Effect of Organic Amendment on Soil-Borne Plant Pathogens

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Plant pathogens may exist in the soil long after initial introduction as facultative parasites or in diseased crop residues. Incorporation of green manure, rotation crop residues, or other organic materials is frequently recommended to prevent the increase of pathogens in newly cultivated soil and to produce conditions less favorable to pathogens in established crop land (7). Nevertheless, the physical, chemical, and biological interactions in soil are so complex and varied that it is a challenge to determine the specific effects responsible for disease control.

Disease prevention.—In arid lands, microfloras are characteristically limited (32). Their "biological buffering capacity" is low, and newly introduced soil-borne pathogens may become established and multiply rapidly (3) because the limited microflora of these soils sometimes enables introduced soil-borne pathogens to increase rapidly without competition (32). Recropping to potatoes (*Solanum tuberosum*) for 3 consecutive years on newly cultivated desert soils in South Idaho increased *Streptomyces scabies* to such an extent that the third potato crop of the highly resistant Idaho Russet potato was unmarketable. We have also found *Verticillium* wilt (*Verticillium albo-atrum*) of potato limiting yields after two potato crops in some new soils. Burke (5, 6) reported beans (*Phaseolus vulgaris*) to be more susceptible to root rot caused by *Fusarium solani* f. sp. *phaseoli* in virgin Washington soil than in soil previously under cultivation for several years. Soybean (*Glycine max*) residues prevented the increase of potato scab in newly cultivated California soils, but failed to control this disease once the pathogen was well established (41, 56).

Pathogen-suppression in cultivated soil is of microbial origin and is influenced more by cropping and management practices than by soil type (5, 6, 32, 57). Evidence of "biological buffering" in older cultivated soils is often seen after sterilization (30, 56). *Rhizoctonia solani* killed entire flats of pepper seedlings in sterilized soil, but remained localized in nonsterile soil (14). *Verticillium albo-atrum* readily colonizes sterilized soil in contrast to its limited rhizosphere activity in natural soil. Attention to this aspect of plant disease control will be important as increased acreage of virgin arid land is brought under cultivation to feed expanding populations.

Disease control.—Use of crop rotation to control soil-borne diseases in established, cultivated soils was initially postulated as a "starving-out" process in the absence of susceptible host plants. However, under standard rotations, *F. solani* f. sp. *phaseoli* survives for long periods without host contact (44), and little correlation was found between the length of time out of beans and the severity of root rot (33, 34). The immediately preceding crop in the rotation, or organic amendment, has much more effect on the severity of diseases caused by *F. solani* f. sp. *phaseoli* (19, 20, 34, 35, 40), *Phytophthora parasitica* var. *nicotianae* (8), *Rhizoctonia solani* (1), *Aphanomyces cochlioides* (1), *Gibberella zeae* (7, 29, 52), *Streptomyces scabies* (41, 43), *Pythium aphanidermatum* (18), *Verticillium albo-atrum* (38), and *Phymatotrichum omnivorum* (50, 56) than crops several years preceding. The effect of a specific crop sequence or organic amendment on a soil-borne disease may, or may not, be correlated with the detectable pathogen population in the soil (19, 27, 40).

Disease control with a corresponding reduction in pathogen numbers.—Garrett (15) pointed out that adequate control of some pathogens could be accomplished by reduction of the numbers of pathogen propagules to a low level rather than by its complete elimination. Partial eradication of several soil-borne pathogens from field soils has been accomplished during the anaerobic decomposition of crop residues under heavy irrigation (54). Resting structures of *Sclerotinia sclerotiorum* (39), *Fusarium oxysporum* f. sp. *cubense* (47), *Verticillium albo-atrum* (37), and *Phymatotrichum omnivorum* (48) have been destroyed, resulting in the control of diseases caused by these pathogens. Anaerobic decomposition of residues results in a low population of other soil microorganisms (42, 54) which may affect the "biological buffering" capacity of soil similar to sterilization. Heavy irrigation of soybean-amended field soil in Idaho resulted in increased root rot of the subsequent bean crop (*unpublished data*) because of the rapid recolonization of the partially sterile soil by *F. solani* f. sp. *phaseoli* as indicated by an increased population of the pathogen. Similar disease increases have been observed following soil fumigation.

Disease control without a reduction in pathogen numbers.—Recent studies (4, 12, 19, 23, 27, 31, 34, 40, 55) demonstrate that disease control is not always related to the numbers of pathogen propagules in soil. Nonhost crops may stimulate germination and recycling of chlamydospores of *F. solani* f. sp. *phaseoli,* resulting in an increased spore load (45) but reduction in disease severity (19, 40). Organic amendments may influence disease because of their effect on the availability of nutrients to the pathogen, but an effect on the host should also be considered. Nitrogen has a greater effect than any other element on individual soil fungi (28, 50) and, in general, disease severity increases as rate of nitrogen increases. Weinke (55) found that nitrogen influenced the severity of bean root rot without affecting the pathogen's population in the soil.

The carbon to nitrogen (C:N) ratio of organic amendments was correlated initially with their influence on disease (36, 46). Since an exogenous source of nitrogen is needed for *F. solani* f. sp. *phaseoli* chlamydospore germination (9), incorporation of residues with a high C:N ratio was postulated to prevent chlamydospore germination or result in nitrogen starvation of the pathogen (46, 50). The addition of nitrogen which nullified the beneficial effects of carbonaceous material such as barley, wheat, or oat straw (6, 19) appeared to support this hypothesis. However, sugar amendments may also increase disease severity (*unpublished data*).

After a detailed study of the effect of 27 organic amendments on specific soil-borne diseases, we were unable to establish a positive correlation between the C:N ratio of the residue and disease severity. Many residues with a low C:N ratio reduce bean root rot as well as those with a high C:N ratio. Conversely, many other residues with high C:N ratios increase the severity of root rot (27, 32). We initially concluded, as did Tyner (51), that the general chemical nature of organic materials added to infested soils was more important than the C:N ratio. A more detailed study revealed that disease severity was correlated with the effect of specific residues on nitrification (27). Residues that stimulated the biological oxidation of ammonium to nitrate nitrogen (Fig. 1) tended to reduce the severity of bean root rot under field conditions, while addition of residues that inhibited or decreased nitrification generally resulted in more severe root rot. The effect of organic amendments on nitrification may account for inconsistencies regarding the effects of specific residues on disease. Barley amendments reduced bean root rot in the absence of added nitrogen (46), but increased this disease when nitrogen fertilizers were applied (6, 19). Ammonium and Uramite (a urea-formaldehyde product) reduced the severity of *Rhizoctonia solani* when added with sawdust (10). With no amendment, ammonium nitrate resulted in the greatest disease reduction.

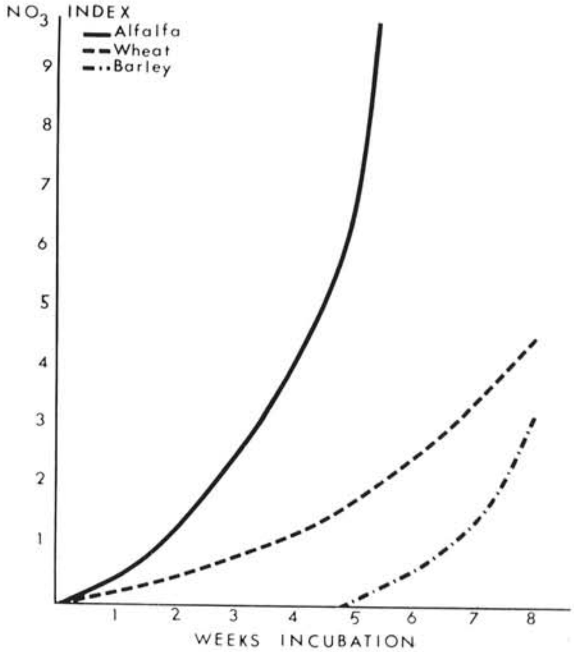

Fig. 1. Effect of organic amendments on the biological oxidation of ammonium nitrogen to nitrate nitrogen (27).

The correlation of nitrification with disease severity may indicate the importance of a specific form of nitrogen available to the plant or pathogen after residue incorporation. It was postulated that selective (nonfungicidal) inhibitors of nitrification such as 2-chloro-6-(trichloromethyl) pyridine (17) would provide a means of testing this relationship. Practical considerations in testing this relationship in the field besides preventing nitrification to maintain an ammoniacal regime as a check against nitrate applications include the effect of 1) superimposing a specific form of nitrogen on the residual soil nitrogen, primarily nitrate nitrogen; 2) preferential utilization of only one form of nitrogen by the crop; and 3) different ammonium-to-nitrate nitrogen ratios.

We selected root rot of bean, *Verticillium* wilt of potato, scab of potato, and take-all of wheat to study the relationship of form of nitrogen to disease severity under field conditions. A definite correlation of disease severity with a specific form of nitrogen was observed (Tables 1, 2, 3); however, different diseases responded to different forms of nitrogen. Potato scab, *Verticillium* wilt, and take-all of wheat were decreased by ammo-

TABLE 1. Effect of form of nitrogen fertilizer on *Verticillium* wilt and yield of potatoes at Aberdeen, Idaho

Form of nitrogen[a]	Dead[b] plants	Yield	Potatoes grading No. 1
	%	*cwt/acre*	%
No nitrogen	86	109	51
Calcium nitrate	75	189	54
Ammonium sulfate	47	208	72
Ammonium sulfate + 2-chloro-6-(trichloromethyl) pyridine[c]	41	234	75

[a] 120 lb. N/acre; side-dress application.
[b] Readings made 1 September 1967.
[c] 1.0 lb./acre 2-chloro-6-(trichloromethyl) pyridine mixed with ammonium sulfate prior to application.

TABLE 2. Effect of form of nitrogen fertilizer on scab and yield of potatoes at Rising River, Idaho

Form of nitrogen[a]	% Surface area scabby	Marketable tubers	Yield
	%	%	*cwt/acre*
No nitrogen	9	36	218
Calcium nitrate	11	31	292
Ammonium sulfate	7	56	312
Ammonium sulfate + 2-chloro-6-(trichloromethyl) pyridine[b]	4	77	301

[a] 180-lb. N/acre; side-dress application.
[b] 1.0-lb./acre 2-chloro-6-(trichloromethyl) pyridine mixed with ammonium sulfate prior to side dressing.

TABLE 3. Effect of nitrogen source and rate on take-all of irrigated winter wheat (24)

Nitrogen rate	Take-all index: Ammonium sulfate	Take-all index: Ammonium nitrate
lb. of N/acre		
0	23	23
60	28	51
120	2	41
180	7	54
240	11	23
300	1	20

niacal nitrogen, but stalk rot of corn and bean root rot were increased. A form of nitrogen effect was not observed with *Verticillium* wilt of potatoes when high levels of residual nitrate nitrogen were present. Immobilization of residual nitrate nitrogen with barley straw resulted in the anticipated reduction of *Verticillium* wilt with ammoniacal nitrogen.

Since ammoniacal nitrogen when applied under field conditions is rapidly converted to nitrate nitrogen (nitrified), inhibition of nitrification appears essential to study the effects of ammoniacal nitrogen on disease severity. Use of materials that inhibit nitrification should intensify the disease response after nitrogen application. Nonfungicidal compounds that inhibit nitrification such as the nematicide 1, 3-dichloropropene ("Telone") (49), or the *Nitrosomonas* spp.-specific compound 2-chloro-6-(trichloromethyl) pyridine (16, 17) intensify the disease response when applied with ammoniacal fertilizers without reducing detectable pathogen populations in the soil (27) (Tables 1, 2, Fig. 2). Control of *Verticillium* wilt and scab of potatoes has been achieved in field trials in Idaho with stabilized ammoniacal nitrogen as anticipated from the effect of specific organic amendments on nitrification and these diseases. Calcium or potassium sulfates (50 to 800 lb./acre) did not influence the severity of potato scab.

Mechanism of biological control.—The mechanism of biological control enhanced by crop rotation, organic amendment, or a specific form of nitrogen involves specific microbial interactions and host physiology. Competition, antibiosis, hyperparasitism, and lysis as well as the lethal effects of anaerobic conditions are probably responsible where pathogen populations are reduced by "flood-fallowing" after residue plowdown for control of *Sclerotinia sclerotiorum*, *F. oxysporum* f. sp. *cubense*, and *Verticillium albo-atrum* (37, 39, 47, 54).

Population of pathogens such as *Fusarium* or *Rhizoctonia* that possess a high "competitive saprophytic ability" are not necessarily related to disease severity in the field (19, 40), especially when more than the minimum number of units needed for maximum infection are present. Specific bacterial-fungal associations have been correlated with disease control without a corresponding reduction in pathogen numbers in the soil. Specific soil-borne bacteria in intimate association with *F. solani* f. sp. *phaseoli* were isolated from bean-field soils using the plate-profile technique (2, 21, 22). The bacteria grew directly upon the mycelium surfaces without greatly affecting the over-all growth or population of this pathogen in soil, although necrosis of older hyphae occurred. *F. solani* pathogenic to beans in pure culture were not pathogenic when associated with the bacterium, and pathogenicity was restored in the absence of the bacterium. Isolation frequency of this association from rotation plots was inversely correlated with the incidence and severity of bean root rot as influenced by specific crop rotations (20).

Since organic amendments inhibited nitrification and ammoniacal nitrogen increased bean root rot, we undertook additional studies to determine the effects of the form of nitrogen on growth of the bacterium and *Fusarium*. *Fusarium*, as well as other pathogens tested, grew well with either an ammoniacal or nitrate form

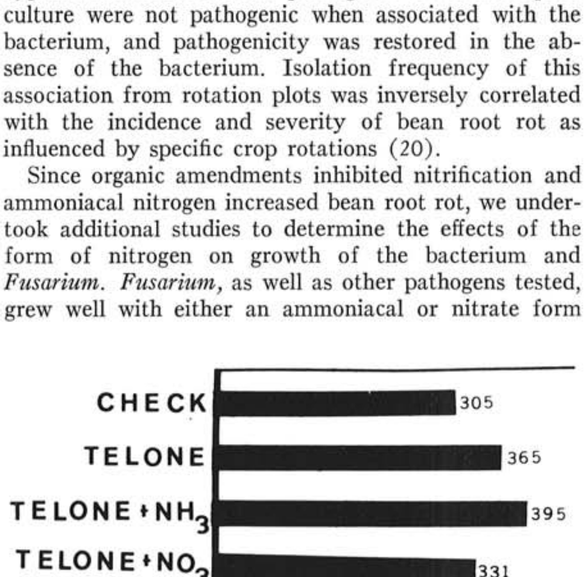

Fig. 2. Effect of form of nitrogen and "Telone" fumigation on yield of potatoes infected with *Verticillium albo-atrum*.

of nitrogen, and were not adversely affected by 2-chloro-6-(trichloromethyl) pyridine. The bacterium, on the other hand, utilized only ammoniacal nitrogen in the absence of *Fusarium*, but grew well on a nitrate medium in association with *Fusarium*. The bacterium appears dependent on *Fusarium* for some essential growth factor when nitrate nitrogen predominates, but is capable of independent utilization of ammoniacal nitrogen. Thus, enrichment of the soil with ammoniacal nitrogen which made conditions more favorable for the bacterium increased disease because association of the bacterium with *Fusarium* was not maintained.

Fungistasis is another type of microbial interaction by which virulence of soil-borne pathogens may be reduced without eradication. Although the pathogen is present in the soil, it is "dormant" or inactive. Venkata Ram (53) isolated two soil bacteria that stimulated chlamydospore formation (dormancy) of *F. solani* f. sp. *phaseoli* either directly or through culture filtrates. We found a similar mechanism operative in snowmold of winter wheat caused by *Typhula idahoensis* where associated psychrophylic soil bacteria prevented germination of *Typhula* sclerotia (23). Sclerotia can readily germinate after removal of associated bacteria.

Altered nutritional status of the host following organic amendment may also alter a disease response without affecting numbers of pathogen propagules in the soil. Studies of *Gibberella saubinetii* on wheat and corn (11, 13) implicate the availability of nitrogen in host tissues. Painter & Simpson (*unpublished data*) increased the incidence of stalk rot of corn caused by *F. moniliforme* by inhibiting nitrification of ammonium sulfate with 2-chloro-6-(trichloromethyl) pyridine, which also altered nitrate levels in plant tissues. The effect of a specific form of nitrogen also affects the incidence and severity of take-all of winter wheat caused by *Ophiobolus graminis* (24). Disease control as a result of modified host physiology may result in decreased infection (24) or delayed pathogenesis after penetration (25, 26).

In summary, it is concluded that organic amendments and crop rotation probably influence the severity of soilborne diseases by (i) increasing the biological buffering capacity of the soil; (ii) reducing pathogen numbers during anaerobic decomposition of organic matter; (iii) affecting nitrification which influences the form of nitrogen predominating in the soil; and (iv) denying the pathogen a host during the interim of unsuitable species. The specific form of nitrogen available to the plant and soil microflora, in turn, influences specific microbial associations and host physiology. These factors should be considered in opening new lands to cultivation to avoid costly results of land pollution from establishment of soilborne plant pathogens.

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