Chapter 20 Rainfed Farming Systems in the USA

Alan Franzluebbers
USDA-ARS, alan.franzluebbers@ars.usda.gov

Jean L. Steiner
USDA-ARS, jean.steiner@ars.usda.gov

Doug Karlen
USDA-ARS, doug.karlen@ars.usda.gov

Tim Griffin
Tufts University, timothy.griffin@tufts.edu

Jeremy Singer
USDA-ARS

See next page for additional authors

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Alan Franzluebbers, Jean Steiner, Doug Karlen, Tim Griffin, Jeremy Singer, and Don Tanaka

Abstract This chapter describes characteristics of four major rainfed farming regions and systems in the USA: Great Plains wheat-sorghum-cattle; midwestern corn-soybean-hogs, southern cotton-peanut-poultry, and coastal diversified crops-dairy. Rainfed farming systems in the USA are highly productive, economically important, ecologically diverse and technologically driven. Management approaches to achieve resource efficiency and agricultural sustainability are described, including the use of improved genetic seed sources, crop rotations, appropriate fertiliser application techniques, conservation tillage and integrated crop-livestock production systems. Issues of increasing oil and fertiliser prices, sustainability of soil and water resources, and climate change are current challenges facing agriculture in the USA.

Keywords Biofuel production • Carbon sequestration • Cattle • Conservation tillage • Corn • Cotton • Crop rotations • Dairy • Environmental quality • Forages • Hogs • Integrated crop–livestock systems • Nitrogen • Peanut • Phosphorus • Poultry • Soybean • Water quality

A. Franzluebbers (✉)
USDA – Agricultural Research Service, J. Phil Campbell Sr. Natural Resource Conservation Center, Watkinsville, GA 30677, USA
e-mail: alan.franzluebbers@ars.usda.gov

J. Steiner
USDA – Agricultural Research Service, Grazinglands Research Labouratory, El Reno, OK 73036, USA

D. Karlen and J. Singer
USDA – Agricultural Research Service, National Soil Tilth Labouratory, Ames, IA 50011, USA

T. Griffin
Tufts University, Friedman School of Nutrition Science and Policy, Boston, MA 02111, USA

D. Tanaka
USDA – Agricultural Research Service, Northern Great Plains Research Labouratory, Mandan, ND 58554, USA

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20.1 Introduction

The United States of America (USA) is a large country (982 million hectares) with a diverse economic base. Agriculture currently contributes about $90 billion to the economy (USDA-ERS 2008), but this is less than 1% of the gross domestic product.

Rainfed farming systems are important throughout the USA, but are most dominant in the eastern half where precipitation is greater than 500 mm/year. Various regions of the country have unique climatic, physical, and socio-economic conditions that have contributed to the development of particular farming systems. Four major regions of the country with rainfed farming systems will be characterised and are outlined in Table 20.1.

North Dakota, Iowa, Georgia, and New York states are similar in size of land area, but different in their socio-economic and agricultural characteristics (Table 20.2).

New York and Georgia have vastly greater human population, somewhat greater per capita income and cultural diversity, and far less farmland than North Dakota and Iowa. Average farm size is largest in North Dakota, followed by Iowa, and smaller in Georgia and New York.

20.1.1 Climate of the USA

The climate of the USA is diverse. Mean annual temperature generally increases from north to south, while mean annual precipitation generally increases from west to east, except for the wetter conditions along the Pacific Coast and Rocky Mountains (Fig. 20.1).

Rainfed farming systems can be found throughout the country, even in areas with significant irrigation. Irrigation water supplies are becoming increasingly challenged by growing urban and suburban human populations in warm, arid and semi-arid regions where irrigated agriculture has traditionally been developed. Rainfed farming alternatives to irrigated agriculture are developing as a means towards maintaining agricultural sustainability in these areas.

Different regions of the country have developed specialised cropping and animal production systems under the influence of temperature and water limitations. Fig 20.2 shows examples of the differences in monthly temperature and precipitation that occur among the four major farming regions.

Table 20.1 Four major rainfed regions of USA

Region	Major enterprises	Representative state
Great Plains	Wheat–sorghum-cattle	North Dakota
Midwestern	Corn–soybean–hogs	Iowa
Southern	Cotton–peanut–poultry	Georgia
Eastern and western coastal	Diversified crops–dairy	New York

Table 20.2 Characteristics of the four representative states

Characteristic	North Dakota	Iowa	Georgia	New York
Area (Mha)[a]	17.9	14.5	15.0	12.2
Total human population (millions)[a]	0.6	2.9	8.2	19.0
Per capita income ($)[a]	17,769	19,674	21,154	23,389
Farm number[b]	30,619	90,655	49,311	37,255
Farmland (Mha)[b]	15.9	12.8	4.3	3.1
Mean farm size (ha) [b]	519.4	141.7	88.3	83.4
Value of machinery/equipment per farm ($)[b]	124,298	100,422	51,847	96,252
Total cropland (Mha)[b]	10.7	11.0	1.9	2.0
Rainfed farmland (%)[b]	99.5	99.6	91.9	99.0
Value of crop products sold ($ billion)[b]	2.5	6.1	1.6	1.1
Value of livestock products sold ($ billion)[b]	0.8	6.2	3.3	2.0
Cattle and calves sold (million head)[b]	1.1	2.9	0.6	0.6
Hogs and pigs sold (million head)[b]	0.4	41.2	1.2	0.3
Meat chickens sold (million head)[b]	0.2	9.6	1,288.5	2.8
Wheat grain harvested (Mt)[b]	5.9	<0.1	0.2	0.2
Sorghum grain harvested ('000 t)[b]	1.2	3.6	25.9	0.4
Corn grain harvested (Mt)[b]	2.8	47.0	0.7	1.1
Soybean harvested (Mt)[b]	2.4	13.3	0.1	0.1
Cotton fiber harvested ('000 t)[b]	NR	NR	351.4	NR
Peanuts harvested ('000 t)[b]	NR	NR	532.5	NR
Forage harvested (dry weight '000 t)[b]	3.2	4.7	1.3	5.2

NR, not reported
[a] Data from the 2000 US Census (http://factfinder.census.gov)
[b] Data from the 2002 Census of Agriculture (USDA-NASS 2002)

20.1.2 Soils of the USA

Soil resources are as diverse as the climate, and all 12 of the soil orders in the USDA Soil Taxonomy classification system can be found (USDA 1999). The most important soils for agriculture are Mollisols, Alfisols, Entisols, Inceptisols and Ultisols.

Mollisols are the dominant soils in rainfed farming areas, occupying 21.5% of the total land area in the USA, and are extensive in the Great Plains region. They were derived from grassland ecosystems, being characterised by a thick, dark surface horizon.

Alfisols occupy 13.9% of the land area, and occur throughout the USA. They were derived from moderately leached forests, are well developed with relatively high native fertility and contain a subsurface clayey horizon.

Entisols occupy 12.3% of the land area and are of more recent origin. They were formed from unconsolidated parent material and usually have no genetic horizons

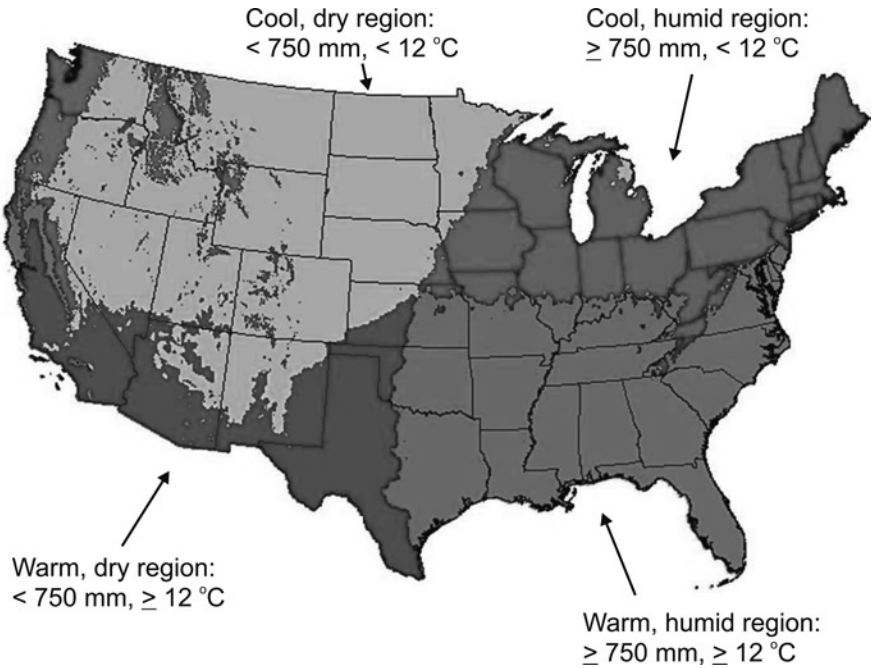

Fig. 20.1 Major climatic regions in the USA based on mean annual precipitation and mean annual temperature. Produced by H.J. Causarano using the spatial climate analysis service (www.prism.oregonstate.edu/)

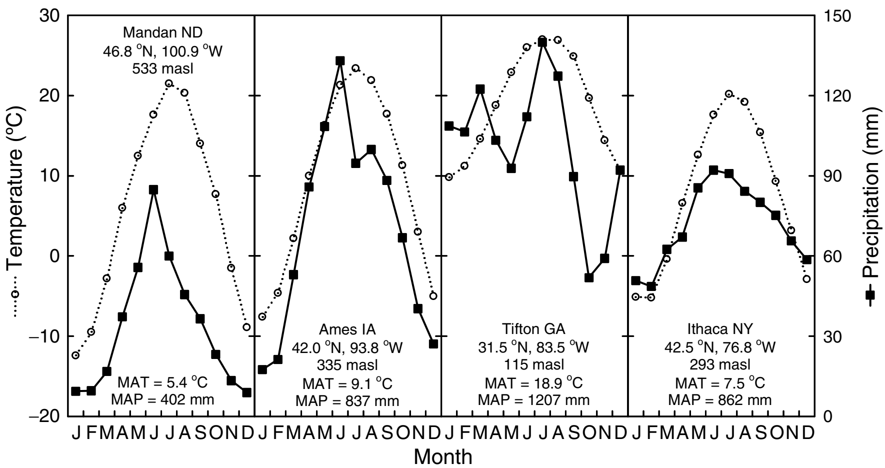

Fig. 20.2 Mean monthly temperature and precipitation at four locations representing the wheat-sorghum-cattle region (Mandan, North Dakota), corn–soybean–hogs region (Ames, Iowa), cotton–peanut–poultry region (Tifton, Georgia), and diversified crops–dairy region (Ithaca, New York). Long-term data (>30 year) from www.worldclimate.com. MAT is mean annual temperature and MAP is mean annual precipitation

except an A horizon. Soils that do not fit into one of the other 11 orders are often considered Entisols. Thus, they are very diverse, both in environmental setting and land use. Although many Entisols are found in rough terrain, they also occur in large river valleys and associated shore deposits where they provide suitable farmland.

Inceptisols occupy 9.7% of the land area. They are more developed than Entisols, but exhibit minimal horizon development and lack distinct features. Inceptisols are widely distributed and occur under a range of ecological settings, but are more typically used for forestry, recreation, and low-input grasslands than for productive farmland.

Ultisols (9.2% of the land area) are soils strongly leached, acidic, and with relatively low native fertility. Because of the favorable climate in the southeastern USA where they predominate, Ultisols often support productive forests. Being acidic with relatively low levels of plant-available Ca, Mg, and K, most Ultisols need liming and fertilising to be agriculturally sustainable. There are a number of minor soil types that are not particularly relevant to rainfed farming systems.[1]

20.1.3 Contrasting Characteristics of Agricultural Regions in the USA

Agriculture in the USA is highly and technologically advanced. It is dependent on fossil fuel for operating tractors and harvest equipment, for supplying energy to dry and process products, and for the manufacture of nitrogen fertiliser and various pesticides. There are more than two million farms in the USA, concentrated more in the east than in the west due to more favorable precipitation in the east (Fig. 20.3). Most of the cropland occurs in the eastern half of the country (Fig. 20.4a) and most of the pastureland (both native and introduced forages) in the western half (Fig. 20.4b).

Cropland constitutes 18% of the country, and pastureland 20%. Concentrated areas of animal sales are a feature of the highly industrial model of concentrated animal feeding operations (CAFOs) in the USA. This model has specialisation in each step of production with vertical integration through either contractual arrangements or ownership by large companies. In 2000, four companies slaughtered 81% of cows, 73% of sheep, 57% of pigs, and 50% of chickens (Swenson 2000).

Because of high technological and fossil-fuel inputs, many farmers in the USA are capable of utilising large land areas. In 2002, 2.1 million farms were operating on 380 Mha of farmland. In general, farm size increases with decreasing precipitation, because of lower yield potential and need for greater land area to support the investments required to farm (Table 20.2).

[1]Soil maps of the USA can be found at: http://soils.usda.gov/technical/classification/taxonomy/.

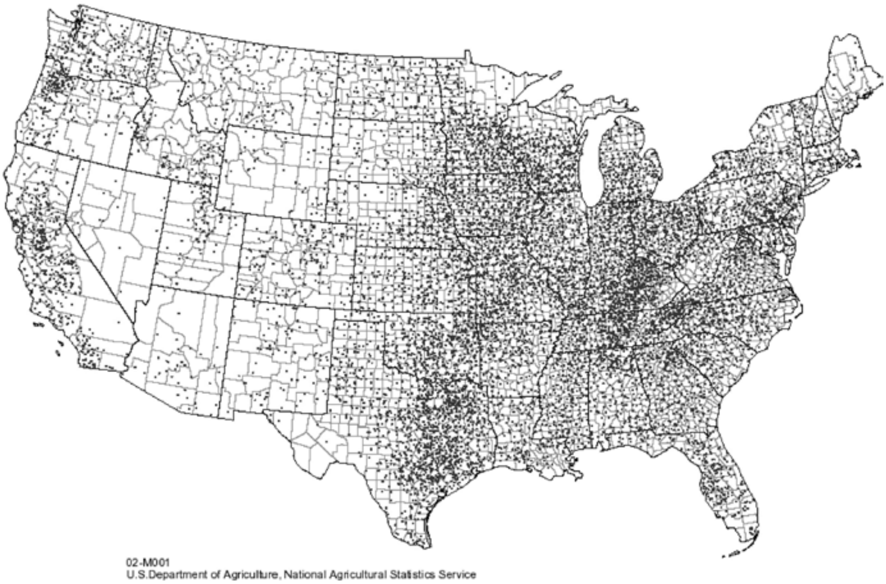

Fig. 20.3 Distribution of farms in the USA. Each dot represents 200 farms with a total of 2,128,982 (USDA-NASS (2002))

Fig. 20.4 Distribution of (**a**) cropland (total of 175.8 Mha) and (**b**) pasture land (total of 197.2 Mha) in the USA. Each dot represents 20,243 ha (USDA-NASS (2002))

20.2 Great Plains Wheat–Sorghum–Cattle Region

20.2.1 Climate and Soils

The Great Plains has a continental climate, characterised by (1) a strong precipitation gradient, decreasing from east to west by as much as 60 mm per 100 km and (2) extreme variability among seasons and years (Garbrecht and Rossel 2002).

The southern portion of the Great Plains is much 'drier', because the warmer temperatures in autumn, winter, and spring contribute to higher evaporative demand.

Precipitation occurs in all months, but predominantly in summer (Fig. 20.2). Evaporative demand greatly exceeds precipitation. For example in the southern portion (Bushland, Texas), evaporative demand is more than twice that of precipitation during each month of the year (Steiner et al. 1988). With year-long water deficit, crop management focuses on capturing and storing water in soil for use during the growing season and minimising evaporation from the soil (Stewart and Steiner 1990). Depending on the magnitude of the water deficit, the type and frequency of cropping is contingent upon soil water storage from previous seasons. In the northern Great Plains, a considerable portion of precipitation falls as snow, providing opportunities for snow trapping strategies to accumulate soil moisture.

Great Plains soils are predominantly Mollisols, rich in basic cations. They are capable of storing sufficient water deep in the soil profile to withstand extended dry periods characteristic of the semi-arid and arid region of the western states of the Great Plains.

20.2.2 Structure and Characteristics of Farming Systems

Wheat in the USA is grown primarily (Fig. 20.5a) in the sub-humid to semi-arid Great Plains region that lies between the Rocky Mountain foothills and roughly the 98th meridian. In the Great Plains region, wheat production was historically a monoculture, interrupted only by bare fallow in areas with unreliable and low precipitation during the growing season (Fig. 20.2). In the northern Great Plains, winter and spring wheat and other small grains (e.g. barley, oat, rye, triticale) are the main crops, as the low mean annual temperature and consequent short, summer growing season limits opportunities for alternative crops. In the central and southern Great Plains, winter wheat is grown for grain, but also as winter forage, especially in the

Fig. 20.5 Distribution of (**a**) wheat harvested for grain (total of 18.4 Mha; each dot represents 4,049 ha) and (**b**) sorghum harvested for grain (total of 2.7 Mha; each dot represents 810 ha) in the USA (USDA-NASS (2002))

southern part of the region. Evapotranspiration for wheat is high, because of a long growing season, and especially in spring and early summer, when wheat is forming and filling grain, while wind speeds, vapor pressure deficits, and solar radiation are high (Howell et al. 1997).

A large portion of sorghum in the USA is grown in the southern Great Plains, often in rotation with wheat to provide flexibility in capturing the widely varying precipitation among years (Fig. 20.5b). Grain sorghum survives extended dry periods in the summer, and therefore offers producers an alternative rotation crop to the continuous winter wheat cycle. In the central Great Plains, where evaporative demand and minimum temperature are lower than in the southern Great Plains, corn rather than sorghum is sometimes grown in rotation with wheat. Across the Great Plains, there are a number of other summer crops that have been explored for their role in wheat-based rotations.

Beef cattle production is also a key component of agriculture in the Great Plains. Some farms integrate beef production with annual and perennial crops and native rangeland, while other farms have more specialised systems (i.e., CAFOs). Cattle production in the USA has the distinct stages of (1) cow/calf production, (2) stockers (grazing after weaning), (3) feedlot, and (4) slaughter and packing. The cow/calf phase of the beef sector is dispersed on many small- to medium-sized farms across the USA (Fig. 20.6a). In the stocker phase, large numbers of weaned animals are transported to the southern and central Great Plains region where they graze for about 9 months on a combination of wheat, Bermuda grass and other warm season pastures, native range pastures, crop residues (sorghum and other warm season crops) and other forages. From the feedlot phase to the packer phase, ownership and geographic distribution of beef cattle are increasingly concentrated. Many of the largest feedlots and packer plants are located in the Great Plains states, particularly in the semi-arid regions of Texas, Oklahoma, Kansas, Colorado, and Nebraska (Fig. 20.6b). Feed grains of corn, sorghum, and wheat are readily available in these regions, from local rainfed and irrigated production, as well as from the midwestern and other regions of the USA.

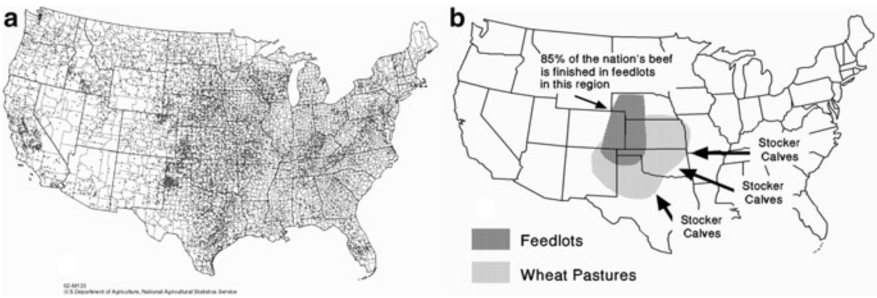

Fig. 20.6 Distribution of (**a**) cattle and calves (total of 95.5 million head; each dot represents 10,000 head) and (**b**) location of beef cattle components in the USA (USDA-NASS (2002) and Steiner et al. (2004))

20.2.3 *Efficiency, Productivity, and Sustainability*

20.2.3.1 Evolution of Cropping Systems

The Great Plains experienced one of the nation's greatest environmental disasters – the Dust Bowl – during the prolonged drought of the 1930s (Egan 2005). The Dust Bowl was associated with massive expansion of intensively tilled wheat; starting in the High Plains of Texas, Oklahoma and Colorado and extending eastward and northward to south-central Nebraska. During initial settlement, wheat was the dominant crop in the Great Plains, and plowing resulted in a large loss of soil organic C and N. Once these soils became exposed without vegetative cover, they were susceptible to erosion by water and wind. Many Great Plains soils are also subject to crusting, which impedes water infiltration and hinders seedling emergence.

To combat erosion, stubble-mulch tillage systems were developed to under-cut the soil, rather than invert it, for weed control. Over several decades, stubble-mulch tillage replaced the moldboard plow to become the 'conventional' tillage system, particularly in the drier portions of the Great Plains. However, with relatively low levels of biomass production and 14 months of bare fallow between wheat crops, residue cover was not adequate to protect the soil from wind and water erosion. As a result, soil organic C and total N declined in this type of system (Unger 2000).

In the middle of the twentieth century, researchers began developing no-tillage (NT) systems with herbicides for weed control. A number of long-term studies determined soil properties, water storage, and crop production under contrasting tillage systems and crop rotations. Reduced tillage and increased cropping intensity have had the greatest impact on increasing efficiency and sustainability of rainfed farming systems in the Great Plains (Peterson et al. 1998). Improved sustainability has been indicated by a number of experiments. For instance, soil organic C increased from 5.5 g/kg under wheat–sorghum–fallow to 5.9 g/kg under opportunity cropping (wheat, sorghum, canola, kenaf, tritacale[2]) (Unger 2001), and soil organic C and N were higher under NT than with other tillage systems and higher under continuous cropping than with fallow-based systems (Potter et al. 1997; Schomberg and Jones 1999). Greater soil organic C and N were also reported in various rotations of wheat, corn, millet, and fallow in Colorado compared with a conventional wheat–fallow system (Ortega et al. 2002), and diverse crop rotations enhanced potential soil microbial activity compared with the conventional wheat–fallow system (Ortega et al. 2005). However, the quantity of crop residue on the soil surface was more important than any other factor in affecting potential soil microbial activity. A number of other researchers have reported similar soil quality improvements with reduced tillage and greater amounts of crop residues returned to soil (Wright and Anderson 2000; Liebig et al. 2004, 2006; Cantero-Martinez et al. 2006).

[2]See glossary of plant names for scientific names

20.2.3.2 Efficiency of Water Use

Water availability is the primary limiting factor to crop production, so a great deal of research has focused on practices to increase water use efficiency (WUE). This has been approached through reduced or no tillage systems, which reduce evaporation from soils, potentially conserving water for transpiration by plants. The other primary approach to increasing WUE has been to intensify the cropping rotation to avoid fallow periods.

In a study of crop rotations and tillage practices in Kansas over 24 years (Thompson 2001), continuous sorghum with reduced tillage gave the highest economic return compared with continuous wheat, wheat–sorghum–fallow, wheat–fallow, and sorghum–fallow under reduced and no tillage. Using NT, it was possible to intensify cropping and enhance precipitation-use efficiency (PUE[3]) by 30% compared to conventionally tilled wheat–fallow systems across a range of soils in the central Great Plains (Peterson and Westfall 2004). Water was conserved in soil using NT and maintaining surface residues rather than being evaporated from bare soil under conventional tillage. Productivity was enhanced with increasing quantity of crop residue returned to the soil.

Examples of improving WUE include the following. Water-use efficiency with long-term sorghum cropping in Kansas was 22.1 kg of grain/ha/mm for stored soil water and 16.4 kg/ha/mm for in-season precipitation (Stone and Schlegel 2006). With wheat, WUE was 9.8 kg/ha/mm for stored soil water and 8.3 kg/ha/mm for in-season precipitation. Sorghum WUE increased from 12.9 kg/ha/mm under conventional tillage to 18.4 kg/ha/mm under NT, while wheat WUE increased from 8.6 kg/ha/mm under conventional tillage to 13.8 kg/ha/mm under NT.

Precipitation-use efficiency (PUE) for a range of crops potentially suited to the central Great Plains was highest (on a mass produced basis) for systems producing forage (14.5 kg/ha/mm) and lowest for rotations with a high frequency of oilseed crops (4.2 kg/ha/mm) or continuous small grains (2.8 kg/ha/mm) (Nielsen et al. 2005). Value of production ranged from $1.20/ha/mm for opportunity cropping to $0.30/ha/mm for wheat–sorghum–fallow. Soil water content at wheat planting in Kansas was lower after sunflower and soybean than after corn and sorghum (Norwood 2000). Sorghum grain yield and WUE increased with NT compared with conventional tillage in a wheat–sorghum–fallow rotation, but no differences in these parameters were found between tillage systems in wheat cropping systems (Schlegel et al. 1999). Production costs were greater with NT than with conventional tillage (CT) for wheat (due to costs of weed control), but similar for sorghum.

While cropping options remain limited for the hot and dry Great Plains environment, several water-efficient crops and management practices have shown potential for use in the region.

[3]PUE and WUE are defined and discussed in Chap. 1

20.2.3.3 System Improvements Through Diversification and No-Till

Research across the Great Plains has demonstrated the potential to increase PUE, generally through reduced tillage and diversification. Such practices have not always been economically feasible in the past, but are now being adopted across the region.

A sorghum–wheat rotation with NT generally increased economic return compared to continuous wheat and wheat–fallow, whenever sorghum grain yield was greater than 3.5 t/ha. Sorghum and sunflower were found to extract water from lower soil depths than wheat (Norwood 1999).

Long-term NT (1962–1989), despite increasing grain yield of wheat and sorghum, resulted in acidification of soil compared with conventional tillage (Tarkalson et al. 2006b). Nitrate leaching was a primary cause of the acidification under NT (Tarkalson et al. 2006a). Crop residue addition appeared to neutralise the acidity. However, this study indicates the need to improve nutrient-use efficiency under NT to mitigate soil acidification.

Diversification may include incorporation of livestock. Grazing of wheat is a common practice in the southern Great Plains; however, research has been much less focused on wheat as forage than on wheat for grain production. Often, protein supplements are required for portions of the wheat grazing period. Redmon et al. (1998) reported that annual legumes inter-sown with wheat could provide forage that met or exceeded cattle dietary quality recommendations from March through May, whereas this was possible with a pure wheat stand only in March. Soil fertility and economic aspects of including a legume in the system were not addressed in their study, but need to be investigated.

20.2.4 Economic Sustainability Through System Design and Management

Wheat has remained a dominant crop in the Great Plains for many decades, despite frequent periods of low market price. Cost pressures, economies of scale, and the need to manage risk have resulted in farm enterprises becoming larger. However, this has resulted in de-population and consequent loss of community infrastructure in some rural areas of the Great Plains. This has placed further pressures on the management of farms.

Traditional agricultural systems in the Great Plains were developed under conditions of cheap fuel, relatively low cost of N fertilisers, low commodity prices, and relatively few incentives to address negative environmental impacts of production systems. These conditions do not exist today. Diversified farms that include wheat, sorghum, and cattle enterprises often realise opportunities to offset risks in one enterprise with a benefit to another. For example, low sorghum prices may be offset by lower cost of feed for cattle.

The recent rapid interest in biofuel production, triggered by record high petroleum prices, government incentives and concerns about global climate change associated with rising CO_2 in the atmosphere, has resulted in a period of great opportunity to redesign agricultural systems to achieve greater sustainability. This new era has also brought uncertainty and risks to traditional agricultural systems in the region. Cellulosic biofuel production, particularly from forages, could bring new opportunities and challenges, especially regarding the balance between food production and energy needs.

There has been considerable change to farming systems in the Great Plains over the last 25 years. The area devoted to wheat production decreased by about 30% (Vocke et al. 2005) due to economic pressures and technical developments. These include changes in consumer preference (i.e. low carbohydrate diets), diversification of cropping systems, expansion of summer crops westward into the drier portions of the Great Plains, and land retirement under government conservation programs. The Conservation Reserve Program, one of USDA's largest conservation programs, was implemented primarily in the Great Plains (85% of enrollment area) (Vocke et al. 2005). Other changes are that some farmers are planting corn and soybean on land previously devoted to wheat, because of irrigation development, the need to diversify cropping systems, and a period of warmer and wetter climate in the region (Garbrecht and Rossel 2002).

While the Great Plains gained 4.3 million people from 1950 to 2000, 67% of the counties lost population. In particular, young adults have been leaving farm-dependent counties (Johnson and Rathge 2006). Off-farm income has become increasingly important for the majority of farms, as have government payments. Without government payments, only 18% of farms specialising in wheat production (i.e. obtaining greater than 50% of farm revenue from wheat) would have net income adequate to meet the full cost of production[4] (Vocke et al. 2005). While government program farm payments provide a short-term cash flow, there are additional effects that may exacerbate some of the challenges facing farming systems and rural communities in the Great Plains. Thus farm subsidies in the USA have resulted in increased land values and rental rates, making it more difficult for beginning farmers to compete for land. In regions of the USA where government payments are highest, cropland is most concentrated, suggesting that government payments are a major incentive to continue current production systems (Key and Roberts 2007). (Chapter 12 discusses social and political influences on the farm system).

Peterson et al. (1996) stated that wheat–fallow cropping was not economically sustainable without government payments. Experimental results have shown alternative rotations may be profitable. For example wheat grain yield was greater following sorghum than following wheat, and sorghum grain yield was greater following wheat than following sorghum (Schlegel et al. 2002).

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[4]Full costs of production include: variable costs (inputs consumed in one production season), cash costs (variable cost plus rent, taxes, insurance, interest), and total economic costs (cash cost plus depreciation, returns to management and land, and family labour).

A wheat–wheat–sorghum–fallow rotation requires a yield of 3.5–4.0 t/ha for sorghum and 2.5–3.0 t/ha for wheat to be more profitable than a wheat–sorghum–fallow rotation. Economic incentive levels for adoption of NT may not have to be as high if yield enhancement with NT is substantial, such as with a significant yield increase under NT in a wheat–sorghum–fallow system (De La Torre Ugarte et al. 2004). The design of cropping systems on the Great Plains needs to take into account environmental costs and benefits and the distortions caused by government payments.

Wheat producers in the Great Plains are facing challenges from all types of risk – production, price or market, financial, institutional and human or personal (see Chap. 12). Recently, higher grain price has offered some economic gain, but rapidly rising input and transportation costs have continued the economic challenge to Great Plains farmers.

20.2.5 Integration of Enterprises

Livestock play a viable and sustainable role in agricultural production in the Great Plains, where about 17% of the agricultural land is used for pasture and grazing (USDA-NASS 2002). The estimated land area in integrated crop–livestock production is less than 10%, although this does not account for substantial grazing of winter wheat in Kansas, Oklahoma, Texas and a few other states (Wight et al. 1983). During the last quarter of the twentieth century, grain and livestock production were gradually separated as farmers tended to specialise in one or the other. This resulted in a decoupling of crop and livestock enterprises for short-term economic gain at the expense of long-term sustainability (McRae et al. 1989; Brummer 1998; Hesterman and Thorburn 1994; Krall and Schuman 1996).

Renewed interest in integrated crop–livestock systems has developed, because of increasing cost of fossil-fuel energy and natural resource degradation. Examples are rising fertiliser and chemical costs, increasing environmental concerns with CAFOs (waste disposal and pollution), and increasing awareness of the environmental effects from over-application of fertilisers and pesticides (Brummer 1998; Russelle et al. 2007).

Agricultural sustainability derived from system diversity can be attained by including multiple annual and perennial crops, such as wheat, barley, pea, sunflower, alfalfa, clovers, and meadows, and most importantly, integrating crops and livestock into a system. A key principle of sustainable agricultural systems should be that waste derived from one part of the system can be returned as food for another part of the system (Kirschenmann 2002). Using this principle, agricultural systems can be designed to take advantage of synergies such as crops providing feed for livestock and livestock helping with the recycling of nutrients and management of weeds.

In the Great Plains, extending the grazing season is crucial to reducing input costs for livestock systems. Literature on integrated crop–livestock systems is

meager since this whole-farm system is one of the most difficult for researchers, who are often specialised (Luna et al. 1994). Whole-farm systems in the southern Great Plains use the traditional winter wheat cropping system to extend the cattle-grazing season by grazing winter wheat during the winter months until mid-March. Growing short-duration legume pigeonpea (*Cajanus cajan*) as a forage crop (and winter wheat in the same year) can supply forage during the summer when native perennial grass lacks sufficient quality and quantity for cattle. Pigeonpea uses water and nutrients below the effective rooting depth of winter wheat. This legume provides N for its own growth and for the following winter wheat crop (Rao et al. 2002a, b).

Livestock provide producers with an opportunity to add diversity to cropping systems, which can create additional opportunities to control weeds, explore synergies among crops, and diversify cash flow. In the central Great Plains, grazing may be as productive as feedlotting. For example, cow performance was similar whether they were grazing annual foxtail millet (*Setaria italica*) (November to December) that was swathed in late July or were fed millet in a feedlot (Munson et al. 1998). Swath-grazing cows during this fall period can also reduce environmental problems associated with cows in confined feedlots. Cropland used for swath grazing provides a means of cycling carbon produced by crops into the soil through manure, while decomposing crop residues also improve soil C sequestration (Singh et al. 1998; Soussana et al. 2004).

In the northern Great Plains, cows are typically wintered in a feedlot and fed hay baled the previous summer. These cows are, therefore, fed the most expensive forage during a period of time when their nutrient requirements are the lowest. Tanaka et al. (2005) demonstrated the feasibility of a 3-year integrated crop–livestock system. In this system, grain could be marketed directly or fed to livestock and marketed indirectly, while minimising purchased inputs, such as fertiliser (due to legume in the rotation) and pesticides, and providing swathed forage for winter cows. The 3-year cropping system provided crop diversity, as well as crop residues and forage with sufficient quality to meet the nutrient requirement of dry-bred cows. Wintering dry-bred beef cows on swathed forages and crop residues reduced winter feeding costs (November to February) by about 33% when compared to cows fed baled native hay in a feedlot (Karn et al. 2005). Crop production and livestock performance were not jeopardised by integrating crops and livestock; long-term impacts may be synergistic for both enterprises.

Just as agriculture has specialised in crops and livestock, so has the scientific community. Future agricultural systems will need to focus on the potential synergies and synchronies of multi-species systems, such as integrated crop–livestock systems, and how we can use them to develop agricultural systems that are more resilient. At present, many of our agricultural systems lack sufficient crop and animal diversity to be resilient, and so cannot be considered sustainable. A goal of integrated crop–livestock systems, from a livestock manager's point of view, is to develop crop and perennial forage systems that can supply year-round nutritional needs of livestock at a reasonable cost.

20.2.6 Natural Resource Issues

Wetland and grassland habitats in the northern Great Plains are important breeding ground for water birds. Higgins et al. (2002) indicated that these habitats are at risk from expanded cultivation in the region.

Future cropping systems based on perennial crops, such as switchgrass, alfalfa, perennial grains, to reduce fuel, labour, traction and other production costs and enhance the natural resource base are being explored (Cox et al. 2006).

20.2.7 Summary of Issues

The Great Plains is a semi-arid region that must necessarily focus on water limitations to production. Agriculture must compete for ground water with municipal and industrial sectors. Stopping both wind and water erosion are goals of sustainable agricultural systems. Conservation tillage systems are being deployed in the region to conserve soil water and to avoid soil erosion. Social issues of importance are loss of population and infrastructure in rural areas, over-reliance on farm subsidies to remain profitable, and uncertainties related to bioenergy policy. The high cost of energy and fertilisers is a concern across the country, as is the threat of climate change. Because the region has become highly specialised in crop and animal production systems, diversification of farm operations is needed to stabilise farm income against the vagaries of market forces and to hedge against future cutbacks in government support payments. Some solutions to these issues are to: (1) increase the use of legumes in cropping systems; (2) develop integrated crop–livestock systems; and (3) diversify cropping systems. Value-added processes should also be enhanced at the farm and rural community level, perhaps including identity-retained marketing (e.g. meeting locally grown, naturally produced, organic, or certified standards).

20.3 Midwestern Corn–Soybean–Hog Region

20.3.1 Structure and Characteristics of System

The midwestern states produce most of the corn (Fig. 20.7a) and soybean (Fig. 20.7b) in the USA, and are often referred to as the Corn/Soybean Belt. The area includes all of Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin and portions of the Dakotas, Kansas, Kentucky, and Nebraska. The region was settled between 1800 and 1875, so agriculture has been practiced for 150–200 years.

Fig. 20.7 Distribution of A corn harvested for grain (total of 27.6 Mha) and B soybean harvested for beans (total of 29.3 Mha) in the USA. Each dot represents 4,049 ha (USDA-NASS (2002))

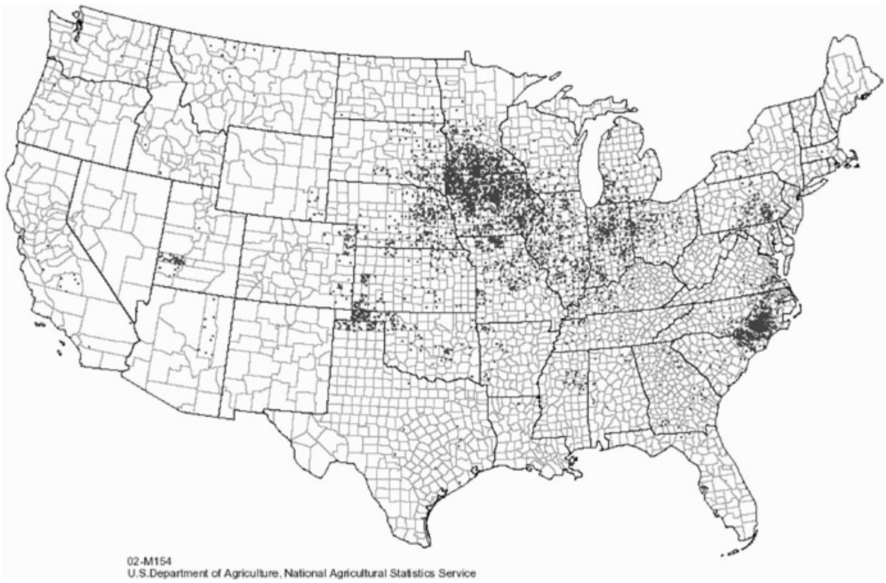

Fig. 20.8 Distribution of swine in the USA. Each dot represents 15,000 head with a total of 60.4 million head (USDA-NASS (2002))

20.3.1.1 Climate and Soils

Cold winters and hot summers are characteristic of the region, generally with sufficient precipitation during the summer to accommodate these warm-season, annual crops (Fig. 20.2). As in the Great Plains, wheat–sorghum–cattle region, the best soils for corn and soybean production are Mollisols, which originally supported grassland vegetation. There is also a significant area of Alfisols, derived from forest vegetation, in the eastern portion of this region. A majority of the hogs and pigs are housed here (Fig. 20.8).

Soils throughout the midwestern USA are characterised by a relatively high soil organic matter. To achieve maximum productivity under conditions of high precipitation and limited internal drainage, many soils have been engineered with subsurface (tile) drainage lines. Farmers in the region recognised early that “on land which is too wet, our cereals will not grow, not so much on account of the water as for the want of air which the water prevents from reaching their roots” (Hoyt 1866). To remedy this situation, county-level drainage projects commenced in the early twentieth century. By 1987, 20.8 Mha in the region had been artificially drained (Zucker and Brown 1998), and drainage systems are still being installed on many farms. This practice helps ensure high productivity, but it also increases the ‘leakiness’ of agrichemicals, resulting in substantial loss of nitrate to drainage waters, streams, rivers, and ultimately to the Gulf of Mexico. Loss of N, P, sediment, and pesticides, together with the presence of pathogens, has accentuated water quality concerns throughout the region in recent years (Dinnes et al. 2002; Dinnes 2004).

20.3.1.2 Historical Conditions

Up to the mid-twentieth century, farms in the midwestern USA were typically diverse operations, producing a variety of crops (including corn, wheat, oat, rye, clover, alfalfa (lucerne), grasses, garden vegetables, sorghum and tobacco) and raising a variety of livestock (including swine, dairy, beef, sheep, poultry and horses). This region is also where, at age 15, Henry A. Wallace scoffed at tradition and developed hybrid corn, which led to an increase in average grain yield in Iowa from 1.6 to 10.7 t/ha between 1931 and 2007. Following World War II, soybean was also converted from a forage crop to the second largest grain crop grown throughout the region (Karlen 2004). These changes were accompanied by a major decrease in on-farm crop diversity, primarily at the expense of small grains (Fig. 20.9). Another major shift in the midwestern USA has been the manner in which pigs and cattle are raised. Previously dispersed among many small farms, most animals are now being raised in CAFOs.

We have begun to experience the negative economic and environmental impacts brought about by this change from farm diversification to specialisation. Promoted on the basis of efficiencies of economy of scale and local consumption of corn grain, CAFOs are now being scrutinised because of concerns about odours and water quality degradation from manure spills. CAFOs and the grain marketing infrastructure associated with decreased crop diversity have also locked land owners and operators into a greater dependence on commodity-specific, government-support payments. Collectively these forces have reduced the number of farms and farm-families, and their spatial and temporal diversity. This specialisation has also made it increasingly impractical, under current market conditions, to move away from corn and soybean production, despite the recognised benefits of diversity on economic stability, labour distribution, ecological and environmental outcomes, and the need to respond rapidly to changing climatic and economic conditions.

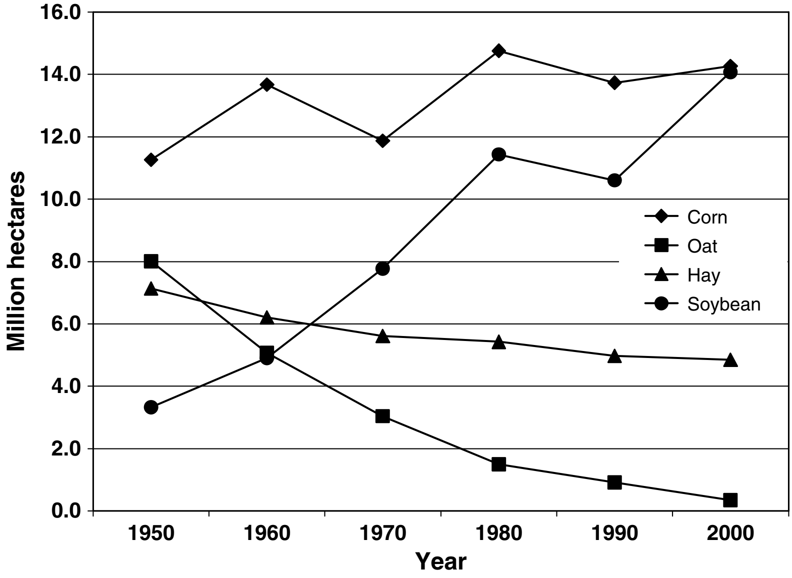

Fig. 20.9 Farmland in the midwestern USA devoted to corn, soybean, hay, and oat during the latter half of the twentieth century (USDA-NASS (2008))

20.3.2 Efficiency, Productivity, and Sustainability

Post World War II increases in efficiency and productivity throughout the midwestern USA have been associated primarily with the specialisation and separation of animal- and crop-production enterprises. Increasing farm size has also occurred, simultaneously with decreasing farm numbers (Fig. 20.10). Separating crop and animal enterprises has reduced the use of animal manure and meadow legumes as N sources, while the application rate of inorganic N fertiliser was increased by an average of 2.4 kg/ha/year from the mid-1960s to the late 1990s (Dinnes et al. 2002).

Adoption of specialised farming system practices has affected the sustainability of soil and water resources throughout the region. Reduced use of perennial legume rotations (alfalfa and clovers) and animal manure has negatively affected many soil physical, chemical, and biological properties and processes (Klapwyk et al. 2006). Specialised cropping systems may also affect water quality because annual cropping systems are inherently 'leaky' in spring and early winter. Thus nitrate that accumulates in the soil before and after annual crop growth is vulnerable to leaching below the crop root zone. It is then lost to groundwater through percolation or into streams and lakes via subsurface drainage lines (Rabalais et al. 1996). Economically-viable cover crop systems need to be explored further in this region to help avoid loss of nutrients during these vulnerable periods (Singer et al. 2007).

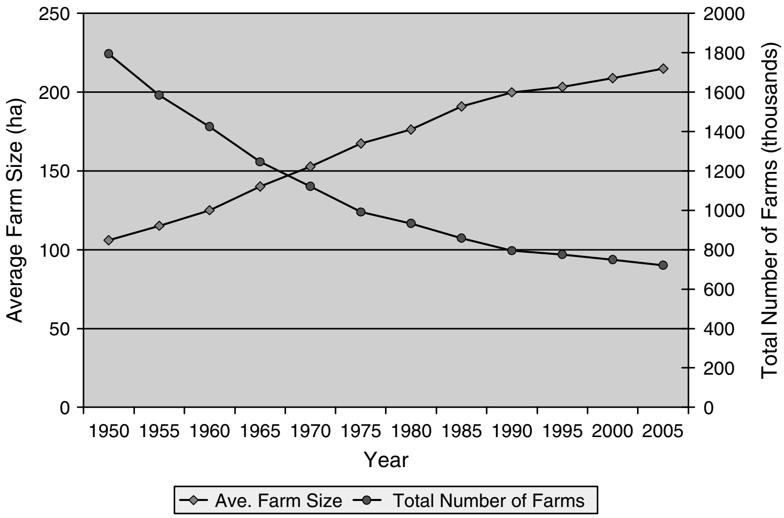

Fig. 20.10 Changes in number of farms and average farm size in the midwestern USA during the latter half of the twentieth century (USDA-NASS (2008))

A positive result of farm specialisation in the region has been a steady increase in the productivity of corn, with mean yield increases of approximately 110 kg/ha/year. The increase has been achieved through improved genetics (~70%) and better management of plant populations, row spacing, weeds, fertility, disease and insects (~30%). Average soybean yield has also improved, for example in Iowa from 1.3 t/ha in 1940, to 1.7 t/ha in 1960, 2.6 t/ha in 1980, and 2.9 t/ha in 2000 (USDA-NASS 2002). During 2006 and 2007, maximum soybean yield of 10.4 t/ha was achieved with intensive management in on-farm yield contests (Pioneer 2008). The difference between contest and regional yields suggests there is great potential to further increase soybean productivity throughout the region (if it is economically feasible).

Conservation of soil resources throughout the midwestern USA was enhanced during the 1990s with the adoption of conservation tillage practices (Fig. 20.11). This change was driven by the development of herbicide (glyphosate)-resistant soybean varieties to control weeds and ensure stability of yield.

The efficiency of use of fertiliser N applied to corn has been estimated at 40–60% (Varvel and Peterson 1990). An additional 16–80 kg/ha/year of fertiliser N is recycled into soil organic N pools when crop residues are returned to the soil (Yamoah et al. 1998). Because no N fertiliser is applied to soybean, it can help reduce the amount of N leached (Varvel and Peterson 1992).

Precipitation use efficiency for continuous corn has ranged from 3.6 to 13.7 kg/ha/mm, and for rotated corn, from 5.7 to 16.5 kg/ha/mm. For soybean, PUE averaged 3.0 kg/ha/mm (2.5–3.3) over an 8-year period (Varvel 1994, 1995).

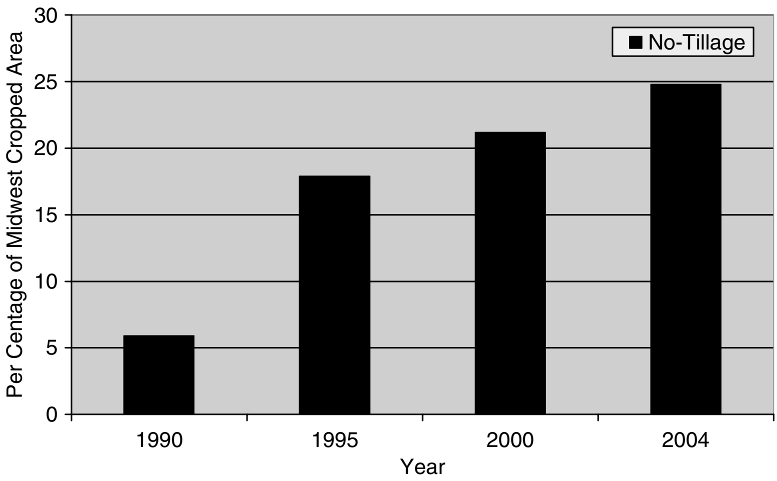

Fig. 20.11 Adoption rate of no-tillage cropping in the midwestern USA (Data from Conservation Technology Information Center)

20.3.3 Economic Sustainability Through System Design and Management

Corn and soybean farmers in the midwestern USA have, until recently, maintained their viability by collecting government farm subsidy payments. In 2002, the federal government paid $1.98 billion to corn producers and $0.67 billion to soybean producers as direct payments. Total farm subsidies peaked in 2005 at approximately $25 billion; they dropped to $16 billion in 2006 and are projected to drop further and remain around $12 billion for the next 10 years (USDA-ERS 2007a). Declining farm subsidies can be attributed to an increase in cash receipts from the expansion of the corn-based ethanol industry. However, greater input costs (such as fuel and chemicals) are projected to erode net farm income during the 10-year expansion period for ethanol production. Farmers will need to lower risk and increase profitability by diversifying their operations, to grow more crops. For example, a 5-year rotation of corn–soybean–alfalfa–alfalfa–alfalfa returned 100% and 158% more income than a corn–soybean rotation using NT and chisel tillage, respectively (Singer et al. 2003). In a tillage experiment, the use of swine- or beef-manure compost reduced the need for commercial N fertiliser by about 35%. This had little effect on economic return for a moldboard-plow system, but a large beneficial effect on economic return for a NT system (Singer et al., unpublished data). Greater returns in the future could likely be obtained by growing crops that would require lower N input than corn, and by using production systems that require less overall energy, because of the high cost of energy-intensive inputs. Lower temporal risk should also be possible through diversification, using crops of different life cycles, thus spreading the risk of unfavorable environmental conditions across the growing season.

20.3.4 Soil Fertility Management

Soils in the midwestern USA were among the most fertile in the world, requiring little supplemental fertilisation for half a century after initial cultivation. The need for lime was recognised in the eastern portion of the region and in areas where forage legumes were grown to support dairy operations. Yield responses to N and P eventually became apparent and, during the 1950s, a typical fertiliser recommendation in Iowa was 44-9-0 kg/ha N-P-K. Since the 1960s, fertiliser N and P rates have increased steadily with increasing corn yield and decreasing animal manure inputs until the farm financial crisis of the 1980s caused many producers to re-examine their fertilisation practices. This trend was evident even on research farms such as the Deep Loess Research Station near Treynor, Iowa. Here, P fertiliser rates, which had averaged 40 kg/ha/year (1964–1982), were reduced to 9 kg/ha/year from 1983 to 1995 (Karlen et al. 1999).

Reduction in fertiliser application was also a response to recognised groundwater and stream quality problems associated with midwestern cropping systems (Dinnes et al. 2002), and also to improved management assessments, such as the late-spring soil nitrate test (Blackmer et al. 1989). Widespread adoption of practices addressing water quality at the watershed scale resulted in a 30% reduction in stream water NO_3-N concentration (Jaynes et al. 2004). Increased awareness of unintended water-quality effects from excessive N and P fertiliser use was good. However, this may have resulted in a reduced effort to manage other essential plant nutrients efficiently. For example, K has been found to be a limiting factor under NT and ridge-till corn production in several locations (Rehm 1992; Borges and Mallarino 2001; Karlen and Kovar 2006). Multiple factors, including depth stratification of K, low soil temperature, and limited plant root exploration, have been postulated as contributing to development of K deficiency.

Sulfur is another essential plant nutrient not commonly recommended as fertiliser in Iowa (Sawyer and Barker 2002) and other parts of the midwestern USA, despite the occurrence of significant corn yield response to S application (O'Leary and Rehm 1990; Stecker et al. 1995; Rehm 2005; Lang et al. 2006). While yield responses to S fertiliser have been inconsistent (Hoeft et al. 1985), the need to apply S is increasing following both government regulation to reduce industrial air emissions of S and rising crop yield potential. The most responsive soils to S have been those with coarse-texture and low organic matter. Responses to S are most likely to occur in eroded areas and where crop residues have been removed for bio-fuel production. Site-specific soil fertility assessments have also revealed increasing surface soil acidification, often due to long-term use of ammonia-based fertiliser N. Site-specific assessments have led to increased use of differential liming by many fertiliser and lime distributors. Soil redistribution by tillage is a significant factor in creating within-field soil variation (Schumacher et al. 2005). Wind and water erosion maps could help target the type of conservation practices, such as cover crops, organic matter additions and NT suitable to address specific erosion processes. Projects focused on soil quality assessment have also successfully addressed soil fertility, organic matter, structure, and erosion issues, essential for sustainable soil resource management (Karlen et al. 2003).

20.3.5 Pest and Disease Management

Reliance on the two dominant crops of the region increases the likelihood of localised and widespread pest outbreaks. Major insect pests of corn in the midwestern USA include the European corn borer (*Ostrinia nubilalis*) and corn rootworm (*Diabrotica* spp.). Since 1997, *Bt* corn[5] has been commercially available to provide transgenic control of the European corn borer and, in 2003, transgenic corn hybrids were released that provided resistance to corn rootworm. Both of these technological advances have contributed to an immediate reduction in insecticide use for field corn. In 2000, insect-resistant (*Bt* only) hybrids occupied 18% of land in corn nationally, compared to 21% in 2007. Stacked hybrids[6] with multiple insect resistances occupied 1% of the land in corn nationally in 2000, but rose to 28% in 2007 (USDA-ERS 2007b).

Disease management of corn is primarily through hybrids with resistance to periodic foliar diseases such as stalk rots (*Gibberella zeae*; *Stenocarpella maydis*; *Colletotrichum graminicola*; *Macrophomina phaseolina*; *Fusarium moniliforme*), common rust (*Puccinia sorghi*), and gray leaf spot (*Cercospora zeae-maydis*), although selection for resistance to ear rots is also currently available. Corn in the northern part of the region is unlikely to respond economically to in-season fungicide applications. It is generally not recommended to spray fungicide on resistant or moderately resistant hybrids. As seen in the large increase (19%) in land planted to corn from 2006 to 2007 and the demand for corn that the corn-based ethanol industry has created, greater occurrence of continuous corn is expected to increase disease severity. Some farmers growing continuous corn have responded by once again burying stubble with inversion tillage to lower the likelihood of disease outbreaks.

Soybean is susceptible to many foliar, stem and root, seed and seedling diseases, as well as attack by viruses, nematodes, and insect pests. Major insect pests of soybean include the bean leaf beetle (*Cerotoma trifurcata*) and the soybean aphid (*Aphis glycines*). Bean leaf beetle can cause economic damage in soybean by foliar feeding and transmitting the bean pod mottle virus, which affects seed quality. Recent discoveries have identified tolerance in soybean varieties to this virus, use of which will probably become the best management tactic in the future. Soybean aphid has also periodically caused economic injury. Since its arrival in 2000, populations of soybean aphid have exceeded economic thresholds in 2001, 2003, and 2005 (Rice et al. 2007). Soybean cyst nematode is another major pest estimated to infest 70% of the production fields in Iowa. Soybean cyst nematode has been managed through a combination of crop rotation and variety selection (Iowa State University 2008).

[5] See Glossary.

[6] See Glossary for definition.

20.3.6 Weed Management

Weed management during the past decade in soybean, and more recently in corn, has relied on herbicide-tolerant crop technology to lower risk and reduce cost. Initial success of glyphosate-tolerant soybean resulted in the repeated use of glyphosate, which contributed to the emergence of glyphosate-resistant biotypes of certain weeds within 3 years after release of glyphosate–tolerant soybean (necessitating the use of alternative, more costly herbicides). The adoption of this technology accompanied a rapid increase in the use of NT for soybean production. Planting of herbicide-tolerant soybean varieties in the USA increased from 54% in 2000 to 91% in 2007. In Iowa, the percentages were 59% in 2000 and 94% in 2007. Only 6% of the corn planted in 2000 was herbicide-tolerant, but this increased to 24% in 2007 (USDA-ERS 2007b). Advantages of using glyphosate-tolerant crops compared to conventional varieties for weed management include broad spectrum weed control, greater flexibility in timing of application, and a large margin of crop safety. Hartzler et al. (2006) compared five weed management systems ranging from total reliance on glyphosate to no glyphosate (but using conventional herbicides) over a 4-year period in a soybean–corn rotation, for both chisel-plow and NT systems. Giant foxtail (*Setaria faberi*), velvetleaf (*Abutilon theophrasti*) and *Amaranthus* spp. were more prevalent in the chisel-plow system than in NT at the conclusion of the experiment, whereas dandelion (*Taraxacum officinale*) was present at higher density in the NT system. While all of these systems provided high levels of weed control, herbicide use was 66% lower in the glyphosate-only treatment compared with the system relying on conventional, pre-emergence and post-emergence herbicides.

Kegode et al. (1999) evaluated the interaction of tillage, rotation, and management on weed seed production. Increasing crop diversity in 5-year rotations that began and ended with corn and that simultaneously reduced tillage intensity resulted in lower grass and broadleaf weed seed production. However, cropping systems in the midwestern USA are currently dominated by the corn–soybean rotation and use high levels of inputs rather than relying on ecosystem or biological functioning. In Iowa in 2007, 95% of the harvested cropland was in corn and soybean, with corn occupying 63% of the harvested cropland (USDA-NASS 2002), suggesting a large potential for diversification in the future.

20.3.7 Integration of Enterprises and Land Management

During the latter half of the twentieth century, animal and crop production enterprises in the midwestern USA were separated to achieve efficiency – despite unknown environmental and social outcomes. The resulting use of feedlots (CAFOs) has concentrated animal wastes, often creating odor, water-quality problems, and excessive nutrient load on the limited land available for manure application.

Although many of these issues are being addressed on a case-by-case basis, this often does not occur without the threat of legal or regulatory action. Further, it is of concern that crop production fields are often managed uniformly without regard to their soil variability, resulting in acidification, erosion, and decreased organic matter content.

Although it is unlikely that wholesale cropping system changes will occur in the midwestern USA or that animal and crop management operations will be re-integrated into small diversified farms, there are opportunities for change if public opinion and government policies change. One vision is to shift our guidelines for natural resource and land management from the individual farm to the community or watershed, where all members would be rewarded for achieving a common good. By requiring watershed management plans to address all production, environmental and social concerns, it would be possible to address bioenergy, quality of air, water and soil, global warming, rural economic development and many other issues simultaneously. Coordinated efforts could also quickly alleviate potential conflicts, such as when the positive response to one issue (e.g. biofuels) might aggravate another issue (e.g. water quality). The key to solving complex problems in the region will be to implement agricultural practices and policies as an entire system, rather than as a collection of individual enterprises.

20.3.8 Biofuels

Resolving the negative external impacts associated with agricultural specialisation will not be easy, but it also will not be insurmountable. There has been increased public awareness that America's energy appetite cannot be ignored in an ever-increasing global community. Initial efforts to address the need for renewable biofuels were based almost exclusively on ethanol and biodiesel production from corn grain and soybean, but the Billion Ton Report (Perlack et al. 2005) stimulated efforts to identify a much broader range of cellulosic inputs that could be used for biofuel production through either biochemical or thermo-chemical pathways.

Cellulosic approaches to biofuel production are projected to be more sustainable and environmentally benign than grain-based scenarios because perennial biomass crops (for example switchgrass (*Panicum virgatum*), Miscanthus (*Miscanthus x giganteus*), and alfalfa (*Medicago sativa*)) can improve soil and water quality in several ways. Perennial biomass crops: (1) provide year-round ground cover that intercepts rain and reduces erosion; (2) develop plant root systems at greater soil depths and more extensively than annual crops – thus stabilising the soil; (3) capture a greater quantity of nutrients, improve water infiltration, but reduce leaching, reduce water runoff, and increase soil organic matter (Mann and Tolbert 2000; Dinnes 2004). They might also require less fertiliser nutrient and pesticide inputs than current row crops (Perlack et al. 2005).

In a comparison of energy budgets, McLaughlin and Walsh (1998) calculated that ethanol cropping systems derived from switchgrass could be 15 times more energy efficient than those derived from corn grain. Others have argued that, if continuous corn grain production were increased by 7.3 Mha, N loss from leaching could increase by 33% or 7.5 kg/ha (Elobeid et al. 2006; Wisner 2007) and, depending upon site-specific conditions and weather patterns, P loss could increase by 9,000 t/year.

20.3.9 Conservation Practices

Consolidation and specialisation of agriculture in the midwestern USA has drastically changed the landscape from one of diversification to near uniformity of corn, soybean and CAFOs. Water erosion potential is serious throughout the midwestern USA (USDA-NRCS 2008a). In the upper Mississippi River Watershed, where soil conservation practices such as contour strip cropping, buffer strips, farm ponds, drainage and water control structures were first installed by the Civilian Conservation Corps in the 1930s, many of the small-scale structures are being removed for the efficiency of larger equipment. Buffers and wildlife corridors, although included in many USDA-Natural Resource Conservation Service programs, are often inadequate for the interface between humans and wildlife, as evidenced by an increasing number of automobile-deer collisions and incidences of crop damage by wild turkey, deer and other animals. There are some small, localised efforts at reforestation throughout the region but, for the most part, on-farm woodlots and non-cultivated areas are rapidly disappearing – if not for agricultural crops, then for rural housing by non-farm families seeking to escape the urban and suburban environment. Such transitions affect not only land use and farming systems, but also demand for roads, bridges and better access to improved internet and telephone services.

A survey in 2005 of conservation practices in the South Fork of the Iowa River Watershed provides a snapshot of current agricultural practices (Tomer et al. 2008). The survey revealed that 85% of the total area (78,000 ha) or 95% of farmland was planted to corn and soybean. About 30% of the cropland received manure annually, before planting corn. Surface crop residues were generally inadequate (less than 30% cover) for soil erosion control. Edge-of-field erosion-control practices, such as grassed waterways and riparian buffers, were installed on 90% of those fields in which 34% of their area was classified as highly erodible. These conservation practices were generally aimed at controlling runoff, but the increased subsurface drainage exacerbated the loss of nitrate to surface waters. This example again illustrates how policies or practices intended to solve one conservation problem may inadvertently aggravate another. The long-term solution for sustainable, rainfed systems in the region should therefore be natural resource-based land management plans, policies and programs designed to ensure soil, water, and air quality, as well as social equity for all persons in the area.

20.3.10 Summary of Issues

The midwestern USA is the 'breadbasket' of North America that has highly fertile soils, relatively mild climatic conditions, and sufficient agronomic infrastructure to produce a steady supply of corn, soybean, cattle, and hogs. High fertiliser inputs in the region have caused concern for nutrient (N and P) runoff into streams, lakes, and rivers, as well as nitrate contamination of ground water supplies for the rural population. Conservation tillage systems have been adopted widely in the region in response to the availability of herbicide-resistant crop varieties, the need to control soil erosion from rainfall, and the need for savings in costly inputs of time, labour and fuel. Recent biofuel production from corn ethanol and soybean biodiesel has caused increased demand for crop commodities, which has fortunately increased gross farm returns at the same time that rising fuel and fertiliser prices have increased input costs. Sustainability of agricultural systems however will have to recognise not only key production and marketing issues at the macro-economic scale, but also key environmental and social issues at the farm and community level – such as soil erosion, nutrient runoff and dependence on government support.

20.4 Southern Cotton–Peanut–Poultry Region

20.4.1 Structure and Characteristics of System

Cotton (Fig. 20.12a) and peanut (Fig. 20.12b) are two characteristic crops of the southern region of the USA, and most of the nation's broiler chickens are also produced here (Fig. 20.13). Both crops are well suited to the sub tropical climatic conditions of the southeastern USA (Fig. 20.2). Soils of the region are dominated by Ultisols. They are generally acidic and low in native fertility and so require substantial inputs of nutrients to be productive in the long-term. Historically,

Fig. 20.12 Distribution of (**a**) cotton (total of 5.0 Mha; each dot represents 2,024 ha) and (**b**) peanuts harvested for nuts (total of 0.5 Mha; each dot represents 810 ha) in the USA (USDA-NASS (2002))

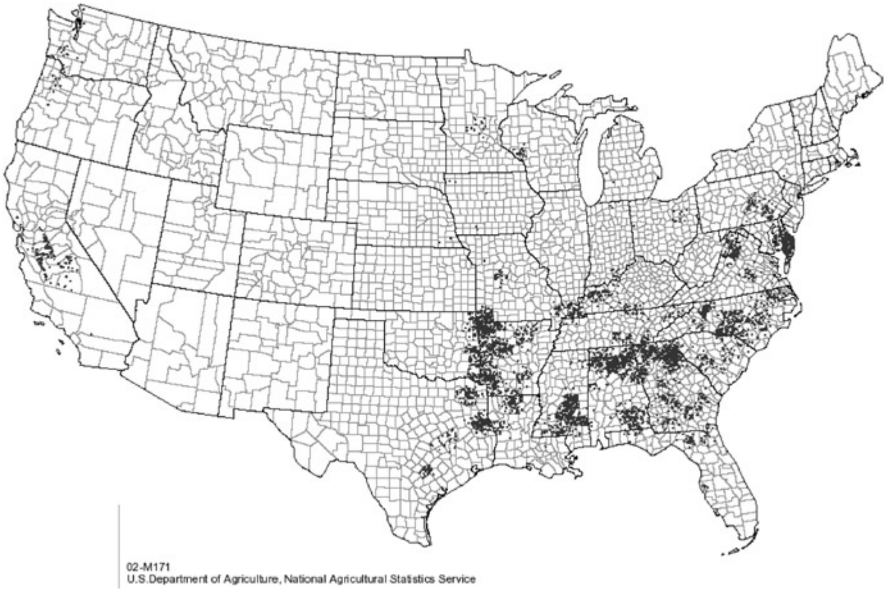

Fig. 20.13 Distribution of broiler and other meat-type chickens sold in the USA. Each dot represents two million head with a total of 8.5 billion head sold. (USDA-NASS (2002))

clearing the native vegetation and planting row crops in rotation with sod-based[7] pastures and the return of animal faeces to the land required few external inputs, but with time, soils became exhausted. Early pioneers abandoned 'worn out' soils and moved westward. Poultry CAFOs were developed in the southeastern USA in response to low heating costs in year-round production systems, and availability of cheap land and labour, and transportation infrastructure.

20.4.2 Efficiency, Productivity, and Sustainability

In the southern region, efficient use of rainfall and applied nutrients have been shown to enhance productivity and reduce environmental threats from agriculture. Adoption of improved cultivars, conservation tillage, appropriate fertiliser use, improved weed/disease/insect control, timely planting, and conservation-oriented crop rotations are management options found to mitigate water and nutrient limitations in the region.

Using conservation tillage[8] has improved crop yields. Across 95 pairs of data reported in the literature from across the southeastern USA, crop yield was an average

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[7] See Glossary.

[8] Refer to Glossary for definition.

of 6% greater under conservation tillage than under conventional tillage (Franzluebbers 2005). Despite abundant precipitation in the summer, high accompanying evapotranspiration makes preservation of soil water vitally important for increasing productivity. Higher yields with conservation tillage can be attributed to the conservation of water in the soil profile under surface residue cover, especially during a critical growth period for cotton from mid-July to mid-August (Endale et al. 2002).

The effect of conservation tillage on soil quality is also generally positive. It often increases surface-soil organic matter, aggregate stability, microbial biomass, and potential N mineralisation compared with conventional, inversion tillage systems in the region (Staley and Boyer 1997; Franzluebbers et al. 1998; Nyakatawa et al. 2001; Franzluebbers and Brock 2007). Increased soil compaction with conservation tillage does not appear to be a problem if sufficient residue cover is maintained. For example, soil bulk density increased with time under conservation tillage at a greater rate when fewer crop residues were returned to the soil (Franzluebbers and Brock 2007). Under conservation tillage, soil organic C sequestration in the southeastern USA was 0.53 t/ha/year with a cover crop and 0.28 t/ha/year without one (Franzluebbers 2005).

Improved soil quality with adoption of conservation tillage can also be expected to improve crop productivity and nutrient cycling in the long-term. From a group of 11 tillage studies in the region, using various crops, the ratio of crop yield under conservation tillage to crop yield under conventional tillage, increased logarithmically with time (Fig. 20.14a). This increase has been attributed to factors that include higher soil organic matter leading to greater water storage efficiency and greater difference in surface soil quality (aggregation, water-holding capacity, and

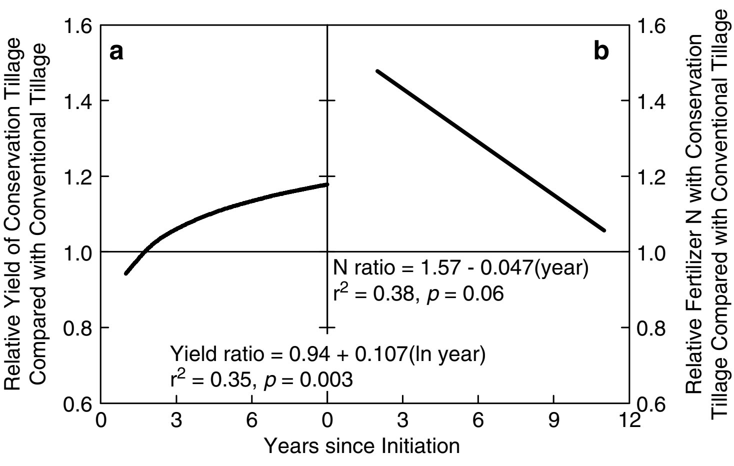

Fig. 20.14 Changes with time in (**a**) relative yield and (**b**) relative N fertiliser requirement to achieve 95% of maximum yield with conservation tillage compared with conventional tillage (Franzluebbers (2005))

nutrient cycling) due to reduced soil erosion (Triplett et al. 1996). However, early in the adoption phase of conservation tillage, nitrogen and other nutrients can be immobilised in the accumulating soil microbial biomass (Franzluebbers et al. 1999). Thus, more N is needed for optimum yield during early years of conservation tillage than later (Fig. 20.14b). In the long-term, accumulation of N and other nutrients and improvement in surface-soil hydraulic characteristics can lead to a greatly improved soil environment for sustainable crop production.

20.4.3 Soil Fertility Management

Fertiliser application programs in the southeastern USA have to consider several factors, including: (1) high precipitation that can cause extensive leaching of NO_3, Ca, and other elements; (2) high temperature that can cause rapid decomposition of organic matter and mineralisation of organically-bound nutrients; (3) kaolinitic mineralogy that can bind P and micronutrients; and (4) low pH that can reduce availability of P, Ca, Mg, S, and Mo and elevate concentrations of Al, Fe, Mn, and Zn (Brady and Weil 1999). Although soils can be sufficiently enriched in nutrients with the application of broiler manure, distributing this manure onto available crop and pasture land has been problematic. There is concern for over-fertilisation of farmland nearest broiler production facilities and its detrimental effect, through nutrient leaching and surface runoff, on water quality in the region (Sharpley et al. 2007).

For cotton production, soils should be limed to a target pH of 6.0–6.3. Application of N is based on soil type, previous crop, growth history, and yield potential. The N application may be split with about 25% at planting to ensure good seedling development and 75% as a side-dressing (first-square to first-bloom).

Low mobility of P allows it to be applied at or before planting. Potassium can be applied pre-plant or with mid-season foliar applications, while S may be applied pre-plant or as a side-dressing of ammonium sulfate (Univ. Georgia 2007a). Boron is recommended for successful flowering, pollination, and fruiting of cotton as a split foliar application applied twice for a total of 0.6 kg/ha. Manganese and Zn may sometimes be needed, especially when soil pH increases above 6.0.

Poultry litter (manure mixed with bedding) is a valuable and locally available source of plant nutrients for many crops in the southeastern USA. Nutrient concentration of litter varies depending upon moisture, season, feed ration, the number of poultry batches prior to clean-out, storage conditions, and handling. Typically, poultry litter contains the equivalent of 3.1-1.2-1.9% of N-P-K (Gaskin et al. 2007). Nitrogen availability from poultry litter applied to a crop generally ranges from 50% to 80%, because a large fraction of N in the manure must decompose and be subsequently released from soil microbial activity. Ammonia-N is often a significant (about 10%) fraction of the total N, and therefore can be easily lost by volatilisation. To avoid volatilisation of N and runoff of nutrients, poultry litter is not recommended for application before significant rainfall events, after liming, or during periods of drought and high temperature.

Due to the discrepancy between the ratio of nutrients required by most non-leguminous crops (7-1-6; N-P-K) and those supplied by poultry litter (3-1-2), poultry litter application rates should be based on the requirement of the crop for P rather than on N. If litter application rates were applied to meet the N requirement, excessive application of P would occur with time. Sharpley et al. (2007) described several management practices that can be employed to minimise P loss from poultry farming systems including: (1) enhancing P utilisation in feed; (2) manure amendment and composting; (3) appropriate method and timing of litter application to fields; (4) soil and litter testing; (5) subsurface application of litter to decrease P runoff; (6) conservation tillage to decrease P runoff; (7) pasture regeneration to enhance infiltration; (8) riparian buffers to trap particulate P; and (9) stream bank fencing to exclude grazing animals from streams.

Application of poultry litter to crop and pasture lands would be expected to increase soil organic matter. Across several field studies, soil organic C was 11% greater with than without poultry litter application (Franzluebbers 2005). Soil organic C sequestration was equivalent to 0.72 ± 0.67 t/ha/year. Poultry litter application combined with conservation tillage and winter cover cropping can greatly reduce soil erosion in cropping systems of the southeastern USA (Nyakatawa et al. 2007).

20.4.4 Pest and Disease Management

The warm and humid conditions of the southeastern USA are conducive to the development of crop pests and diseases; thus their management is more intensive than in other regions. Historically, the focus of cotton insect management has been on boll weevils. The Boll Weevil Eradication Program was initiated in 1978 by the USDA in North Carolina and Virginia (USDA-APHIS 2002), and so far Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Kansas, New Mexico, Arizona, and California have effectively eliminated the weevil problem. Three main techniques are used during a 3- to 5-year eradication period: pheromone traps for detection; cultural practices to reduce the weevil's food supply; and malathion treatments to kill. During the first year, malathion is applied every 5–7 days starting in late summer, then every 10 days during the later part of the growing season until the first frost. Cotton stalks are shredded and plowed to eliminate a source of winter shelter. During Years 2–5, the automatic spraying is supplemented with traps (1–2 traps/ha), and malathion is applied only in those fields where weevils are detected. Finally, traps are set for every 4 ha and areas spot-sprayed when detected. Upon elimination of the boll weevil in Georgia, insecticide applications had been reduced from 15/year to only 4–5/year by 1995 (Univ. Georgia 2007a).

For successful control of pests, integrated pest management (IPM) relies on multiple approaches, such as cultural practices, variety selection, biological control, and insecticides as needed. A successful IPM program lowers production costs, delays resistance problems, and improves profitability. Specific strategies include

insect scouting (every 5 days), promotion of beneficial insects (e.g. big-eyed bugs (*Geocoris* spp.), minute pirate bugs (*Orius* spp.), fire ants (*Solenopsis invicta*) and *Cotesia* wasps) (Univ. Florida 2007; OISAT 2007), spraying only when insect populations exceed a threshold, alternating insecticides to avoid resistance, and planting varieties containing Bt genes (Univ. Georgia 2007a).

Other pests and diseases of economic concern in cotton are nematodes and seedling diseases. When environmental conditions are cool and wet, seedling diseases can develop from *Rhizoctonia solani, Pythium* spp., and *Fusarium* spp. (Univ. Georgia 2007a). Seedling diseases can be controlled with a range of chemicals and agronomic management practices. Various nematodes can infect cotton and cause economic damage. As symptoms are ambiguous (Univ. Florida 2007), control of nematodes has not been adequately addressed. Crop rotation of cotton with non-host crops is a key strategy to control nematode damage. Some non-host crops to rotate with cotton are peanut, corn, various summer forage crops, and many different grass and leguminous winter cover crops. A variety of rotations is needed because crops may be non-hosts for some nematode species, but not others.

Peanut diseases (e.g. cylindrocladium black rot, sclerotinia blight, early leaf spot, web blotch, and tomato spotted-wilt virus) are most effectively and economically controlled using a combination of strategies, including sanitation, crop rotation, resistant varieties, scouting, and judicious use of pesticides (Virginia Cooperative Extension 2007). Equipment should be cleaned to avoid transport of inoculum across fields. Although moldboard plowing to bury crop residues is still recommended, harvest or burning of vines is not, since much of the potential disease inoculum remains in the field, and soil fertility declines. In Virginia, a 4-year rotation of peanut–corn–sorghum–grass is recommended for control of diseases. Since soybean and other leguminous crops share many of the same diseases with peanut, they should be avoided in the rotation or used sparingly with grass cover crops and separated by a summer cereal or grass phase. Resistant varieties are available for some of the common diseases found in peanut. Life cycles of peanut diseases and strategies for control have been developed (Univ. Georgia 2007b).

Non-chemical alternatives to conventional pest control are becoming more widely discussed, researched, and promoted in different parts of the USA (SARE 2007). These approaches rely on greater understanding of the life cycle of pests and management decisions to avoid outbreaks, such as through crop rotation, variety selection, residue management, timing of field operations, and promotion of beneficial organisms. Other sources of information for non-chemical alternatives to pest control include ATTRA (2007) and Rodale Institute (2007).

20.4.5 Weed Management

Weeds are a serious concern in cotton and peanut production because of the long growing season and their potential to severely reduce yield and distribute seeds to infest cropland for years to come. Many chemical control strategies are available

to help control weeds but, when used alone, in conventional, monoculture cropping systems, they are costly and can contribute to environmental degradation. Moreover, they are often only marginally effective in controlling weeds in the long term unless diverse cropping systems are developed to limit the weed competitiveness that thrives under monoculture.

Several technologies have been developed that allow greatly reduced chemical inputs for weed control. These include herbicide-resistant crop varieties, conservation tillage, and more diverse crop rotations with winter cover crops. Together, these can create a dynamic, biologically-intensive agro-ecosystem with a smothering mat of surface residues that discourages weed growth and seed dispersal. Transgenic cotton varieties allow glufosinate and glyphosate to be sprayed directly to the crop to kill emerging and established weeds during a critical period prior to crop canopy closure. Winter cover cropping and high-residue-producing crop rotations offer significant physical impediments to the establishment of weeds under a thick coating of surface residues. A wide variety of chemical and non-chemical weed control strategies can be found on state extension service websites in the southeastern USA (Alabama Cooperative Extension System 2007; Clemson Univ. 2007; Louisiana State Univ. 2007; Mississippi State Univ. 2007; North Carolina State Univ. 2007; Texas A&M Univ. System 2007; Univ. Georgia 2007a; Virginia Extension Service 2007).

Conservation tillage avoids soil mixing, thus inhibiting weed-seed germination. In Georgia, conservation tillage is implemented primarily using strip tillage, which provides a narrow zone of tillage in the crop row. Strip-tillage implements remove weed or cover crop debris, typically loosen soil under the row, and provide a suitable seedbed for planting (Univ. Georgia 2007a). This operation allows for optimum seedbed preparation while maintaining inter-row residue cover.

20.4.6 Integration of Enterprises

The cotton–peanut–poultry region of the southeastern USA contains nearly equal quantities of crop (20%) and pasture (15%) land areas, along with the dominant land use of forest (USDA-NASS 2008). Integration of crops and livestock (e.g. poultry, swine, and cattle) is currently limited compared to its historical predominance in the region. Manure and feed grains provide significant transfer of matter and energy between crop and livestock operations, although within-farm integration of these components is not generally practiced.

Integrated crop–livestock systems have potential to impart major benefits to the environment and help to develop sustainable agricultural production systems for the region by: (1) more efficiently utilising natural resources; (2) exploiting natural pest control processes; (3) reducing nutrient concentration and consequent environmental risk; and (4) improving soil structure and productivity (Franzluebbers 2007). Sustainable agricultural systems should consider profitability but also maximising investment in natural capital and reducing environmental impacts, and consider social values of animal treatment and human exposure to synthetic chemicals.

Some reasons to shift from a specialised production system to an integrated crop–livestock production system are: (1) specialised farms operating on marginal profit; (2) economic vulnerability with specialised production; (3) high cost of fuel and nutrients; (4) pests becoming more damaging with monocultures; (5) yield decline due to long-term management-induced constraints on soil quality and biological diversity; (6) spatially and temporally improved nutrient cycling on a field and landscape level with integration of enterprises; and (7) conservation of soil and water resources with greater adoption of sod-based management approaches (Franzluebbers 2007). With the accumulation of soil organic C and N during a perennial pasture phase, long-term data have shown that crop requirements for external N inputs can be greatly reduced and yield potential can increase. These responses may be due to a number of causes, including better soil physical condition, disease suppression, increased diversity of soil biological communities and enhanced fertility. Information on enhanced yield responses to pasture–crop rotations (e.g. peanut, cotton, and corn) was synthesised in Franzluebbers (2007).

Different forms of integrated rainfed farming systems are possible, including: (1) the growing of grain as a home-grown source of high-energy feedstock to supplement a primarily livestock-based production system; (2) rotating cropland with pasture to alleviate pest and disease problems in a predominantly cash-crop production system; (3) introducing stocker cattle onto winter cover crops to diversify farm operations; and (4) spatially and temporally diversifying farm operations with crops, forage, and woodland plantations.

Integrated crop–livestock systems are being investigated again at several research locations throughout the southeastern USA. Near Tifton Georgia and Headland Alabama, research and extension projects were developed to evaluate the impacts of stocker cattle grazing winter cover crops following cotton and peanut (Hill et al. 2004; Siri-Prieto et al. 2007a, b). Crop yield and soil properties have been variable in response to winter grazing; being both unaffected and negatively affected in different evaluations. The additional cattle gain of 178–561 kg/ha in these studies has increased income and justified diversification. Pasture–crop rotations are being investigated near Quincy Florida to improve production potential (Katsvairo et al. 2006, 2007a, b). Peanut following bahiagrass yielded greater than following cotton, due probably to reduced nematode and disease pressures after bahiagrass (Katsvairo et al. 2007b).

Marois et al. (2002) used an economic model to compare a conventional system (53 ha cotton, 27 ha peanut) with a sod-based rotation system (20 ha cotton, 20 ha peanut, 40 ha bahiagrass). Net profit was estimated to be \$15,689/year on the conventional farm, \$35,552/year on the pasture-based farm with hay harvest only, and \$44,840/year on the pasture-based farm with cattle grazing second-year bahiagrass.

Near Watkinsville Georgia, the impact of stocker cattle and cow-calf herds is being investigated in cotton and diversified grain production systems; these impacts include their effect on soil and water quality, crop and animal production, and economic return (Franzluebbers 2007; Franzluebbers and Stuedemann 2007; Schomberg et al. 2007). Livestock grazing of cover crops has had variable effects on subsequent

crop production, but has almost always increased economic return and diversity of income. Cattle gain on cover crops has been excellent with 200–350 kg/ha/season and greater gain on cover crops managed with NT than with conventional tillage (330 vs. 240 kg/ha) (Franzluebbers and Stuedemann 2007). Cover crop production has been consistently greater with NT than with conventional tillage – probably due to more efficient utilisation of precipitation and conservation of nutrients in surface soil organic matter. The impact of cattle trampling on soil compaction has been minimal. With conventional tillage, the frequent cultivation can alleviate surface compaction. With NT, the high surface soil organic matter following perennial pasture resists the compactive force of cattle traffic (Franzluebbers and Stuedemann 2008a, b). Using conservation tillage with cover crop grazing by cattle has helped to avoid the negative effects of sod-busting on soil organic matter decline and nutrient cycling deterioration.

The effects of tall fescue and orchardgrass pastures on cotton and peanut production characteristics and soil quality responses are being investigated near Suffolk Virginia (Faircloth et al. 2007; Weeks et al. 2007).

Within-farm integration of crops and livestock can provide stability to a farm operation – as well as complementary nutrient cycling, biological pest control, and economic diversity. Among-farm integration has also been proposed to avoid imbalances in regional nutrient transfers, better utilise regional resources, and allow more participants to share in responsibilities and outcomes (Russelle et al. 2007). The complexity and potential for public benefit of within-farm and among-farm integrated systems should justify the establishment of regional, national, or even international research initiatives. These could overcome constraints in current (i.e. conventional) agriculture and move rainfed farming systems towards greater sustainability through better integration of crops and livestock (Russelle et al. 2007).

20.4.7 Summary of Issues

The southeastern USA is a warm, humid region that has a variety of options available to produce a diversity of crops and animals for local, regional, and international markets. Although precipitation is generally abundant, periods of inadequate water availability occur due to high evaporation, especially in summer. Therefore, conservation tillage systems are needed to improve water-use and nutrient-use efficiencies. Cropping-system diversification, for example peanut–cotton–corn–wheat–pasture rotations with winter cover crops, along with conservation tillage, can help to control weeds, diseases, and insects with reduced inputs of synthetic chemicals. High-intensity storms in the summer can cause enormous soil losses and can make fertiliser applications from both inorganic and manure sources ineffective. The development of a sustainable agricultural system has to take into account the interests of the growing human population in the region. Abundant surface water resources, appreciated by year-round recreational enthusiasts, need to be protected from contamination by nutrients, pesticides, and faecal-borne pathogens. Runoff from animal manure applications

is of increasing concern in the area. Integration of crop and livestock systems in the region will help improve productivity of soils, increase the utilisation and distribution of nutrients, increase the economic stability and diversity of farming systems, and reduce environmental pollution from agriculture.

20.5 Coastal Diversified Crops–Dairy Region

20.5.1 Structure and Characteristics of System

Although not designated as a single region, the west coast and east coast regions have significant rainfed agricultural production. Tree-fruit production occurs in California, Washington, and Oregon on the west coast and in Florida, New Jersey, and New York on the east coast. Harvested forage and pasture are also significant components of the agricultural landscape in the northeastern USA (Fig. 20.15a), making perennial pasture the single largest agricultural land use system in every state in the region. Dairy production is one of the largest animal enterprises on both coasts (Fig. 20.15b). The following discussion on rainfed diversified agricultural systems will focus mostly on the humid, temperate region of the northeastern USA.

Precipitation in the region is generally 1,000–1,200 mm/year, distributed relatively uniformly throughout the year (Fig. 20.2). However, precipitation may be as low as 750 mm (western New York) and as high as 1,800 mm at the coast. Growing-season drought is more common and more severe in the southern third of the region. Temperature follows a distinct north–south gradient, with mean annual temperature of 3–4°C in northern Maine and 13–16°C in Delaware and Maryland. Soil resources and properties vary widely and, in many instances, the combination of soil type and topography constrain the type of cropping system (USDA-NRCS 2008b). The northern half of the region (New York and all of New England) is a glaciated landscape, resulting in soils formed from both glacial till and glacial outwash.

Fig. 20.15 Distribution of (**a**) hay including haylage grass silage and greenchop (total of 25.9 Mha; each dot represents 4,049 ha) and (**b**) dairy cows (total of 9.1 million head; each dot represents 2,000 head) in the USA (USDA-NASS (2002))

Soils formed from marine sediments and coastal plains are common in the southern half of the region. Soils formed from sedimentary bedrock are common throughout southern Appalachia (e.g. Pennsylvania and West Virginia).

Agriculture in the northeastern USA is characterised by its diversity – in resource base and climate, in the crops grown, and in markets. Parts of this region, which stretches for nearly 1,500 km along the Atlantic coast, from northern Virginia through Pennsylvania and New York to New England (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont), have been actively farmed for more than 350 years. During that time, there have been cycles of afforestation and deforestation; for example, much of New England was deforested and farmed by the mid-nineteenth century but is more than 80% forested now. Throughout much of the northeastern USA, diversity of production has been a characteristic at the farm level for centuries, lacking the profound shift to specialisation that has occurred in the last half century in the Corn/Soybean Belt and the Wheat Belt.

Distinct, diversified cropping systems in the northeastern USA can be categorised as: (1) arable agronomic crops (e.g. corn, soybean, small grains, oilseeds), (2) forage and pasture crops (e.g. alfalfa, clovers, timothy, orchardgrass), and (3) intensive horticultural crops (vegetable, fruit, and ornamentals). Agronomic and forage production is almost exclusively rainfed, while horticultural crops rely to varying degrees on supplemental irrigation, (e.g. Maine potato production is less than 15% irrigated whereas New Jersey horticultural crops are greater than 90% irrigated (USDA-NASS 2008)).

Maryland and Delaware are dominated by grain and poultry production. Pennsylvania, New York, and New England have systems that are integrated at the farm level, primarily as small- to medium-scale dairy farms, which will be the primary focus of following sections. Small-scale beef production is prevalent throughout the region. Although there are striking examples of concentrated, vertically integrated animal production systems in the region (e.g. poultry on the eastern shore of Maryland, some dairy systems in western New York), agriculture still exists primarily on moderately sized family farms.

One notable difference in the production of corn and soybean in this region is the prevalence of more diverse rotational cropping systems; for example, dairy farms may have four to five different crops present on a field during a 10-year period. An alfalfa–grass mixture with a projected stand life of 5–6 years may be planted in the first year with a nurse crop of wheat or oat. Two or three successive corn crops may be followed by soybean or a return to perennial pasture.

20.5.2 Efficiency, Productivity, and Sustainability

Although farmers in the northeastern USA have not specialised to the extent of other parts of the USA, they have adopted similar technological and management tools, and hence productivity and efficiency have increased. Changes in dairy production components are illustrated in Fig. 20.16 for New York, with similar

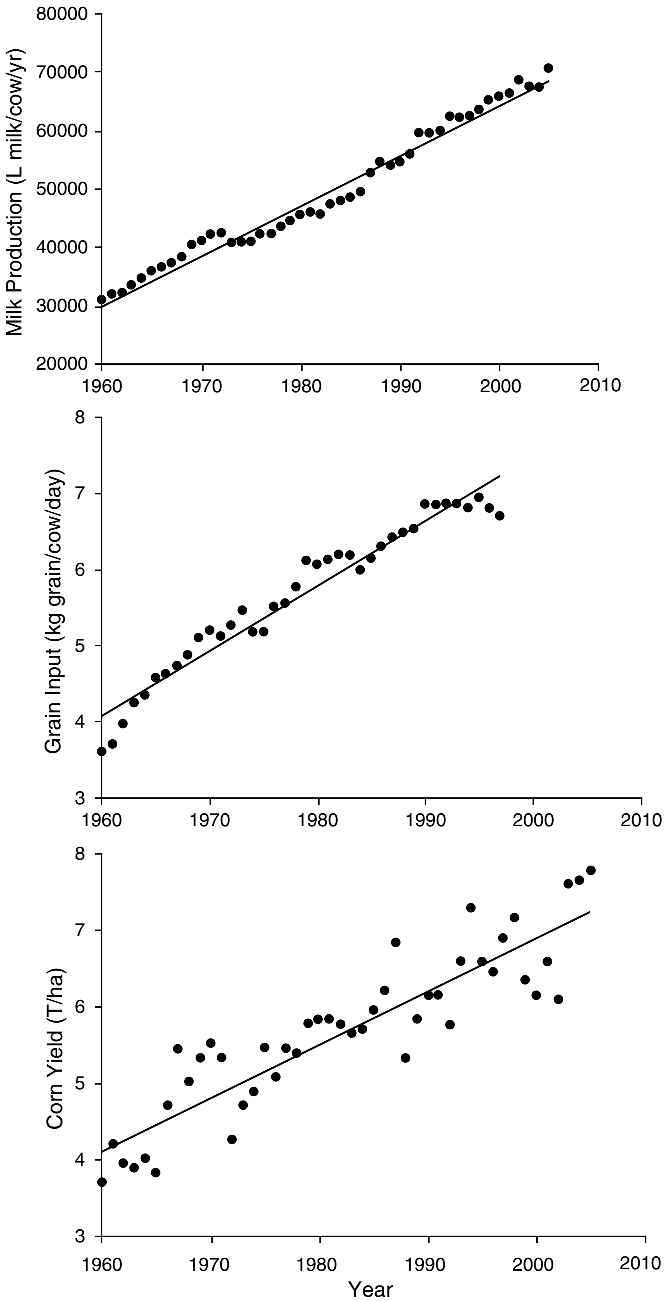

Fig. 20.16 Historical trends in milk production (*top*), grain input in dairy rations (*center*), and corn yield (*bottom*) for the state of New York from 1960 to 2005 (USDA-NASS (2008))

changes having occurred in other states of the region. Milk production per cow has more than doubled since 1960, which is attributable to a combination of factors, including animal genetics, breeding, health, and feeding strategies. The quantity of supplemental grain fed to dairy cattle has doubled, as has corn grain yield. Increasing corn grain yield can be attributed to improvements in hybrid variety yields, soil fertility and chemical weed control.

Increased efficiency of the dairy production system in the northeastern USA has resulted in stable to increased milk production in different states, despite dramatic reductions in the number of farm operations and dairy cows. New York and Pennsylvania had a total of about 80,000 dairy operations in 1965, but only about 15,000 operations in 2005 (USDA-NASS 2008). Compared to large dairy operations in the southwestern USA, dairy farms in the northeastern USA have higher costs of production, partly due to a difference in economy of scale, but also due to higher costs for energy and other inputs (Short 2004).

Although farm size and productivity have increased since 1965, agriculture in the northeastern USA has shrunk considerably; for example, cropland in Maryland declined from 1.5 to 0.8 Mha, and in Maine from 1.4 to 0.6 Mha. This contraction has had severe effects on the agricultural infrastructure, such as input suppliers and marketing services, making continuation of existing operations more difficult.

20.5.3 Soil Fertility Management

Inherent fertility of soils in this region varies widely. The Connecticut River Valley of Connecticut, Massachusetts, New Hampshire, and Vermont is characterised by highly productive alluvial soils. In contrast, the mountainous soils are highly weathered and the coarse-textured soils of the coastal plains are relatively infertile, requiring significant nutrient inputs.

The use of commercial, inorganic fertilisers, especially N and P since the mid-twentieth century, has increased in the coastal areas, although there has also been significant recycling of nutrients from animal agriculture. The environmental outcome of this recycling has depended to some extent on location; long-term application of poultry litter in Maryland and Delaware has resulted in accumulation of P in soil (Sharpley et al. 1996) and similar results would be expected in areas with high concentration of dairy operations. The primary source of P accumulation at the landscape scale has been animal manure via imported feed grains (Bacon et al. 1990), and subsequent crops in many fields no longer respond to further P application (Heckman et al. 2006).

Several approaches have been made to mitigate the negative effects on water quality of increasing P from agriculture. A national network was established to develop a P Index that could rank sites on their vulnerability to P loss, including effects of P source, transport mechanisms (e.g. runoff and leaching), and other factors (Lemunyon and Gilbert 1993; Sharpley et al. 1993, 2001; Sims 1993). Refinement and validation of the P Index have continued over the past 15 years

(Gburek et al. 2002; Kleinman et al. 2006; Kogelmann et al. 2006), as have developments of soil and manure analyses and management practices to help reduce the potential for P movement into streams and lakes (Magdoff et al. 1999; Van Kessel et al. 1999; He and Honeycutt 2001; Dou et al. 2003; He et al. 2004; Kleinman et al. 2006, 2007). Although positive P balances – related to high animal density – still exist for many dairy regions in New York, the difference between P input and output (in products) at the county level has declined significantly and steadily since 1992 (Mekken et al. 2006).

For both economic and environmental reasons, there has been a significant effort to refine estimates of N availability from soil, crop residue, and animal manures. Accounting for residual soil N from current and past manure applications, and from incorporated legumes such as alfalfa, was the primary rationale for the development and use of the pre-sidedress soil N test (PSNT) in Vermont (Magdoff et al. 1984). By analysing soil nitrate-N when corn is 30–45 cm tall, the need for additional N fertiliser can be decided at the latest possible time, thus accounting for N from mineralisation of organic N from animal and green manures (Magdoff 1991). The PSNT has been widely tested throughout the Corn Belt and eastern USA (e.g. Guillard et al. 1999; Balkcom et al. 2003). On-going evaluation of other management tools such as post-harvest stalk nitrate concentration (Balkcom et al. 2003) and soil amino sugar content (Mulvaney et al. 2001; Klapwyk and Ketterings 2006; Klapwyk et al. 2006) may also provide valuable tools to quantify the contribution of N from soil and manure. These tests should help minimise the negative environmental impacts and waste from leaching and denitrification of N.

20.5.4 Pest and Disease Management

Although there are numerous insect pests and diseases of the major agronomic crops in the northeastern USA, damage severe enough to reduce yield or cause crop failure is sporadic. University recommendations vary within the region, but are based on IPM principles. These require monitoring and establishment of threshold populations before implementing control strategies. Recommendations for pest control are available for different states in the region (Cornell University 2008; Penn State University 2008).

Corn plant population can be significantly reduced by seed rot and larval insects feeding on seed (e.g. seedcorn maggot, grubs, and wireworm). Some of these problems can be exacerbated when rotating corn with perennial forages – a common rotational strategy in dairy cropping systems. Because of the increasing use of NT in corn production and low soil temperature early in the season, more corn is now being treated with fungicide, insecticide, or both. Other in-season insect pests, such as earworm, armyworm and European corn borer, are a more serious problem for sweet corn production because of market appearance, than for corn grain crops. As described in Sect. 20.3.5, the use of genetically-engineered *Bt* corn has increased

rapidly since 2000, and damage from many foliar and stalk diseases of corn has been minimised with the development and selection of resistance in hybrids.

Soybean pests in the region are less problematic than in the midwestern USA because soybean is less common and is often grown in more diverse rotations. Some of the same pests that have reduced corn populations by predation of seed have also impacted soybean populations (e.g. seedcorn maggot). Similar strategies have been employed to minimise these problems. The recent occurrence of Asian Soybean Rust in the southern USA has not yet impacted this region, but several states (e.g. New York) have developed management guidelines for this emerging pest.

Soil-borne diseases that can shorten stand life of alfalfa in the region include bacterial, *Verticillium*, and *Fusarium* wilts, *Phytophthera* root rot, and anthracnose. Most of these organisms are ubiquitous in the region and chemical control is not effective, except for seed treatment to establish a good stand. Primary management strategies are identification of locally-important disease problems, including those specific to soil type, and the use of improved, disease-resistant varieties.

Established alfalfa stands can be affected by three main insect pests – potato leafhopper (which also affects alfalfa seedlings), alfalfa weevil, and alfalfa snout beetle (which is especially problematic in some parts of New York). IPM guidelines and chemical and cultural control strategies are available for all three of these pests.

20.5.5 Weed Management

The important aspects of managing weeds in corn and soybean have been covered in earlier sections of this chapter, and similar management strategies are being increasingly adopted in the northeastern USA. In the diverse rotational dairy farm cropping system mentioned in Sect. 5.1 an alfalfa–grass mixture with a projected stand life of 5–6 years may be planted in the first year with a nurse crop of wheat or oat. Weed management during this stand establishment phase may rely only on competition from the cereal crop. During the pasture phase of the rotation, annual weeds are generally not problematic although perennial weeds such as quackgrass (*Agropyron repens*) may encroach. Perennial pastures may be chemically killed (e.g. with glyphosate) before planting corn.

Long rotations create fluctuations in resource availability (i.e., light, nutrients, and water) that negatively and differentially affect weed emergence and growth. Liebman and Dyck (1993) found that a reduction in weed emergence was a prominent feature of rotations compared to monoculture production systems in a number of studies that were reviewed. Westerman et al. (2005) noted that the survival of weed seeds of *Abutilon theophrasti* was substantially lower in 4-year rotations than in 2-year rotations. In reduced tillage systems that include long rotations of corn, soybean, and winter wheat, increased weed diversity has been observed, but the increased crop diversity generally prevents the dominance of a single weed species (Murphy et al. 2006).

20.5.6 Integration of Enterprises

Many farms in the northeastern USA can be characterised as integrated crop–livestock production systems. Many dairy farms in the region are self-sufficient in terms of forage production, and may be partially self-sufficient in grain production. Even so, substantial feed grain may be imported at the farm, watershed, and county levels, which effectively concentrates nutrients at these scales.

In areas where crop and livestock farms are spatially intermixed, or that have some diversity in the types of farming operations present between farms, efforts have been made to increase integration between pairs of farms, or among groups of farms. For example in Maine, over a 10–15 year period, some potato and dairy farms have developed business and social relationships (Hoshide et al. 2006), in which dairy manure is transported to potato fields and feed from potato farms transported to dairy farms.

The demand for forage by dairy farmers has encouraged some potato farmers to establish longer crop rotations with forage crops to harvest and sell, as well as to increase the ecological stability of their own potato production system. Beneficial outcomes of this among-farm integration include: (1) distribution of manure nutrients over a larger area (in many cases, allowing the dairy partner to increase farm size knowing that manure can be spread onto neighboring fields); (2) local marketing of grain and forage resources; and (3) importation of organic matter onto potato fields, which were previously characterised by short rotations, limited crop residue, and intensive tillage. This example of among-farm integration has been successful because of the local availability of diversified operations. Transfer of this model to other parts of the USA may not be as successful, because of the loss of local agricultural diversity resulting from regional specialisation.

20.5.7 Summary of Issues

The northeastern USA is a cool, humid region with an assemblage of relatively small farms, many of which can be characterised as integrated crop–livestock systems. Dairy production in the region requires sufficient forage and energy resources. Thus, high-quality pastures for grazing and conserved forage for feeding in the winter are a significant part of the landscape. In addition, production of commodity grain crops (e.g. corn and soybean) are an important source of feed for these integrated systems and they occupy a significant area of crop-only farms in parts of the eastern USA. The importation of feed grains from other regions may further add to the concentration of nutrients at the farm and watershed level. Recycling of manure onto nearby land is common and reduces the need for inorganic fertilisers. Nutrient management strategies are a key focus to minimise nutrient losses to runoff and leaching and reduce fertiliser input costs. Diversification of agricultural operations in the region has allowed both within-farm and among-farm integration of resources and outputs from crop and livestock operations.

20.6 Conclusions

Rainfed farming systems in the USA are defined by unique soil and climate conditions found in different parts of the country. The Great Plains region (or Wheat Belt) is characterised by limited precipitation resulting in the predominance of wheat and sorghum production, along with a significant number of cattle brought to the region for finishing in feedlots. Wheat–fallow has been the traditional cropping system but, with the adoption of conservation tillage that conserves soil moisture and protects soil from erosion, more intensive cropping systems are being adopted to make the most efficient use of available water.

The midwestern region (or Corn/Soybean Belt) has highly fertile soils and relatively mild climatic conditions that allow excellent production of corn and soybean. The region also has large numbers of hogs and cattle. A major resource issue in the region is excess N and P that can cause deterioration of surface and ground water resources in the region, as well as downstream into the Gulf of Mexico. Conservation management systems are being developed to limit nutrient losses.

The southeastern region (or Cotton Belt) has generally adequate precipitation, although summer water deficits are common due to high evaporative demand during the long-hot summer. Conservation tillage systems are needed to reduce evaporation from soil and protect the soil surface from the common threat of high-intensity storms that can cause serious erosion. Soils are relatively infertile, with subsoil acidity, but can be improved with permanent vegetative cover and application of animal manures. Management approaches are needed to avoid over-application of animal manures that can threaten surface water quality.

The northern coastal regions represent a diversity of farming operations that have little specialisation. Resource issues are related to high-density animal operations and the need to balance nutrient inputs and outputs to avoid water quality concerns.

In all regions, farming is pressured by economic concerns with rising costs of production, because of the reliance on fossil-fuel based energy, fertiliser, and synthetic chemical weed and pest control. Government support payments are an integral component to maintain profitability of many current agricultural systems. Agricultural biofuel production (based on corn ethanol) is increasing dramatically and is creating a renewed interest in agriculture by the government, following a century in which the contribution of agriculture to the gross domestic product has gradually declined from nearly 10% at the beginning of the twentieth century to less than 1% at the beginning of the twenty-first century. The opportunities for USA agriculture to supply corn-based ethanol, soybean-based diesel, and eventually cellulose-based ethanol are expanding, yet the challenges that this new era brings will be certainly as daunting as ever before. Can farmers in the USA and the world expect to supply the ever-increasing demand for staple grains, high-protein diets, and diversity of safe and affordable food products without harming the environment? Can both food and bio-based energy demands be met without further tapping into dwindling ground water resources and threatening the quality of fresh-water

supplies with the by-products of agricultural production (e.g. nutrients, pesticides, and pathogens)? Adoption of conservation-tillage systems in the USA has helped to conserve water, preserve soil, and even increase production, but further advances (e.g. increasing crop diversity, integration of crops and livestock, and balancing nutrients within watersheds) will likely be needed to make rainfed farming systems more water- and nutrient-efficient and ecologically sustainable in the future.

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