HOW TO DETERMINE YOUR GARDEN MICROCLIMATE

By
Don McMoran, Director and Extension Educator, WSU Skagit County Extension, **Sheri Hunter**, WSU Extension Master Gardener volunteer, **Sacha Buller**, Coordinator, WSU Skagit County Extension Master Gardener program (past)

WSU PEER REVIEWED

FS181E

How to Determine Your Garden Microclimate

Understanding how climate affects your growing conditions is essential to successful gardening. **Climate** is a measure of average variation in overall weather patterns over time and over a very wide geographic region or **zone**. In a garden, climate strongly influences growing conditions: air and soil temperatures, precipitation, and heat accumulated over the growing season.

Throughout western Washington, however, varied topography gives rise to a large number of **microclimates**—small-scale areas where local conditions may differ from those of the surrounding climate zone. Microclimates are created by local factors such as elevation and slope, proximity to mountains or foothills, location with respect to predominant wind and weather, and distance from Puget Sound.

A microclimate can encompass an area as small as the south side of a building or one that spans many acres on a sloped face of a mountainside. An entire valley located inland between mountains can exhibit microclimate phenomena not experienced in the climate zone overall.

Limitations of USDA Hardiness Zones

In the United States, the Department of Agriculture (USDA) geographically divides areas with different climatic conditions into **hardiness zones**. Each hardiness zone supports a specific category of plant life capable of growing and able to withstand the minimum low temperatures of that zone.

Determined largely by elevation, latitude, and proximity to the coast, USDA hardiness zones experience a range of *average* annual minimum low temperatures. However, the *actual* minimum low temperature in any given year may differ. It may never reach the same low range, or it may fall lower. Caution is advised, therefore, when using hardiness zones for plant selection.

Nurseries use USDA hardiness zones on plant tags to indicate a minimum low temperature that a plant can survive. If the *actual* minimum temperature falls below the *average* minimum range indicated on the plant tag, the plant may fail to thrive.

The USDA hardiness zone map typically provides little detail in mountainous areas where hardiness zone changes can occur within a few miles. If you could enlarge the zone map, you would see rapid zone changes with elevation at many locations across the United States.

The Grand Canyon, for example, exhibits a steep change in elevation of some 5700 ft. The canyon floor harbors plants which thrive in Mexican deserts, while plants found on the north rim are native as far north as southern Canada.

Explore your local zone by visiting USDA's interactive map (USDA 2012). Type in your zip code and use the zoom-in feature to locate a particular region. Notice the split designations "a" and "b" in the colored chart, which reflect changing elevation. Keep in mind that other factors—wind, humidity, snow, and winter sunshine, as well as soil type, pH and moisture—also determine whether a plant will thrive. For a complete discussion of the limits of hardiness zones as a gardening guide, consult the About page on the USDA's interactive map.

Recognizing Microclimate

Hardiness zones represent years of plant trials over a wide area, but they are of limited value unless coupled with local knowledge and experience. When you recognize your microclimates and pair this information with USDA hardiness zone recommendations, you will make better plant choices and site plants wisely.

There are many online tools to help you establish a picture of your regional climate. One of them is Washington State University's AgWeatherNet (AWN) (WSU 2014). The site links to automated weather stations in Washington where variables such as air and soil temperature, rainfall, frost dates, heat accumulation, and climate summary information are tracked. Measurements are taken every five seconds and summarized every fifteen minutes, so the data are always current.

Registered users who log in can access the entire AWN data set and web-based tools. There are, for example, useful but more technical models and decision aids to inform irrigation settings as well as timing of insect spray or disease treatment. Unfortunately, all western Washington weather data collection points are at lowland locations, so if you live at higher elevations, you may still need to extrapolate the data or measure your microclimate independently. (Note: registration information is confidential. It is used by AWN staff solely for statistical reports and to provide better services.)

Once you are aware of your *regional* climate, you can begin to study your *local* climate. You can, for example, measure actual winter low temperature with an outside air thermometer. If your readings vary from the regional reports, you are undoubtedly in a local microclimate.

Keep a log of minimum low readings—generally the daily temperature at sunrise—to track your actual minimum low temperature. Is it reasonably stable or does it change from year to year? A remote sensor with a memory for daily high and low temperatures makes the work easy. Relocate a remote thermometer at ground level in beds around the yard to discover warmer protected areas.

The Influence of Elevation

Few gardeners in western Washington reside at **high altitude**, elevation at or above 4,500 ft. Those who do will know that a truly frost-free season is nonexistent while summers can be quite warm. If you garden on or near foothills or at elevations between 500 and 2,500 feet, air temperature, frost likelihood in winter, precipitation levels and possibly heat accumulation can differ from conditions at lower elevation.

In general, air temperature declines 3.5–5°F for every 1,000 foot increase in elevation. At elevations of 3,000–4,000 feet in winter, freezing generally occurs when surface temperature at sea level hovers around 40°F (Mass 2008). However, atypical cold is possible even in coastal lowlands. As an example, in winter the Fraser River Valley becomes an important conduit of cold northeasterly airflow to Puget Sound. When this air arrives, a temperature inversion forms: cold heavy arctic air displaces warmer air at low level coastal areas, pushing it inland and upland, with the result that coastal areas experience frost while protected inland and upland temperatures remain above freezing.

Another winter phenomenon occurs at low elevation in an intermountain valley. Sandwiched by mountains, the valley receives heavier cold air originating at high elevation that slides downslope to form a pocket of static cold air known as a **cold sink** (Figure 1**).** This freezing air may become trapped for a prolonged period by warmer Pacific air as it lifts over the mountains. The result is an atypical-for-zone freeze that is otherwise undetectable on the USDA hardiness zone map.

In a cold sink, plants thought hardy can fail to thrive. If cold persists, trees and shrubs may be slow to break bud and flower. Soil warming, and therefore seed germination, may also be slow.

For some intermountain gardeners, snow cover may protect against freezing. Acting as an insulator against extreme cold, snow protects the root system of dormant plants. Thus, where snow cover is reliable, your plants may be shielded from the worst of winter low temperatures.

Figure 1. Static cold air in a cold sink can produce atypical-for-zone frost (Mass 2008). The numbers in this diagram refer to temperatures (F) as they “sink” into a sub-freezing area.

Because garden conditions are more extreme in and around mountains, it’s a good idea to follow weather patterns and be prepared to intervene should temperatures suddenly drop. Keeping a garden log of frost and minimum night air temperatures will help you know what to plant, when to plant, and when to protect plants, especially in spring and fall when plants may not be fully dormant and therefore are more vulnerable to damage caused by low temperatures.

If you are just becoming familiar with your garden, err on the side of caution and choose plants whose cold tolerance exceeds what you initially expect.

Regional Influences on Rainfall

Western Washington experiences wave-on-wave of moisture as it arrives on our coast from both the northern and southern Pacific Ocean. In winter, warm moist Pacific air collides with frigid arctic air in a turbulent marriage of maritime influence and altitude extremes. Whether you live at elevation or within view of Puget Sound, you are undoubtedly the recipient of generous annual precipitation. Our land contours respond to directional storms with quite a peculiar rainfall pattern: rainfall can be staggering in some places but oddly light in others.

In the region overall, precipitation follows a predictable pattern, as shown in Figure 2. As moist air is blown uphill, it cools and drops moisture in a process called **adiabatic cooling**. Tumbling downhill on the other side of the mountains, the air warms and dries, producing a drier area we commonly refer to as a **rain shadow**. This microclimate phenomenon is experienced throughout western Washington, although on average, annual rainfall becomes heavier as you travel east into the Cascades.

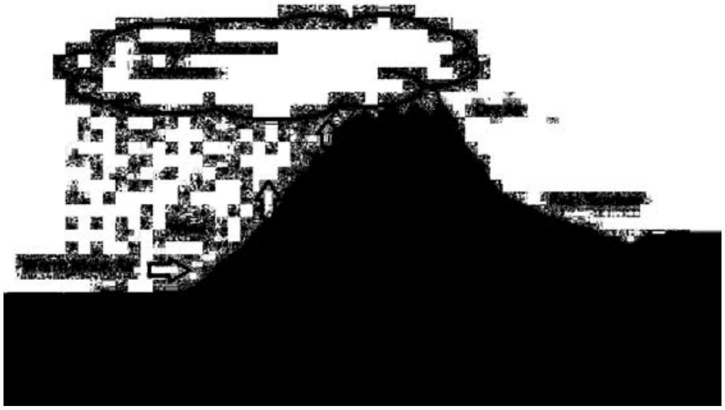

Figure 2. **Adiabatic cooling**: moist ocean air is lifted uphill over elevated ground, cooling and shedding moisture as it rises. Over the mountain, then, air moving downhill warms and dries as it returns to lower elevation, producing a **rain shadow**.

Watch the direction of incoming storms to discover if you live in a local rain shadow or, conversely, an area of heavy rainfall. Precipitation levels are posted on AWN, enabling you to compare and identify yours as a predominantly wet or dry environment. If you live on or around mountains, a simple outdoor rain gauge sometimes provides more accurate information.

Also take note of ground areas where water pools and where it drains away quickly. Consider this important local knowledge as you build a picture of your local microclimate.

When you choose plants, be alert to their water and drainage requirements. If you garden in a rain shadow, decide whether you'll be able to meet these needs with or without supplemental irrigation during dry months.

The Effects of a Marine Layer

The influence of the eastern Pacific Ocean is felt throughout western Washington, seasonally moderating temperature, elevating humidity, and, where humidity is high enough and cooling sufficient to create condensation, generating fog. This influence is felt far inland in western Washington and is commonly called the **marine layer**.

The marine layer is a moist air mass that forms over the ocean, Puget Sound, or really any large body of water inland, and becomes trapped by a temperature inversion. It is evident in all seasons except winter but is especially apparent in spring and early summer.

Figure 3 shows how the marine layer and an overhead air pressure system interact. The depth of the marine layer, and therefore how far inland it is felt, depends on large-scale weather patterns above it.

For example, when there is a high pressure system at 15,000–30,000 ft, cool ocean air is trapped, compressed and confined to lower elevations where it may only be evident near the beach as fog. At the same time, only a mile or so inland it is sunny and warm. As pressure above diminishes, marine layer moisture travels inland and upward to higher elevations as fog and low clouds, which appear to spill over the mountains. When air pressure aloft diminishes and air above the marine layer cools sufficiently, the inversion dissipates and the marine layer eventually disappears.

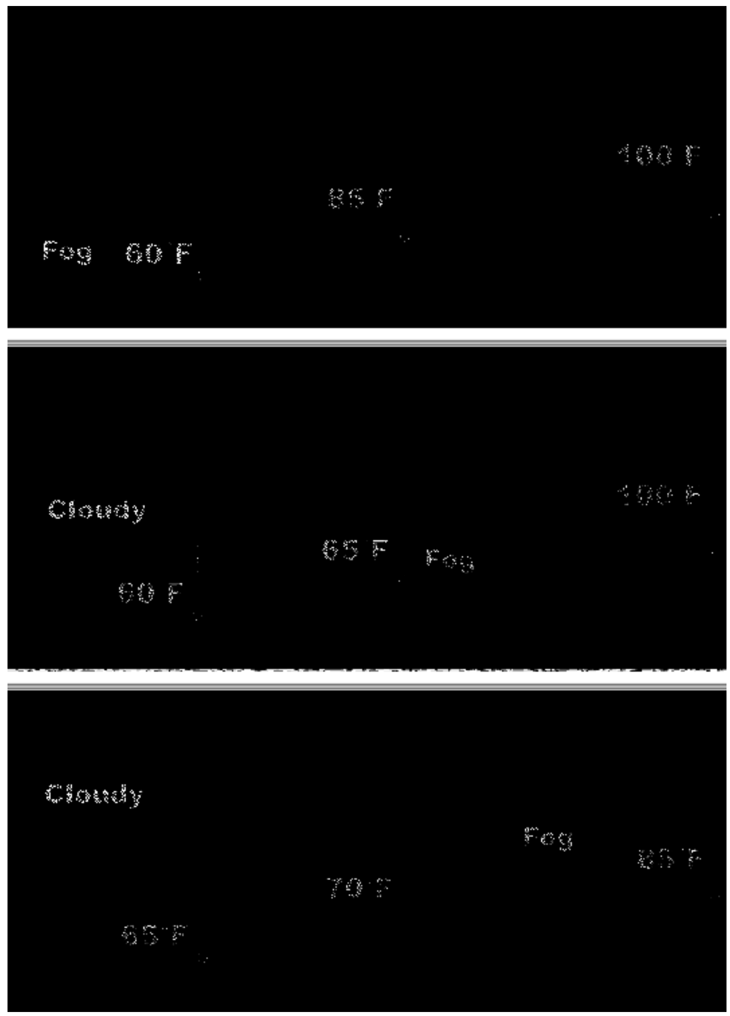

Figure 3. The marine layer travels inland and uphill as a temperature inversion diminishes. While it is relatively stable, it can fluctuate with approaching storms, high wind or other destabilizing conditions. Thus, foothill and mountain communities may experience waxing and waning of this layer and its influence. (NWS 2011)

To the extent that the marine influence predominates and the region experiences overcast skies, our growing season is shortened and warm season crops can suffer. The lower Skagit Valley area, for example, has a long growing season of approximately 230 growing days, while the upper valley has approximately 200 days related in part to the waxing and waning of the marine layer. Altitude, especially beyond the marine influence, may shorten it further.

Topographical Influences on Microclimate

Orientation to the sun and slope inclination toward the sun affect how much sun energy your garden absorbs. Level land absorbs more sun energy in summer when the sun is high. But in spring and fall, slope aids sun absorption, especially on south-facing terrain. North slopes stay cooler all year long, as do east slopes, especially in areas of morning fog. Gardens with south and southwest orientation and an optimum slope inclination between 20–30° absorb the greatest solar energy overall (Pirzadeh 2002).

Use a compass or map to determine the orientation of your growing area to the sun. Notice how many hours of sunlight your garden receives. The more sunlight over the season it receives, the more likely it will support warm season plants, fruits and vegetables.

The location and land contour of your garden determine not only the nature of your soil but also how well your soil drains. In coastal lowlands—but even at elevation over bedrock—excess moisture may show where the land contour is concave, bowl-like or otherwise lower than the surrounding area.

So, for example, gardens situated at the base of a slope (bottomland) may have overly wet soil. Gardens situated on slopes or on tops of hills may have soils that drain well and warm early, yet too steep a slope or too high a hill results in problematic dryness, especially in late summer. Because our rainy season is as pronounced as our dry summer, garden location and contour can have great impact on your growing conditions, not only in spring but throughout the season.

Soil Characteristics of Microclimate

Another crucial step in sizing up your microclimate is taking stock of soil characteristics—its depth, texture and moisture holding capacity. (See Home Gardeners Guide to Soils and Fertilizers [Cogger 2005] for an in-depth guide to analyzing soil texture, structure, drainage and pH.)

Soil depth is a feature of your microclimate that you'll appreciate when you consider the water and nutrients your plants require. Here in western Washington, soil depth varies with location. If you garden at elevation or atop a hill, for example, your soil is likely thin, poorly developed, and nutrient-deficient related to the geologically young nature of the mountain range near which we live. In lowland areas, soil is deep and well developed. Shallow soil holds less water than deeper soil, while at the same time space available for root development is limited.

Soil depth can be restricted by compacted, even cemented, gravelly layers or actual bedrock. In winter, the oxygen-deprived, waterlogged root zone of shallow soil can be a challenge to many plants. In summer drought, shallow soils dry out quickly. It can be very difficult to find plants for shallow soils that will tolerate both a very wet winter and a very dry summer.

Dig below the topsoil in your garden to determine its moisture-holding capacity. The deeper you can dig before hitting a restrictive layer, the greater the soil volume for holding water. Now assess soil texture. Once the air begins to warm in spring, take a handful of soil and squeeze it. If water drips from it, try again after a few rain-free days. If too much moisture persists, your soil may be poorly drained. Alternatively, the soil ball will crumble if your soil is sandy and well drained. Adding organic matter will improve conditions, but in extreme circumstances steps to alter drainage may be called for.

No plant can tolerate moisture extremes for very long. It is important to assess how well moisture drains and is retained at various times in the growing season. A digital soil moisture meter rates moisture, typically on a one-to-ten scale. Many provide advisory tables for vegetables and landscape plants and suggest their **wilting point,** that is, a reading on the one-to-ten scale at which a plant will begin to show drought stress and at which watering is strongly advised. The manufacturer may also advise how frequently moisture should be checked as well as any special watering needs for plants listed in a table of hundreds of plants. Always couple your own observations with the guidelines provided to determine when and how much to water.

Alternatively, you may wish to use online technology. AWN tracks field capacity at sea level agricultural areas throughout Washington State. **Field capacity** is the water content held in soil after excess water has drained away and downward percolation movement has decreased. Gardeners should refrain from planting a garden during periods of high soil water content as this is when seed damping-off is likely to occur and when the risk of disease is highest.

To locate measures of field capacity, registered users can log in to the AWN website and select Daily Budget Table. The middle column shows soil water content as Available Water (in percentage). Check the most recent data. Planting should be postponed if a reading of 100 percent is logged. Ideally, planting should occur nearer 75 percent.

Microclimate Influences Warming in Spring

While the growing season in western Washington is long, it is comparatively cool. In order for plants to emerge and grow in spring, the sun must warm the soil. However, soil warming is affected not just by direct absorption of the sun's energy but also by the amount of moisture in the soil. As wet soil absorbs sun energy, the sun energy is given off again as the moisture in soil evaporates. Not all energy is given off, however, so gradually, as sufficient moisture *evaporates*, the soil warms. Alternatively, soil warms as sufficient moisture *drains*. At a point that too much moisture evaporates or drains, the soil can become too warm and dry.

Seeds are especially sensitive to moisture and warmth. Soil temperature must reach a certain minimum for seeds to activate. In cool soil, some seeds will fail to germinate or germinate but stall in development and become vulnerable to disease. Similarly, adequate moisture is necessary for seeds to germinate, but excessive moisture can give rise to a fungal soil disease that causes **damping-off**, an interruption of seed germination.

You are likely to be more successful when you plant once the soil has warmed and the soil itself is neither overly wet nor overly dry. Orientation to the sun, slope and land contour of your garden, as well as the depth and character of your soil, are features of your microclimate that affect sun absorption and moisture retention. Whether your garden lies on a slope, a ridgetop, or bottomland, soil moisture and warming in spring can be affected.

You can easily monitor your soil temperature to know when it becomes ideal for seed germination. Table 1 displays the minimum soil temperatures necessary to germinate seed of various vegetable varieties. Seeds planted in cool soil will often germinate, but it takes longer to happen and requires that you watch them more carefully. Planted in cool soil, seed may damp-off, especially if soil remains overly moist. Insert a soil thermometer 3–4 in. into the soil and note the temperature when it stabilizes. Any thermometer measures soil temperature provided it reads to 40°F. Nurseries, hardware stores, home supply depots and occasionally thrift stores carry inexpensive soil thermometers. Keeping a log of soil temperature may help you decide when to plant and when to wait until the soil warms.

Table 1: Soil temperature conditions for seed germination of common vegetables (adapted from Maynard and Hochmuth 2007).

Vegetable	Soil Temperature Condition (°F)		
	Minimum	Optimum	Maximum
Bean, snap	60	60–85	95
Cabbage	40	40–95	100
Chard, Swiss	40	50–85	95
Cucumber	60	60–95	105
Lettuce	30	40–80	85
Onion	35	50–95	95
Parsnip	35	50–70	85
Pepper	60	65–95	95
Squash	60	70–95	100

Heat Accumulation: the Plant Growing Season

Reduced sunlight and a cool growing season is a problem for plants that need a certain amount of accumulated heat in order to grow, flower, set fruit and ripen. This is particularly true of fruits and vegetables. Exactly how much heat is necessary is unique to each plant variety and is expressed in **growing degree days (GDD)**.

A GDD unit is the difference between the average air temperature of any given day and a plant's **base temperature**, the temperature below which it does not grow. Consequently, if a plant requires a minimum temperature of 50°F to grow and the average high temperature for the day reaches 70°F, the plant accumulates 20 GDD units. If over a growing season this plant requires 1,200 GDD units yet accumulates only 1,060 by the end of the growing season, this plant's fruit will not fully mature during that growing season.

In the Puget Sound region, many Mediterranean and subtropical plants can survive a mild winter but will never develop mature fruit because they are unable to accumulate enough heat units over the growing season (Campbell and Norman 1998). Fruit maturation is more complicated for **photoperiod-sensitive** plants such as corn or onions.

Flowering in these plants is initiated by a specific day length, although they also require a certain number of heat units for fruit to mature.

Unfortunately, it can be difficult to find a source of growing degree-day requirements for most plants. Oregon State University Small Farms team is developing a vegetable degree day website called CROPTIME, which provides at least 60 variety-specific degree day models for the following vegetables: beans, broccoli, cabbage, carrot, cauliflower, cucumber, kale, head lettuce, sweet pepper, pumpkin, spinach, summer squash, sweet corn, tomato and winter squash. Once the site is available online (scheduled for 2015), it will allow for "open-source" development of new vegetable GDD models by anyone interested (Andrews and Coop 2011).

For the present, selecting plants based on native environment is one strategy for ensuring your plant will develop optimally. Reserving a warm microclimate or protected location for heat-loving perennials is another.

Some seed suppliers provide an optimal seed germination range noted in their catalog or on seed packages. In addition, seed companies test seed to determine how many "days to maturity" a plant variety requires and note this on seed packages.

Strategies for selecting seed for your garden microclimate include:

- When you buy seed, notice where the seed company is located. If it's in a different USDA zone or where growing conditions are different, you may not achieve their results. When possible, purchase from a seed company nearby.
- Select plant varieties that mature early.
- At higher elevations, sow seed and plant out two to three weeks *later* in the spring; for fall harvest, two to three weeks *earlier* in summer.
- If you seed directly in the ground, keep a log of air and soil temperature, then time planting at optimum soil temperature.
- Transplant mature seedlings when growing certain warm season vegetables and fruits, and using season-extending techniques like row cover, cold frame, or greenhouse to ensure ripening.

Strategies for Successful Gardens

Now that you have a sense of your growing conditions, develop a strategy to ensure plants will survive them. Look for plants thriving in neighborhood gardens. Are they drought-tolerant or moisture-loving plants you're familiar with? These may be good choices for your problem areas. Amend your soil and correct drainage problems before choosing plants, or select native plants that tolerate native conditions.

There are a number of strategies to fall back on when wet soils are inevitable:

- Avoid perennials and other plants that perform poorly in wet winter conditions.
- Use raised beds for perennials that require well-drained soil and for early season vegetables.
- Investigate whether a drain on a slope will remove excess water in your situation.
- Installing drainage can be expensive, so when considering drainage, make sure there is a place to drain the water. Also check with local regulatory agencies to see if you may incur restrictions.

Similarly, here are a few suggestions when your soils are persistently dry:

- Add organic matter to improve the moisture-retaining capacity of your soil.
- Choose drought-tolerant plants, especially natives adapted to dry soil.
- Use raised beds filled with amended soil.
- Install an irrigation system.
- Group moisture-loving plants together in one area where you can water them together.

Taking the time to observe your local growing conditions and making the effort to take simple measurements has great payoffs in terms of saved energy and expense. Learning to cooperate with climate overall and your microclimates in particular may enable you to generate a garden that thrives and yields abundant harvests.

Glossary of Terms

adiabatic cooling. A process that occurs as moist air is blown uphill; as the air rises, it cools and its moisture is deposited.

base temperature. The lowest temperature at which a plant's metabolic process results in growth (an increase in the plant's size).

climate. A measure of average variation in overall weather patterns over time and over a very wide geographic region.

cold sink. A pocket of static cold air found typically in valleys sandwiched by mountains; formed by heavier cold air originating at high elevation that slides downslope to fill the valley.

damping-off. A condition caused by a number of different pathogens which kill or weaken seeds or seedlings before or just after they germinate. It is most prevalent in wet and cool conditions.

field capacity. The amount of water held in the soil after excess water has drained away and the rate of downward movement has decreased.

growing degree days (GDD). A measure of heat accumulation used to predict plant development rates for a crop and when it will reach maturity.

hardiness zone. A geographical area, defined by climatic conditions, where specific plants can grow, based on their ability to withstand the minimum temperatures of the zone.

high altitude. Regions on the Earth's surface which are often understood to be greater than 4,500 feet above sea level.

marine layer. Ocean currents and cold-water upwelling create a dense mass of cool, moist maritime air immediately below a temperature inversion; often augmented by clouds, these conditions reduce summer temperatures in areas closer to the coast.

microclimate. The climate of a small area that is different from the area around it. It may be warmer or colder, wetter or drier, or more or less prone to frosts.

photoperiod-sensitive plants. Plants for which flowering is initiated by a specific day length (e.g. corn, onion); they also require a certain number of heat units for their fruit to mature.

rain shadow. A dry area on the sheltered side of a mountainous area; caused when cool moist air rises and falls as rain on the windward side of the mountain.

wilting point. The minimum amount of soil moisture required by a plant to avoid wilting.

zone. An area or stretch of land having a particular characteristic, purpose, or use, or subject to particular restrictions.

References, Further Reading, and Helpful Websites

Gardening Guides

Bauer, M., D.L. Barney, and J.A. Robbins. 2009. Growing Tomatoes in Cool Short-Season Locations. *University of Idaho Extension Bulletin* 864. University of Idaho.

Elliot, C., and E. Peterson. 2009. *The Maritime Northwest Garden Guide*. Seattle: Seattle Tilth Association.

Kohlhaase, B. 2012. *High Altitude: Getting Results from a Short Growing Season*. Bozeman, MT: Planet Natural.

Love, S., K. Noble, and S. Parkinson. 2009. Garden Strategies for Short-Season, High-Altitude Zones. *University of Idaho Extension Bulletin* 859. University of Idaho.

Maynard, D., and G. Hochmuth. 2007. *Knott's Handbook for Vegetable Growers, 5th edition*. Hoboken, NJ: John Wiley & Sons.

Potts, L., and I. Shonle. 2008. Colorado Mountain Gardening Basics. *Colorado State University Extension Fact Sheet* No. 7,244. Colorado State University.

Potts, L., I. Shonle, and S. Ballus. 2013. Flowers for Mountain Communities. *Colorado State University Extension Fact Sheet* No. 7,406. Colorado State University.

Hardiness Zones

United States Department of Agriculture (USDA). 2012. *USDA Plant Hardiness Zone Map.* Washington D.C.: U.S. Department of Agriculture. planthardiness.ars.usda.gov

Heat Accumulation, Growing Degree Days

Andrews, N., and L. Coop. 2011. Using Heat Units to Schedule Vegetable Plantings, Predict Harvest Dates and Manage Crops. *Oregon Small Farm News* 6 (4). Oregon State University.

Department of Horticulture, Cornell University. 2014. *Cornell Gardening Resources: Growing Degree Days (GDDs)*. Ithaca, N.Y.: Cornell University.

Miles, C.A., and P. Labine. 2009. Portable Field Hoophouse. *Washington State University Extension Publication* EM015. Washington State University.

Parker, J., C. Miles, T. Murray, and W. Snyder. 2012. How to Install a Floating Row Cover. *Washington State University Extension Publication* FS089E. Washington State University.

Pirzadeh, A. 2002. "Figure 3: Table of Solar Radiation Variation With Respect to Slope and Aspect of the Okanagan Valley (1987)." *Atlas of Suitable Wine Grape Growing Regions of Napa County in California* (student project). Vancouver: University of British Columbia.

Saunders, D.C, H.J. Kirk, and C. Van Den Brink. 1980. Growing Degree Days in North Carolina. *North Carolina Cooperative Extension Resource* No. AG-236. North Carolina State University.

University of California Agriculture and Natural Resources. 2014. *Statewide Integrated Pest Management Program: Home, Garden, Turf and Landscape Pests*. Davis: University of California.

Soil

Cogger, C. 2005. Home Gardeners Guide to Soils and Fertilizers. *Washington State University Extension Publication* E1971B. Washington State University.

Weather and Climate

Campbell, G.S., and J.M. Norman. 1998. *An Introduction to Environmental Biophysics, 2nd Edition*. New York: Springer-Verlag.

Community Collaborative Rain, Hail and Snow Network (CoCoRaHS). 2013. *Climate Resources for Master Gardeners*. Fort Collins: CoCoRaHS, University of Colorado.

Hopkins, D. 1938. BioClimatics: A Science of Life and Climate Relations. *U.S. Department of Agriculture Publication* No. 280. U.S. Department of Agriculture.

Mass, Cliff. 2008. *The Weather of the Pacific Northwest.* Seattle: University of Washington Press.

National Weather Service (NWS), 2011. The Ocean: The Marine Layer. *JetStream Online School for Weather.* Silver Spring, MD: National Oceanic and Atmospheric Administration's National Weather Service.

Washington State University. 2014. *AgWeatherNet* (AWN). Prosser: WSU. weather.wsu.edu

Wikipedia contributors. Rain Shadow. *Wikipedia, The Free Encyclopedia.* en.wikipedia.org/wiki/Rain_shadow (accessed June 30, 2015).

Copyright 2015 Washington State University

WSU Extension bulletins contain material written and produced for public distribution. Alternate formats of our educational materials are available upon request for persons with disabilities. Please contact Washington State University Extension for more information.

Issued by Washington State University Extension and the U.S. Department of Agriculture in furtherance of the Acts of May 8 and June 30, 1914. Extension programs and policies are consistent with federal and state laws and regulations on nondiscrimination regarding race, sex, religion, age, color, creed, and national or ethnic origin; physical, mental, or sensory disability; marital status or sexual orientation; and status as a Vietnam-era or disabled veteran. Evidence of noncompliance may be reported through your local WSU Extension office. Trade names have been used to simplify information; no endorsement is intended. Published August 2015.