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CITRUS IN FLORIDA

Ecological management and nature's latest intervention through freeze

With 11 figures and 2 tables

WOLFGANG WEISCHET and CESAR N. CAVIEDES

Zusammenfassung: Citrus in Florida. Ökologisches Management und die Frostkatastrophe 1983/85

Ende der 70er Jahre wurde in Florida auf 310 000 ha Citrus-Plantagen mit nahezu 11 Millionen Tonnen über ein Viertel der auf der Welt für den Markt bestimmten Citrusfrüchte mit einem Wert von mehr als einer Milliarde US-Dollar produziert. Zwei Drittel der Gesamtmenge wächst unter den ökologischen Bedingungen der Sandhügelländer der Central Ridges, ein Drittel entstammt den grundwassernahen Sandebenen der Flatwoods. Die Central Ridges bestehen aus einer mächtigen Auflage pleistozäner Quarzsande über einem Karstrelief in Kreidekalken. Die Flatwood-Ebenen sind pleistozäne Abrasionsflächen, die ebenfalls eine Quarzsanddecke tragen.

Als subtropische Spezies vertragen die Citrusbäume leichten Frost, bei Temperaturen unter – 3.3 °C erfrieren die Früchte, bei mehr als 4 Stunden unter – 5.6 °C wird der ganze Baum schwer geschädigt. Auf Grund der Frostkatastrophen am Ende des 19. Jhs. sowie zu Anfang der 40er und 60er Jahre ist der Schwerpunkt der Citruskulturen auf den mittleren und südlichen Teil der Central Ridges und in die Flatwoods Zentralfloridas gewandert. Die beiden Frostkatastrophen vom Dezember 1983 und Januar 1985 haben insgesamt 40% der Kulturen, diejenigen nördlich der Breite von Orlando total vernichtet.

Hauptgegenstand der Darstellung ist das technologisch ausgefeilte ökologische Management der Citrus-Kulturen auf den stark sauren, höchst durchlässigen, extrem nährstoff- und humusarmen, nur mit sehr niedriger Austauschkapazität ausgestatteten Quarzsandböden. Die Citrus-Kulturen sind vollständig auf „künstliche Ernährung" angewiesen; sie gleichen einem „hydroponic system", in welchem der Boden nur dem Halt der Wurzeln dient und die Rolle des Übermittlers der vom Menschen verabreichten Nährstoffe spielt. Aber wie kann er das bei der exzessiv großen Permeabilität, für die sich der rasche Durchsatz nicht absorbierter Elemente mit Hilfe des Modells von NOFZIGER a. HORNSBY rechnen läßt? In der Kombination eines möglichst tief reichenden Wurzelstocks als Abfangsystem, bestimmter Eigenschaften des subtropischen Niederschlagsrhythmus und daran angepaßter Portionsdüngung ist dies im Normalfall möglich.

Citrus was first introduced into Florida by the Spanish settlers in the St. Augustine and St. Johns Rivers region. Citrus production achieved significant importance as a commercial enterprise, especially in the vicinity of the St. Johns River, following the

Fig. 1: Great division of natural regions and soil groups in Florida
Großgliederung der Naturräume und Bodengruppen in Florida

Civil War. During the 1880s, the groves had expanded as far south as the present counties of Alachua, Marion, Lake and Orange while the southern boundary extended to the latitude of Orlando (see Fig. 1 a. 11). The severe freezes of 1894–95 and the record low temperature of 1899 were devastating to the entire region, especially in Alachua County where no trees survived. It was not until fifteen years later that citrus production returned to its former level; it increased after the newly planted trees on the higher ridges of Central Florida came into bearing. BEIN (1971) locates the main center of citrus production in northern Polk County. Later expansions moved southward into the vicinity of a town pertinently called Frostproof. During this expansion sophisticated ecological management was devised that would permit the establishment of citrus cultivation and make it profitable on the sterile Florida sands. Well-drained soils were considered a fundamental prerequisite for citrus growing. Root depths to six feet, without interference from the water table, were deemed indispensible for optimal citrus production.

The killing freeze of December 1962 cast doubts as to whether the main center of citrus production, especially the northern section in the vicinity of Apopka, Eustis, and Leesburg, was as frostproof as had earlier been assumed. Consequently groves were extended southward along the southernmost section of the Lake Wales Ridge in Highlands County and also, under different growing conditions, into the artificially drained parts of the flatwood region of Indian River and St. Lucie counties. By 1969, the center of citrus groves had moved southward to the area northwest of Lake Okeechobee and by the mid-1970s production was in full swing. Expansion of the citrus groves is still in progress in the southern flatwood counties and includes the newly planted groves of the Coca Cola Company.

During their best years, Florida's bearing citrus groves covered about 310,000 ha, producing approximately 11 million metric tons of citrus fruit (over 25% of the world's total commercial production) with the on-the-tree value of more than one-billion dollars (ANDERSON 1981). Two-thirds of the citrus crop is grown under ecological conditions typical of the sandhills of the Central Ridge, one third under environmental conditions inherent to the flatwoods.

The natural background

At present the relief of the Florida peninsula does not rise above 100 m of elevation. Indeed, the highest point of the state of Florida (106 m a.s.l., 345 feet) lies in the northern corner of the Florida panhandle - a land corridor that stretches between the northern shore of the Gulf of Mexico and the southern hills of the Alabama highlands. The spine of the Florida peninsula is the "Central Ridge" (also known as "Central Highlands") which consists of a karst substratum dotted with lakes and interspersed with sandy hills (see Fig. 1 a. 11). According to HEAD and MARCUS (1984), the Central Ridge is subdivided into five segments: the northern ridges of Orlando and Brooksville and the southern ridges of Lake Wales, Winter Haven, and Lakeland. The boundary between the northern and the southern Central Highlands is the "Peninsular Divide", a watershed that runs - from E to W - from Cape Canaveral to the Tampa Bay (see Fig. 11). This is the widest part of the peninsula, and also the highest with the Iron Mountain (290-300 feet, around 90 m) near Lake Wales.

The Florida divide appears to have been established way back in the geological evolution, for it represents a decisive boundary-zone between two different geological basements in the northern and southern part of the peninsula. The geological foundation consists of Cretaceous and late-Tertiary deposits which, north of the central divide, are dominated by the thick Ocala limestone series (early Tertiary). They are overlaid by the substantially thin, facies-built, horizontal series of the Hawthorne formation consisting of clays, mollusc-bearing breccie, sands, silts, or phosphates. In the vicinity of the Florida divide and towards the south, the facies of the early Tertiary sediments give way to an alternation of limestones and clastic sediments.

The dome-like tectonic uplift of the peninsula began during the Miocene and culminated in the Pliocene. The maximum intensity of this process is evident in the northern part of Central Florida, particularly in the "Ocala Uplift". In phase with the tectonic activity and concomitant stresses began the exogeneous shaping of the limestone surface which is still patent in the geomorphological make-up of Central Florida.

Yet another morphogenetic event occurred during the Pleistocene when quartz sands covered preexisting karst features with layers of varying thickness which, at the southern edge of North-Central Florida, are assumed to reach 1,000 feet (HEAD a. MARCUS 1984, p. 67).

The Pleistocene was characterized by successive changes in sea-level. During the high sea stands, sand deposits accumulated over the flooded areas and also along the coastal rim. The thickness of sand deposits depends upon the coastal outline, the submarine topography, and the karst relief in littoral areas. In general, the sand deposits are less mighty (around some feet) in the interior of the southern Florida plains, but very thick (several to many meters) around the uplands of the Central Ridge. Because of their marine origin the sand deposits contain only small amounts of silt and clay.

In relation to its geological origin, morphogenetic development in the Central Highlands resulted in a rolling landscape whose lower parts consist of karst depressions and whose upper features are built up by thick layers of quartz sands. These sands constitute the ground on which Florida's Central-Highland citrus groves have been established.

Fig. 2 depicts the distribution of the citrus cultures and retraces the ridges so characteristic of the Florida Highlands as the areas of major citrus concentration. This trend is even more apparent south of the peninsular divide in the counties of Polk and Hardee. Two important citrus areas are located in the flatwood region of the coastal lowlands: one in the eastern plains that encompass the Indian River, St. Lucie, and Martin counties - well-known as the Indian River citrus-producing country - and a second one in the hinterland of Charlotte Bay, particularly De Soto county. The boundary between lowland and highland has to be drawn at the 100 ft (33 m) contour line, which coincides with the fossil shoreline of the Wicomico transgression developed during the Illinois/Wisconsin interglacial period.

Highland as well as lowland citrus groves owe their development first to the properties of the atmospheric environment and second to the special pedological conditions that relate closely to the properties of the geological fundament mentioned above.

Climate and weather conditions

Weather and climate in Florida reflect conditions of the warm-humid summer-rain subtropics. During winter, the monthly radiation values for the sub-

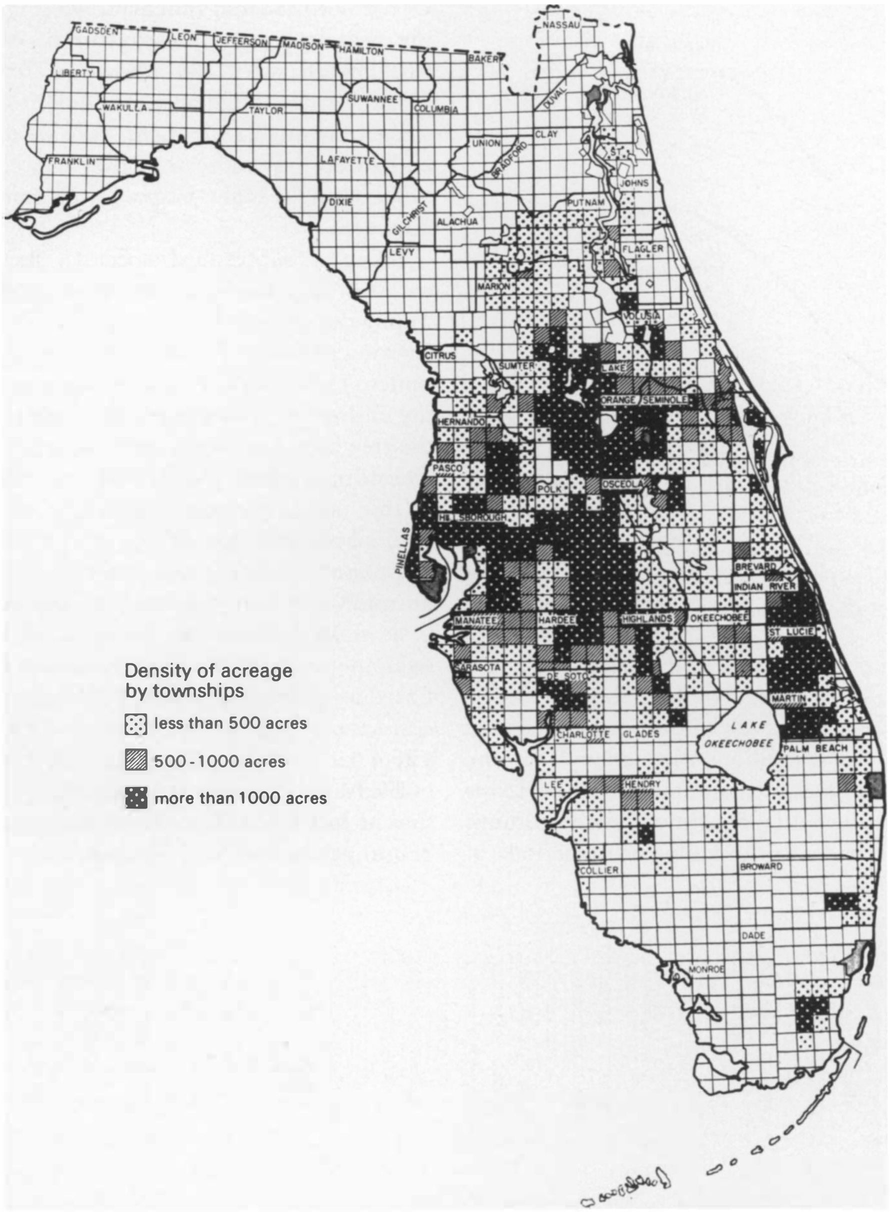

Fig. 2: Distribution of citrus production areas before the killing frosts of December 1983 and January 1985 (with kind permission of Agricultural Research and Education Center, Lake Alfred, Fl.)

Verteilung der Produktionsflächen der Citruskulturen vor den Schadfrösten vom Dezember 1983 und Januar 1985

tropical latitudes between 27° and 29° N are 10,000 to 15,000 kilojoules, which is far more energy than is needed for the growth of plants. In May, the values reach around 22,000 kilojoules. According to their heat absorption capacity, the central and south Florida soils classify as hyperthermic. Anderson (1981) states that the annual mean soil temperature at 50 cm depth is above 22 °C. Based on this value, and on the general rule of the hyperbolical temperature decrease curve, surface temperatures during the summer months must soar to over 50 °C.

The thermal conditions of the air are illustrated by the yearly course of the mean daily maximum and minimum temperatures at Lakeland as a typical station of the area (Fig. 3). Normally, mid-summer temperatures range from 20 °C during the night to 32 °C in the early afternoon, while winter temperatures oscillate between 12 °C and 25 °C. These

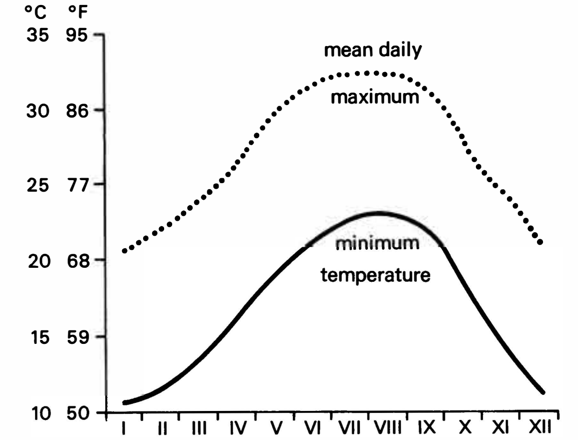

Fig. 3: Yearly course of mean daily maximum and minimum temperatures at Lakeland, Central Highlands of Florida

Jahresgang der mittleren täglichen Maximum- und Minimum-Temperaturen in Lakeland in den Central Highlands Floridas

values do not reveal, however, the whole reality of the thermal winter conditions as are shown by the fluctuation of the absolute minima since the 1890s (Fig. 4) and by the actual course of daily minimum temperatures related to the killing frost periods of December 1983 and January 1985 (Fig. 5). Comparing these diagrams, three conclusions can be reached: light frosts to – 2 °C (28 °F) happen almost every year in the Central-Highland counties; frosts in general strike only during the night, subside during the day and rarely last more than two consecutive nights. Still, a single night might be of damaging consequences.

Being a subtropical species, the genus citrus endures light frosts, but is killed by severe freezes. Temperatures of below – 3.3 °C (– 26 °F) cause freezing and loss of fruit. Moreover, if temperatures under – 5.6 °C (22 °F) last for more than four hours, the entire tree is damaged: the bark splits open and the tree bleeds to death after the frost has subsided. The critical temperature is – 4.4 °C (24 °F) because, at this point, protection measures such as heating with oil burners, sprinkling, or ventilating with fans must be applied if the trees are to be saved. Heating is normally not untertaken when only the loss of fruit is at stake because the expenses of operating the equipment are greater than the return from the crop. Based on 1969 prices, Bein (1971) calculated the total cost for one hour of cold protection by heating to be $ 26.4 per acre. (In relation with the frost occurrences of 1983 and 1985 a grower near Orange Lake reported that he lost $ 60,000 in the attempt to save 80 acres of orange trees with oil burners.)

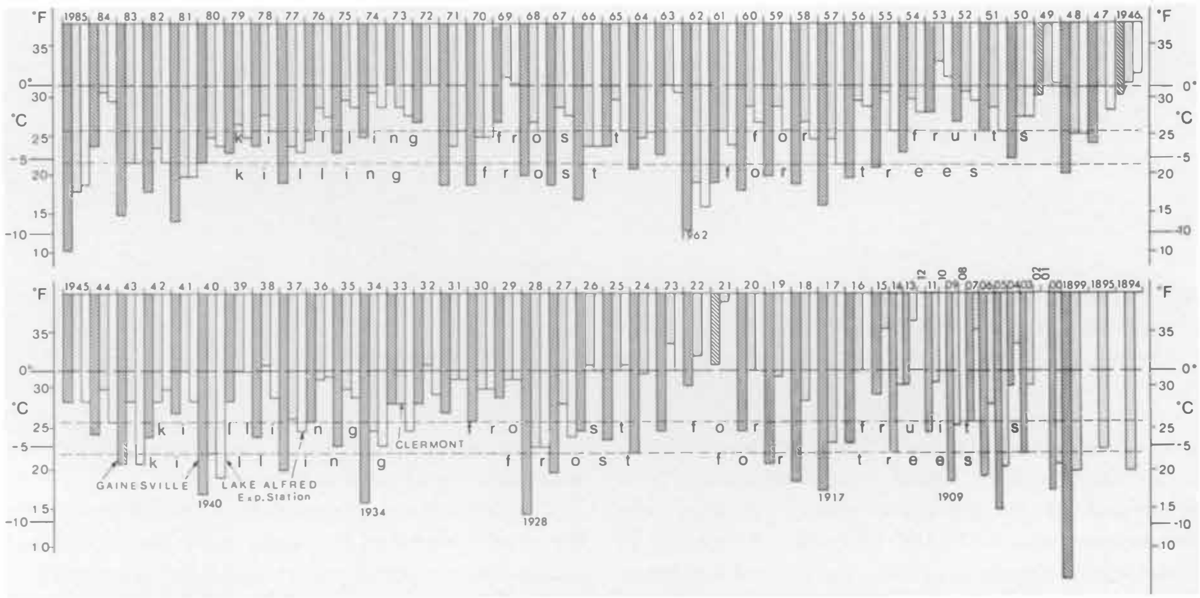

Fig. 4: Yearly absolute minimum temperatures since 1894 in the northern part (Gainesville) and the central part (Lake Alfred and Clermont) of Florida

Absolute Minimum-Temperaturen der Jahre seit 1894 im Nord- (Gainesville) und Zentralteil (Lake Alfred und Clermont) Floridas

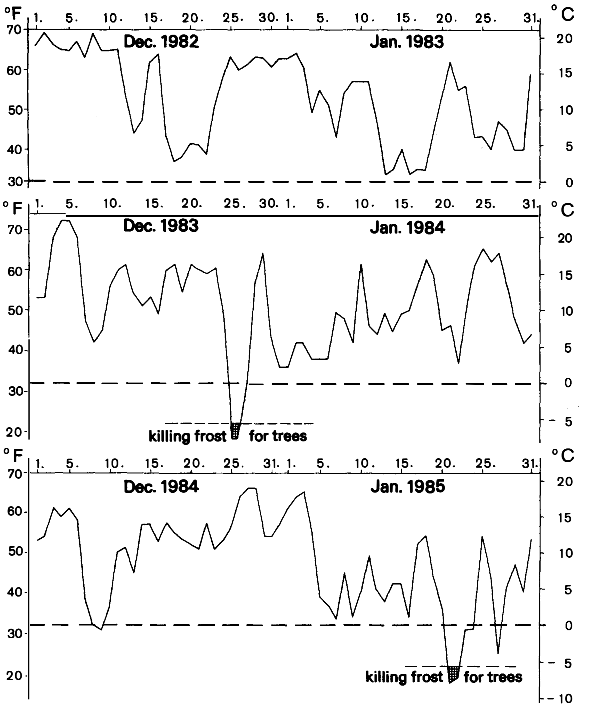

Fig. 5: Course of daily minimum temperatures during the winter periods 1982/83, 1983/84 and 1984/85 at Clermont, Central Florida

Verlauf der täglichen Minimum-Temperaturen während der Winter 1982/83, 1983/84 und 1984/85 in Clermont, Zentralflorida

Precipitation is characterized by a winter minimum between 25 and 40 mm in November and December and by a summer maximum between 180 and 200 mm in June and July (see Fig. 7). The critical period for plant growth lasts from March until the middle of May when radiation values have risen already above 20,000 kilojoules per month, air-temperatures around noon surpass 25 °C, and precipitation amounts do not exceed 60 mm. (This is the most pleasant time for people; later, from May through October, there is a persistent mugginess resulting from the combination of high temperatures and high air humidity.) Moisture conditions for plant growth are regularly critical in spring and early summer and it is then that the water supply in the groves must be managed by man. But even in summer, when the average precipitation amounts are relatively high, the water balance and water management of soils face difficulties. This has to do with the precipitation structure, (see Fig. 6 with daily precipitation values for Clermont). The rains fall in the form of convective showers whose frequency and intensity are shaped by Florida's closeness to the tropics and by its location between two warm tropical waters. During the summer months, the center of the subtropical anticyclone with its stabilizing effects is frequently located north or northeast of the peninsula over the Atlantic Ocean. Over land the thermo-convective impulses are relatively high. Since, at the same time, the surrounding oceans supply the air masses with a high content of water vapor, the result is a high frequency of daily showers from June through September, ranging mostly between 2 mm and 10 mm. Between March and October during the specified years in Lake Alfred and Clermont, 140 and 141 out of a total of 233 and 256 days respectively stayed within this range. On 45 and 67 days respectively, precipitation was between 10 mm and 30 mm. Apart from these regularities there are several downpours of typically tropical nature each year. For example, in 1974, Lake Alfred experienced two three-day spells of heavy rainfall, one with 200 mm and one with 115 mm of precipitation. In 1975, the amount of rain reached 117 mm in three days and there were three single-day downpours each between 40 mm and 65 m. In 1976, amounts above 50 mm fell on four days; once the amount was 96 mm. The picture is practically the same for Clermont, only the dates and the amounts vary. The summer of 1976 was especially extreme for that station: on two occasions 100 mm or more were measured, and three times the amount exceeded 50 mm.

In view of these rainfall conditions, coupled with the soil's extreme poverty in nutrients, low exchange capacity, and high permeability, it is amazing that the annual yield in biomass per hectare amounts to 35 tons of oranges or 50 tons of grapefruit. This achievement results from perfect management. Indeed, the citrus-producing area is "a prime example of humanized nature, an area of man-made beauty and productivity that exceeds that of nature" (Ebeling 1979; cited from Anderson 1981).

The pedological conditions

The uplands of Central Florida consist of sandhills underlain by limestone beds with a karst landscape. The topography is mostly gently rolling; however, there may be steep slopes with a gradient as high as 40%. The lower areas are dominated by sinkholes and depressions with numerous lakes, interspersed with sandhills of 80 m (maximum 90 m) above sea-level. Generally the thickness of the sand cover on the hills is several meters. In the highland groves the soils fall mostly into the category of sandy entisols

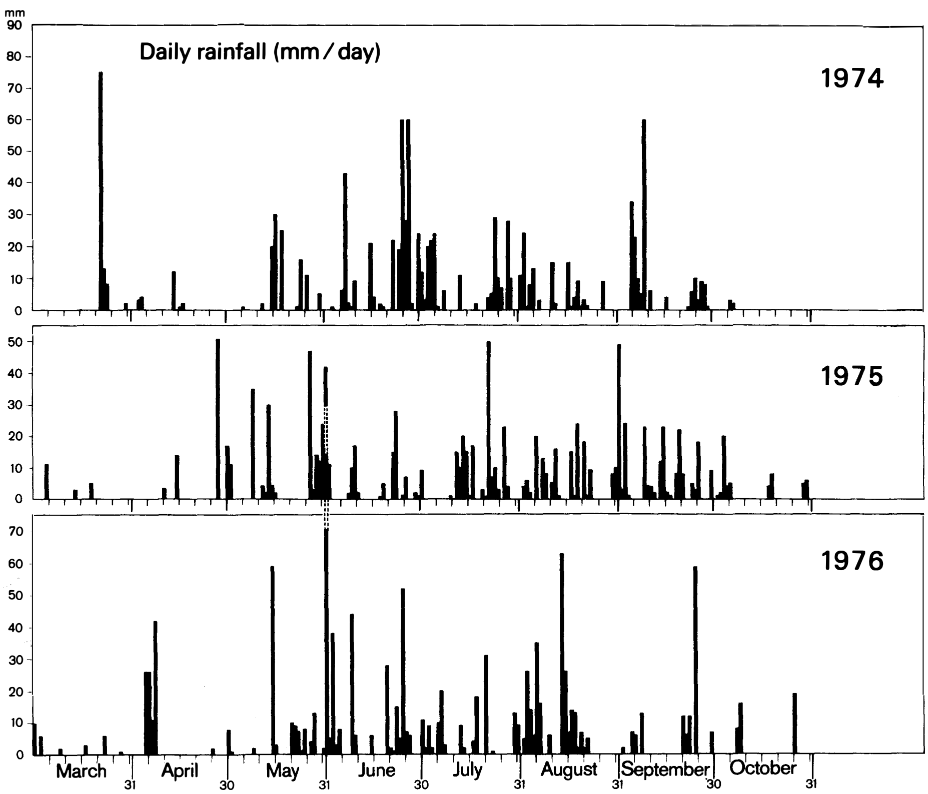

Fig. 6: Daily rainfall values during the main growing periods of 1974, 1975 and 1976 at Clermont, Florida
Tageswerte des Niederschlags während der Hauptwachstumsperioden der Jahre 1974, 1975 und 1976 in Clermont, Florida

(arenosols, in the FAO-UNESCO classification). The term "quartzispamments" indicates pertinently their dominant quartz composition, with only a small percentage of silt and clay. They are soils with little development over thick deposits of unconsolidated marine or eolian sands. In the "General Soil Map of Florida" (CALDWELL a. JOHNSON 1982), the entisols are regionally differentiated according to associations, individualized by means of local names. The dominant soils on the Central Florida ridges belong to the "Astatula association" and the "Candler-Apopka-Astatula association".

Tables 1 and 2 offer the data for different locations, vegetation cover, soil use, and slope forms (extracted from CALHOUN et al. 1974 and CARLISLE et al. 1978). From these values, six common characteristics are obvious:

1) Particle sizes between 0.5 and 0.1 mm in diameter, i. e. middle and fine sands, are predominant. Coarse and very fine sands are as scarce as the amounts of silt and clay. The largest deviation from the norm occurs where very fine sands, silt, and clay amount to only 8–9% of the total.

2) The very low total content of extractable bases, Ca, Mg, Na, and K, of the order of 0.1 meq/100 g or less, in all horizons below the first 15 cm, indicates that the subsoil consists almost entirely of pure quartz sand.

3) Organic carbon values around 0.7% represent a very low organic matter content in the A-horizon. Only in a 75-year-old citrus grove were higher values (2.4%) found.

4) The almost total absence of clay minerals and the low humus content are responsible for the very low cation exchange capacity, which in the first 15 cm ranges between 3.5 and 6.8 meq/100 g soil. In the deeper horizons one might as well speak of a cation exchange "incapacity".

5) Normally, the soils are strongly acid. Only in those groves where artificial liming is applied (extractable Ca close to 4.6 meq/100 g) can moderate acid conditions be detected.

6) Over the entire soil profiles, the bulk density values reveal pore spaces between 40 and 45%. In fact, all the soils are characterized by "rapid", or even "very rapid", permeability.

Table 1: Soils of Central Florida Highlands
Böden der zentralen Florida Highlands

Depth (cm)	No. soil sample	Particle size (mm) % Sand 2-.5	.5-.25	.25-.1	Total 2-.05	Silt .05-.002	Clay <.002	Org. C %	Bulk density field moisture	Percol.-rate hydraulic conductivity cm/hr	Extr. bases sum meq/100 g	Cation exch. capacity meq/100 g	ph H_2O	General characteristics of the soil horizons
0 –	1	1.1	24.5	64.5	97.0	1.9	1.1	0.7	1.45	33	0.4	6.0	5.0	Dark gray fine sand; loose; many clean sand grains; many fine and medium roots; strongly acid
15	2	5.5	53.9	35.1	96.3	1.8	1.9	0.6	1.49	93	0.8	3.5	5.7	
15 –	1	0.9	21.3	66.6	97.0	1.6	1.4	0.3	1.51	32	0.1	2.9	5.3	Grayish-brown or brown fine sand; single grain; loose; many fine and medium roots; strongly acid
25	2	5.0	49.7	39.0	96.0	1.1	2.9	0.2	1.59	62	0.1	1.7	5.5	
25 –	1	1.0	22.9	66.4	97.8	1.4	0.8	0.2	1.53	37	tr	0.9	5.4	Yellowish-brown fine sand; single grain; loose; common fine and medium roots; strongly acid
50	2	5.0	49.7	39.0	96.0	1.1	2.9	0.2	1.59	62	0.1	1.7	5.5	
50 –	1	1.0	21.2	68.3	97.8	0.5	1.7	0.1	1.53	43	tr	1.1	5.4	Yellowish-brown fine sand; single grain; loose; common fine and medium roots; strongly acid
100	2	4.6	49.2	40.1	96.3	1.0	2.7	0.1	1.50	92	tr	1.3	5.3	
100 –	1	0.9	19.0	70.6	98.2	0.6	1.2	0	1.55	34	tr	1.6	5.4	Strong or very pale brown fine sand; single grain; loose; strongly acid
200	2	5.0	51.7	37.9	96.6	0.8	2.6	0.1	1.56	75	tr	1.3	5.2	

Location of soil samples: 1 = Hernando County; 2 = Osceola County
Soil association after General Soil Map of Florida: 1 = Candler fine sands; 2 = Astatula sand
Soil classification: 1–2 = Typic quartzispamments
Vegetation or use: 1 = Bluejack, post and live oak, longleaf pine forest; 2 = Various annual weeds on cleared land, previous citrus grove
Source: CALHOUN et al. 1974; CARLISLE et al. 1978

To summarize these findings: the quartzispamments are strongly acidic, of rapid permeability, extremely poor in natural nutrients, and exhibit a very low cation exchange capacity. As favorable properties, convenient bulk density and good pore conditions can be mentioned. These soils provide a fair basis for the rooting of citrus trees, but they contribute almost nothing to their nutrition. The latter must be completely supplied by artificial means which has its difficulties that arise from the low cation exchange capacity and pH values. Since clay minerals are almost lacking a harmful aluminum toxicity does not develop.

The ecological management of citrus growing

Key questions to be addressed in this section are: (1) which nutrients must be supplied to citrus trees to meet their nutritional needs and (2) how can one supply these nutrients to the trees under the dominating pedological and meteorological conditions?

In reference to the first point, citrus trees require fifteen essential chemical elements for satisfactory growth and production. Carbon (C), hydrogen (H) and oxygen (O_2) are furnished by air and water. The other twelve: nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), manganese (Mn), copper (Cu), zinc (Zn), calcium (Ca), sulfur (S), boron (B), iron (Fe) and molybdenum (Mo) come via natural soils or from commercial fertilizers applied by man.

With the spatial displacement of the citrus groves from the St. Johns River area to the sandhills of the central ridge, as a consequence of the freezes of the 1890s, complex nutritional problems became apparent. First, the alluvial soils of the St. Johns River region were much richer in nutrients than the pure sands of the central ridge. Second, with the areal expansion of the citrus groves and the increasing

Table 2: Soils of Central Florida Lowlands
Böden der zentralen Florida Lowlands

Depth (cm)	No. soil sample	Particle size (mm) % Sand 2–.5	.5–.25	.25–.1	Total 2–.05	Silt .05–.002	Clay <.002	Org. C %	Bulk density field moisture	Percol.-rate hydraulic conductivity cm/hr	Extr. bases sum meq/100 g	Cation exch. capacity meq/100 g	ph H_2O	General characteristics of the soil horizons
0 –	3	1.1	23.3	59.3	96.3	2.6	1.0	0.6	1.38	20	0.5	4.6	4.9	Dark gray or black sand; week medium granular; many fine and few medium roots; strongly acid
13	4	11.9	58.9	22.4	96.8	2.5	0.7	0.8	1.63	34	0.1	4.4	4.7	
13 –	3	1.9	23.0	60.0	97.7	1.6	0.7	0.1	1.45	27	0.1	1.4	5.5	Gray or grayish-brown sand; single grain; loose; common fine and medium roots; slightly acid
40	4	12.6	59.0	23.6	99.1	0.8	0.1	0.1	1.55	80	tr	0.3	6.7	
40 –	3	1.9	18.6	49.1	79.2	2.7	18.1	0.1	1.60	9	20.9	23.8	6.6	Yellowish-brown mottles; weak medium subangular blocky; light gray sand; few fine and medium roots; slightly acid to neutral
80	4	11.6	56.6	25.9	98.7	1.0	0.3	0	1.63	74	tr	0.4	7.0	
80 –	3	1.9	18.6	49.1	79.2	2.7	18.1	0.1	1.60	13	20.9	23.8	6.6	
90	4	12.4	57.0	24.3	97.9	1.1	1.0	0.1			tr	0.4	6.5	
90 –	3	1.9	18.6	49.1	79.2	2.7	18.1	0.1	1.60	3	20.9	23.8	6.6	Dark reddish-brown sand; yellowish-brown mottles along old root channels; moderate medium subangular blocky; sand grain coated with clay; few roots; strongly acid
110	4	7.2	38.9	42.2	95.8	2.1	2.1	0.5			1.4	6.2	5.7	
110 –	3	2.0	20.6	56.8	88.0	6.2	5.8	0.2	1.59	4	24.0	25.4	7.6	Lightgray loamy fine sand; pale olive tongues; weak medium subangular blocky
150	4	2.7	25.4	46.6	82.6	1.7	15.7	0.2			5.9	9.8	5.9	
150 –	3	1.2	18.7	42.7	70.3	5.8	23.9	0.1			18.7	20.4	7.8	Pale olive or greenish-gray sandy loam; subangular blocky; slightly acid or neutral
200	4	1.8	19.5	50.1	81.7	2.5	15.8	0.2			6.5	10.5	5.7	

Location of soil samples: 3 and 4 = St. Lucie County
Soil association after General Soil Map of Florida: 3 = Riviera fine sands; 4 = Oldsmar sand, depressional
Soil classification: 3 = Arenic glossaqualfs; 4 = Alfic arenic haplaquods
Vegetation or use: 3 = Slash pine, cabbage palm, wax myrtle, saw palmetto; 4 = St. Johns wort, dwarf arrow grass, low depressed natural areas
Source: Calhoun et al. 1974; Carlisle et al. 1978

demand for fertilizing, there were not sufficient supplies of organic materials available at that time. Thus, the latter had to be replaced by synthetic chemical fertilizers. By the mid 1950s, a large number of commercial fertilizers were developed to meet the needs of artificial nutrition. The macronutrients and some of the micronutrients are applied to the soil, the rest (Zn and Mn, and others) as foliage spray. Since the roots absorb, at most, 60% of the nutrients contained in the soil solution, it is necessary to apply more fertilizer than the amounts that are traceable in the leaves and fruits.

The fertilization program consists of two parts (see Fig. 7): the maintenance procedures, which are applied regulary at specified times of the year, and the deficiency control applications, which are rendered as needed. The maintenance program involves liming and the regular application of nitrogen, potassium, and boron fertilizers. Liming is indespensable when starting new groves since the soils, with pH-values

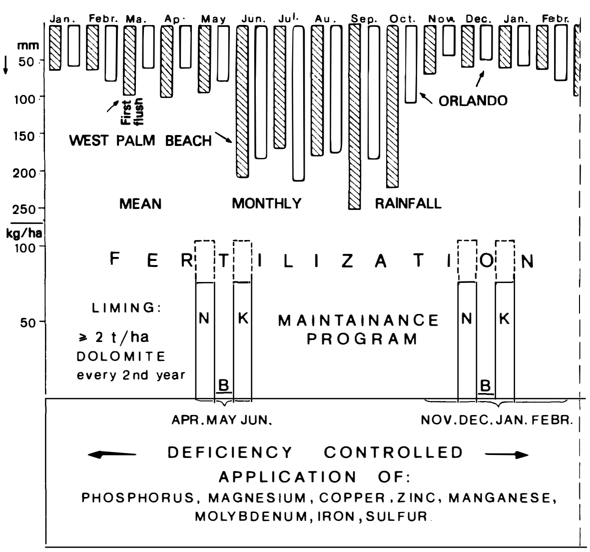

Fig. 7: Florida Citrus Fertilization Program related to mean annual course of precipitation

Düngungsprogramm für Citruskulturen in Zusammenhang mit dem mittleren Jahresgang der Niederschläge

between 4.5 and 5.5, are too acidic and this acidity is further enhanced by the application of N-fertilizers and pesticides. Yearly tests are conducted to establish if liming is necessary. If so, limestone or dolomite granules are added in order to lower the soil acidity o about pH 6. The normal application rate is approximately two metric tons per hectare every two years.

Liming to control the soil-pH apparently provides sufficient Ca. Once, that it was established that magnesium deficient trees were also more vulnerable to cold damage than trees with adequate Mg nutrition (Anderson 1981), the use of dolomitic limestone (a combination of magnesium and calcium carbonates) became a common practice for pH-control. Nevertheless, if Mg deficiency symptoms persist, magnesium sulfate or magnesium oxide should be added to the fertilizer, at a rate not exceeding 30% of the nitrogen rate. Foliage sprays also are effective in correcting Mg deficiency symptoms (Koo et al. 1984).

Experiments conducted by Khomvilae and Blue (1976) showed that, with the supply of both limestone and dolomitic lime, the cation exchange capacity in the upper soil horizons doubles. However, in the Astatula fine sands, a decrease in potassium retention was observed as a consequence of the competition for absorption sites by Ca and, to a lesser extent, by Mg. This side-effect is very undesirable in view of the low cation exchange capacity of these soils.

For some years during the 1960s, liming was questioned by farmers because they suspected it to have an unfavorable influence on the nitrogen balance. But, the relevance of liming for maximum citrus yields has been proven by Anderson (1984) in a long-term project. The soil acidity in a two-year-old block of Valencia oranges on Candler sands was maintained at pH 7 for fifteen years through regular applications of dolomitic limestone, and this resulted in an increase of the net returns by $ 4600 to $ 4800 per acre over a cropping period of eleven years. Eighty percent of the increased fruit yields were explained by differences in tree size, for the trees on limed plots had grown significantly larger than those on the untreated plots before reaching bearing age, an effect which continued as the trees matured. During these fifteen years, however, a total of five tons of dolomitic limestone per acre was required for the treatment.

The maintenance program comprises the application ofnitrogen (N), potassium (K), and boron (B). "Healthy orange trees are usually fertilized at a rate of about 4.44 kg N and 2.93 kg P per ton of fruit per year. Mature bearing grapefruit trees are fertilized with 3.53 kg N and 2.93 kg K per ton of fruit per year. Good fruit yields in Ridge groves are about 35 metric tons of oranges per ha and 50 metric tons of grapefruit per ha." (Anderson 1981). This means, an average fertilization of at least 155 kg N and 102 kg K per ha orange grove, and 175 kg N and 146 kg K per ha grapefruit grove. For the Central Highland groves, agricultural experimental stations recommend yearly nitrogen amounts between 160 and 170 kg per ha for oranges and 160 and 180 kg per ha for grapefruit (Koo et al. 1984). These figures, translated into the most common 33.5% N-fertilizer (ammonium nitrate, NH_4NO_3), mean applications of about 500 kg per hectare, while a little over a ton per hectare must be applied if the fertilizer contains 15% as sodium nitrates, calcium nitrates, or potassium nitrates.

As to potassium, it is recommended to "apply the same quantity of potash (K_2O) as nitrogen up to a maximum of about 250 pounds per acre" (Koo et al. 1984). If use is made of the common 50–60% K_2O commercial fertilizers (potassium nitrate, potassium chloride, or potassium sulfate) applications should range from 320 to 360 kg per hectare a year. Boron-containing fertilizers (in the form of borax or soluble borates) are also necessary as a regular supplement, but a few kg can be mixed with the above mentioned applications.

All other essential nutrients besides the maintenance program must be added when the need for a particular element is evident through incipient deficiency symptoms on fruits or foliage, or when it has been established by means of prophylactic soil or tissue tests.

Phosphorus (P) is usually applied as ammoniated phosphate or as normal or triple superphosphate. The need of a young bearing grove will be met by administering 400–500 kg of 20% superphosphate. However, as phosphorus from fertilizer applications accumulates in the sandy soils of the Florida ridges in a form available to the plants, most older groves no longer need annual phosphorus applications.

Manganese (Mn) and zinc (Zn) are applied through foliage sprays at two-year intervals in order to prevent extensive deficiency symptoms. The standard dosage is approximately 11.2 kg of Zn and 8.5 kg of Mn per hectare, from inorganic sources such as neutralized sulfates (Anderson 1981). Molybdenum sprayings are recommended to correct the specific deficiency commonly known as "yellow spot", while the sulfur (S), applied for mite control more than meets the nutritional needs of citrus trees. Even iron (Fe) must be added to Florida soils. However, iron chelates, which correct iron chlorosis, must be used with great caution since the fine powdery substance may severely burn fruit on which it settles and young trees are damaged by over-dosages.

Copper deficiencies, referred to as "die back", were corrected with copper sulfate or copper oxide before the fungicidal sprays based on Cu-compounds became common usage. Their application is also not free from problems since most of the copper accumulates in the topsoil. If the copper content of the upper 15 cm exceeds 50 ppm the effect is phytotoxic, so that great care must be taken to keep the soil pH-values between 6.5 and 7 (Anderson 1981).

The opinion may be expressed that the rather detailed information about the various deficiency symptoms and the corresponding methods of treatment is too elaborate, but – in our view – this is the only way to give the reader an idea about the intricacies involved in citrus growing. Still, familiarity with these essential facts does not address the core of the problem, namely, how is it possible – under the given soil and weather conditions of Florida – to supply the trees with the nutrients they need?

Because of their total dependency on "artificial feeding", the nutrient management of the citrus groves resembles that of hydroponic systems, where the soil is no more than the rooting base and the medium for transmitting the man-supplied nutrients. The only difference with true hydroponic practices pertains to the water dosage: the citrus groves receive water by sprinkling only in cases of water shortage. Normally, the water budget is regulated by the natural rainfall.

Fig. 6 shows rainfall for Clermont, station located in the central part of Florida. The rain distribution according to amounts and dates stresses the reality that the system consists of randomly scattered showers which make it impossible to predict how much rain, where, and during what period they occur. In this respect, the grower is faced with nature's lottery. 55–60% of the values lie between 0 and 10 mm of precipitation per day and 20–25% between 10 and 30 mm. These values are sporadically mixed with extremes of 70 mm or more per day (the time series show a maximum of 112 mm per day, and 200 mm over three consecutive days).

This is one side of the problem, the other is constituted by the physical properties of the soils and their consequences for water circulation and nutrient retention. Particle size, bulk density, pore space, and hydraulic conductivity (see Tables 1 a. 2) characterize these soils as being "excessively drained" and having "a rapid to very rapid permeability and a slow runoff" (Calhoun et al. 1974; Carlisle et al. 1978). Slow runoff means that the rainwater is mostly infiltrated and that, at the same time, there is little capillary rise after rainfall resulting in few evaporation possibilities.

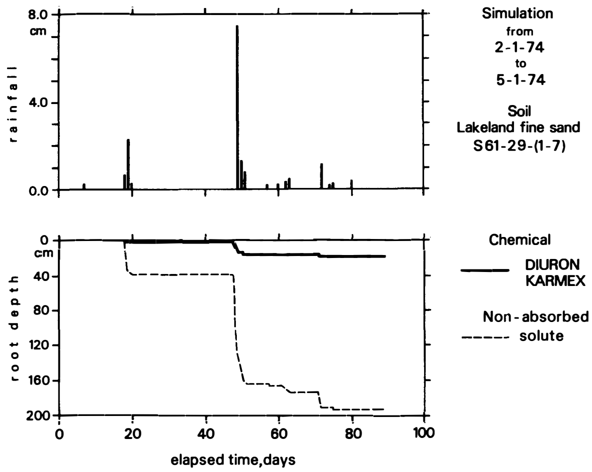

Fig. 8: Percolation of non-absorbed nitrogenated fertilizer as function of rainfall between February 1, 1974 and May 1, 1974 in Astatula fine sands near Clermont (utilizing an analog model of percolation developed by Nofziger a. Hornsby 1985)

Einsickern nicht absorbierter Stickstoff-Kunstdünger in Abhängigkeit von den Regenfällen zwischen dem 1. Februar 1974 und 1. Mai 1974 in Astatula Feinsandböden in der Nähe von Clermont (berechnet mit dem Analog-Modell von Nofziger a. Hornsby 1985)

Most of the rain reaches the deeper soil layers through percolation. As most of the fertilizers consist of water-soluble salts, the nutrients are washed down with the soil solution. Leaching effects, first of all, the negatively charged elements (anions) of the nutrients, especially those of nitrates. In the case of the positively charged elements (cations) which make the bulk of the nutrients, the cation exchange capacity (CEC), under "normal" conditions in most of the outertropical soils, curtails the leaching. However, in the Astatula and Candler fine sands and sands in depths of more than 15 cm the CEC es very low (0.9 to 2.9 meq/100 g soil), and even the upper humic topsoil shows CEC values between 3.5 and 6.8 meq/100 g soil, that is five to ten times lower than in normal agriculturally used topsoils.

Under these circumstances the question arises: What happens if immediately following the application of nitrogen or potassium fertilizers rain falls in normal or even excessive amounts? The response can be given by utilizing an analog model of percolation developed by NOFZIGER and HORNSBY (1985) that permits the calculation of infiltration rates by including variables such as daily precipitation, evapotranspiration, depth of roots, bulk density, and chemical soil properties. Considering values of precipitation for the station of Clermont between February 1, 1974 and May 1, 1974 (the core of the spring season, when strong fertilization is applied) Fig. 8 demonstrates that a nitrogenated fertilizer applied at the beginning of February descends to a depth of 41 cm after the rain of February 20 (23 mm), and plunges to 161 cm after the 88 mm of rain fallen on March 22 and 23, 1974. After the light rain of April 14, 1974, the nitrogenated solution is at 200 cm, i. e., beyond the reach of the deepest roots. In sum, a full application can be easily lost by rapid percolation in poor sandy soils if abnormal rain occurs shortly after the application.

The above mentioned facts make it necessary for the citrus trees to have deep reaching root systems. Thus, most quality oranges and grapefruit trees are grafted on strong and well-devoloped stocks of rough lemon. These rootstocks have their largest concentration of absorbing roots between 30 and 180 cm, and in the deep sandy soils, with lower concentration, they usually reach down to 300 cm (see Fig. 9). Since fertilization with nitrogen and potassium is conducted during the winter months (December to February) (Fig. 7), the soil solution moves slowly from 0 to 200 cm during normal years. This practice helps secure adequate nutrition during the growth period that precedes the spring flush and blooming (usually in March). After a mild and rainy winter, however, budding may start earlier. Fortunately, incidences of a late frost at that time are very infrequent. However,

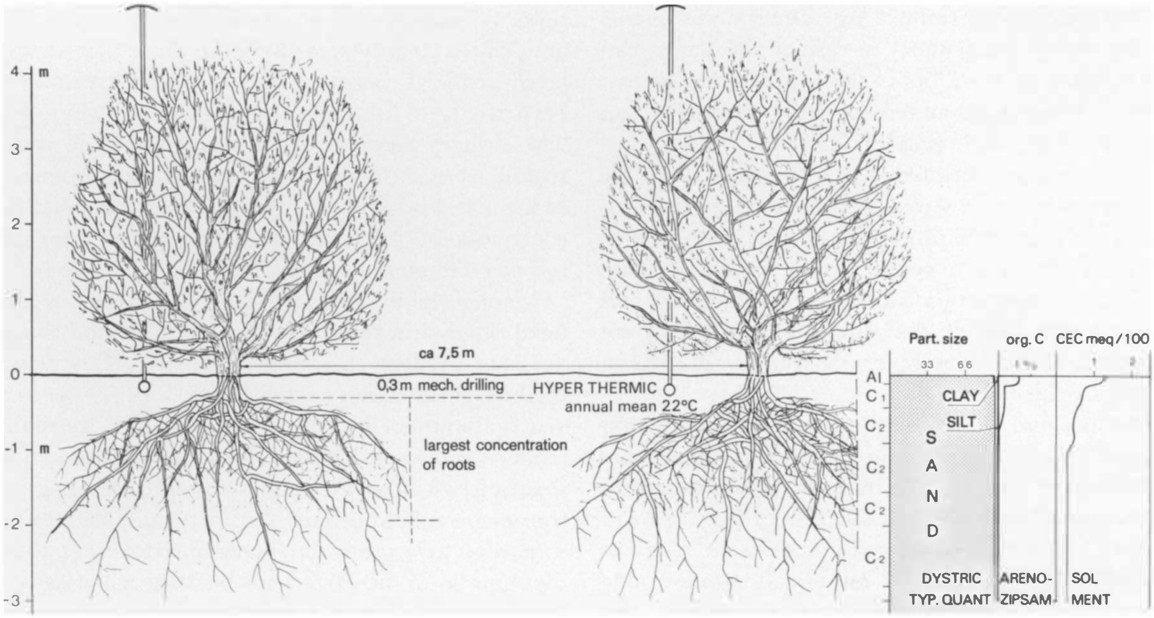

Fig. 9: Growing conditions of citrus groves on the sand hills of the Central Highlands
Anlage der Citruskulturen auf den Sandhügeln Zentralfloridas

when they occur, even if only slight, the consequences are grave, because the so-called "feather growth" (recent sprouts) is particularly vulnerable. Further, there exists the danger that in the case of unusually heavy spring rains - such as those of 1974 - percolation down to a depth of 200 cm takes place within three weeks. If that happens, and if fertilization was applied too early, the trees will suffer from nutritional deficiency during their main growth period. The growers are, of course, aware of this hazard, and with the help of private rain gauges and by drawing from years of personal experience, they usually manage very well. On a few occasions it is necessary to repeat fertilization, a situation which may not result in a financial disaster if the crop turns out well.

The second application of fertilizers in a normal maintenance program (Fig. 7) is due several weeks before the onset of the tropic-like summer rains of May or June. By then the fertilizer applied in early winter has been used by the trees or has been leached out and the plants are in dire need of nutrients for the early summer flush and for fruit development. More than ever, applications during that time of year are subject to the hazards of sudden heavy showers. Particularly prone to losses are the accessory nutrients and the micronutrients which, due to their low rates of application, will be leached out before the root system has had time to absorb them.

As can be gathered from these considerations, nutrient management is not totally under human control. The sequence and amount of water input into the system is determined by atmospheric events whose effects, particularly in case of deficiency, can be corrected by man, but in the case of water excess, man is a helpless bystander who, only afterwards, can try to salvage whatever is left.

Citrus groves work like a percolating hydroponic system in which the percolation rates are, in general, still quite high and prone to random decreases or increases. Based on experience or on methodical data analysis, human action can add to this dynamic and almost unpredictable flow the nutrients which are supposed to be brought to the plants' absorbing organs by this flow.

It is because of the mentioned uncertainties that man's first aim is the elimination of the controllable complicating factors. One of those factors is natural secondary growth. Weeds and spontaneous growth under the trees, considered undesirable nutrient competitors and hosts of an equally undesirable fauna, from insects to snakes, are eradicated with herbicides. Well-kept Highland citrus groves stand on bare sand. The resulting diminution of the humus content of the topsoil is irrelevant since the root system of the trees absorbs nutrients from the deeper layers anyway. Considering the large amounts of fertilizers applied, the frequent treatments with pesticides and fungicides, and the transportation of bulky and heavy fruit crops, the groves must be able to accomodate large agricultural machines. Therefore, a distance of 7 m from one tree to another is considered normal (see Fig. 9). To control size and shape of the trees, many of the older groves are periodically pruned with mechanical equipment. The sides of the trees are trimmed to maintain the width of the lanes, and about every third year the tree tops are cut down to reduce harvesting cost, improve spray coverage against disease and pests, and to increase fruit size and quality (Anderson 1981).

Flatwood groves

The ecological and managerial considerations about the highland groves detailed in the foregoing section also apply to the flatwood groves, since climate and weather conditions are roughly similar, and so are the lowland soils, especially those on the artificially created ridges (Table 2). The natural lowland soils are as poor in nutrients and as low in cation exchange capacity as the highland soils. They may have a somewhat higher content of salt and organic matter in the upper 13 cm of the top layers, and below 40 cm they evince an illuvial horizon. But these differences are immaterial, since the citrus trees are planted 80 to 100 cm above the watertable on low-level, artificial ridges consisting of the dirt that has been dredged from the drainage canals (Fig. 10). These ridges vary in width to accomodate one or two rows of trees. Ecologically important is the proximity of the water table in the canals. This means that the rootstocks of the citrus and grapefruit trees are restricted to no more than 100 to 120 cm of depth.

Managerial implications of growing trees on artificial ridges are: (1) the trees in the Flatwood groves are kept smaller, their tops are more slender, and their height does not exceed 2.5 to 3 m; (2) the total yearly amount of fertilizers required within the maintenance program is applied in four increments (instead of two as in the highlands) to counteract the shorter percolation time. The yields per hectare are somewhat lower, but the financial returns are about the same as in the Highlands because of the usually better quality of the Flatwood citrus.

The closeness to the water table of cultures that are treated with an array of chemical products poses an

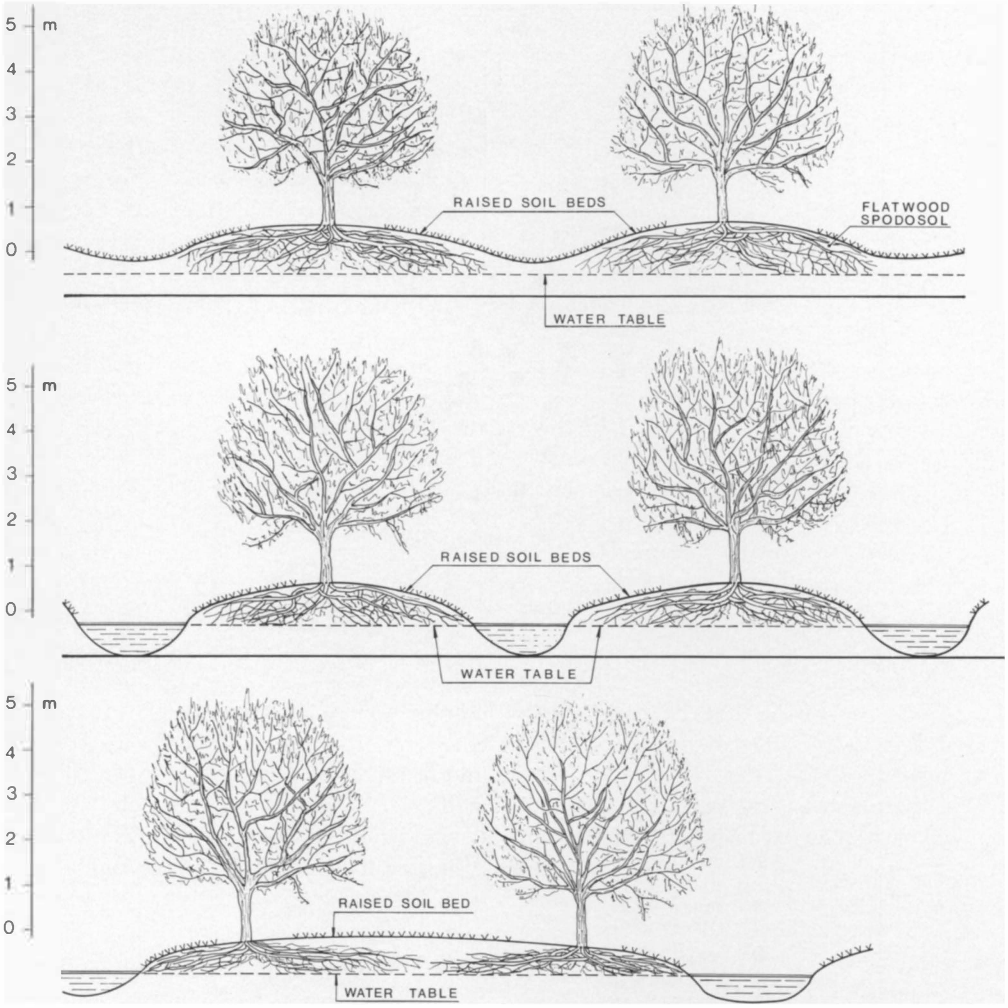

Fig. 10: Growing conditions of citrus groves in the Flatwood Region
Anlage der Citruskulturen in der grundwassernahen Flatwood Region Floridas

environmental threat, namely chemical contamination of the ground water. This is especially precarious because the Flatwood groves lie in the hinterland of the densely populated sea resorts of the east Florida coast. In the Highlands citrus groves, contamination has not yet been recognized as a problem, because in the most productive years environmental protection was not a main issue and, also, because it is hoped that the enormous thickness of the sand cover (several tens to 100 m) will filter and trap the chemicals before they reach the water table. In the Flatwoods the contamination danger is imminent and population awareness of this hazard is high. Consequently, resistance to the further expansion of citrus groves is to be expected, especially because the sea-side resorts are dependent on the water reserves from the hinterland.

Nature's latest intervention

Recently, this sophisticated artificially-managed production system was harshly confronted with its natural delimitations. During the catastrophic freezes of December 1983 and January 1985, 40% of the citrus groves in Florida were destroyed (oral report from C. ANDERSON). This was the worst disaster ever to strike Florida's citrus industry. The boundary of the damage stretched much further than ever before. While the groves south of a line from Ormond Beach to Inverness had not been affected by the major freezes of 1894, 1895, and 1899 (in northern Marion County, small outlier-groves were still cultivated close to Orange Lake up to 1983), the January freeze of 1985 extended much further south: almost 90 km

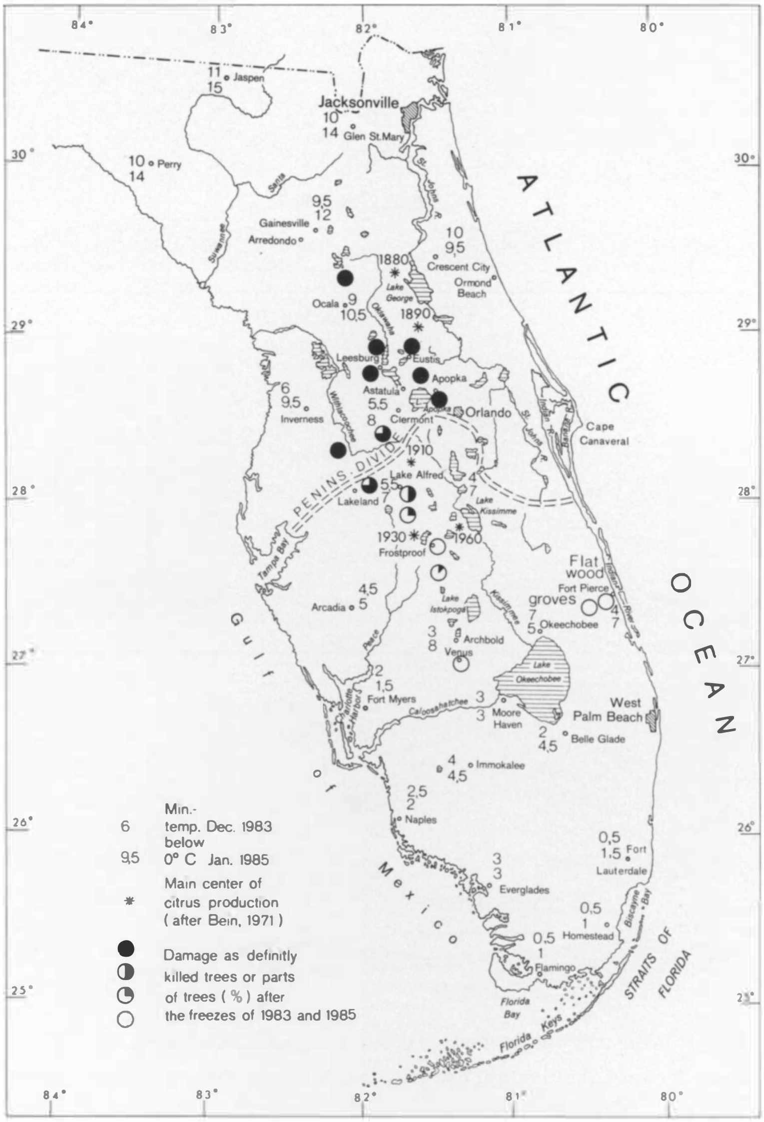

Fig. 11: Distribution of absolute minimum temperatures during the killing frosts of December 1983 and January 1985, grades of damage after the two frost events and main centers of citrus production since 1880

Absolute Minimum-Temperaturen während der Schadfröste vom Dezember 1983 und Januar 1985, regionale Differenzierung der Schäden in den Citrus-Kulturen und Hauptzentren des Citrusanbaus seit 1880

further in the west, 50 km further in the central Highlands, and 40 km further in the east. The frost damages map shows the extent of the total and partial losses as surveyed in the field in March-April 1985 (Fig. 11). During a subsequent survey conducted in October of the same year, observations were made on the recovery of the citrus trees by checking on the state and number of new buds, the intensity of bark destruction, and the general condition of the trees. These observations were particularly detailed in a transitional zone between Clermont and Lakeland. The term "transitional" in this context means that the groves located north of Clermont suffered total and irreversible frost damage, while the groves south of Lakeland remained without lasting damages[1].

[1] For special reference to the freezes see CAVIEDES and WEISCHET in Verhandlungen des Deutschen Geographentages München 1987 (in preparation).

Perspectives for future developments

North of the line that delineates the area of total damage, the citrus industry will probably cease. In October 1985, the formerly densely cultivated areas offered a picture of desolation: weeds had started to sprout around dead trees, some of which had been cut and were being offered as firewood. "For Sale" signs lined the roadside north of Clermont. In many places the only indicators of former cultivation were the irrigation devices that were still left.

The financial resources needed for starting new groves have been exhausted in the course of the past years' poor harvests and many of the citrus growers have become insolvent. They are trying to sell their land and houses and find jobs elsewhere. The alternative of switching to different agricultural crops is limited because of the inefficiency of shallow root systems in the extremely poor and permeable sandy soils and because of the competition faced from less expensively produced crops. A transformation into retirement communities and mobile home parks - modalities that are very popular in Florida - is hampered by a general land offer surplus and by the existence of poor infrastructures in some rural areas far from the main transportation arteries. Only a few locations sport enough facilities to be considered prime land for future dwelling development.

The larger citrus companies are probably considering the moving of their holdings into the eastern and western flatwood regions, a trend which seems to be confirmed by new grove developments in the relatively frost-free Manatee, Hardee, and De Soto counties. Only these companies have the financial strength to carry out the necessary drainage works, plant the new groves, and, then, maintain them for another 8 to 10 years before the first yields will render actual profits.

However, in the case of expanding plantations in the flatwoods there are severe ecological problems that will have to be solved, namely the effects of such fertilizer-intensive cultures on the water table which, in those areas, is vital to the survival of the densely-populated coastal strips.

Gloomy as these perspectives may seem, some citrus growers recognize benefits in the effect of the 1983 and 1985 freezes: These events brought to light many deficiencies in citrus cultivation in the central Florida Highlands. Most of the groves in that area have been in production since the 1950s, others even since the late 1920s when land usage was rather uneconomical: 70 trees per acre, where they now could hold as many as 150 trees.

Moreover, little innovation was tried with cold-hardy varieties (Florida Agriculture, February 1, 1985, p. 13). Rootstocks cultivars that have proven to be cold-hardy such as the trifoliate orange, sour orange, and Cleopatra orange, were not preferred in the Central Highlands because of a choice of the cold tender "rough lemon" that assured vigorous growth and productive trees (WILTBANK 1985).

Despite the alleviated effects that the introduction of cold hardy cultivars will bring to the battered citrus industry of the Florida Ridge, one development appears to be irreversible: the northern boundary of the former active citrus groves, which used to run from the central part of Marion county into the northern section of Lake and Volusia counties (roughly 27.5 °N), has now moved to the southern sections of Lake and Orange counties, at latitude 26 °N. A shift of such magnitude in the active zone of citrus cultivation has not occurred since the devastating freezes of 1895 and 1899, when citrus groves from the lower Saint Johns River were abandoned forever.

Acknowledgment

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ÖKOLOGISCHE BEWERTUNG UND BEWERTUNG DES LANDNUTZUNGSPOTENTIALS NACH NATURRÄUMLICHEN EINHEITEN IN DER TRANSECTA BOTÁNICA DE LA PATAGONIA AUSTRAL

Mit 4 Abbildungen (Beilage VIII), 3 Tabellen und 8 Photos

PAUL SEIBERT

Summary: Ecological evaluation and evaluation of land-use potential within landscape units of the Transecta Botanica de la Patagonia Austral

This paper is concerned with studies of vegetation geography and landscape evaluation. These were done as part of an international botanical research project, covering a transect between the 51st and 52nd degrees of latitude from the Atlantic to the Pacific Oceans. Based on an vegetation map (scale 1:250 000), a geographical division of the vegetation into vegetation districts (Vegetationsbezirke) and growth districts (Wuchsdistrikte) was established following SCHMITHÜSEN's scheme (1959/68). This was compared with the deductive divisions of other authors (CABRERA 1976, HUECK u. SEIBERT 1972/81).

The ecological evaluation and evaluation of land-use potential (synoptic suitability evaluation) follows methods published by the author (SEIBERT 1975, 1979, 1980). The evaluation was done on the growth districts taking account of the recent vegetation and the former natural vegetation. The ecological suitability value, the forestry value and the pasture land value were each ascertained. The comparison of the values shows where, and to what degree, they have changed under human influence. These changes are demonstrated in charts which show that in the west of the cordillera and in the island and channel area with high rainfall no changes have taken place. In the east of the cordillera range, where pastoral use with cattle grazing occurs, the ecological and forestry values have largely decreased. In the drier areas of the eastern transecta part, where only sheep grazing is possible, forestry and pastoral land-use values have also decreased.

1. *Die Transecta Botánica de la Patagonia Austral (TBPA) – Entstehung und landeskundliche Einführung*

Der Ursprung der Transecta geht auf das Jahr 1958 zurück, in dem eine Gruppe von Engländern, Chilenen und Neuseeländern zum Gedächtnis an das