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Upper Klamath Basin Soil Resources

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Background

A brief general introduction to the geography and geologic development of the Upper Klamath Basin provides some perspective to the following discussions on Upper Klamath Basin soils as they influence productivity and land values. The Upper Klamath Basin is a high-elevation, short-growing-season area created from volcanic and sedimentary events. Klamath Basin geology reflects repeated volcanic activity, erosion, and sedimentary rock deposition with episodes of landscape faulting and folding.

It is an area where the high desert and the Cascade Mountain range meet. This provides the two dominant geophysical features that influence the climate and drainage of the Basin. Elevations range from 4,000 ft. in the southern end of the Basin to 8,700 ft. at Crater Lake in the northern end. This variation in elevation causes wide temperature ranges with a possibility for frost any day of the year. The CascadeMountain range to the west traps most of the coastal moisture, leaving the east side cooler and drier and exposing the Basin to a rain-shadow effect. Sage- and juniper-covered fault blocks and ridges form the eastern and southern sides (Powers, et. al.).

Upper Klamath Lake is the largest lake in Oregon and the main storage reservoir for the USBR Klamath Project. It is 60,000 to 90,000 acres in size with a mean summer depth of 7 feet, as described elsewhere in this report. The lake fills a graben (sunken area of earth's crust bound by faults) many thousands of meters deep, mainly with volcanic debris and sediments. This sedimentation continues today, producing a large shallow lake. The outlet for Upper Klamath Lake is the mile-long Link River that empties into Lake Ewauna, which then becomes the Klamath River, eventually reaching the Pacific Ocean through northern California. The town of Klamath Falls fans out south and east of Link River and Lake Ewauna.

The California-Oregon border approximately cuts the Basin in half. Clear Lake on the California side of the Basin is the second main source of water to the Klamath Reclamation Project with a 25,760-acre surface area and maximum summer depth of 30 feet. It is the source of the Lost River, which flows north out of Clear Lake, turning west and south and eventually ending up in the Tule Lake sump, a closed Basin system until man's manipulation in the 20th century (United States Department of the Interior Bureau of Reclamation, Klamath Project Map).

Soil formation

Soils, as used in this discussion, are dimensioned segments of landscape capable of supporting such higher plants as trees, shrubs, grasses, and agricultural crops. Soils are formed through the interaction of five major factors: climate, parent material, relief (topography), plant and animal life, and time. Most of the precipitation in the Upper Basin area occurs from October to March and is sufficient to moisten the soil to a depth of up to 5 feet. Evaporation greatly exceeds precipitation during the growing season.

Parent material is the unconsolidated mineral or organic matter in which soils form. Many distinctive kinds of parent material have influenced the formation and properties of soils in the survey area. The influence of parent material in soil formation can be profound where materials are contrasting and other soil-forming factors are weak. The soil properties most affected by differences in parent material in the survey area are bulk density (weight per unit volume), available water holding capacity, fertility, and availability of nutrients.

Soils generally are described from organic to mineral depending on their origin, and vary from peat to sandy loam and clay loam soils throughout the irrigable areas of fertile farmland. Soils in Klamath, Siskiyou, and Modoc counties in general can be divided into two broad categories. Highly organic muck soils are found in drained lakebeds, and mineral soils, ranging from sands to loams, are found in upland areas. The muck soils are characterized by having high fertility and water-holding capacities. The mineral soils tend to vary more and are more dependent on textural differences in regard to water and fertility status. Parent material and relief cause most of the differences in soils of the area.

Most of the agriculturally significant soils in the Upper Basin formed in lacustrine (lakebed) or alluvial (water borne) sediment weathered mainly from diatomite, tuff, and basalt. Soils on lake terraces in the Basins commonly are underlain by diatomite, or diatomite stratified with lacustrine sandstone. Some soils formed partly in sediment that washed off the lake terraces and partly in alluvium from outside the Basins. Soils that formed in lacustrine and alluvial sediment in the survey area have somewhat lower bulk density and somewhat higher available water-holding capacity compared to soils of similar texture and other mineral origin.

Fibrous organic material covers the floor of much of Upper Klamath Lake and large areas and bays around the lake, which have been diked and drained for irrigated cropland. The organic soils formed in this material have low bulk density, high available water-holding capacity, critical plant and animal nutrient deficiencies including copper and selenium, and low thermal conductivity. When farmed, this soil is subject to continuing subsidence (lowered soil surface elevation) due to oxidation of organic material.

Relief and landforms have been important factors both in soil formation and in determining the distribution of soils in the survey area. Relief also determines the location of lakes, streams, marshes, and soils that have a water table, soils that have alkali, and soils that are subject to flooding.

Man also has influenced differences in soils. He has diked and drained large areas of marsh, and cut and filled the land in leveling for irrigation. Man has also had an extensive, though recent, influence in modifying soil properties, by removing parts of soils from the landscape, and creating new areas of soils. It is estimated that more than 100,000 acres in the survey area has been leveled and smoothed for irrigation. Deep ripping to break up the hardpans, intensive fertilization, and irrigation have changed the reaction of the upper part of some soils from alkaline or neutral to slightly acid to strongly acid. Irrigation and drainage also have redistributed carbonates in the soils, decreased their salt and sodium contents, and lowered the depth of water tables. Tile drainage systems have been installed in many of the fields in the region to facilitate the lowering of perched water tables.

The Klamath Reclamation Project

The focus of this report is on soils of the Upper Klamath Basin and in particular within the United States Department of the Interior, Bureau of Reclamation's Klamath Reclamation Project, which encompasses 233,625 acres of irrigable lands in Klamath County, Oregon, and Modoc and Siskiyou counties in California. Man's activities during the early part of the 20th century started the change from a natural shallow lake-marsh system to an agricultural and waterfowl refuge system. Project development was begun in 1906 with construction of the main A-Canal out of Upper Klamath Lake. In 1908, the Keno Reef in the Klamath River below Keno was lowered, which began turning Lower Klamath Lake into agricultural land and a wildlife refuge. Tule Lake also was reclaimed for agriculture and a wildlife refuge with the diversion of part of the Lost River drainage area to the Klamath River and establishment of an evaporation Basin by expansion of Clear Lake.

Other major elements of the modern-day Klamath Project include the Lost River Diversion Channel that can control flooding in the Tulelake area by diverting water from the Lost River to the Klamath River, and the Tule Lake Tunnel that conveys drainage water from the Tule Lake sumps to the Lower Klamath National Wildlife Refuge and back to the Klamath River via the Klamath Straits Drain. The Diversion Channel also can augment irrigation supplies to the Klamath Project from the Klamath River.

Soil capability classes and crop yield potential

U.S. Department of Agriculture (now USDA Natural Resources Conservation Service, formerly USDA Soil Conservation Service) soil capability classes show, in a general way, the suitability of soils for most kinds of field crops. Soils are classified according to their limitations for field crops, the risks of damage from cultivation, and their response to treatment. The grouping does not consider major and generally expensive land forming that would change slope, depth, or other characteristics of the soils, possible but unlikely major reclamation, and does not apply to horticultural or other crops that require special management.

Soils are placed in Capability Classes represented by Roman numerals I to VIII. The numerals indicate progressively greater limitations and narrower choices for practical use. These classes are defined as follows (Soil Conservation Service, 1985):

- Class I soils have few limitations that restrict their use.
- Class II soils have moderate limitations that reduce the choice of plants or that require moderate conservation practices.
- Class III soils have severe limitations that reduce the choice of plants or that require special conservation practices, or both.
- Class IV soils have very severe limitations that reduce the choice of plants or that require very careful management, or both.
- Class V soils are not likely to erode but have other limitations, impractical to remove, that limit their use.
- Class VI soils have severe limitations that make them generally unsuitable for cultivation.
- Class VII soils have very severe limitations that make them unsuitable for cultivation.
- Class VIII soils and miscellaneous areas have limitations that nearly preclude their use for commercial crop production.

Limitations for soils in the Upper Klamath Basin include the following (Soil Conservation Service, 1985):

- Erosion: soils susceptible to erosion.
- Water: poor soil drainage, wetness, high water table or overflow.
- Soil limitations: shallow or stony rooting zone, low water holding capability, low fertility, salinity, and sodium.
- Climatic limitations: frost risk or lack of moisture.

Because of the high-altitude-induced short growing season and nearly constant possibility of frost, there are no designated capability Class I soils in the Upper Klamath Basin. Soils have essentially been down rated one class as a result.

However, for frost-tolerant crops normally grown in the area, the tables of estimated crop yields in the referenced USDA soil surveys generally underestimate current crop production potential. Irrigation and drainage within the Klamath Reclamation Project and advances in crop varieties, crop-protection strategies and agronomic systems developed in recent decades in cooperation with local producers by Oregon State University and University of California agricultural experiment stations have contributed to production capabilities beyond the basic soil survey ratings. Higher crop yields in test plot experiments and on-farm field trials are documented in annual reports of the two university stations. Yields in excess of those estimated in the original soil surveys also are documented in annual crop reports prepared by Modoc and Siskiyou County Agricultural Commissioners, Tulelake Irrigation District, Klamath County Cooperative Extension, and the U.S. Bureau of Reclamation.

An example of this is shown with a Poe fine sandy loam soil found at the Klamath Experiment Station (KES). The Klamath County Soil Survey states that alfalfa yields expected would be 5 tons/acre. However, in a variety trial conducted from 1997 to 2000 with 28 varieties, the average yield was 6.5 tons/acre. In the soil survey it also shows that expected yields of wheat would be 5,100 lb/acre. In the 2000 Western Regional Spring Wheat Nursery at KES across 39 varieties, average wheat yield was 6,150 lb/acre. For barley, soil survey yield estimates are 4,560 lb/acre. In the 2000 Western Regional Spring Barley Nursery at KES across 36 varieties, average barley yield was 5,730 lb/acre. Soil survey potato yields were estimated to be 330 cwt/acre. In the 2000 Western Regional Potato Trial across 16 varieties, average yield was 550 cwt/acre (Klamath Experiment Station).

Prime farmland

Soils falling in soil Capability Class I through Class III usually are designated Prime Farmland. When irrigated, or irrigated and drained, most of the agricultural soils in the Klamath Project can be considered Prime Farmland as defined and recognized by the United States Department of Agriculture. Prime Farmland is of strategic importance in meeting the nation’s short- and long-range needs for food and fiber. State and local land-use planning laws are designed to protect and preserve Prime Farmland. The cutoff of irrigation water to Klamath Project lands during the 2001 crop season, in effect, resulted in a temporary loss of many thousands of acres of Prime Farmland by preventing the production of economic crop yields.

Specific soil series data

An analysis was completed investigating specific soil series properties within the southern Klamath County and California portions of the Klamath Project. Data for Oregon was obtained from the "Soil Survey of Klamath County Oregon, Southern Part," issued April 1985. For the Oregon portion of this analysis, a very diverse set of soils are encountered. Seventy-five series, complexes, and associations of soils are considered fit for irrigated crops or pastures. Of these 75 series, 22 are considered Prime Farmland. These 22 series are found on more than 133,000 acres in Klamath County.

Data for the California portion of the analysis were obtained from the "Soil Survey of Butte Valley—Tule Lake Area, California, Parts of Siskiyou and Modoc Counties," issued February 1994. For the area of California considered, less diversity of the soils was apparent with most of the soils being found on the drained lakebeds of Lower Klamath Lake and Tule Lake. The soils analyzed in California included those found in the Klamath Irrigation Project and in the Tule Lake and Lower Klamath Lake National Wildlife Refuges. Ten soil series were analyzed, which accounted for more than 148,000 acres. The data for both the Oregon and the California Prime Farmland soils are included in Table 1.

Table 1. Textural class, slope, area, depth to hardpan, depth to water table, and available water for the Prime Farmland soils of southern Klamath County, Oregon, and the Klamath Project portion of Modoc and Siskiyou counties in California.

State	Soil series name	Soil textural class	Slope	Acres	Percent of total	Depth of hardpan	Depth of water table	Avail. water	Avail. Water
						inches	inches	in/depth	in/ft
OR	Calimus	fine sandy loam	0-2	3,022	1.1%	>60	>60	9.5	1.9
OR	Calimus	loam	0-2	10,543	3.7%	>60	>60	9.9	2.0
OR	Calimus	fine sandy loam	2-5	5,653	2.0%	>60	>60	9.5	1.9
OR	Calimus	loam	2-5	9,427	3.4%	>60	>60	9.9	2.0
CA	Capjac	silt loam	0-1	43,700	15.5%	>60	>60	28.2	5.6
CA	Capjac	silt loam ponded	0-1	4,240	1.5%	>60	>60	28.2	5.6
OR	Capona	loam	0-2	843	0.3%	20-40	>60	4.4	2.1
OR	Capona	loam	2-5	2,550	0.9%	20-40	>60	4.4	2.1
CA	Dehill	fine sandy loam	0-5	6,350	2.3%	>60	>60	7.2	1.4
OR	Deter	clay loam	0-2	3,503	1.2%	>60	30-72	9.9	2.0
OR	Deter	clay loam	2-7	915	0.3%	>60	>60	9.9	2.0
OR	Dodes	loam	2-15	4,693	1.7%	20-40	>60	3.9	2.1
CA	Dotta	sandy loam	0-5	4,630	1.6%	>60	>60	7.0	1.4
CA	Eastable	loam	0-5	6,250	2.2%	>60	>60	9.8	1.9
OR	Fordney	loamy fine sand	0-2	29,592	10.5%	>60	24-72	6.9	1.4
CA	Fordney	loamy fine sand	0-2	7,760	2.8%	>60	>60	6.9	1.4
OR	Fordney	loamy fine sand terrace	0-3	1,006	0.4%	>60	>60	6.9	1.4
OR	Fordney	loamy fine sand	2-20	8,964	3.2%	>60	>60	6.9	1.4
OR	Harriman	loamy fine sand	0-2	1,930	0.7%	40-60	30-72	6.9	2.0
OR	Harriman	loam	0-2	4,210	1.5%	40-60	30-72	9.0	2.3
OR	Harriman	loam	2-5	2,990	1.1%	40-60	>60	8.8	2.2
OR	Lakeview	silty clay loam	0	2,957	1.1%	>60	30-60	10.7	2.1
CA	Laki	fine sandy loam	0-2	9,570	3.4%	>60	>60	14.2	2.8
CA	Klamath	silt loam	0-1	11,720	4.2%	>60	>60	12.8	2.6
OR	Modoc	fine sandy loam	0-2	7,645	2.7%	20-40	>60	4.4	1.7
OR	Modoc	fine sandy loam	2-5	2,438	0.9%	20-40	>60	4.4	1.7
OR	Poe	loamy fine sand	0	6,100	2.2%	20-40	24-48	3.5	1.4
OR	Poe	fine sandy loam	0	1,526	0.5%	20-40	24-48	3.5	1.4
CA	Truax	fine sandy loam	0-5	4,520	1.6%	>60	>60	7.5	1.5
OR	Tulana	silt loam	0	16,671	5.9%	>60	24-60	38.2	5.0
OR	Tulana	silt loam sandy substratum	0	5,904	2.1%	>60	24-60	25.6	5.1
CA	Tulana	silt loam	0-1	7,930	2.8%	>60	>60	25.4	5.1
CA	TuleBasin	mucky silty clay loam	0-1	41,560	14.8%	>60	>60	24.0	4.8
		Total Acres		281,312					

(Soil Conservation Service 1985; and Soil Conservation Service 1994.)

For these Prime Farmland soils, depth to hardpan, depth to the water table, and available water holding capacity were determined. Hardpans, some which could be ripped by deep chisels, and bedrock at depths of less than 60 inches were indicated for 12.4 percent of the soils. These layers, if not mechanically altered, will limit water-holding capacities and rooting depth. During some portion of the year, 25.7 percent of the soils would be affected by shallow water tables found less than 60 inches below the soil surface. Drainage tiles would help these soils and extensive systems have been employed in the Klamath Basin.

The diversity of the soils is apparent when water-holding capacities were analyzed. Water-holding capacity is both a function of the inherent ability of a soil to hold water and the depth of the soil. Water-holding capacity is a key parameter in irrigation scheduling, being a principal determinant of the maximum allowable time between irrigations. Categorizing the soils in Table 1 by their relative water-holding capacities reveals the following:

- 57.3 percent of the area has soils that hold less than 3 inches of water per foot of soil.
- 14.8 percent of the area has soils that hold less than 5 inches, but more than 3 inches of water per foot of soil.
- 27.9 percent of the area has soils that hold less than 6 inches, but more than 5 inches of water per foot of soil.

When the soil depth of the different series was combined with the water-holding capacities, the amount of the water held in the total depth of the soil (down to 60 inches) was:

- 48.8 percent of the area has soils that hold less than 10 inches of water for the depth of the soil.
- 8.6 percent of the area has soils that hold less than 20 inches, but more than 10 inches of water for the depth of the soil.
- 36.8 percent of the area has soils that hold less than 30 inches, but more than 20 inches of water for the depth of the soil.
- 5.9 percent of the area has soils that hold less than 40 inches, but more than 30 inches of water for the depth of the soil.

Klamath County Tax Assessor data

In Klamath County, recent map-digitizing efforts have allowed NRCS Soil Capability Classes to be assigned to soils for tax assessing purposes. The Klamath County Tax Assessor divides the Klamath Project into six irrigated areas; Midland/Henley/Olene, Poe Valley, Merrill/Malin, Lower Klamath Lake, Shasta View/Malin, and Malin Irrigation District. Table 2 includes the soils in these areas divided into their Capability Classes.

Table 2. Capability Classes of privately owned land in six irrigated areas of Klamath County and the percentage that did not receive full irrigation in the 2001 growing season.

Area	Total acres	Crop and pasture land Class II	Class III	Class IV	total	Non-crop total	Grand total
		Percent of Land in Each Class					
1	50,700	15.0	36.6	23.5	75.1	24.9	100.0
2	36,260	13.6	18.1	20.2	52.0	48.0	100.0
3	25,362	8.0	55.1	24.5	87.5	12.5	100.0
4	20,630	1.4	90.3	6.1	97.7	2.3	100.0
5	5,345	18.7	58.0	20.6	97.3	2.7	100.0
6	3,525	8.5	82.4	3.4	94.3	5.7	100.0
Total	141,822	11.4	44.9	19.7	76.0	24.0	100.0
		Percent of each class that did not receive full water					
1	50,700	84.4	88.1	91.3	88.4	100.0	91.3
2	36,260	59.1	68.5	59.9	62.7	100.0	80.6
3	25,362	78.0	81.8	83.3	81.9	100.0	84.1
4	20,630	89.6	70.8	76.9	71.4	100.0	72.1
5	5,345	61.0	76.0	88.4	75.7	100.0	76.4
6	3,525	28.7	82.0	96.7	77.7	100.0	79.0
Total	141,822	73.5	78.8	80.5	78.4	100.0	83.6

Klamath County Tax Assessor irrigated areas:

1 - Midland/Henley/Olene
2 - Poe Valley
3 - Merrill/Malin
4 - Lower Klamath Lake
5 - Shasta View/Malin
6 - Malin Irrigation District

For the six areas considered, no Class I (due to climatic limitations) and very limited amounts of Class V soils are present. Overall, more than 140,000 acres of land are found in the six areas. Of this land, 76 percent is classed suitable for crops. The 24 percent found in classes V to VIII are found mainly on hills and mountains that limit their use for crops.

Klamath County has decided to alter the tax liability for property for the 2001 growing season depending on whether the land received full irrigation or not. Full irrigation was defined by Klamath County Assessor Reg LeQuieu as irrigation that was available for cropland throughout the growing season (LeQuieu). A land-based survey was completed on August 3 to verify the land area that did not receive full irrigation. The special assessed value for these lands not receiving full irrigation will be $28.41 per acre. Also included in Table 2 are the percentages of each of the soil Capability Classes that did not receive full irrigation.

For the Midland/Henley/Olene area, mainly serviced by the Klamath Irrigation District, more than 88 percent of the land did not receive full season irrigation. This was the highest percent of any of the Tax Assessor's areas to not receive full irrigation. In contrast only about 63 percent of the Poe Valley area did not receive full season irrigation. This reflects more irrigation wells operating in this area and land serviced by the Horsefly Irrigation District that did receive irrigation water during the 2001 growing season from Gerber Reservoir and Clear Lake. Overall, about 108,000 acres are considered cropland in Klamath County, and of this area more than 78 percent did not receive full irrigation.

For the California portion of the Klamath Basin, the soils are in general more homogeneous than those found in the Oregon portion. The bulk of the soils are mucky silt loams, which, due to climatic, high water table, and sodicity factors, fall into the Capability Class III. . Nonetheless, high organic-matter soils common in this region produce some of the highest-yielding crops in the Project. The installation of tile drainage systems and the use of overhead irrigation systems for frost protection have mitigated most of the innate limitations of these soils. Some of the sandier, alkali-affected area near the Oregon-California border south of Malin would fall into the Class IV capability soils.

Land values

Another aspect of the loss of irrigation water in the Klamath Project that must be considered is the effect on land values. Data provided by Reg LeQuieu, Klamath County Tax Assessor, for the years 1998 to 2000 indicate the magnitude of this effect. More than 6,000 irrigated acres were sold in Klamath County during this period at an average price of $1,687 per acre. For the same time period, close to 1,300 dryland acres were sold at an average price of $783 per acre. This resulted in the dryland acres returning more than $900 less per acre as compared with the irrigated land (LeQuieu). This land value analysis is not complete, but at the time of the communication was the best available data.

Soil erosion

The wearing away of land by water, wind, ice, or other geologic processes continues to occur naturally or can be accelerated by man or catastrophes such as fires and floods. Since the Klamath Project is essentially a closed-Basin system, deposition from running water occurs at the Tule Lake Sump and in drainage ditches and canals. This loss in topsoil results in reduced farm productivity and additional expense to the irrigation districts for maintenance of the irrigation system. Adoption of efficient sprinkler irrigation systems limits soil erosion caused by water transport of soil particles. Most of the farmland in the Klamath Project is under sprinkler irrigation (80 percent) with minor acreages (20 percent) of cereal crops and pastures being surface irrigated (U.S. Department of the Interior, Bureau of Reclamation, annual Crop Reports).

Wind erosion is the major cause of soil loss, especially in the spring during field preparation. Several thousand acres of Klamath Project soils are rated as Highly Erodable Lands (HEL) by NRCS. Several thousand additional acres of deep, organic soils escape the HEL designation due to their great depth and high tolerance for incremental soil loss under the Universal Soil Loss Equation (USLE) used by the agency to determine soil loss tolerance. Nonetheless, these light, organic soils are highly subject to wind erosion when dry, and present air quality and public safety hazards beyond their modest erodability ratings.

The recent decision to deny Klamath Project water deliveries to farmers threatened to transform the productive Basin into a major dust bowl (Woodley, R.). With 30,000 acres of bare soil exposed to the Basin’s historically windy springs, serious soil erosion was a certainty. In response, the Klamath Soil and Water Conservation District (KSWCD) implemented the largest single soil-conservation effort in the Northwest (Woodley, personal communications). The KSWCD, with resources from the USDA Natural Resource Conservation Service, was able to institute a cover crop program for farmers to cover bare soil on their farms. Growers were offered cost sharing to plant a small cereal grain crop to protect exposed soil.

This effort resulted in the planting of cover crops on more than 37,500 acres in the Klamath Project, which includes portions of Klamath, Modoc and Siskiyou counties. The cost of the program for these planted acres was $1,725,000. The growers participated on a cost-share basis, providing a 25 percent match and receiving a 75 percent cost-share payment. The amount paid to participants of the cover crop program was nearly $1,293,750. Growers were reimbursed after they were determined to be eligible and their cover crop planting was certified to be complete. Some growers who reacted quickly to the situation and planted a cover crop before the program started were not eligible for the cost-share payment.

With some limitations, the program was able to conserve topsoil in the Basin. It is estimated that 95 percent of the cover crops seeded did emerge with a significant reduction in Upper Klamath Basin soil erosion. (Woodley, R.)

The Oregon Department of Environmental Quality monitors Upper Klamath Basin air quality for particulates during the firewood-burning season for health and safety reasons. There is no such air quality data available for the early 2001 spring time period, but residents greatly appreciated the cover crop program for reducing dust in the air, and farmers benefited by saving tons of soil from loss to wind erosion.

Crop rotations

Crop rotations are essential for sustainable, long-term farming operations. In general, productive rotations for the Klamath Basin include alfalfa with grain crops between no more than two row crops in an 8- or 9-year cycle. Most of the Basin’s mineral soils are low in soil organic matter. The alternating use of alfalfa and grain crops and residue management can help build organic matter while reducing insect and disease buildup in the soil. Rotations in which potatoes are grown 3 or more years apart increase yields and reduce quality losses due to soil-borne pests.

Organic soils, while naturally high in organic matter, also benefit from crop rotations in reducing insect and disease problems while improving soil tilth. There is interest in including green manure crops of sudangrass, white mustard, and rape for their beneficial effects on nematode population reductions and general soil improvement.

Economics and physical management considerations often override long-term goals, but short-term strategies are not sustainable from a soil-building perspective and can cause long-term problems. Appropriate rotations that include a diversity of both row and field crops improve soil tilth (structural integrity and organic matter) while avoiding or reducing pest problems. The loss of a dependable water source for agriculture has disrupted normal cropping rotations while adding another difficult consideration for choice of crop. Without a dependable water source, high value, input-intensive row-crop farming is not possible. This will restrict crop rotations to a less-diverse mix of crops that can survive if water is restricted and that are generally of lower value than row crops. These crops would include alfalfa, cereal grains, and pastures.

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