Alnus formosana*, *Cinnamomum camphora*, and *Zelkova formosana* (11) and results revealed the similar effect. Thus we concluded that (i) the kikuyu grass suppressed the growth of weeds without application of synthetic herbicide; (ii) the kikuyu grass stimulated the growth of woody plants without fertilizer, which reduced the use of agrochemicals, and (iii) the suppression of weed growth saved expensive labour costs.

4. ALLELOPATHY IN FORESTRY

4.1. Allelopathic potential among bamboo species

Chou and Hou (14) evaluated 14 bamboo species in Taiwan and found that several species: *Dendrocalamus latiflorus*, *Phyllostachys edulis*, *Bambusa oldhami* and *Bambusa pachinensis*, exhibited strong allelopathic phenomenon. Seven phytotoxic phenolics, namely *o*-hydroxyphenylacetic, *cis-p*-cinnamic, *trans-p*-hydroxycinnamic, vanillic, *o*-hydroxybenzoic, ferulic and syringic acids were found. Chou and Yang (21) further investigated the mechanism of allelopathic dominance in *P. edulis* and showed that the lacking understory species on the *P. edulis* floor was not due to the physical competition of light, soil moisture, or minerals but was primarily due to the hydrophilic metabolites leached out from leaves of *P. edulis* and its fallen litter. Thus, the fallen leaves and litter of bamboo plants can be used for bio-agrochemical resource.

4.2. Allelopathic potential of *Leucaena leucocephala*

L. leucocephala, a tropical and subtropical legume plant was introduced into Taiwan and becomes an invasive plant in southern Taiwan. Underneath the trees, there was no understory species except *L. leucocephala*, Chou and Kuo (16) had conducted extensive studies in the field, greenhouse and laboratory and confirmed that the aqueous leachate or extract of *Leucaena* leaves exhibited significant inhibition of seed germination and radicle growth of test plants, such as *Lactuca sativa*, *O. sativa*, *Casuarina glauca*, *Acacia confusa*, *Alnus formosana*, *Ageratum conyzoides* and *Mimosa pudica*. A significant quantity of mimosine and its derivative, 3, 4-dihydroxypyridine was responsible for the allelopathic effect. Mimosine exhibited phytotoxicity on lettuce seedling at the concentration as low as 20 ppm. Besides aforementioned alkaloid, phenolic acids and flavonoids are also present in the plant parts. Thus, leaves and other *Leucaena* parts can be used as naturally occurring herbicide to control weeds of understory species in the field.

4.3. Allelopathic potential of *Acacia confusa*

Similar pattern of allelopathic phenomenon has been found in dominant stand of *A. confusa* (13). *A. confusa*, an endemic species, as well as several exogenous species were found to be allelopathic. In addition to phytotoxic phenolics present in leaves of *A. confusa*, flavonol galloylglycosides were found in leaves (36) and flavonoid aglycones and indole alkaloids were also found in the roots of *A. confusa* (35). These natural products can be used as naturally occurring herbicides or agrochemicals. The application of allelopathic natural products used as agrochemical is being undertaken in field practice (Chou 2009 unpublished).

4.4. Allelopathic potential of *Macaranga tanarius*

Macaranga tanarius (Euphobiaceae family) has accumulated a great amount of fallen leaves on its floor and distributed wildly in old field area. The plant often invades into grassland area and becomes dominant vegetation. Underneath the vegetation, only a few species, such as *Alocasia macrorrhiza*, can be found. However, in the adjacent area, several weed species, namely *Bidens pilosa*, *Miscanthus floridulus* and *Chloris barbata*, were absent on the floor of *M. tanarius*. Tseng *et al.* (50) evaluated the mechanism of dominance and found that leaves of *M. tanarius* exhibited significant allelopathic effects on the growth of aforementioned plants, particularly, *B. pilosa*. We further isolated and identified the allelopathic compounds in leaves and litter of *M. tanarius* stand and found many natural products [nymphaeol-A, nymphaeol-B, nymphaeol-C, quercetin, abscisic acid (ABA), blumenol A, blumenol B, reseoside II, tanariflavanone A, tanariflavanone B and D-mannitol]. Of them, ABA plays the most important role in regulating species diversity of understory. We assumed that the fallen leaves can be used for naturally occurring herbicide.

5. AGRICULTURAL AND FORESTRY DEBRIS AS BIO-AGROHEMICALS

Sustainable agriculture is a way to save energy and protect the environment from further deterioration. As mentioned previously, the advanced agriculture practice should be used by avoiding synthetic fertilizers and agrochemicals. Organic farming is an excellent practice to achieve the goal of sustainable agriculture. Naturally, compost of organic debris could be used as fertilizer and naturally occurring allelochemicals constituted in different plant debris would contain tremendous natural products, such as phenolics, flavonoids, terpenoids, alkaloids and fatty acids, which could be utilized as natural bio-agrochemicals. In a western saying "To waste the waste is waste". Agricultural and forestry debris should not be regarded as wastes, which contain a variety of natural products as mentioned above. Indeed, the allelopathic potential trees mentioned can be further used if a proper technology is developed. Recently we have successfully tried to mix leaves powder of different allelopathic plants to control the weeds growth. Several promising examples are given as follows:

5.1. Natural agrochemicals: Agrostemin and neem plant

Agrostemin was isolated mainly from the corn cockle of *Agrostemma githago* L., which is a common weed in the field of wheat and other cereals (25). Agrostemin has been applied into agriculture practice as herbicide or weed controller in eastern European countries. The story was well described (55).

In addition to Agrostemin, natural products from neem plant (*Melia azedarach* L.) have extensively been used in agricultural practice, such as herbicide, fungicide, or nematicides in India (48).

Chou (10) suggested that following necessary studies must be done in future: (a) the allelopathic genes transfer to crop cultivars, (b) the allelopathic plants used in crop rotation, (c) residues of agronomic crop used as mulches to suppress weed growth, particularly, in the conservation and no-tillage crop production.

5.2. Cocktail mixture of allelopathic tree debris used as bio-agrochemicals

Recently, we have conducted experiments by using the abovementioned allelopathic plants, such as *A. confusa*, *L. leucocephala*, *Litchi chinensis*, *Delonix regia*, *Eucalyptus* spp. and other plants, ground into powder and thoroughly mixed in a certain ratio to form a small granule of less 4 mm ID, which named CMU-Agro XX (X is number registered). The granules are applied into either pots or orchard plantation. According to the intellectual property rights, the details of material preparation could not be described hereafter (Chou, 2009 unpublished data).

6. CONCLUSIONS

Allelopathy has played important roles in sustainable agriculture. The cause of yield reduction of several crops, such as rice, sugarcane, mungbean, asparagus, corn, wheat, etc, in continuous monoculture, was due primarily to the phytotoxins produced during the decomposition of their crop residues in soil, although some soil-borne plant pathogens, such as *F. oxysporum*, *T. basicola*, or *Pythium* spp. were also involved. The best solution to enhance the productivity of aforementioned cause was crop rotation, depending on a variety of crops, such as tobacco/ryegrass/corn system, potato/sugar beet/oat/bean/winter wheat system, or corn/bean system, in which the system varied with time and place. The introduction of a pasture grass, such as kikuyu grass, into a deforested land would provide an excellent weed control due to the kikuyu grass has strong potentiality of allelopathy. This practice is particularly meaningful in sustainable agriculture because (i) the kikuyu grass suppressed the growth of weeds without application of synthetic herbicides, (ii) the grass stimulated the growth of tree plants without application of fertilizer and (iii) the suppression of weed growth saved expensive labour costs. It is important for sustainable agriculture, if we successfully use the organic debris, such as leaves, twigs, flowers or litter, of allelopathic potential plants, in which allelochemicals can be used as naturally occurring agrochemical (NOA). The application of NOA into agricultural land is most ecological friendly and met with farmer need; however, further investigation concerning the field practice of NOA has to be carried on.

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