EVERGLADES AGRICULTURAL AREA SOIL SUBSIDENCE AND LAND USE PROJECTIONS

Prepared December, 2003

Revised January, 2004

George H. Snyder
Distinguished Professor, Emeritus – Soil and Water Science
University of Florida/IFAS, Everglades Research and Education Center

EXECUTIVE SUMMARY

The organic soils (Histosols) of the Everglades Agricultural Area (EAA) formed when organic matter (OM) production exceeded OM decomposition because flooded conditions limited the oxygen needed by aerobic soil organisms which convert the OM to carbon dioxide and water. Since the onset of extensive drainage in the EAA, OM decomposition has been exceeding production, resulting in loss of soil and a lowering of the surface elevations (subsidence). Prior to Everglades drainage, organic soil subsidence was well known in other locations, and it has been carefully documented in the EAA for nearly a century. In terms of agricultural production, it is a particular problem because most of the Histosols in the EAA are underlain by dense limestone rock. In 1951, following an extensive study of soil depths and subsidence rates, it was predicted that agricultural production would largely end by 2000 because of subsidence. In fact, production almost reached one billion dollars in 2000-2001, because growers found ways of adapting to decreasing soil depths, and sugarcane, which is fairly water tolerant, became the principle crop. What about the next 50 years? There is little scientific information dealing with subsidence rates of shallow Histosols in the EAA, which may have higher mineral content and be composed of less easily degraded OM than earlier. Nevertheless, it is projected that in 2050 nearly half of the EAA will have soils less than 8 inches in depth. Most of the shallow soils will be south of the Bolles canal. Based on today's production practices, sugarcane production will be difficult and costly, but not impossible. The area should be suitable for pasture, but not for most vegetables. Water control will be crucial, requiring a means for rapidly removing excess water and for obtaining irrigation water since soil storage will be minimal. With aggressive implementation of proven and yet-to-be proven soil conserving practices, much more of the EAA could be suitable for agricultural production. Whether or not there is extensive agricultural use of lands in the EAA from now until 2050 depends on many factors that are difficult to predict. Commodity prices and governmental policies are two prime examples of factors that may affect agriculture more than soil depths. Urban planners do not anticipate large population increases in the EAA, although developers are likely to find agricultural land prices in the region highly attractive relative to those on the Florida east coast. Urban development on severely subsided soils should be easier than on deep organic soils, if services can be provided. Unfortunately, from an agricultural perspective, most of the anticipated urban growth will be on deep Histosols near Lake Okeechobee. Particularly on severely subsided soils, landowners may explore biomass production, aquaculture, hunting reserves, water storage, and mining as alternatives to traditional agriculture

PREVIOUS PREDICTIONS

In 1951, John C. "Jake" Stevens and Lamar Johnson published a paper in which they predicted that by 2000 "most of the Everglades Agricultural Area will have subsided to the point where there will probably be wide scale abandonment over much of the area". In response, an Associated Press report concluded that "it is unquestionable that . . . the agricultural life of the organic soils in the Everglades Agricultural Area will be almost ended by the year 2,000 A. D."

Agricultural productivity in the 2000-2001 season amounted to $ 689,000,000 for sugarcane (including refining value), approximately $ 168,000,000 for vegetables, $ 30,000,000 for sod, and $ 9,000,000 for rice, i.e., nearly one billion dollars total (PBCCES, 2002).

SUBSIDENCE

As used herein, subsidence refers to the lowering of the land surface elevation as a result of draining organic soils. Organic soils (Histosols) contain a minimum of 20 to 30% organic matter (OM), by weight, depending on the clay content (higher OM required as clay content increases). Most of the soils in the Everglades Agricultural Area (EAA) are classified as Histosols. Histosols form when the rate of OM accumulation exceeds the rate of decomposition. In most regions, this occurs because the land is flooded much of the year, resulting in insufficient soil oxygen to maintain an active population of aerobic microorganisms that decompose OM (Tate, 1980). When the soils are drained, soil oxygen increases. A general stimulation of the microflora occurs. Increases in saprophytic bacteria, nitrifiers, denitrifiers, and cellulose oxidizers have been recorded (Tate, 1980). The rate of OM decomposition increases to the point that the rate of decomposition exceeds the rate of accumulation. As the soil disappears, the surface elevation decreases (subsides). Histosol subsidence also can result from a loss of buoyancy following drainage, shrinkage, compaction, soil loss by wind erosion and by burning. Subsidence shortly after drainage and initial land preparation for agriculture can be attributed largely to the first three factors. While subsidence by these methods is relatively rapid, it is not accompanied by a loss of OM. The latter two methods of soil loss occur only when the soil is very dry, and are largely avoidable in irrigated fields. Wind erosion is considered to have had little effect on subsidence in the EAA (Stephens and Johnson, 1951). Most soil subsidence, lasting over decades, is caused by microbial decomposition that converts the organic matter to carbon dioxide and water (microbial oxidation). Since it is microbially mediated, the rate is affected by temperature (Volk, 1973), and generally is greater in warm than in cold climates. Stephens and Stewart (1977) suggested a Q_{10} value of 2.0, i.e., a doubling in rate for each 10 degree centigrade temperature increase.

Subsidence was well known at the time the Everglades were drained in the early 1900s. The Fens of Great Britain were drained in the 1600s. To begin measuring the subsidence that had been observed since drainage was initiated, in 1848 a graduated iron column was sunk through 18 feet (5.4 m) of organic soil down to the underlying clay near Holme, England. By 1913, approximately the time Everglades drainage began in earnest, a reduction in surface elevation of 10 feet (3.0 m) had been documented. When the author visited the site in 1992, approximately 15 feet (4.5 m) of subsidence was evident (Figure 1). In 1924, to measure

Fig. 1. Post sunk into the Fens near Holm, England. In 1848 the organic soil surface was even with the top of the post. Photographed by the author in 1992.

subsidence which was anticipated in the EAA, a graduated concrete post was driven to the underlying rock at the present location of the University of Florida/IFAS Everglades Research and Education Center (EREC) near Belle Glade. The soil surface was even with the top of the post, which was 9 feet in length (2.7 m). Today, just over 3 feet (1 m) of soil remains at this site (Fig. 2).

Fig. 2. Concrete post driven into the organic soil at the University of Florida Everglades Research and Education Center, Belle Glade, in 1924, when the soil surface was even with the top of the post. Photographed in 2003.

The rate of subsidence in the EAA has been investigated and documented in several other ways. Starting in 1913, and further augmented in the 1930s, a series of transects (termed subsidence lines) were established in the EAA over which the surface elevation relative to mean sea level has been measured at 25 to 50-foot intervals over a distance of several thousand feet at approximately 5 to 20-year intervals. Two approximate east-west elevation transects across the entire EAA were made in 1912, and a much more detailed measurement of surface elevations was made throughout the entire Everglades in 1939-1940. In the 1930s, a study was conducted at the EREC to relate the rate of subsidence to the depth to water table (Neller, 1944). Based on all these studies, Stevens and Johnson concluded that the rate of subsidence in the EAA would be approximately one foot per decade, after the initial subsidence following compaction had occurred, based on the assumption that water tables would be maintained at 18 - 24 inches depth. This conclusion was used to develop soil-depth maps of the EAA at ten-year intervals from 1950 through 2000 (Fig. 3). Although slightly greater than the rate of subsidence used by Stevens and Johnson (one foot per decade) in making their predictions, an average subsidence rate of one inch per year often is quoted, and was substantiated by Shih et al. in 1978.

Shih et al. (1998) re-measured surface elevation along the subsidence lines in 1997, following a 19-year absence in these measurements. They concluded that subsidence during this period averaged 0.57 inches per year (1.45 cm $year^{-1}$), down from previous measurements, and speculated that maintenance of higher water tables in recent years was one of the major reasons for the reduction in subsidence rate. In addition to measuring the surface elevation, they also measured the rock elevation and, therefore, the actual depth of organic soil over the bedrock.

In light of the conclusion by Shih et al. (1998), I find it interesting to have observed that when I arrived on the job at the Everglades Research and Education Center in 1967, the soil elevation at the well known "subsidence post" on the property was very close to the 5-foot mark. As was mentioned previously, the post was installed in 1924 when the soil depth was 9 feet. Therefore, during the 43-year period from 1924 to 1967 there was an elevation drop of 48 inches, for an average subsidence rate of 1.12 inches per year, or very close to one foot per decade. At the time of my retirement in 2003, the soil depth was approximately 3.25 feet (Fig. 2). Thus, during the 36-year term of my employment, the elevation reduction was 21 inches (1.75 feet), for an average subsidence rate of 0.58 inches per year. This anecdotal recollection compares very favorably with Shih et al.'s more extensive and scientific investigation which concluded the rate over the previous 19 years (12 years after I started to 5 years before I retired) was 0.57 inches per year! A subsidence rate of approximately 0.6 inches per year probably is more accurate for prediction purposes today than the earlier used rate of 1.0 inch per year or 1 foot per decade.

Organic soil depths were measured throughout the Palm Beach County portion of the EAA (78% of the total EAA) for the Soil Survey Report of Palm Beach County (McCollum et al, 1978), and in 1988 by the use of ground-penetrating radar (Cox et al., 1988). Since the Histosols of the EAA are classified in part by the depth to concentrated mineral matter (rock, sand), a comparison of the location of various soil types in these two documents (Cox et al., 1988) provides a rather striking visual measure of soil subsidence (Fig. 3). In 1978, Pahokee muck with a depth of 36 - 51 inches covered most of the central and southern EAA. By 1988, the same

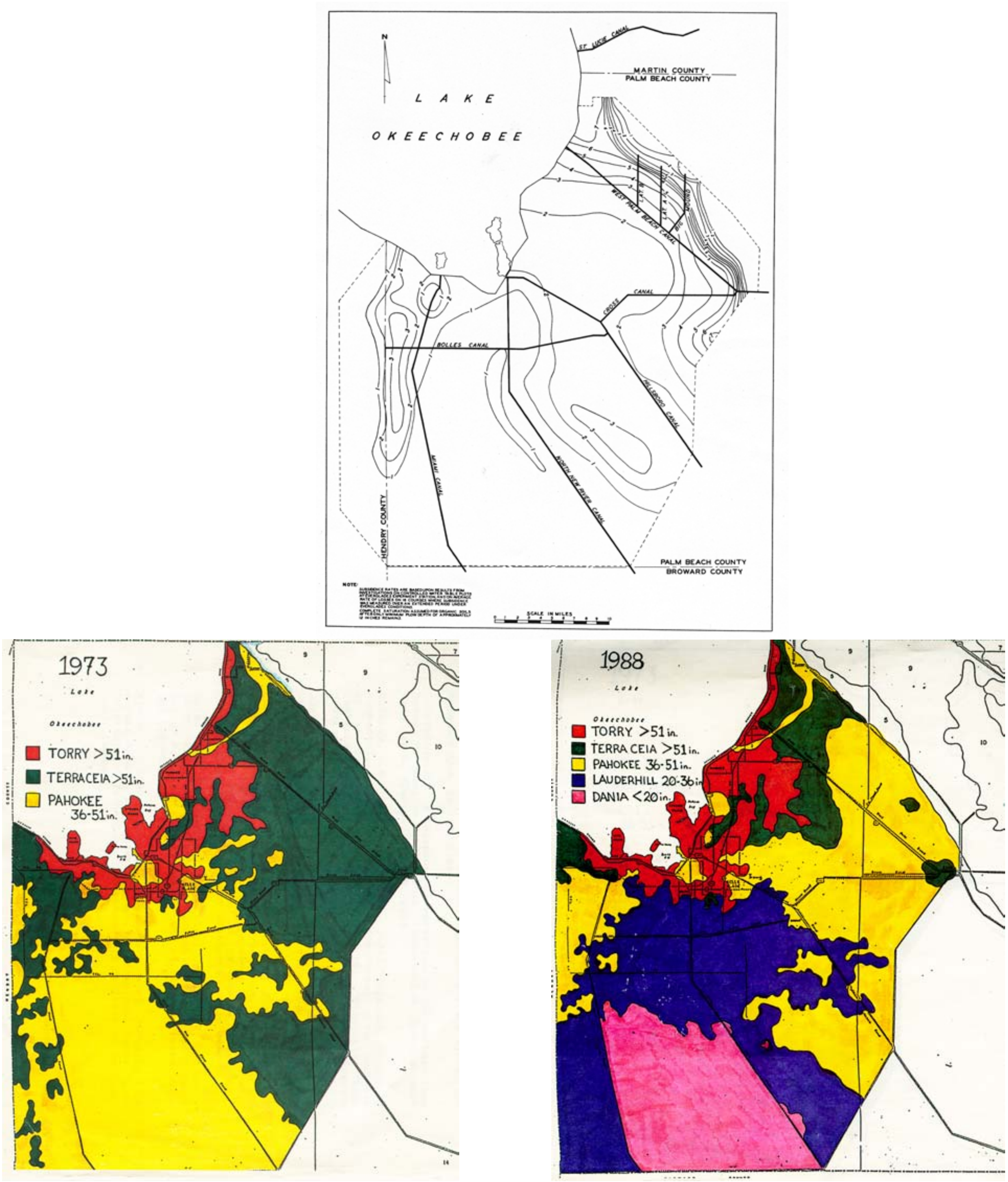


Figure 3. Top: Stephens and Johnson (1951) Prediction of soil depth in 2000.
Bottom: Soil Series designations in 1973 and 1988, from Cox et al., 1988.

area was comprised almost entirely of Lauderhill muck (20 - 36 inches depth) and Dania muck (8 - 20 inches depth).

The EAA extends west of Palm Beach county approximately 4 miles into Hendry county to the L-2 canal. The soils were most recently surveyed in 1985 and this survey was published in 1991 (Belz et al., 1991). At the time of the survey, approximately half the "soils of the Everglades" were organic, and half were mineral (sand) soils. Of the organic soils, approximately half were underlain by rock, and 10% of this area was mapped as the very deep Terra Ceia soil. The remainder were composed of organic deposits over sand, so that even after extensive subsidence it can be expected that these soils will remain tillable. Thus crop production is threatened on only about one fourth of the soils in the Hendry county portion of the EAA, or 3% of the total EAA (assuming approximately 12% of the total EAA is in Hendry county). This small portion of the EAA is omitted from most further discussion both because of its small extent, and because virtually all subsidence studies have been conducted in the larger Palm Beach county portion of the EAA.

In November, 2003, the author, with the assistance of Mr. Patrick Burke, Nodarse & Associates, Inc., checked soil depths at 15 locations around the EAA (Fig. 4). A 10-foot steel rod was inserted into the soil down to rock approximately 10 times at each location and the distance from the point of the rod to the soil surface was measured (Fig. 5). The soil depth thus determined was compared to the depth predicted by Stephens and Johnson (S&J) for the year 2000, and the depth range reported by Cox et al. in 1988 (Table 1). The two locations that were determined to be Torry mucks in 1988 had soil deeper than the S&J predictions, and more than deep enough to still be Torry mucks in 2003. The one sampling at a 1988 Terra Ceia muck site was very close to the S&J prediction, and still was deep enough to qualify as a Terra Ceia muck (> 51 inches). However, the soils in four of the five 1988 Pahokee muck locations were more shallow than was predicted for year 2000, and were too shallow in 2003 to fall into the Pahokee series. On the other hand, the four 1988 Lauderhill sites were deeper than the year 2000 prediction, and three of the four were within the depth range for Lauderhill in 2003. A site that was located right on the borderline between 1988 Lauderhill and Dania soils was deeper than the S&J prediction, and qualified as the deeper Lauderhill soil (20-36 inches). The remaining site, which was Dania in 1988, was somewhat more shallow than the S&J prediction for 2000, and fell into the Dania classification. In summary, all of the Torry, and Terra Ceia, and all but one of the Lauderhill and Dania site (1988) soils were deeper than the S&J prediction for year 2000. However, four of the five soils in the mid-depth (36-51 inches) Pahokee series locations (1988) were less deep than the S&J prediction for 2000, and all five were too shallow to qualify as Pahokee soils in 2003.

The above described depth survey was nowhere as comprehensive as those conducted by Stephens and Johnson (1951), by Cox et al.(1988), or those conducted in conjunction with measurements of the subsidence lines. Because of the importance of knowing both the soil depths in the EAA and the current rate of subsidence for the purpose of making present and future management decisions, the time has come for another detailed look at soil depths throughout the EAA, and for a re-measurement of subsidence lines. This project, however, will require both interested parties and a modest amount of financial support.

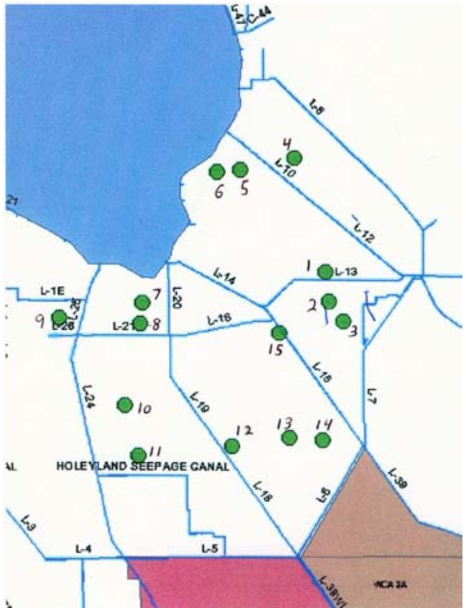


Figure 4. Fifteen places where soil depth was determined in the EAA on November 10, 2003

.

Fig. 5. A10-foot steel rod did not reach rock in the Torry muck at site 6 (left), whereas the rod penetrated only 8 inches (hat on top of rod) when inserted to rock in Dania soil at site 11.

Table 1. Depth to rock measured on November 10, 2003 at various locations in the EAA compared to Year 2000 prediction and soil types determined in 1988

Site	Latitude	Longitude	Average measured depth to rock (inches)	Year2000 Prediction (inches)	Soil Type 1988	Depth Range (inches)
1.	26° 41.256N	80° 29.774W	45	24	Pahokee	36-51
2.	26° 39.053N	80° 29.524W	21	32	Pahokee	36-51
3	26° 37.652N	80° 28.395W	29	48	Pahokee	36-51
4.	26° 49.760N	80° 32.336W	57	56	Terra Ceia	> 51
5.	26° 48.921N	80° 36.747W	> 90	36	Torry	> 51
6.	26° 48.705N	80° 38.697W	> 114	34	Torry	> 51
7.	26° 39.000N	80° 44.914W	33	12	Lauderhill	20-36
8.	26° 37.440N	80° 45.090W	29	12	Lauderhill	20-36
9.	26° 37.820N	80° 51.756W	21	36	Pahokee	36-51
10.	26° 31.302N	80° 46.338W	22	12	Lauderhill/ Dania	20-36/ 8-20
11.	26° 27.554N	80° 45.286W	8	12	Dania	8-20
12.	26° 28.260N	80° 37.577W	16	12	Lauderhill	20-36
13	26° 28.862N	80° 32.840W	20	36	Pahokee	36-51
14.	26° 28.736N	80° 30.156W	25	34	Pahokee	36-51
15.	26° 36.720N	80° 33.604W	28	24	Lauderhill	20-36

ASSUMPTIONS BEHIND LAND USE PREDICTIONS

Stephens and Johnson (1951) made the first and most detailed predictions about land use in the EAA based on a forecast of soil depths. Considering that they predicted up to 50 years into the future, they were remarkably accurate in their subsidence predictions. Working in their favor was the fact that they had solid data on the relationship between depth to water table and the rate of subsidence (Jones, 1948). For most of the soils, and for most of the period within their prediction, they could assume that an 18-24 inch water table could be maintained for satisfactory crop production, so predicting the resulting soil depths by decades was fairly straight forward.

During the 1930s and 1940s, vegetable production dominated in the EAA. For example, in 1943 it was estimated that in the upper Everglades nearly 70% of the cultivated land was in vegetables (Elvove, 1943). Sugarcane and cattle were minor commodities in comparison to vegetables. Consequently, the presence of soil depths suitable for vegetable production probably played heavily in the minds of Stephens and Johnson when making predictions about future land use. Most of the vegetable crops being grown in the EAA required good water control, They did not tolerate flooded or waterlogged soils. Stephens and Johnson made many references to the drainage problems that could be expected in shallow organic soils. Clearly, they considered “mole drainage” (underground horizontal non-reinforced channels leading to canals and field ditches) to be very important for water control, and stated that “it is impractical to mole drain organic soils of less than 3 feet depth” (Stephens and Johnson, 1951). They felt that soils of less than 3 feet in depth would only be suitable for “crops having a greater tolerance to water”. They further stated that it was not believed that soils of less than 1 foot in depth could be farmed economically.

FACTORS UNKNOWN WHEN LAND USE PREDICTIONS WERE MADE

When Castro rose to power in 1959, approximately 40,000 acres of sugarcane were harvested in the EAA. Over 300,000 acres were harvested in 2000-2001. Sugarcane appears to be an example of a “crop having greater tolerance to water” which Stephens and Johnson suggested would be suitable for shallow soils in the EAA. Today, acceptable sugarcane can be found growing in soils of only 6 to 8 inches depth in the southern EAA (Fig. 6). At the time the previously mentioned water table studies were conducted, it was noted that plots planted to cane subsided less than those in vegetables and grasses. At the time, Clayton and Neller (1941) discounted this observation. However, Shih et al. (1982) verified the reduction and attributed it to reduced soil temperatures under sugarcane, resulting in a 16% reduction in the rate of subsidence. The widespread cultivation of sugarcane may have resulted in decreased soil subsidence.

Fig. 6. Sugarcane growing on very shallow Dania muck in the southern EAA. The men in the foreground are sanding on limestone bedrock.

Growers have made changes in their cultural management practices to deal with drainage and irrigation problems caused by shallow soils. Examples are adding more field drainage ditches, cutting canals into the bedrock, installing more water control structures, and upgrading pumping facilities. Some use bedding for vegetables to raise the planted soil surface. In at least one place, soil has been scraped away from areas adjacent to major canals and used to fill in low spots within cultivated fields. Growers also have modified field operations in response to shallower soils. Tilling less deeply and making fewer passes over fields are a few examples. Whether or not growers can continue to develop ways of coping with increasingly shallow soils remains to be seen, but it should not be assumed that they cease to make such efforts. Growers may prove the statement of Walter Bigalow Wriston (former Citibank chairman) “The doomsayers have always had their uses, since they trigger the coping mechanism that often prevents the events they forecast”. Even more apropos may be the statement of the politician Adlai Stevenson who said “Man has wrested from nature the power to make the world a desert, and to make the desert bloom”.

SOIL SUBSIDENCE AND RESULTANT SOIL DEPTHS OVER THE NEXT 50 YEARS

Whereas Stephens and Johnson had scientific data upon which to base their predictions of soil subsidence and future soil depths, and were able to assume that steady water tables could be maintained throughout most of the EAA during most of the time period covered by their predictions, neither of the latter two assumptions can be made during the next 50 years, and there are no detailed studies available on which to predict subsidence rates under conditions prevalent throughout much of the EAA today and which can be expected in the future. Therefore, predictions of subsidence rates and soil depths over the next 50 years are based on even more speculation that had to be used for the previous 50-year period.

Because of their high mineral content, it can be assumed that the Torry muck soils along the southern rim of Lake Okeechobee will subside slowly (Zelazny and Carlisle, 1974), and will be deep enough for cultivation well beyond the next 50 years. As an aside, it seems clear that Stephens and Johnson (1951) did not consider the much greater mineral matter content of the Torry muck soils when making projections of soil depths by decades (their figures 18 through 22), since they showed a loss of one foot per decade in areas now classified as Torry muck, and did not differentiate subsidence of these soils from that on soils in adjacent areas.

The Terra Ceia soils are of a depth (> 51 inches) that, if one assumes a subsidence rate of approximately 0.6 inches per year, they still will be sufficiently deep for cultivation 50 years from now. Together, the Torry muck and the Terra Ceia muck soils comprised 16.6% of the EAA in 1988 (Palm Beach County only, Cox et al., 1988). Combined with the Okeelanta muck (3.6 % of the EAA in 1988), which is underlain by sand that can be tilled, it can be assumed that approximately 20% of the EAA in Palm Beach County (120,000 acres or 188 square miles) will not be limited for cultivation by soil depth 50 years from now.

Predicting future depths for soils that were in the proper depth range (36 to 51 inches) to be classified as Pahokee muck in 1988 is more difficult and uncertain than for the Torry and Terra Ceia Series soils. The Pahokee Series is important because in 1988 it represented 27% of the Palm Beach County EAA (166,000 acres). If a straight-line subsidence rate of 0.6 inches per year is assumed for the period from 1988 to 2050, then a loss of 37 inches in soil depth is predicted. This would, of course, wipe out the more shallow Pahokee mucks, but leave as much soil in the deeper Pahokee mucks as is being cultivated for sugarcane today in portions of the southern EAA. However, our own survey conducted in November 2003 indicated that soils in the Pahokee Series in 1988 often were more shallow than Stephens and Johnson predicted for 2000, and were too shallow to be classified as Pahokee soils. Countering this is the long-standing question (argument) of whether the assumption of a straight-line rate of subsidence is valid for shallow muck soils in the EAA, and whether a point will be reached when subsidence essentially ceases.

One argument for a decline or actual ceasing of subsidence is the idea that mineral matter within the organic soil profile will, over time, become a major component of the soil matrix. Much of the currently farmed EAA had soils 10 feet or deeper in 1912, according to Stephens and Johnson (1951). Assuming an organic matter content of 85 to 90% by weight, Snyder et al. (1978) concluded that a 10-foot profile of organic soil would produce only 3 to 4 inches of mineral matter. Due to the great difference in bulk density between mineral matter (assume 1.6 g/cc) and organic matter (assume 0.3 g/cc), a soil with only 20% organic matter would have a depth of 8 inches if the mineral matter alone constituted a depth of 4 inches.

As part of this project, on two separate occasions I determined the mineral matter content of very shallow (< 10 inches) organic soils in the southern EAA, on the former Talisman property that is destined to be converted to a water storage reservoir. The range in mineral matter content among the 6 sampled sites was 26 to 52% by weight, and averaged 40%. While no precise data are available on the original mineral matter content of the soil in this region, far from Lake Okeechobee, certainly the present-day mineral matter content of the soil remaining at this site is much elevated, and approaches that of the Torry muck soils adjacent to the Lake which subside very slowly. While it must be acknowledged that the mineralogical composition of the inorganic material at the two locations probably is quite different, the argument that the mineral matter content of the soil will increase appears to have merit. In the 1978 report, Snyder et al. concluded that soils containing only 3 to 4 inches of mineral matter would not have sufficient depth for crop production. However, sugarcane is being grown in soils at or approaching the soil conditions that previously were predicted to be inadequate for agricultural production. As the French dramatist Eugene Ionesco said, “You can only predict things after they have happened”.

Humification is the process involved in the decomposition of organic matter which leads to the formation of humus (Brady and Weil, 1999), and it is generally accepted that humus is less easily decomposed than most other soil organic matter fractions. Since oxygen was limiting during the time the organic soils formed in the EAA, they were not fully humified. Because of this, Zelazny and Carlisle (1974) recognized the principle that organic soils should become less easily oxidized with time as they become more humified. In addition to accumulation of mineral matter, such a theory could predict or account for a reduced subsidence rate as soils in the EAA become very thin over bedrock. However, there are insufficient data to firmly support this speculation at this time.

An important production problem occurs on very shallow soils. While the surface elevation in the EAA is fairly level, the underlying bedrock elevation often is quite variable (Shih et al., 1979). It has been observed that as the soil become thinner over bedrock, high spots in the rock have become exposed. Such exposure is accelerated by land leveling, which scrapes soil from the rock surface even if it contains mineral matter. Crops grow poorly, or not at all, when the bedrock is very close to the surface or exposed (Fig. 7). In addition, the thin layer of organic soil over the high spots of bedrock dries out faster than the surrounding soil and can burn away when sugarcane is burned for harvest (Fig. 8). Consequently, the areas of exposed bedrock grow in size over time. With awareness of this problem, and implementation of special soil conservation practices, not all of which have necessarily been developed at this time, it should be possible to minimize or at least delay the problem. Whether or not this occurs will have a major impact on the long-term usefulness of the shallow soils for agricultural production. Fields have been taken out of production not because the “average” soil depth is too shallow, but because the area of exposed rock has become too great. In addition, such areas damage planting, cultivation, and harvesting equipment.

Fig. 7. Exposed bedrock in the lower right-hand side of a sugarcane field (left), and spots devoid of cane in a field (right), both in the extreme southern EAA.

Fig. 8. Muck soil burning after sugarcane harvest on a shallow soil in the extreme southern EAA.

The Lauderhill soils are important because in the 1988 study (Cox et al.) they covered 40% of the EAA (240,000 acres). These soils are 24 to 36 inches deep over limestone rock. Using a straight-line projected subsidence rate of 0.6 inches per year, even the deepest of these soils will be exhausted by 2050. However, in our November 2003 survey, all 1998 Lauderhill soils were deeper than the S&J prediction for 2000. North of the Bolles canal, they were more than twice the S&J predicted depths. Can this be taken to be evidence that the subsidence rate slows as the soils become more shallow? Perhaps. The shallow (8- 20 inches) Dania soils comprised about 10% of the EAA in 1988. Much, though not all of the 1988 Dania soil region now is, or is slated to be, in government-owned water storage or conservation areas.

In summary, it appears that even in 2050, the Torry, Terra Ceia, and optimistically, the

Pahokee soils, as mapped in 1988, will be of sufficient depth to support at least some of the agricultural enterprises that are known today, using essentially the same cultural practices that are used presently. For the next 20 to 30 years almost for certain, and perhaps on through the next 50 years, about 50% of the EAA should have soils of suitable depth to support agriculture as we now know it. With innovation, the arable land area may be greater, as it may include a portion of the 1988 Lauderhill soils. This will only happen, however, if growers observe the problems they are having today with the Dania soils and chose to make important changes in their agricultural practices to forestall the day when the same problems occur on soils that today can be classified as Lauderhill and Pahokee.

There are things that the growers can do that will impact the rate of subsidence, and the agricultural use that can be made of the remaining soils in the future. It long has been recognized that maintenance of high water tables is the key to reducing subsidence (Stephens and Johnson, 1951; Snyder et al., 1978). Previously-mentioned practices that have come into use in recent years will help maintain production on shallow soils. Since shallow soils have less capacity to store excess water and provide water during water deficit periods, there likely will be more dependency on public water storage facilities. The planned EAA Storage Reservoirs should help in this regard. In addition, some in the area envision a time when EAA agriculture can be sustainable, controlling soil loss, providing water storage for urban and natural uses, contributing to improved habitat of threatened Everglades species, and providing other ecological benefits to the surrounding Everglades (Glaz, 1995). Sugarcane would be a key crop in this vision, because of its adaptability to wet soils. It should be possible to develop even more water tolerant sugarcane varieties in the future (Deren et al., 1991a). Rice, which can be grown on flooded soils, and perhaps other aquatic crops could be part of the entire package (Snyder et al., 1999). Research, and grower enthusiasm for this vision are the keys to making it a reality.

FUTURE LAND USE IN THE EAA

The full reasons agricultural corporations have for making decisions are not always well publicized, so it is difficult to determine the degree to which soil subsidence has affected decision making. However, in the past decade some agricultural enterprises have departed or made substantial changes in the most southern EAA, where the soils are the thinnest over bedrock, and subsidence may have contributed to those decisions. A sod farm in the extreme southern EAA ceased production on land that had bare rock exposed, and another only a little north of that one switched from sod to sugarcane because of harvest problems. When sod cutting machines hit bedrock outcroppings, both the machines and the operators can be injured. The Talisman corporation, which grew substantial sugarcane on very shallow soils in the southern EAA, ceased production recently. While a number of factors probably were involved in that decision, many feel production was low and expenses were high because of shallow soils.

Of course, factors that are much less predictable than soil subsidence have governed land use to date, and probably will continue to do the same in the future. No one in the EAA agricultural industry with whom I have talked currently is making plans to get out of agriculture. Some are very enthusiastic about the future. Sugar corporations continue to make large capital investments that must be amortized over many decades. Some, and the United States Sugar Corporation is a prime example, cultivate the deep Torry and Terra Ceia soils adjacent to Lake Okeechobee, and have farms on sand lands near the EAA. Such enterprises should be little affected by subsidence. Others are in seemingly more vulnerable locations, but only Talisman has made outward signs of closing up shop.

The biggest factor affecting land use over the past 50 years was an external one. When the US government placed an embargo on sugar from Cuba, the Florida sugarcane industry expanded from roughly 40,000 acres to over 300,000 acres today. A cow-calf cattle industry that had gained some prominence in the 1950s and 1960s completely left the EAA as growers turned from the roller coaster prices of that industry to the more dependable prices of the sugar industry. The vegetable industry declined considerably for the same reason, but still remains. Today, concerns about the continuance of government programs that help support and stabilize the domestic sugar price are much greater than are those about subsidence. There have been government programs affecting sugar prices since the founding of this country, and an alliance of cane, beet, and corn-based sweetener interests effectively lobbies the Federal government to maintain sugar prices at a level where the respective sweeteners can be profitably grown. Although there have been and continue to be many threats to the present-day sugar program, there also appears to be general confidence that it will remain in effect in some form for the foreseeable future. If it does, there may be barely enough organic soil of suitable depth in the EAA to sustain sugar production at its current level over the next 50 years.

Currently, only about 15,000 acres are devoted to vegetable production in the EAA, and some of this, especially sweet corn, in grown in rotation with sugarcane. While vegetables generally require deeper soils than sugarcane, there should be sufficient areas for vegetable production over the next 50 years. Prices and government regulations will have a greater impact on vegetable production than soil subsidence. Sod farming has been very profitable at times, and the demand for sod generally follows the construction industry. Sod may be a casualty of subsidence in the future, but prices will play a big role in the total EAA sod acreage. Each sugar mill requires a set amount of sugarcane annually for profitable operation. If sugar prices remain profitable, it is unlikely that sod growers will out compete sugar growers for land, especially those sugar growers who have mill ownership. Thus a competition for land may arise between vegetable growers and sod growers which will be based on current prices for each commodity.

Over the next 50 years, appreciable acreage of shallow organic soil will come into being in the EAA. Pasture grasses are an option for such land, and there may be a re-emergence of a cattle industry in the EAA for this reason. For example, even today the forage Cali bermudagrass can be seen growing on very shallow organic soils and even on limestone rock sugarcane loading ramps (Fig. 9). Production of water-tolerant crops for biomass to provide energy are possibilities. Research has been conducted both on water-tolerant sugar-cane-like grasses (Deren et al., 1991b) and on cypress trees in the EAA. Already, three electrical generating plants utilizing biomass have been built in the EAA.

Fig. 9. Cali bermudagrass growing on a limestone sugarcane loading ramp in the EAA.

As long as there is water and sunshine, some form of agriculture likely will be possible and attractive in those parts of the EAA in private hands. Aquaculture is a possibility. In addition, land may be placed into wetlands to satisfy wetland mitigation requirements for development elsewhere. Hunting reserves also are a possibility. Already the State of Florida provides land for duck hunting in the EAA along the Miami canal on land leased from the State for sugarcane and rice production by a sugar corporation. Land owners may operate privately built water storage facilities, with the possibility of locating such a facility in a previously or yet to be mined site.

Finally, what about urbanization? South Florida has seen remarkable population growth during the past thirty years, and Palm Beach county has grown especially fast in the past decade. However, the EAA portion of western Palm Beach county has experienced little change in population, and actually has been losing population in recent years. On an annual basis, the University of Florida Bureau of Economic and Business Research estimates the future population of all Florida counties on five-year increments. Currently the estimates go out to 2030. For Palm Beach County the estimate is for a population of 1,872,400 persons in 2030. The Planning Division of the Palm Beach County Planning, Zoning, and Building Department has determined that the eastern County can accommodate another 1,600,000 persons within areas already platted for development, and expects most population growth to continue to occur in the eastern County. There have been well-publicized predictions that the remaining 272,400 persons will located in the EAA. There are large tracts of residential future land use-designated vacant and underutilized parcels adjoining the EAA municipalities, and the Planning Department does not expect them to be developed out over the next 30 years. In fact, they only project a population increase of 34 persons per year in the EAA. Consequently, the County planners foresee no large cities being founded in the farmlands of the upper Everglades.

Of course, the Planning Division could be underestimating population growth in the County, and especially in the EAA, particularly toward the end of their 30-year projection and beyond. As land prices escalate in the eastern County, farm-land in the EAA that traditionally sells for $ 3,000 per acre becomes especially attractive. Unfortunately, from an agricultural standpoint, growth is most likely to occur on the better and deeper soils adjacent to the Lake and closer to 20-mile bend. If farmland in the southern EAA becomes too shallow for economic production, it may be attractive for development as home sites that seem not too distant from current population and employment centers in Miami and Ft. Lauderdale. Without any changes in County zoning laws, 10-acre homesteads could be sold. Subsidence actually makes development easier by providing a solid surface on which to place structures. Providing water and sewerage services, however, will be difficult in the southern EAA. The traditional well and septic tank system for obtaining these services is close to impossible in that region because below-ground fresh-water does not exist and infiltration is blocked by the limestone and shell bedrock.

In conclusion, the County is not projecting large population increases in the EAA. Developers have, nevertheless, shown that they can attract people into areas previously overlooked for population growth. The town of Weston in Broward County was developed in the Everglades far west of Ft. Lauderdale on land dominated by the same Lauderhill/Dania soil association that occurs in the southern EAA. There is no reason to think there will not be attempts at urbanization if agriculture becomes unprofitable in the EAA.

MAPPING THE FUTURE

Based on the foregoing discussion, maps have been prepared of predicted soil Orders in the Palm Beach county portion of the EAA, both assuming that current farming practices are continued, and assuming that intensive soil-conserving measures are undertaken (Fig. 10). The Okeelanta muck soil, which represents less than 4% of the Palm Beach County EAA and is underlain by sand making it arable even when the organic material has oxidized away is not depicted. The Dania soil has a minimum described depth of 8 inches. Two variants of Dania,

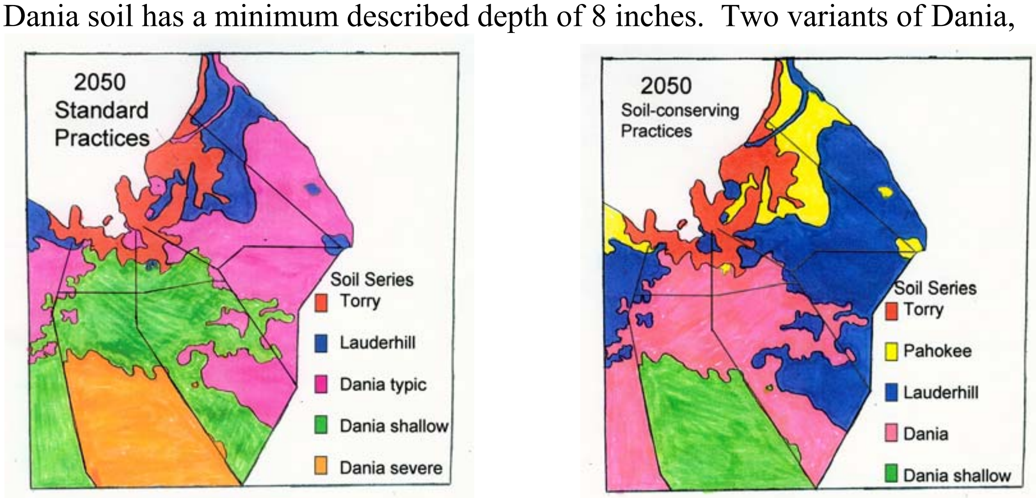


Fig. 10. Predicted soil Orders in the EAA assuming (left) continuance of current-day agricultural practices, and (right) implementation of intensive soil-conserving measures.

Dania "shallow" and Dania "severe" are proposed for Dania soils less than 8 inches depth over limestone rock. Dania variants are proposed because no soil Series has been mapped as yet in the EAA to describe these conditions. Dania "shallow" is envisioned to have rock outcroppings covering approximately one third of the land area, and Dania “severe” has rock outcroppings covering approximately two thirds of the area. The former can be farmed with difficulty, but the latter can not be farmed with conventional practices.

Assuming currently-used agricultural practices are continued, the Pahokee series, and much of the Terra Ceia series will cease to exist by 2050. Nearly 70% of the EAA will have soils suitable only for water tolerant crops, which includes rice, certain cultivars of sugarcane, and some pasture grass species (Table 2). The Dania variant termed “shallow” will have rock outcroppings that will restrict their use and make cropping difficult. Somewhat over 10% of the area (Dania variant “severe”) likely will be unsuitable for any known crop production, but much of that land may be in conservation/water storage uses anyway. If soil-conserving practices are implemented (Glaz et al., 1995), and it is admitted that not all beneficial practices have been proven and some may reduce crop production, then nearly half the EAA soils should be suitable for all crops being currently grown, and most of the remainder should be suitable for water-tolerant crops through 2050. To the arable soils in these figures can be added, regardless of scenario, about 75% of the “Everglades” soils in Hendry county which are composed of or are underlain by sands. These total approximately 65,000 acres.

Table 2. Estimated acreage of various soil series in the Palm Beach county EAA in 1988, and in 2050 for use of standard agricultural practices and for use of intensive soil-conserving practices. The 1988 figures are from Cox et al., 1988.

				2050	
Series	Depth	Use	1988	Std	Conserv
	(inches)		- - - - - - -	(acres) - - - - - - - -	
Torry	> 51	All crops	42,660	42,660	42,660
Terra Ceia	> 51	All crops	57,962	0	0
Pahokee	36-51	All crops	166,246	0	57,962
Lauderhill	20-36	All Crops	240,807	57,962	166,246
Dania	8-20	Water tolerant	61,914	166,246	240,807
Dania shallow	< 8	Water tolerant	0	240,807	61,914
Dania severe	< 8	None	0	61,914	0
			Total - - - - - - -	569,589	- - - - - - - -

While it is officially anticipated that there will be little urbanization in the EAA in the foreseeable future, a planned urban community may be established on land that is not agriculturally productive, profitable, or in response to large land price differentials between the urban coastal Palm Beach county and the EAA. The County Planning Department, however, anticipates that lands already designated “Residential Future Land Use” adjacent to South Bay, Belle Glade, and Pahokee (Fig. 11) will accommodate future urban growth, at least to 2030. All these areas are on Torry and Terra Ceia muck soils.

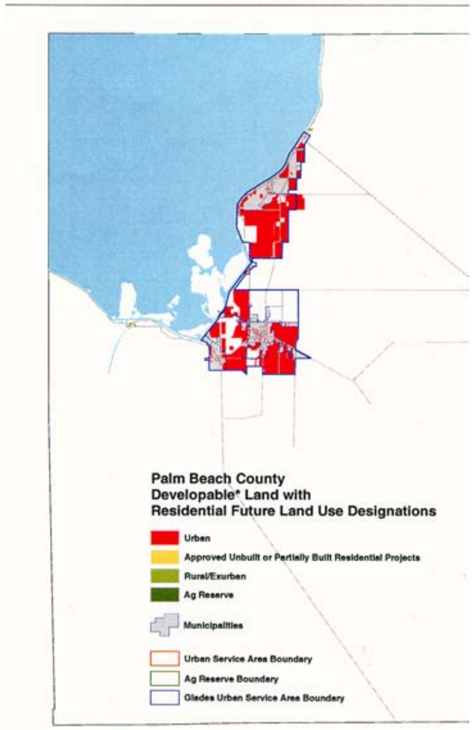


Fig. 11. Palm Beach county land in the EAA with Residential Future Land Use designations.

Acknowledgements

The time, patience, information, materials, excellent ideas and suggestions provided by many agricultural industry and government officials in the preparation of this manuscript are greatly appreciated. Since the author assumes responsibility for interpreting these comments, contributing individuals will not be identified, but they are remembered. Ms. Kathleen Krawchuk, Librarian at the University of Florida Everglades Research and Education Center, provided valuable library services. Sponsorship for this report was provided by the South Florida Water Management District both financially, and through the direct help of several of their dedicated employees.

Literature Cited

Belz, D. J., L. J. Carter, D. A. Dearstyne, and J. D. Overing. 1991. Soil Survey of Hendry County, Florida. USDA, SCS. Washington, DC.

Brady, N. C., and R. R. Weil. 1999. The Nature and Properties of Soils, 12th edition. Prentice-Hall, Upper Saddle River, NJ. pp. 881.

Clayton, B. S., and J. R. Neller. 1941. Water control investigations. Fla. Agric. Expt. Stn. Ann. Rpt. Pp. 164-164.

Cox, S., D. Lewis, S. McCollum, M. Bledsol, and R. Marrotte. 1988. Subsidence study of the Everglades Agricultural Area. USDA, SCS, Greenacres, FL. pp. 25.

Deren, C. W., G. H. Snyder, J. D. Miller, and P. S. Porter. 1991a. Screening for and heritability of flood-tolerance in the Florida (CP) sugarcane breeding population. Euphytica 56:155-160.

Deren, C. W., G. H. Snyder, P. Y. P. Tai, C. E. Turick, and D. B. Chynoweth. 1991b. Biomass production and biochemical methane potential of seasonally flooded inter-generic and inter-specific Saccharum hybrids. Bioresource Technology 36:179-184.

Elvove, J. T. 1943. The Florida Everglades - A region of new settlement. J. Land Public Util. Econ.19:464-469.

Glaz, B. 1995. Research seeking agricultural and ecological benefits in the Everglades. J. Soil and Water Conserv. 50:609-612.

Jones, L. A. 1948. Soils, Geology, and Water Control in the Everglades Region. Bull. 442, Univ. Fla. Agric. Expt. Stn., Gainesville, FL. pp. 168.

McCollum, S. H., V. W. Carlisle, and B. G. Volk. 1976. Historical and current classification of organic soils in the Florida Everglades. Soil and Crop Sci. Soc. Fla. Proc. 35:173-177.

McCollum, S. H., O. E, Cruz, L. T. Stem, W. H. Wittstruck, R. D. Ford, and F. C. Wahs. 1978. Soil Survey of Palm Beach County Area, Florida. USDA, SCS. Washington, DC.

Neller, J. R. 1944. Oxidation loss of Lowmoor peat in fields with different water tables. Soil Sci. 58:195-204.

PBCCES. 2002. Palm Beach County Agricultural Production 2000-2001. Palm Beach County Cooperative Extension Service, West Palm Beach, FL. pp. 2.

Shih, S. F., E. H. Stewart, L. H. Allen, Jr., and J. W. Hilliard. 1979. Variability of depth to bedrock in Everglades organic soil. Soil and Crop Sci. Soc. Florida Proc. 38:66-71.

Shih, S. F., G. S. Rahi, H. Y. Ozaki, and A. G. Smatjstrla. 1982. Effect of water table and crops on soil temperature. Soil Crop Sci. Soc. Florida Proc. 41:47-54.

Shih, S. F., B. Glaz, and R. E. Barns, Jr. 1998. Subsidence of organic soils in the Everglades Agricultural Area during the past 19 years. Soil and Crop Soc. Fla. Proc. 57:20-29.

Snyder, G. H., H. W. Burdine, J. R. Crockett, G. J. Gascho, D. S. Harrison, G. Kidder, J. W. Mishoe, D. L. Meyer, F. M. Pate, and S. F. Shih. 1978. Water Table Management for Organic Soil Conservation and Crop Production in the Florida Everglades. Bull. 801, University of Florida/IFAS Agric. Exper. Stns., Gainesville, Florida. pp. 22.

Snyder, G. H., C. W. Deren, and B. Glaz. 1999. Wetland Crops Versus Wetland Drainage. HortSci. 34:46-49.

Stevens, J. C., and L. Johnson. 1951. Subsidence of organic soils in the upper Everglades region of Florida.. Soil Sci. Soc. Fla. Proc. 11:191-237.

Stephens, J. C., and E. H. Stewart. 1977. Effect of climate on organic soil subsidence. Int. Assn. Hydrological Sci. 121:647-655.

Tate, R. L. III. 1980. Microbial oxidation of organic matter of Histosols. *In* Advances in Microbial Ecol. Vol 4, Chapt. 5, pg. 169-201. M. Alexander (ed.). Plenum Pub. Corp.

Volk, B. G. 1973. Everglades Histosol subsidence. 1. CO2 evolution as affected by soil type, temperature, and moisture. Soil and Crop Sci. Soc. Florida 32:132-135.

Zelazny, L. W., and V. W. Carlisle. 1974. Physical, chemical, elemental, and oxygen-containing functional group analysis of selected Florida Histosols. Chapt. 6 in Histosols: Their Characteristics, Use, and Classification. Soil Sci. Soc. Amer., Madison, WI.

APPENDIX

1. Classification of soils in the EAA

2. Estimated acreage of various soil series in the EAA
   in 2050 and possible agricultural land uses.

Classification of Soils in the EAA

The primary source of information on the classification of soils in the EAA is the Soil Survey of Palm Beach County Area, Florida, issued in 1978 and published by the United States Department of Agriculture and the University of Florida/IFAS. A summary version, excerpted and reproduced in part herein, is in Snyder et al., 1978 (see Literature Cited). A comparison of previous and current classification systems was provided by McCollum et al., 1976.

The organic soils (Histosols) of EAA are classified on the basis of their organic matter content, the degree of decomposition of the organic matter, the depth over the mineral layer, and the composition of the mineral layer (Table A).

Table A. Summary of characteristics of EAA Histosols

Soil Series	Mineral Content (%)	Thickness of organic layer (inches)	Underlying material
Torry	> 35	> 51	Limestone
Terra Ceia	< 35	>51	Limestone
Pahokee	< 35	36-51	Limestone
Lauderhill	< 35	20-36	Limestone
Dania	< 35	< 20	Limestone
Okeechobee*	< 35	>51	Limestone
Okeelanta	< 35	16-40	Sand

* Surface layer of muck over an underlying layer of peat (less well decomposed organic matter). Because of extensive decomposition, this soil may no longer exist in the EAA, i.e., it has become Terra Ceia or Pahokee. The other soils are only composed of muck (more highly decomposed than peat).

As stated in Snyder et al., 1978, the Series description may be summarized as:

“Torry Series. Very poorly drained organic soils with black organic layers more than 51 inches thick. Portions of this soil are high in fine-textured, inorganic material. Limestone occurs at depths of 52 to more than 80 inches. This soil, known locally as custard apple muck, may contain between 35 and 70% mineral matter, most of which is sepiolite and montmorillonite clay.

Terra Ceia. Very poorly drained organic soils with dark organic layers more than 51 inches thick over limestone.

Pahokee. Poorly drained organic soils with dark organic layers from 36 to 51 inches thick over limestone.

The Terra Ceia and Pahokee soils are similar, differing only in thickness. They both are comprised of muck (well decomposed organic matter) throughout the profile. They contain less than 35% mineral mater by weight, and average 5 to 15%. The other soil series closely related to the Terra Ceia and Pahokee are the Lauderhill with 20 to 36 inches of muck over limestone rock, and the Dania with 8 to 20 inches of muck over limestone rock.

The Okeelanta soil has muck over sand. The sand is encountered at 16 to 40 inches and may extend to considerable depths, although rock may be found below 51 inches.

The organic soils are decreasing in thickness. Because of this phenomenon, soils now classified as Terra Ceia will be classified as Pahokee, Lauderhill, and Dania, in that order, with the passage of time (Fig. A).

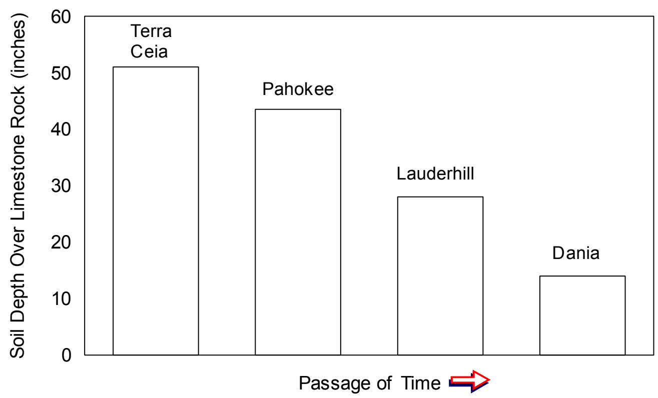


Figure A. Classification of muck soils relative to thickness over limestone rock. Upon drainage the thickness and hence the soil type changes with time. Adapted from Snyder et al., 1978.

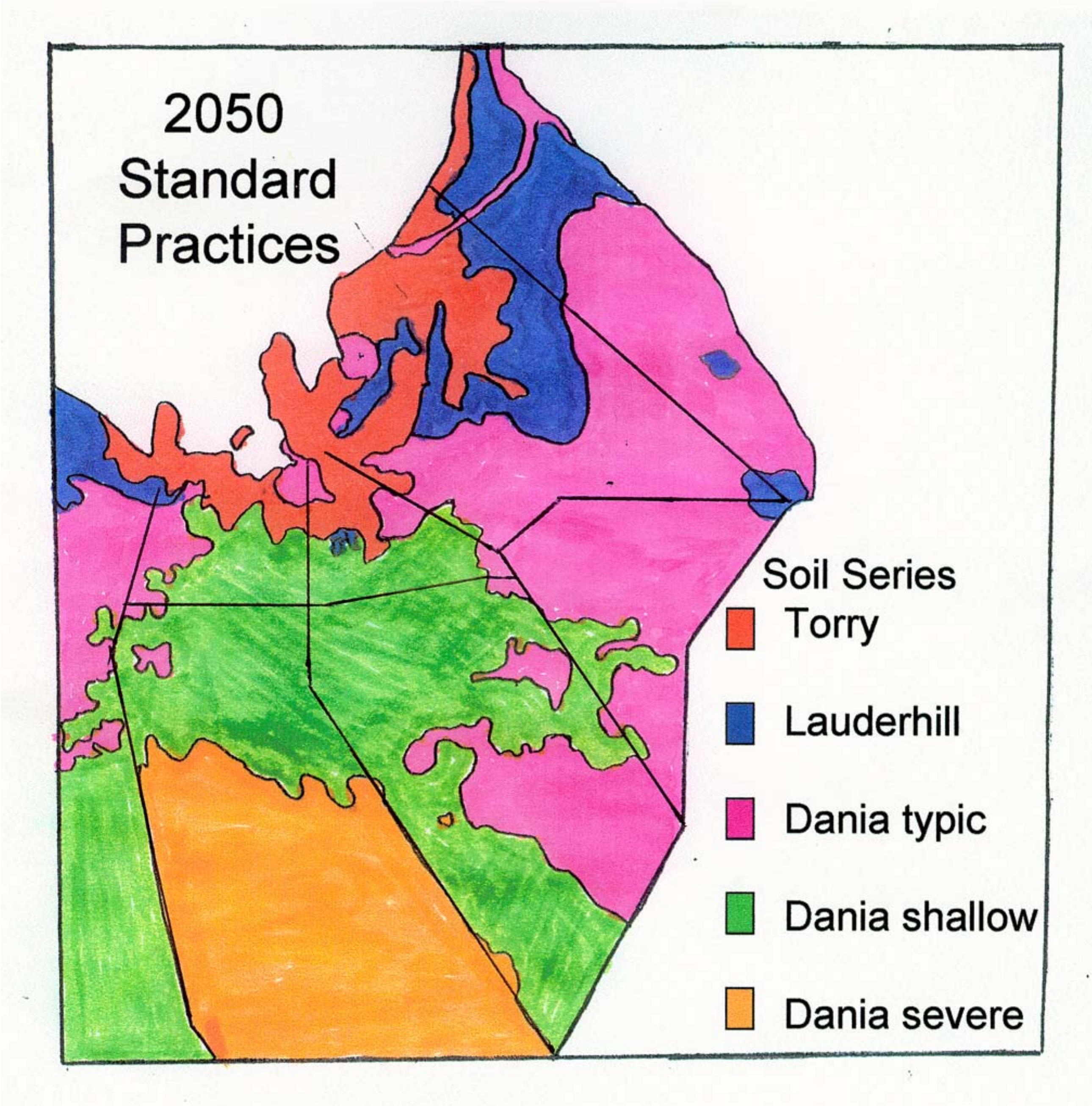
Estimated acreage of various soil series in the EAA in 2050 and possible agricultural land uses

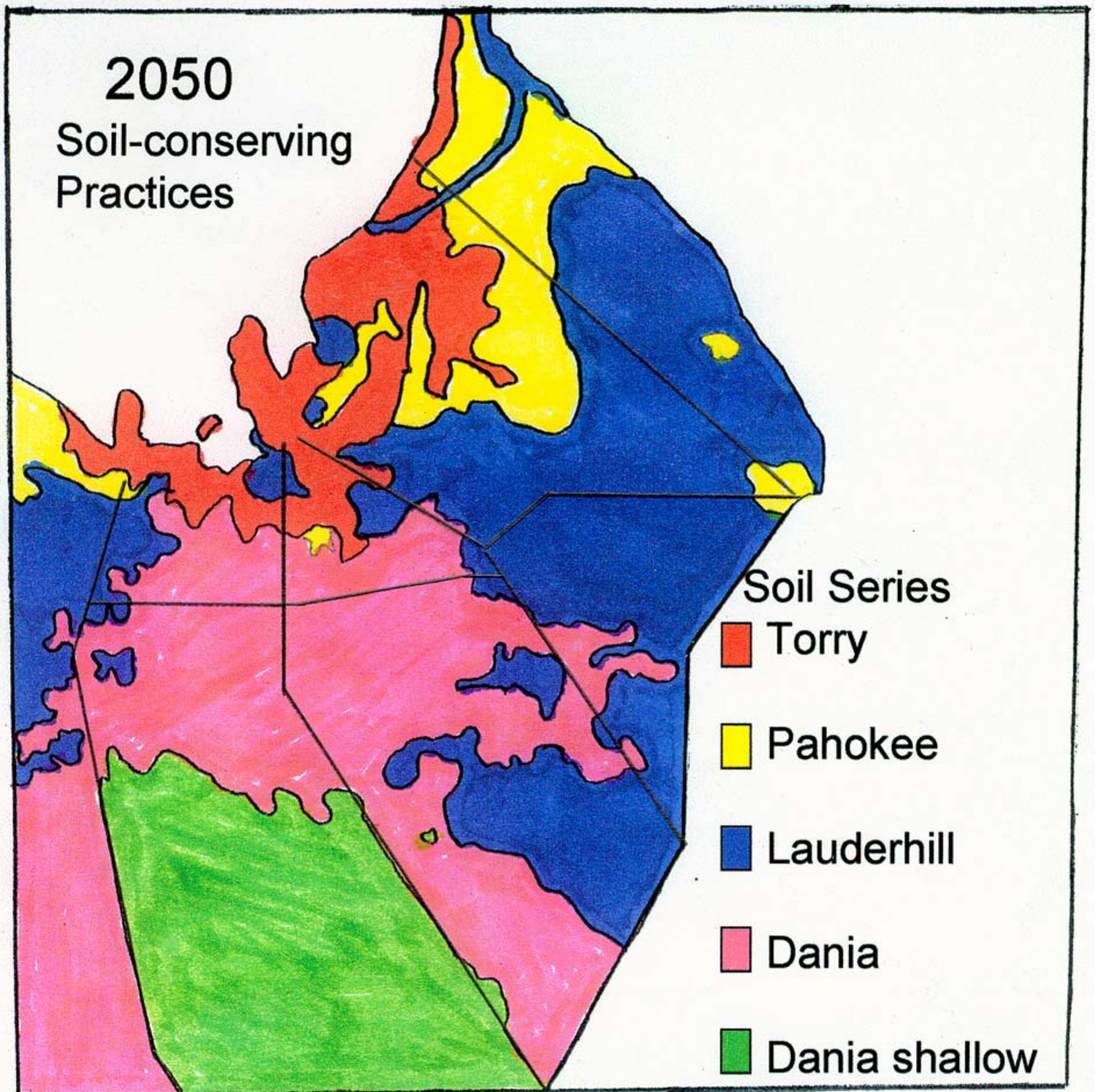
---

Estimated acreage of various soil series in the Palm Beach county EAA in 1988, and in 2050 for use of standard agricultural practices and for use of intensive soil-conserving practices. The 1988 figures are from Cox et al., 1988.

Series	Depth	Use	1988	2050* Std	2050* Conserv
	(inches)		- - - - - - -	(acres)	- - - - - - - -.
Torry	> 51	All crops	42,660	42,660	42,660
Terra Ceia	> 51	All crops	57,962	0	0
Pahokee	36-51	All crops	166,246	0	57,962
Lauderhill	20-36	All Crops	240,807	57,962	166,246
Dania	8-20	Water tolerant	61,914	166,246	240,807
Dania shallow	< 8	Water tolerant	0	240,807	61,914
Dania severe	< 8	None	0	61,914	0
			Total - - - - - - -	569,589	- - - - - - - -

* See maps on pages 25 and 26 for predicted locations


2050
Standard
Practices
Soil Series
Torry
Lauderhill
Dania typic
Dania shallow
Dania severe


2050
Soil-conserving
Practices
Soil Series
Torry
Pahokee
Lauderhill
Dania
Dania shallow