Appendix 3 Agronomy of cranberries

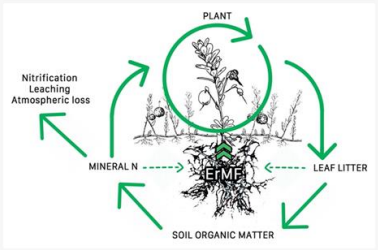
There is a huge amount of data available regarding the agronomy of cranberries. This has been collated by the USDA to provide simple indications of optimal growing regions in the U.S. (figure **). This appendix provides a summary of the agronomic requirements for cranberry production. It has compiled using a number or sources as a summary, more detailed information may be found in resources published by the Universities of Massachusetts (Massachusetts Cranberries, no date; www.ag.umass.edu/cranberry see: here), University of Wisconsin-Madison Fruit Program (www.fruit.wisc.edu/cranberries) and research repositories (see here) and growers guides (see here and here)

Table ** Table detailing the agronomy of cranberries.

Element of agronomy	Detail & signposting
	Establishing the cranberry bed
Land preparation	When creating a new cranberry bog sites with a slope of 2% or less are chosen out of preference. The land is cleared of trees and vegetation and the growing substrate is applied. Growing substrate is either sphagnum ('peat moss') or sand. If sand is used approximately 10" of sand is laid down on the peatland.
Soil profile – use of sand	In the early 1800s Henry Hall, a veteran of the Revolutionary War who lived in Dennis Massachusetts noticed that sand blown in from nearby dunes helped vines grow faster. Today, growers spread a inch or two of sand on their bogs every three years. The sand not only helps the vines grow but also slows the growth of weeds and insects. Sanding is a Best Management Practice and is also part of a Integrated Pest Management program. Sanding can aid in pest control by burying weed seeds, fungal spores, insect eggs and over-wintering insects. The primary benefit of the sand layer is to stimulate the development of new roots and to cover the bare wood at the base of the plants, leading to renewal of the root system and the production of new shoots. By sanding, growers can reduce the need to prune and for fertilizers and pesticides but this can limit production for the year. This impact is lessened when sand is applied on the ice rather than directly on the vines in the spring. Sand applications serve multiple purposes in cranberry production (see video here). Renovated bogs typically apply 0.3–0.5 m of sand to ensure adequate aeration in the root zone, particularly for new

	plantings (DeMoranville and Sandler, 2000 a). Periodic winter applications of 1–5 cm of sand serve a purpose similar to pruning. Cranberries can withstand inundation with sand up to 12-19 inches deep.
Water management	Reduce the level of water in ditches as much as possible prior to application of fertilizer. Lowering the water level in ditches before a fertilizer application will allow for adsorption of nutrients onto sediment and vegetation in the ditches and increases the water holding time in the system. Research has shown the cranberry bogs have a great capacity to filter nutrients from water. Slowing the water movement through the system maximizes this process.
Cranberry cultivars	There are approximately 30 different cultivars with new ones being developed all the time. Popular cultivars include: *Malaca Queen, Ben Lear, Bergman, Early Black, Pilgrim, Howes, Grygleski* and *HyRed.* Different regions prefer different cultivars. For example in Wisconsin *Stevens* and *Malaca Queen* (Jones no date) are preferred. *Stevens* account for approximately 60% of all cranberry acreage in Nova Scotia and in Massachusetts: smaller varieties called *House* and *Early Black* tend to be planted.
Planting	**Plugs** Cranberry beds are established using plugs. These are expensive, 25c a piece, but germination from seeds is lengthy (up to 3 years) and the seedings are dominated by weeds before they can become productive. Plugs are planted during the Autumn (October to early November) or in Spring from mid-April to end May. Plugs are planted at a depth of 2 to 6 inches and spacing is as follows: between plants 11 to 12 inches; between rows 12 inches. **Cuttings** Brash (cuttings from cranberry beds) is spread on the sand to avoid the cranberries becoming overcome by weeks. It is also cheaper. They save £75K than if they used plugs. **Seeds** Cranberry beds are not established using seeds.
Dormancy	A period of dormancy of 3 months is required for the fruit production. It occurs when temperatures reach 32-45°F. Abnormal dormancies resulting 'umbrella bloom' where stems do not grow above flowers, resulting in a 50% lower yield with only 1 or 2 fruits on the fruiting stem. 
Crop rotation	Currently, there is no crop rotation build into any of the cranberry farming systems. It is possible that cranberries could be grown in sphagnum. This would replicate how cranberries are naturally grown. The sphagnum would maintain the

	moisture in the soil and help protect and add to the peat carbon store. It has been shown that ten years of *Sphagnum* growth can result in an organic layer up to 30 cm thick. The formation of this layer is significant in terms of its sequestering of carbon (Temmink et al. 2024). It appears that there are certain species of sphagnum that are more adapted to high nutrient levels found on agricultural soils (see here). If it is not practical to plant directly into sphagnum it may be that sphagnum could be incorporated into a rotation or some form of strip cropping could be used to protect and support additional peat formation.
Inter-cropping	Inter-cropping or strip cropping with cranberries is not practised in any current farming systems. It may be possible for strip cropping or inter-cropping to be established with sphagnum or other wetland plant species which it occurs with naturally in the wild. This would maintain moisture and add to the carbon store.
Soils	Cranberries grow best in loamy, sandy, clay, which is moist and boggy (see here for research). In the US they are grown either on sand or on peat with the addition of sand layers. In Wisconsin, there appears to be little consideration of GHG emissions according to researchers at the Centre for Ecology and Environment, University of Wisconsin- Madison but there is research at the Arlington Research Centre see here.
Soil nutrients	The nutrient requirements of the cranberry plant vary according to the stage of growth. The root system of the cranberry plant may be extensive extending down as far as 9 inches into the subsoil. Cranberry response to fertilisation is cultivar, yield and region specific (Parent et al. 2021). Nutrient applications are subject to precision technology informed by tissue sampling. Cranberries need high amounts of phosphate 100ppm and specific micronutrients such as boron. Very little boron is required 0.2ppm but a soil deficient in boron would not support cranberry growth. It may also be toxic to cranberries at high levels (see Prouse 1999). Phosphorus and Nitrogen in the form of ammonia are critical along with a number of others. The recommendation is that there is no phosphorus application until late spring, and then apply 20 lbs actual P (45 lbs P2O5) in 2-3 doses (see here). There is interesting research focusing on the use of biochar to retain water and nutrients in the soil.
Mycorrhizal fungi	The mutualistic relationship between cranberries and Ericoid mycorrhizal fungi appears to be significant in facilitating the uptake of nutrients by cranberry root systems.

	 Figure 3. N pathways in the cranberry agroecosystem. The solid arrows indicate the standard N cycling pathway, which has a tendency towards N loss from through nitrification, leaching, and atmospheric loss. The cycle around the shoot system indicates resorption of N from leaves during the aging process and leaf fall. Because of this, cranberry leaf litter tends to be low quality, with a high C:N ratio. Leaf litter breaks down to become a part of the soil organic matter and to then be mineralized to ammonium and thus accessible to plants. Dotted arrows represent the pathways of ErMF symbiosis, where plants can directly take up N from fertilizers, mineralization, or even organic N. Figure concept adapted from Stackpoole et al (2012) and central illustration sourced from Kim Patten via Davenport et al (1994) [11, 12]. Source: here
Fertilisers – organic	Mineralization, the process through which organic N is released as ammonium, is microbe-mediated and temperature/moisture dependent. Moist soils and hot weather (>85 degrees Fahrenheit or 30 degrees Celsius) causes mineralisation and reduces the need for fertiliser application (Roper 2008). Further research is required to determine the rate of mineralisation. Application should occur when temperatures are over 55 degrees Fahrenheit to avoid volatisation. When nutrients are likely to bind to the soil or leach from root zone before uptake by plants.
Fertiliser application	Cranberries produced on sand require high levels of nutrient inputs because the sand is nutrient poor. The timing of nitrogen and phosphorus applications is an important factor affecting the potential for nutrient loss to the environment. The greater the time between application and plant uptake, the greater the chance for loss to ground or surface water. It is best to time fertilizer applications based on the stage of plant growth. Applications should be delayed when spring temperatures are cold. Cranberry plants respond to nutritional support during initial leaf expansion in the spring, during bloom, during fruit set, and during bud development for the following season. The greatest demand occurs during vigorous shoot growth, bloom, and early fruit development (set). In most years, this period occurs between mid-June and mid-July. Fertilizer requirements at the other growth stages (early spring and late summer) are less.

	Signposting for fertiliser reduction Fertiliser applications are avoided when there is a late water flood. The Spring fertilizer dose is eliminated when there is late flooding of bogs or reduced by 20-30%. The first fertiliser application should be applied instead when the cranberries bloom. Fertiliser application should be avoided on recently sanded bogs. These are warmer which causes the soils to release more native N (see here). There is some interesting research coming out regarding the stores of nitrogen and phosphorus. Peat's below ground pools primarily act as a stores of C and N (91% and 78% respectively) whereas the majority of P was stored in sand, which accounted for 78% of the belowground pool of P. (Kennedy et al., 2018)
Pollination	Bumble bees are used for pollinating cranberries. In Wisconsin and other areas East of the Rocky Mountains *Bombus imaptiens* is used. Elsewhere other species are used (see Stubbs et al 2002). Use of pollinators improves production and is of significant economic value, e.g. in the USA alone, pollination by honey bees, bumble bees, native bees and flies results in USD 16 billion annually (see: Khalifa et al., 2022). At Lake Nokomis, bees and bumble bees are used. Bumble bees make honey pods not suitable for honey. IPM monitoring is conducted by trapping insects and analysing contents for beneficial and pest species.
Pruning	Pruning is key to a productive cranberry bog. Sanding is used instead of pruning. It acts to bury old growth and only leaving new growth and let light in. Pruning occurs in Oregon, Vancouver, British Columbia, New Brunswick and Washington and Chile
pH	**Requirements** Cranberries have a very narrow pH range of between 4.5-5.5 for optimal growth & pH needs to be regularly monitored. One of the main effects of a sub-optimal pH is the unavailability of nutrients. This may be amended with application of sulfur and different types of sawdust/brash. There is emerging research which also suggests that soil pH may be reduced with the use of free-living and symbiotic fungi as well as bacteria. These organisms can produce and secrete organic acids (for example, oxalate or citrate), which can cause a lowering of the soil pH (Phillipot et al., 2024). In high intensity (HIC) systems soil pH and SOC are tested every 2-4 years. The use of sphagnum also acts to amend soil pH with the release of H+ (see here).
Moisture	**Requirements** Top 6 inches of substrate need to be moist but saturated (cf. 25 mm rule but soil tension, volumetric water content (VWC), might be a better indicator of water moisture and optimal growing conditions see here. This equates to, on average, approximately 2 cm of water (rainfall/irrigated) per week. **Monitoring**

	Moisture and aeration in the soil can determine nutrient availability (DeMoranville et al. 1996 and DeMoranville, 2010). Plants take up nutrients dissolved in the soil water. If soil is too dry, minerals cannot dissolve and move to the roots and uptake cannot occur. Conversely, if soil is waterlogged, oxygen the plant needs for root respiration to drive active uptake will be limited. In fact, an irrigation study showed that when the bog is too wet, fruit set declines. High manganese levels on a tissue test may indicate poor drainage. Proper soil drainage improves fertilizer efficiency so that less fertilizer is required. Continuous monitoring using water-level floats, sensors, and/or tensiometers is highly recommended. If this is not possible the recommendation is to measure soil moisture at least twice a week. Soil should be moist but not saturated in the top 6 inches. Research is being carried out to look at the efficacy of incorporating biochar into the growing substrate to improve water retention.
Aspect	Cranberries require full sun.
Temperature	For optimum growth: 60 to 70 degree Fahrenheit or around 15 degrees Celcius (Armstrong, 2017). During ripening: cooler temperatures are required.
	Harvesting
Harvesting - dry	US Large farms use a wet harvest, small farms use a dry harvest method www.cranberries.org A Guide On How To Harvest Cranberries | OutdooRight
Harvesting – wet	A Guide On How To Harvest Cranberries | OutdooRight
	Issues affecting productivity
Hybridsation	Contamination of cranberry beds with wild genotypes is a key issue affecting productivity. This is monitored by assessing the colour and patterns across cranberry bogs.

Frost	Protection against frost is achieved in HIC systems by flooding the cranberry beds which then freezes protecting the flower bud. UW-Madison is modelling cold hardiness of different cranberry cultivars to determine when flooding is required. This is important with the need for more sustainable management of water. Innovation in frost protection will be required in the UK such as using fleece. It may be possible to use techniques like those used in Chile where wind turbines are used in reverse to blow warm air over the crop.
Pests	There are a number of pests of cranberries including deer, insects and fungal and bacteria. Grazing by deer is controlled by exclusion using fencing or culling. Integrated Pest Management approaches are adopted by all cranberry farmers. Some are more reliant on pesticides than others. Phytophthora leaf spot, fruit rot, red leaf spot, end rot, black-headed fireworm, cotton ball, cranberry blossom worm, cranberry fruitworm, cranberry tipworm, cranberry weevil and gypsy moth all impact production significantly if not controlled. There are up to 15 types pathogenic fungi associated with fruit rot (see here). This is controlled using fungicides (Holland, 2021). UW-Madison (see here) are undertaking research to improve fruit quality and hardiness by increasing the uptake of calcium using *Stephens* and *Malaca Queen* in an attempt to resist fruit rot.
Insecticides	Flooding and sanding are used to help control them but is not always successful. Organic practices are promoted (see here). Research is carried out by a number of Government associated research centres (see here). Insecticides are used but agronomists use stakeholders such as Koppert Global to inform their choices based on the impact on pollinators (see www. Koppert.com)
Biological controls	Wolf spiders (family: *Lycosidae*) have been introduced to cranberry bogs as a means of biological pest control. They target cutworms, fruit worms and weevils (see here). Microbial Biological Controls are also used (see here). Nematodes are used to control a variety of pests including the cranberry flea beetle, over 1.5 million nematodes per square acre are required for effective control. Shawn Steffan, (Centre for Ecology and the Environment, University of Wisconsin - Madsion) reported that cranberry growers are growing nematodes to target this beetle but they are inbred and they do not follow best practise when it comes to application. The inbreeding causes issues in terms of the maintaining the natural behavioural profile necessary to function as effective biological controls. Shawn Steffan (see profile here) is researching the requirements for effective breeding and application. He has found that the nematodes need to be kept in the dark and the cranberries to be irrigated with sprinklers before, during and afterward nematode application to wash the nematodes down into the substrate. They also need to be applied at low pressure or to avoid effects on the predatory behaviour of these nematodes that makes them so effective.

Weed control	Weed control takes place throughout the growing season. Timing of herbicide application is critical at the following stages: new planting, dormant, emergent, full fruit set and when beds are abandoned. Cranberries are in a low fruiting herbicide group. New herbicides are being developed to combat resistance.
Bog renovation	Bog renovation may be required for a number of reasons, this process potentially has environmental implications in terms of GHG emissions and release of nutrients depending on the management decisions taken (see here).

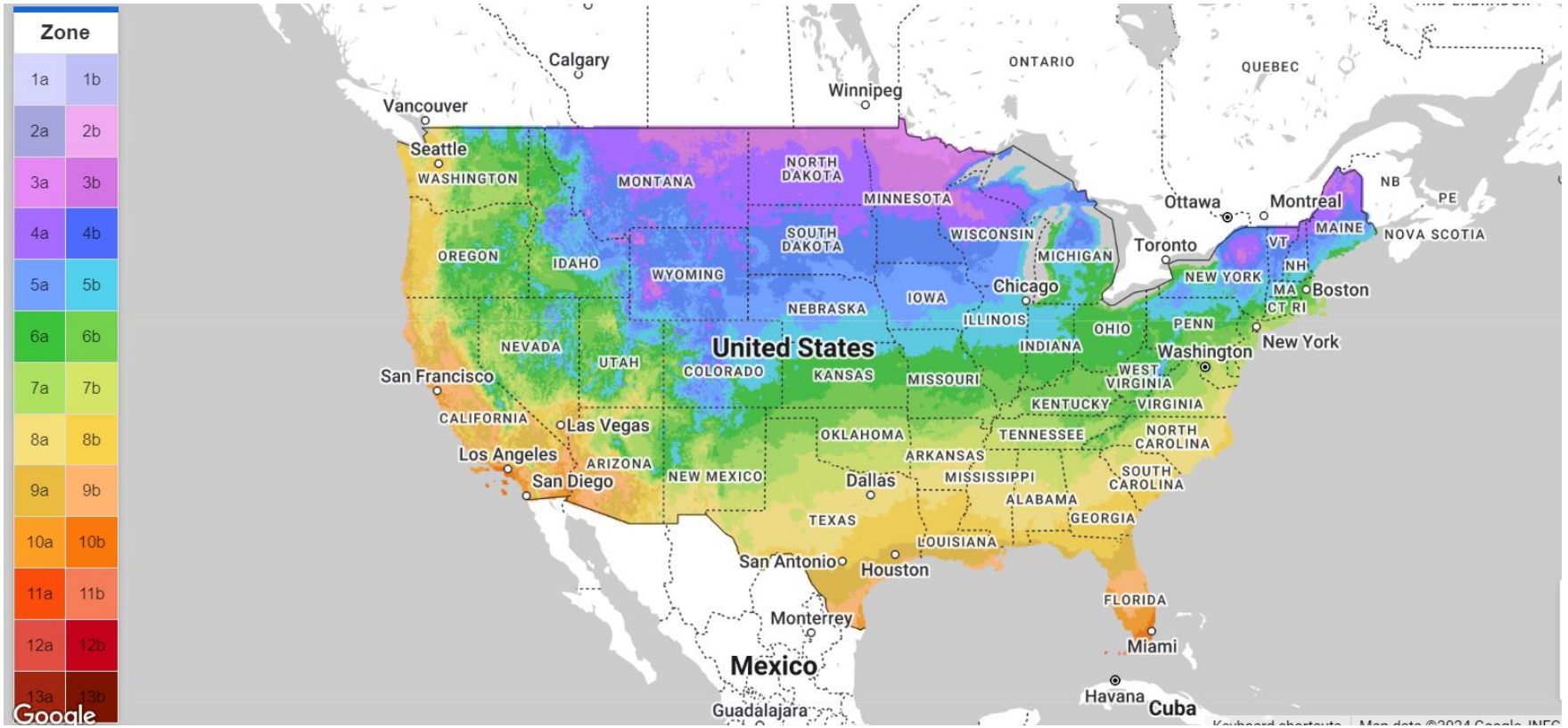


Figure ** Planting zones map of USDA plant hardiness (source www.morningchores.com)