Commercial Dry Bean Production in Western Washington State

WASHINGTON STATE UNIVERSITY EXTENSION • EM092E

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Crop at a Glance

Growing season: Summer

Time of planting: May 15–June 1

Spacing: Plant seeds 2–4 inches apart in the row; space rows 18–36 inches apart; plant from 19–244 lb/acre depending on seed weight and target plants per acre.

Days to harvest: 100–120

Average yield: 1,900 lb per acre

Introduction

This publication provides an overview of bean production in western Washington, including marketing, variety selection, crop management, and production methods appropriate for small- and mid-scale production of bush-type dry beans, which are well suited to mechanical cultivation and harvest.

Production Overview

Pulse crops (which include dry beans, dry peas, lentils, and garbanzo beans or chickpeas) are grown on 115,000 acres in Washington State. About 20% (23,000 acres) of Washington's pulse acreage is dry beans, and the remaining 80% is garbanzo beans (Mertz 2013). Nationally, Washington is ranked 7th in production of pulse crops (USDA ERS 2012). Pinto is the largest dry bean market class grown in Washington, accounting for 10,600 acres (Mertz 2013). Washington is also a major bean-seed-producing state, with 9,516 acres of certified dry bean seed production in 2014 (WSDA 2014). Commodity bean and seed production occurs almost exclusively east of the Cascade Mountains; however, interest in locally produced staple crops is driving demand for dry bean production in western Washington.

Marketing

Demand for regionally produced staple crops has created an opportunity for direct marketing of dry beans. Dry beans can be easily stored for long periods of time, allowing growers to diversify the crops they have for sale during the winter. Price varies greatly depending on the market outlet; however, specialty dry beans can retail for $2 to $6 per pound. Dry beans can be sold at farmers markets, as part of Community Supported Agriculture shares, and to restaurants or regional distributors. Dry beans are a healthy food choice as they are an excellent source of plant-based protein (approximately 22%), and they are high in dietary fiber, which can help reduce cholesterol and prevent heart disease and Type II diabetes. Thus, larger scale producers may consider developing connections with regional schools or other institutions as interest in promoting healthy, locally sourced food increases. Cull dry beans (splits, immature, or weather damaged) can be offered as high protein animal feed; however, beans must be processed prior to feeding (Rush et al. 1998; Hawkins et al. 2006).

Variety Selection

The capacity to fix nitrogen makes dry beans well suited to diverse cropping systems common in western Washington, including vegetable and grain rotations. All the major market classes of dry beans can be grown in this area. However, colored, patterned, and heirloom varieties allow growers to differentiate from commodity bean production and command a market premium. In western Washington, dry beans are best planted in mid- to late May and harvested in late August or early September. Thus, variety selection is critical because varieties have a wide range of days to maturity. Varieties also differ in productivity, appearance, and disease resistance.

Local climate, production practices, disease pressure, and markets are all essential factors to consider when selecting a suitable variety. Dry bean varieties are commonly differentiated by growth habit and market class. There are four widely recognized dry bean growth habits (Figure 1). Climbing or pole varieties (Type IV) require physical support for successful cultivation and will not be discussed in this publication.

The Type I determinate bean plant has branches and stems that terminate in flowering points; the Type II indeterminate bean plant has an upright structure that ends in a short vegetative growing point; the Type III indeterminate prostrate bean plant has a prostrate growth habit with more vegetative side-branching and longer terminal growing point; the Type IV indeterminate climbing bean plant has vigorous climbing growth.

The major dry bean market classes in the U.S. are (in order of acreage planted) pinto, navy, black, great northern, light red kidney, dark red kidney, pink, small red, and cranberry (USDA NASS 2012). In addition to these primary commodity market classes, there are a wide range of colored-patterned and heirloom market classes suitable for niche marketing (Figure 2). Within each market class, there are many different bean varieties. Most modern commercially available varieties can be grown successfully in central and eastern Washington as long as there is adequate irrigation, crop nutrition, and protection from pests. In western Washington and other areas with relatively cool summer growing conditions, it is essential to choose early maturing varieties.

Bean varieties with an upright plant architecture are particularly desirable for their ease of weed cultivation and mechanical harvest. Many modern varieties have been selected for resistance to common bean diseases (see Disease and Insect Pests Management sections in this publication) and improved agronomic traits. Not much is known about disease resistance or production potential of colored-patterned and heirloom varieties; however, they offer unique market potential. For a more complete list of dry bean market classes and varieties that have been evaluated in western Washington, see the Washington State University website at http://vegetables.wsu.edu/NicheMarket/BeanVarieties.html.

Plant Management

Field Selection

Plant dry beans in fertile, well-drained soil to maximize production. Heavy clay soil will retain excess moisture and encourage growth of most pathogens, while sandy soils have limited water-holding capacity, which can limit yields if irrigation is not adequate. Dry beans have weak root systems, so care should be taken to avoid fields with a shallow plow pan and heavily compacted soils.

Crop Rotation

To reduce disease pressure, it is best to plant dry beans only once every 3 to 4 years in a given location (Osorno et al. 2013). To break disease cycles, dry beans are best rotated with members of the grass family, including small grains and corn. Rotations can also include vegetable crops, such as members

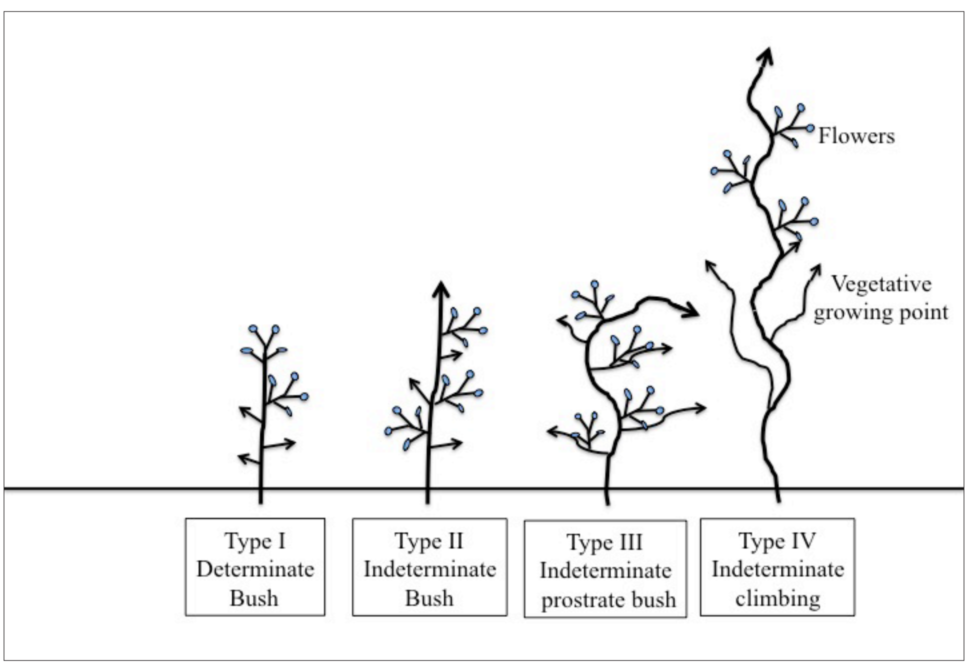

Figure 1. Four primary dry bean growth habits. Diagram adapted from Morphology of the Common Bean Plant (Phaseolus vulgaris) (Debouck and Hidalgo 1986).

Figure 2. Representative photos of dry bean market classes (left to right, top to bottom) pinto, navy, black, red kidney, brown, cranberry, and various colored-patterned varieties. (Photos by B. Brouwer, WSU)

of the Brassicaceae family (for example, broccoli and cabbage) and members of the Solanaceae family (such as tomato and potato). However, when rotating with these vegetable crops, be aware of diseases with large host ranges, such as white mold (*Sclerotinia sclerotia*), or root rot pathogens such as Rhizoctonia root rot (*Rhizoctonia solani*) (Schwartz 2011). Dry beans are resistant to Verticillium wilt (*Verticillium dahliae)*, as well as certain forms of Fusarium wilt (*Fusarium oxysporum* f. sp. *lycopersici*), and they may help disrupt the life cycle of these diseases when included in a crop rotation (McCain et al. 1981). (See Disease Management section in this publication for more information on common dry bean disease problems.)

Dry beans can contribute 20–40 lb of nitrogen per acre to the next crop if bean plant residue is incorporated after harvest (Gerwing and Gelderman 2005; Canevari et al. 2010). The amount of nitrogen available to the next crop will vary with the amount of biomass and the nitrogen content of plant tissue prior to incorporation, as well as the rate of organic matter breakdown in the soil. Breakdown of organic matter and release of nitrogen is influenced by factors such as soil moisture, temperature, tillage, and microbial activity. In general, moderate soil moisture, high temperatures, and tillage will stimulate the release of nitrogen from organic matter.

Seeding Guidelines

Plant beans 2–4 in. apart and 1–2 in. deep in rows on 18–36 in. centers. The number of seeds to plant per acre can be found in Table 1. To facilitate cultivation between rows and good airflow between plants, wider spacing between rows (24–36 in.) is recommended. This is especially important for production in western Washington where foliar diseases are prevalent due to cool, humid conditions. Dry beans can be seeded with hand-push seeders, tractor-mounted vegetable seeders, or row crop drills (Figure 3A). The size and weight of dry bean seed varies greatly depending on the variety. If seed weight is not available, count and weigh 100 seeds, and calculate the seeding rate (pounds per acre) with the following equation:

Seeding rate (lb per acre) =
(lb per 100 seeds x number of seeds per acre) ÷ 100

Do not plant beans when the soil temperature is below 55 ˚F as cool temperatures can slow germination and increase opportunities for disease and insect pests to damage or kill plants prior to emergence. Bean seed is often coated with fungicide seed treatments to help control seedborne and soilborne pathogens. Insecticidal seed treatments are also available. (See the section on Pest Management in this publication for additional information on these treatments.) Poor plant emergence will result in thin stands, causing increased weed pressure and reduced yield. Seed will germinate more quickly when soil temperature is above 60 ˚F; however, delaying planting after early June will result in a limited time for the crop to reach maturity. Based on trial observations in western Washington, white seed market classes, such as white kidney and navy, are particularly sensitive to cool soil temperatures (Figure 3C).

Table 1. Number of seeds per acre based on in-row and between-row spacing.

Between-row spacing (in.)	In-row spacing (in.)		
	2	3	4
18	174,240	116,160	87,120
24	130,680	87,120	65,340
30	104,544	69,696	52,272
36	87,120	58,080	43,560

Prior to planting in a new area, or if dry beans have not been grown in that field for 5 or more years, inoculate seed with *Rhizobium leguminosarum* to insure formation of root nodules, which are necessary for nitrogen fixation (Moore et al. 2012). Inoculant is available in dust and granulated formulations and can be mixed directly with seed prior to planting. *Rhizobium* bacteria induce nodule formation on the plant roots and form a symbiotic relationship with the plant to fix nitrogen from the atmosphere. A healthy root nodule will be pink on the inside (Figure 4). Do not apply too much nitrogen fertilizer,

Figure 3. (A) Row crop seeder suitable for planting dry bean rows on 22-in. to 36-in. centers; (B) bean row 8 days after planting at a rate of 1 seed every 2 in. in rows on 24-in. centers; (C) comparison of two bean varieties planted side by side, the variety on the right did not emerge well in cool soil, resulting in a thin stand and increased weed pressure. (Photos by B. Brouwer, WSU)

Figure 4. (A) Dry bean roots with nodules; (B) pink interior of a healthy root nodule. (Photos by B. Brouwer, WSU)

as this will prevent the bacteria from forming root nodules (see Fertilizer section in this publication).

Fertilizer

Dry beans can fix 20–40% of their own nitrogen through association with *Rhizobium*; however, adequate soil nutrition is necessary to maximize yields (Long et al. 2010). Prior to applying fertilizer, test the soil for available nutrients. Use the soil test information to determine how much of each nutrient to apply. For information on how to collect and interpret soil tests, see *Soil Testing: A Guide for Farms with Diverse Vegetable Crops* (Collins 2012) at http://cru.cahe.wsu.edu/CEPublications/EM050E/EM050E.pdf.

Broadcast and incorporate fertilizer prior to planting, or apply fertilizer in a band next to the row after beans have emerged. For more information on fertilizing dry beans as well as information on micronutrient deficiencies, see *Fertilizing Dry Beans* (Davis and Brick 2009) at http://www.ext.colostate.edu/pubs/crops/00539.html.

Nitrogen (N): If available soil N-NO_3 is below 30 ppm, apply 30–50 lb of N per acre. If following a heavily fertilized crop, residual soil N may be sufficient. High rates of N can cause excessive vegetative growth and delay time to maturity. Excessive N application will also suppress root nodule formation and subsequent N fixation (Davis and Brick 2009).

Phosphorous (P): Soils in western Washington are often low in P. However, if the field has a history of dairy or poultry manure application, soil P levels can be very high. If soil testing indicates P levels are below 15 ppm, apply 20–40 lb P_2O_5/acre to achieve a yield goal of 2,000 lb/acre (Long et al. 2010).

Potassium (K): Generally K is not a limiting nutrient for crop production in western Washington. If soil testing shows K levels below 80 ppm, supplemental fertilizer may be needed.

For information on calculating fertilizer rates when using manure, compost, and cover crops, see *Soil Fertility in Organic Systems: A Guide for Gardeners and Small Acreage Farmers* (Collins et al. 2013) at http://cru.cahe.wsu.edu/CEPublications/PNW646/PNW646.pdf. Use caution when fertilizing with manure or compost as beans are especially sensitive to residues of several common grain and forage herbicides, such as those containing aminopyralid. Herbicide residues can persist through the ruminant digestive system as well as through composting (Dow AgroSciences n.d.; Rhodes and Phillips 2011). If aminopyralid herbicide residues are present, plants will become distorted (the damage looks much like virus symptoms) and plants can die (Figure 5).

Irrigation

Dry beans can be grown successfully without irrigation if there is adequate moisture from precipitation. Sufficient water during plant establishment and flowering is important for maximizing yield. In areas that do not receive any precipitation during the growing season, water beans once a week from seeding until the bean pods turn yellow, usually early to mid-August. Apply approximately 1 inch of water per week and adjust the amount as needed based on crop symptoms.

Use drip irrigation to provide an even amount of water throughout the field, to avoid water loss from evaporation, and to avoid watering weeds in the alleyways. Drip irrigation also helps prevent foliar

Figure 5. Damage to dry bean seedlings caused by aminopyralid applied to potting soil in a dose response study (T. Miller personal communication). From left to right, the treatments were: 0 ppb, 5 ppb, 10 ppb, 50 ppb, 100 ppb, 250 ppb, 500 ppb, and 1000 ppb aminopyralid. (Photo by T. Miller, WSU)

diseases by applying water to the base of the plant. When using overhead watering in western Washington, water plants early in the morning to allow them to dry before nighttime. Wet plants are more susceptible to foliar diseases. Stop irrigating bean plants in early to mid-August, or as soon as the pods turn yellow, to allow bean pods to dry.

Pest Management

Weed Management

Weed management is critical in dry bean production because beans compete poorly with weeds, and yield can be substantially reduced by the presence of weeds. Because beans are harvested very late in the season, many of the weeds present will have the opportunity to set seed prior to harvest, adding to the weed seed bank. An integrated approach to weed management that includes variety selection, row spacing, careful field management prior to planting, cultivation, and selective herbicide applications can be used to minimize weeds in dry bean production. For current herbicide recommendations for dry beans, see the *Pacific Northwest Weed Management Handbook*, available online at http://pnwhandbooks.org/weed/.

Dry bean varieties with an aggressive upright growth habit are better able to compete with weeds (Malik et al. 1993; Blackshaw et al. 1999). Reducing row spacing from 27 in. to 18 in. has also been found to reduce weed biomass in dry bean production (Malik et al. 1993). However, narrow row spacing can hamper between-row cultivation, as well as decrease air circulation, which can slow drying and increase foliar disease problems. For these reasons, 24-in. to 36-in. row spacing is recommended for production in western Washington.

One of the most effective ways to reduce weed pressure is to allow weeds to germinate and then cultivate fields prior to planting beans (Peachy 2011). This can be achieved by irrigating fields during dry weather, or cultivating after the soil surface has dried following rain. A light surface cultivation tool, such as a tine weeder, is sufficient to control annual broadleaf seedlings. More aggressive tillage may be needed to control perennial or grass weeds. Winter cover crops such as cereal rye can help suppress winter annual weeds; however, the cover crop should be incorporated a minimum of 2 weeks before planting. Planting too soon after cover crop incorporation may increase the risk of damage from seedcorn maggots (see Insect Management section in this publication). These maggots are attracted to decomposing organic matter, and they reduce nitrogen availability.

Shallow cultivation with a tine weeder after planting, and prior to bean emergence, can help control a first flush of weeds (Figure 6A, B). Tine weeding is most effective during hot, dry weather when weeds are just visible as thin threads with two cotyledons (Figure 6C). If the soil surface is wet, weeds will not dry out and can easily reestablish. From 3 to 5 days after planting, check the field to determine if beans are safely below the surface, and then harrow the soil surface. Beans are very vulnerable to mechanical damage when they first emerge, so be sure germinating seeds are below the tillage depth (Figure 6D).

Once bean plants have emerged, between-row cultivation is a primary method of weed control. Various

Figure 6. (A) Tine weeding with a light tractor-mounted harrow; (B) tine weeding soil surface prior to bean emergence; (C) weed seedling at ideal stage for control with tine weeder; (D) bean seedling 7 days after planting, when the crooked neck is very vulnerable to mechanical damage and too close to the surface for tine weeding. (Photos (A) and (B) by L. Winkler, WSU; (C) and (D) by B. Brouwer, WSU)

tools can be used for this, including cultivators, discs, and strip tillers (Figure 7). Setting cultivating equipment to mound soil towards the row can help cover small weeds within the row; however, care needs to be taken to avoid covering bean plants early in the season. Avoid aggressive tillage at the base of bean plants as this can damage plant roots and create entry points for root pathogens.

Hairy nightshade (*Solanum physalifolium)* is a particularly problematic weed in bean production because the berries contain poisonous compounds and are difficult to separate from dry beans during harvesting and cleaning (Figure 8). If other control methods are not adequate, nightshade plants should be removed from the field prior to harvest.

Disease Identification and Management

Due to the importance of bean seed production in Washington, there are a number of bacterial and fungal diseases that are considered quarantine pests. It is illegal to transport bean seed for planting into any of the following 20 counties: Adams, Asotin, Benton, Chelan, Columbia, Douglas, Ferry, Franklin, Garfield, Grant, Kittitas, Klickitat, Lincoln, Okanogan, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman, and Yakima, unless it has been certified free of five bacterial pathogens: Halo blight (*Pseudomonas syringae* pv. *phaseolicola*), Common bean blight (*Xanthomonas axonopodis* pv. *phaseoli*), Fuscous blight (*Xanthomonas phaseoli var fuscans*), Brown spot disease (*Pseudomonas syringae* pv. *syringae*), Bean bacterial wilt (*Corynebacterium flaccumfaciens spp*. *flaccumfaciens*), and the fungal pathogen, Bean anthracnose (*Colletotrichum lindemuthianum).*

If seed is being produced commercially or for personal use, monitor the crop very carefully for the presence of these diseases and for bean common mosaic virus (BCMV). If any disease symptoms appear, or if environmental conditions are conducive to disease

Figure 7. (A) Strip tillers for cultivating between rows; (B) cultivating tractor with belly-mounted implements; (C) discs set to cut soil and weeds away from the bean row; (D) discs set to throw dirt into the row to smother weeds within the row. (Photo (A) by K. Atterberrry, WSU; (B), (C), and (D) by B. Brouwer, WSU)

development, seed should be tested by a certified diagnostic lab prior to sale or use.

The following are some common viral, fungal, and bacterial pests of dry beans. For more information on bean pest identification and control, see the *Handbook of Bean Diseases* (Hagedorn and Inglis 1986) at http://learningstore.uwex.edu/assets/pdfs/A3374.PDF, the *Compendium of Bean Diseases* (Hall 1994) at http://www.apsnet.org/apsstore/shopapspress/Pages/43275.aspx, as well as the *Pacific Northwest Plant Disease Management Handbook*, available online at http://pnwhandbooks.org/plantdisease/. Additional images of common dry bean problems may also be found online at the Pacific Northwest Vegetable Extension website at http://mtvernon.wsu.edu/path_team/bean.htm.

Viral: Bean common mosaic virus (BCMV) and bean common mosaic necrosis virus (BCMNV) are two seedborne viruses that can cause significant crop loss (Mukeshimana et al. 2003). BCMV and BCMNV are also transmitted by aphids. Symptoms of infection include rolled leaves, banding of light green

Figure 8. (A) Hairy nightshade plant in mature bean field; (B) green nightshade berries in sample of light red kidney beans after harvest. (Photos by B. Brouwer, WSU)

and dark green tissue, a mosaic pattern on leaves, and necrosis (Figure 9). BCMNV can cause a hypersensitive reaction in bean varieties with resistance to BCMV, causing necrotic lesions and plant death in severe cases. Plants grown from infected seed can be severely stunted and may not produce seed. Selecting resistant varieties is the most effective way to control these viruses; most modern bean varieties have been bred with resistance to BCMV. Maintaining virus-free seed is particularly important when cultivating older bean varieties, which do not have genetic resistance. When susceptible varieties are grown for seed production, they should be isolated from other beans.

Beet curly top virus (BCTV) has a broad host range that includes beans, beets, spinach, squash, cucumbers, tomato, potatoes, and pepper and is transmitted by the beet leafhopper *Circulifer tennellus* (Davis and Frate 2010). Leafhoppers thrive in arid environments, thus populations are typically very low, or not present, in western Washington. However, beet leafhoppers have been found to occasionally migrate west of the Cascades (Cook 1967). While curly top virus is likely to be of minor importance, it has been known to infect tomatoes in western Washington (Jenny Glass personal communication), and it may infect beans. Signs of infection include strong downward curling, darkening and thickening of foliage, and stunting of plants as well as yellowing of foliage (Figure 10). The most effective method of pest control is planting resistant or tolerant bean varieties.

Fungal: Bean Anthracnose, *Colletotrichum lindemuthiana*, is a potentially damaging seedborne fungal disease (Markell et al. 2012). Symptoms include dark lesions that develop on the underside

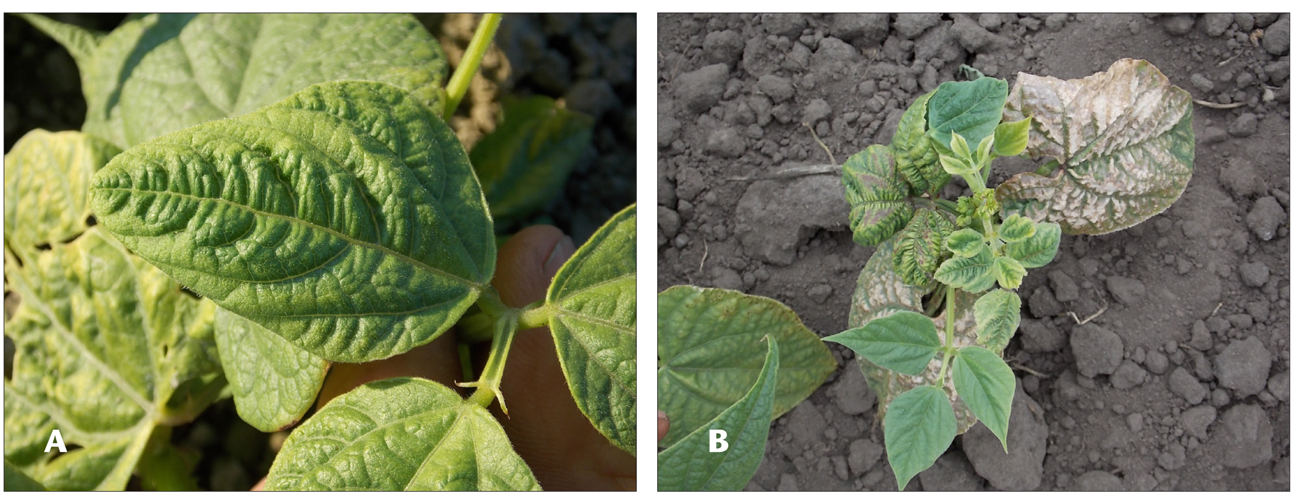

Figure 9. (A) Typical banding of dark and light green tissue and leaf-cupping symptoms of BCMV; (B) severely stunted bean plant grown from seed infected with BCMV. (Photos by B. Brouwer, WSU)

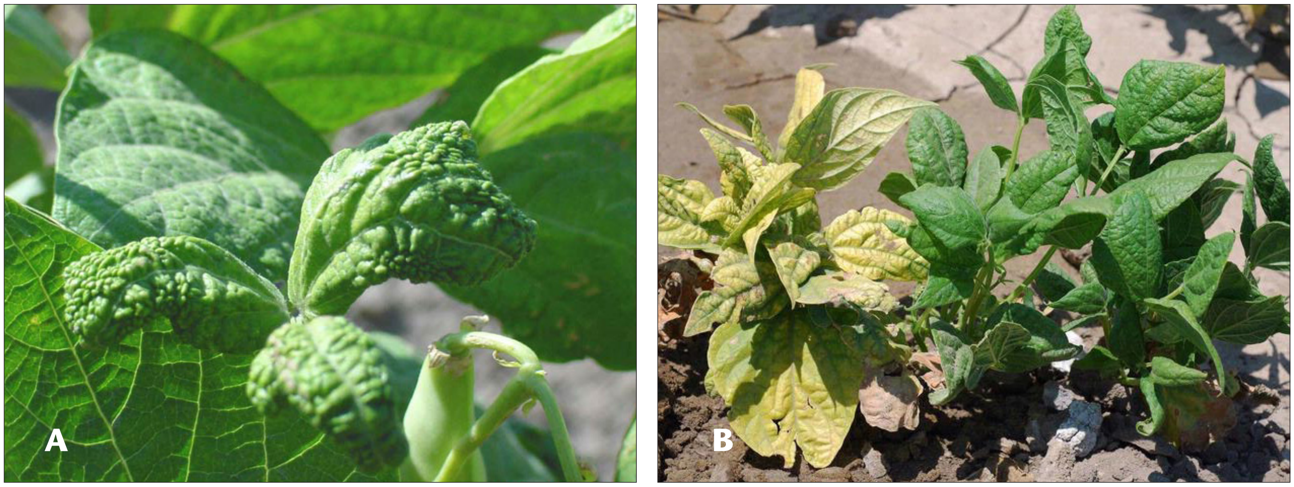

Figure 10. (A) Severe leaf-cupping symptoms of BCTV infection; (B) stunting and chlorosis symptoms of BCTV infection. (Photo (A) by L. du Toit, WSU; (B) by H. F. Schwartz, Colorado State University, Bugwood.org)

of the leaf petiole and veins and spread to the surrounding leaf area (Figure 11). Infected pods can have sunken tan- to rust-colored lesions with a slightly raised dark border. Anthracnose spores are easily spread from infected plants by wind and splash dispersal and can be transmitted by equipment or other physical contact, particularly when leaves are wet. Using a 3- to 4-year crop rotation with non-host crops, such as small grains and corn and other vegetables (for example, members of the Brassicaceae and Solanaceae families), can help reduce the buildup of inoculum in the soil. Foliar fungicides applied at early and late bloom may reduce losses caused by anthracnose (Markell et al. 2012). Many modern dry bean varieties have been bred with resistance to anthracnose. Planting resistant varieties may help reduce yield loss from this disease. (For known disease resistance information, consult variety description information in seed company webpages or catalogues, and variety release documentation.) Seed from fields infected with anthracnose should not be used for planting.

Sclerotinia white mold, *Sclerotinia sclerotiorum,* is a common fungal disease, which can be particularly damaging in wet growing conditions with high rates of nitrogen fertilizer (Strausbaugh and Forster 2003). Losses due to white mold have exceeded 50% in parts of the United States, and infectious sclerotinia (black survival structures) produced by the fungus can persist in fields for over 3 years, making this disease difficult to control with short crop rotations

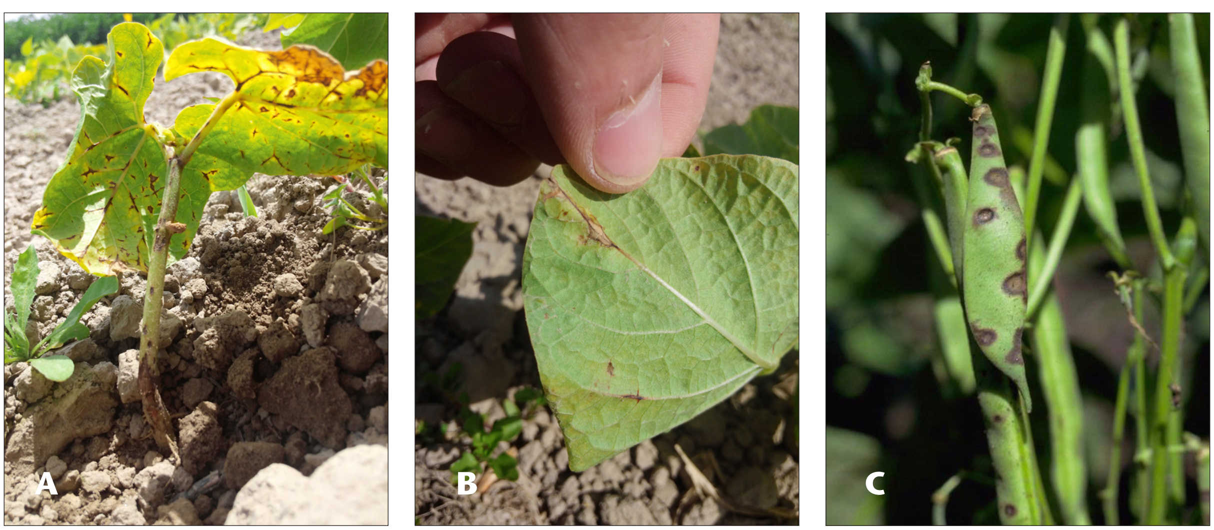

Figure 11. (A) Severe foliar symptoms of bean anthracnose associated with seedborne infection; (B) anthracnose lesions on underside of bean leaf; (C) sunken lesions on bean pods. (Photos (A) and (B) by B. Brouwer, WSU; (C) by H. F. Schwartz, Colorado State University, Bugwood.org)

(Schwartz et al. 2011). White cottony mycelium grows on flowers and spreads to pods of infected plants (Figure 12). Lesions on leaf tissue spread from small, circular, dark green spots, which can develop cottony mycelial growth.

To control white mold, rotate with non-host crops such as small grains or corn (for as long as 8 years), apply nitrogen at a reduced rate, reduce irrigation, increase space between plants, and select upright varieties with an open canopy. Fungicides can also be effective in reducing losses from white mold. Apply fungicide when all plants have at least one flower and before the disease is widespread in the field. (See the *Pacific Northwest Plant Disease Management Handbook* for current fungicide recommendations, as well as information on potential biological control agents.)

Several widespread fungal diseases can contribute to root rot symptoms in dry beans (Schwartz 2011; Harveson 2011). Fusarium root rot, *Fusarium solani f. sp. phaseoli,* causes red discoloration of the root system that later darkens and turns brown (Figure 13). In severe cases, plants are stunted and leaves turn yellow and drop prematurely. Fusarium wilt, *Fusarium oxysporum* f. sp. *phaseoli,* also causes discoloration of the roots and wilting symptoms. Rhizoctonia root rot, *Rhizoctonia solani,* typically causes sunken lesions with a reddish border, which can girdle the stem. Severely infected plants will also have dark red lesions within the stem. Pythium damping off, *Pythium spp.,* can cause seeds to rot as well as stunt root growth and constrict the stem at the soil surface. Pythium is particularly problematic in wet soils.

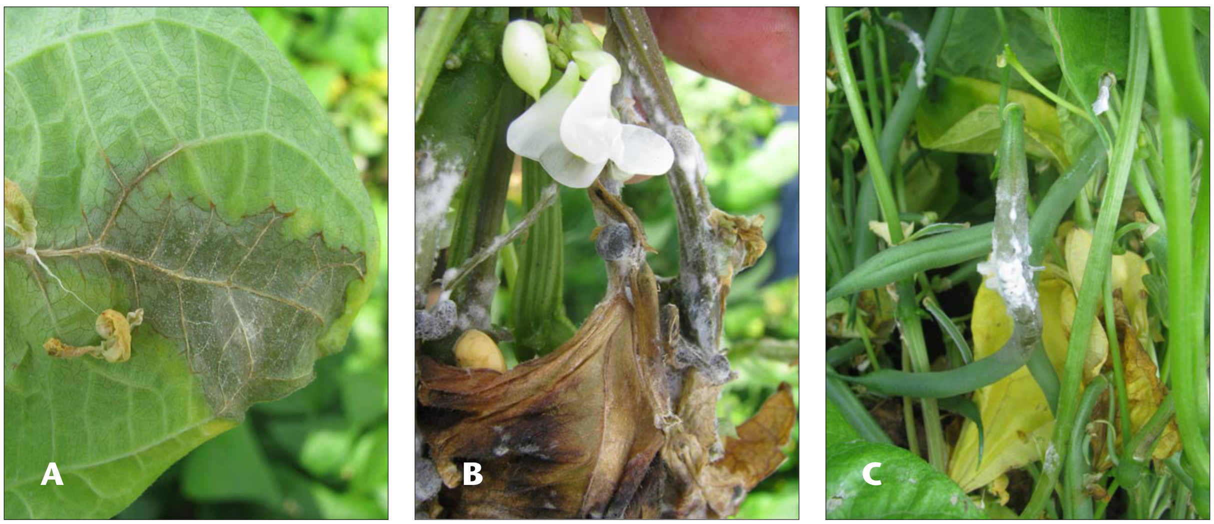

Figure 12. (A) Water-soaked lesion and early mycelial growth on the underside of a leaf; (B) white mold mycelium on flower and stems; (C) white mold mycelium on bean pod. (Photos by L. du Toit, WSU)

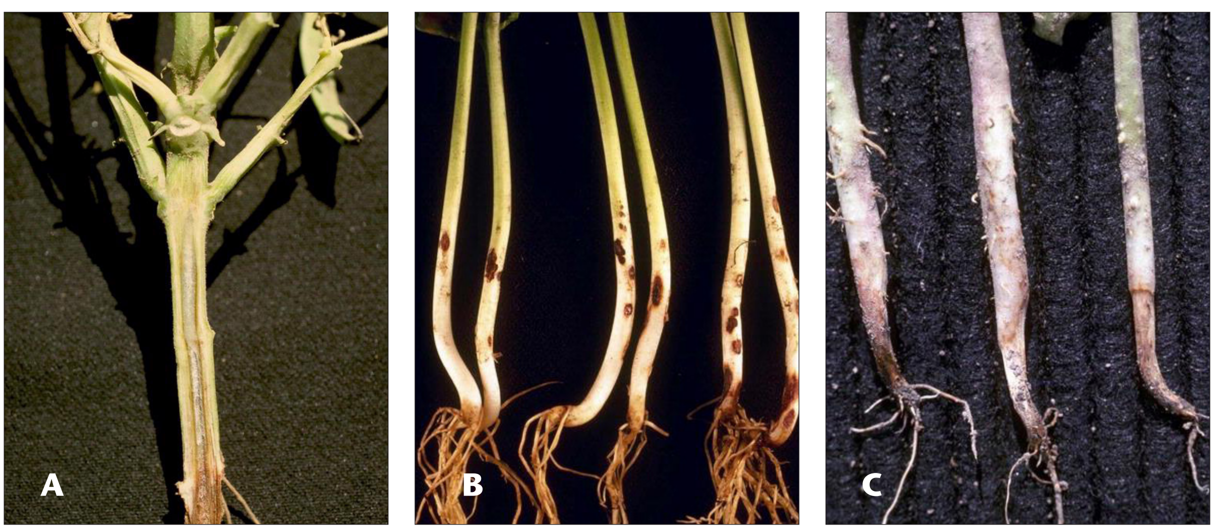

Figure 13. (A) Vascular discoloration caused by Fusarium wilt; (B) Rhizoctonia lesions on bean seedlings; (C) root constriction symptoms of Pythium damping off. (Photos by H. F. Schwartz, Colorado State University, Bugwood.org)

Management of root rot disease includes crop rotation for 3 to 4 years with non-host crops such as small grains; *Rhizoctonia solani* in particular is known to be a problem with potatoes and beets. Aggressive cultivation near the base of plants can damage the roots and increase susceptibility to root pathogens and thus should be avoided. Incorporate bean crop residue following harvest to reduce inoculum. Fungicide seed treatments and planting in favorable conditions to promote rapid growth of seedlings can help protect plants from root rot pathogens. For current fungicide and seed treatment recommendations for control of these pathogens, see the *Pacific Northwest Plant Disease Management Handbook*. Some bean varieties have been bred for tolerance to root rot pathogens. (Consult variety description and release documentation for known disease resistance information.)

Bacterial: Common blight, *Xanthomonas axonopodis* pv. *phaseoli,* and Halo blight, *Pseudomonas syringae* pv. *phaseolicola,* are two seedborne bacterial diseases that are considered quarantine pests in Washington State (Wohleb and du Toit 2011). Common blight causes water-soaked lesions on leaves that enlarge into dry, brown patches with a yellow margin (Figure 14). Halo blight has a similar appearance; however, the lesions are typically small points with larger yellow margins. Planting disease-free seed is critical to limiting introduction and spread of these pathogens, and beans harvested from infected plants should not be used for seed.

Insect Identification and Management

Seedcorn maggot and wireworms are two important insect pests that negatively impact dry bean production in western Washington. For additional information on insect pest identification and management, see the *Pacific Northwest Insect Management Handbook* available online at http://insect.pnwhandbooks.org/.

Seedcorn maggot, *Delia platura,* is the larval form of the seedcorn fly, and it can cause severe damage to emerging bean seedlings (Godfrey and Long 2010). Bean seedcorn maggots feed on the embryo of germinating seeds and can damage the cotyledons and stem of young seedlings, killing the plants or causing severe stunting (Figure 15). Seedcorn maggots are particularly damaging in cool, wet soils with high organic matter content. To reduce damage, delay planting for several weeks after cover crop incorporation, and wait for optimum soil temperature to encourage rapid germination and emergence. Insecticide seed treatments can also be effective in reducing damage from seedcorn maggots.

Wireworms, *Limonius spp.,* are the larval form of click beetles and are a widespread insect pest throughout Washington State. They cause damage by feeding on seeds, roots, and stems of bean plants, which can stunt or kill seedlings (Figure 16). Wireworms are attracted to soils with high organic matter, and the highest populations are found in fields that have been in pasture or intensive grain crop production. Prior to planting, the wireworm population can be estimated by counting wireworms present in soil samples taken from representative portions of the field, or by setting up a buried bait trap using methods described by Esser (2012) in *Wireworm Scouting: The Shovel Method and the Modified Wireworm Solar Bait Trap* at http://smallgrains.wsu.edu/wpcontent/uploads/2013/10/Wireworm-Scouting-FS059E2.pdf. Summer fallow with frequent cultivation or

Figure 14. (A) Dry leaf tissue with light yellow margin typical of Common bacterial blight; (B) Halo blight symptoms on bean leaves. (Photo (A) by H. F. Schwartz, Colorado State University, Bugwood.org; (B) by C. Wohleb, WSU)

Figure 15. (A) Bean seedcorn maggot feeding on seed; (B) stunted plant resulting from seedcorn maggot damage. (Photos by T. Waters, WSU)

Figure 16. (A) Wireworm larvae; (B) wireworm feeding on stem of barley plant. (Photo (A) by L. du Toit, WSU; (B) by B. Brouwer, WSU)

rotation with non-host crops, including alfalfa and mustards, may reduce wireworm populations (Andrews et al. 2008). Insecticide seed treatments can also help protect seedlings from damage.

Production Methods

Harvesting

Depending on the scale of production, availability of equipment, and weather, dry beans can be harvested by hand, direct cut with a combine, or swathed and combined. Dry beans are ready to harvest when the pods have turned tan and papery (Figure 17A). Timely harvest is critical for minimizing bean losses in the field due to mold or pod shattering (Figure 17B). In cool climates like western Washington, it is not uncommon for bean plants to remain green, even after the pods are dry and ready to harvest. To minimize splitting beans during harvest, beans can be threshed between 15% and 18% moisture, however, additional drying (to 13% moisture) will be necessary for long-term storage (Osorno et al. 2013). (See Drying and Storage section in this publication.)

Hand Harvest: Pull whole plants or cut them at the soil surface, and place them in a sunny area or in a sheltered area with good airflow to dry completely. Thresh dry plants in a stationary mechanical thresher. Clean the beans by sifting

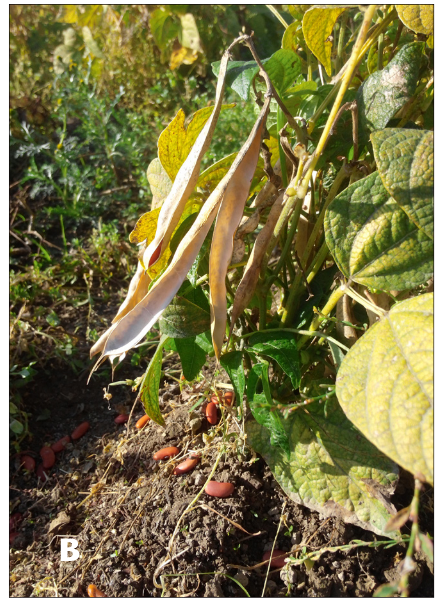

Figure 17. (A) Bean row ready to harvest; (B) pods shattering and dropping seed prior to harvest. (Photos by B. Brouwer, WSU)

them in front of a fan. See *Growing Dry Beans in Home Gardens* (Miles and Atterberry 2014) at http://cru.cahe.wsu.edu/CEPublications/FS135E/FS135E.pdf for more information about harvesting beans on a small scale. Examples of small-scale threshing and winnowing equipment can also be found on the Washington State University Vegetable Horticulture website at http://vegetables.wsu.edu/NicheMarket/SmallScaleHarvesting.html.

Direct Cutting: A standard grain combine with rasp bar cylinder can be used to harvest dry beans (Figure 18). Crop lifters attached to the combine header will help facilitate harvesting close to the ground and reduce losses by lifting plants to the cutter bar. The combine should be adjusted according to manufacturer recommendations; however, general combine guidelines are provided here (see text box). For direct combining, select varieties with upright plant architecture (Figure 18C) to reduce harvest losses caused by damaging or missing low-hanging pods (Figure 18D). If these losses are too great, beans may need to be swathed and harvested as described in the Windrow Harvesting section of this publication. Additionally, if too much green plant material is present at harvest, a chemical desiccant (drying agent) may be applied according to label instructions.

Windrow Harvesting: If direct harvest is not possible because pods are too close to the ground, or if plants do not dry down in a timely manner, beans can be harvested by windrowing. Cut plants just below the soil surface using a sharpened blade mounted on a tractor tool bar. Rake plants into windrows to dry for 7–14 days prior to threshing. Drying time will vary greatly with weather conditions, and windrows should be checked frequently to determine if they are ready to thresh. If necessary, turn windrows with a rake to allow plants on the underside to dry. Avoid windrowing if rain is forecast as this can substantially reduce bean quality. When plants are dry (stems snap easily), thresh using a combine (adjusted according to the Combine Guidelines provided earlier) with a pick-up header.

Drying and Storage

Immediately following harvest, clean beans to remove damp plant material, weed seed, dirt, and other high moisture material that can cause beans to mold in storage. For long-term storage, beans should be at or below 13% moisture. If a bean seed coat can be dented with a fingernail, it is too wet for storage. To measure bean moisture, grind a representative sample of approximately ½ cup in a blender, food processor, or food mill. Measure the weight to the closest ounce (this is the wet weight). Microwave the sample for short intervals (30 seconds to 1 minute) and weigh; continue this process until the weight does not change (this is the dry weight). The percent moisture is calculated by:

$$(\text{wet weight} - \text{dry weight}) \div \text{wet weight}$$

If needed, dry harvested beans in bins with perforated bottoms using high airflow fans or circulating batch driers. Add supplemental heat to the intake air to reduce the relative humidity if necessary. Do not

Figure 18. (A) Direct-cutting commercial dry bean field; (B) direct cutting a bean variety trial with a small research combine; (C) dry bean variety with desirable upright plant architecture for direct cutting; (D) field losses when pods hang below height of cutter bar. (Photo (A) by K. Atterberrry, WSU; (B), (C), and (D) by B. Brouwer, WSU)

General Combine Guidelines

To minimize cracking and splitting beans, operate the combine at a slow cylinder speed (130 to 300 rpm depending on size of cylinder and field conditions), and adjust sieves to minimize return of threshed beans to the threshing chamber (Watkins 2005; Osorno et al. 2013). Use lower cylinder speeds when the crop is drier, and increase cylinder speed if pods are not threshing cleanly. Similarly, increase the concave clearance if beans are dry, and reduce the concave clearance if plant material is damp and pods are not threshing well. Because dry beans are relatively heavy, high wind speed can be used to blow out plant debris. When unloading the combine, avoid dropping beans onto a hard surface from a height greater than 4 ft as this can damage the bean embryo, reduce germination and seedling vigor, as well as reduce cooking quality. Periodically check harvested beans for damage, and check combine tailings (threshed plant debris) for unthreshed pods and adjust combine settings accordingly (Figure 19). If excessive bean splitting and seed-coat damage is still occurring after adjustments have been made, harvest beans early in the morning or late in the evening when moisture content is higher.

Figure 19. (A) Bean sample on left was threshed at higher moisture resulting in few split beans relative to sample on right; (B) checking combine tailings for unthreshed pods. (Photos by B. Brouwer, WSU)

raise the temperature more than 20 °F above ambient air temperature, and do not dry beans at greater than 110 °F (Holman and Smith 1999). Store beans in a cool, dry place that is protected from insects and rodents.

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Use pesticides with care. Apply them only to plants, animals, or sites as listed on the label. When mixing and applying pesticides, follow all label precautions to protect yourself and others around you. It is a violation of the law to disregard label directions. If pesticides are spilled on skin or clothing, remove clothing and wash skin thoroughly. Store pesticides in their original containers and keep them out of the reach of children, pets, and livestock.

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