

The Role of Allelopathy in Biochemical Ecology: Experience From Taiwan

CHANG-HUNG CHOU

Institute of Botany, Academia Sinica, Taipei,
Taiwan 115 29, Republic of China

Abstract. Allelopathic compounds, including fatty acids, phenolics, flavonoids, terpenoids, and alkaloids, have been found in various plants and soils of different habitats in Taiwan since 1972. For example, in a monoculture of rice plants, phytotoxins were produced during the decomposition of rice residues in soil, suppressed the growth of rice seedlings, and reduced the numbers of tillers and panicles, leading to yield reduction. The allelopathic metabolites are also affected by environmental factors, such as oxygen, temperature, soil moisture, microbial activity, and levels of fertilizers in soil, and allelopathy was pronounced in areas where environmental stresses were severe. Substantial amounts of phytotoxic mimosine and phenolics were released into soil by plant parts of *Leucaena leucocephala*, and these suppressed the growth of many understory species except that of *L. leucocephala* itself. A unique pattern of absence of understory plants was ubiquitous beneath *Phyllostachys edulis*, due primarily to an allelopathic effect. In a forest pasture intercropping, an aggressive kikuyu grass was planted in a deforested land where Chinese fir grew previously, to help in understanding the mechanism of biological interactions between plants. Aqueous soil leachate and extracts of the grass significantly retarded the growth of local weeds but not that of the Chinese fir. Allelopathy thus plays an appreciable role in natural vegetation and plantations in Taiwan.

Taiwan is located near the southeastern coast of the Chinese mainland and has an area of approximately 36 000 km². About two thirds of the island is occupied by mountains, particularly the central mountain range with more than 60 peaks that exceed 3000 m in elevation. The western part of the island is a vast plain intensively used for agriculture. The weather of the island is subtropical and tropical with high annual precipitation, resulting in a great productivity of agricultural crops and luxuriant growth of natural vegetation. However, because the precipitation is often concentrated in the summer and the mountains are steeply sloped, much rain runs off from the mountainous area, causing serious soil erosion. To maintain high productivity of agricultural land and yet avoid applying large amounts of agricultural chemicals, appropriate agricultural management practices become necessary. Biological control of weeds by means of allelopathy could be used to lessen the considerable labor cost and to minimize agricultural pollution. In allelopathy,

a plant can release a toxic chemical that suppresses the growth of neighboring plants or its own species in the same habitat (MULLER 1966). Allelopathy has been recognized as one of the important ecological factors and research has been carried out by scientists of different disciplines. A tremendous increase of publications dealing with allelopathy has occurred since 1970 (MULLER 1966, 1974, CHOU and MULLER 1972, CHOU and WALLER 1983, RICE 1984, PUTNAM and TANG 1986, WALLER 1987). Particularly, more biochemists and natural product chemists got involved since a Symposium of Allelochemicals and Pheromones was held in Taiwan in 1982. Since 1972 many case studies have been conducted by CHOU and his coworkers (CHOU and CHUNG 1974, CHOU and YOUNG 1975, CHOU and LIN 1976, CHOU *et al.* 1977, 1981, 1987, CHOU and CHIOU 1979, CHOU and WALLER 1980, CHOU and YANG 1982, CHOU 1983, 1986, CHOU and KUO 1986). The aim of this paper is not to cite all published works, but to focus attention on some aspects in order to clarify the role of allelopathy in biochemical ecology on the basis of the work done in Taiwan.

BIOCHEMICAL-ECOLOGICAL RELEASE OF ALLELOPATHIC SUBSTANCES FROM PLANTS

Allelopathic substances may be released from plants by means of four biochemical ecological processes: volatilization, leaching, root exudation, and decomposition of plant residues in soil. Because of the humidity of the climate of Taiwan, the volatilization process has scarcely been found there. This section of the paper thus describes findings based on the other three processes.

Allelopathic Compounds Released by Leaching

The allelopathic nature of some leaching metabolites from plants was extensively reviewed by TUKEY (1969, 1983) and RICE (1984). Regarding such metabolites from tropical and subtropical grasses, CHOU and CHUNG (1974) found that an aqueous leachate of *Miscanthus floridulus* significantly suppressed the radicle growth of the species tested. CHOU and YOUNG (1975) evaluated the phytotoxic nature of leaching metabolites from 12 subtropical grasses and found that *Digitaria decumbens* (pangola grass) produced the highest phytotoxicity, leachates being active even at an osmotic concentration as low as 10 milliosmols. LIANG *et al.* (1983) assayed 8 cultivars of pangola grass and found that the phytotoxicity of leachates varied with cultivars and habitats. Of them, *Digitaria decumbens* A254 and A24 revealed the highest phytotoxicity. CHOU and LEE (1988) further compared the allelopathic potential of pangola grasses and two weed species, which were treated under different levels of nitrogen fertilizer to make leachates used to irrigate the four grasses. The leachate of *D. decumbens* A254 generally exhibited a high phytotoxicity regardless of the levels of nitrogen fertilizer dressing, and was autotoxic. The

autotoxic effect could be responsible for the yield reduction of pangola grasses observed for several years (usually 5 to 7) after planting in the Hengchun area (CHOU 1983).

On the other hand, allelopathic metabolites that are leached out from woody plants often suppress the growth of understory species sharing the same habitat. CHOU and CHEN (1976) compared 25 dominant woody species in the northern part of Taiwan and concluded that some species, *Bauhinia purpurea*, *Bridelia balansae*, *Ficus gibbosa*, *F. retusa*, *F. vasculosa*, *Glochidion fortunei*, *Phyllostachys makinoi*, *Psidium guyava*, *Rhododendron* spp., and *Sinocalamus latiflorus*, contained significant phytotoxins in the leaves and litter. CHOU and HOU (1981) evaluated the allelopathic potential of 14 bamboo species in Taiwan and found some, such as *Bambusa oldahamii*, *Phyllostachys edulis*, *Sinocalamus latiflorus* and *S. oldahamii* that showed a remarkably high phytotoxicity. This was confirmed by CHOU and YANG (1982), who showed that leachate of *P. edulis* (bamboo) contains significant amounts of allelopathic compounds that can suppress the growth of understory weeds. Under the same edaphic and climatic conditions, however, weeds underneath *C. japonica* (conifer) grew luxuriantly even though the light intensity was comparatively lower under the canopy of the conifer than that of the bamboo. Light competition therefore was proved not to be a limiting factor in the regulation of population dynamics of understory species underneath the bamboo plants while allelopathy played an appreciable role therein.

In addition to the aforementioned cases, an almost total lack of weed species underneath *Leucaena leucocephala* has been found several years after establishment of *Leucaena* plantations. CHOU and KUO (1986) demonstrated that the absence of understory species on the floor of *L. leucocephala* at the study site in Kaoshu was due primarily to the allelopathic effect. The leaf leachate of *L. leucocephala* suppressed the growth of local weeds, *Ageratum conyzoides* and *Mimosa pudica*, as well as lettuce, and that of woody plants: *Acacia confusa*, *Casuarina glauca*, and *Alnus formosana*. However, seedlings of *L. leucocephala* were not affected by leachates or extracts of *Leucocephala* itself, indicating that substances released from *L. leucocephala* possessed a selective allelopathic effect on plant growth.

The allelopathic substances released by the above-mentioned grasses and woody plants are water soluble; those that have been identified are phenolic acids, flavonoids, and alkaloids. Phenolic acids in particular, such as *p*-hydroxybenzoic, vanillic, *p*-coumaric, and ferulic acids, are ubiquitously distributed in many grasses. These compounds released into the soil may be accumulated in soil micelles or fixed in humic acids, which play an important role in the regulation of plant growth. On the other hand, water-soluble mimosine and its derivative 3,4-pyridinediol are present in the aqueous extract or leachate of *Leucocephala* leaves, litter, stems, and seeds. The additional allelopathic action of compounds produced during the decomposition of plant residues in soil is described below.

Phytotoxins Produced by Decomposition of Plant Residues in Soil

It is well known that a certain quantity of unharvestable portions of plants is left on and in the soil. During the microbial decomposition and enzymatic degradation of such plant material, a wide variety of chemicals are formed and released into the soil, where many of them have important biological activities. Allelopathic substances arising by this kind of decomposition inhibited the respiration, germination, growth, and yield of many crops (BORNER 1960, MCCALLA 1972, CHOU and LIN 1976, CHOU and KUO 1986). Their findings are described as follows.

For nearly a century in Taiwan, the yield of rice in the second crop has been generally lower by 25 % than that of the first crop, the reduction being about 1000 kg per hectare. The decrease is particularly pronounced in areas of poor water drainage. Because the local farmers always leave rice stubble in the field after harvesting and submerge these residues in the soil during the fallowing period, phytotoxins are produced during the decomposition of the stubble in soil through microbial activity. The author and his associates conducted a series of experiments to elucidate the mechanism of yield reduction. They concluded that when rice straw (even below 1 % in amount) was incorporated into soil and allowed to decompose for 1, 2, 4, and 8 weeks, the aqueous extracts of the straw-soil mixture exhibited significant phytotoxicity toward rice seedlings. This phytotoxicity persisted till 16 weeks of decomposition, indicating that the toxins were retained in the soil mixture. Six phytotoxic phenolic acids were found : vanillic, ferulic, *trans-p*-coumaric, *cis-p*-coumaric, *p*-hydroxybenzoic, and *o*-hydroxyphenylacetic acids (CHOU and LIN 1976). In addition to these compounds, short-chain fatty acids (acetic, propionic, and butyric) were also identified (WU *et al.* 1976). Besides *o*-hydroxyphenylacetic acid, which exhibited phytotoxic effect on the radicle growth of rice seeds at a concentration of 10^{-4} M as was first reported by CHOU and LIN (1976), these compounds were already known to be allelopathic (RICE 1984). During the decomposition of rice residues in soil, there are many factors involved, such as soil moisture, soil temperature, oxygen level, and minerals. The amount of phytotoxins produced therefore varies with decomposition condition. CHOU *et al.* (1981) incorporated enriched ^{15}N -ammonium sulfate in soil-straw mixtures, which were incubated at various temperatures for different periods of time. The amount of phytotoxins produced reached its maximum at 25 °C to 30 °C six weeks after incubation. Temperature above 30 °C expedited their production but the compounds rapidly degraded. The amount of phytotoxins produced was positively correlated with the phytotoxicity of aqueous extract of the mixtures. The pattern of phytotoxins produced in different soil treatments also correlated with that found in field experiments.

In forests, litter and debris of plant parts are left on the ground and allowed to decompose. During this decomposition, a substantial quantity of phytotoxins is produced. Such production of allelopathic compounds produced by litter and plant

parts has been well documented (RICE 1984, CHOU and MULLER 1972). CHOU and YANG (1982) indicated that such compounds were produced by litter of *Phyllostachys edulis*, which suppressed the growth of its understory species. As has also been mentioned, CHOU and KUO (1986) also observed that weed growth underneath *Leucaena leucocephala* was suppressed by allelopathic compounds. Moreover, the growth of *Ageratum conyzoides* was retarded by the decomposition of *Leucaena leucocephala* litter mixed with soil in pots.

It was also showed that litter of the Chinese fir (*Cunninghamia lanceolata*) retarded the growth of many weeds in fields during the first 6 months after deforestation. Even the freshly fallen leaves of the fir released phytotoxins that significantly suppressed the growth of local weeds and tested species in laboratory bioassays (CHOU *et al.* 1987, 1988 paper submitted). Furthermore, a heavy accumulation of litter clearly exhibited allelopathic effect in the field. Naturally the persistence of phytotoxins in soil depends upon plant species and environmental conditions. Humid weather generally favors microbial activity and consequent degradation of phytotoxins during decomposition of plant residues in soil, as do higher temperatures.

Allelopathic Substances in Plant Root Exudates

Root exudate is one of the most difficult problems dealing with allelopathic substances. ROVIRA (1971) made a comprehensive review on the nature of root exudates, methods of collecting them, factors affecting exudation, mechanisms of such exudation, and root exudates in relation to nutrients and microflora in soil. Exudation from roots into soil may be quite different from exudation into solution or sand because of the difference in edaphic environments. It is also difficult to distinguish organic substances originating in roots from those already present in soil. The use of radioisotopes may overcome this difficulty (ROVIRA 1971). Owing to the complexity of soil, compounds exuded from plant roots may be easily converted into either toxic or nontoxic substances and thus lead to different effects on plant growth. Recently, TANG (1986) made a root exudation device using XAD-4 resin and employed it to obtain some phenolic compounds derived from plants. YOUNG (1986) used this apparatus to collect root exudates from *Asparagus officinalis* and these suppressed the growth of *Asparagus* seedlings. He considered that the 40 % reduction of asparagus seedling production in a plantation was probably due to an autointoxication mechanism. The allelopathic compounds from the root exudates and plant extracts of *Asparagus officinalis* are 3,4-dihydroxybenzoic, 3,4-dimethoxybenzoic, 2,5-dihydroxybenzoic, 3,4-dihydroxyphenylacetic, and β (*p*-hydroxyphenyl) propionic acids, and 3,4-dimethoxyacetophenone. YOUNG (1986) also concluded that the level of phytotoxins was significantly higher in the stem than in the root, and was well correlated with phytotoxicity. Furthermore, the reduction of asparagus productivity in old asparagus plantations is due primarily to phytotoxins

released from the plant parts and those produced from the decomposition of residues remaining in soil.

BIOCHEMICAL INHIBITION BETWEEN PASTURE AND FOREST

Due to the limited availability of prime agricultural land and increased demand for agricultural products in Taiwan as a result of human population growth in the last decade, mountainous areas are now being brought into production. To increase livestock production and control erosion, a pasture-forest intercropping system has been developed for these mountains. In this system, grasses are planted in forest areas where timber has been harvested and tree seedlings are expected to regenerate naturally. It is important that grass species suitable for such an intercropping system are selected. Of the grassland species that grow at high elevations in Taiwan, kikuyu grass (*Pennisetum clandestinum*), Italian rye grass (*Lolium multiflorum*), bahia grass (*Paspalum notatum*), and white clover (*Trifolium repens*) do best. Because weed control by either herbicides (causing pollution problems) or by hand labor (expensive), the ideal grass should be established soon after deforestation and should possess through selective allelopathic characteristics the ability to suppress weed growth but allow that of forest and orchard seedlings. The author therefore conducts experiments in the field, greenhouse, and laboratory to demonstrate the effects of grassland plants upon forest regeneration and orchard plantations and to determine the potential of ground-cover grasses for improving forest, orchard, and pasture management.

Allelopathic Interaction between Kikuyu Grass and Forest

An allelopathic interaction of a pasture-forest intercropping system was evaluated by experiments (CHOU *et al.* 1987). After deforestation of *Cunninghamia lanceolata* (Chinese fir), a split plot design of four treatments (litter removed, litter retained, litter removed and kikuyu grass planted, and litter retained and kikuyu grass planted) was imposed. Field experiments showed that fir litter left on the ground slightly suppressed the growth of weeds in the first four months after deforestation, while kikuyu grass significantly suppressed the growth of weeds longer than four months. Neither fir litter nor kikuyu grass reduced growth of fir seedlings. Bioassay of aqueous extracts of fresh fir leaves, fir litter, and kikuyu grass showed that the fresh leaves produced significant phytotoxicity while litter and kikuyu grass have less toxicity. Nine phytotoxic phenolics and many unidentified flavonoids were found in the plant materials.

In addition to the above experiments, allelopathic interactions between kikuyu grass and three hardwood forest species, *Alnus formosana*, *Cinnamomum camphora*, and *Zelkova formosana*, were also evaluated (CHOU *et al.* 1988, unpublished data). Eight field treatments (open ground without planting as control, planted with

kikuyu grass, planted with kikuyu grass and *A. formosana*, planted with kikuyu grass and *C. camphora*, planted with kikuyu grass and *Z. formosana*, planted with *A. formosana*, planted with *C. camphora*, and planted with *Z. formosana*) were conducted. As in the above experiments, kikuyu grass retarded the growth of weeds soon after it was established but did not suppress the seedling growth of the three hardwood plants. However, aqueous extracts of the three hardwood plants significantly retarded the root growth of kikuyu grass, indicating that the growth of kikuyu grass might be suppressed when the woody forest became reestablished. Of them, *Z. formosana* exhibited the highest amount of allelopathic compounds, which might be responsible for the reduction of weed growth beneath *Z. formosana* forest.

The aforementioned findings show a good correlation between the degree of phytotoxicity and phytotoxin levels, indicating that allelopathic mechanisms may play a significant role in the interaction of forest–pasture intercropping systems, and thus potentially reduce the need of herbicides and decrease the labor cost of weed control.

Competitive and Allelopathic interaction between Grasses and Orchard Plants

These experiments, conducted at the Meifeng Highland Experiment Station farm of National Taiwan University, were designed to evaluate the competitive and allelopathic nature of cover grasses, namely *Bromus catharticus*, *Dactylis glomerata*, *Eragrotis curvula*, *Lolium multiflorum*, *L. perenne*, *Paspalum notatum*, *P. dilatatum*, *Pennisetum clandestinum*, and *Trifolium repens* (CHOU 1988). The soil leachate of each grass was used for watering pear seedlings (*Pyrus lindleyi*) of about 10 cm in height. Soil leachate collected from soil without grass was used as a control. The *Pyrus* seedlings were planted in soil with fertilizer and in soil without fertilizer. When they were grown in fertilized soil and watered with the nine soil–grass leachates, all leachates stimulated the growth of *Pyrus* seedlings. When they were grown in soil without fertilizer and were watered with the nine grass–soil leachates, only four of the leachates (*D. glomerata*, *B. catharticus*, *L. multiflorum* and *E. curvula*) stimulated seedling growth. The remaining grass extracts, however, caused a relatively low inhibition of seedling growth. WU *et al.* (1975) evaluated the effect of three cover crops, *Centrocema* sp., *Indigofera* sp. and *Paspalum notatum* on the growth of banana and orchard plants. They found that *Centrocema* and *Indigofera* exhibited the highest phytotoxic effect and leachate of *Centrocema* inhibited the growth of banana.

Furthermore, to compare the growth performance of cover grass, *B. catharticus*, *P. clandestinum* (kikuyu grass), *L. multiflorum*, *D. glomerata*, and *T. repens* (white clover) were studied (CHOU 1988). Each was planted in a quadrat, 1 × 1 m without furrow, using a Latin square layout. Eight months after planting, the growth performance and ground cover of each grass were measured. Kikuyu grass and white clover were the most aggressive plants, with the remaining three species growing

more slowly. When the two aggressive grasses grew together, white clover invaded the kikuyu plot faster than kikuyu grass invaded the white clover plot. Kikuyu grass quickly invaded open areas unprotected by cover grasses, but orchard grasses proved to be a good ground cover and better habitat for orchard plants such as pear, apple, and banana. The allelopathic nature of these grasses was evaluated and the degree of phytotoxicity found to vary with species (CHOU and YOUNG 1975, CHOU 1988).

Dynamics of Allelopathic Substances as Affected by Environmental Stresses

There is evidence that allelopathic phenomena are more pronounced in areas under stress conditions. This is also of particular importance to plant adaptation. KÖEPPE *et al.* (1976) indicated that sunflower produced significantly high amounts of phytotoxic substances when grown under phosphorus-deficient soil conditions than under normal conditions. Perhaps the production of phytotoxins can be interpreted as an adaptation strategy aimed at suppressing growth of competitive plants that utilize the same nutrients. The author and his coworkers have found such significant findings, described below.

Plants under Water-Logged and Oxygen-Deficient Stress

In many paddy fields in Taiwan, particularly in areas of Tsingsui (the central west coast part), Chiatung and Yuanlin (the southern west coast), and Tungshan (the east coast), there is a high water table and poor water drainage, leading to oxygen deficiency. For these reasons, many phytotoxic organic acids were produced during the decomposition of rice stubble in soils. The phytotoxic substances, including simple fatty acids and phenolic acids, were produced in amounts varying with habitats and suppressed the growth of rice seedlings. CHOU (1983) indicated that the roots of rice seedlings under water-logged and oxygen-deficient conditions developed abnormally. Cell differentiation was severely retarded and abnormal adventitious roots developed, resulting in a decrease in the number of tillers, panicle initiation, test mass and yield (CHOU and LIN 1976, WU *et al.* 1976, CHOU *et al.* 1977, 1981, CHOU and CHIOU 1979). CHOU (1983) and WALLER and NOWACKI (1975) suggested that environmental stresses can change the pathway of secondary metabolites. They argued that when plants grew under favorable conditions, growth-promoting substances were produced in a relatively high amount. However, under unfavorable conditions plants tended to produce growth-inhibiting substances (CHOU 1983). CHOU (1986) considered that the higher amount of phytotoxic phenolics produced in water-logged and oxygen deficiency condition could be a survival strategy for rice plants. Under such unfavorable conditions, rice plants need to minimize their respiratory activity to reduce energy consumption. Self-thinning by producing allelopathic compounds to retard rice growth and thus to limit the population would be the best way for rice adaptation in unfavorable conditions.

When the unfavorable conditions were removed the phytotoxic substances accumulated in soil were leached out, and there was a significant increase of rice yield, up to 40 % (CHOU 1983).

Plants under Drought Stress

On the southwest coast of Taiwan there is a vast agricultural area with a severe drought period of about four to six months. Here *Leucaena leucocephala* was planted for timber. Four to five years after plantation, there was an almost complete absence of understory species except *Leucaena leucocephala* seedlings during the winter season. The absence of weeds is due to a heavy accumulation of *Leucaena* litter that releases a certain amount of phytotoxic substances, leading to the suppression of weed growth on the floor. The phytotoxins responsible are 9 phenolic acids (gallic, protocatechuic, *p*-hydroxybenzoic, *p*-hydroxyphenylacetic, vanillic, caffeic, syringic, *p*-coumaric, and ferulic acids), quercetin, and mimosine.

Phytotoxicity as Affected by Levels of Nutrient

As mentioned above, pangola grass (*Digitaria decumbens*) exhibited a strong competitive nature and often acted as a dominant grass when sufficient nitrogen fertilizer was applied onto the field (CHOU 1983). Four grasses, namely *Digitaria decumbens* A24 and A254, *Panicum repens*, and *Imperata cylindrica*, were evaluated by both field and laboratory experiments (CHOU and LEE 1988). Of them, *D. decumbens* A254 generally exhibited the highest dominance. The more the nitrogen fertilizer (up to 800 kg ha⁻¹) applied on the pangola grass soil, the higher the quantity of phytotoxic phenolics produced, indicating that the high growth rate of *D. decumbens* cultivars may give them the advantage of producing more phytotoxins, which may suppress the growth of inferior competitors, such as *P. repens* and *I. cylindrica*. On the other hand, WU *et al.* (1976) conducted field experiments in the area of poor-drainage paddy soil of Lotung by applying ammonium sulfate, lime, and green manure in order to compare the phytotoxic effect of rice residues decomposing in soil. The paddy soil treated with lime produced significantly higher yield than that treated otherwise. The increase of rice yield was considered due simply to a detoxification of phytotoxins, which were converted into nontoxic substances. CHOU and CHIOU (1979) reported that ammonium sulfate fertilizer produced a higher yield of rice than nitrate nitrogen fertilizer, indicating that the ammonium nitrogen fertilizer may overcome the phytotoxic effect of decomposing rice residues in soil. This agreed with the findings of CHANDRASEKARAN and YOSHIDA (1973), who concluded that some nutrients may play a chelating role in inactivating the phytotoxins in soil. Furthermore, CHOU *et al.* (1981) used 30 %-enriched ¹⁵N-ammonium sulfate which was incorporated into soil-straw mixture in order to see the behavior of nitrogen in soil as affected by phytotoxins. In the absence of straw, most of the fertilizer

N remained in the mineral form. Straw enhanced N immobilization only moderately. The gradual decrease in the proportion of fertilizer N in the mineral form was accompanied by a steady increase of fertilizer N in the amino acid fraction of organic N. A small accumulation of fertilizer N in the amino sugar or insoluble humin fraction was found. The above findings indicated that the amount of phytotoxic substances released from plant parts may be influenced by the levels of nutrients leading to phytotoxic effect of different degrees on plant growth.

Detoxification of Allelopathic Substances by Polymerization of Organic-Mineral Complex

Under natural conditions, allelopathic compounds released into soil may soon be converted into a nontoxic form through abiotic or biotic processes. The phytotoxic phenolics rapidly bind with soil minerals, forming so-called "organic-mineral complex", or part of the humic substances (WANG *et al.* 1971, 1978, 1983). Formation of humic substances has long been recognized as a biological process (WANG *et al.* 1986). However, many observations have showed the heterogeneous catalytic effect of clay minerals on polymerization of phenolics reported by soil biochemists (SCHEFFER *et al.* 1959, ZIECHMANN 1959, KUMADA and KATO 1970, WANG *et al.* 1986). In particular, WANG *et al.* (1986) made an extensive study on the role of soil minerals in the abiotic polymerization of phenolic compounds and formation of humic substances. They used suspension and plate methods (WANG *et al.* 1983) to study the synthesis of humic substances and concluded that the polymerization of vicinal dihydric and trihydric phenolic compounds was activated in the presence of clay minerals. Polymer formation was not the only reaction taking place in the various systems, but through oxidation, formation of anions and radicals, and polymerization, the humic substances are formed. Decomposition and mineralization of the various intermediate products and even humic substances may take place. Oxidative ring cleavage and formation of low-molecular-mass products with acidic character are also possible. The relative importance of abiotic and biotic processes in the formation of humic substances may depend on soil parent materials, nature of soil inorganic components, climatic and topographic conditions, plant cover, microbial population and activity, and land utilization practices. CHOU (1987) further indicated that the polymerization of phytotoxic phenolics by clay minerals is an important ecological phenomenon. The nature of polymerization and depolymerization of allelopathic compounds via humic acids needs to be thoroughly investigated in order to clarify the mechanism of soil organic-mineral complex formation. The natural organomineral complexes of humic acid may actually be a pool serving to detoxify allelopathic substances released from plants. Of course, the capacity of humic acid to function in this way depends totally upon the physico-chemical nature of soil as well as the degree of microbial activity in soil.

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