CANADIAN JOURNAL OF PLANT PATHOLOGY 11: 180-183. 1989

Organic amendments and soil-borne diseases

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Accepted for publication 1989 01 31

This paper was presented at a symposium on "Integrated control of soil-borne diseases", held during the annual meeting of the Canadian Phytopathological Society, Vancouver, British Columbia, 13-17 August, 1988.

Organic amendments to soil can affect soil-borne diseases of plants, sometimes enhancing but frequently decreasing them. Some pathogens use amendments as an energy source, thereby enhancing inoculum potential. More often, however, other soil microbes colonize the substrate, and products of their metabolic activity or decomposition products influence behavior of pathogens. Products of organic matter decomposition released into soil can be absorbed by plant roots, frequently damaging or predisposing them to enhanced infection by pathogens. Organic residues or amendments may favor the build-up of antagonistic microbes that can decrease the inoculum potential of root pathogens. Thus, the kind of organic matter and its state of decomposition and/or microbial colonization determines the effects on root diseases. The final stage of organic matter decomposition in soil is humus. Humic substances may affect soil by increasing buffering capacity, chelating or complexing with various mineral elements, and increasing formation of soil aggregates. They may also have profound effects on microbial activity, stimulating increases in populations of some groups and depressing populations and/or activity of others. Of special concern is their effects on root pathogens and mycorrhizal fungi. Humic substances frequently enhance plant growth by one or more physiological mechanisms: enhanced nutrient uptake, altered membrane permeability, altered growth regulator activity (i.e. enhanced root growth), or increased seed germination. The relationship of humic substances to plant and root health, as well as to soil microbes, is discussed in relation to the literature and to on-going research.

Linderman, R.G. 1989. Organic amendments and soil-borne diseases. Can. J. Plant Pathol. 11: 180-183.

L'apport d'amendements organiques au sol se manifeste à l'occasion par une stimulation des maladies racinaires d'origine tellurique, mais plus fréquemment par une diminution de celles-ci. Certains organismes pathogènes utilisent ces amendements comme source d'énergie, augmentant ainsi le potentiel d'inoculum. D'autres microorganismes du sol sont cependant en mesure de coloniser ce substrat, influençant ainsi, par le biais des produits résultant de leur métabolisme ou de la décomposition du substrat, le comportement des organismes pathogènes. Les produits résultant de la décomposition de la matière organique et qui sont ainsi libérés dans le milieu peuvent être absorbés par les racines et les endommager ou favoriser l'infection par les organismes pathogènes. L'utilisation des résidus ou amendements organiques peut stimuler les populations de microorganismes antagonistes envers les organismes pathogènes des racines entraînant ainsi une dimution du potentiel d'inoculum. Le type de matière organique ainsi que son niveau de décomposition sont des facteurs qui, combinés à la population microbienne, déterminent l'impact de cet apport sur les maladies racinaires. L'humus représente le stade final de décomposition de la matière organique dans le sol. Les substances humiques peuvent affecter le sol en augmentant sa capacité tampon, en formant des complexes avec divers éléments minéraux et en augmentant la formation d'agrégats dans le sol. Elles peuvent également avoir des effets importants sur l'activité microbienne en stimulant l'accroissement des populations chez certains groupes et en réduisant les populations et/ou l'activité de certains autres. Leur effet sur les organismes pathogènes racinaires et les champignons mycorhizateurs représente un aspect particulièrement important. Les substances humiques peuvent avoir un effet stimulateur sur la croissance des plantes et ce par le biais d'un ou plusieurs mécanismes physiologiques: augmentation de l'absorption de nutriments, altération de la perméabilité de la membrane, altération de l'activité des régulateurs de croissance (c'est-à-dire stimulation du développement racinaire ou augmentation de la germination). La relation entre les substances humiques et l'état sanitaire des plantes et des racines, ainsi que leur effet sur les microorganismes telluriques, sont présentés ici en fonction de la littérature et des travaux de recherche actuellement en cours.

Historical perspectives. Organic matter can be added to soil as the result of the natural cycling of plants, or as a result of intentional amendment with large quantities of various materials to increase fertility, to enhance growth of subsequent crop plants, or to suppress plant diseases. Regardless of the intent or reason organic residues are added to soil, diseases can be affected. The effects of organic soil amendments on soil-borne diseases and pathogen antagonists has recently been reviewed by Lumsden et al. (12), so many examples of these effects will not be repeated here. Rather, examples will be used to demonstrate that residues or organic amendments in soil sequentially decompose over time, and their effects can largely be correlated to the relative stage of decomposition, both in terms of substrate availability and the kinds and amounts of decomposition products.

Some pathogens respond to organic amendments and colonize them as nutrient substrates. *Sclerotium rolfsii* is a good example of such a pathogen which is enhanced by organic residues from previous crops in the vicinity of the infection court. Volatile compounds emanating from such residues can stimulate germination of sclerotia of the pathogen, followed by colonization of the residues (9). Such volatiles may be released from residues due to enzymatic degradation (3), and stimulate eruptive germination of sclerotia which have enough energy to infect the host without new energy from colonized residues. Furthermore, the mycelial growth is chemotaxically oriented to the residues. If the pathogen contacts the residues first, then the energy boost could increase the distance it could grow to reach a host plant, and overall disease incidence and severity could be greater.

Many other examples could be cited where inoculum density or potential of root pathogens was reduced by organic amendments. In some cases, the residue products stimulate germination of the pathogen propagules which die in the absence of the host, thereby reducing the pathogen population (20). Other reports indicate that organic amendments stimulate microbial activity, which depletes the nitrogen level or changes its form so that the infection process by the pathogen is impaired (7).

In the early stages of decomposition of organic crop residues, toxic chemicals can be released that can damage roots (15,20). Some, such as the aromatic acids identified by Toussoun et al. (25), may predispose roots to pathogen attack by increasing their susceptibility, even with resistant cultivars (10,11,19), as a result of induced changes in membrane permeability and root exudation.

The concept of adding copious amounts of organic matter to soil to stimulate microbial activity and thus induce pathogen suppression has a logical basis in natural settings. Frequently, soil-borne pathogens common to cultivated ecosystems are absent from undisturbed ecosystems (5,6,21). For example, many forest ecosystems accumulate layers of litter that are deposited year after year. Thus, a vertical profile of the organic material above the mineral soil surface reflects many years of accumulation as well as degrees of decomposition. If such layers or decomposition stages are assayed for pathogen suppressiveness, as was done in regards to phytophthora root rot in the Australian rainforest (5), the most suppression was associated with the humus layer, which had the most microbial activity and was the most decomposed. Reconstruction of such a sequential decomposition of organic matter in avocado orchards has been accomplished, and a suppressiveness similar to that of the natural rainforest was established (2). This organic layer also supported a profusion of avocado roots supplying water and nutrients to the trees.

The notion that the humus layer or humic substances could contribute to the health of plants and somehow suppress root diseases has motivated me in recent years to examine the subject in more detail by a) evaluating different sources and types of organic materials b) examining the fate of organic amendments in soil in relation to the decomposition process, c) considering how humic substances form, and how they can be extracted from soil, and d) the effects of humic substances on plant growth, soil-borne diseases, and soil microflora. A general sense of the literature and results of some of our own research follow.

Fate of organic amendments in soil. The general consensus of thought concerning the decomposition of organic matter is that microorganisms from soil or on the surface of organic material produce enzymes that degrade the substrate, utilizing it nutritionally to grow and multiply. Products of this microbial metabolism are more enzymes for further degradation of the substrate, and carbon dioxide and heat from respiration. The heat generated by microbial activity is well known from studies of aerobic composting systems, and this heat can accumulate in a pile of decomposing organic material. In soil the same decomposition may occur, but the heat generated readily dissipates and does not accumulate to reach pasteurizing temperatures as in a compost pile. Decomposition of organic material by microbes continues as long as the critical elements of carbon and nitrogen are not limiting. When carbon and nitrogen concentrations are reduced, however, microbial activity and the rate of substrate degradation is reduced. The ultimate products of the degradation process are humic substances, which are relatively stable compounds because they cannot readily be further degraded from the parent material, or because they are the result of the polymerization or condensation of phenolic compounds produced by microorganisms (27). The evidence is strong that such polymerization does occur, and synthetic humic substances have been produced. Whether humic substances are the product of degradation or polymerization, or both, their molecular size varies greatly, making their chemical characterization very difficult. Humic substances are initially defined on the basis of their solubility in alkaline solution, and are further separated by lowering the pH. Fulvic acids are soluble in acidic solution, but humic acids are precipitated. Some studies use humic fractions separated and characterized on the basis of molecular weight, the fulvic acid compounds having relatively low molecular weights, while the humic acid compounds have molecular weights in excess of 10 000 (23).

Effects of humic substances and extracts on plants and soil organisms. In our studies, we have used various materials with high levels of extractible humic substances, such as different peat mosses, composted grape pomace, composted yard debris, and ground leonardite. These materials have generally exhibited effects on soils and plants commonly attributed to humic substances, i.e. strong chelation or complexation of various materials in soil, increased buffering or exchange capacity of soil, and enhanced aggregation of soil particles due to chemical binding or to enhanced microbial activity (4). These charactertics have made the materials attractive as soil amendments to improve the chemical and physical properties of the soil (26).

Frequently, use of materials with a high humic content has also induced improved plant growth (8,13,16,27,28). The literature contains a wealth of information and documentation of physiological effects of humics on plants. For example, they are known to a) alter membrane permeability, b) increase nutrient uptake, c) function as growth regulators (root and shoot growth, flowering), d) enhance seed germination, and e) enhance microbial growth and activity (1,27,29,30). Thus there is good basis to hypothesize that humic substances can improve plant growth and health by their effects on roots and organisms associated with roots.

Research findings. We found that addition of several materials with high humic content to soil or potting mix can significantly enhance plant growth. One explanation for enhanced plant growth is increased root size, which increases the potential for nutrient and water uptake. Another is the enhancement of mycorrhizal fungi, known for their capacity to increase water and nutrient uptake while in association with plant roots. Our studies showed that development of roots on cuttings is stimulated in a manner supporting the auxin or auxin synergist concept, as previously demonstrated by other workers (14,17,18). The activity curve is typical of humic acid response curves in that activity increases to a narrow peak, and concentrations beyond the peak often exhibit decreased activity. In greenhouse trials with Douglas-fir seedlings inoculated or not with ectomycorrhizal fungi, we demonstrated enhanced growth, but the response was independant of the establishment of ectomycorrhizae, which was not enhanced by the humic substances. We have shown, however, that in vitro vegetative growth of ectomycorrhizal fungi as well as that of some edible mushroom fungi can be dramatically stimulated by addition of small amounts of the humic extracts to the growth medium (24, Barclay and Linderman, unpublished results). The suggestion from such experiments is that humic substances enhance the capacity of plant roots and fungi to absorb nutrients. This effect has been previously documented (1,27).

We recently studied (22) three conifer nursery soils amended with several levels of three high humic content materials and planted with Douglas-fir seedlings under greenhouse conditions. This experiment was intended to determine if the humics could enhance plant growth in field soils, and if the response was mediated by effects on root pathogens and/or mycorrhizal fungi. The responses were varied, largely depending on the soil. For example, amendments caused growth stimulation in some soils and depression in others. One amendment stimulated tree growth and also stimulated increases in several microbial groups in the soil. Damping-off by *Fusarium* was reduced in one soil by all three amendments. Ectomycorrhizal development was stimulated by one amendment, but only in one soil. This study convinced us that addition of humic substances to soils can induce a variety of plant physiological and microbial responses, but in such an unpredictable fashion as to make their use as a cultural practice unreliable. Clearly, further work is needed to clarify the specific effects of specific humic components.

Conclusions. It is difficult to draw other than conceptual conclusions from this discussion and from our research. It seems clear that organic amendments to soil can have a range of effects on soil-borne plant diseases, and these effects are strongly related to the kind of material added and its state of descomposition. At intermediate stages of substrate degradation, decomposition products can enhance or decrease disease, and the response is largely dependent on the pathogen involved and whether the amendment supports specific stages of its life cycle, or favors other microbes which can effectively out-compete and antagonize the pathogen. At the end of the decomposition process are humic compounds that induce a variety of responses from plants and soil microbes. The challenge to harness these humics for specific purposes will certainly involve improved fractionation and purification procedures that will allow specific humic fractions to be associated with specific responses. Without these refinements, we will continue to juggle the wide range of kinds and sizes of humic compounds in relation to a wide range of plant and microbial responses without any justifiable expectation of a predictable response when humics are added to agricultural and forest soils.

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