to us. Photosynthesis works best with red and blue wavelengths. Bush Doctor (1993b) described the wavelengths emitted by commercial light bulbs.

Ultraviolet (UV) radiation consists of wavelengths shorter than deep purple light. **UV-A** contains wavelengths from 420 to 315 nm, **UV-B** ranges from 315 to 280 nm, and **UV-C** ranges from 280 to 100 nm. UV radiation damages nucleic acids and proteins in plants and people, especially UV-C. Ozone in the Earth's upper atmosphere absorbs all UV-C, about 95% of UV-B, and about 50% of UV-A. It has been suggested that *Cannabis* biosynthesizes THC as a UV protectant (Pate 1983, 1994). Indeed, under conditions of high UV-B exposure, *Cannabis* produces more THC (Lydon *et al.* 1987).

Table 2.2: Soil nutrient extraction of different crops during one growing season.[1]

CROP	N ($kg\ ha^{-1}$)	P_2O_5 ($kg\ ha^{-1}$)	K_2O ($kg\ ha^{-1}$)	CaO ($kg\ ha^{-1}$)	MgO ($kg\ ha^{-1}$)	S ($kg\ ha^{-1}$)
Maize (*Zea mays*) 12,200 kg grain ha^{-1}	302	130	302	93	123	37
Wheat (*Triticum* sp.) 5200 kg grain ha^{-1}	152	61	184	34	45	23
Oats (*Avena sativa*) 3600 kg grain ha^{-1}	131	43	165	21	37	22
Hemp-whole plant ≈200,000 dry kg ha^{-1}	177	53	184	199	35	18
Hemp-stems only 6000 kg ha^{-1}	52	12	99	68	12	8
Hemp-seeds only 700 kg ha^{-1}	33	18	8	3	6	9
Hemp-flowers only 1200 kg ha^{-1}	56	30	15	6	10	9

1. Data for rows 1-3 converted from Wolf (1999), rows 4-6 from Berger (1969), row 7 from McEno (1991).

Most experts describe *Cannabis* as a *short-day plant.* It flowers in the autumn, when the photoperiod drops below 12–13 hours per day, depending on the variety and its geographical origin. Actually, *Cannabis* is best described as a *long-night plant*—interruption of dark periods by a short light period will completely prevent flowering, while an interruption of the light period by even a long dark period will not prevent flowering.

ATMOSPHERE

Plants, like all living things, require oxygen to survive. But unlike all other creatures, plants provide their own O_2 as a by-product of photosynthesis. Atmospheric carbon dioxide (CO_2) is often the limiting factor for photosynthesis. Frank (1988) reported peak growth at CO_2 levels of 1500 to 2000 ppm (=1.5–2.0%), five or six times greater than current atmospheric concentrations.

SOIL

Soil science is an interdisciplinary field, the most complex feature a farmer must manipulate. In the USA about 20,000 types of soil are recognized (Brady & Weil 1999). Soil series are named by their sites of discovery—my garden is dense Vergennes clay; up the hill, the soil lightens to a Covington silty clay loam. *Cannabis* grows best in a nutrient-rich, well-drained, well-structured, high organic matter, silty loam soil. To create this hypothetical substrate, you have to evaluate the soil's nutrient content, pH, type, and texture.

Macronutrients are elements required by plants in relatively large amounts. Organic materials in soil provide three of the six macronutrients—nitrogen (N), phosphorus (P), and sulphur (S). Minerals in soil provide the other three macronutrients—potassium (K), magnesium (Mg), and calcium (Ca).

Micronutrients (formally called **trace elements**) are also essential for plant growth, but in relatively small amounts. Most micronutrients become toxic to plants if they exceed trace amounts. Minerals in soil provide all seven micronutrients—iron (Fe), zinc (Zn), boron (B), copper (Cu), manganese (Mn), chlorine (Cl), and molybdenum (Mo). Some nutrients are needed in extremely tiny amounts. For instance, a plant needs a million N atoms for every Mo atom (Jones 1998). Some researchers argue that nickel (Ni), cobalt (Co), sodium (Na), vanadium (V), titanium (Ti), and silicon (Si) are also plant micronutrients (Jones 1998).

Cannabis places greater nutrient demands upon the soil than other crops. See Table 2.2. Fibre crops require high soil N, high K, then in descending order: Ca, P, Mg, and micronutrients. Seed crops, compared to fibre crops, extract less K and more P from the soil. The nutrient extraction of drug crops has not been measured, but we present estimates in Table 2.2. Drug crops have a high P requirement (Frank & Rosenthal 1978, Frank 1988), and Mg, Fe, and Mn may play a role in the enzyme regulation of THC synthesis (Kaneshima *et al.* 1973, Latta & Eaton 1975).

Storm (1987) described the function of *Cannabis* plant nutrients in detail. A summary is found in Table 2.3. Plants lacking nutrients produce telltale symptoms. For deficiency symptoms and their correction see Chapter 7.

Soil acidity, measured as **pH**, directly affects the availability of nutrients in the soil. See Fig 2.1 for an illustration of this relationship in organic soils. In soils with insufficient organic materials, pH has a greater influence on nutrient availability (Wolf 1999). Duke (1982) summarized pH data from 44 reports and suggested a soil pH of 6.5 is best. Test the pH of a tablespoon of wet soil by adding a pinch of baking soda. If it fizzes, then pH < 5.0 (too acid). Then test a tablespoon of dry soil by adding a few drops of vinegar—if it fizzes, then pH > 7.5 (too alkaline). Meters to measure pH are relatively inexpensive and accurate. Frank & Rosenthal (1978) provided charts and tables for adjusting different soils to a proper pH.

Understanding soil, however, is more than measuring pH and nutrients. Digging up soil for chemical tests is like grinding up your finger and conducting the same tests—you learn a lot about pH and chemistry, but nothing about structure and function of the soil.

Soil structure and function is determined by mineral particles, organic material, and microbiology. The **particle size of minerals** determines the three major soil types—sand, silt, and clay. **Sand** consists of relatively large particles, from 2.0 to 0.05 mm in diameter (these sizes are USDA standards—the British standard is 2.0-0.06 mm). Sandy soil feels gritty when rubbed between the fingers. **Silt** consists of particles from 0.05 to 0.002 mm in diameter, with a floury feel. **Clay** particles are smaller than 0.002 mm, invisible under light microscopes. Wet clay soil