

TR-42
Agriculture and Drainage
“Inseparable Science”
Research Summary
2002



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Foreword

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The purpose of this technical report is to provide important information available to PPI on the importance of drainage for the agriculture industry.

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Originally published July 2002
Reviewed and Reaffirmed March 2008

Agriculture and Drainage –

Inseparable Science

Introduction

US agriculture is an important contributor to the world's food supply and a major component of the US economy. Nearly one-fifth of the world's agricultural exports are shipped from the US. We have a heritage of productive agricultural lands and favorable climate that provides us with a comparative advantage. (Bucks, 1992)

All agricultural soils require drainage. Natural drainage processes are not sufficient for agricultural production on about 25% of the cropland in the USA and Canada. Artificial or improved drainage is necessary to produce crops on these lands. Improved drainage is needed on over 50 % of the cropland in some states and provinces. (Skaggs and Breve, 1991)

Current agricultural production would be very difficult to sustain if not for the drainage technology that has been developed over the past decades. Agricultural drainage continues to play a vital role in the sustainability of the world's food and fiber production. Drainage technology development and research has been a cooperative effort between universities and public and private sponsoring organizations.

The purpose of this white paper is to summarize many of the issues relating to agriculture, drainage and water quality and much of the research that has been performed. This information will be used to formulate a platform to support the on-going drainage activities and direct future developments and research.

History of Drainage

It has been said that those who ignore lessons from history are doomed to repeat them. This section is a brief compilation of historical documentation that drainage has not always been for agricultural production alone. In many instances, drainage served the purpose of making lands productive and even habitable.

Historically, water management for agricultural purposes can be traced to Mesopotamia some 9,000 years ago. A major reason for the decline and disappearance of some ancient civilizations based on irrigation was their failure to heed the need for drainage. Drainage, the practice of removing excess water from agricultural land, has its origin at least 2,500 years ago when Herodotus wrote about drainage works near the city of Memphis in Egypt. Marcus Porcius Cato, 234 to 149 BC, apparently wrote the first specific directions for draining land. Land drainage is also apparent in the records of the Greek, Egyptian, and Roman civilizations. Land drainage to re-claim areas adjoining the North Sea in England began in the tenth century. The Dutch began converting land by draining and diking around 1550. Russia inaugurated drainage works in 1710 to make St. Petersburg habitable. (Economic Research Service, 1987), (Donnan)

Much of the United States was not habitable or capable of agricultural production in its pre-development condition. Much of East central Illinois, for example, was..."swampy land considered worthless for farming. Problems of human health were frequently reported such as epidemics of malaria, cholera, milk sickness, ague, and fever. Plagues of mosquitoes and flies were also reported. It is easy to understand the account of the young man who refused to trade his horse and saddle for a full section (640 acres) of swampy land in that period." (Economic Research Service, 1987) A 640-acre tract would sell for more than three million dollars at the highest agricultural land prices in that same area within the last several years.

Pickels (1925) noted that Government Land Office records show that one-fourth of Illinois and still larger portions of other states were swampland. Twenty-one counties in northwestern Ohio and northeastern Indiana included much low land originally too wet to cultivate. Much of the land in north central Iowa, at the time of settlement, was in shallow sloughs too wet for normal cultivation. Large areas in western Minnesota, northeastern Arkansas, the gulf plains of Texas, and the delta areas of Mississippi and Louisiana were originally swamp and overflow areas. Drainage permitted cultivation of these areas. (Economic Research Service, 1987)

The report on Long's expedition to the source of the St. Peter's River in 1823 stated, "Near to this house we passed the state line which divides Ohio from Indiana...The distance from this to Fort Wayne is 24 miles, without a settlement; the country is so wet that we scarcely saw an acre of land upon which a

settlement could be made. We traveled for a couple of miles with our horses wading through water, sometimes to the girth. Having found a small patch of esculent-grass (which from its color is know here by the name of bluegrass), we attempted to stop and pasture our horses, but this we found impossible on account of the immense swarms of mosquitoes and horse flies. From Chicago to the place where we forded the Des Plaines, the country presents a low, flat and swampy prairie, very thickly covered with high grass, aquatic plants, and among others, the wild rice.” (Economic Research Service, 1987)

The first known colony-wide drainage law was enacted in New Jersey in 1772. A City of New Orleans drainage outlet was constructed around 1794. Patterns for molding the first subsurface drains in the United States were recorded as imported from Scotland in 1835. (Economic Research Service, 1987)

Early interest in the United States was not confined to development and enhanced agricultural production, but also stressed human health aspects, as illustrated by the draining of Central Park in New York City in 1858. In recent years, these health benefits were taken for granted, or overlooked. Most of the great swamps and extensive breeding grounds for mosquitoes have been eliminated, although just in the last few years mosquito-born diseases, such as the Nile virus, have become a concern in many parts of the United States.

Drainage in the United States occurred in two primary developmental periods, during 1870-1920 and during 1945-1960. The first period was initiated around 1830 when increased public pressure was brought to Congress to release federal swamp and wetlands for private development. By 1920, more than 53 million acres out of a total of 956 million acres of US farmland had received some form of drainage. The United States Department of Agriculture (USDA), 1982 Natural Resources Inventory (NRI) inventory identified about 107 million acres of wet soils as being prime or adequately drained, of which 72 percent was then cropland. (Economic Research Service, 1987) The NRI of 1982 indicated that nearly 28 million acres of existing non-irrigated crops and pastures had drainage problems, of which 15-20 percent were also considered wetlands. More recently, an added 12 million acres of rural land have been found to have at least a medium potential for drainage and conversion to crop production. (Brown and Zucker, 1998)

An estimated 110 million acres of agricultural land in the United States benefited from artificial drainage as of 1985. At least 70 percent of this drained land is in crops, 12 percent in pasture, 16 percent in woodland, and 2 percent in miscellaneous uses. (Economic Research Service, 1987) In eastern Canada over 6.2 million acres of farmland had been tile drained, as of 1992. (Madramootoo, et. al, 1992)

It is estimated that the accumulated total investment in drainage since 1855 is \$56 billion (1985 dollars). The average US real cost of providing subsurface

drainage has fallen to \$415 / acre from 1965 to 1985 which reflect the impact of drainage technology: trenching machines, corrugated plastic tubing installed with laser controlled high-speed trenchers or plows, and computerized design methods and models. (Economic Research Service, 1987)

On state and regional basis, approximately 40 percent of the crops in North Carolina are grown on poorly drained soils. The drainage of cropland has been one of the most important components of land management in eastern North Carolina with drainage projects initiated as early as the late 1600's. (Evans and Skaggs, 1987. Real estate values for 256 predominately agricultural counties throughout the Eastern States with a high incidence of drainage averaged 27 percent more than values in 1,422 other agricultural counties, according to an analysis of 1982 Census of Agriculture data. (Economic Research Service, 1987) In Minnesota, although the percentage of cropland drained is lower than other Midwestern states, the 1985 NRI estimates for total cropland acres drained (6.37 million) are significant. (Brown and Zucker, 1998)

Drainage, while currently viewed as an agricultural production practice, has accomplished many purposes in water management, conservation and improvement of human health conditions throughout human development history.

Effects of Drainage

Drainage practices are broadly viewed as having both strengths and challenges. The following discussion is to point out the diversity and interaction of drainage effects. This section must be read in context with the following one on water table management and sub-irrigation to gain an overall feel for the existing research and its variability in results.

The effects of drainage can be categorized broadly into ten groups. These ten groups will be discussed: soil aeration, soil moisture and trafficability, nutrient / pesticide effectiveness and transport, soil temperature, toxic substances and disease, soil erosion and flooding, plant health and crop yield, water supply, and salinity control. All of the impacts are positive from an agricultural perspective and illustrate the value of drainage technology to agricultural production. The sum total of the effects indicate that agriculture, as we know it, would be unsustainable in many regions of the world despite the challenges in water quality.

Soil Aeration:

The first purpose of a system designed to drain land for agricultural production in humid areas is to improve soil aeration. Water logged soils decrease the air exchange between soil and the atmosphere resulting in a decrease in O_2 around the plant roots and an increase in CO_2 . It has been found that at low O_2 concentrations there is a decrease in mineral content in plants. Low O_2 concentrations in the soil also exert an influence on the growth rate. Aeration conditions in soils have a large influence on the availability of nitrogen. (Van Schilfgaarde, 1974) The better soil aeration resulting from good drainage permits deeper and more extensive root development and a more favorable environment for beneficial soil microorganisms. (Palmer, 1977)

Soil Moisture and Trafficability:

Several factors make drainage a necessity for agricultural production on some land. These factors include slow soil permeability, flat or depressional topography, restrictive geologic layers underlying the soil profile, and periods of excess precipitation. (Brown and Zucker, 1998) Performing farming operations when the soil is too wet results in soil compaction, soil structure degradation and equipment becoming stuck during field operations. (Van Schilfgaarde, 1974) Compaction on agricultural land from the use of production equipment on wet soils also creates a layer that restricts the downward movement of water. Compaction research conducted by the USDA and the University of Minnesota provided new insight into how soil water content affects the potential for soil compaction. This research points to the benefits of subsurface drainage to

reduce compaction, and furthermore the need to maintain existing drainage systems. (Brown and Zucker, 1998)

Reduction in labor has forced farms to larger and larger sizes and more mechanized equipment, reinforcing the need to pay attention to trafficability. (Irwin, 1981) Trafficability is a term that has been used to describe the capability of a soil to permit the movement of a vehicle over the land surface. Trafficability in agriculture means being able to perform the required farm operation in such a way as to create a desired soil condition or to get an operation done expediently. Drainage plays an important role in all aspects of trafficability for farm operations. The effect of lack of timeliness in performing farming operations may range from complete crop failure, if planting is delayed too long, to reduced yields if tillage, weed control, harvesting, or other operations are not performed on time. (Van Schilfgaarde, 1974)

Research in Indiana showed that most of the measurable improvements in soil tilth and organic matter in the cover crop and rotation treatments were greater in the presence of subsurface drainage than in its absence, and no-till treatments performed better with subsurface drainage. Perhaps the most significant benefit of subsurface drainage is in areas of a field where surface drainage is poor – in some years the swales without subsurface drainage had enough ponded water to destroy the crop in that area, whereas drained plots were able to more quickly remove the ponded water. (Brown and Zucker, 1998)

Drainage removes soil water and at the same time makes more soil moisture available to the plants. This paradox occurs because of the improved physical condition of the soil, that is, better soil structure that results in larger volumes of water held under low tension. (Irwin, 1981) This results in deeper root depths and increased water availability during dry periods.

Longer growing seasons can be achieved with good drainage due to the possibility of earlier planting dates. (Palmer, 1977) In Ontario, there are about five fewer days for spring planting available to the farmers on poorly drained soil compared to those who farm well drained soil. (Irwin, 1981) In Finland, the world's most northern agricultural country, the growing season is short, only 100 days in northern Finland and only 160 days in the southern areas of the country. Drainage is a must to prepare the soil for cultivation as quickly as possible. The rule of thumb "a day in spring is a week in autumn" well describes this aim. (Saavalainen, 1987)

The most recent technological change is the application of water management systems that incorporate drainage, drainage restriction, and sub-irrigation in one sophisticated operation to optimize soil water conditions for crop growth. Economic optimization procedures can be applied to develop "best" drainage systems. (Economic Research Service, 1987)

Nutrients / Pesticides (Effectiveness and Transport):

Agriculture is listed as a source of pollution for 70% of the impaired river miles surveyed in the United States. (EPA Contract #68-C99-249, 2000). Agricultural drainage, whether surface or subsurface, sometimes contains nutrients and chemicals in sufficient concentrations to be of significance to subsequent users of the water or to the aquatic environment. Agricultural drainage is never pure, nor is the precipitation from which it originated. (Van Schilfgaarde, 1974)

The primary issues related to water quality in drainage projects are sediment transport, salinity discharges, agricultural chemicals and trace elements that are leached or that run off. Sediments often carry agricultural chemicals that are adsorbed on soil particles. Thus practices such as filter strips, grass protection of channels and sediment traps can help control these types of water quality problems. Agricultural chemicals not adsorbed on soil particles such as nitrate nitrogen, which often leaches into drainage effluent, can contribute to eutrophication of water bodies downstream. Eutrophication is a process where algae and related organisms feed on excess N, expire and their decay robs water of oxygen, thus favoring plants over animal life. (Ochs, 1987)

Extensive research conducted in the United States, Canada and Europe has documented some of the effects of subsurface and surface drainage on hydrology, soil erosion, and water quality. In most cases, surface drainage has been related to higher peak runoff rates and greater sediment losses than subsurface drainage. Some studies have indicated subsurface drainage reduces both nitrate N and phosphorus losses, while other researchers have found subsurface drainage can increase both NO₃-N and P losses. It is obvious there is not universal agreement on which drainage method produces minimum effects on water quality. This controversy indicates that the mechanisms governing loss of pollutants from drained soils are complex and vary with management practices, soil, crop and climate. Promising research has shown that drainage systems can be designed and managed to minimize nutrient losses. (Skaggs and Breve, 1991)

The total cultural energy input from fertilizers is estimated to be 36% of the total "cultural" energy used by the farm in corn production. (Baker et al., 1974) Increasing the intensity of subsurface drainage generally reduces losses of phosphorus and organic nitrogen while increasing losses of nitrates and soluble salts. (Skaggs and Breve, 1992)

Nitrate and soluble Phosphorus are the nutrients probably affected most by fluctuating aeration status. Nitrate is the most sensitive. Nitrate nitrogen is usually rapidly de-nitrified to N₂ gas by submergence of the soil. (Baker and Johnson) For ammonia (NH₄) and phosphate (PO₄), less surface runoff because of increased percolation should reduce losses of these ions because they are

adsorbed by soil particles. Opposite these beneficial effects are the higher NO_3 losses expected. Because of lower water tables, shorter times of saturation in the organic zone after precipitation, and shorter transit times in the subsoils, less denitrification will occur. Within the root zone, this would be an economic plus; however, once below the root zone the higher NO_3 concentrations would result in greater losses from the system. (Van Schilfgaarde, 1974) Fleming (1990) in an Ontario study found that $\text{NO}_3\text{-N}$ concentrations in tile drain flow were not related to manure usage at the farm, but appeared to be related to total N applied to cropland regardless of the source. (Madramootoo, et. al, 1992)

The data clearly show that the magnitude of loss (nitrogen) is highly variable and depends on the soil type and its management. No single value can be applied to either concentration or total quantity of N loss. A frequent error in the literature is to relate the losses to percentage of the fertilizer N applied. Although fertilization may have increased the loss, the conclusion cannot be drawn that the N lost came from the fertilizer or that stopping fertilizer use would stop N loss. All fertile soils lose nitrate by percolation regardless of the source of the N-fertilizers, animal wastes, soil organic matter, or nitrate accumulated in the past. (Van Schilfgaarde, 1974)

Although the data is highly variable, it can be concluded that subsurface drainage expedites the transport of nitrate nitrogen from the soil to surface waters. (Brown and Zucker, 1998) Because of the improved productivity of the tile-drained land, the impact of additional nitrate losses must also be weighed against the need for production. Hopefully, better N management, either by existing means or those developed in the future, will allow a close matching of nitrate availability to plant needs, and thus reduce losses. (Baker and Johnson)

Research in Ohio and Minnesota shows that subsurface drainage promotes mellower soil conditions and reduces compaction potential. Where soil infiltration is promoted by practices such as subsurface drainage and conservation tillage, significant reduction has been found in total dissolved phosphorous and sediment concentrations of surface waters. At an Ohio site, subsurface drainage reduced the losses of sediment, phosphorous and potash by 40, 50 and 30%, respectively, over a 14-year period, compared to surface drained cropland. In another study, the reduction in loss of phosphorus ranges up to 45%, and is related to the reductions in total runoff, peak runoff rate, and soil loss. (Brown and Zucker, 1998)

One of the ways phosphorus does move through the soil profile is through the series of macropores, cracks and earthworm and root channels, also known as preferential flow paths. Stamm measured soluble-reactive and particulate phosphorus fluxes and attributed the phosphorus transport to flow in preferential flow pathways based on the characteristics of the relationship between phosphorus concentration and drain flow rate.

It has been estimated that about 50 percent of the phosphorus entering Lake Erie is by runoff from agricultural land, the other major source being discharges from wastewater treatment plants. There is a strong consensus among the jurisdictions in the US and Canada that the most effective means of significantly reducing agricultural sources of phosphorus is through erosion control, and that this control can best be achieved through wide spread adoption of conservation tillage practices, including no-till. No-till can potentially reduce total phosphorus losses by as much as 90 percent and conservation tillage phosphorus reductions may be as high as 50 percent. Tile drainage can potentially affect the impact of conservation tillage and no-till on phosphorus losses in two ways: a) crop yields are often reduced with no-till adoption on very poorly drained soils; and b) tile drainage may enhance the increased infiltration which is often observed with no-till compare to plowing. It is assumed here that any water that flows through tile will have lower concentrations of phosphorus than those in surface runoff because of the adsorption of phosphorus to soil particles. (Logan, 1987)

Water quality monitoring at the Klamath Experiment Station of Oregon State University during 1998-2000 provided data on nutrient loading of surface waters in the upper Klamath Basin indicating that agricultural contributions are less than predicted from previous studies.

The primary reason for our interest in preferential flow processes is the impact that such processes have on the quality of surface water and ground water resources. Preferential flow has always been conceived to have a detrimental impact on water quality because it moves solutes beyond the soil zone where both biotic and abiotic chemical reactions are usually at their highest potentials. (Nieber, 2001)

Small amounts of pesticide can move quickly through the soil into subsurface drainage water during the first several rainstorms after application. The amounts are less than 1% of what was applied (often less than 0.1%), while the majority of the pesticide is sorbed and / or degraded in the topsoil. Preferential flow of pesticides occurs during the first month or two after pesticide application in the spring. (Brown and Zucker, 1998) Characteristics of preferential flow processes include an early arrival time, a large peak concentration and a long-tailed recession. Rapid transport of tracers has been observed to occur, with breakthrough times on the order of 5 minutes for wet initial conditions. (Nieber, 2001)

At least six processes: volatilization, chemical, photochemical and microbial decomposition, movement, and adsorption are responsible for the behavior, fate, and persistence of pesticides in soils. Pesticides in waters may be toxic to fish, wildlife, and plants. Chlorinated hydrocarbon insecticides are potentially injurious to aquatic organisms. Many are highly toxic to aquatic animals. Chronic effects may be caused by the assimilation and storage of residues in the animal tissues. The carbamate insecticides are similar to the organic phosphates in that their