Importance of Plant Health-Promoting Rhizobacteria for the Control of Soil-Borne Fungal Diseases and Plant Parasitic Nematodes.

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Abstract

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The rhizosphere of every plant is colonized by bacteria that are important in supporting overall plant growth and in stabilizing plant health by protecting the root system from disease. Under natural growing conditions, bacterial colonizations of the rhizosphere after seed germination is extensive. The influence of these microbial communities on root health is not known. Specialized forms of rhizosphere bacteria that are dependent on the root surface interface for growth and survival have been identified which have plant health promotion attributes. These rhizobacteria are a component of the natural antagonistic potential in soil ecosystems. Such antagonists can be applied as seed dressings or to planting material to protect the root system from fungal, bacterial or nematode infection. One class of beneficial rhizobacteria, the plant health-promoting rhizobacteria (PHPR), are found in different genera and have diverse modes-of-action in combating soil-borne diseases and nematodes. Suppression of spore germination, inhibition of pathogenic and deleterious nonpathogenic bacterial growth and/or reduction in hatching or penetration of plant parasitic nematodes are just a few of the mechanisms thus far detected. The present state of knowledge on PHPR as well as some of the advantages and disadvantages of this biological control approach will be presented.

Key Words: Rhizobacteria, Biological control, Nematodes, Fungi, Seed-dressing, Soil-borne Diseases.

Soil Ecosystem Pathology and Root Health

Soil-borne fungal diseases and plant parasitic nematodes are important factors affecting crop growth and yield in sub-tropical agricultural production zones throughout the world. Wilt, damping-off and root-rot diseases caused by fungi and bacteria as well as cyst, root-knot and lesion nematodes are major factors limiting crop production in north Africa and west Asia (13,16). Furthermore, the occurrence of complex and often synergistic interactions between these rhizosphere organisms leads to serious degradation in root health and host yield.

Control of many fungal and nematode problems has been attained with cultural practices, crop rotation, pesticides and in some instances with resistant cultivars. Solarization, flooding and antagonistic crop and trap cropping technologies have been developed, but are limited to high value crops, restricted to certain growing regions or specific seasons. Increased population growth in most areas of the world will significantly increase demand for food. With the amount of unused arable land available for food production almost nonexistent, attemps to increase crop production will require effective control of plant pests and diseases - in both the phyllosphere and rhizosphere.

Losses caused by soil - borne organisms can be severe and must be considered when attempting to increase yield through integrated crop production and protection technology. With this in mind, I found it rather surprising that less than 28 of the over 300 research projects presented at the meeting involved soil-borne problems, and that of these 28, only 3 dealt with biological control approaches. This area of agricultural science must be expanded upon within the region, to help detect new biological control agents and to assist the grower in evaluation and application of new systems when they become available.

The technology responsible in large part for increased yield in many crops in the past is being lost, because of adverse effects on the environment. Excessive irrigation, over fertilization and near monoculture cropping systems are being criticized because of adverse effects on erosion, fertility and water quality. The restricted use and/or loss of many fungicides and nematicides will drastically limit grower ability to effectively counter soil-borne disease and nematode epidemics. Therefore the future mandate for soil ecosystem pathologists and nematologist must be to increase biological control components in integrated pest and disease management systems. This approach predominates in many parts of the world.

Biological Control Alternatives

Research on the biological control of soil-borne fungi and plant parastic nematodes has emphasized specific organisms that are part of the natural antagonistic potential in the soil ecosystem. The most important antagonists investigated for the biological control of soil-borne fungal pathogens include: cross-protection with nonvirulent strains, application of parasites and pathogens, and stimulation of naturally occurring competitor systems e.g. endomycorrhizae.

Research with plant parasitic nematodes has concentrated on: **fungal egg, juvenile and females parasites, predators and pathogens; bacterial parasites of juveniles** and; control by competition with endomycorrhizae. These forms of biological control have greatly increased our knowledge of interactions in the rhizosphere, but have seldom led to commercial production and large scale acceptance of biological control systems by growers. Stabilizing efficacy and development of adaptable formulation technology are major constraints to commercial development.

Recent attempts to develop biological control systems for soil-borne fungal diseases and plant parasitic nematodes have been redirected toward nonpathogenic bacteria specific to the rhizosphere. The importance of these rhizosphere competent microorganisms, or rhizobacteria, for biological control of soil-borne fungal diseases and plant parasitic nematodes, will be summarized in this article. Review articles on the subject should be consulted for detailed coverage (8, 23, 24, 26, 34).

Rhizobacteria

Rhizobacteria occupy the ecological niche in the soil-ecosystem that is under the chemical influence of the root system. Rhizobacteria can have either beneficial, deleterious or no affect on the plant.

Lugtenberg *et al.* (17) divided plant-beneficial bacteria into three classes 1) microbes responsible for biofertilization e.g. *Rhizobium* 2) those that stimulate plant growth indirectly through their inhibitory effects on plant pathogens e.g. *Pseudomanas* spp. and 3) bacteria that are responsible for direct biological plant growth promotion e.g. *Azospirillum* spp. Whether such strict lines of demarkation can be drawn between the three classes is doubtful, because of the complex interrelationships that exist in the rhizosphere between the bacteria, plant and other biotic and abiotic factors. The term plant growth promoting rhizobacteria, has been used in the past for all forms of beneficial rhizobacteria. The term plant health-promoting rhizobacteria (PHPR) has been suggested for those bacteria that stimulate plant growth by limiting plant pathogens or parasites (26).

Although the majority of bacteria that are present in the rhizosphere have no direct or indirect influence on plant growth, the number of species that have biological control potential is large. Sikora (25, 26) reported that approximately 9 % of the rhizobacteria isolated from the rhizosphere had plant health promoting activity toward plant parasitic nematodes. The level of biological control varies with species present and in turn is influenced to various degrees by microbial competitors, plant species, cultivar and abiotic environmental factors.

Application

Biological control can be attained by: 1) single inoculative release of an organism that becomes established in the ecosystem, 2) repeated applications as with pesticides and 3) through management of the natural soil antagonistic potential. In this respect, rhizobacteria have unique advantages as potential biological control agents since they can be pelleted onto seed, applied through drip-irrigation systems or directly to transplants. These forms of application place PHPR directly at or in close proximity to the infection site of the disease or nematode targeted for control. PHPR are the dominant microorganisms in the rhizosphere directly after treatment. They actively and passively colonize the rhizosphere as the root system expands after germination and are therefore unique agents for biological control systems.

The level and duration of control is influenced by a number of factors, especially microbial density on the rhizosphere with time. Control can be considerable in the seedling stage or during the early root infection period when many soil-borne pathogens and nematodes induce the greatest amount of damage to the root system.

In addition, rhizobacteria are: 1) responsive to mass production 2) easy to storage 3) adaptable to formulation technology and 4) are not necessarily manipulated genetically. Since they are nonpathogenic, occur naturally in the soil ecosystem and are largely dependent on the rhizosphere for multiplication, they are considered environmentally safer for use than many pesticides.

Sensitive Targets

Soil-borne fungi. Fungal pathogens.especially those that infect the plant within the first few days after germination or transplanting, are highly sensitive to biological control with PHPR technology. Pathogens are dependent on seed and root exudates which direct spore germination and determine host recognition. Biological control following seed treatment with rhizobacteria is associated with either alteration of these exudates or with production of metabolites which interfere with the infection process. Examples of plant pathogenic fungi and bacteria that have been controlled with plant health promoting rhizobacteria are listed in table 1.

Biological control with rhizobacteria is not necessarily limited to pathological problems existing early in the season. Significant control of *Rhizoctonia solani* late season root rot of peanut, for example, has been obtained following rhizobacteria seed treatment (12). In addition, a single strain of PHPR has been shown to reduce fungal and nematode infection simultaneously on a single plant species (28, 29).

Table 1. Plant health promoting rhizobacteria exhibiting biological control activity toward fungal and bacterial plant pathogens, host combination, mode-of-action and literature citation.

Bacteria	Pathogen	Plant	Possible MoA	Ref.
I. Fungi				
Pseudomonas fluorescens	*Gaeumanomyces Graminis* var. *tritici*	wheat	antibiotics (siderophore)	(34)
Pseudomanas fluorescens	*Pythium ultimum* var. *sporangiiferum*	wheat	siderophores	(3)
Pseudomonas fluorescens	*Pythium* sp.	sugar beet		(28,29)
Pseudomanas fluorescens	*Verticillium dahliae*	potato		(14)
Serratia marcescens	*Sclerotium rolfsii*	bean, peanut chicpea		(20)
Pseudomonas fluorescens	*Rhizoctonia solani* *Thielaviopsis basicola* *Alternaria* sp. *Verticillium dahliae*	cotton	antibiotics	(7)
Pseudomanas sp.	*Fusarium oxysporum* f. sp. *dianthi*	carnation	induced resistance siderophore antibiotics	(21)
Pseudomonas fluoresens	*Thielaviopsis basicola*	tobacco	siderophore HCN	(5)
Erwinia herbicola	*Fusarium culmorum*	wheat	antibiotics	(9)
Bacillus subtilis	*Tiletia caries*	wheat	antibiotics	(2)
II. Bacteria				
Agrobacterium radiobacter	*Agrobacterium tumefaciens*	stone fruit rose	antibiotics	(10)
Pseudomonas sp.	*Erwinia carotovora*	potato		(11)

Plant parasitic nematodes. These obligate parasites have been shown to be highly sensitive to rhizobacteria, because of their total dependence on root exudates for successful completion of their life cycle (Sikora, Interlaken). The life cycle of a typical cyst nematode, the stages of development sensitive to root exudates and the possible mode-of-action of PHPR are shown in Fig. 1. Similar interactions between rhizobacteria and root system interfere with developmental biology of root-knot nematodes *Meloidogyne* spp. These forms of interrelationships are also important in reducing root damage caused by fungal pathogens (33).

Mode-of-Action

The mechanisms considered responsible for increased root health or for plant growth promotion are varied and in many cases have not been elucidated. The major categories of action are shown in figure 2 for both forms of rhizobacteria. It is evident that a certain amount of duplicity exists. This is an indication that additional basic research into mode-of-action is required. Three mode-of-action can be visualized 1) alteration of root exudate patterns that lead to modifications in the behavior of the pathogen or parasite 2) production of toxic or inhibitory metabolites by the bacteria that reduce infection or suppress development of the target organism and 3) the existence of a physical barrier at the penetration site. Known modes-of-action for specific rhizobacteria plant and pathogen combinations, are listed in table 1 and 2.

The mechanisms thought to be responsible for rhizobacteria growth promotion are given in table 3. The influence of plant growth promoting rhizobacteria on plant nutrition are significant and such substrate alterations in the tissue of plants can indirectly influence pathogen and nematode infection behavoir.

Management of Antagonistic Potential

It has been suggested that biological control of nematodes and other organisms can be attained by management or manipulation of naturally occurring antagonistic potentials (27). Whether this approach can be used to manage specific PHPR or microbial communities to maintain root health, is still

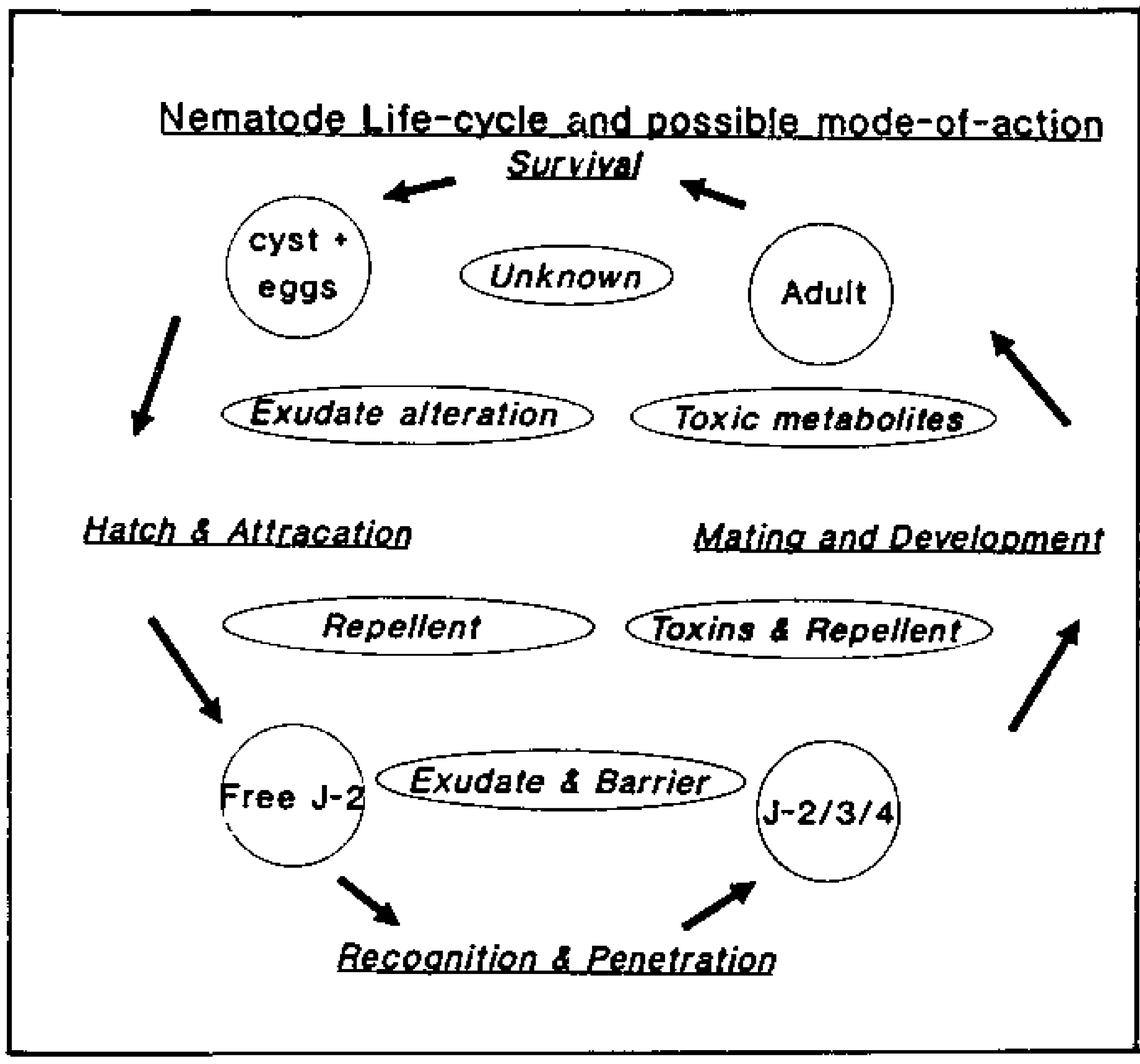

Figure 1. Typical life-cycle of a cyst nematode with stages in development sensitive to plant promoting rhizobacteria and mode-of-action.

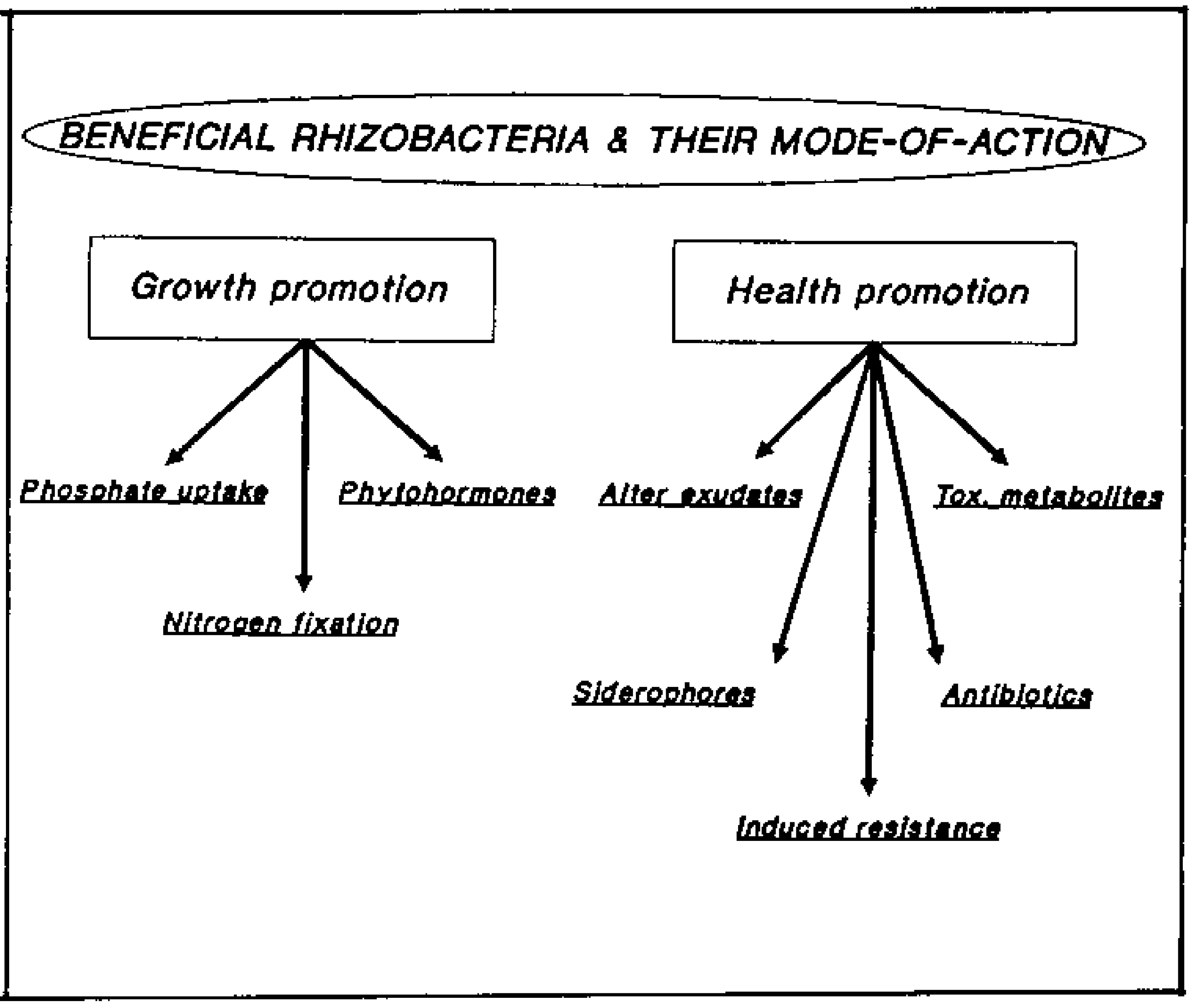

Figure 2. Mode-of-action associated with rhizobacteria growth and health promotion activity.

Table 2. Plant health promoting rhizobacteria exhibiting biological control activity plant parasitic nemadotes, host combination, mode-of-action and literature citation.

Bacteria	Pathogen	Plant	possible MoA	
Pseudomonas fluorescens	*Meloidogyne incognita*	tomato cucumber	nematicidal components	(8)
Pseudomonas chitinolytica	*Meloidogyne javanica*	tomato	toxic metabolites	(30)
Pseudomonas fluorescens	*Heterodera schachiti*	sugar beet	alteration of root exudates	(18,19)
Agrobacterium radiobacter	*Globodera pallida*	potato	alteration of root exudates	(22)
Bacillus subtilis	*Meloidogyne incognita* *Meloidogyne arenaria* *Rotylenchulus reniformis*	cotton		(25)

unclear but considered feasible. Many components of integrated crop production systems could have an influence on rhizobacteria and could be used to prolong activity to control soil-borne diseases. Rhizobacteria densities on the root are influenced among others by: crop, rotation, tillage, cultivar, fertilizer, pesticides, irrigation and organic matter. These could be used to manage PHPR for control purposes.

Another alternative is «biological therapy» or stimulation of the antagonistic potential of a host through controlled manipulation of the phyllosphere or rhizosphere, to suppress or reduce the deleterious effect of a pathogen or parasites (27). A number of chemicals applied as foliar treatments in plant production and protection influence root exudates and could be used to manipulate naturally occurring rhizobacteria communities or PHPR applied directly to the plant (figure 3).

Conclusion

Soil-borne plant pathogens and plant parasitic nematodes are important limiting factors that reduce overal crop yield. The loss of a number of important fungicides and most major nematicides for grower use will have a major impact on food production if acceptable alternatives are not found. Many bacteria live in the rhizosphere and have been shown to be of potential importance as antagonists of soil-borne pathogens

Table 3. Plant health promoting rhizobacteria exhibiting plant growth-promotion activity, host combination, mode-of-action and literature citation.

Bacteria	Pathogen	Plant	possible MoA	Ref.
Bacillus subtilis		peanut		(32)
Azospirillum sp.		cereals	nitrogen fixation hormonal effects improvement of mineral uptake	(1)
Pseudomonas putida		canola	enhanced phosphate uptake phytohormones	(15)
various bacteria			phytohormones	(6)

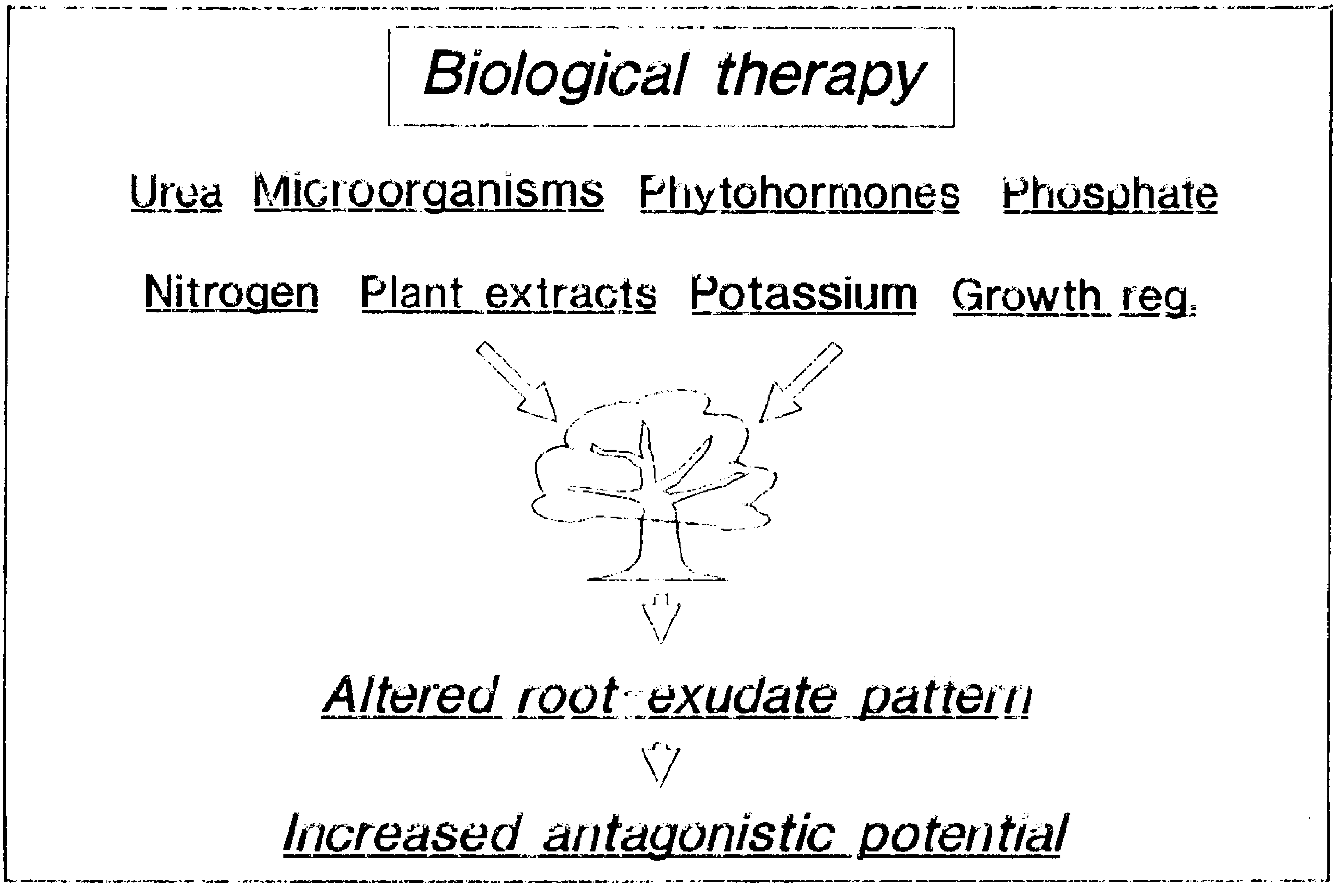

Figure 3. Components of biological therapy used in treatment of the phyllosphere that influence root exudates and rhizosphere microorganisms.

and nematode parasites. These plant health-promoting rhizobacteria are highly dependent on the root-soil environment for survival and multiplication.

Plant health promoting rhizobacteria are especially suitable for the control of organisms that attack the root early in the season. They have commercial advantages over other biological control agents and will be important components of future integrated disease and nematode management systems. A minimal amount of information exists concerning the presence and importance of plant health promoting rhizobacteria in tropical and subtropical soils. Research must be generated in north Africa and west Asia on biological control as it relates to soil-ecosystem pathology and nematology to support increased food production and a clean environment.

الملخص

سيكورا، ريتشارد وسابين هوفمان ـ هرجارتن. 1992. أهمية بكتريا الجذور المحفزة لصحة النبات في مكافحة الأمراض الفطرية والديدان الثعبانية المنقولة مع التربة. مجلة وقاية النبات العربية. 10 (1): 48-53.

يوجد في جو الجذور (الريزوسفير) لأي نبات كـائنات بكتيرية تسهم بدور هام في دعم نموه واستقرار حالته الصحية عن طريق حماية مجموعه الجذري من الأمراض. ويبدو أن استعمار البكتيريا لجو الجذور، بعد إنبات البذور، تحت الظروف الطبيعية للنمو يكون كبيراً جداً. على أن تأثير هذه المجتمعات الميكروبية في صحة الجذور غير معروف. وقد تم تعريف بعض الأشكال المتخصصة من بكتيريا جو الجذور التي تعتمد في نموها وبقائها على سطح الجذور، وتبين أنها تحوي على مواد مخفزة لصحة النبات. وتعتبر هذه الكائنات البكتيرية الجذرية إحدى مكونات الطاقة التضادية الطبيعية للنظام البيئي للتربة. ويمكن استخدام هذه الكائنات المضادة في تغليف البذور على هيئة كاسيات أو إضافتها لمواد الإكثار لحماية المجموع الجذري من الإصابات الفطرية أو البكتيرية أو من الإصابة بالديدان الثعبانية. وقد وجدت إحدى طوائف الكائنات البكتيرية الجذرية النافعة (PHPR) في عديد من الأجناس وتبين أن لها طرائق عمل متنوعة في مكافحة الأمراض والنيماتودا المنقولة مع التربة. ومن الآليات التي تم كشفها حتى الآن منع إنبات الأبواغ، إعاقة نمو البكتيريا الممرضة والبكتيريا الضارة غير الممرضة و/أو خفض نسبة الفقس أو التقليل من اختراق النيماتودا النباتية لنسج العائل. وستناقش المقالة المعلومات المتوافرة عن (PHPR) ومزايا ومساوىء هذه الطريقة من المكافحة الإحيائية.

كلمات مفتاحية: البكتيريا الجذرية، مكافحة احيائية، نيماتودا، فطور، كاسيات بذور، الأمراض المنقولة مع التربة.

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