CHEMICAL SOIL PROPERITES OF A CAROLINA BAY WETLAND AFTER 15, 20, AND 30 YEARS OF DRAINAGE AND AGRICULTURAL PRODUCTION

Abstract: Wetland hydrology is being restored to a drained Carolina bay wetland in Robeson County, North Carolina called Juniper Bay that was drained for agriculture 30 years ago. The objective was to examine the chemical properties of the soil in Juniper Bay, compare the changes relative to undrained reference Carolina bays, and evaluate the potential for successful wetland vegetation establishment. Sampling locations in Juniper Bay were determined by randomly placing an equilateral triangle grid over a map of Juniper Bay. Paired pits for each location were dug, profiles described, and samples. Three reference bays were selected on their similarity to soils present in Juniper Bay and lack of management. Transects were cut through the dense vegetation from the outer rim to roughly the center of each Carolina bay. Sampling locations were chosen randomly along the transect. Profiles were described and samples taken using a bucket auger and McCauley peat sampler. Three general soil types were identified in all the Carolina bays, organic, histic and mineral. Comparisons within soil types were made using SAS procedure PROC MIXED. Compared to the reference bays; the organic soils at Juniper Bay have increased levels of extractable K, Ca, Mn, and base saturation, and decreased level of CEC, organic carbon and total nitrogen; the histic soils in Juniper Bay are higher in extractable Ca, Mg, P, Mn, and base saturation while extractable K, organic carbon, total nitrogen and CEC are lower; and the mineral soils had higher levels of Extractable Ca, Mg, P, Zn, base saturation, and pH. Differences were due to fertilizer and lime amendments and organic matter oxidization. The differences in the soils at Juniper bay when evaluated at the crest in the center of the field and ditch locations

near the edge of the field showed that Extractable Zn was higher at the crest in organic soils, extractable Mg, P, Mn, Zn and base saturation were higher at the crest in the histic soils, and extractable K, Ca, Mg, Mn, and Zn were higher at the crest in the mineral soils. When looking at changes over time, the trend for all soil types are for higher nutrient levels, base saturation and pH and lower organic carbon, CEC, and total nitrogen the longer the soil has been drained and in agricultural production. The length of time influenced the depth to which there were differences. The changes in soil chemical properties due to agricultural production are large. We believe that the increases in nutrient levels and pH will negatively influence the establishment of plant communities in Juniper Bay that are typical of Carolina bays, which thrive under acidic and nutrient poor conditions.

INTRODUCTION

Section 404 of the Clean Water Act (1977) requires the replacement, or mitigation, of destroyed wetlands. Wetland mitigation includes, enhancement and preservation of current wetlands, creation of new wetlands, or the restoration of prior wetlands (USCOE, 2002). Success of such mitigation projects is mixed. Erwin (1991) found that of 40 mitigation projects in south Florida 60% were judged incomplete or failures, Wilson and Mitsch (1996) found that only 38% of the desired wetland was established at mitigation sites in Ohio, and Gallihugh and Rogner, (1998) found that 99 ha of 128 mitigation sites involving 144 ha, were found to have unsatisfactory hydrology. The probability of success should be greater in an area that once supported wetland hydrology, hydric soils, and hydrophytic vegetation.

Drained Carolina bays found along the Atlantic Coast in the southeastern U.S., are being utilized for wetland restoration. Carolina bays are elliptical depressions in the landscape that are orientated along the long axis SE to NW. They range in size from 10 m to more than 4 km along the long axis. The bays are usually surrounded by a light colored sandy rim and have a dark colored depression resulting from high amounts of organic matter (Johnson, 1942). The extent of these bays range from Northern Florida to Delaware with the highest concentration in North and South Carolina. Estimates on the number of these bays are as high as 500,000 (Johnson, 1942), but the actual number maybe less than 100,000 (Nifong, 1998). Many theories for bay formation have been proposed, from the most popular, meteor impact (Johnson, 1936), artesian springs (Prouty, 1952; LeGrand, 1953), whale wallows (Grant 1945), and ice push (Bliley and Burney, 1988). Currently the most plausible explanation is that originally there were shallow depressions in the landscape with an aquitard that allowed the water table to be held above the surface. Prevailing winds then shaped the depressions into the now familiar orientated shape (Thom, 1970; Odum, 1952). During the past century agricultural and community development have led to the drainage and use of these bays. It is estimated that 50% of all Carolina bays in Bladen County, NC, were drained and developed in some manner by 1982 (Weakley and Scott, 1982). This figure would be higher if other management practices such as logging were included. As these bays are used for agriculture and other activities, their defining characteristics of sand rims and organic surfaces, become blurred into the surrounding landscape.

Plant communities typically found in undrained Carolina bays include non-riverine swamp forest, low pocosin, high pocosin, pond pine woodland, peatland Atlantic White Cedar forest, and Bay forest (Schafale and Weakly, 1990). These plant communities are found in nutrient poor soils that may be organic soil or mineral soils. Variability in these plant communities depends on depth of organic matter, seasonal water table depths, fire and mineral input if any (Schafale and Weakly, 1990). Soil series associated with theses plant communities (Croatan, Pamlico, Ponzer, Lynn Haven, Torhunta, Rutlege, and Pantego) are very strongly acidic (4.5-5.0) to ultra acidic (<3.5). Cation exchange capacity tends to be very low ranging from 1 to 30 cmol kg^{-1}, but can be as high as 100 cmol kg^{-1} in the surface layers. Extractable phosphorus has found to be strongly limiting to plant production in High Pocosin plant communities (Schafale and Weakly, 1990).

The North Carolina Department of Transportation (NCDOT) purchased a 256 ha drained Carolina bay in 1999, near Lumberton, North Carolina with the intent of earning wetland mitigation credits. The Carolina bay being restored by the NCDOT is called Juniper Bay. Juniper Bay was drained, cleared, and put into agricultural production incrementally in 1971, 1981 and 1986. A review of the history of the clearing process was described by in chapter 2. Agricultural practices in the organic soils include the addition of lime to achieve a pH of 5.5 to 5.0 (Lilly and Baird, 1993). To reach this target pH up to 13470 kg ha^{-1} may have to be applied to overcome the large reserve of acidic cations present in organic soils (Lilly, 1981). The North Carolina Cooperative Extension Service recommends the application of 135-180 kg N ha^{-1}, 35-55 kg P_2O_5 ha^{-1}, and 90-115 kg K ha^{-1} for corn production (Crozer, 2000). Organic soils in North Carolina have been shown to leach nitrogen and phosphorus and have to be applied yearly (Lilly, 1981). Crop cultivation, depending on the crop, can include the use of chisel plows, moldboard plows, disks, and sub-soilers. The overall objective of the Juniper bay project is to restore Juniper bay back to an ecosystem that is typical of Carolina bays. This includes restoration of hydrology, vegetation, and soils typically found in Carolina bays.

The objective of this study was to evaluate the changes in soil chemical properties created by agricultural practices in Juniper Bay. Changes resulted from the addition of fertilizer and lime over 30 years as well as tillage and drainage of the area.

MATERIALS AND METHODS

Juniper Bay is located 10 km southeast of Lumberton, North Carolina in Robeson County (34°30’30”N 79°01’30”E). The Bay was logged, drained, and put into agricultural production in three stages. The western third of Juniper Bay was drained by ditches in 1971, the central third and most of the eastern third was drained in 1981, the area to the north in the eastern third was drained in 1986 (Figure 5.1). A perimeter ditch was dug in 1971 around the entire bay, as well as two main drainage ditches that run NE to SW and many lateral ditches that run NW to SE. The perimeter ditch and the main ditches were approximately 7 m wide and 4 m deep. The lateral ditches were roughly 1.5 m wide and 1m deep. Areas that are enclosed by ditches are called ‘cuts’. There was only one outlet in Juniper Bay and it is located at the SW end of the main ditch on the western side. An initial survey of the soils at Juniper Bay indicated three broad groups of soil that are based on the thickness of the organic layer. Soils without a histic epipedon (<20cm organic material) were classified as Aquic Haplorthods and will be referred to as mineral. Soils with a histic epipedon (20-40 cm organic material) were classified as Histic Humaquepts and will be referred to as histic soils. Finally soils having greater than 40 cm organic material were classified as Terric Haplosaprists and will be referred to organic soils (Figure 5.1).

Sampling locations were chosen by randomly placing an equilateral triangle grid over a map of Juniper Bay. Grid points were spaced far enough apart to allow 24 sampling points to be within the site bordered by the perimeter ditch, with ten located in organic soil, eight in mineral soil, and six in soils with a histic epipedon. Some points are closer than others to improve statistical analysis. Points were found in the field using GPS. Using the location point from the grid as a reference, we dug a 1.0 to 1.5 m pit at the center of a field cut and a pit near the closest lateral ditch, resulting in a pair of pits at each location. Figure 5.2 shows the location of all pits. Soil profiles were described and bulk samples for laboratory analysis were taken from each horizon.

Three reference bays were selected in Bladen County, North Carolina based on their similarity of soils to Juniper Bay, lack of drainage or agricultural applications, and ownership cooperation. Three reference sites were named Charlie Long-Millpond Bay (34^{o}46’00”N 78^{o}33’30”E), and Tatum Millpond Bay (34^{o}43’00”N 78^{o}33’00”E), both located in the Bladen Lakes State Park and Causeway Bay (34^{o}39’45”N 78^{o}25’45”E), which was located 10 km N of White Lake, N.C. A trail from the rim of each bay to the center was cut through the dense vegetation (Fig. 5.3). Vegetation in the three bays were evaluated and reported by Lees et al. (2003). They reported that CW, CL, and TM had pond pine woodland and high pocosin plant communities based on the system of Schafale and Weakley (1990). TM also had nonriverine swamp forest and bay forest plant communities. Trees found in the reference bays included: pond pine (*Pinus serotina*), swamp gum (*Nyssa biflora*), sweet bay (*Gordonia lasianthus* and *Magnolia virginiana*), red maple (*Acer rubrum*), and Atlantic white cedar (*Chamaecyparis thyoides*) (Lees et al. 2003). Shrubs found in the reference bays included: giant cane (*Arundinaria gigantean*), coastal sweetpepper bush (*Clethroa alnifolia*), blue huckleberry (*Gaylussica frondosa*), large gallberry (*Ilex coriacea*), smooth winter berry (*Ilex laevigata*), coastal doghobble (*Leucothoe axillaries*), swamp doghobble (*Leucothoe racemosa*), fetterbush (*Lyonia lucida*), red bay (*Persea palustris*), laurel greenbriar (*Smilax laurifloia*), and high bush blueberry (*Vaccinium corymbosum*) (Lees et al. 2003).

The three broad soil groups described in Juniper Bay, mineral, histic, and organic, were also found in all three reference bays. Plots were marked off at 50 m intervals along the transect. Plots to be sampled were then randomly selected in each soil. There were a total of eight sampling plots in each reference bay, two in the mineral and histic soils, and four in the organic soils. Soil profiles in the selected plots were described from samples extracted with a McCauley peat sampler and an open bucket auger. Bulk samples were taken for laboratory analysis from each horizon.

Bulk samples from Juniper Bay and the reference bays were air dried and ground with an electric grinder to pass through a 2-mm sieve. Extractable K, Ca, Na, Mg, Mn, Zn, and Cu were determined by running Mehlich III extract (Mehlich, 1984) through an inductively coupled plasma emission spectrograph. Cation exchange capacity and sum of base cations were also determined (Mehlich, 1976). The pH was determined using a 1:1 soil to water ratio. Nutrient analysis was conducted through the North Carolina Department of Agriculture, Soil Testing Services, Raleigh, North Carolina. Organic carbon and total nitrogen were determined through dry combustion with a Perkin-Elmer PE2400 CHN Elemental Analyzer (Culmo, 1988) by the North Carolina State University Soil Science Analytical lab, Raleigh, North Carolina.

Soil types, organic, histic, and mineral, were analyzed separately using the SAS procedure PROC MIXED (SAS, 2000), with an AR(1) covariance structure to compare years since drainage and proximity to a ditch. The number of locations for a given soil type and years in agricultural production can be seen in Table 5.1. Each location had paired pits with one located at the crest of the cut and one near the ditch. The horizon type and depth present at each location varied and were evaluated as a spatially repeated measure. The data were not balanced so least square means (LSMEANS) were used to obtain estimated means. Comparisons among crest and near ditch pits were made with $p>0.1$ being significant.

The comparisons between the reference bays and Juniper Bay were analyzed separately depending on, soil type, organic, histic, and mineral, using the SAS procedure PROC MIXED (SAS, 2000), with an AR(1) covariance structure. Data from the crest locations in Juniper Bay were used in this analysis after determining that differences in crest and ditch locations were minimal. Organic, histic, and mineral soils were combined into one data set among the three reference bays, resulting in 12 organic, six histic, and six mineral locations. Horizons varied depending on location and pit and were evaluated as a spatially repeated measure. The reference Carolina bays were considered random variables so results could be inferred to natural Carolina bays as a whole. Soils from the reference bays were assumed to be equal to the Juniper Bay soils prior to drainage and chemical application. Data were not balanced so LSMEANS were used to obtain estimated means. Comparisons among Juniper Bay and the reference bays and time since drainage were made with $p>0.1$ being significant.

RESULTS AND DISCUSSION

Organic and mineral materials have very different bulk densities. The same mass of organic material occupies approximately 10 times more volume than mineral material, however, results of this study were reported on a weight basis. Although values were different, statistical results were the same whether the data were evaluated on a weight or volume basis. This is because soil material types were not evaluated against each other, i.e. mineral was compared to mineral and organic was compared to organic, to avoid the large density differences. Appendix C provides the raw data on a weight basis and it also provides a weight/volume conversion factor.

Typical profile descriptions for organic, histic, and mineral soils from Juniper Bay and the reference bays are given in Table 5.2, and profile photos and descriptions of all locations are in appendix E and F. The soils in Juniper Bay have been affected by tillage and drainage. The surface horizons do not have an organic mat, Oi or Oe horizons that are typically found in undrained Carolina bays. The surface horizons in Juniper Bay have moderate to strong structure while the reference bays have weakly developed structure. Drainage has allowed the deeper organic soil in Juniper Bay to develop structure while similar soils in the reference bays are massive. The soil fertilizer records in 1976 from the agriculture producer who owned the land prior to the NCDOT 1976, showed 2240-6720 kg ha^{-1} of dolomitic lime, 56 to 226 kg P_2O_5 ha^{-1}, and 226 to 336 kg K ha^{-1} were applied that year. Mr. Freeman (2001, personal interview) also indicated that fertilizer recommendations were followed yearly.

Organic Soils

JUNIPER BAY VS. REFERENCE BAYS

There were significant differences in organic carbon, extractable K, Ca, Mn, BS, CEC, and total N between the organic soils of Juniper Bay and the organic soils of the reference bays (Table 5.3). The organic soils in the reference bays had 8.4 g kg^{-1} more organic carbon at the surface than in Juniper Bay (Fig. 5.4a). The reference bays soils decreased in organic carbon content with depth, 37.6 g kg^{-1} at the surface to 3.7 g kg^{-1} at 175 cm. The change from organic soil to mineral soil in the reference bays occurred around 150 cm. Knight et al. (1985) found over 29.1% organic carbon in northern South Carolina. Shartiz and Gibbons (1982) reported the surface peat layer had an organic carbon content of 8.1 - 44.2% in North Carolina. The organic carbon increased in Juniper Bay from 29.2 g kg^{-1} at the surface to 35.2 g kg^{-1} at 32 cm, and then decreased with depth to 2.5 g kg^{-1} at 108 cm. This shows that oxidization at the surface was reducing the soil organic carbon content, but below the plow layer the rate of oxidation was slower and organic carbon was similar to that of the reference bays. The change from organic soil to mineral soil material in Juniper Bay occurred at approximately 75 cm. Total nitrogen followed a similar trend as organic carbon and was higher through the profile in reference bays. Total N content in general, corresponds with the amount of organic matter in the soil, however it does not relate to the amount available to plants (Tomapa, 1974). Nitrogen levels in Juniper Bay were 0.87 g kg^{-1} at the surface, decreasing to 0.5 g kg^{-1} at 108 cm, and in reference bays they decreased from 1.46 g kg^{-1} at the surface to 0.07 g kg^{-1} at 173 cm.

Organic soils have very high CEC's, which in general increases as OM increases (Kamprath, and Welch, 1962). Such is the case in Juniper Bay where the CEC is lower throughout the profile ranging from 24.0 $\text{cmol}_c\ \text{kg}^{-1}$ at the surface to 4.0 $\text{cmol}_c\ \text{kg}^{-1}$ at 108 cm while in the reference bays it ranged from 46.6 $\text{cmol}_c\ \text{kg}^{-1}$ at the surface to 6.6 $\text{cmol}_c\ \text{kg}^{-1}$ at 171 cm. This means higher amounts of lime are required to change pH values because of the large reserves of acidic cations (Juno and Kamprath, 1979) and the ability to adsorb large amounts of basic cations from lime (Evans and Kamprath, 1970). Such was the case in Juniper Bay where agricultural producers added several tons of lime per ha each year to increase and maintain an elevated pH (Freeman, 2001 personal interview). The pH in Juniper Bay was 0.72 to 0.24 units higher through the profile than in reference bays. The pH in both decreased with depth through the organic material and then increased when mineral material was encountered. Due to the high amounts of lime applied extractable Ca was higher in the surface horizons of Juniper Bay and decreased with depth to a level found in reference bays (Fig 5.4b). Extractable Ca was 4.5 cmol Ca kg^{-1} higher at the surface in Juniper Bay and continued to be elevated over levels in the reference bays to a depth of 88 cm. There was a similar trend with extractable Mn was 6.83 mg kg^{-1} higher at the surface in Juniper Bay and continued to be elevated over reference bays levels to a depth of 75 cm. Histosols in North Carolina have been found contain no or very little K-supplying or K-fixing silicate minerals and essentially all the K present is held on the OM exchange complex and is readily avaible (Lilly, 1981). It would be expected that Juniper Bay has equal or higher amounts of K due to fertilizer additions, however, extractable K was higher in the upper 20cm of the reference bays, 1.10 cmol kg^{-1} compared to Juniper Bay 0.33 cmol kg^{-1}. This might be because crops had removed the readily available K^+ or competition with Ca^{++}. As a result of the decreased

CEC and increased level of base cations, particularly Ca and Mg, base saturation percentages in Juniper Bay was consistently higher than the reference bays (Fig 5.4c). The reference bays had a BS of 12.0% at the surface and decreased with depth while at Juniper Bay it was 61.4% at the surface decreasing to 15.4% at 84 cm, then increased slightly to 20.0% at 108 cm.

It was expected that levels of extractable P would show signs of leaching through the profile in Juniper Bay because organic soils are low in Al and Fe oxides are not expected to hold inorganic P, and can be leached from pure organic soils or quartz sand (Fox and Kamprath, 1971; Larson et al., 1959). However extractable P, as well as Mg and Zn, were not significantly different but had some notable trends. Extractable P and Mg followed a familiar trend of having higher levels in Juniper Bay and decreasing with depth to levels found in the reference bays, but the opposite was true for extractable Zn, which had higher values at the surface in the reference bays. The ability of organic soils to hold P will increase with time as subsidence, ditch spoil, and lime increase the mineral content in the root zone (Larson et al., 1958) and may be the case in Juniper Bay. Reese and Moorhead (1996) reported 0.18-0.72 $\text{cmol}_c\ \text{kg}^{-1}$ exchangeable Ca, 0.19-0.62 $\text{cmol}_c\ \text{kg}^{-1}$ exchangeable Mg, and 0.21 $\text{cmol}_c\ \text{kg}^{-1}$ exchangeable K. Knight et al. (1985) reported Total Kieldahl Nitrogen of 1.0 to 14.8 g kg^{-1}, extractable P <0.013 g kg^{-1}, extractable Ca of 0.3 g kg^{-1}, extractable Al of 0.023 to 1.28g kg^{-1}, and extractable Fe of 0.003 to 0.124 g kg^{-1}. Because of low amounts of base cations, base saturation (BS) tends to be low, as reported by Reese and Moorhead (1996), with a BS of 4-11%. However, Stolt and Rabenhorst (1987) reported that as depth increased BS increased, not due to the increase in base cations but from decreasing CEC that is a result of decreasing organic matter.

TIME IN AGRICULTURAL PRODUCTION

Nutrient levels, pH and base saturation have been reported to increase in Carolina bay soils when under agricultural production (Ewing et al., 2002; Hanchey et al., 2000). Increased periods of time in agricultural production resulted in significant increases of BS and extractable Ca. (Fig 5.5a,b) in the organic soils of Juniper Bay. Base saturation increases reflect combined impacts of Ca, Mg, Na and K. Depths of apparent leaching of Ca also increased with time in agricultural production. Calcium levels were increased over these in the reference bays down to depths of approximately 40, 70, and 90 cm after 15, 20, and 30 years in production. This results in an estimated leaching rate of 2.5, 3.4, and 2.9 cm yr^{-1} for 15, 20, and 30 years of agricultural production. LSMEAN estimates for chemical constituents in organic soils relative to time in agriculture can bee seen in Appendix A.1.

CREST VS. DITCH

There was a significant difference in the amount of zinc between the crest and ditch locations (Fig 5.6). Extractable Zn was higher at the crest than the ditch, 10.40 and 5.6 mg kg^{-1} in the surface 15 cm respectively and decreased with depth to 0.38 and 0.22 mg kg^{-1} at depths of 107 and 110 cm. Levels of Zn reached a low constant level below 1.00 mg kg^{-1} at 48 cm at the ditch and 74 cm at the crest. The higher levels at the crest could be due to over lapping applications of fertilizer. Another possibility could be that the common practice for clearing fields of debris included piling and burning debris in the center of the cut. This could have resulted in accumulation of more nutrients in at the crest compared to the ditch.

Although there were no differences found in extractable P, K, Ca, Mg, Mn, CEC, BS, and pH for the organic soil there was a similar depth trend of higher levels in the surface 15 cm at the crest relative to the ditch and tended to be elevated through the profile at the crest compared to the ditches. For example, extractable P was 81.0 mg kg^{-1}, at the crest and 59.0 mg kg^{-1} at the ditch. Organic carbon was above 12 g kg^{-1} from 0 to 74 cm at the crest and 0 to 48cm at the ditch. The trends seem to indicate that there is more oxidation of the organic soil near the ditch due to better drainage. However, the process of crowning the field could have also played a role for thinner organic layers near the ditch. The trends in nutrients indicate a continued overlap during application of fertilizer and lime, or that nutrients have been remove near the ditch through drainage or surface runoff. The LSMEANS comparing soils at the crest and ditch for organic soil type in Juniper Bay can be found in Appendix A.2.

Histic Soils

JUNIPER BAY VS. REFERENCE BAYS

LSMEANS estimates comparing Juniper Bay and the reference bays for histic soil types can be seen in Table 5.4. The general trend for both Juniper Bay and reference bays is to have the highest amount of nutrients in the surface horizon and decrease with depth. There were two different trends, one, like extractable P (Fig. 5.7a), had higher levels the upper 30 cm at Juniper Bay and then decreased to levels found in the reference bays, and the other, like extractable K (Fig 5.7b) had higher levels in the upper 30 cm at the reference bays.

Base saturation, extractable Ca, Mg, Zn, followed the trend illustrated by extractable P. Extractable P levels at the surface for Juniper Bay were 96.4 mg kg^{-1} and decreased with depth to levels found in reference bays. There was 36.6 mg kg^{-1} of extractable P in the surface 20 cm at the reference bays and decreased to 9.5 mg kg^{-1} at 32 cm and remained constant through the rest of the profile. Extractable Ca in the surface 20 cm at Juniper Bay was 3.88 cmol kg^{-1} and 0.43 cmol kg^{-1} at reference bays. Extractable Mn at the surface in Juniper Bay was 8.05 mg kg^{-1} and 3.37 mg kg^{-1} at the reference bays. Extractable Mg at

Juniper Bay was 1.54 cmol kg^{-1} in the surface 20 cm at Juniper Bay and 0.86 cmol kg^{-1}, at the reference bays. Base saturation in the surface 20 cm is 63.0% at Juniper Bay and 9.6% in the reference bays. Organic carbon, total N, and CEC followed the trends illustrated by extractable K. Extractable K was higher in the surface 20 cm at the reference bays 0.71 cmol kg^{-1}, compared to Juniper Bay 0.28 cmol kg^{-1}. Levels below 20 cm were similar for both locations and decreased with depth. The histic soils in Juniper Bay had lower amounts of OC (17.0%) at the surface 20 cm compared to the histic soils at the reference bays (30.5%). This is reversed at 30 cm with 24.7% OC at Juniper Bay and 13.5% at reference bays. Below 40 cm the OC levels decrease with depth for Juniper Bay and reference bays. The organic mineral boundary in Juniper Bay was at 30 cm and 32 cm in reference bays. Total N was 1.08% at the surface in the reference bays and 0.51% in Juniper Bay. CEC in Juniper Bay is 33.05 cmol$_c$ kg^{-1} in the surface 20 cm and decreased with depth, reference bays is highest at the surface, 17.83 cmol$_c$ kg^{-1}. Although not significant the pH in Juniper Bay was highest in the surface horizon 4.29, and ranged to a low of 3.81, while at the reference bays the high pH, 4.37 was in the C horizon and ranged to 3.51 near the surface.

TIME IN AGRICULTURAL PRODUCTION

Differences based on the amount of time since drainage was significant for percent organic carbon, CEC, base saturation, and extractable Ca, and Mn. The amount of organic carbon after 0, 15 and 20 years of drainage, in the surface 18 cm were 30.5, 20.2, and 13.4% respectively and decreased with depth (Fig. 5.8a). However, areas drained for 30 years first increased to 39.2% at 32cm, then decreased. Extractable Ca was highest, 5.08 cmol kg^{-1} in the surface 20 cm in the areas under agricultural production for 20 years, followed by 2.69 cmol kg^{-1} in the areas under production for 15 years. Time zero had 0.43 cmol kg^{-1} or less extractable Ca throughout the profile. The Ca content in the 15 year areas decreased with depth and reached low levels (<0.20 cmol kg^{-1}) found in the reference bays at 52cm, and the 20 year areas reached reference bays levels at 104cm. This means that Ca moved through the soil 2.0 and 3.6 cm yr^{-1} for 15 and 20 years of agricultural production. Extractable Mn followed the same trend as extractable Ca and had 10.38 mg kg^{-1} in the surface 20 cm in the areas under agricultural production for 20 years, and 5.71 mg kg^{-1} in the areas under production for 15 years with 3.37 mg kg^{-1} at time zero. Extractable Mg moved through the soil 2.0 and 3.6 cm yr^{-1} for 15 and 20 years of agricultural production. CEC at time zero was higher than at 15 or 20 years in the upper 50 cm due to higher amounts of organic matter, but lower below 50 cm because of lower amounts clay (Fig 5.8b). CEC in the reference bays was 33.05 cmol$_c$ kg^{-1} in the surface 16 cm, areas in production for 20 years had 19.36 cmol$_c$ kg^{-1} in the surface 19 cm. Base saturation was highest through the profile after 20 years of production, followed by areas in production for 15 years (Fig 5.8c). Base saturation at time zero were never above 9.6%, but ranged from 52.4 to 12.9 for areas drained for 15 years and from 73.4 to 12.5% for areas drained 20 years. LSMEANS estimates for the time in agriculture for histic soil types can bee seen in Appendix A.3.

CREST VS. DITCH

There were significant differences between crest and ditch for extractable P, Mg, Mn, and Zn, and base saturation. Extractable P levels were 48 to 25 mg kg^{-1} higher at the crest compared to the ditch in the upper 30 cm (Fig 5.9). Extractable P levels for both crest and ditch dropped to low (<3.5 mg kg^{-1}) levels below 40 cm. The same trend of higher levels in the surface 30 cm at the crest decreasing to similar low levels is evident in extractable Mg, Mn, and Zn and BS. The surface soils in the histic soil type had extractable Zn levels of

6.38 mg kg^{-1} at the crest and 4.07 mg kg^{-1} at the ditch. Extractable Mn was higher in the surface horizon at the crest 8.07 mg kg^{-1} than the ditch 4.07 mg kg^{-1}. Extractable Mg in the surface horizon was higher at the crest 1.58 cmol Mg kg^{-1} compared to the ditch 0.77 cmol Mg kg^{-1}. The base saturation was higher in the upper 30cm crest surface soil (23%) when compared to the ditch (11%).

Although not significant the trends of CEC, extractable K and Ca were similar to that of extractable P and tended to be higher in the surface 30 cm at the crest position and decrease to similar low levels. The pH values were similar at both locations with highest at the surface and ranged from 3.80 to 4.88 at the crest and 4.07 to 4.68 at the ditch. Organic carbon was above 12% in the surface 30 cm at both positions. Organic carbon increased from 15 cm to 30 cm before decreasing below 12%. The lower levels of OC at the surface could be due to increased oxidation or addition of ditch spoil. The LSMEANS comparing soils at the crest and ditch for the histic soil type in Juniper Bay can be found in Appendix A.4.

Mineral Soils

JUNIPER BAY VS. REFERENCE BAYS

LSMEANS estimates comparing Juniper Bay and the reference bays for mineral soil types can be seen in Table 5.5. Base saturation, pH, extractable Ca, P, and Zn had higher levels in the surface 30 cm in Juniper Bay then decreased with depth to levels found in the reference bays. This trend is illustrated with extractable P (Fig 5.10a). Levels of extractable P in the surface 10 cm are 0.3 mg kg^{-1} at the reference bay and 87.1 mg kg^{-1} at Juniper Bay respectively. Extractable P decreases rapidly to 16.0 mg kg^{-1} at 44 cm in Juniper Bay, and were near levels found in the reference bays for the remainder of the profile. Base saturation was highest in the upper 10 cm, 16.3%, at the reference bays and 74.6% in Juniper Bay, and decreased with depth. Extractable Ca in the surface 10 cm was 1.15 cmol kg^{-1} in the reference bays and 3.34 cmol kg^{-1} in Juniper Bay. Zinc levels in the surface 10 cm were 12.4 mg kg^{-1} in Juniper Bay and 5.96 mg kg^{-1} in the reference bays. The pH in Juniper Bay in the surface 30 cm was approximately 5.0 and decreased to around 4.3 below 62 cm while in the reference bays the pH was approximately 3.65 in the upper 25 cm increasing to 4.1 below 52 cm. Organic carbon, total N, CEC, extractable K and Mg had the opposite trend with higher levels in the surface layers in the reference bays decreasing to levels that are similar to those in Juniper Bay. This trend is illustrated with extractable K in Figure 5.10b. Extractable K levels in the surface horizon were 0.26 cmol kg^{-1} at Juniper Bay and 0.75 cmol kg^{-1} at the reference bays. Juniper Bay decreased to 0.04 cmol kg^{-1} at 24 cm and the reference bays decreased to 0.14 cmol kg^{-}. Below this depth extractable K remained around 0.04 cmol kg^{-1} for the rest of the profile in Juniper Bay, but continued to decrease to 0.01 cmol kg^{-1} in the reference bays. Organic carbon in the surface 10 cm of the reference bays is 24.9% and 7.64% in Juniper Bay. The high OC in the reference bays is due to an accumulation of leaf litter at the surface. Total nitrogen in the surface 10 cm was higher in the reference bays, 0.73% than in Juniper Bay, 0.19%. CEC levels in the reference bays were highest in the surface horizon, 32.6 cmol$_c$ kg^{-1}, and decreased with depth to 8.67 cmol$_c$ kg^{-1} at 22cm. Juniper Bay soils had a CEC of 12.7 cmol$_c$ kg^{-1} in the surface horizon, decreased with depth to 2.63 cmol$_c$ kg^{-1} at 126 cm. Extractable Mg in the surface horizon for Juniper Bay was 1.12 cmol Mg kg^{-1} and 1.23 cmol Mg kg^{-1} for the reference bays. There were no significant differences in extractable Mn between Juniper Bay and the reference bays; however, it did follow the trend of having higher levels at the surface in Juniper Bay and decreasing to levels found in the reference bays.

The extractable nutrient are in the mineral soils at Juniper and the reference bays are similar to those reported for rim soils, by Reese and Moorhead (1996) 2.44 cmol Ca^{2+} kg^{-1}, 8.0 cmol Mg^{2+} kg^{-1}, 0.12 cmol K^{+} kg^{-1} , and a base saturation, less than 21%. However, organic carbon, and CEC are higher and pH lower in the reference bays than what has been reported for the rims. Reported pH values for rim soils range from 4.1 (Stolt and Rabenhorst, 1987) to 5.3 (Reese and Moorhead, 1996). Organic carbon was reported by Reese and Moorhead (1996) to be less than 2.7 g kg^{-1}, resulting in a low CEC of 13.9 $cmol_c$ kg^{-1}. The difference in organic carbon indicates a difference in hydrology and thus makes it difficult to compare mineral soil in the depressions to reported values for the rim soils.

TIME IN AGRICULTURAL PRODUCTION

Significant effects due to the time of drainage and agricultural production were found in base saturation (Fig 5.11). Time zero, the reference bays, had a BS of 16.3% at the surface and decreased with depth to 4.98 at 82 cm. After 25 years of agricultural production the BS in the surface 10 cm was 76.48% and decreased with depth to 27.08% at 120cm. After 30 years of agricultural production BS in the surface 10 cm was 72.76% decreased rapidly to 46.79% 23 cm, and continued to decrease with depth to 25.08% at 57 cm before increasing to 37.43% at 132 cm.

LSMEAN estimates for the time in agriculture for mineral soils can be seen in the Appendix A.5. Although not significant extractable Ca, Mg, P, Mn, and Zn followed the same trend with areas drained for 30 years having higher levels in the surface soils, closely followed by areas drained for 20 years, followed by time zero levels. Levels of these constituents, from either drainage time, decreased with depth to levels found in the reference bays. In areas drained for 20 years the pH levels were higher than areas drained for 30 years, and both drainage areas were generally higher than pH from the reference bays. The surface horizon at time zero was above 12% organic carbon and was 10 cm thick. The area drained for 30 years had 10.5 and 13.0% organic carbon in the surface two horizons or 23 cm. These values may indicate that this location may once had a histic or organic horizon. The organic carbon in the areas drained for 20 years is less than 5% through out the profile.

CREST VS. DITCH

Although not significant extractable P and CEC followed the trend of having higher levels in the surface horizons at the crest and decreasing with depth to levels similar to that of the ditch (Table 5.6). Organic carbon and total nitrogen were very similar at both locations with the highest level being at the surface and decreasing with depth.

Levels of extractable Ca, K, Mg, Mn, and Zn, pH and BS in the surface horizon were significantly higher at the crest compared to the ditch. All of these variables decrease with increasing depth down to 30-50 cm where the values reach a relatively constant equilibrium (Fig. 5.12). Extractable Ca was twice as high at the crest compared to the ditch in the surface horizon, then decreased to similar levels by 30 cm and continued to decrease through the profile. Extractable K was 0.21 cmol kg^{-1} at the crest and 0.07 cmol kg^{-1} at the ditch in the surface horizon. Extractable Mg was 0.66 cmol kg^{-1} higher in the surface horizon at the crest but decreased to similar levels found in the ditch profile by 50 cm. Extractable Mn and Zn were 3.65 mg kg^{-1} and 6.77 mg kg^{-1} higher at the crest in the surface horizon. The pH in the surface horizon at the crest was 5.04 then decreased to 4.47 at 50 cm then varied between 4.47 and 4.23 for the remained of the profile. At the ditch pH was 4.68 in the surface horizon, increased to 4.76 at 50 cm, and then decreases to 4.23 at 125 cm. Because of the elevation in Ca and Mn, base saturation is 22.4% higher at the crest compared to the ditch.

CONCLUSIONS

The soils at Juniper Bay have changed since being drained and placed in agricultural production. The reference bays had higher nutrient levels at the surface of its profiles that at greater depths due to biocycling, however, those levels were significantly less than those found at the surface in Juniper Bay. The organic soils at Juniper Bay have increased levels of extractable K, Ca, Mn, and base saturation, and decreased levels of CEC, organic carbon and total nitrogen in the surface 75 cm as compared to the reference bays. The increases in nutrient levels and base saturation are a result of fertilizer and lime applications from agricultural practices. The decreases in organic carbon, total nitrogen and CEC are due to oxidization of the organic soil. The histic soils in Juniper Bay are higher in extractable Ca, Mg, P, Mn, and base saturation in the surface 30 to 50 cm compared to the reference bays as a result of agricultural additions. Extractable K, organic carbon, total nitrogen and CEC are lower in Juniper bay due to oxidization of organic matter and crop up take. The mineral soils at Juniper bay had higher levels of Extractable Ca, Mg, P, Zn, base saturation, and pH compared to the reference bays because of agricultural additions. There were lower levels of extractable K, organic carbon, total nitrogen, and CEC in Juniper bay because of the loss of a litter layer and plant uptake. Extractable K may have leached more in Juniper Bay due to higher Ca saturation.

The differences in the soils at Juniper bay when evaluated at crest and ditch locations showed that extractable Zn was higher at the crest in organic soils. Extractable Mg, P, Mn, Zn and base saturation were higher at the crest in the histic soils. Extractable K, Ca, Mg, Mn, and Zn were higher at the crest in the mineral soils. The increased levels at the center of the field may be due to continual practice of overlapping application passes due to the spacing of the cuts and/or the mounding and burning of debris in the center of the fields. Additionally, nutrients at the ditch may have been lost through surface runoff or diluted by additions of spoil from ditch maintenance. While differences exist between crest and ditch locations in each soil, they both are well above levels found in the reference bays and could be managed in a similar fashion.

When looking at changes over time, the trend for all the soils is for higher nutrient levels, base saturation and pH and lower organic carbon, CEC, and total nitrogen the longer the soil has been drained and in agricultural production. However, only extractable Ca and base saturation were shown to be affected in this manner in the organic soils. The histic soils had more extractable Ca, Mn, base saturation, and lower CEC and organic carbon after 20 years of production compared 15 years of production, which had higher levels than time zero. In the mineral soils, base saturation and CEC were the only variable that shows a correlation to the length of time in production with base saturation increasing over time and CEC decreasing. The length of time influenced the depth to which there were differences, i.e. the longer in production the deeper the greater downward movement of lime and fertilizer.

The changes in soil chemical properties due to agricultural production are large. We believe that the increases in nutrient levels and pH will negatively influence the establishment of plant communities typical of Carolina bays, which thrive under acidic and nutrient poor conditions. Invasive plant species will thrive and out compete species that are planted for restoration purposes for nutrients and light resources. To better understand how these differences will affect establishment of desired species, and to find soil management practices that facilitate the re-vegetation efforts, further studies should be conducted.

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Table 5.1. Number of locations in relation to general soil type and years of agricultural production.

	15 years	20 years	30 years
Organic Soil	2	2	4
Histic Soil	3	3	---
Mineral Soil	---	5	4

Table 5.2. Example profile descriptions of organic, histic, and mineral soils from the reference bays and Juniper Bay.

Horizon	Depth	Description
	cm	**Reference bay Mineral**
Oi	0-10	Brown (7.5YR 3/4) fibric organic material, root mat and leaf litter. Weak medium platy structure. Clear boundary.
A	10-20	Black (10YR 2/1) sandy loam. Weak fine granular structure. Clear boundary.
E	20-40	Gray (10YR 6/1) sand. Single grain structure. Clear boundary.
Bh1	40-70	Black (10YR 2/1) sandy loam. Weak medium sub-angular blocky structure. Clear boundary.
Bh2	70-100	Very dark grayish brown (10YR 3/2) loamy sand. Weak coarse sub-angular blocky structure.
		JB17C Core17: Mineral
Ap	0-20	Black (10YR 2/1) loamy sand with 95% organically coated sand grains. Weak medium (2-5mm) granular structure. Abrupt boundary.
E	20-47	20-47cm. Gray (N 6/0) loamy sand with 12% A horizon material in root channels. Single grain structure. Clear boundary.
Bhir1	47-70	Very dark brown (10YR 2/2) sandy loam with 25% E material in upper half of horizon. Massive structure. Clear boundary.
Bhir2	70-92	Black (10YR 2/1) and dark brown (10YR 3/3) sandy loam in alternating layers 2-7cm thick. Massive structure. Abrupt boundary.
Bh	92-120	Black (10YR 2/1) sandy loam with 10% gray (10YR 6/1) sandy grains. Massive structure. Firm and slightly brittle.
		Reference bay Histic
Oi	0-15	Very dark brown (10YR 2/1) hemic muck. Weak medium platy structure. Clear boundary. Root mat.
Oa	15-36	Black (N 2.5/0) sapric muck. Massive structure. Clear boundary.
OC	36-65	Black (N 2.5/0) sandy loam. Massive structure. Gradual boundary.
C	65-100	65-100cm. Very dark brown (10YR 2/2) sand. Single grain structure.

Table 5.2 continued

JB61C: Histic

Ap	0-22	Black (N 2.5/0) mucky sandy loam with 60% organically coated sand grains. Moderate medium granular structure. Clear boundary.
Oa	22-36	Very dark brown (10YR 2/2) sapric muck. Strong coarse granular structure. Clear boundary.
Bw	36-56	Dark brown (10YR 3/3) sandy loam with 2% gray (10YR 6/1) sand. Weak medium sub-angular blocky structure. Clear boundary.
BC	56-74	Dark yellowish brown (10YR 4/6) loamy sand with 2% gray (10YR 6/1) sand. Weak medium sub-angular blocky structure. Gradual boundary.
C	74-108	Brownish yellow (10YR 6/6) with 2% gray (10YR 6/1) sand. Single grain structure.

Reference bay Organic

Oi	0-20	Black (10YR 2/1) fibric to hemic muck that is part of the root mat. Weak coarse platy structure from layering of plant debris. Gradual boundary.
Oe	20-50	Very dark brown (10YR 2/2) hemic muck. Massive structure with many organic bodies 0.5 to 1.0 cm in diameter. Gradual boundary.
Oa	50-85	Black (10YR 2/1) sapric muck. Massive structure. Gradual boundary.
OC	85-110	Very dark brown (10YR 2/2) mucky loam or mucky sandy loam. Massive structure. Gradual boundary.
2C1	110-140	Very dark brown (10YR 2/2) sandy loam. Massive structure. Gradual boundary.
2C2	140-180	Dark gray (10YR 4/1) sand. Single grain structure.

JB10C: Organic

Ap	0-10	Very dark brown (10YR 2/2) sandy loam. Moderate medium (3mm) granular structure. Abrupt boundary.
Oa	10-20	Black (N 2.5/0) sapric muck. Moderate fine (2mm) granular to sub-angular blocky structure. Abrupt boundary.
OA1	20-51	Black (10YR 2/1) mucky silt loam. Weak very coarse (20cm) prismatic structure. Clear boundary.

Table 5.2 continued

OA2	51-61	Very dark brown (10YR 2/2) mucky silt loam with 25% black (N 2.5/0) charcoal. Weak coarse (10cm) prismatic structure.
OA3	61-68	Dark brown (10YR 3/3) mucky fine sandy loam. Very weak coarse (10cm) prismatic structure. Clear boundary.
Bw	68-107	Yellowish brown (10YR 5/4) very fine sandy clay loam. Weak very coarse (20cm) platy to moderate medium (5cm) sub-angular blocky structure. Clear boundary.
C	107-120	Light brownish yellow (10YR 6/2) sandy clay loam. Strong medium (1cm) angular blocky structure. Faint reaction to alpha-alpha.

Table 5.3. LSMEANS estimates for Juniper Bay and the reference bays in an organic soil.

Horizon	Depth	K*	Ca*	Mg	P	Mn*	Zn	BS*	CEC*	pH	C	N*
	(cm)	---------- (cmol kg^{-1}) ---------			---------- (mg kg^{-1}) -----------			-- (%) --	(cmol$_c$ kg^{-1})		------- (%) -------	
						Juniper Bay						
Op	15	0.33	5.16	2.01	76.90	11.44	10.41	61.37	23.97	4.43	29.23	0.83
Oa1	32	0.25	2.6	1.12	32.36	5.06	3.93	34.69	21.45	4.03	35.17	0.75
Oa2	54	0.17	1.41	0.58	12.31	2.91	1.56	21.89	15.63	3.75	21.49	0.50
Oa3	75	0.13	0.82	0.34	7.91	2.25	0.88	15.84	13.26	3.77	16.40	0.37
Bw	87	0.08	0.35	0.14	6.03	0.63	0.28	16.81	6.23	3.88	6.52	0.14
2C	108	0.07	0.23	0.10	4.06	0.53	0.18	20.05	4.01	3.97	2.54	0.05
Error		0.18	0.28	0.37	6.20	0.68	4.90	2.03	6.03	0.07	4.90	0.21
						Reference Bays						
Oi	19	1.10	0.62	1.75	70.77	4.61	15.05	11.97	46.60	3.73	37.58	1.46
Oe	48	0.35	0.31	0.50	25.14	2.06	16.48	9.26	23.30	3.51	28.11	0.97
Oa1	88	0.07	0.21	0.28	10.96	1.14	7.46	5.46	17.92	3.5	20.45	0.54
Oa2	123	0.01	0.09	0.07	3.87	0.40	2.56	3.27	10.70	3.87	16.10	0.34
OC	148	0.02	0.14	0.10	2.67	0.65	1.35	3.52	10.48	3.95	13.66	0.27
2C	171	0.05	0.07	0.10	0.10	0.36	0.47	4.41	6.59	3.98	3.77	0.07
Error		0.11	0.23	0.23	5.10	0.58	3.60	2.39	3.88	0.06	3.70	0.14

(*) Significant at $p<0.10$

Table 5.4. LSMEANS estimates for Juniper Bay and the reference bays in a soil with a histic epipedon.

Horizon	Depth	K*	Ca*	Mg*	P*	Mn*	Zn	BS*	CEC*	pH	C*	N*
	(cm)	---------- (cmol kg^{-1}) ---------			--------- (mg kg^{-1}) ----------			-- (%) --	($cmol_c$ kg^{-1})		------- (%) -------	
						Juniper Bay						
Ap	18	0.28	3.88	1.54	96.4	8.05	6.34	62.96	17.83	4.90	17.0	0.51
Oa	30	0.23	1.83	0.83	35.1	3.57	2.16	30.76	16.06	4.02	24.7	0.46
Bw1	51	0.13	0.59	0.37	1.4	1.81	0.46	16.61	10.29	3.83	10.2	0.23
Bw2	65	0.08	0.21	0.10	2.2	0.46	0.28	13.74	9.88	3.81	1.0	0.06
BC	95	0.07	0.17	0.11	0.2	0.42	0.24	20.18	3.63	3.97	0.8	0.04
C	112	0.06	0.16	0.09	2.7	0.53	0.28	15.10	4.61	3.87	1.0	0.06
Error		0.08	0.28	0.15	5.8	0.70	1.02	2.75	2.8	0.10	3.1	0.09
						Reference bays						
Oi	16	0.71	0.43	0.86	36.6	3.37	6.34	9.57	33.05	3.63	30.5	1.08
Oa	32	0.18	0.16	0.15	9.5	1.23	3.84	7.04	11.02	3.51	13.5	0.47
OC	56	0.08	0.18	0.09	9.6	0.98	1.19	6.05	8.48	3.72	6.5	0.21
2C1	82	0.06	0.10	0.01	3.9	0.26	0.39	6.17	5.20	3.98	3.6	0.10
2C2	118	0.04	0.06	0.02	3.8	0.14	0.87	4.84	3.65	4.37	1.9	0.05
Error		0.08	0.31	0.13	7.4	0.70	1.39	2.61	2.80	0.10	3.3	0.09

(*) Significant at $p<0.1$

Table 5.5. LSMEANS estimates for Juniper Bay and the reference bays in a mineral soil.

Horizon	Depth	K*	Ca*	Mg*	P*	Mn	Zn*	BS*	CEC*	pH*	C*	N*
	(cm)	------- (cmol kg^{-1}) -------			------- (mg kg^{-1}) ------			--- (%) ---	(cmol$_c$ kg^{-1})		----- (%) -----	
						Juniper Bay						
1	10	0.26	3.34	1.12	87.1	9.05	12.44	74.62	12.71	5.10	7.64	0.27
2	27	0.04	1.68	0.66	33.5	2.37	5.23	56.13	7.85	4.91	7.31	0.22
3	44	0.03	0.54	0.31	16.0	0.09	0.49	35.01	4.70	4.55	2.48	0.06
4	62	0.06	0.34	0.18	7.4	0.54	0.17	27.36	4.23	4.31	1.83	0.04
5	85	0.05	0.34	0.13	8.1	0.64	0.50	30.91	2.96	4.34	1.43	0.03
6	101	0.03	0.28	0.12	10.3	0.27	0.38	31.21	2.63	4.55	0.73	0.01
7	126	0.03	0.26	0.09	5.0	0.34	0.38	32.25	2.41	4.29	0.19	---
Error		0.07	0.35	0.30	5.6	2.80	1.31	4.52	3.02	0.25	3.10	0.07
						Reference bays						
1	10	0.75	1.15	1.23	33.3	8.69	5.96	16.30	32.62	3.74	24.9	0.73
2	22	0.14	0.11	0.16	8.7	1.08	0.97	8.47	8.67	3.62	6.09	0.19
3	52	0.01	0.03	0.04	3.1	0.26	0.49	7.80	1.71	4.07	0.26	0.01
4	82	0.01	0.07	0.06	8.0	0.27	0.24	4.98	3.58	4.12	0.96	0.02
Error		0.08	0.38	0.23	6.8	1.90	1.37	4.97	3.51	0.21	2.50	0.07

(*) Significant at $p<0.1$

Table 5.6. LSMEANS estimates for mineral soils in a crest vs. ditch comparison.

Horizon	Depth	K*	Ca*	Mg*	P	Mn*	Zn*	BS*	CEC	pH*	C	N
	(cm)	------ ($cmol\ kg^{-1}$) -----			------ ($mg\ kg^{-1}$) -----			-- (%) --	($cmol_c\ kg^{-1}$)		----- (%) -----	
						Crest						
1	15	0.21	3.36	1.07	85.67	8.37	12.02	71.5	12.54	5.04	7.69	0.27
2	31	0.04	1.52	0.52	32.11	2.12	3.99	52.9	7.26	4.93	6.42	0.17
3	48	0.03	0.45	0.24	14.61	0.42	0.56	31.9	4.06	4.47	1.87	0.04
4	67	0.05	0.27	0.18	5.67	0.62	0.22	24.2	4.18	4.29	1.56	0.03
5	92	0.05	0.27	0.16	6.53	0.59	0.37	27.7	3.41	4.30	1.47	0.03
6	107	0.03	0.18	0.10	8.99	0.27	0.17	26.6	2.33	4.47	1.01	0.01
7	122	0.33	0.19	0.08	4.35	0.30	0.05	25.0	2.08	4.23	0.63	0.01
Error		0.03	0.31	0.11	6.17	0.61	0.99	5.50	1.20	0.17	1.80	0.04
						Ditch						
1	15	0.07	1.76	0.39	66.51	4.48	5.25	49.1	8.57	4.68	7.54	0.25
2	32	0.04	1.33	0.33	27.44	2.13	3.54	45.6	7.01	4.75	6.89	0.19
3	49	0.04	0.65	0.18	9.47	0.92	1.09	37.2	4.61	4.76	3.91	0.06
4	70	0.02	0.38	0.18	14.61	0.48	0.29	29.5	4.08	4.5	1.67	0.03
5	89	0.03	0.24	0.13	15.17	0.34	0.21	24.5	2.97	4.38	1.21	0.02
6	107	0.06	0.19	0.09	10.86	0.42	0.31	16.1	3.51	4.11	1.45	0.04
7	125	0.05	0.14	0.07	15.14	0.31	0.45	14.5	3.00	4.04	0.91	0.02
Error		0.03	0.31	0.11	6.17	0.61	0.99	5.5	1.20	0.17	1.70	0.04

(*) Significant at $p<0.1$

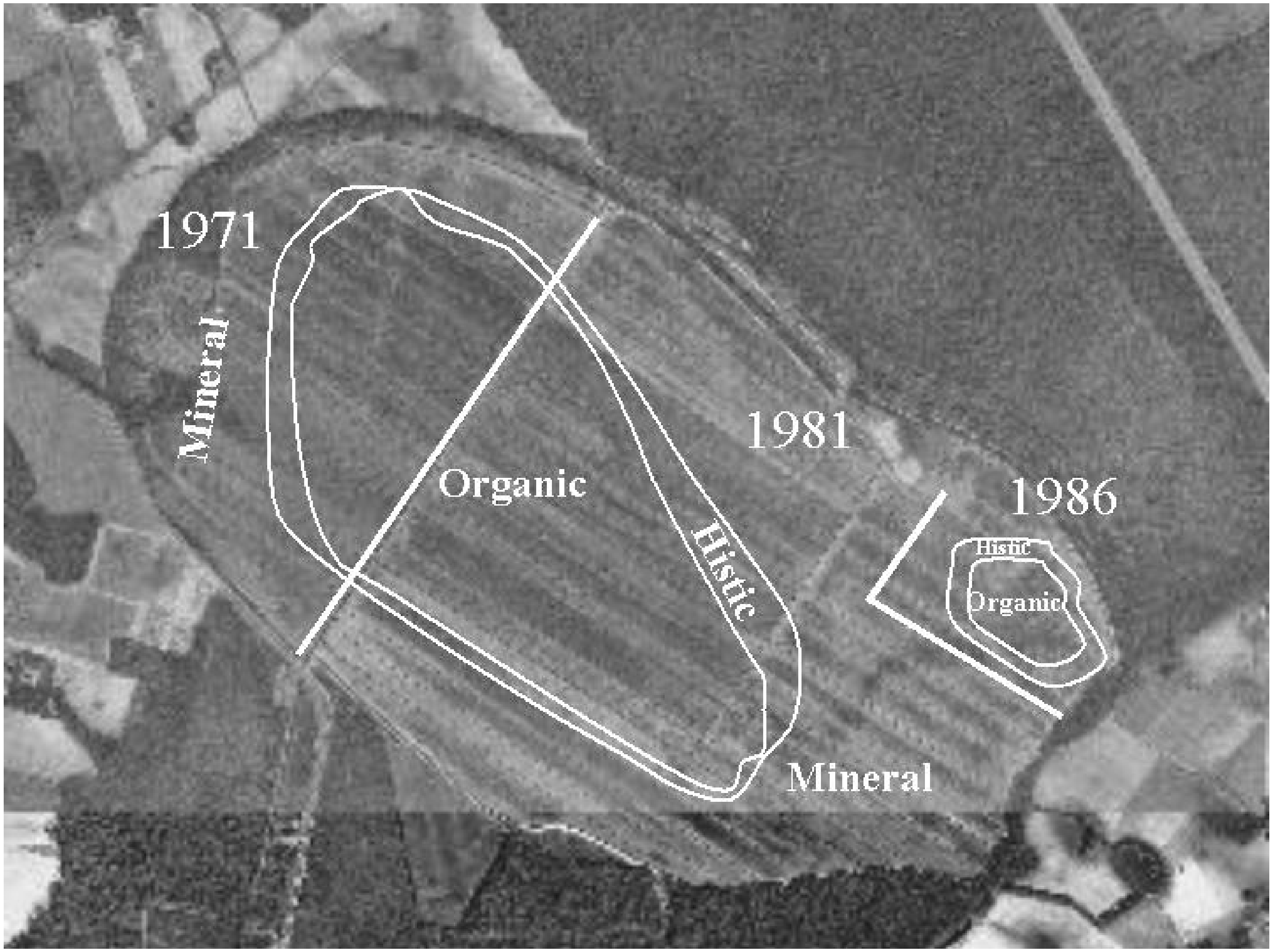

1971
Mineral
Organic
Histic
1981
1986
Histic
Organic
Mineral

Figure 5.1. Aerial photo of Juniper Bay (2.4 x 1.6 km) showing the time of drainage and areas where organic, histic, and mineral soils are located.

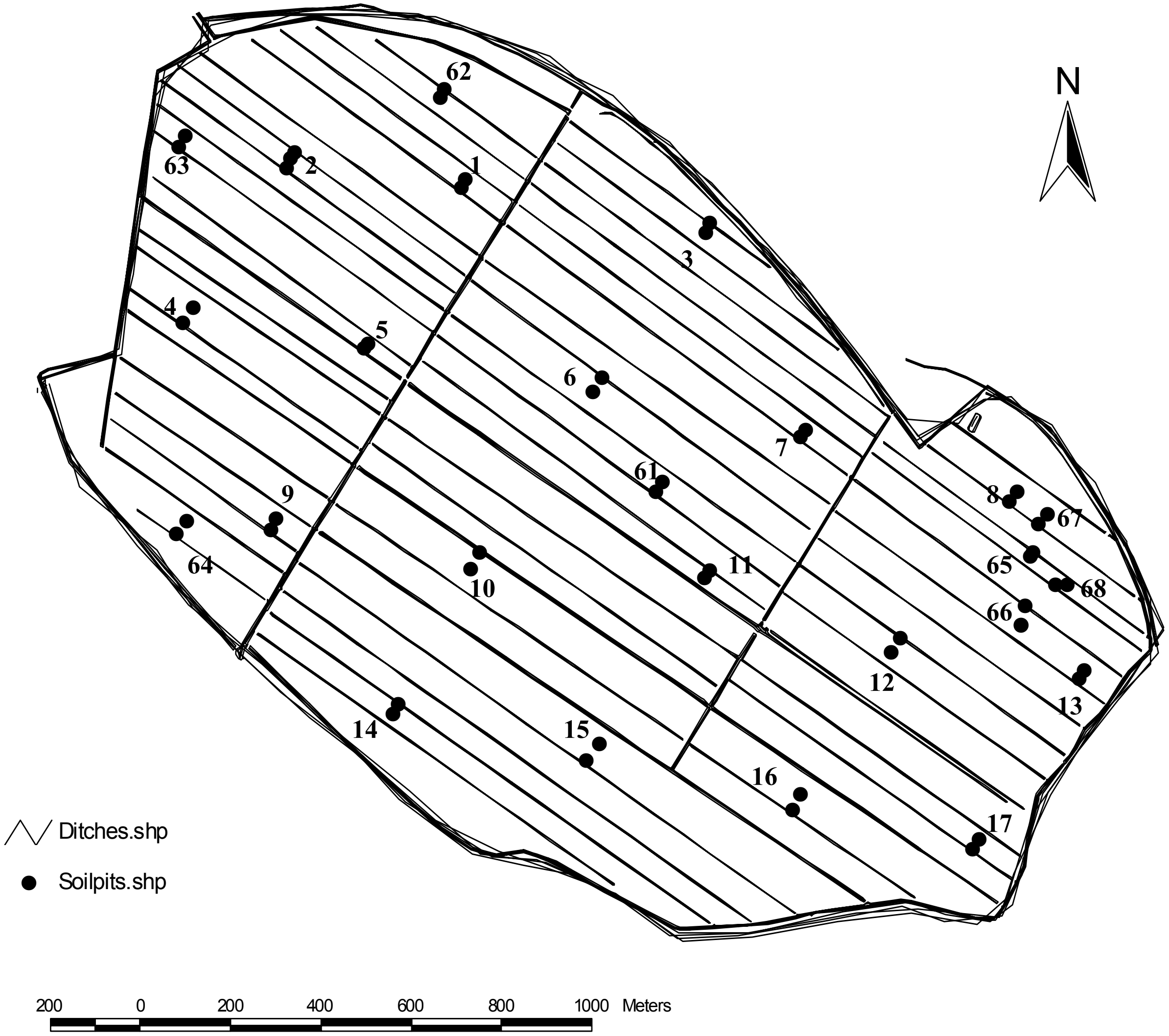


Figure 5.2. Pit locations at Juniper Bay.

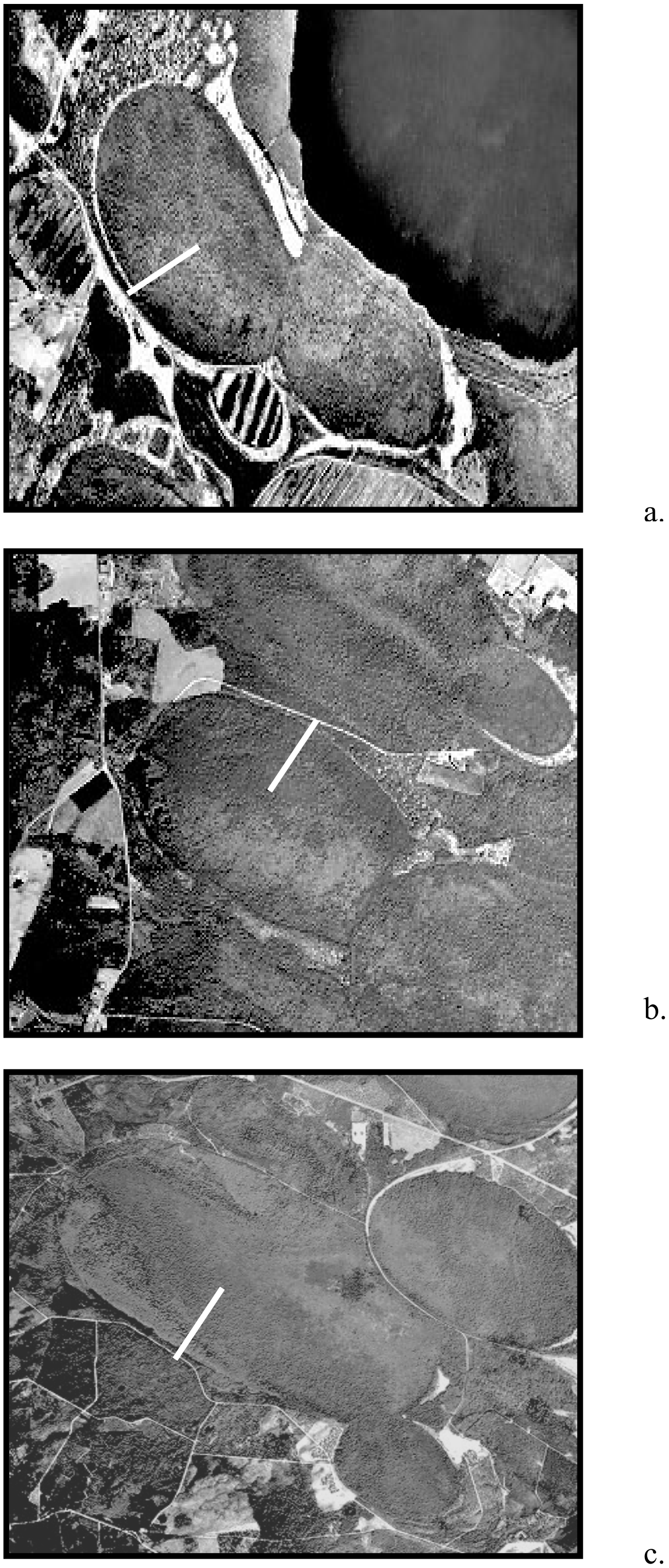
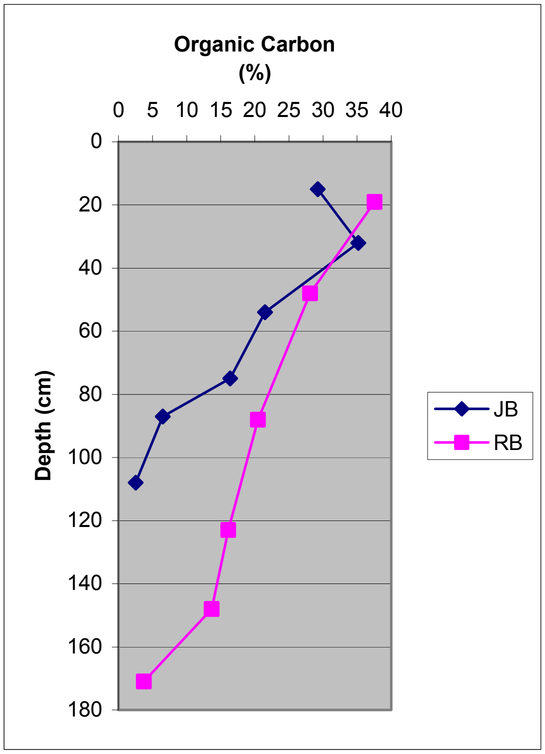
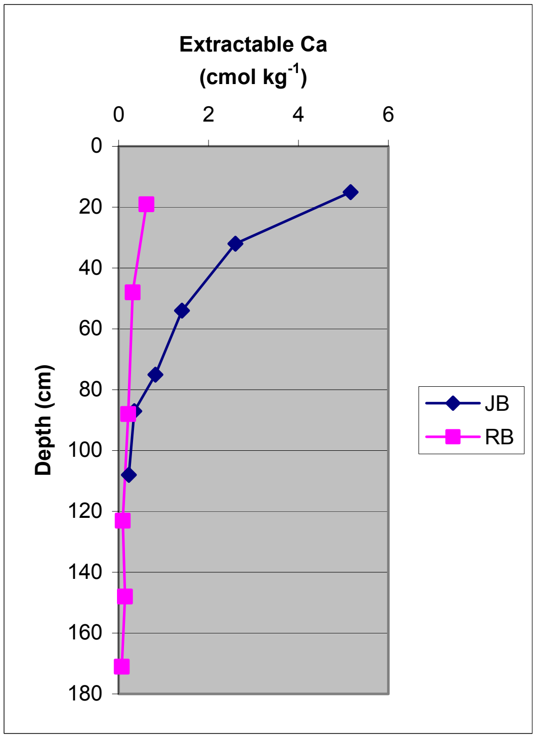


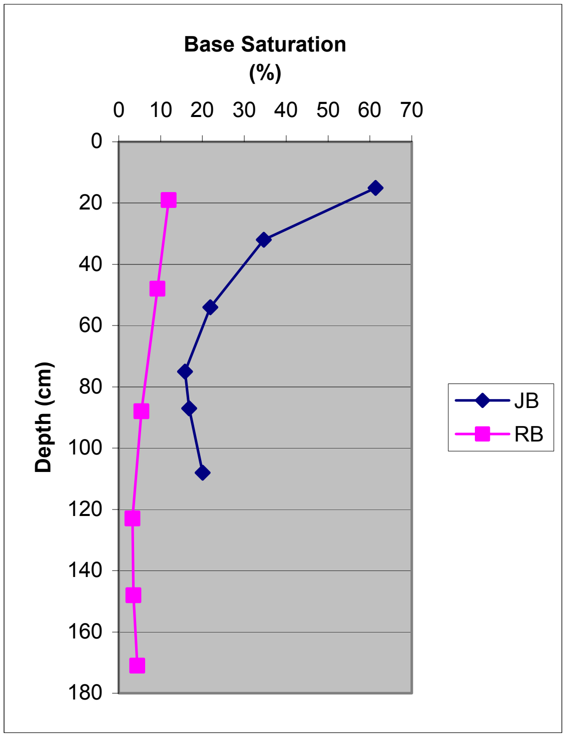
Figure 5.3. Location of transects in (a) Causeway Bay, 1.8 x 1.15km, (b) Charlie Long Millpond Bay, 1.9 x 1.2 km, (c) and Tatum Millpond Bay, 4.4 x 2.2 km.


Organic Carbon
(%)
0 5 10 15 20 25 30 35 40
0
20
40
60
80
100
120
140
160
180
Depth (cm)
JB
RB

a.


Extractable Ca
(cmol kg-1)
0 2 4 6
0
20
40
60
80
100
120
140
160
180
Depth (cm)
JB
RB

b.



c.

Figure 5.4. Comparison of organic carbon (a), extractable Ca (b), and base saturation (c), or organic soils from Juniper Bay (JB) and the reference bays (RB).

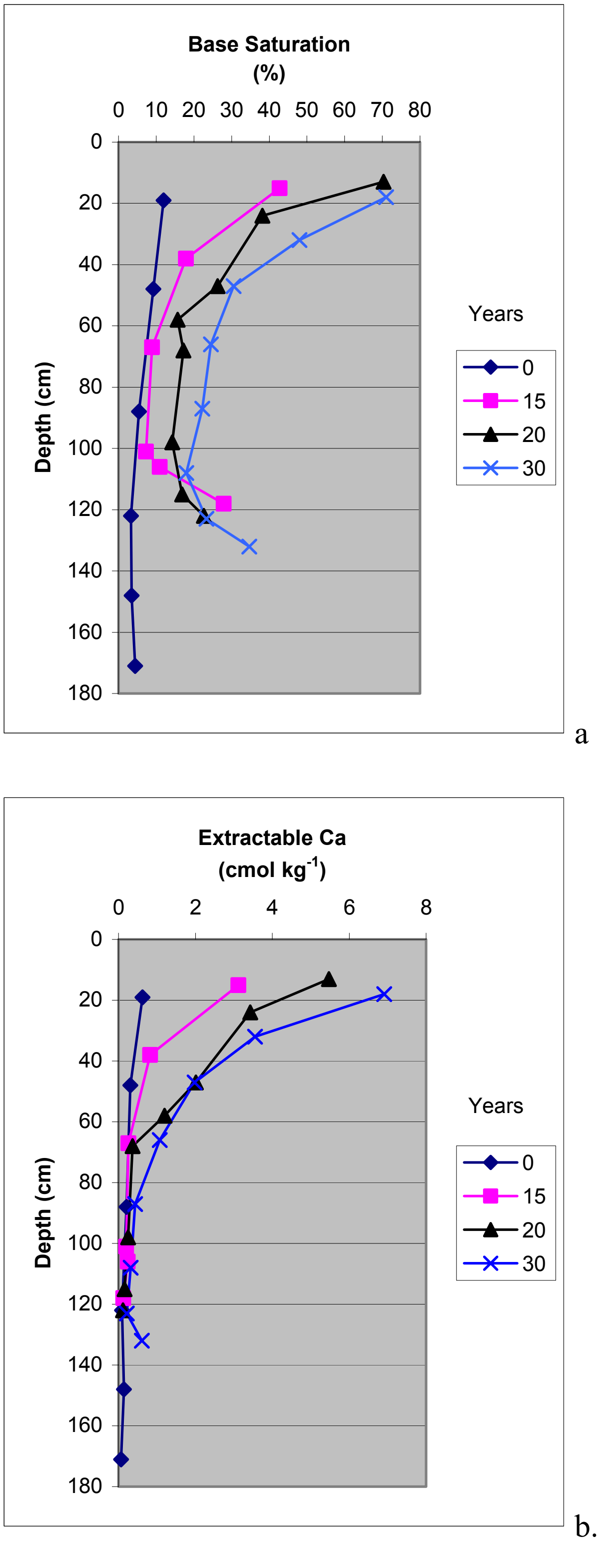


Figure 5.5. Relation of years in agricultural production on base saturation (a) and extractable Ca (b) in organic soils.

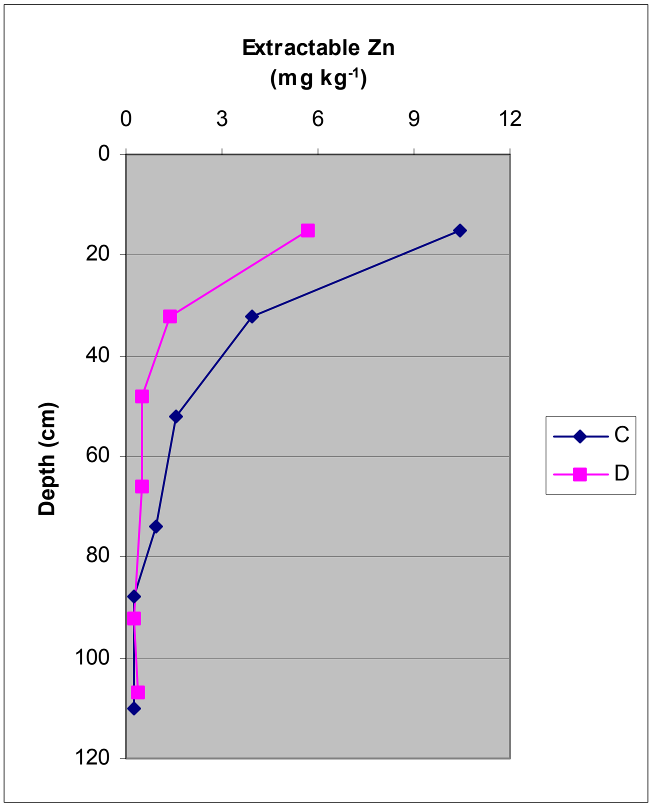
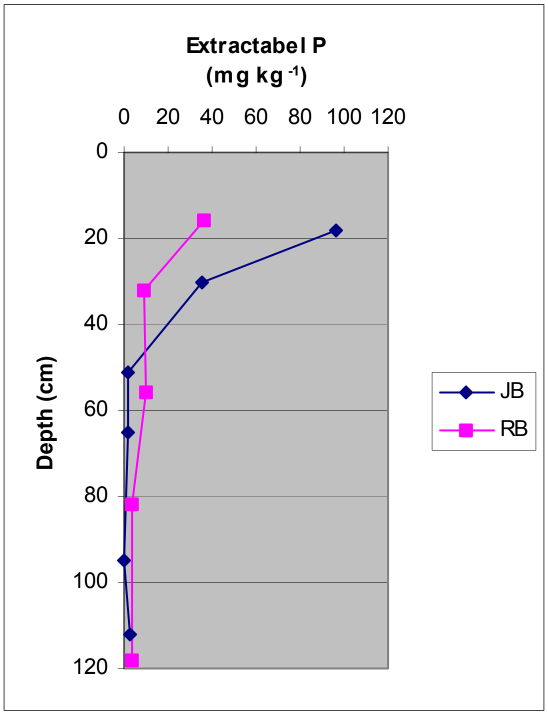
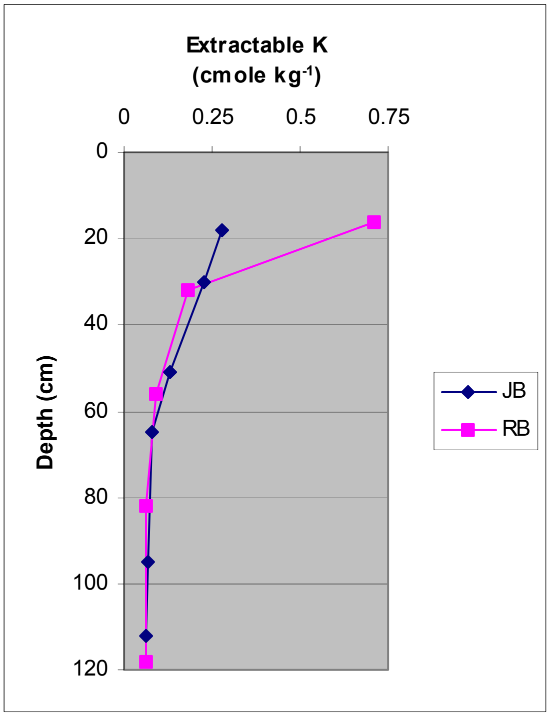


Figure 5.6. Comparison of extractable Zn at the crest (C) and ditch (D) in organic soils at Juniper Bay.

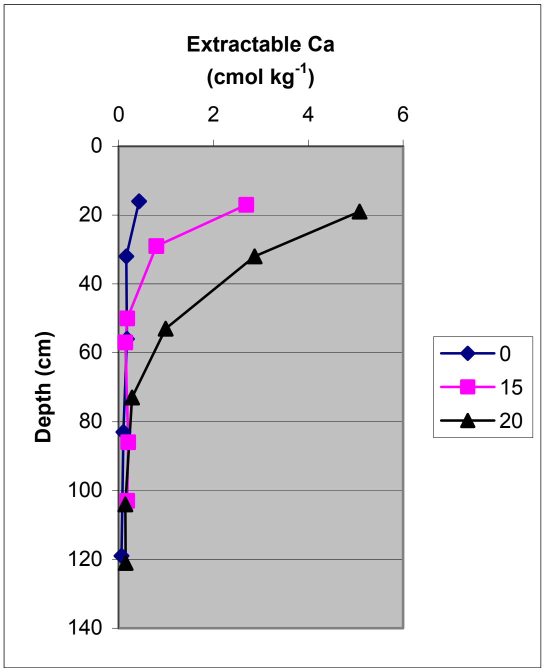


a.

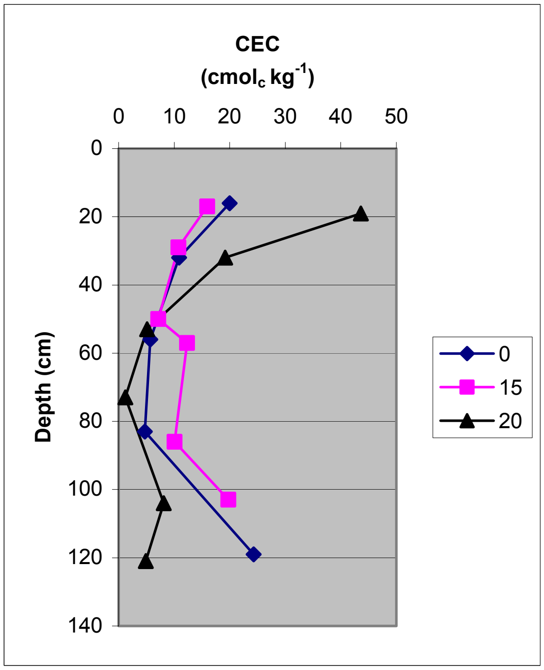


b.

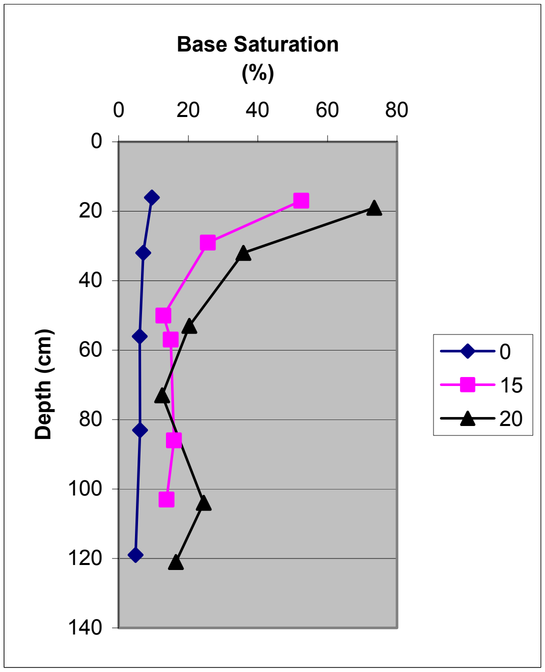
Figure 5.7. Comparisons of extractable P (a) and K (b) in soils with a histic epipedon at Juniper Bay (JB) and the reference bays (RB).


Extractable Ca
(cmol kg^{-1})
0
2
4
6
0
20
40
60
80
100
120
140
Depth (cm)
0
15
20

a.


CEC
(cmol$_c$ kg^{-1})
0
10
20
30
40
50
0
20
40
60
80
100
120
140
Depth (cm)
0
15
20

b.



c.

Figure 5.8. Relationship of time in agriculture on extractable Ca (a), CEC (b), and base saturation (c) in soils with a histic epipedon.

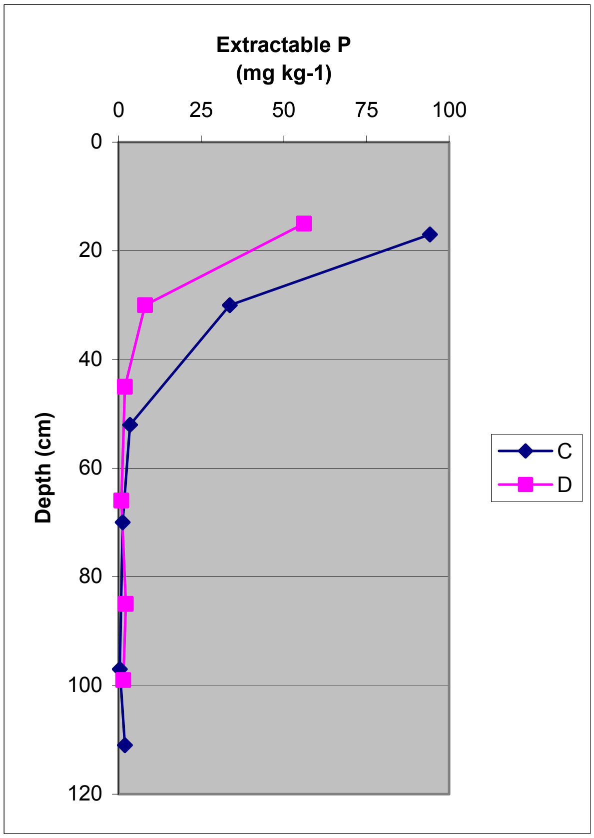
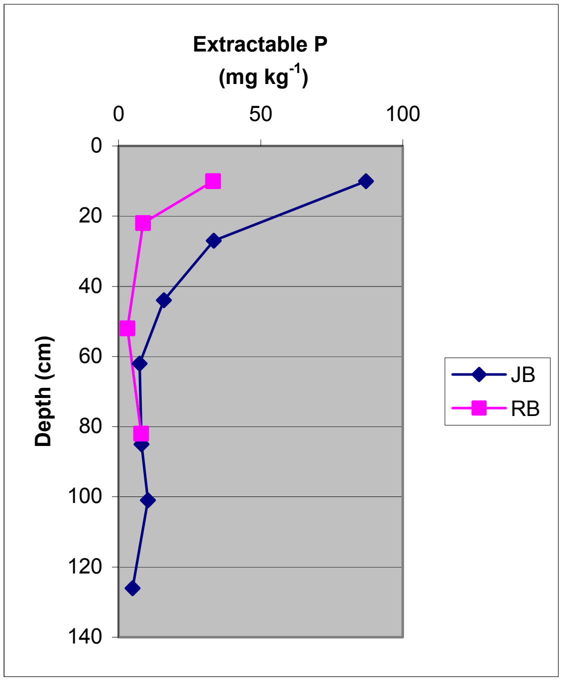
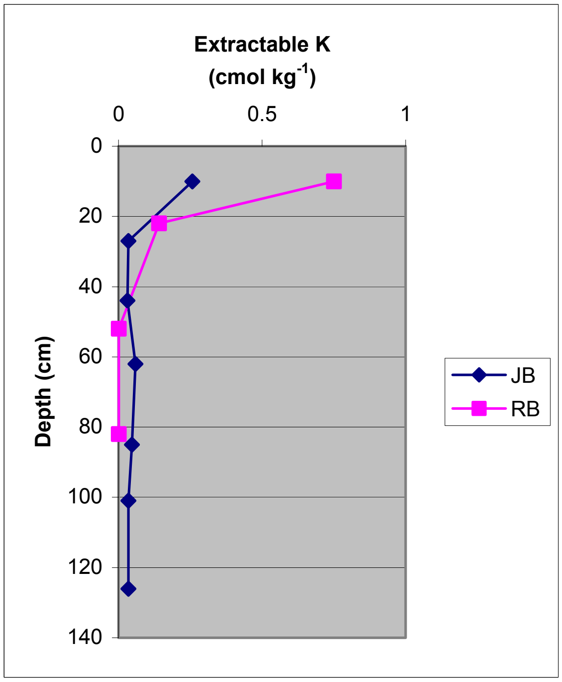


Figure 5.9. Crest (C) vs. Ditch (D) comparison of extractable P in soils with a histic epipedon at Juniper Bay.



a.



b.

Figure 5.10. Juniper Bay (JB) versus Reference Bays (RB) on extractable P (a) and K (b) in a mineral soil.

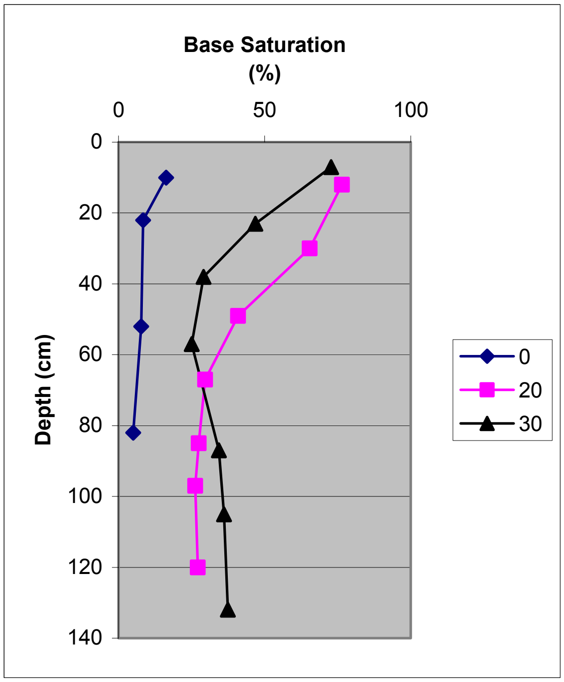


Figure 5.11. Time of agricultural practices on base saturation in a mineral soil.

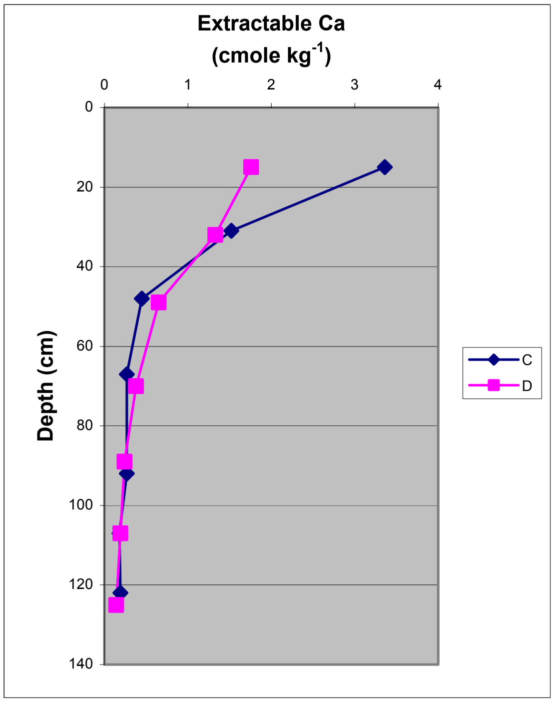


Figure 5.12. Crest (C) vs. Ditch (D) comparison of extractable Ca in mineral soils of Juniper Bay.