ADVANCES IN SEED TREATMENT TECHNOLOGY

Denis C. McGee

Professor of Plant Pathology
Seed Science Center, Iowa University, Ames, IA 50011, U.S.A.

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ABSTRACT

The use and expectations of seed treatments are greater today due to the impact of environmental regulations that have either banned or restricted the use of older fungicides and the development of biological and chemical control agents that offer the potential to control bacteria, viruses, insect and nematodes and provide plant protection well into the growing season. Seed treatment technology also has application in control of insect vectors of plant pathogens, more efficient, and safer use of herbicides, application of growth regulators and fertilizers, and sizing and shaping of seeds to improve plantability. These new uses often require improved application systems to better establish dosages and coverage of materials. This paper reviews the current status and future uses of these new seed treatment materials and their application methods as well as the economic and regulatory constraints that effect deployment in both developed and developing countries.

INTRODUCTION

Seed treatment is the oldest practice in plant protection. Its origins can be traced to the 18 th century with use of brine for control of cereal smuts (Neergaars 1997). The modern era of seed treatments began with the introduction of organo-mercury fungicides in 1912 which were widely used for several decades. The post-World War II period saw the development of new fungicide chemistry and the first use of seed treatment for insect control. Today, the most widely used application of seed treatment in the traditional one of protecting the germinating seedling against seed-and soil-borne fungi in the period immediately after planting. However, the uses and expectations of seed treatments are greater today due to the impact of environmental regulations that have either banned or restricted the use of the potential to control bacteria, viruses, insect and nematodes and provide plant protection well into the growing season. Seed treatment technology also has application in control of growth regulators and fertilizers; and sizing and shaping of seeds to facilitate planting. These new uses often require improved application systems to better establish dosages and coverage of materials. This paper will review the current status and future uses of these new seed treatment materials and their application methods as well as the economic and regulatory constrains that affect their development in both developed and developing countries.

MODE OF ACTION OF SEED TREATMENTS

Seed treatments can be classified as physical, biological or chemical. Regardless of type, successful seed treatment practices must be satisfy the following biological requirements.

* Consistently effective
* Safe to operators during handling and planting
* Wide safety margin between diseases harmful to the pathogen and that to plants
* Safe to wildlife
* Compatible with other materials used on seeds
* Should not produce harmful residues on plant or soil
* Chemical or biological methods it should have desirable qualities with respect to application and retention on the seeds.

The principles and effectiveness of these various methods are discussed.

PHYSICAL

Physical treatments usually apply heat to the seeds in order to kill the seedborne pathogen but cause minimal damage to the seed tissues. Hot water treatment has been used since the 1920's, and, before the advent of systemic fungicides in the 1960's, was the only treatment available to eradicate deep-seated infections of seeds. This characteristic is still being exploited a indicated hot water eradication of internal infection by *Xanthomonas campestris* pv *malvacearum* in cotton (Honervogt and Lehmann-Danziger 1994). The treatment has limitations in that it has not always successful in eliminating low infections of bacteria that are of epidemiological significance such as *Xanthomonas campestris* pv *campestris* in cabbage seeds (Williams 1980). It also can have a detrimental influence on seed germination, which is a special concern in high value seeds such as hybrid cabbage (Williams 1980). Adverse effects of hot water on germination of rooibos tea seeds was minimized without compromising the efficacy of pathogen control by reducing the length of exposure to hot water and following treatment with scarification (Smit and Knox-Davies 1989). Hot vegetable oil treatment gave some control of *Phomopsis longicolla* infection of soybean seeds, but usually caused loss in germination (Pyndjii et al. 1987).

Treatment of seeds with dry heat also has been investigated since the 1920's, but frequently has been only partially effective and has been little used in practice (Neergaard 1977). Recently, however, dry heat was shown to eliminate *Xanthomonas campestris* pv *translucens* from barley seeds at temperature ranging from 71 - 84^{0}C for up to 11 days, with minimal adverse effects on germination (Fourest et al. 1990). Dry heat, applied with a microwave oven, successfully eradicated several bacterial and fungal pathogens from cassava seeds (Lozano et al. 1986). Microwave heating also reduced transmission of soybean mosaic virus, with little reduction in germination in seeds treated at 8.5% moisture content, but germination was considerably reduced in seeds treated at 16% (Jolicoeur 1982). A technique using low energy electronic beams eliminates *Tilletia caries* and *Septoria nodorum* from wheat seeds in the pericarp and testa without adverse effects on germination (Burch et al. 1991)

BIOLOGYCAL CONTROL AGENTS

Biological seed treatments are microorganisms that protect seed and seedlings from plant pathogens. Biological control of plant disease, in general, has a history of inconsistency that has greatly restricted its practical application. Public concerns over chemical pesticides in the past 20 years have stimulated scientific interest in biocontrol agents.

Significant advances have been made, because attention has been paid to the mechanisms of control, particularly in the soil environment (Cook 1993, Harman and Nelson 1994). Schroth and Hancock (1981) describeed increase yield in several crops with *Pseudomonas* seed treatment. They suggested that it results from displacement of root-infecting fungi and bacteria that, in total, reduce plant growth. Possible mechanisms for this are growth promoting substances, antibiosis, or involvement of siderophores (*Pseudomonads* that utilize iron in the soil). There are numerous reports of potentially valuable biological control microorganisms, some of which are supplied as seed treatments, but the developmental process to bring these into commercial practice is long and arduous (Cook 1993). As of 1994, only six microorganisms were commercially available, one of which, *Bacillus subtilis,* is marketed a the seed treatment, Kodiak, by Gustafson Inc. Dallas, Texas (Rhodes and Powell 1994). As Cook (1993) points out, development of biological control agents is hindered by the expectation that it will function across a broad range of environments as most successful chemical pesticides do, when, in fact, the ecological niche in which a biological control agent can function may be relatively narrow.

Naturally occurring microorganisms also can be exploited for biological control. Seed-transmitted endophytes, *Acremonitum coenophialum* and *A. Lolii*, cause animal toxicity problems in pastures, but infested grasses often have superior growth habits due to insect and pathogen control (Siegel et al 1987). Endothytes are now introduced into turf grass varieties to improve agronomic performance.

NATURAL PRODUCTS

Considerable research activity has occurred in the Asian-Pacific region on the potential for plant extracts to control seed-borne fungi. The oils of cassia and clove inhibited growth of established seed borne infections *of Aspergillus flavus*, *Curvularia pallescens* and *Chaetomium indicum* in maize (Chatterjee 1990). Aqueous extracts of *Strychnos nux-vomica*, garlic bulbs, ginger rhizomes, basil leaves, and fruits of *Azadirachta indiica* were used to control *Alternaria padwickii* in rice seeds (Shetty et al 1989), while extracts from peppermint and garlic reduced rice seed infection by *Cochliobolus miyabeanus* (Alice and Rao 1986). Garlic bulb extract inhibited the spore germination and mycelial growth of seed-borne fungal pathogens of jute, including *Macrrophomina phaseolina*, *Botryodiplodia theobromae* and *Colletotrichum corchori* (Ahmed and Sultana 1984). Homeopathic drugs, *Filix mas* and *Blatta orientalis*, completely suppressed the population of *Fusarium oxysporum* in the seed mycoflora of wheat (Raka et al. 1989). *Aspergillus ruber* infection and weevil oviposition of *Zabrotes subfaciatus* were reduced by mineral oil and soybean oil treatment of dry beans stored in Ecuaddor (Hall and Harman 1991). Soybean oil, applied at a rate used to suppress grain dust, reduced storage fungi growth in maize and soybeans during 12 months in field storage bins in Iowa (McGee et al 1989, White and Toman 1994).

FUNGICIDES

A survey in 1991 of seed treatment product segments throughout the world showed that fungicides dominated the market with a 68% share, followed by insecticides at 11% (Schwinn 1994). The range of products on world markets today are quite different from those in the early part of the century when organo-mercurials and dithiocarbamates, eg thiram, and heterocyclics, eg captan, that acted by direct contact with the pathogens, were the primary products used in seed treatment. Organo-mercurials are now banned in most countries because of toxicity to animals and humans, and uses of captan and thiram have been restricted in use in some countries. The latter materials, however, still are the mainstay of seed treatment chemistry for many crop species. They have a broad spectrum of activity, are easily applied, and are relatively inexpensive. On a worldwide basis, systemic products that contain carboxin or triademinol occupy 40% of the fungicide seed treatment market. Oxine-Cu, pencycuron, captan, benomyl, TBZ and mercury hold 30% of the market, and another 51 products constitute the remaining 30% (Schwinn, 1994). The insecticides, carbofuran and methiocarb, both introduced some 30 years ago, comprise 70% of the insecticide seed treatments sold (Schwinn, 1994).

The change in the landscape of fungicide seed treatment chemistry can be attributed to the need to replace of older chemistry because of environmental concerns and the discovery of systemic compounds that provided new opportunities to control foliar and systemic pathogens by seed treatment. The primary active ingredients that have come into common use include: carbithiins for control of rusts, smuts, and *Rhizotonia*; carboxin which is particularly effective against loose smut; benzimidazoles for control of *Leptosphearia maculans* in crucifers; metalaxyl, which is effective against Phycomycetes such as *Phytophthora* and downy mildews; and ethirimol and triademenol for control of the powdery mildews. Other systemic chemistry that has potential for use a seed treatments includes iprodone and imazilil.

BACTERICIDES AND VIRICIDES

Reliable chemical seed treatments for bacteria are not available. Materials such as $Ca(OCL)_2$, Na(OCL), and HCL, has had limited success, either because lack of control of internal inoculum or phytotoxicity to the seeds (Fatmi et al. 1991, Honervogt and Lehmann-Danziger 1992). Antibiotics, applied in polyethylene glycol (PEG), did reduce infection by *Xanthomonas campestris* pv. *phaseoli* in bean seeds, but were phytotoxic (Liang et al 1992).
Virus seed treatment is not known except for trisodium phosphate, which is sometime used to reduce TMV contamination of tomato seeds. This will control surface-borne, but not internal infections.

SEED TREATMENTS IN CURRENT USE

Seed treatments registered in the U.S.A indicate the types of diseases amenable to control by the most commonfungicides in the major world crops (Table 1). Seed treatments are labelled for control of soilborne seedling diseases for almost every crop.they also are labelled for several seedborne diseases of small grains, smuts of maize and sorghum, pod and stem blight of soybean, and downy mildew of sorghum. No seedborne diseases are listed for other cropss. Small grain seeds are unique, in that seedborne pathogens can be controlled by the systemic products triademenol and difenoconazole. Older contact fungicides, including captan, thiram and PCNB are registered for many crops for control of the soilborne seedling pathogens, Pythium, Fudarium or Rhizoctonia. This reflects the broad spectrum of activity of these systemic activity ofthese products. Other chemicals express a narrower spectrum of control. Carboxin exercises systemic activity against smut diseases and Rhizoctonia. The dithiocarbamates, mancozeb and maneb are registered for covered smuts. Metaxyl is active against the Phycomyctes including Pythium, Phytophthora and downy mildews.

In Europe, seed treatment fungicides are registered for control of seed and soilborne pathogens of peas, beans, oilseed rape, and sugar beets. Chemicals include most of those registered in the U.S. (Table 1) and others, such as iprodione and guazatine. The primary focus of attention in this region of the world is on seed treatment of small grain crops for control of seedborne fungi. The banning of organo-mercurial treatments has led to their replacement by a range of new products, in particular the ergosterol biosynthesis inhibitors. These fungicides are systemic and are highly effective against pathogens in the Ascomycetes, Basidiomycetes, and Deuteromycetes. The range of pathogens controlled by triadimenol and difenoconazol (Table 1) is typical for these fungicides. Other fungicides currently registered in Europe in this group include, flutriafol, tebucinazole, diniconazole, imazalil, and bitertanol. Two new seed treatment fungicides, referred to as phenylpyrroles, have aa similarly broad spectrum of activity (Leadbitter et al 1994). One of these products, fludioxonil is scheduled to be labelled in 1995 in the U.S. as a seed treatment with activity against Fusarium, Rhizoctonia, and Helminthosporium spp.

A recent review of the literature on seed diseases indicated that approximately 8% of the papers related to fungicide seed treatment in the Asian Pacific region. Most of fungicides discussed above were used in these studies, and a broad range of crops were covered, including those primaryly used in tropical regions of the world.

EFFICACY OF CHEMICAL SEED TREATMENTS

Efficacy of seed treatment is one of several factors that influence the cost, risk and benefits of seed treatments. For some crops, such as corn, peanuts, rice and cereals, fungicide seed treatment is routine and there is little argument that seed treatment is a necessary and effective means of protecting seeds and seedlings from seed and seedborne pathogens. After almost 30 years of continual use of captan seed treatment of maize, Pedersen et al (1986) reevaluated the need for this practice and reached the conclusion that it was essential to assure stand establishment in the corn belt of the U.S.A.

While inexpensive organo-mercury seed treatments were in use in the U.K, cereal diseases were rate or unknown (Yarham and Jones et al 1992). The replacement of organo-mercurials with more expensive products has led several studies of benefits of seed treatment of cereals in the U.K. (Richardson 1986, Sutherland et al 1994). In all of these reports, no benefit to yield was evident in plotts grown from treated compared to untreated seeds. At individual sites, however, significant differences were evident. Because control of seed-borne pathogens is a major reason for seed treatment, it was suggested that decisions to apply seed treatments should be determined by seed health test results (Brodal 1993).

Many of the incosistencies in efficacy of seed treatment can be related to a lack of understanding of the epidemiological conditions under which the benefits of seed treatment can be realized. (McGee 1981) criticized seed treatment research in general with the following statement:

"-- Application practices are usually determined by relating seed treatment rates to subsequent emergence and yield in a series of field tests in different locations and under a variety of environmental conditions. If repeated often enough, this type of experiment may provide reasonably reliable information on application rates, but very little information is obtained about disease epidemiology. As a result, failures in control practices cannot be explained and more fungicides tend to be used than are necessary.--"
At least one major crop failure, resulting in multimillion dollar court settlements, has since been attributed to the indequacies of research into efficacy of the product (McGee, unpublished).

With ssome crops, such as soybean, the need for seed treatment has always been unclear. An extensive epidemiological study of soybean seed treatment (Wall et al. 2983) led to the precise a definition of conditions under which soybean seed treatment could be justified (Table 2). An important characteristic of this recommendation is hat the grower can easily obtain the required information to make the decision to use seed treatment.

Economic and environmental considerations will require that seed treatment products developed in the future be applied at low and efficient dosages. To meet these standards, research will have to include studies tht eclucidate the mechanisms and epidemiology of disease control.

DELIVERY SYSTEMS FOR SEED TREATMENTS

For reasons of economy, efficacy of the material, and enviromental protection, the application and delivery of chemicals or biopesticides to seeds has become a much more sophisticated process than the traditional dust or slurry methods for seed treatment fungicides. This has had an impact on formulation chemistry and seed treatment application systems and equipment.

FORMULATIONS

Dust and wettable powder syatems are inefficient and environmentally hazardous, but they remain in use in less developed countries where modern application machinary is too expensive or not available (Frank 1994). Modern formulationa are all liquid-based and include:
* True solutions (LS).
* Emulsion (ES) which contain small liquid droplets
* Flowables (FS), which contain finely ground particles
* Capsule suspensions (CS), which contain small polymer balls filled with active ingredient.

The formulation of a particular product is dependent on the proposed use of the mateial and the physical properties of active ingredient. Also considered are the human and animal toxicology and phytotoxicity of the active ingredients and inert component. The performance of the formulation during application to seeds with different equipment under a range of environmental conditions must also be established.

APPLICATION SYSTEMS

Standards

Successful application syatems require to meet acceptable standards of:
* Safety - dust-off is minimizedd to ensure that operators are protected from health hazards.
* Loading efficiency - the target dose of active ingredient is applied and maintained on the seeds until planting.
* Uniform Coverage - materials are distributed uniformally cross the individual seeds.
* Flowability - materials adhere to the seed, do not cause seeds to stick together, and will not discrupt planting equipment.
* Seed damage - mechnical damage is minimized as also is the increase in moisture content for seeds that subsequently go into storage.
* Appearance - the cosmetic aspects of appearance is very much dependent on the system used, but this can be an important marketing tool.

Planter box application

Fomulations of chemiicals are designed to mix with seeds at planting time. This method allows the decision to treat to be made with full knowledge of planting conditions. Disadvantages are that it is very difficult to achieve appropriate dosage and coverage.

Direct application of chemicals to seeds

Formulations are usually diluted in water and applied directly to seeds with approprriate equipment in a seed processing plant. Properly operated seed treaters can meet acceptable standards off dosage and coverage. Treated seeds will have a speckled appearance.

Pelleting

Seed pelleeting was developed in the 1940's. The original purpose was to build up individual or groups of small, irregularly shaped seeds into spherical capsules that would ensure precision planting (Halmer 1988). It is used for a large number of vegetable seed species.

Pelleting materials include inert filler materials, such as chalk, peat, sand ect which is bound with ahhesives such as calcicum sulphate, starch etc. These are applied to seeds in aqqueous suspensions in totating mills. Incremental layers are added to the seed until the approproate size and shape is achieved. Rice seed pelleted with calcicum peroxide to increase oxygen availability in submerged paddy conditions can be obtained in Japan (Halmer 1988). Fungicides also are applied to pellets for some vegetable and sugar beets seeds.

Film coating

This coating technique uses polymer binders with firm-forming abilities to treat seeds. These products may be obtained from specialist suppliers and are co-formulated with colorants and plasticizers to improve coverage (Halmer 1994). Film coating has become a standard method for applying fungicide and other chemicals to vegetable seeds (Ester 1994). Field crops, including, maize, oilseed rape and sunflowers are now being treated with film coatings in Europe (Barlett 19944), and there is much interest in it's application to these crops in the U.S. Particularly attractive features of this technology include reduced dust-off of chemicals, uniform coverage between and on individual seeds, and improved flow through the planter.

Arias (1994) found no evidence that polymer film coatings applied alone to seeds could provide protection sgainst *Pythium* spp. infection of maize seedlings under field conditions. The potential for use of film coatings as moisture barriers for seeds stored at high humidity was demonsstrated by McGee et al (1988) in that a polyvinylidene chloride copolymer emulsion applied to maize and soybean seeds effectively controlled storage fungi invasion during storage for three months at 85% relative humidity and 25^0C by reducing the rate of uptake of moisture by the seeds.

Fluid Drilling

Seed priming is used to complete the early phases of germination in aerated water in controlled environmentt before seeds are planted in the field. One version of this is fluid drilling by which seeds are mixed in a liquid gell and planted in the field. Both chemical and biological control agents may be delivered by this technique. Metalaxyl, etridiazole and captan applied by fluid drilling controlled *Pythium* damping-off toatoes (Taylor and Harman 1990). *Enterobacter* spp. were found to proliferate in priming solutions and provide protection of beet seeds planted in *Pythium* - infested soil (Taylor and Harman 1990).

Solid matrix priming

This also is a method of priming by which the seeds are mixed with solid material and water in known proportions. The combination facilitates uptake of water by the seed to a threshold level. After priming, the solids can be washed away before the seeds are planted. This technique also can be used as a delivery system for chemical and biological control agents (Taylor and Harman 1990). It was demonstrated that the population of the bioprotectant fungus, *Trichoderma* spp., applied to seeds, increased significantly during the priming period (Harman and Taylor 1988).

EQUIPMENT

Dust and wettable powders

Jeffs and Tuppen (1986) descibed a range of seed treating machinery used for dust and wettable powders. Because these formilations have been superseded by liquid and film coating products, most of this type of equipment is no longer commercially available (Elsworth, 1988). Nevertheless, simple on-farm seed treaters are still necessary in many circumstances in developed and developing countries. Methods used for on-farm treatment include mobile commercial equipment specifically designed for this purpose, such as drum mixers and homemade devices using augers, cement mixers, hand-cranked revolving drums, or gravity feed syatems (Neergaard 1977).

Liquids

Modern equipment for application of pesticides to seeds is designed to apply liquid formulations. Operational criteria can be summerized a follows (Halmer 1994):

* Accuracy and uniformity of application.
* Ease of operation
* Ability to handle a range of formulations and seed species
* Causes minimal damage to seeds
* Easy clean-out to prevent cross-contamination of products

To meet these criteria, equipment design emphasizes:

* Control of liquid and seed metering.
* Distribution of the liquid onto the seed
* Inclusion of secondary re-mixing.

Liquid are usually applied to seeds as they fall through a mist of liquid. Seeds then pass through revolving coating chambers or polishing drumss that complete coverage. Most rotary atomizer machines include mixing augers which considerably improve distribution capabilities of flowable formulations.

Film coatings

Film coating requires uses specialized equipment that to spray seeds with replatively large volumes of formulations and polymer binders with simultaneous drying to ensure that seed moisture content is unchanged. (Halmer, 1994). Seed usually go through several cycles of spraying and drying, providing the opportunity to apply different solutions sequentially.

Various fluidized bed systems for film coating have been described (Bacon et al 1988, Horner, 1988). In sprouted bed systems, seeds are coated by a mist of the chemical a they move through the aairstream in a systematic flow pattern. In drum coaters, seeds are held in a rotating cylinddrical pan with spraying units. Dry warmed air is drawn through perforations in the drum wall and holds the seed in a fluidized state. Stirrer blades gently mix the seeds to ensure even coverage from the spray nozzles (Halmer, 1994).

Continuous throughput high volume film coating equipment is now coming onto the market.

REGULATORY IMPACT OF THE WORLD SEED TREATMENT INDUSTRY

PESTICIDE REGISTRATION REQUIREMENTS FOR NEW PRODUCTS

The primary sources of new pesticides are in the U.S., Western Europe and Japan.

Registration is a major component of the time and costs for development of new products in these countries due to the need to satisfy environmental concerns and assurance of safety to workers exposed to the product (Boardman 1986). This can have limiting effect on the emergence of new seed treatment products, because, unless there are other uses for the product, the seed treatment market alone may not justify developmental costs.

SAFETY TO OPERATIONS IN SEED PLANTS AND ON THE FARM

The likeliest points for operator exposure to pestticides in a seed treatment operation are described by Chambers (1994) as follows:

* Reception of pesticide
* Transport of pesticide on mobile containers
* Moving pesticide from storage to treating equipment
* Introduction of pesticides into seed treatment equipment
* Calibration
* Application of pesticide to seed
* Adjustments to the calibration or change of chemical during treatment
* Bagging
* Sampling
* Disposal of container and waste

Various measures are now in place in many seed treatment plants to minimize pesticide contamination. Examples include dust control by ventilation and filters, packing materials that do not expose temperature chemical to the atmosphere, protective clothing and breathing equipment for operators. These and many other safety features add significantly to production costs.

EFFECTS ON INTERNATIONAL MOVEMENT OF SEEDS

The world seed market is estimated to be a $60 bollion per year. The international component of this market that moves seed internationally is substantial, and a large segment of this includes fungicide treated seeds. Unlike phytosanitary certification, which costs the world seed industry many millions of dollars annually, seed treatment regulations do not cause significant disruption of world seed trading. Concerns do exist, however, that warrant clarification and improvements in the system. One problem is the diversity of regulations among countries and the difficulty of finding and keeping track of changes in these regulations. Organo-mercurials and captan-treated are frequently restricted, for example. Another problem is in the use of different formulations of the same active ingredient. The importing country may request that a seed lot be treated with a particular formulation before entry, but the formulation may be not labeled for seed treatment of the crop in the exporting country.

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Table 1. Seed treatment fungicides registered in the U.S.A.

CROP	DISEASE	FUNGICIDE												
		1	2	3	4	5	6	7	8	9	10	11	12	13
FIELD CROPS														
Cotton	Seedling Disease	*	*			*	*			*		*		
	Pythium			*					*					
	Fusarium				*					*				
	Rhizoctonia		*	*						*				
	Sclerotium blight			*										
	Thielaviopsis				*									
Maize	Seedling disease	*					*					*		
	Pythium							*	*					
	Fusarium									*				
	Rhizoctonia		*							*				
	Head smut		*											
Peanuts	Seedling disease	*				*	*							
	Fusarium									*				
	Rhizoctonia		*							*				
	Southern blight		*											
Rice	Seedling disease		*			*						*		
	Pythium							*						
	Fusarium									*				
	Rhizoctonia		*							*				
Safflower	Seedling disease		*											
	Fusarium									*				
	Rhizoctonia									*				
	Rust					*								
Sorghum	Seedling disease	*				*								
	Pythium							*	*					
	Fusarium													
	Rhizoctonia									*				
	Kernel smut	*								*				
	Covered kernel smut					*								
	Downy mildew							*						
Soybean	Seedling disease	*	*	*			*		*			*		
	Pythium			*				*						
	Fusarium									*				
	Rhizoctonia			*						*				
	Phytophthora							*						
	Pod and stem blight										*	*		
	Sclerotium blight			*										
Suggar	Seedling disease	*										*		

beat	Pythium								*					
	Fusarium													
	Rhizoctonia			*										
	Sclerotium blight			*										
Sunflower	Seedling disease						*							
Wheat	Seedling disease	*				*	*					*		
barley	Pythium							*	*					
Oats	Fusarium				*									*
Rye	Rhizoctonia									*				
	Common bunt					*	*			*		*	*	*
	Loose smut												*	*
	Covered smut					*				*		*	*	
	False loose smut					*	*						*	
	Flag smut												*	*
	Oat smuts						*							
	Dwarf bunt										*			*
	Stripe smut												*	
	Barley leaf stripe				*									
	Net blotch				*								*	
	Septoria glume blotch				*								*	*
	Septoria seedling blight													
	Common root rot				*								*	*
	Powdery mildew												*	*
	Take-all												*	*
	Typhula rot												*	
	Leaf rust												*	*
	Stripe rust												*	
	Barley rust												*	
	Crown rust												*	
	Rye rust												*	
VEGETABLES														
Beans	Seedling disease	*	*									*		
	Pythium			*				*						
	Fusarium									*				
	Rhizoctonia			*						*				
	Phytophthora							*						
	Sclerotium blight			*										
Carrot	Seedling disease											*		
	Pythium								*					
Celery	Pythium								*					
Brassicas	Seedling disease	*										*		
	Pythium								*					
Cucurbits	Seedling disease	*										*		
	Pythium								*					
Eggplant	Seedling disease											*		
	Pythium								*					
Lentils	Seedling disease	*												

	Pythium			*		
	Phytophthora			*		
Lettuce	Seedling disease					*
Onion	Seedling disease					*
Peas	Seedling disease	*				*
	Pythium			*		
Peppers	Seedling disease					*
	Pythium				*	
Radish	Seedling disease					*
Spinach	Seedling disease	*				*
	Pythium				*	
Tomato	Seedling disease	*	*			*
	Pythium				*	

1: captan
2: carboxin
3: chloroneb
4: imazlil
5: mancozeb
6: maneb
7: metalaxyl
8: oxadixyl
9: PCNB
10: TBZ
11: Thiram
12: Triadimnol
13:Difenoconazole

Table 2: Seed treatment guidelines for soybean in lowa

Planting date	Quality characteristics	Minimum soil temp. (^{0}C)		
		<11	11 to 14	>11
Before May 15	Good quality, germinaion >90%	l[a]	No[b]	No
	small size, germination >90%	l	No	No
	10--30% mechanical damage	Yes[c]	l	No
	At least two years old	Yes	l	No
	>15% Phomopsis infection	Yes	Yes	Yes
After May 15	Good quality, germination >90%	No	No	No
	small size, germination >90%	No	No	No
	10--30% mechanical damage	l	No	No
	At least two years old	l	No	No
	>15% Phomopsis infection	Yes	Yes	Yes

[a]Treatment response inconsistent
[b]Treatment not recommended
[c]Treatment recommended