CANADIAN JOURNAL OF PLANT PATHOLOGY 18:176–185, 1996

Practice and precept in cultural management of bean diseases

Robert Hall and Luiz C.B. Nasser

Department of Environmental Biology, University of Guelph, Guelph, Ontario N1G 2W1; and (L.C.B.N.) Cerrados Agricultural Research Center, EMBRAPA, CPAC Caixa Postal 08.0223, Planaltina - DF73301-997, Brazil.

Accepted for publication 1995 03 13

This paper was presented at a symposium on disease management through cultural practices held during the annual meeting of the Canadian Phytopathological Society, Edmonton, Alberta, July 31–August 3, 1994.

A review of four comprehensive sources of information reveals that cultural practices, i.e. practices not employing host resistance, pesticides, or specific biological control agents, are important to the management of all of the 50 principal diseases of common bean (*Phaseolus vulgaris*) and essential to the control of 40. Thirty-one groups of cultural practices contribute to the control of bean diseases. The practices most frequently recommended are rotation, pathogen-free seed, weed control, and tillage. The number of cultural practices recommended per disease ranges from 1 to 15. Several precepts relating to the development and rational use of cultural practices in bean disease control are derived from this quantitative analysis. Control of diseases through cultural practices is essential to sustainable bean health.

Hall, R., and **L.C.B. Nasser.** 1996. Practice and precept in cultural management of bean diseases. Can. J. Plant Pathol. 18:176–185.

Une examination de quatre sources compréhensives d'information démontre que les pratiques culturales, c'est-à-dire des pratiques qui ne dépendent pas de la résistance de l'hôte plante, des pesticides ou des agents spécifiques de lutte biologique, se révèlent importantes à la lutte contre toutes des 50 maladies principales du haricot commun (*Phaseolus vulgaris*) et essentielles pour en contrôler 40. Trente et un groupes de pratiques culturales contribuent au contrôle des maladies du haricot. On recommande le plus souvent la rotation, les semences exemptes d'agents pathogènes, le contrôle des mauvaises herbes et le labour. Le nombre de pratiques culturales recommandées par maladie s'échelonne de 1 à 15. On retire de cette analyse quantitative des principes ayant trait au développement et à l'usage raisonné des pratiques culturales pour le contrôle des maladies du haricot, pratiques qui s'avèrent essentielles au maintien d'un état de santé du haricot.

This review examines the role of cultural practices in managing diseases of the common bean (*Phaseolus vulgaris* L.). Worldwide, the crop is affected by at least 50 infectious diseases caused by 29 fungi, four bacteria, 14 viruses, two groups of nematodes (root knot and lesion) and one mycoplasmalike organism (MLO) (Table 1). Two recent books provide detailed accounts of the control of bean diseases (Hall 1991, Schwartz & Pastor-Corrales 1989), and two recent treatments of cultural control of plant disease refer extensively to the bean plant (Palti 1981, Thurston 1992). Since an exhaustive review is not possible here, information from these four publications is used to illustrate the range of practices and to draw conclusions regarding the importance of cultural practices for managing bean diseases. According to these works, 33 groups of practices are used to control bean diseases (Table 2). General comments on the control of bean diseases and statements of fact made in this review without a specific citation are based on these collections of observations and recommendations. Experiences of the authors in Ontario and Brazil are also used to illustrate certain points. It is recognized that recommendations may vary according to location. Certain practices fall under the headings of genetic resistance in the plant and chemical control; the remaining 31 groups of practices are referred to here as cultural practices.

Genetic resistance of bean to disease is moderately to highly important for controlling 14 fungi, 10 viruses, and root knot nematodes. Highly effective resistance is available for three fungal diseases (angular leaf spot, anthracnose, and rust) and six viral diseases (bean common mosaic, bean pod mottle, bean rugose mosaic, bean yellow mosaic, clover yellow vein, and peanut mottle), but may not be used in all regions. Chemical control is moderately to highly important for 15 fungi, four bacteria, and five viruses, but by itself provides satisfactory control for only one fungal disease (seed decay) and one viral disease (bean curly dwarf mosaic). Specific biological control agents are not widely available for any bean pathogen.

Cultural practices

Cultural practices are essential to the management of most bean pathogens, including 25 fungi, eight viruses, and all bacteria, nematodes, and MLOs. In declining order of the number of diseases for which they are effective, cultural practices to control bean diseases take account of rotation, pathogen-free seed, weed control, tillage, multiple cropping, drainage, plant spacing, removal of bean debris, separation of crops, seeding date, soil fertility, soil organic matter, removal of volunteer bean plants, restricted movement in the field, soil temperature, harvest date, clean fallow, mulch, soil pH, plant architecture, flooding,

Table 1. Bean pathogens and diseases, and practices for their control

Pathogen	Disease	Control practices[†]
Fungi infecting roots and seeds		
Aphanomyces euteiches f. sp. *phaseoli*	aphanomyces root and hypocotyl rot	1,8,14,24
Thielaviopsis basicola	black root rot	1,2,8,14,21
Fusarium solani f. sp. *phaseoli*	fusarium root rot[‡]	1,6,8,9,10,13,14,17
Phymatotrichum omnivorum	phymatotrichum root rot	1,5,6,9,13,14,21,30
Pythium spp.	pythium seed decay, root rot[‡]	3,6,8,9,13,17
Rhizoctonia solani	rhizoctonia root rot[‡]	1,6,8,14,17,33
Sclerotium rolfsii	southern blight	1,2,3,4,5,6,8,9,13, 14,17,20,21
Fungi infecting shoots		
Alternaria spp.	alternaria leaf and pod spot	1,2,3,9,18,31
Phaeoisariopsis griseola	angular leaf spot	1,2,3,4,6,7,8,10,12
Colletotrichum lindemuthianum	anthracnose[‡]	1,2,3,4,7,12,16
Ascochyta spp.	ascochyta leaf spot	1,3,4,9
Macrophomina phaseolina	ashy stem blight	2,3,4,6,14,17
Cercospora spp.	cercospora leaf spot and blotch	1,2
Chaetoseptoria wellmanii	chaetoseptoria leaf spot	1,2
Phytophthora spp.	downy mildew	1,3,22
Entyloma sp.	entyloma leaf smut	1,3
Ramularia phaseoli	floury leaf spot	1,3
Fusarium oxysporum f. sp. *phaseoli*	fusarium yellows	1,2,3,6
Cercospora spp.	gray leaf spot	1,2,3
Botrytis cinerea	gray mold	1,2,5,6,9,13,18,22, 25,26,27
Phyllosticta phaseolina	phyllosticta leaf spot	1
Trichothecium roseum	pink pod rot	6,18
Erysiphe polygoni	powdery mildew	1,2,4,7
Uromyces appendiculatus	rust	1,2,3,7,9,10,12,15
Elsinoe spp.	scab	1,3,4,7
Sterile basidiomycete	stem rot	6
Thanatephorus cucumeris	web blight	1,4,5,6,7,9,10,20,22,29
Pseudocercosporella albida	white leaf spot	1,2,3
Sclerotinia sclerotiorum	white mold[‡]	1,2,3,4,6,7,8,9,10,13,18,
Bacteria		
Pseudomonas syringae pv. *syringae*	bacterial brown spot[‡]	1,3,5,10,15
Curtobacterium flaccumfaciens subsp. *flaccumfaciens*	bacterial wilt	1,3,4,5,10,15
Xanthomonas campestris pv. *phaseoli*	common bacterial blight[‡]	1,3,4,5,6,7,10,11,15,16
Pseudomonas syringae pv. *phaseoli*	halo blight[‡]	1,3,4,5,6,7,8,15,16
Nematodes		
Meloidogyne spp.	root knot	1,2,5,6,19,23,28
Pratylenchus spp.	root lesions	1,5,6,19,23,28
Viruses		
Alfalfa mosaic virus	alfalfa mosaic	4,11
Bean common mosaic virus	bean common mosaic	2,4,7,12
Quail pea mosaic virus-B	bean curly dwarf mosaic	2,3,11
Bean dwarf mosaic virus	bean dwarf mosaic	2,3,11,12
Bean golden mosaic virus	bean golden mosaic	3,5,11,12,20
Bean mild mosaic virus	bean mild mosaic	3
Bean pod mottle virus	bean pod mottle	2,5,11,32
Bean rugose mosaic virus	bean rugose mosaic	2,7
Bean yellow mosaic virus	bean yellow mosaic	2
Clover yellow vein virus	clover yellow vein	2,4,5
Cucumber mosaic virus	cucumber mosaic	1,4,5,12
Beet curly top virus	curly top	2,3,5,11
Peanut mottle virus	peanut mottle	2,11
Southern bean mosaic virus	southern bean mosaic	2,7
Mycoplasmalike organisms		
MLO	machismo	1,5,11.12,2

[†]Control practices listed in Table 2. Information from Hall (1991), Palti (1981), Schwartz & Pastor-Corrales (1989), Thurston (1992).
[‡]Major disease of white bean in Ontario.

Table 2. Number of fungal, bacterial, nematode, viral, and MLO diseases of common bean for which genetic resistance, chemicals, or cultural practices are currently important components of disease control and primary target of control practice

		Pathogen						Primary target		
	Practice	Fungus	Bacterium	Nematode	Virus	MLO	Total	Pathogen	Plant	Environment
1	Rotation	25	4	2	1	1	33	+	+	+
2	Resistance	14	0	1	10	0	25	–	+	–
3	Chemical	15	4	0	5	0	24	+	+	+
4	Pathogen-free seed	9	4	0	4	0	17	+	–	–
5	Weed control	4	4	2	5	1	16	+	+	+
6	Tillage	12	2	2	0	0	16	+	+	+
7	Multiple cropping	7	2	0	3	0	12	+	+	+
8	Drainage	10	0	0	0	0	10	+	+	+
9	Plant spacing	9	0	0	0	0	9	+	+	+
10	Bean debris	5	4	0	0	0	9	+	–	–
11	Crop separation	0	1	0	7	1	9	+	–	–
12	Seeding date	3	0	0	4	1	8	+	+	+
13	Soil fertility	6	0	0	0	0	6	+	+	+
14	Soil organic matter	6	0	0	0	0	6	+	+	+
15	Volunteer bean	1	4	0	0	0	5	+	–	–
16	Movement in field	1	4	0	0	0	5	+	–	–
17	Soil temperature	5	0	0	0	0	5	+	+	+
18	Harvest date	4	0	0	0	0	4	+	+	+
19	Clean fallow	1	0	2	0	0	3	+	–	+
20	Mulch	2	0	0	1	0	3	+	+	+
21	Soil pH	3	0	0	0	0	3	+	+	+
22	Plant architecture	3	0	0	0	0	3	+	+	+
23	Flooding	1	0	2	0	0	3	+	+	+
24	Soil test	2	0	0	0	0	2	+	–	–
25	Row direction	2	0	0	0	0	2	+	+	+
26	Irrigation	2	0	0	0	0	2	+	+	+
27	Storage	2	0	0	0	0	2	+	+	+
28	Cover crop	0	0	2	0	0	2	+	+	+
29	Roguing	1	0	0	0	1	2	+	–	–
30	Barrier	1	0	0	0	0	1	+	–	–
31	Seed moisture	1	0	0	0	0	1	+	–	–
32	Trap crop	0	0	0	1	0	1	+	–	–
33	Seeding depth	1	0	0	0	0	1	+	+	+

Information from Hall (1991), Palti (1981), Schwartz & Pastor-Corrales (1989), Thurston (1992).

soil test, row direction, irrigation, storage conditions, cover crops, roguing, barriers, seed moisture, trap crops, and seeding depth (Table 2). In this review we consider how these factors, individually or in concert, contribute to the control of bean diseases. The practices are considered in an order that reflects the series of decisions made by a grower before, during, and after crop growth.

Crop rotation. Robertson and Frazier (1978) emphasized the importance of an organized cropping system for bean production. It has been suggested that beans should not be grown more than once in three years (Palti 1981). One reason for this view is that crop rotation is the most powerful and the most frequently recommended cultural practice for controlling bean diseases. It is moderately to highly effective for 33 of 50 bean diseases, including most diseases caused by fungi, all caused by nematodes and bacteria, and "machismo" caused by an MLO. Apart from cucumber mosaic, it has not been recommended for viral diseases. Nor has it been specifically recommended to control *Pythium* spp., *Macrophomina phaseolina*, *Trichothecium roseum*, and a sterile basidiomycete causing stem rot. The first three fungi have wide host ranges and the fourth is not well understood.

Rotation affects plant disease by its impact on pathogen populations in a field and on a broad range of biological, chemical, and physical characteristics of soil (Palti 1981). Effects of rotation on pathogen populations in a field can be taken as an example. Rotation is highly effective in reducing populations in soil of specialized pathogens of bean such as *Fusarium solani* f. sp. *phaseoli* (Hall & Phillips 1992) and is therefore recommended to control fusarium root rot. However, the population density of this pathogen can be maintained at low levels in the rhizosphere of nonsusceptible crops such as tomato, lettuce, and corn (Schroth & Hendrix 1962). Similarly, populations of *F. oxysporum* f. sp. *phaseoli* can be maintained in soil by the symptomless host sweet potato (Hendrix & Nielsen 1958). Rotation has also been recommended to control unspecialized pathogens such as *Sclerotinia sclerotiorum* and *Botrytis cinerea*. The effectiveness of rotation suggests that it reduces the population density of some unspecialized pathogens in the field and that disease produced by these pathogens can result largely from inoculum produced within the field. Evidence for the importance of locally produced inoculum by unspecialized pathogens has been presented for white mold (Boland & Hall 1988). Rotation can therefore be used to manage populations of specialized and unspecialized pathogens in a field. A wide range of symptomatic and nonsymptomatic hosts, while favouring the presence of the pathogen in the field, does not necessarily preclude the use of rotation.

Cover crop. Rotation with antagonistic crops such as marigold (*Tagetes* spp.) and other members of the Compositae is recommended to control nematodes and is currently under active investigation (Potter & Olthof 1993). The mechanisms are not well understood but may involve the release of toxic chemicals from the roots of the cover crop.

Soil test. Testing soil before seeding for its root rot potential has been recommended for root rot caused by *Aphanomyces euteiches* f. sp. *phaseoli* (Kobriger & Hagedorn 1983) and *F. solani* f. sp. *phaseoli* (McFadden et al. 1989) and would probably be useful for root rots caused by other fungi such as *Rhizoctonia solani*, *Thielaviopsis basicola*, and *Pythium* spp. The root rot potential of a field can be estimated from the severity of root rot in plants grown in samples of the soil in a controlled environment or from the density of pathogen populations in the soil. Soils suppressive to fusarium wilt caused by *F. oxysporum* f. sp. *phaseoli* have been described (Burke 1965, Furuya et al. 1979).

Soil pH. The optimum pH range for bean productivity is 6.5–7.0 (Robertson & Frazier 1978). Highly acid soils, commonly found in tropical and subtropical areas, lead to sulphur and phosphorus deficiency, and aluminum and manganese toxicity, and should be limed before bean production. Acid soils also favour southern blight; the optimum pH range for germination of sclerotia of *Sclerotium rolfsii* is 2.6–4.4 (Coley-Smith & Cooke 1971). On the other hand, pH levels above neutrality favour black root rot and phymatotrichum root rot.

Soil fertility. Adequate and balanced soil fertility is important to obtain optimum bean yields but diseases differ in their response to added fertilizer. Addition of nitrogen fertilizer has been recommended to stimulate plant growth when productivity has been diminished by root rots but excessive nitrogenous fertilizer increases the severity of gray mold and white mold. Ammonium nitrogen is recommended to control phymatotrichum root rot but increases fusarium root rot (Snyder et al. 1959) and fusarium wilt (Huber & Watson 1970). Early application of nitrogen tends to increase damage from bean fly and this in turn increases the severity of fusarium root rot (Letourneau & Msuku 1992). Specific diseases may be managed by specific fertility regimes but moderate use of nitrogen fertilizer seems to be appropriate where no disease is of major concern.

Soil temperature. Cool soils (10–20°C) favour seed decay, root rot, and stem rot caused by *R. solani*, *F. solani* f. sp. *phaseoli*, and certain species of *Pythium* (e.g. *P. ultimum*) whereas warm soils (25–30°C) favour diseases caused by other species of *Pythium* (e.g. *P. myriotylum*) and southern blight caused by *S. rolfsii*. In the Cerrados (savanna) region of Brazil, fusarium wilt is an increasing problem in warmer areas at elevations of 450–800 m under centre pivot irrigation, where extensive losses have occurred after only two crops of beans (L. Nasser, pers. obs.). Planting into soils at a temperature of 18°C is recommended for navy beans (Robertson & Frazier 1978). Sanitization of soil by solarization (50°C) has been suggested to control root rots, although exposure to even lower temperatures (30°C) may limit ashy stem blight by reducing the number of sclerotia of *M. phaseolina*.

Soil moisture. Flooding the soil for 1–2 weeks before planting reduces populations of nematodes and of sclerotia of *Sclerotinia sclerotiorum*, cause of white mold. However, excess soil moisture during crop growth often favours disease. Drainage of soil is recommended for bean production (Robertson & Frazier 1978) and is highly effective in disease management. For example, high soil moisture (0 to -5 kPa) favours pythium and fusarium root rots in short term experiments in controlled environments (Pieczarka & Abawi 1978, Sippell & Hall 1982), and flooding or high soil moisture during crop growth increases the severity of fusarium root rot (Miller & Burke 1977). However, fusarium root rot reduces bean yields more in a dry year than in a wet year (Burkholder 1919). High soil moisture increases several diseases of the shoot, such as angular leaf spot, gray mold, and white mold, possibly by increasing the duration of surface wetness periods. High soil moisture also favours white mold by stimulating carpogenic germination of sclerotia of *S. sclerotiorum* (Teo & Morrall 1985). Moderate levels of soil moisture near field capacity, achieved through drainage and careful irrigation, are most suitable for bean growth and health.

Soil organic matter. High levels of organic matter in the soil are desirable for bean production (Robertson & Frazier 1978) and are specifically recommended to control seven fungal diseases, viz. ashy stem blight and six root diseases. High levels of organic matter in the soil improve physical and chemical conditions for root growth, and therefore increase the resistance of roots to disease or help to compensate for the destructive effects of disease. They may also facilitate natural biological control through increased microbial activity in soil. However, raising the organic level of aerated mineral soils is difficult and is achieved usually through crop sequence and green manure crops. Addition of mature residues of plants to soil can also reduce some bean diseases. Mature residues of alfalfa, corn, and oat, and of buckwheat, oat, rye, and sorghum reduced the severity of root rots caused by *T. basicola* and *F. solani* f. sp. *phaseoli*, respectively (Lewis & Papavizas 1975). Residues that reduced disease also lowered population densities of the pathogens in soil. The mechanism of these effects is not clear, although effective residues often produced high C/N ratios in the soil.

Tillage. Tillage has been recommended to "loosen a compacted soil, kill weeds, incorporate fertilizer, lime, manure or crop residues, reduce insects and diseases, control soil erosion, mix pesticides with soil or prepare for harvest by ridging the rows" (Robertson & Frazier 1978). Tillage is specifically recommended to control root knot nematodes, two bacterial diseases, and 12 fungal diseases, including five of the roots and seven of the shoot. It could increase plant health by stimulating root growth, by increasing the resistance of roots to pathogens, or by decreasing pathogen populations or inoculum production in soil. Chisel plowing can relieve soil compaction, a major environmental factor contributing to fusarium root rot (Burke & Miller 1983), and possibly other root diseases. Plowing is a convenient way to eliminate bean debris, a practice recommended to control five fungal and four bacterial diseases. However, there are conflicts to be resolved in using tillage. For example, mounding tilled soil around stems compensates for fusarium root rot but increases southern blight.

Clean fallow. Clean fallow removes alternative hosts of bean pathogens and has been recommended in particular to control phymatotrichum root rot and nematodes. It no doubt would be effective for many bean diseases caused by nonhost-specific pathogens.

Pathogen-free seed. Palti (1981) noted that 26 fungi, six bacteria, and 10 viruses pathogenic to bean are transmitted by bean seed. Planting pathogen-free seed is recommended for nine fungal, four bacterial, and four viral diseases (Hall 1991, Schwartz & Pastor-Corrales 1989). It is the major approach to controlling bacterial diseases and is routinely used to control common and fuscous bacterial blights (Webster et al. 1983).

Seeding date. Adjustment of seeding dates to avoid coincidence of susceptible plants and vectors is recommended for four viral and one MLO disease. For example, sowing late in the dry season in Brazil can reduce bean golden mosaic by allowing plants to emerge in cool weather when populations of the white fly vector are low (Costa 1975). However, recent expansion of soybean production has increased the population densities of white fly vectors and bean golden mosaic has caused losses of up to 90% in bean production despite the use of insecticides and cultural practices (L. Nasser pers. obs.). Seeding dates that reduce exposure of plants to cool temperatures and long wetness periods are advised to control rust and bacterial diseases. Delayed seeding in temperate areas increases the severity of white mold (Mwiindilila 1991). Seeding date also affects soil temperature and therefore the speed of emergence and vigour of plants.

Seeding depth. Beans should normally be planted 5 cm deep in moist soil (Robertson & Frazier 1978). However, the appropriate depth of seeding depends on soil moisture and temperature. In moist, cool soil, shallower seeding is recommended to control rhizoctonia root rot. The depth selected should provide the seed with suitable conditions of moisture and temperature, and optimize disease control and rapidity of emergence.

Plant architecture. Plant architecture can facilitate disease avoidance. Upright architecture, open canopy, and pods borne away from the soil are plant characteristics recommended specifically to control downy mildew, gray mold, web blight, and white mold and would be appropriate for many other diseases of the shoot. These features might shorten periods of surface wetness, lower relative humidity, limit high tissue moisture content in the canopy, and restrict contact of aerial organs with inoculum in the soil.

Row direction. Rows planted parallel to the direction of prevailing winds develop less white mold (Haas & Bolwyn 1972), possibly because of the drying action of the wind on the canopy and soil. The practice is recommended in some areas to control white mold and gray mold.

Plant spacing. Beans are commonly grown in rows spaced 15 to 75 cm apart. Effects of row spacing on yield are inconsistent (Robertson & Frazier 1978), but wide spacing between plants in a row or between rows is recommended for the control of nine fungal diseases. Close spacing of plants in the row favours fusarium root rot, pythium root rot, and southern blight, whereas narrow spacing between rows favours alternaria leaf and pod spot, ascochyta leaf spot, gray mold, rust, web blight, and white mold. In general, bean plant health is promoted by maximum spacing between plants.

Multiple cropping. Multiple cropping is widely used in bean production in tropical and subtropical areas (Thurston 1992) but its effects on bean diseases are not extensively documented. Intercropping of bean with corn helps to control web blight, presumably because corn is not a preferred host of the pathogen *Thanatephorus cucumeris*. Corn may restrict or promote development of populations of chrysomelid beetles, and thereby suppress or exacerbate beetle-transmitted virus diseases such as bean rugose mosaic and southern bean mosaic. Van Rheenen et al. (1981) reported that bean grown in association with corn generally showed lower incidences of anthracnose, scab, ascochyta leaf spot, powdery mildew, common blight, halo blight, and bean common mosaic. Effects on angular leaf spot are variable (Boudreau 1993, Van Rheenan et al. 1981).

Weed control. Suppression of weeds has been considered vital for bean production (Robertson & Frazier 1978) and is recommended for the control of four fungi, four bacteria, root knot and lesion nematodes, five viruses, and one MLO. Weeds act as hosts for bean pathogens or their vectors. They might also favour infection by fungi and bacteria by altering the microclimate of the canopy, and by providing sources of nutrient such as pollen and senescent plant parts.

Mulch. A coconut mulch reduced southern blight and increased yield but the mechanism is not clear. Web blight has been reduced in Costa Rica by applying herbicides to weeds and allowing the weed debris to remain in place. This practice may be effective by restricting formation of basidiospores of *T. cucumeris* or their dissemination to the plant. A coloured mulch was found experimentally to protect plants from bean golden mosaic by repelling whiteflies, but the procedure is probably not practical.

Volunteer bean. Volunteer bean plants could serve as a source of all bean pathogens. Their elimination is specifically recommended for control of rust and the bacterial pathogens.

Roguing. Removal of symptomatic crop plants is effective when it eliminates a major source of inoculum early in the development of an epidemic. In the bean crop, it has been recommended for the control of an MLO disease ("machismo"). It would also be useful in the production of seed free from fungal and bacterial pathogens.

Irrigation. Irrigation can affect root diseases through effects on soil moisture discussed above. In addition, it influences diseases of the shoot by conditioning surface wetness duration and relative humidity in the canopy. Irrigation water can also spread pathogens that cause halo blight (Walker & Patel 1964), common bacterial blight (Steadman et al. 1975), and white mold (Steadman 1983). In the Cerrados region of Brazil it has been observed that frequent light irrigation favours rust, angular leaf spot, and anthracnose whereas infrequent heavy irrigation favours rhizoctonia root rot, white mold, gray mold, pythium seed decay, and common bacterial blight (L. Nasser pers. obs.). Accurate use of surface or overhead irrigation is therefore recommended.

Barrier. Barriers to prevent the growth or movement of a pathogen are not commonly used to manage bean diseases. They have been recommended, in the form of a ditch or rows of monocotyledons, to limit the growth of rhizomorph-like strands of *Phymatotrichum omnivorum* through soil and thus suppress the spread of phymatotrichum root rot from infested areas.

Crop separation. Separation of bean from bean or other hosts of bean pathogens has been suggested for the control of common bacterial blight, seven viruses, and one MLO. In particular, bean fields dedicated to the production of pathogen-free seed should be separated from other bean crops. Separation limits the exposure of the bean crop to airborne bacterial pathogens, and to insect vectors of viruses and MLOs. The practice is logical wherever a crop serves as a major source of bean pathogens.

Trap crop. Overwintered insect vectors attracted to beans sown early along the edge of the field can be destroyed before the main crop is planted. This technique has been suggested as a means of eliminating the beetles that vector bean pod mottle virus, but it is not vital because the virus is controlled effectively by high levels of resistance in the plant. The practice might be useful for diseases such as bean mild mosaic where effective control depends on suppression of beetle populations.

Movement in the field. Limiting or avoiding movement of people, machinery, and animals through the growing crop, particularly when it is wet, restricts the mechanical dissemination of inoculum and is specifically recommended to control anthracnose and bacterial diseases.

Harvest date and storage temperature. Timely harvest is advisable as a general practice and is specifically recommended to control alternaria leaf and pod spot, gray mold, pink pod rot, and white mold. These are fungal diseases of the pod or seed that are favoured by cool, moist weather and often develop rapidly late in crop maturation. Timely harvest reduces the period during which the plant is exposed to inoculum and to environmental conditions favourable for disease development. Harvesting at 18% seed moisture is recommended to restrict colonization of seed of dry bean by species of *Alternaria*. Harvesting green beans at the earliest opportunity and storing them immediately at 7–10°C is an effective cultural means of controlling gray mold and white mold.

Precepts

A major challenge facing agriculture is to develop technologies that will permit a sustainable increase in the productivity of cropland (Postel 1994). Sustainable agriculture will increasingly depend on the development of cultural practices that focus on resource conservation, and provide stability and flexibility through diverse technologies. The identification of principles of cultural control of plant diseases will aid in the discovery and development of environmentally sound cultural practices to manage bean diseases.

Production practices. Cultural practices effective in disease mangement evolve partly from existing production practices. Systems of cropping, tillage, plant nutrition, water management, row width, plant spacing, planting depth, seed quality, varietal selection, weed and insect control, and harvesting and storage practices affect general aspects of production of dry bean (Robertson & Frazier 1978) and also contribute to disease management (Table 2).

Changes in production objectives influence cultural control of plant disease. For example, increased emphasis on soil conservation will force re-examination of tillage as a disease control practice. Indeed, conservation tillage may contribute to disease control in bean, as shown by the following experiences in Brazil. White mold was introduced into the Brazilian savanna in the early 1980s. With the adoption of overhead irrigation, mainly through centre pivots, farmers began to grow dry bean, pea, and tomato in winter (April–September) and soybean in summer (October–March). As a consequence, residues of soybean infested by *S. sclerotiorum* acted as a source of inoculum for other crops. Losses up to 70% were observed in dry bean crops. However, a decline in the incidence of white mold in dry bean grown under zero tillage was observed in areas that had previously been sown to upland rice in the summer. The soil in zero-till fields was covered by a layer of rice residue 3–5 cm thick that appeared to blanket sclerotia of the pathogen and prevent emergence of apothecia. Dry bean crops in nearby fields under conventional tillage continued to suffer high losses from white mold. The combination of zero till and accumulation of an organic mulch on the soil surface appears to have led to a reduction in the severity of white mold despite the continued production of susceptible crops under overhead irrigation (Nasser & Sutton 1993).

Pathosystem. Some cultural practices are specifically designed to manage disease and are developed from an understanding of the pathosystem, and a recognition that plant disease results from the interaction of a pathogen with a plant under the influence of chemical, physical, and biological components of the environment. A fundamental principle therefore is that cultural practices should target one or more components of the pathosystem.

The targets may be primary or secondary. The primary target is the target at which the practice is directed. For example, the primary targets of genetic resistance and chemical control are the plant and the pathogen, respectively. Secondary targets are those affected by a strike on the primary target. For example, the pathogen, by experiencing a population decline, becomes a secondary target of genetic resistance. A personal assessment of the primary targets of practices used to control bean diseases is provided in Table 2. The environment can influence disease only by affecting the plant, the pathogen, or both. Therefore, the plant or the pathogen is also listed as a primary target wherever the environment is considered to be a primary target.

According to this analysis, 32 practices target the pathogen (the only exception is genetic resistance in the plant), 22 target the plant, 22 target the environment, and 21 target all three components of the disease triangle. Most cultural practices used to control bean diseases manipulate inoculum and many modulate the environment. Altered environments generally affect both the plant and the pathogen. Most practices that affect the plant, such as rotation, tillage, and drainage, do so by altering the environment. Only a few cultural practices, principally weed control, multiple cropping, plant spacing, plant architecture, and seeding depth, affect the plant directly. Management of inoculum and regulation of the environment are widely recognized as key strategies in cultural control of bean diseases. Less is known about how cultural practices affect receptivity of the plant to the pathogen or biological control exerted by other organisms. The disease triangle reminds us to consider the plant and the biological community in our attempts to explain or devise cultural controls. Environmental effects on the susceptibility of the plant are not well documented and are particularly worthy of further investigation.

Comparisons. The development of new disease management strategies and tactics for the bean crop can be guided by noting gaps in the present list of practices. For example, the list for the bean crop (Table 2) does not include many cultural practices identified by Palti (1981), such as burning, shade, multistory cropping, raised beds, and production on hillsides exposed to the morning sun. A systematic comparison of methods recommended for the bean crop with those recommended for plants in general may reveal further practices potentially useful for disease management in bean.

Comparison of cultural practices used for different pathogens may also generate new ideas. Of the 31 cultural practices identified in Table 2, 28 are used for fungi, 10 for bacteria, seven for nematodes, 10 for viruses, and five for MLO. Fifteen practices appear to be unique to fungi and one to nematodes. In some cases, this apparent uniqueness may reflect the limitations of the source literature. For example, none of the four sources used specifically mentioned irrigation management or roguing to control bacterial diseases. However, for the most part, Table 2 provides a structure facilitating the transfer of ideas from one group of pathogens to another. For example, cover crops are recommended only to control nematodes. Since cover crops contribute to the control of fungal pathogens in other crops, such as *Verticillium dahliae* in potato (Powelson & Rowe 1993), their effectiveness for controlling fungal pathogens of bean should be examined. Table 2 may also help to focus attention on the need for additional epidemiological information. Crop separation was recognized as extremely important in managing viral and bacterial diseases but was not mentioned for fungal diseases, many of which are also caused by propagules dispersed through the air. Comparative studies on aerial dissemination of viral, bacterial, and fungal pathogens of bean would be revealing.

Location. The cultural practices adopted and their relative importance vary with location. The protection of the white bean crop in Ontario can be taken as an example (Fig. 1). The major infectious diseases of the crop are anthracnose, white mold, root rots caused by species of *Pythium*, *Fusarium*, and *Rhizoctonia*, common bacterial blight, halo blight, and bacterial brown spot (Tu 1984, Tu & Dhanvantari 1994). Of the 16 cultivars of white bean recommended for use in Ontario in 1994, 16 were resistant to race 1 of bean common mosaic virus, 15 were resistant to race 15 of the virus, 11 were resistant to the alpha race of anthracnose, and 8 were

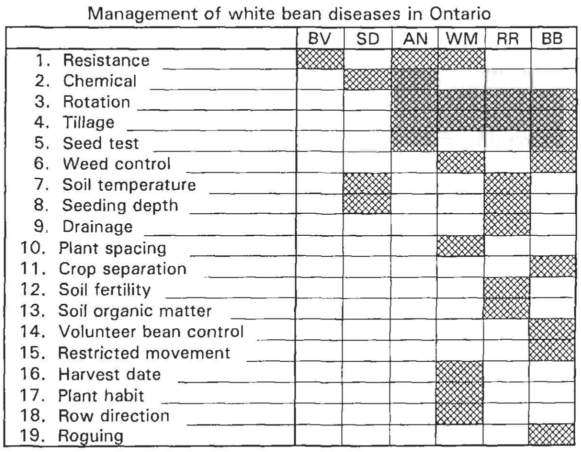

Figure 1. Management of white bean diseases in Ontario. Diseases: BV = bean common mosaic, SD = seed decay, AN = anthracnose, WM = white mold, RR = root rot, BB = bacterial blights. Management practices are listed on the left and their application to each disease is indicated by cross-hatching. (Information from Tu & Dhanvantari 1994).

resistant to the delta race. Susceptibility (per cent symptomatic plants) to white mold ranged from 10 to 56 (Gillard 1994). Pesticides are rarely used for disease control, except for the application of fungicides to seeds to control anthracnose and seed decay. Cultural practices are essential to the control of white mold, root rots, and bacterial diseases. Cultural practices used to manage diseases of white bean in Ontario include rotation (all major diseases), pathogen-free seed (anthracnose and bacterial diseases), weed control (white mold and bacterial diseases), tillage (hilling and chisel plowing for root rots, and plowing-in of bean refuse for anthracnose, white mold, and bacterial diseases), drainage (root rots), wide plant spacing (white mold), crop separation (bacterial diseases), fertile soils (root rots), high soil organic matter (root rots), control of volunteer bean plants (bacterial diseases), restricted movement in fields (bacterial diseases), warm soil at planting (seed decay and root rots), timely harvest (white mold), upright plant architecture (white mold), rows parallel to the wind (white mold), roguing (bacterial diseases), and appropriate seeding depth (seed decay, root rots). Thus, at least 17 kinds of cultural practices can be identified as important to the management of diseases of white bean in Ontario. The absence of effective disease resistance or chemical treatments renders cultural controls absolutely essential to the management of root rots and bacterial diseases, and vital to the control of anthracnose and white mold.

Integration. The control of many bean diseases relies on the use of several technologies (Table 1). Occasionally, a single cultural practice is highly effective, such as the use of pathogen-free seed to control bacterial blights. For most diseases, however, a suite of cultural practices is required. Cultural practices remain important even where genetic resistance or chemical control provide satisfactory disease control alone. A genetic change in the pathogen population can enable it to circumvent control based on a single practice. For example, anthracnose of white bean has been controlled effectively in Ontario for many years by genetic resistance. In 1993, a new race of *Colletotrichum lindemuthianum* appeared that was virulent to all cultivars of white bean recommended for use in the province. To combat the new race, a set of practices including fungicide seed treatment, rotation, tillage, and seed testing was recommended (Tu & Dhanvantari 1994).

Conclusion

Our review of the literature revealed relatively few examples of conflicting considerations in the selection of cultural practices for control of bean diseases. Fertility and irrigation management present problems but careful use of the information available provides the best approach to disease control. Tillage usually is considered to assist disease management, except for a reported increase in southern blight following mounding of soil around stems.

A generalized set of cultural practices for control of bean diseases can therefore be given, with the caveat that any of these practices may not apply to particular circumstances. Grow bean in rotation with other crops in soil of moderate and balanced fertility at pH 6.5–7.0. The soil should contain adequate levels of organic matter, and be well structured and friable. Tillage is widely recommended to prepare a seed bed, loosen compacted soil, control weeds, and bury infested crop debris, but may be less necessary than thought for disease control. Test soil for root rot potential and seed for freedom from major pathogens where necessary. Plant seed at a depth of 5 cm into moderately moist soil (field capacity) at 18°C. Adjust the date of seeding to favour early establishment of the crop, to escape insect vectors of viruses and MLOs, to avoid weather favourable to disease development, and to permit reproductive development of the crop during favourable weather. Choose the growth habit of the plant appropriate to reduce disease severity. Space plants widely in the row and between rows, and plant rows parallel to the direction of prevailing winds. Use overhead or furrow irrigation judiciously. Practice multiple cropping where appropriate. Use barriers, separation of crops, and an organic mulch on the soil surface to restrict pathogen development or dissemination. Control weeds and volunteer bean plants, and rogue infected bean plants to reduce pathogen or insect vector populations. Restrict movement through the growing crop. Harvest dry and green beans on time, and cool and market green beans rapidly.

Cultural practices are essential to the control of 80% of bean diseases and contribute to the control of all diseases of the crop. The 31 groups of cultural practices we identified is a gross simplification of the vast number of cultural practices available. This diversity of practices provides effective, stable, flexible, and adaptable disease management. Cultural management of diseases is a key component of sustainable bean productivity and health.

Preparation of this review was supported financially by the Natural Sciences and Engineering Research Council of Canada, the Ontario Ministry of Agriculture, Food and Rural Affairs, and the Brazilian Ministry of Agriculture — EMBRAPA, CPAC.

Boland, G.J., and **R. Hall.** 1988. Numbers and distribution of apothecia of *Sclerotinia sclerotiorum* in relation to white mold of white bean (*Phaseolus vulgaris*). Can. J. Bot. 66:247–252.

Boudreau, M.A. 1993. Effect of intercropping beans with maize on the severity of angular leaf spot of beans in Kenya. Plant Pathol. 42:16–25.

Burke, D.W. 1965. Fusarium root rot of beans and behavior of the pathogen in different soils. Phytopathology 55:1122–1126.

Burke, D.W., and **D.E. Miller.** 1983. Control of Fusarium root rot with resistant beans and cultural management. Plant Dis. 67:1312–1317.

Burkholder, W.H. 1919. The dry root-rot of the bean. Cornell Univ. Agric. Exp. Stn. Mem. 26:999–1033.

Coley-Smith, J.R., and **R.C. Cooke.** 1971. Survival and germination of fungal sclerotia. Annu. Rev. Phytopathol. 9:65–92.

Costa, A.S. 1975. Increase in the populational density of *Bemisia tabaci*, a threat of widespread virus infection of legume crops in Brazil. Pages 27–50 *in* J. Bird and K. Maramorosch, eds., Tropical Diseases of Legumes, Academic Press, New York. 171 pp.

Furuya, H., **M. Owada**, and **T. Ui.** 1979. A suppressive soil of common bean rot in Kitami District, Hokkaido. Ann. Phytopathol. Soc. Japan 45:608–617.

Gillard, C.L. 1994. White bean varieties for 1994, what's hot and what's not. The Emerging Bean, Spring 1994:9–11.

Haas, J.H., and **B. Bolwyn.** 1972. Ecology and epidemiology of sclerotinia wilt of white beans in Ontario. Can. J. Plant Sci. 52:525–533.

Hall, R. (ed.). 1991. Compendium of Bean Diseases. APS Press, St Paul, MN. 73 pp.

Hall, R., and **L.G. Phillips.** 1992. Effects of crop sequence and rainfall on population dynamics of *Fusarium solani* f.sp. *phaseoli* in soil. Can. J. Bot. 70:2005–2008.

Hendrix, F.F., and **L.W. Nielsen.** 1958. Invasion and infection of crops other than the forma suscept by *Fusarium oxysporum* f. *batata* and other formae. Phytopathology 48:224–228.

Huber, D.M., and **R.D. Watson.** 1970. Effect of organic amendment on soil-borne plant pathogens. Phytopathology 60:22–26.

Kobriger, K.M., and **D.J. Hagedorn.** 1983. Determination of bean root rot potential in vegetable production fields of Wisconsin's Central Sands. Plant Dis. 67:177–178.

Letourneau, D.K., and **W.A.B. Msuku.** 1992. Enhanced *Fusarium solani* f. sp. *phaseoli* infection by bean fly in Malaŵi. Plant Dis. 76:1253–1255.

Lewis, J.A., and **G.C. Papavizas.** 1975. Survival and multiplication of soil-borne plant pathogens as affected by plant tissue amendments. Pages 84–89 *in* G. Bruehl, ed., Biology and Control of Soil-Borne Plant Pathogens, American Phytopathological Society, St. Paul, Minnesota. 216 pp.

McFadden, W., **R. Hall**, and **L.G. Phillips.** 1989. Relation of initial inoculum density to severity of fusarium root rot of white bean in commercial fields. Can. J. Plant Pathol. 11:122–126.

Miller, D.E., and **D.W. Burke.** 1977. Effect of temporary excessive wetting on aeration and Fusarium root rot of beans. Plant Dis. 61:175–179.

Mwiindilila, C.N. 1991. Epidemiology and prediction of white mold in common bean. Ph.D. thesis, University of Guelph, Guelph, Ontario, Canada. 182 pp.

Nasser, L.C.B., and **J.C. Sutton.** 1993. Palhada de arroz pode controlar importante doença do feijoeiro irrigado (Rice residue may control an important disease: white mold on dry beans under centre pivot irrigation). Cerrados Pesquisa & Tecnologia 3(1):6. (Original in Portuguese).

Palti, J. 1981. Cultural Practices and Infectious Crop Diseases. Springer-Verlag, New York. 243 pp.

Pieczarka, D.J., and **G.S. Abawi.** 1978. Influence of soil water potential and temperature on severity of Pythium root rot of snap beans. Phytopathology 68:766–772.

Postel, S. 1994. Carrying capacity: earth's bottom line. Pages 3–21 *in* L.R. Brown, ed., State of the World 1994. Worldwatch Institute Report, W.W. Norton and Co., New York. 265 pp.

Potter, J.W., and **T.H.A. Olthof.** 1993. Nematode pests of vegetable crops. Pages 171–207 *in* K. Evans, D.L. Trudgill, and J.M. Webster, eds., Plant Parasitic Nematodes in Temperate Agriculture. CAB International, Oxford. 648 pp.

Powelson, M.L., and **R.C. Rowe.** 1993. Biology and management of early dying of potatoes. Annu. Rev. Phytopathol. 31:111–126.

Robertson, L.S., and **R.D. Frazier.** 1978. Dry Bean Production — Principles and Practices. Extension Bulletin E-1251, Michigan State University, East Lansing. 225 pp.

Schroth, M.N., and **F.F. Hendrix.** 1962. Influence of non-susceptible plants on the survival of *Fusarium solani* f. sp. *phaseoli* in soil. Phytopathology 52:906–909.

Schwartz, H.F., and **M.A. Pastor-Corrales.** (eds.). 1989. Bean Production Problems in the Tropics. Second edition. CIAT, Cali, Colombia. 726 pp.

Sippell, D.W., and **R. Hall.** 1982. Effects of pathogen species, inoculum concentration, temperature, and soil moisture on bean root rot and plant growth. Can. J. Plant Pathol. 4:1–7.

Snyder, W.C., M.N. Schroth, and **T. Christou.** 1959. Effect of plant residue on root rot of bean. Phytopathology 49:755–756.

Steadman, J.R. 1983. White mold — A serious yield-limiting disease of bean. Plant Dis. 67:346–350.

Steadman, J.R., C.R. Maier, H.F. Schwartz, and **E.D. Kerr.** 1975. Pollution of surface irrigation waters by plant pathogenic organisms. Water Resour. Bull. 11:796–804.

Teo, B.K., and **R.A.A. Morrall.** 1985. Influence of matric potentials on carpogenic germination of sclerotia of *Sclerotinia sclerotiorum*. II. A comparison of results obtained with different techniques. Can. J. Plant Pathol. 7:365–369.

Thurston, H.D. 1992. Sustainable Practices for Plant Disease Management in Traditional Farming Systems. Westview Press, San Francisco. 279 pp.

Tu, J.C. 1984. Bean Diseases and Their Control. Publication 1758/E, Agriculture Canada, Ottawa. 36 pp.

Tu, J.C., and **B.N. Dhanvantari.** 1994. Dry bean diseases to watch for in 1994. The Emerging Bean, Spring 1994:18–21.

Van Rheenen, H.A., O.E. Hasselbach, and **S.G.S. Muigai.** 1981. The effect of growing beans together with maize on the incidence of bean diseases and pests. Neth. J. Plant Pathol. 87:193–199.

Walker, J.C., and **P.N. Patel.** 1964. Splash dispersal and wind as factors in epidemiology of halo blight of beans. Phytopathology 54:140–141.

Webster, D.M., J.D. Atkin, and **J.E. Cross.** 1983. Bacterial blights of snap beans and their control. Plant Dis. 67:935–940.