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[8]Author(s) Mr. Henry K. Gee Mr. Edwin T. Murabayashi Dr. Reginald H.F. Young	[9]Grant Agency Hawaii State General Fund
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[12]Abstract (Purpose, method, results, conclusions)

A preliminary investigation was undertaken to determine the effectiveness of using treated municipal wastewater for irrigation and nutrient stripping by three agricultural crops. Alfalfa and guinea grass were chosen because local production could reduce the large amounts of alfalfa cubes and hay imported for the dairy and cattle industry. Papaya was selected because it is a developing export crop with an established marketing infrastructure. Health hazards were not a factor in this study. Forage crops are consumed by animals before reaching the human food chain. Papayas are harvested 5 to 10 ft above the ground (where drip irrigation lines were located), with no direct contact by the irrigated wastewater. Alfalfa produced 16.6 tons/acre/yr dry wt or 85 tons/acre/yr wet wt; guinea grass yielded 21.0 tons/acre/yr dry wt or 126 tons/acre/yr wet wt. Guinea grass contained 1.5 times more water than alfalfa, and although dry wt production was higher, its crude protein content was lower, amounting to 1.96 tons/acre/yr compared with 3.49 tons/acre/yr for alfalfa. Both forage crops stripped N from the effluent but guinea grass was more efficient than alfalfa. Nitrate levels of the guinea grass percolate were below the drinking water limit of 10 mg/ℓ as NO_3-N after the first harvest, while alfalfa gradually increased its stripping ability and exceeded the limit after the fifth harvest. Difficulty was encountered in obtaining a viable crop of papaya. Of the transplanted seedlings, only 25% survived and became established. Thus, female papaya plants were not culled and fruit production rate was measured for all the plants. Extrapolation of the total yield of 122,000 lb/acre/yr, of which 30% was marketable, indicated papaya production amounted to 36,000 lb/acre/yr which is comparable to commercial production in Kapoho, Hawai'i.

2540 Dole Street • Honolulu, Hawaii 96822 • U.S.A. • (808) 948-7847

AUTHORS:

Mr. Henry K. Gee
Research Associate
Water Resources Research Center
University of Hawaii at Manoa
2540 Dole Street
Honolulu, Hawaii 96822
(808) 948-8008

Mr. Edwin T. Murabayashi
Research Associate
Water Resources Research Center
University of Hawaii at Manoa
2540 Dole Street
Honolulu, Hawaii 96822
(808) 948-8008

Dr. Reginald H.F. Young
Associate Dean, College of Engineering
and Professor of Civil Engineering
University of Hawaii at Manoa
2540 Dole Street
Honolulu, Hawaii 96822
(808) 948-7886

$4.00/copy

Mail to: University of Hawaii at Manoa
Water Resources Research Center
2540 Dole St.
Honolulu, Hawaii 96822

Tel.: (808) 948-7847 or -7848

WASTEWATER IRRIGATION FOR ALFALFA, GUINEA GRASS, AND PAPAYA PRODUCTION IN HAWAI'I

Henry K. Gee
Edwin T. Murabayashi
Reginald H.F. Young

Technical Report No. 170

September 1985

Project Completion Report
for
Wastewater Reuse in Irrigation of Alfalfa,
Guinea Grass, and Papaya

Project No. S-011

Principal Investigator: Reginald H.F. Young

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WATER RESOURCES RESEARCH CENTER
University of Hawaii at Manoa
Honolulu, Hawaii 96822

ABSTRACT

A preliminary investigation was undertaken to determine the effectiveness of using treated municipal wastewater for irrigation and nutrient stripping by three agricultural crops. Alfalfa and guinea grass were chosen because local production could reduce the large amounts of alfalfa cubes and hay imported for the dairy and cattle industry. Papaya was selected because it is a developing export crop with an established marketing infrastructure.

Health hazards were not a factor in this study. Forage crops are consumed by animals before reaching the human food chain. Papayas are harvested 5 to 10 ft above the ground (where drip irrigation lines were located), with no direct contact by the irrigated wastewater.

Alfalfa produced 16.6 tons/acre/yr dry wt or 85 tons/acre/yr wet wt; guinea grass yielded 21.0 tons/acre/yr dry wt or 126 tons/acre/yr wet wt. Guinea grass contained 1.5 times more water than alfalfa, and although dry wt production was higher, its crude protein content was lower, amounting to 1.96 tons/acre/yr compared with 3.49 tons/acre/yr for alfalfa.

Both forage crops stripped N from the effluent but guinea grass was more efficient than alfalfa. Nitrate levels of the guinea grass percolate were below the drinking water limit of 10 mg/ℓ as NO_3-N after the first harvest, while alfalfa gradually increased its stripping ability and exceeded the limit after the fifth harvest.

Difficulty was encountered in obtaining a viable crop of papaya. Of the transplanted seedlings, only 25% survived and became established. Thus, female papaya plants were not culled and fruit production rate was measured for all the plants. Extrapolation of the total yield of 122,000 lb/acre/yr, of which 30% was marketable, indicated papaya production amounted to 36,000 lb/acre/yr which is comparable to commercial production in Kapoho, Hawai'i.

CONTENTS

Figures

Tables

INTRODUCTION

A small-scale integrated preliminary investigation was undertaken to determine the effectiveness of using treated municipal wastewater to irrigate alfalfa (Medicago sativa), guinea grass (Panicum maximum), and papaya (Carica papaya), and to determine these crops' nutrient stripping qualities.

In large continental areas such as the mainland U.S., fresh surface water is typically reused many times between its initial appropriation at the source to eventual entry into the sea. Municipalities adjacent to surface water sources draw water as needed, cleanse it for use, collect it after use, cleanse it again, and dispose the treated discharge back into the stream. This continues until the flow reaches the ocean. In contrast, stream reaches in Hawai'i are so short that municipal water is just used once, then disposed into the ocean. If the once-used water could be reused for irrigation, its utility would be greatly enhanced. This reuse also reduces the drain on potable water resources which are presently used for irrigation.

Municipal wastewater irrigation reuse is a common and accepted practice on golf courses in Hawai'i. But in the agricultural sector where the results of production enter the human food chain, great caution has been exercised because harmful organisms, viruses, and heavy metals contained in sanitary sewage can be recycled through such reuse. Much work has been done nationwide as well as locally to ascertain the safety of irrigating with treated wastewaters (Crane and Moore 1984; Bitton and Gerba 1984; Young and Burbank 1973). In Hawai'i, Lau et al. (1972, 1974, 1975) studied the effectiveness of irrigating sugarcane with treated sewage effluent. Their work showed that with slight modification from standard cultural practices, wastewater can be successfully used in commercial sugar agronomy.

Sugarcane is a good candidate for sewage effluent irrigation because the cane is processed before the sugar is consumed by man. This is in contrast to direct consumption, such as vegetables eaten raw or only partially cooked, which would be poor choices for such irrigation. Forage crops, such as alfalfa and guinea grass selected for this study, are also good candidates since they only indirectly enter man's food chain. Papaya, although eaten raw, is also a good candidate since the fruits are borne high above the ground, thus reducing the possibility of direct contact with irrigation wastewater (presupposing no sprinkler irrigation) as compared to crops grown close to the ground. Aerosol contamination is possible but was not investigated in this study. Alfalfa, guinea grass, and papaya were specifically selected for their attributes and characteristics which make them potentially viable and useful crops as well as being well suited to effluent irrigation.

As mentioned above, sugarcane, Hawai'i's major agricultural crop ($23 million in sales as of 1982 [DPED 1983]), is a good candidate for effluent irrigation. In recent years, however, its long-term viability has increasingly shown signs of vulnerability due to low sugar prices, smaller profit margins, and lower yields, due partly to drought conditions.* Thus, as the economic viability of sugarcane becomes more tenuous, the state needs to reexamine the potential of other crops as land is withdrawn from growing sugarcane. However, it should be made clear at the outset that while alfalfa, guinea grass, and papaya are possible alternative crops, none of these can utilize the large acreage presently in sugarcane. No single crop, or combination of crops, are available today to match or replace sugarcane in acreage and economic return.

Alfalfa was selected for this experiment because a large amount of alfalfa cubes and hay (33,192 tons in 1983 values at $6.3 million) is imported for the dairy and cattle industry (Hawaii Agricultural Reporting Service 1983). It has been recognized for some time that if local production could supplant these imports, outgoing monies could be retained for use within the state. Numerous attempts have been made in Hawai'i over the years to grow alfalfa on a commercial scale with some limited success. The cultural difficulties involved in such production have been discussed by Goodell and Plucknett (1972). A positive change today is the availability of varieties better suited to tropical environments than were available during that earlier study.

Besides alfalfa, there is a continuing need for fresh green feed, commonly called "green chop" because it is cut in the field and fed as is to animals. Pineapple green chop filled this need until its discontinuance

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*<u>The Honolulu Advertiser</u>, 30 Aug. 1984, p. A-1; 31 Aug. 1984, p. A-1; 31 Aug. 1984, p. A-10.

after heptachlor, an insecticide which had been applied to the plants, was found in fresh milk.

Guinea grass, which is grown locally as a pasture grass in drier areas, is thought to be a good replacement for pineapple green chop as well as have export potential as hay.* It is well adapted and grows wild and aggressively in dry to moderately wet areas at low (warm) elevations. When allowed to grow uninhibited, it will reach 7 to 8 ft (2.1-2.4 m). But at that height its nutrient value is minimal, consisting mainly of cellulose. As with virtually all grasses, feed value is highest at a young stage when the protein percentage is higher and there are relatively more green leaves as opposed to coarser, less nutritious stems as the grass matures. This means more frequent harvesting at a younger stage as opposed to growing taller stands which would yield more tonnage per harvest. The strategy of judicious timing of harvest balances the higher quality and lower tonnage of young growth with the lower quality and higher tonnage of greater maturity to attain optimum quality and tonnage.

Under natural rainfall conditions, guinea grass grows mainly during the wetter winter months, becoming dormant as rainfall wanes during the summer. Thus, irrigation would not only extend the growing season, but also greatly increase yields during the long days of summer when solar insolation is highest. Although moisture is plentiful during the winter, yield is actually reduced during this period because of a combination of shorter day length (less solar radiation) and flowering of the grass which greatly reduces foliar growth by diverting energy to seed production.

Alfalfa, a legume, is the preferred forage because of its high protein content, but it is relatively difficult to grow in Hawai'i. On the other hand, guinea grass grows aggressively with no care but, being a grass, is lower in protein even when harvested at a young stage. Alfalfa and guinea grass fit into different niches of the feed ration scheme by virtue of their differing nutritional composition. At the same time, however, both are competitors for the same feed dollar in that the rancher would like to obtain maximum feed value for money spent. In the case of forage, protein content is one of the major criteria of feed value. The dilemma is in balancing the high quality, lower tonnage, and more difficult culture of

*W.W. McCall 1985: personal communication.

alfalfa against the lower quality, higher tonnage, and ease of culture of guinea grass.

Papaya was selected for testing because it is a developing export crop with an established and ongoing marketing infrastructure which is a major advantage in export commodities. With irrigation, the plant is well adapted to the warm climate, high sunlight, and well-drained soils of many areas presently in sugarcane. The key is good drainage because papaya grows very well in wet areas as long as the drainage is satisfactory.

Aside from irrigation, wastewater applied in excess of evapotranspiration can be used to recharge the groundwater aquifer if it can be cleansed to an acceptable level. The initial cleansing steps begin in the wastewater treatment plant wherein the primary treatment process mechanically removes settleable suspended solids and the biological secondary treatment extracts dissolved solids and nonsettled suspended solids. Tertiary treatment, also a biological process, is used to polish off the cleansing process, mainly by removing nitrogen and phosphorus. Most treatment plants in Hawai'i do not attain tertiary treatment levels, but all effluent discharged on land is chlorinated before leaving the treatment plant.

Additional cleansing takes place in the plant-soil regime where the treated effluent is applied in irrigation. A wide variety of soluble plant nutrients, such as nitrogen, phosphorus, potassium, and sulfur, is discharged in sewage effluent and their recovery through crop intake is a bonus as well as an important part of water cleansing.

Nutrients are further removed from a particular environment by harvesting the crop, whereas if the growth were allowed to remain in place, the nutrients absorbed by the plant would accumulate and, on decomposition, would leach into groundwater. Therefore, crop harvesting enhances water quality and is an essential part of the cleansing process. Thus, in using wastewater for irrigation three tasks occur simultaneously: (1) water is provided for crop needs, (2) nutrients are recycled through crop production, and (3) water is cleansed for groundwater recharge.

In addition to the removal of nutrients through plant uptake, the soil itself is capable of tying up other chemical elements. For example, because of their mineralogic composition, most of the highly weathered soils in Hawai'i can immobilize large amounts of phosphorus, an element frequently found in wastewater. The soil can also remove bacteria and viruses from the percolate under certain conditions (Gerba and Bitton 1984).

Domestic sewage is preferred for irrigation and recharge because it is cleaner and less likely to contain undesirable heavy metals, such as mercury, lead, chromium, or other contaminants that come from industrial wastewater. The Mililani Wastewater Treatment Plant secondary-treated sewage used for this project is almost entirely of domestic origin. There are few industrial and commercial discharges into the Mililani sewer system.

The intent of this project was to obtain as much data as possible to determine whether this preliminary effort shows promise for further development.

EXPERIMENTAL PLOTS

Five experimental plots were located at the Mililani Wastewater Treatment Plant (MWWTP) from which secondary-treated sewage was readily available. The growth plots were placed nearby the final effluent chlorination tank and discharge box. The MWWTP main recirculation pumps, operated 24 hr/day for sewage effluent, were used to provide pumping pressure for the irrigation reuse project.

Two plots each of alfalfa and guinea grass were arranged diagonally opposite each other in a square layout (Fig. 1). The plots were separated by sheets of polyethylene plastic and by an earth berm to prevent lateral flow of the irrigation water. The fifth plot contained papaya plants located next to the guinea grass plot (G-2) and arranged in rows spaced 7 ft (2.13 m) apart, with 6 ft (1.83 m) between plants.

The Lahaina soil (Tropeptic Haplustox [Oxisol]; clayey, kaolinitic, isohyperthermic) at the site is characteristic of the central plain of O'ahu. At an elevation of 480 ft (146 m), the normal average rainfall at Mililani is 40 in./yr (1 016 mm/yr).

Seed Bed Preparation

The plots were graded and tilled to a depth of 3 ft (0.91 m) by using a D-8 tractor. Trenches for the installation of the plastic sheeting and Porvic (PVC) tubes for water sampling were dug using a back-hoe. Plastic

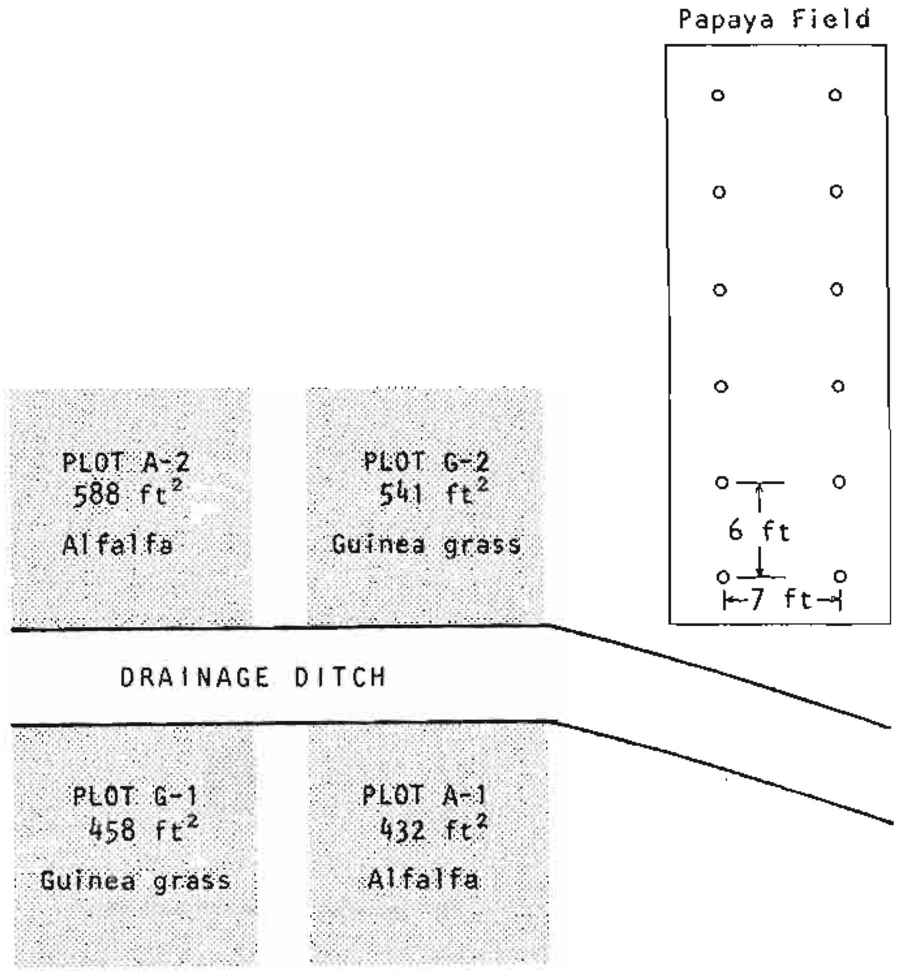

Figure 1. Schematic layout of alfalfa, guinea grass, and papaya experimental plots at Mililani, O'ahu

sheets were extended down to a depth of 3 ft to separate the alfalfa and guinea grass plots and prevent lateral movement of water during flood irrigation periods. Final grading and berm installation were accomplished with a "Bobcat" which could easily maneuver in the small space. The Bobcat was also used to bore 1.5 to 2 ft (0.46-0.61 m) deep by 1 ft (0.3 m) diameter holes for the papaya seedlings. The final preparation was rototilling to a depth of 1 ft using a front-tine tiller and pick and shovel, finishing with a rear-tine tiller.

To reduce the competition of weeds with the alfalfa, the two alfalfa plots (A-1, A-2) were fumigated with Dowfume* (98% methyl bromide and 2% chloropicrin) to kill any ungerminated weed seeds, insects, nematodes, and

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*Farm Chemicals Handbook (Meister Publishing 1981).

fungi which may have been in the soil. These plots were allowed to aerate for five days before seeding.

Alfalfa seeds treated with <u>Rhizobium</u> sp. were sowed by hand at an application rate of approximately 25 seeds/ft², using sand as a diluent. Guinea grass was transplanted from a nearby standing crop (using one stem with roots) into rows 18 in. (0.46 mm) apart with 1 ft between plants. The plots for guinea grass were not rototilled and were left rough.

Irrigation

The forage crops were initially sprinkler irrigated with sewage and fresh water to establish a firm stand before using a flood irrigation system. A month after the alfalfa plants had been established, all plots were flood (border) irrigated using a network feed system of 0.5 in. (12.7 mm) polyethylene tubes as laterals connected to 1 in. (25.4 mm) PVC submains. Sewage was obtained from the MWWTP main pumps through a 4-in. (101.6-mm) pipe that feeds a 2 in. (50.8 mm) PVC main line.

The one papaya and four forage plots were irrigated twice weekly on Tuesday and Thursday by an automatic timer operating a solenoid valve controlling the flow of sewage. The length of each watering cycle was set for one hour and the flow rates were adjusted by ball valves installed on the 1-in. submains leading to each plot. Total volumetric flows were recorded weekly from 1-in. water meters attached in front of the ball valves.

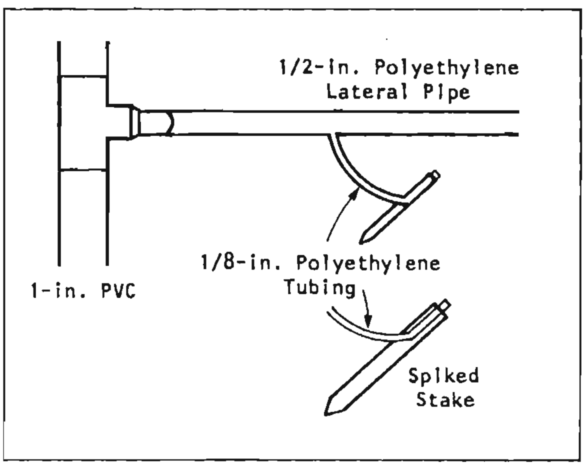

Figure 2. Irrigation system for papaya

The papaya seedlings were irrigated with fresh water and sewage using a garden hose, and later drip-irrigated using 1/8 in. (3.18 mm) polyethylene tubes with 0.06-in. (1.52-mm) emitters. The tubes were fed from 0.5 in. (12.7 mm) polyethylene pipe laterals connected to a 1 in. PVC submain (Fig. 2).

ANALYTICAL METHODS AND SAMPLING AND HARVESTING TECHNIQUES

Porous PVC tubes 1½ in. (38.1 mm) in diameter for water sampling were buried below the planting surface at an approximate depth of 3 ft (1 m). Teflon suction tubes (¼ in. [6.35 mm]) were attached and extended to the surface to provide a vacuum source to withdraw the percolate. A PVC pipe, 1½-in. in diameter, was perforated with 1/8 in. diameter holes spaced 1½ in. apart. These holes were then covered with a layer of PVC window screen and a sheet of grade "M" Porvic membrane (Sedgley and Millington 1957) was wrapped over the screen around the tube and cemented in place with PVC cement. Use of these drainage tensiometers was described by Ekern (1967). Tests for nitrate and nitrite nitrogen, total Kjeldahl nitrogen, and total phosphorus were according to Standard Methods (APHA, AWWA, and WPCF 1980) and the Methods for Chemical Analysis of Water and Wastes (EPA 1976).

An X-ray quantometer was used to analyze plant tissues for selected elements. Crude protein was calculated by multiplying the amount of ammoniacal nitrogen by 6.25 since protein is 16% nitrogen. The amount of ammoniacal nitrogen was calculated as the difference between the total nitrogen and the nitrate nitrogen.

To approximate the nutritional value of the harvested forage as a feed, proximate analyses were performed by the Agricultural Diagnostic Service Center of the University of Hawaii at Manoa, Cooperative Extension Service, Feed and Forage Analysis Program.

The alfalfa crop was hand-harvested using a commercial 22 in. (0.56 m) hedge trimmer, and the guinea grass using a gas-powered weed cutter to which a weed cutting blade was attached. The alfalfa was cut leaving approximately 1 to 2 in. (25.4-50.8 mm) of plant stem, while the guinea grass was cut leaving 3 in. (76.2 mm) of stem. After harvesting, the plants were immediately irrigated to reduce water stress.

CROP CHARACTERISTICS

Guinea grass (Panicum maximum) is a perennial "weed" from Africa that grows 3 to 7 ft (0.91-2.13 m) high. The 10 to 30 in. (254-762 mm) leaves grow erect and are covered with stiff hairs at the base. Propagation of guinea grass is by seed from the flowering heads which are 8 to 20 in. (203–508 mm) long and by underground stems or stolons (tussocks). This grass is found at low elevations in areas of low rainfall along roadsides and in cultivated areas. When planted as forage in a pasture, guinea grass has a crude protein content of 10 to 11%.

Alfalfa (Medicago sativa L.), the most common legume used as a pasture grass for cattle fodder (hay or silage) in temperate climates, has the highest water requirement of any forage crop. Propagation of alfalfa is by direct seeding. The recommended rate for an optimum stand in Hawai'i is 200 lb/acre (0.02 kg/m^2) of seed or 100 seeds/ft^2 (Goodell and Plucknett 1972).

Papaya (Carica papaya) has hollow, single stems crowned with large palmate leaves. The melon-like fruit varies greatly in size and shape for different varieties. The commercial solo variety, used in this experiment, produces two types of trees: the female and the continuously fertile hermaphrodite. Female trees produce round fruits and in commercial production are always cut and removed, even though the fruits produced taste the same as those from the more desirable hermaphrodite tree. Fruits produced by the hermaphrodite tree are long and cylindrical, ovoid or pyriform- (pear-) shaped, and are preferred by growers and consumers. These trees produce fruit year round; however, with seasonal changes a shift occurs in the type of flowers produced and deeply furrowed, pumpkin-shaped fruits or distorted fruits result. These fruits, carpellodic in shape, are produced from January to April. Seasonal changes in fruit types are related to temperature and excess water application.

ALFALFA PRODUCTION

Some die-off occurred in the two plots of alfalfa planted by hand seeding because irrigation by an oscillating sprinkler may have caused droplets to beat down the germinated seedlings. Any residual herbicide from previous land use can be ruled out as a cause of die-off because initial germination was good. Plots A-1 and A-2 had respective die-offs of 36.4 and 16.2% of the seeded area.

Questions on the necessity of nitrogen application to alfalfa crops have often been raised. Generally, applied nitrogen has reduced nitrogen fixation in legumes (Bezdicek, Mulford, and Magee 1974) and, where plants are heavily nodulated and producing nitrogen fixation, application of nitrogen produces only minor gains in dry matter and protein production (Lee and Smith 1972). Nuttall (1976) reported that under heavy irrigation with low soil-moisture tension, alfalfa is succulent, with low protein content, and that additional nitrogen application does not economically increase the forage quality.

The first crop of alfalfa was harvested 71 days after seeding and contained 10 to 20% flower blooms. Alfalfa generally does not flower well under low elevation, Hawai'i conditions; thus, the crop maturity cannot be judged by the amount of bloom. Fifteen "mature" alfalfa crops were harvested between December 1982 and August 1984. One immature crop (2 wk growth period) was harvested in July 1983 when installation of a new pipe line through the experimental plots was imminent. During the construction of a new sewer line, one of the guinea grass plots (G-1) was completely destroyed and a section of the alfalfa plot (A-2) was dug up leaving 39% of the original area planted.

The average wet-weight yield of the fifteen mature cuttings of alfalfa was 8.5 tons/acre (1.90 kg/m^2), with a moisture content of 82.8% and a crude protein content of 20.7% on a dry matter basis. Although the two "immature" crops harvested in July produced a low yield of 4.31 tons/acre (0.97 kg/m^2) with a high moisture content of 87.2%, the crude protein on a dry-matter basis (DMB) was the highest (26.4%) of all the harvested crops. In comparison, experimental trials for ten different alfalfa varieties at low elevation on irrigated fields at Kekaha, Kaua'i produced green matter yields ranging from 2.8 to 4.4 tons/acre/cutting (0.63-1.0 kg/m^2) or an average of 3.7 tons/acre (0.83 kg/m^2) (Britten and Wallis 1964). Yields of 45 to 50 tons/acre/yr (10.09-11.21 kg/m^2/yr) of fresh-cut forage from ten cuttings in the year planted were reported by Goodell and Plucknett (1972). The two experimental plots at Mililani averaged 90.4 tons/acre/yr (20.26 kg/m^2/yr) under various irrigation regimes, ranging from 1.70 to 11.10 acre-in./wk (174.68 to 1 140.53 m^3/wk) of sewage effluent application.

Dry matter (DM) yield for two harvests of alfalfa grown with municipal wastewater in Canada averaged 4.27 tons DM/acre or 2.14 tons DM/acre/

harvest (Bole and Bell 1978). At Mililani 15.55 tons/acre/yr of dry matter was produced for eleven harvests or 1.41 tons DM/acre/harvest (0.32 kg DM/ m^2/harvest). Variety effects may account for the difference in yield production.

The yield of alfalfa for each plot and growth period for Mililani is summarized in Table 1.

Since no actual sunlight data were taken at the Mililani site during the course of the experiment, global radiation data taken in Honolulu was extrapolated to Mililani. Correlations between the Honolulu station and stations OS 260 and 541, located in central O'ahu, were respectively 0.864 and 0.812 for r^2 (Ekern and Yoshihara 1977). Mililani is located between the two stations OS 260 and 541, and the correlation from Honolulu to Mililani would have a value of $r^2 = 0.81$ to 0.86.

Water and Nutrient Budget Estimates

A water budget for the alfalfa crops was determined by estimating evapotranspiration, using available global radiation data recorded for Mānoa. Using the net radiation equal to two-thirds of the global radiation and the energy equivalent for the evaporation of one inch of water as equal to 1500 cal/cm^2 of net radiation, the evapotranspiration rates could be approximated (Ekern 1965; Larcher 1980). The amount of water percolated would be equal to the difference of the applied effluent and the estimated evapotranspiration.

Water quality analyses of the applied sewage and percolate for total Kjeldahl nitrogen, nitrate nitrogen (NO_3^--N), and orthophosphate phosphorus (Table 2), together with the water budget and forage analyses provided a nitrogen and phosphorus balance (Table 3). The average nitrogen balance for the A-1 and A-2 alfalfa test plots was -541 lb/acre/yr (-0.06 kg/m^2/ yr). This large deficit indicated that some form of nitrogen fixation was taking place since the soil could not likely provide the large amount of nitrogen required. Of the total amount of sewage applied to the alfalfa, 49% of the nitrogen was lost by percolation. Uptake of the net applied nitrogen is shown in Figure 3.

The total nitrogen in the harvested alfalfa crop ranged from 22 to 159 lb/acre/mo (2.46×10^{-3} to 1.78×10^{-2} kg/m^2/mo) with an average of

TABLE 1. ALFALFA GROWTH PERIOD AND YIELD FROM EXPERIMENTAL PLOTS

Harvest Date	Growth Period (days)	Sewage Applied (acre-in./wk)	Fresh Weight	Dry Weight	Plot Area (ft^2)
			—(lb/acre/day)—		
29 March 1983	71*	5.18	218	44	275
	71†	3.95	244	43	493
03 May 1983	35	5.41	663	114	275
	35	4.40	597	125	493
27 May 1983	24	5.87	838	125	275
	24	4.30	731	111	493
17 June 1983	21	4.62	1003	148	275
	21	3.90	791	114	493
01 July 1983	14	5.57	667	86	275
	14	3.52	564	71	493
09 August 1983	39	2.96	349	74	275
05 August 1983	35	1.70	117	26	299
08 September 1983	30	4.09	567	101	275
	34	3.32	524	86	299
20 October 1983	42	4.85	503	90	275
	42	4.72	676	111	299
22 November 1983	33	3.26	439	72	275
	33	3.41	501	76	299
29 December 1983	37	flooded	349	69	275
	37	flooded	384	57	299
01 February 1984	34	3.20	508	66	275
	34	2.86	450	61	299
14 March 1984	42	4.08	357	73	275
	42	4.26	386	78	299
11 April 1984	28	9.50	506	104	275
	28	11.10	445	84	299
16 May 1984	35	9.04	450	103	275
	35	10.21	464	101	299
20 June 1984	35	7.59	527	107	275
	35	8.72	496	97	209
20 July 1984	30	8.10	265	59	214
	30	10.65	275	63	79
Mean	34.4		495	84.9	

*A-1 plot.
†A-2 plot.

TABLE 2. PERCOLATE AND SEWAGE QUALITY

1983	Sample	PO_4 (mg/ℓ)	TKN (mg/ℓ)	NO_3^--N (mg/ℓ)	TN (mg/ℓ)	NO_3^--N % of TN
07 June	Sewage	4.37	20.6	6.6	27.2	24.3
	A-1	0.12	0.3	18.0	18.3	98.3
	A-2	0.15	1.1	19.4	20.5	94.6
	G-1	0.08	0.8	12.2	13.0	93.8
	G-2	0.12	0.6	7.5	8.1	92.6
21 June	Sewage	5.72	10.6	5.3	15.9	37.1
	A-1	0.09	0.3	16.5	16.8	98.2
	A-2	0.05	0.9	15.8	16.7	94.6
	G-1	0.12	0.8	2.8	3.6	77.8
	G-2	0.10	0.7	1.2	1.9	63.2
05 July	Sewage	5.02	12.6	3.9	16.5	23.6
	A-1	0.17	0.8	13.2	14.0	94.3
	A-2	0.06	1.5	12.7	14.2	89.4
	G-1	0.13	1.1	1.2	2.3	52.2
	G-2	0.12	0.9	1.4	2.3	60.9
09 August	Sewage	4.84	18.1	2.6	20.7	12.6
	A-1	0.04	0.6	7.2	7.8	92.3
	G-2	0.08	0.8	1.1	1.9	57.9
04 October	Sewage	4.30	16.4	4.0	20.4	19.6
	A-1	0.03	0.4	5.8	6.2	93.5
	G-2	0.03	0.3	1.5	1.8	83.3
Mean	Sewage	4.85	15.7	4.5	20.1	22.4
	A-1	0.09	0.5	12.1	12.6	96.0
	A-2	0.09	1.2	16.0	17.2	89.3
	G-1	0.11	0.9	5.4	6.3	76.6
	G-2	0.09	0.7	2.5	3.2	59.8

TABLE 3. WATER AND NUTRIENT BALANCES FOR ALFALFA PLOTS

DATE	DAYS	GLOBAL RADIATION (cal/cm²)	IRRIGATION	ESTIMATED ET	ESTIMATED Perc.	APPLIED N	APPLIED P	PERCOLATE N	PERCOLATE P	HARVESTED N	HARVESTED P	N Balance	P Balance	APPLIED Net N	APPLIED Net P	DRY MATTER (tons/acre/yr)
			(acre-in.)			(lb/acre/yr)										
PLOT A1																
03/05/83	35	589.5	27.05	9.17	17.88	1284	310	604	4	1305	96	-625	210	680	306	20.8
27/05/83	24	518.7	20.13	5.54	14.59	1393	343	719	5	1518	127	-844	211	674	339	22.8
17/06/83	21	573.1	13.86	5.35	8.51	1089	308	479	3	1927	151	-1310	154	617	305	27.0
01/07/83	14	563.5	11.14	3.51	7.63	1313	319	645	4	1363	120	-687	195	676	315	15.7
09/08/83	39	541.3	16.49	9.39	7.10	689	167	215	1	800	68	-313	98	487	166	13.5
08/09/83	30	552.9	17.53	7.38	10.15	964	235	400	3	1272	108	-702	125	570	232	18.4
20/10/83	42	492.6	29.10	9.20	19.90	1143	278	560	4	1046	91	-455	183	591	274	16.4
22/11/83	33	373.6	15.37	5.48	9.89	768	186	354	2	981	87	-561	97	420	184	13.1
29/12/83	37	326.4	636.93	5.37	631.56	28400	6907	20186	127	797	63	—	—	—	—	12.6
01/02/84	34	341.8	15.54	5.17	10.37	754	183	361	2	1003	85	-605	96	398	181	12.1
14/03/84	42	451.2	24.48	8.43	16.05	962	234	452	3	853	72	-337	159	516	231	13.4
11/04/84	28	496.6	38.00	6.18	31.82	2239	544	1344	8	1280	117	-370	419	910	536	18.9
16/05/84	35	538.4	45.20	8.38	36.82	2131	517	1244	8	1140	99	-239	410	901	509	18.9
PLOT A2																
03/05/83	35	589.5	22.00	9.17	12.83	1037	252	434	3	1244	103	-634	146	610	250	19.0
27/05/83	24	518.7	14.74	5.54	9.20	1013	251	453	3	1464	121	-897	127	567	248	20.2
17/06/83	21	573.1	11.70	5.35	6.35	919	261	358	2	1490	125	-923	134	567	259	20.8
01/07/83	14	563.5	7.04	3.51	3.53	830	202	298	2	1175	92	-638	108	537	200	12.9
09/08/83	35	542.1	8.50	8.44	0.06	401	60	2	0	273	22	+128	38	401	60	4.7
08/09/83	34	550.6	16.12	8.32	7.80	782	190	271	2	1126	92	-610	96	516	188	15.7
20/10/83	42	492.6	28.32	9.20	19.12	1505	270	538	3	1336	122	-754	145	582	267	20.2
22/11/83	33	373.6	16.08	5.48	10.60	804	195	380	2	983	103	-554	90	429	193	13.9
29/12/83	37	326.4	568.74	5.37	563.37	25360	6166	18007	113	690	60	—	5363	—	6053	10.4
01/02/84	34	341.8	13.89	5.17	8.72	674	164	303	2	860	80	-485	82	375	162	11.0
14/03/84	42	451.2	25.56	8.43	17.13	1004	244	482	3	937	88	-408	235	529	241	14.2
11/04/84	28	496.6	44.40	6.18	38.22	2616	635	1614	10	1044	98	-25	527	1019	625	15.2
16/05/84	35	538.4	51.05	8.38	42.67	2406	584	1442	9	1109	111	-129	464	980	575	18.4

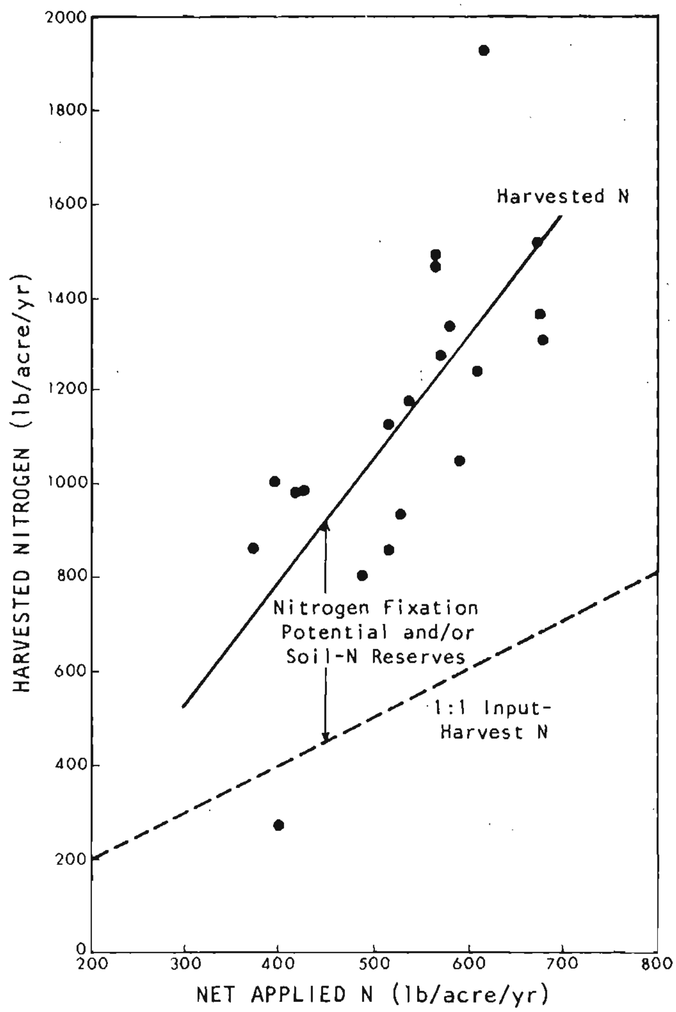

Figure 3. Harvested nitrogen as function of net applied N for alfalfa

92 lb/acre/mo (1.03×10^{-2} kg/m²/mo). Low nitrogen uptake (< 0.01 kg/m²/mo) occurred during the winter months when the day length was less than 12.0 hr and also when the plants received minimum irrigation and were stressed (2.3 in./wk [58.42 mm/wk] in August). The tabulated values of nitrogen uptake for each harvested crop are shown in Table 4. Variations of nitrogen uptake with hours of day length are shown in Figure 4. The linear regression curve takes the form,

$$N = -0.0177 + 0.00236T$$

$$r^2 = 0.76,$$

where N is nitrogen uptake (kg/m²/mo), T is day length (hr), and r^2 is the

TABLE 4. CALCULATED NITROGEN UPTAKE FROM TISSUE ANALYSIS OF ALFALFA

HARVEST NO.	NITROGEN UPTAKE A-1 ($kg/m^2/mo \times 10^{-2}$)	NITROGEN UPTAKE A-2 ($kg/m^2/mo \times 10^{-2}$)	DAY LENGTH (hr)	GLOBAL RADIATION (cal/cm^2)
2	1.20	1.15	12.51	589.5
3	1.40	1.35	13.00	518.7
4	1.78	1.37	13.24	573.1
5	1.26	1.08	13.30	563.5
6	0.74	0.25	13.13	541.7
7	1.17	1.04	12.60	551.8
8	0.96	1.20	11.87	492.6
9	0.90	0.91	11.17	373.6
10	0.73	0.64	10.77	326.4
11	0.92	0.79	10.85	341.8
12	0.79	0.86	11.45	451.2
13	1.18	1.12	12.15	496.6
14	1.05	1.12	12.74	538.4

NOTE: Mean value of N uptake = 92 lb/acre/mo (1.03^{-2} $kg/m^2/mo$).

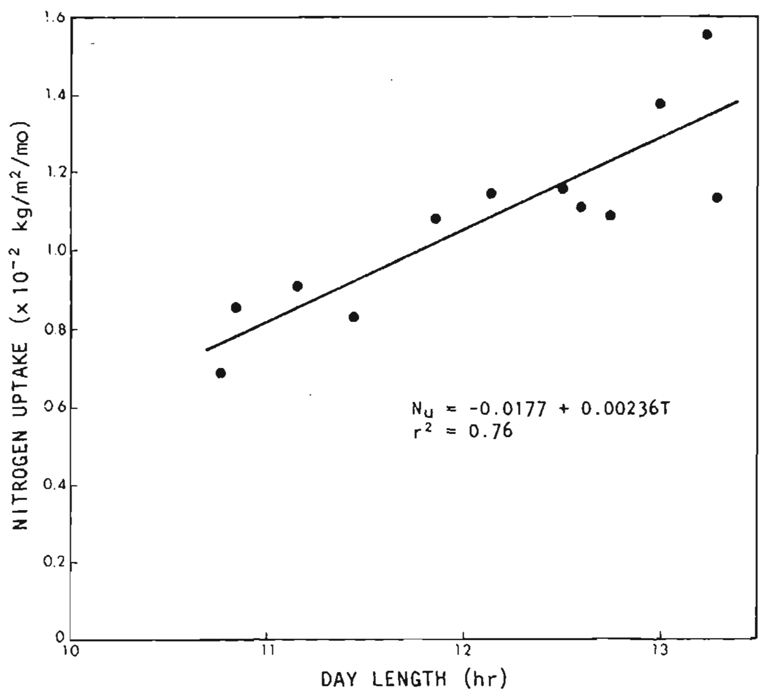

Figure 4. Uptake of nitrogen in alfalfa as function of day-length hours

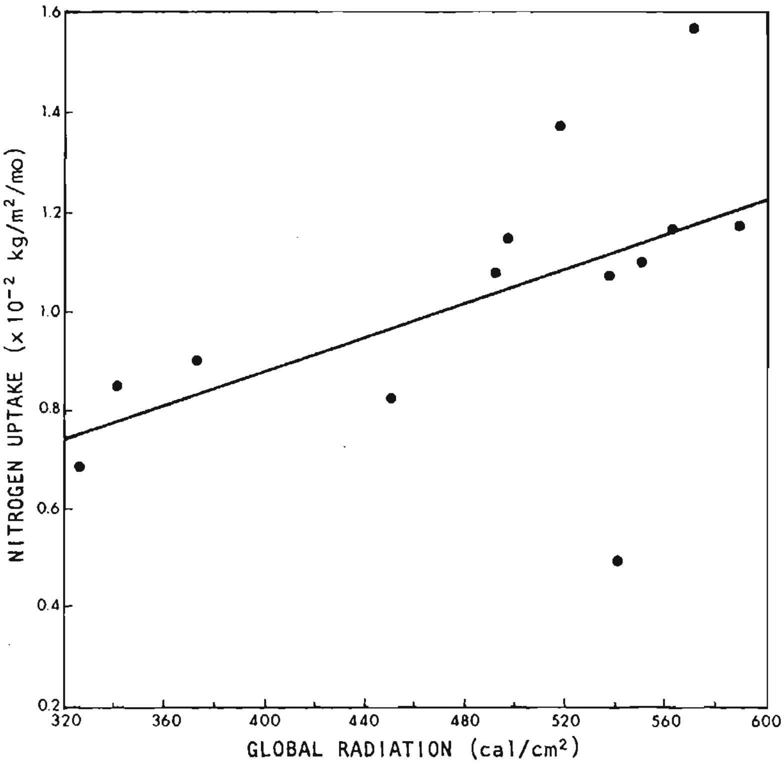

Figure 5. Uptake of nitrogen in alfalfa as function of global radiation

coefficient of determination.

A corresponding plot of nitrogen uptake vs. global radiation is shown in Figure 5. An increase of 100 cal/cm^2 global radiation resulted in 17.25 kg/ha/mo nitrogen uptake.

Most of the applied phosphorus is either taken up by the alfalfa or by adsorption by the soil particles, and very little is percolated into the groundwater. An average of 98% of the applied phosphorus was removed by the soil and the crop.

Alfalfa is a heavy user of potassium. The mean concentration of K found in the tissues of the two plots was 3.1% dry matter basis (DMB) which meant 10.5 lb (4.8 kg) of K would be removed per ton of harvested wet forage. The amount of K uptake by the plants is shown in Figure 6 for an 11½-mo period. The uptake increases in succeeding harvests after the addition of KCl and then decreases to an equilibrium level.

The depletion of available iron by alfalfa is a logarithmic function as shown in the plot of iron in the plant tissue as a function of time

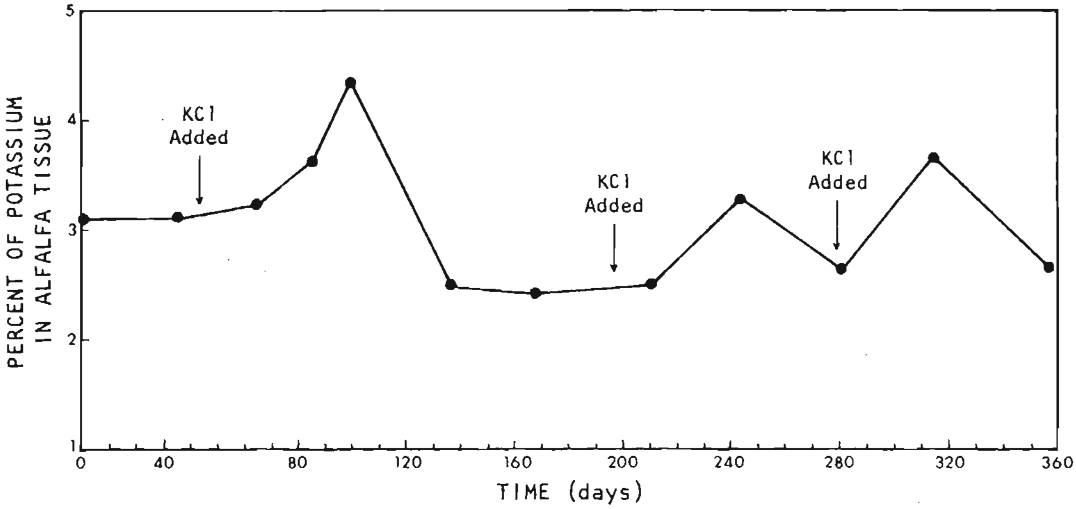

Figure 6. Tissue uptake of potassium in alfalfa as function of time

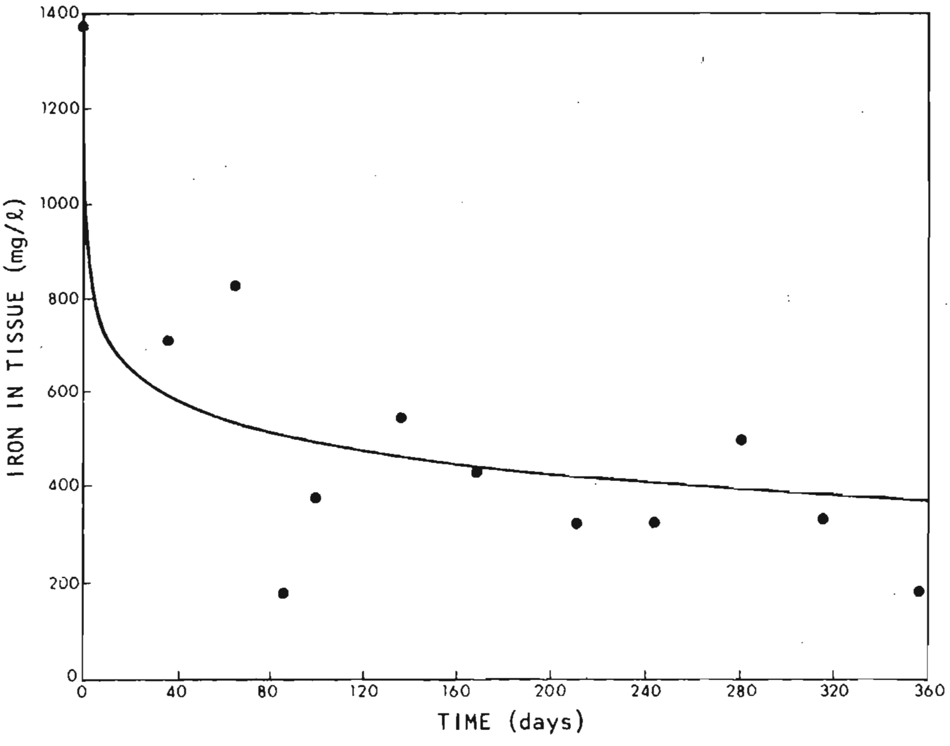

Figure 7. Tissue uptake of iron in alfalfa as function of time

(Fig. 7). The regression curve equation is $Fe = 933.9 - 95.69 \log_e D$ with a coefficient of determination, r^2, equal to 0.75 (Fe = ppm iron; D = days). Most of the iron in the soil exists in the ferric state and is unavailable for plant usage. The availability of iron is closely associated with soil manganese. Wahiawa soils have about 25% total Fe but iron deficiency in pineapple occurred because of the high Mn content of 3%. The manganese is being reduced at the expense of iron oxidation: $Fe^{++} + Mn^{+++} \rightarrow Fe^{+++} + Mn^{++}$ (Johnson 1924). Studies by Asghar and Kanehiro (1981) indicated that the addition of fertilizer Fe in high-Mn soils provided no benefit to Fe deficiency in pineapples and may, in fact, aggravate the balance by bringing more Mn into solution. Iron deficiency in alfalfa can be ameliorated by supplying Fe as a foliar spray, such as the present industry practice for pineapples.

Figure 8 shows the amounts of manganese found in the plant tissue of harvested alfalfa over an 11½-mo period. Essentially, no decreasing trend occurs, indicating sufficient manganese was available for crop utilization.

One of the main concerns with continuous irrigation with wastewater effluent is the accumulation of non-protein nitrogen as nitrates, in the plant tissue. Toxic symptoms may result in animals fed nitrate at levels greater than or equal to 0.44% dry weight (Prewitt 1975). Tissue analysis of the alfalfa crops showed nitrate nitrogen levels ranging from 0.074 to 0.197%, which is below the tolerable limit. Nitrate levels for the first seven harvests are shown in Table 5.

The amount of dry matter produced is dependent on the length of time allowed for growth. Immature crops of alfalfa may contain a very high

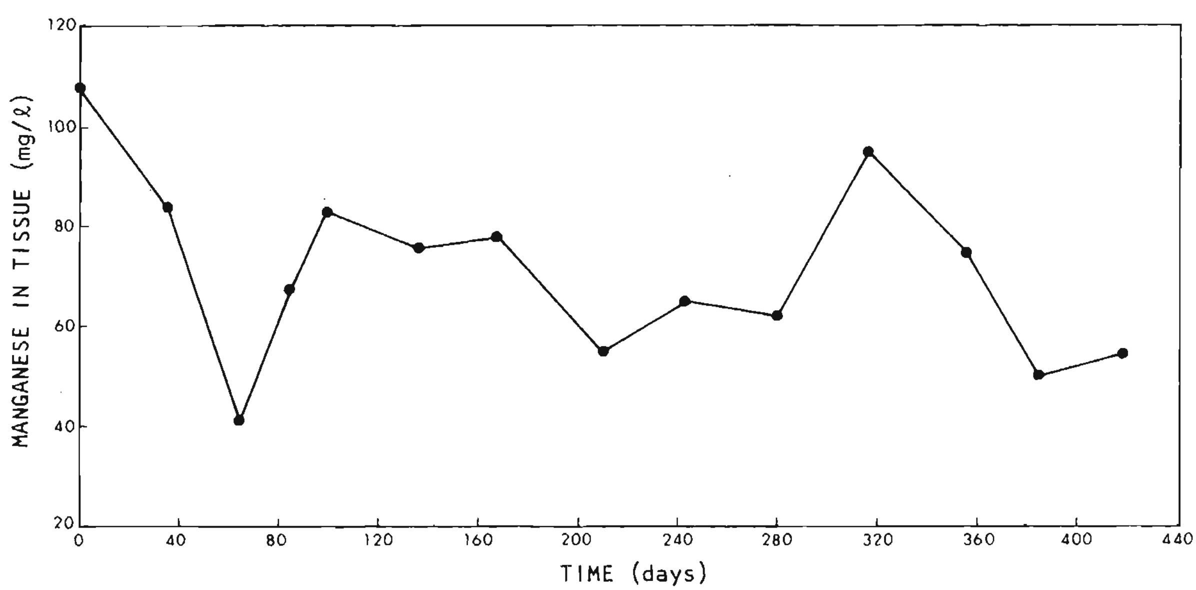

Figure 8. Tissue uptake of manganese in alfalfa as function of time

TABLE 5. NITRATE NITROGEN CONTENT OF ALFALFA ON DRY WEIGHT BASIS

Harvest No.	Plot No.	% NO_3^--N
1	A-1	0.0759
	A-2	0.0741
2	A-1	0.1010
	A-2	0.1970
3	A-1	0.1680
	A-2	0.1050
4	A-1	0.1750
	A-2	0.1320
5	A-1	0.1690
	A-2	0.1480
6	A-1	0.1160
	A-2	0.0927
7	A-1	0.1110
	A-2	0.1180

NOTE: A-1 mean value = 0.1273%,
A-2 mean value = 0.1170%.

percentage of protein, but the total dry matter produced is relatively low, whereas an over-mature crop may produce large quantities of dry matter but very stemmy plants low in protein.

The average harvesting period cited in the literature is 33 days and may be as low as 28 days during the summer months and as long as 40 days in the winter (Goodell and Plucknett 1972). For the experimental plots in this study, the harvesting periods ranged from 14 to 42 days. For equal irrigation rates, the relationship between growth interval and dry matter yield is shown in Figure 9. Regression analysis showed that the line of best fit is exponential with an equation of $DM = -2.88 + 1.34 \ln GP$, where GP is the growth period in days and DM is the dry matter yield in tons/ acre. The coefficient of determination, r^2, is 0.95.

As the amount of dry matter increases, the protein content of the plant decreases. The plant becomes woody with an increase of cellulose and lignin. The relationship between percent dry matter (DM) and percent crude protein (CP) is shown in Figure 10. The resulting equation of the curve

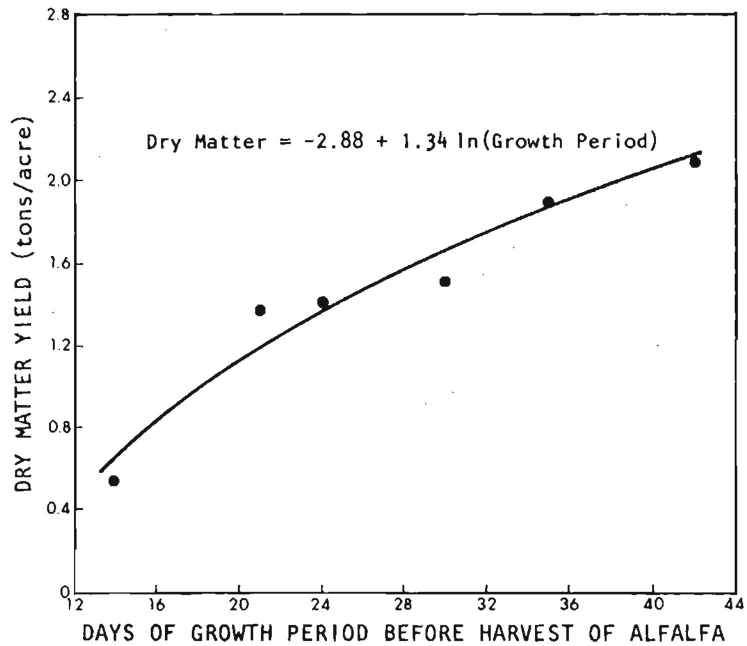

Figure 9. Dry matter yield as function of days of growth for alfalfa

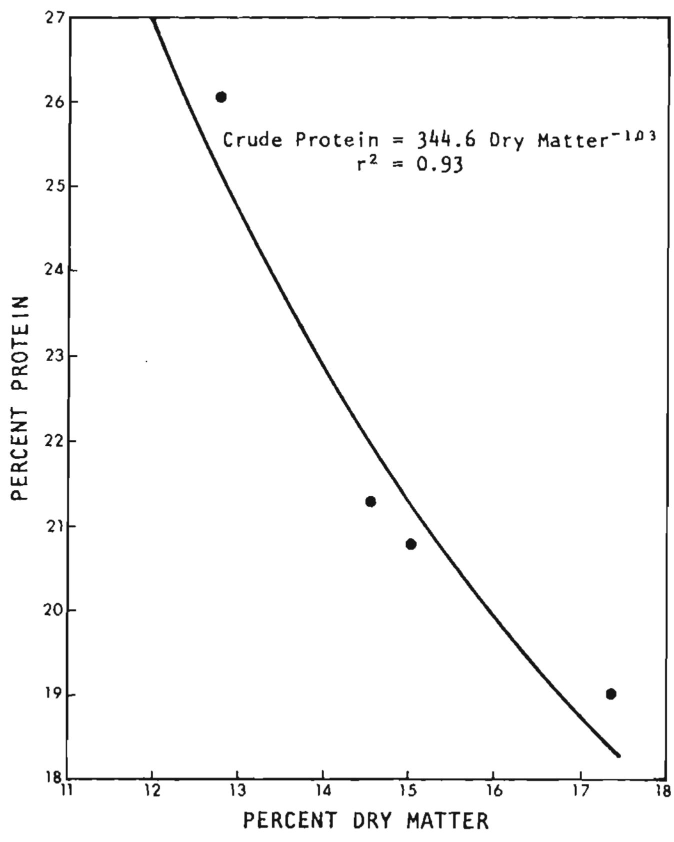

Figure 10. Percent protein as function of percent dry matter in alfalfa

$CP = 344.6\ DM^{-1.03}$ with a coefficient of determination, r^2, of 0.93.

Effect of Environmental Conditions on Crop Yield

DAY LENGTH. The alfalfa plots were grown during mean day lengths ranging from 10.85 hr (29 Dec. 1983-1 Feb. 1984) to 13.24 hr (27 May-17 June 1983). An increase of 2.24 hr/day in the day length from an initial 11.0 hr caused an increase in weight production of 1.30 tons/acre (0.29 kg/m²) or an increase of 16.35%. Similarly, the dry matter increased 18.5% in total production. Thus, an increase of 1.0 hr/day in the day length would result in a wet-weight production increase of 0.59 ton/acre (0.13 kg/m²). These curves are shown in Figure 11 along with the regression curve equations.

As the day length increased, the length of the growing period and the amount of sunlight available increased. The amount of dry matter produced is dependent on the total calories of radiation available for leaf photosynthesis. Figure 12 shows the relationship between dry matter yield and global radiation.

IRRIGATION RATES. The effects of irrigation have been studied for the

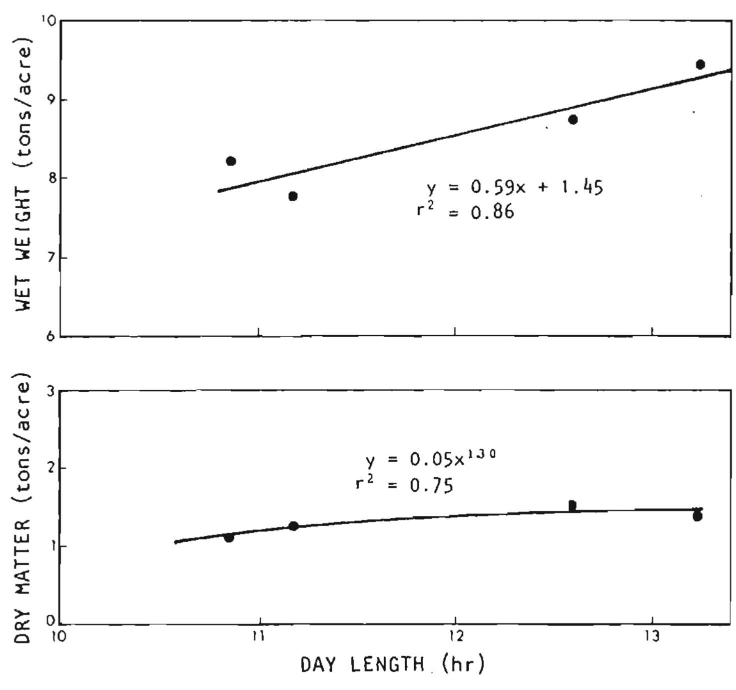

Figure 11. Mean wet weight and dry matter as function of day-length hours

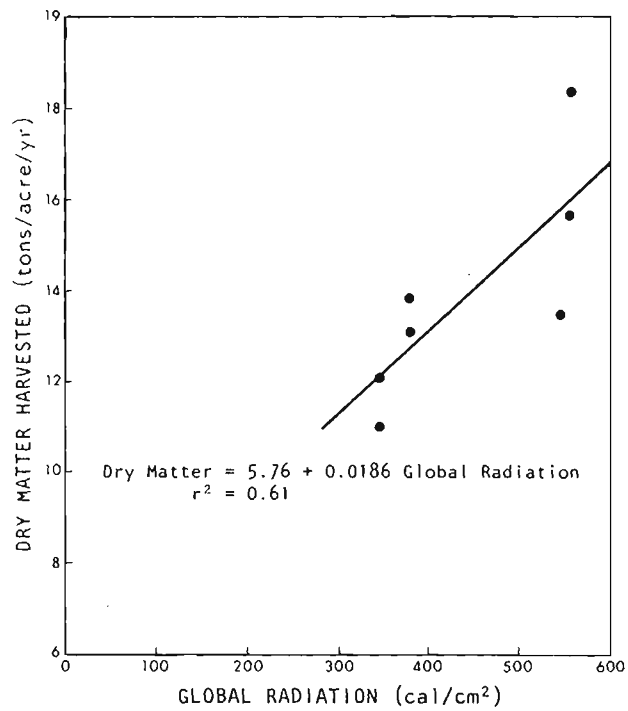

Figure 12. Dry matter as function of global radiation for alfalfa growth under similar irrigation rates and growth period

growth and quality of alfalfa (Vough and Marten 1971; Wahab and Chamblee 1972; Donovan and Meek 1983; Meek, Donovan, and Graham 1980; Carter and Sheaffer 1983). Alfalfa grown at high soil-moisture stress yielded less dry matter than that grown at low soil-moisture stress. A higher percentage of leaves and lower percentages of acid detergent fiber and lignin often occurred, but the percentage of crude protein was inconsistent with high soil-moisture stress (Vough and Marten 1971). Wahab and Chamblee (1972) found that supplemental irrigation on alfalfa in addition to natural rainfall produced superior growth for the first year and that the benefits ceased when excessive soil moisture contributed to the loss of stands because of disease infestation.

Donovan and Meek (1983) concluded that water management is critical for maximum alfalfa production and that under-irrigation resulted in a loss of stand. A good approximation of an optimum irrigation treatment was 75% of the pan evaporation, which is equal to the alfalfa evapotranspiration. Flooding of the stand which results in soil oxygen levels of 6% or less for periods greater than 24 hr resulted in losses of alfalfa stands (Meek, Donovan, and Graham 1980).

Flooding of the alfalfa stands occurred during the 19 December 1983 to 3 January 1984 period when over 100,000 gal (378.5 m^3) of effluent were accidentally applied because of a faulty solenoid valve. The alfalfa stand was reduced 23% (wet weight harvested). The effects of under-irrigation were more pronounced than over-irrigation. During the summer months when water is essential for growth, a decrease of 48% in irrigation resulted in a production loss of 62% in the wet weight yield and 32% decrease in the crude protein content of the forage (1 July 1983 and 9 August 1983 harvest).

Percolate Water Quality from Alfalfa Plots

One of the primary objectives of sewage irrigation is to reclaim the water through groundwater recharge after the nutrients are stripped from the excess irrigation flow by the ground-cover crop. Because alfalfa roots have nodules containing nitrogen-fixing bacteria, not all of the harvested nitrogen in the plant material came from the sewage. Nitrate analyses of eight percolate samples taken in June, July, August, and October 1983 showed that the concentration of nitrate nitrogen for the 4-mo period decreased after each harvest. Values of NO_3^--N ranged from 5.8 to 19.4 mg/ℓ, averaging 13.6 mg/ℓ (Table 2). A plot of NO_3^--N concentration versus time showed the nitrates reached acceptable limits (10 mg/ℓ as NO_3^--N) after the fifth harvest or 188 days after seeding (Fig. 13). The curve takes an exponential form,

$$N = 20.37\ e^{-0.01T}$$

$$r^2 = 0.99$$

where N is nitrate nitrogen in mg/ℓ and T is time in days after seeding.

A plot of the NO_3^--N concentration of the effluent is shown in Figure 13. The mean concentration of NO_3^--N in the effluent is 4.5 mg/ℓ. It should be noted that even after seven harvested crops, the percolate NO_3^--N concentration did not fall below that of the sewage irrigation water. Extrapolation of the two curves indicated that the NO_3^--N of the alfalfa-plot percolate would be equal to or less than that of the irrigation water after the eighth harvest. Of the total nitrogen percolated into the

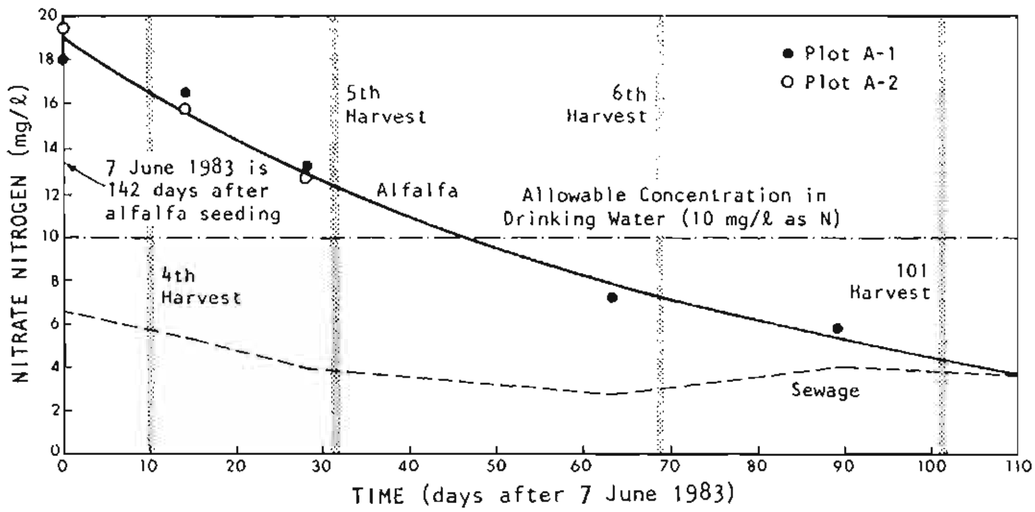

Figure 13. Nitrate nitrogen in percolate from alfalfa plots and in the applied sewage

ground, an average of 94.4% is in the form of nitrates.

Total nitrogen of the percolate showed signs of reaching an equilibrium value approximately 4 to 6 mg/ℓ after seven harvests.

Phosphorus was taken up by plants and fixed in unavailable form on soil particles so that 98.2% of the applied P was removed. The average P concentration in the percolate was 0.09 mg/ℓ. The soil removal of P, however, will continue only until the P-fixing capacity is exceeded.

Forage Value of Alfalfa Grown in Mililani

A comparison of the nutrient composition of alfalfa grown at Mililani and average mainland values is shown in Table 6. Also shown is a partial analysis of alfalfa irrigated with municipal wastewater in Taber, Alberta, Canada. On a green-chop (fresh) basis, an animal in Hawai'i would have to consume 33% more forage to obtain enough dry matter and crude protein as compared to irrigated mainland alfalfa. The forage at Mililani contained 33% more water than average mainland material, while the nutrients and minerals are comparable on a dry matter basis (DMB).

Proximate analysis is based on the separation of feed components according to their feed values. Usually the components are water, crude protein (CP), crude fat or ether extract (EE), crude fiber (CF), nitrogen-free extract (NFE), and mineral matter or ash. Nitrogen-free extract in-

TABLE 6. COMPARISON OF NUTRIENT COMPOSITION OF ALFALFA GROWN AT MILILANI EXPERIMENTAL PLOTS WITH AVERAGE MAINLAND AND CANADIAN VALUES

Location	% DM	% CP	P	K	Ca (%)	Mg	Na	Mn	Fe (mg/ℓ)	Cu	Zn
Mililani	17.3	20.7	0.30	2.99	1.42	0.22	0.18	70.8	461	9.6	47.7
Mainland*	25.9	21.9	0.30	2.10	1.68	0.30	0.16	50.1	310	9.5	....
Canada†	....	19.4	0.31	....	....	0.33	....	37.0	226	7.4	32.0

NOTE: All values given on dry matter basis except DM (as sampled basis).
NOTE: CP = crude protein.
*Average values obtained from National Research Council (1969) of National Academy of Sciences.
†Alberta.

cludes most sugars, starches and soluble lignins, and hemicellulose. NFE is usually determined by difference, as

$$\%NFE = [100 - (\%H_2O + \%CP + \%EE + \%CF + \%\ ash)].$$

The crude fiber determination was revised by another procedure developed by Van Soest and Moore (1966). This involves the separation of the feed into two fractions: one of low digestibility (neutral detergent fiber, NDF); the other of high digestibility (neutral detergent solubles, NDS). Neutral detergent fiber consists primarily of cellulose, lignin, silica, hemicellulose, and some proteins. Because all of the lignin and hemicellulose are included in the fiber analysis, the value for NDF is higher than the conventional crude fiber analysis.

Since all the proximate analyses for all conventional feedstuff published in 1969 by the National Research Council (NRC) used the conventional crude fiber determination, the calculated nitrogen-free extract does not correspond with newer analyses using NDF. A more reasonable value for crude fiber in the NFE calculation would be from the acid detergent fiber procedure used to determine acid insoluble lignin. This value of crude fiber called ADF (acid detergent fiber), obtained by boiling the sample in sulfuric acid and detergent, is similar to the conventional crude fiber value obtained by boiling in sulfuric acid and sodium hydroxide base. A comparison of proximate analyses for alfalfa grown on the mainland and at Mililani is shown in Table 7.

True digestibility (TD) of the forage is determined by the equation, $TD = 0.98\ NDS + (1.473 - 0.789\ \log_{10}\ lignin)\ NDF$, where TD is true digesti-

TABLE 7. COMPARISON OF PROXIMATE ANALYSES FOR MILILANI AND MAINLAND AVERAGES OF ALFALFA

FRESH BASIS	ALFALFA LEAF AND STEM (%)		
	Mean Values*	Pre-Bloom†	Full Bloom†
Dry Matter	17.8	21.1	25.3
Ash	9.8	9.6	8.4
Crude Fiber	28.8	26.0	31.7
Ether Extract	2.9	2.2	3.0
Nitrogen-Free Extract	37.2‡	41.7	40.0
Protein	21.3	20.5	16.9

*Mililani alfalfa.
†Mainland alfalfa.
‡Calculated using acid detergent fiber value for crude fiber.

bility, NDS are neutral detergent solubles, and NDF are neutral detergent fibers (Cullison 1982). The mean TD for Mililani alfalfa was 88.85%, ranging from 86.05 to 92.3%.

GUINEA GRASS PRODUCTION

Guinea grass was first harvested four months after transplanting the slips, and subsequent harvests were made at 38-day intervals except for three cuttings at 59 days between February and June 1984. Nine crops were harvested between January 1983 and June 1984 (Table 8). The average wet-weight yield was 14.41 tons/acre (3.33 kg/m^2) or 655.5 lb/acre/day (0.07 kg/m^2/day), with an average moisture content of 82.14% and a 120 tons/acre/yr crude protein content of 9.52% (DMB). Irrigation rates varied from 1.20 to 3.78 acre-in./wk (123.35-388.55 m^3/wk), averaging 2.75 acre-in./wk (282.67 m^3/wk).

After the 20 September 1983 harvest, seed heads began to appear on the guinea grass and after a 38 day growth period, the plants all had seed heads. Also noticeable was the chlorotic appearance of the plants in the center of the plot in comparison to the lush green growth at the edge of the plot. This condition continued on through the 31 May 1984 harvest. Analyses of the soil and foliage yielded no causative deficiency in

TABLE 8. GUINEA GRASS GROWTH PERIOD AND YIELD FROM EXPERIMENTAL PLOTS

Harvest Date	Growth Period	Sewage Applied (acre-in./wk)	Fresh Weight	Dry Weight
			--(lb/acre/day)--	
27/05/83	38	3.26	784	115
	38	2.95	736	123
05/07/83	39	3.06	1019	142
	39	2.48	1268	187
12/08/83	38	1.50	686	113
20/09/83	39	2.80	868	152
28/10/83	38	3.12	591	114
06/12/83	39	2.76	387	71
03/02/84	59	flooded	536	93
02/04/84	59	2.57	469	93
31/05/84	59	3.78	399	86
Mean	44	2.83	655	117

nutrients or minerals.

Nutrient and Mineral Uptake of Guinea Grass

A similar nutrient balance for nitrogen and phosphorus was made for one guinea grass crop as was done for alfalfa. The tabulated results are shown in Table 9.

Studies of Porvic percolate and influent sewage quality showed nitrogen removal by the soil and plant system ranging from 52 to 91% with a mean value of 77%. Ortho-P removal averaged 97.9% of the sewage applied amount (Table 2).

A plot of the amount of nitrogen harvested versus the applied sewage quantity showed no perceptible relationship. Since guinea grass requires low quantities of water to maintain growth and is drought resistant, the data obtained at the irrigation rates selected are at maximum production levels and the irrigation rates are excessive. A comparison of dry matter produced as a function of net applied nitrogen for irrigated guinea grass and California grass is shown in Figure 14. California grass is able to utilize nitrogen linearly up to 2700 lb/acre/yr (0.30 kg/m^2/yr). High

TABLE 9. WATER AND NUTRIENT BALANCES FOR GUINEA GRASS PLOTS

DATE	PLOT	DAYS	GLOBAL RADIATION (cal/cm²)	IRRIGATION (acre-in.)	ESTIMATED ET (acre-in.)	ESTIMATED Perc. (acre-in.)	APPLIED N (lb/acre/yr)	APPLIED P (lb/acre/yr)	PERCOLATE N (lb/acre/yr)	PERCOLATE P (lb/acre/yr)	HARVESTED N (lb/acre/yr)	HARVESTED P (lb/acre/yr)	N Balance (lb/acre/yr)	P Balance (lb/acre/yr)	APPLIED Net N (lb/acre/yr)	APPLIED Net P (lb/acre/yr)	DRY WEIGHT (tons/acre/yr)
27/05/83	1	38	506.5	17.70	9.12	8.58	774	187	118	2	904	81	-248	+104	656	185	21.04
	2	38	506.5	14.33	9.12	5.21	628	151	36	1	711	89	-119	+61	592	150	22.38
05/07/83	1	39	568.2	17.05	10.14	6.91	728	175	92	2	685	88	-49	+85	636	173	26.02
	2	39	568.2	13.82	10.14	3.68	579	142	25	1	769	136	-215	+5	554	141	30.04
12/08/83	2	38	541.6	8.14	9.50	0.00	347	86	0	0	742	78	-395	+8	347	86	20.65
20/09/83	2	39	551.8	15.60	9.36	6.24	661	160	42	1	844	116	-225	+43	619	159	27.70
28/10/83	2	38	452.1	16.94	7.98	8.96	744	179	62	2	803	108	+79	+69	682	177	20.75
06/12/83	2	39	367.9	15.38	6.24	9.14	645	158	45	2	460	78	+140	+78	600	156	12.92
03/02/84	2	59	320.3	flooded	8.85	runoff	—	—	—	-	628	85	—	—	—	—	17.31
02/04/84	2	59	462.2	21.66	12.39	9.27	612	147	42	1	578	88	-8	+58	570	146	16.95
31/05/84	2	59	534.6	31.86	14.16	17.70	893	216	79	3	342	60	-472	+153	814	213	15.71

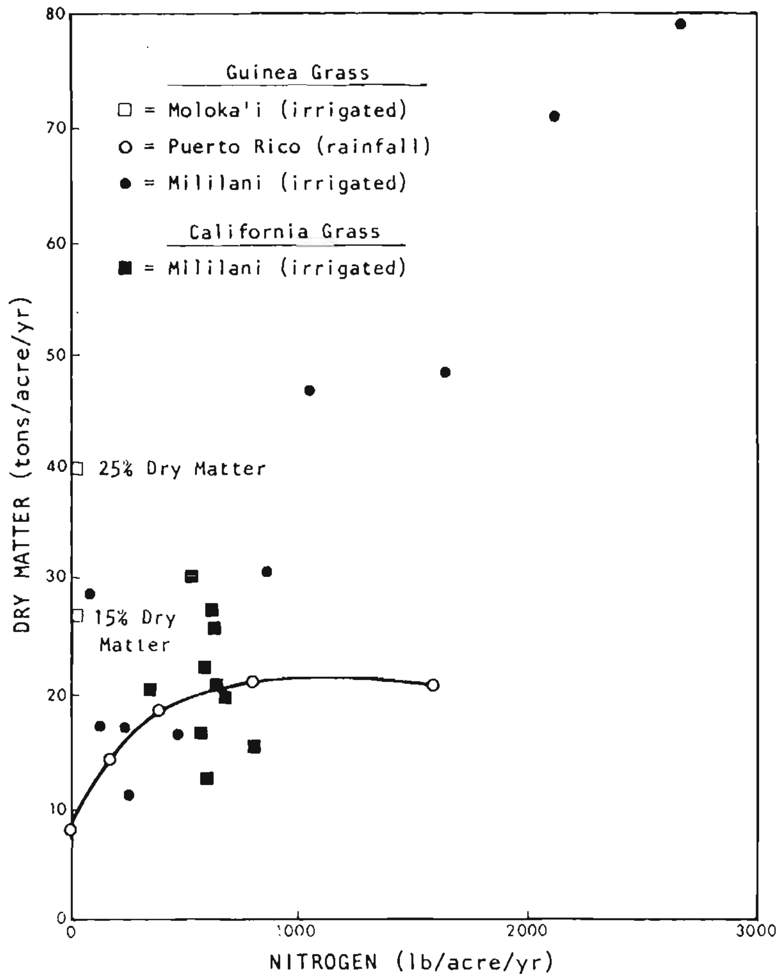

Figure 14. Dry matter harvested as function of net applied nitrogen

application of sewage and corresponding nitrogen was not achieved at Mililani because of the chlorotic symptoms arising in the center of the guinea grass plot.

Guinea grass also takes up potassium in fairly large quantities similar to alfalfa. The mean concentration in the harvested plant tissue was 2.36% (DMB) which meant for each ton of wet forage harvested, 7.93 lb (3.6 kg) of K would be removed—a contrast to the 10.5 lb (4.8 kg) K removed per ton of alfalfa. The uptake of K for nine consecutive harvests of guinea grass is shown in Figure 15. The regression curve is exponential with the equation of the line as percent in tissue = $2.87\ e^{-0.00212T}$ with a correlation coefficient of 0.95 (T = time in days).

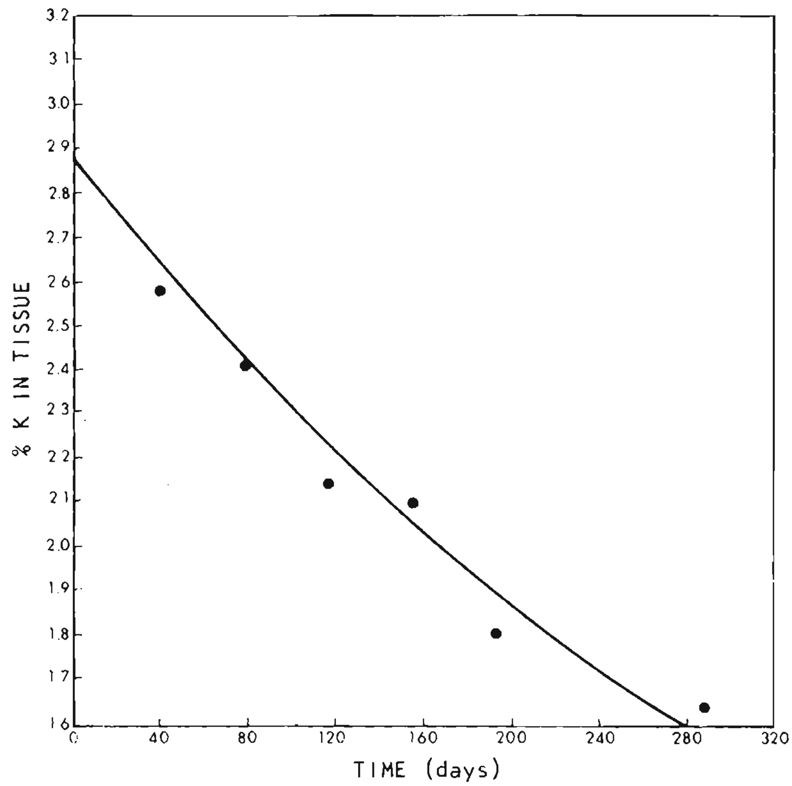

Figure 15. Variation of potassium in plant tissue with time for guinea grass

Iron uptake by guinea grass is a logarithmic function similar to alfalfa (Fig. 16). The regression curve is Fe = 1145 - 181.5 $\log_e D$ with a coefficient of determination, r^2, of 0.97 (Fe = ppm iron, D = days). With an average concentration of Fe = 0.0249% (DMB) in the plant tissue, 1 ton (907.2 kg) of harvested guinea grass will remove 0.08 lb (0.04 kg) of Fe from the soil.

Uptake of manganese by guinea grass is dissimilar to alfalfa. Whereas alfalfa showed no decreasing concentration trend of Mn with time, guinea grass showed a linear decrease in manganese in the plant tissue with each consecutive harvest. This indicated that the amount of manganese available for plant tissue uptake was decreasing and may have been a limiting factor. The decrease of Mn in the plant tissue versus harvest intervals is shown in Figure 17 with a linear regression curve of Mn = 131.57 - 0.22 D and a coefficient of determination, r^2, of 0.85 (Mn = ppm manganese, D = days).

The uptake of nitrate by guinea grass was similar in magnitude to alfalfa with values ranging from 0.031 to 0.214% which are below the toler-

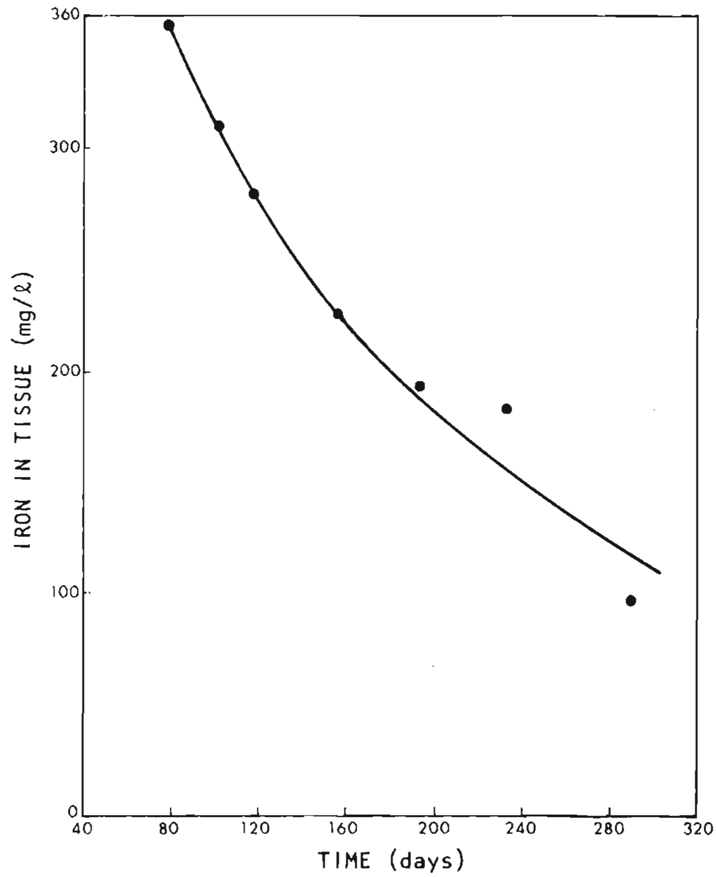

Figure 16. Variation of iron in plant tissue with time for guinea grass

able limit of ⩾0.44%. Nitrate levels in the plant tissue for the first six harvests are presented in Table 10. The calculated nitrogen uptake for each guinea grass crop, using the tissue analyses data, is listed in Table 11. The mean uptake for eight harvested crops is 57.2 lb/acre/mo (64.1 kg/ha/mo). In comparison, sugarcane assimilated 19.6 lb/acre/mo (22 kg/ha/mo) as reported by Lau et al. (1975).

Effect of Environmental Conditions and Crop Yield

DAY LENGTH. Guinea grass was grown during mean day lengths ranging from 10.81 hr (6 Dec. 1983-3 Feb. 1984) to 14.27 hr (27 May-5 July 1983). A plot of wet-weight yield in tons per acre versus mean day length in hours under similar irrigation rates showed that each hour increase in day length resulted in an increased yield of 6.5 tons (5 896.8 kg) of forage

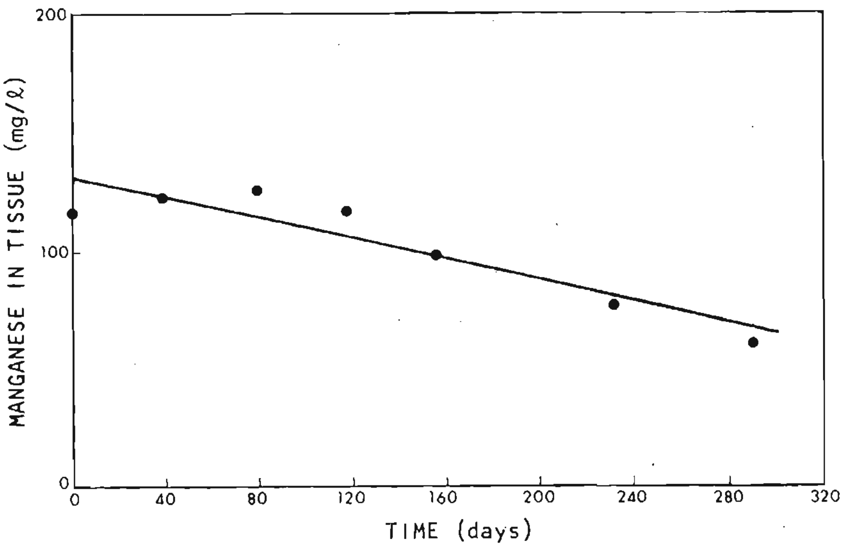

Figure 17. Variation of manganese in plant tissue with time for guinea grass

TABLE 10. NITRATE NITROGEN CONCENTRATION IN GUINEA GRASS ON DRY WEIGHT BASIS

Harvest No.	Plot No.	% NO_3^--N
1	G-1	0.214
	G-2	0.102
2	G-1	0.193
	G-2	0.038
3	G-1	0.063
	G-2	0.031
4	G-2	0.197
5	G-2	0.043
6	G-2	0.052

NOTE: Mean value = 0.104%,
Median value = 0.063%.

TABLE 11. CALCULATED NITROGEN UPTAKE FROM TISSUE ANALYSIS OF GUINEA GRASS

HARVEST NO.	NITROGEN UPTAKE G-1 (kg/ha/mo)	NITROGEN UPTAKE G-2 (kg/ha/mo)
2	83.2	65.9
3	63.2	70.8
4		68.4
5		77.8
6		55.6
7		44.9
8		57.8
9		53.4

NOTE: Mean value = 64.1 kg/ha/mo (57.2 lb/acre/mo).

(Fig. 18). This is in contrast to alfalfa which yielded only a 0.59 ton/acre (0.13 kg/m^2) increase for each hour of day length. The variation of yield with total global radiation is shown in Figure 19. Guinea grass is a C_4 plant since it has the low CO_2 compensation point typical of C_4 plants (Krenzer and Moss 1969, Table 3). Sugarcane and some tropical grasses which use the C_4-dicarboxylic acid pathway for CO_2 fixation can photosynthesize at rates significantly greater than temperate latitude grasses which use the conventional C_3 (Calvin) cycle found in algae and many other plants (Bull 1969; Kortschak, Hartt, and Burr 1965; Hatch and Slack 1966; Burr et al. 1957; El-Sharkawy and Hesketh 1964; Hesketh and Moss 1963; Murata, Tayama, and Hanma 1965). Several anatomical features of the leaf as well as the physiological lack of photorespiration in C_4 plants have been linked to their greater photosynthetic capacity (Bull 1969; Rechel and Walsh 1985). This heightened ability for carbon dioxide utilization also gives the C_4 plants a greater nitrogen-use efficiency (Brown 1985). The efficient use of sunlight by C_4 plants makes them likely to respond to the 20% increase in sunlight from the longer summer days.

IRRIGATION RATES. Unlike alfalfa, guinea grass growth rate and yield is highly dependent on the day length and temperature. Wide variations in the rate of sewage irrigation had minor effects on the yield and were overshadowed by the effects of day length and temperature. To determine the

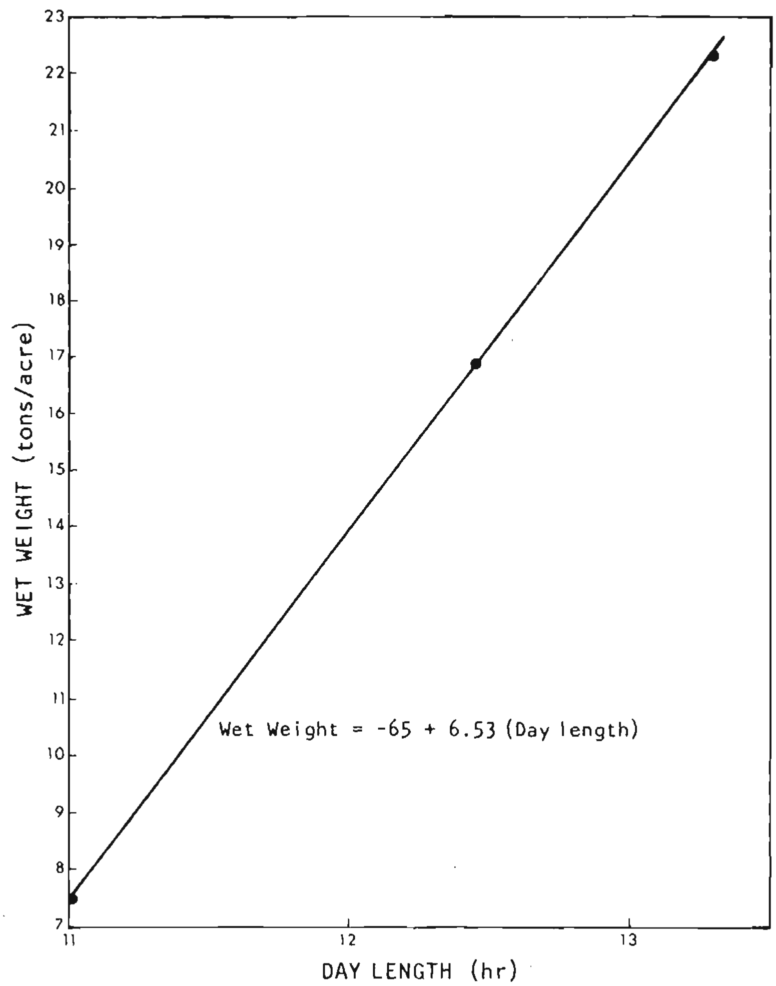

Figure 18. Productivity of guinea grass as function of day-length under similar irrigation rates

effects of irrigation rates, the guinea grass crop must be grown under similar day length and temperature. A period of one year with nine harvests was insufficient time to produce any meaningful data for the consumptive use determination or rate effects.

Consumptive use of water by guinea grass has been reported by Vásquez (1965) for Puerto Rico. The highest water use and yields were obtained during the spring and summer months. The total use for the year was 57.7 in. (1 465.6 mm) of water. The sewage applied at Mililani totaled > 150 in. (> 3 810 mm) and would represent an over-irrigation condition.

Phosphorus concentrations in the percolate were similar to the alfalfa plots, averaging 0.10 mg/ℓ, thus indicating fixation by the soil.

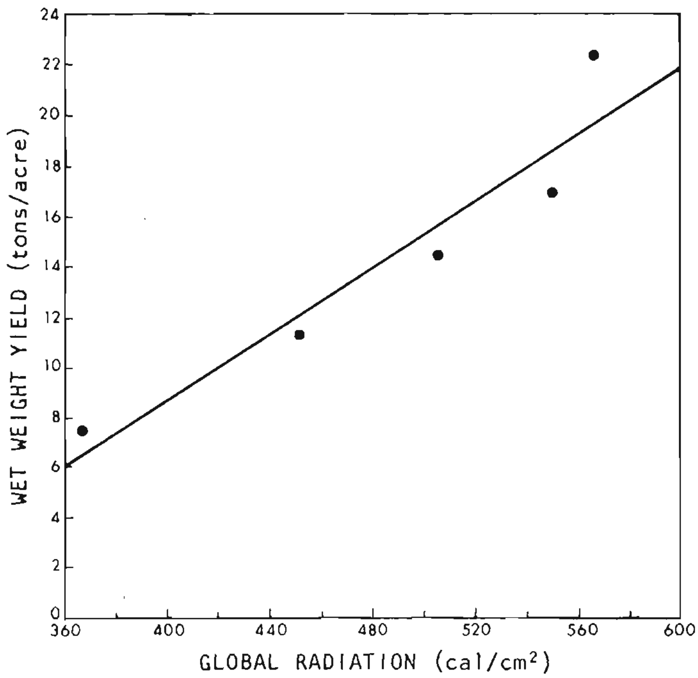

Figure 19. Productivity of guinea grass as function of global radiation under similar irrigation rates

PERCOLATE WATER SAMPLING. A plot of nitrate nitrogen versus time showed that just before the second harvest, the nitrate level in the percolate dropped below 2 mg/ℓ as N and remained fairly constant at that level (Fig. 20).

For guinea grass, the concentration of nitrate nitrogen in the percolate was less than that of the incoming effluent after the first crop was harvested. The average nitrate nitrogen ranged from 60 to 77% of the total nitrogen percolated into the ground. The total nitrogen in the percolate ranged from 9 to 10% of the total application.

Forage Value of Guinea Grass

A comparison of a partial proximate analysis of guinea grass grown at Mililani and selected tropical countries is given in Table 12. The average percent dry matter grown at Mililani is lower than in other tropical countries. This can be attributed to the over-irrigation of the crop and the consequent decrease in productivity. The mean calculated true digestibility of guinea grass was 89.02% and ranged from 83.49 to 95.77%.

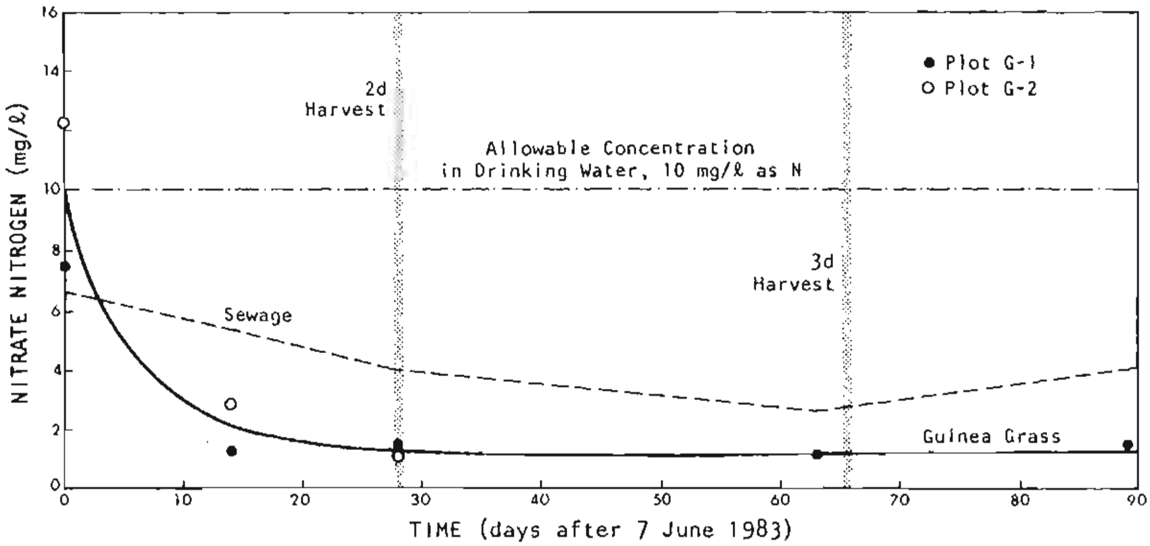

Figure 20. Nitrate nitrogen in percolate from guinea grass plots and in the applied sewage

TABLE 12. COMPARISON OF GUINEA GRASS GROWN AT MILILANI, O'AHU, WITH OTHER TROPICAL COUNTRIES

LOCATION	DRY MATTER (%)	% OF DRY MATTER Crude Protein	Ether Extract	Ash
Mililani	16.8	9.5	1.8	10.6
Malaysia	23.0	11.7	1.3	13.0
Nigeria	25.7	7.8	1.4	12.2
Tanzania	28.0	8.8	1.5	12.9

NOTE: Data for Malaysia, Nigeria, and Tanzania from Göhl (1975).

PAPAYA PRODUCTION

Difficulty in establishing a papaya stand was encountered at the beginning of the project. Initially, no viable seedlings emerged when seeds obtained from the University of Hawaii seed supply were planted directly in the plot. Subsequently, of the 53 Waimanalo low-bearing papaya seedlings purchased at a nursery on 9 June and transplanted on 13 and 14 June 1983, only 13 survived the transplanting phase.

After the surviving transplants were established, female plants were not culled and all were allowed to produce fruits because there were so few plants left. In commercial practice, female plants, which yield small round fruits, are culled before fruits are produced. The desirable and common shape sold on the market is the hermaphroditic pyriform or ovoid, with the pyriform predominating. The ratio of ovoid to round fruits varied from 2.86:1 to 1:6. Under imposed growth conditions, irrigation rates, and seasonal changes, the hermaphroditic plants changed types and reverted from a predominant pyriform or ovoid shape (Type IV) to a predominant round shape (Type II) and distorted ovoid shapes (Type III). Type I or female trees produce only round fruits and remain stable, unaffected by seasonal and environmental changes. Studies by Awada and Ikeda (1957) showed that under high irrigation where soil moisture was maintained between 32.0 to 34.3%, the percentage of Type II and III fruits (carpellodic) were significantly higher than in low irrigation plots (25.8% soil moisture) suggesting that there is a relationship between sex expression and moisture level of the soil. A plot of the percent number of ovoid or Type IV fruits as a function of time showed an increase during the months of April and August (Fig. 21).

Irrigation Rates

The average irrigation rate to the papayas was approximately 1.8 in. (45.7 mm)/wk or 94 in. (2 387.6 mm)/yr. This would supply 0.41 lb of nitrogen and 0.10 lb P per year per plant which is below the recommended practice of adding 1 lb of 10-10-10 mixture per month per plant or 1.2 lb N and 0.52 lb P per year. To meet the nitrogen requirements, the current irrigation rate can be tripled, and to meet phosphorus requirements, increased by five times.

Mature papayas with a yellowish tinge at the apical end were harvested weekly and weighed according to their shapes, and tabulated. A plot of the weekly normalized harvested weights of ovoid and round papayas are shown respectively in Figures 22 and 23. A trend curve was drawn through the data points by taking a 5 wk moving average of the weekly weights.

Since the sampling period for mature fruits extended over only a 12-wk period, no seasonal variations in fruit production were observed. A trend line constructed with 5-wk moving averages for total fruit production is shown in Figure 24.

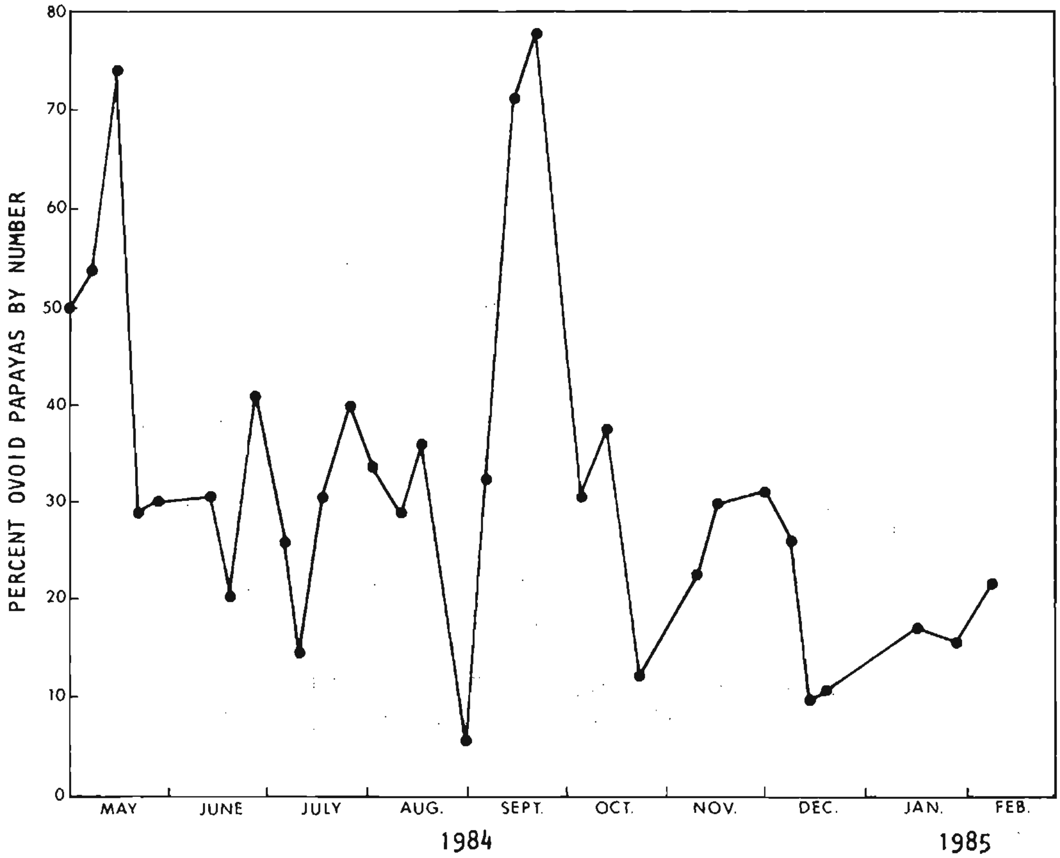

Figure 21. Percent number of ovoid papaya as function of time

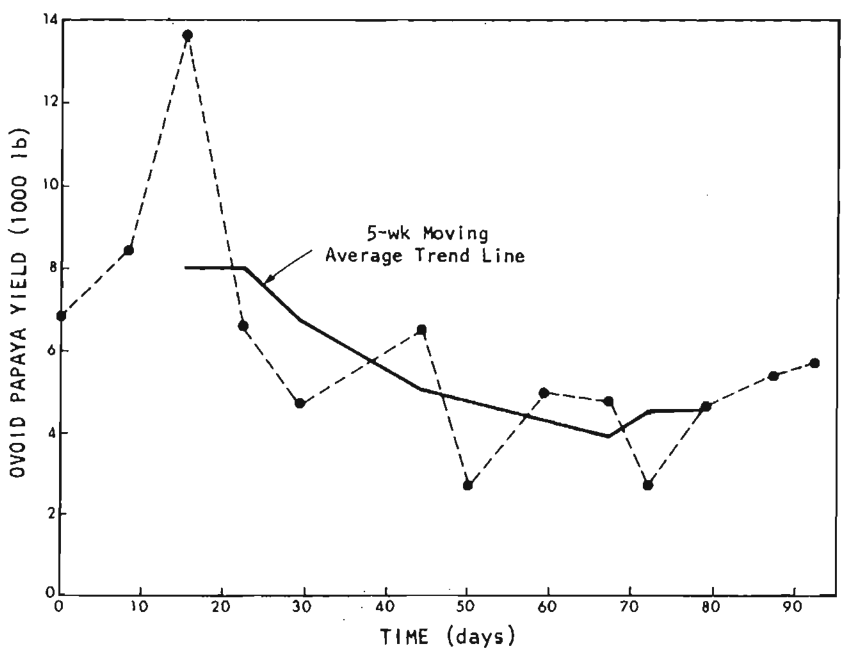

Figure 22. Ovoid papaya yield normalized to weekly yields, 5-wk moving average trend

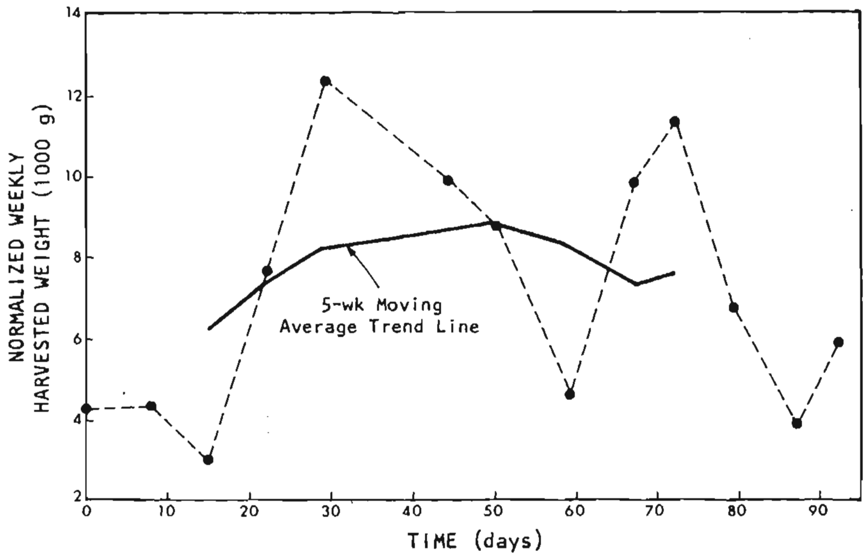

Figure 23. Round papaya yield normalized to weekly yields, 5-wk moving average trend

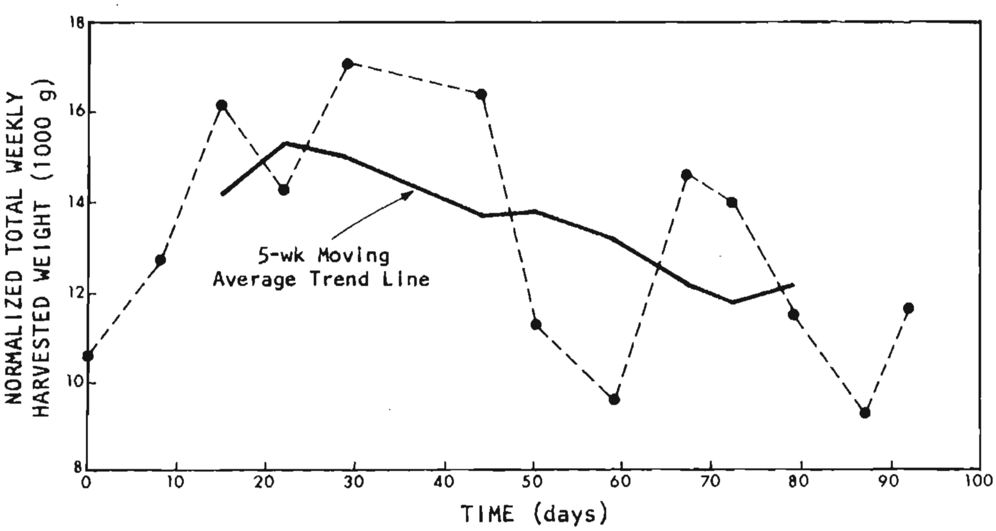

Figure 24. Total papaya yield normalized to weekly yields, 5-wk moving average trend

Fruit Size and Weekly Production Rates

Weekly mean fruit sizes for ovoid papayas vary from 18.2 to 28.9 oz (0.518-0.820 kg) and for round fruits from 12.4 to 20.8 oz (0.351-0.589 kg). The average size of ovoid and round fruits harvested from 27 March to 3 July 1984 was respectively 23.5 and 14.9 oz (0.665 and 0.422 kg). During this period, 373 fruits were harvested. The trend variation in sizes for each type of fruit is shown in Figure 25.

Fruit Quality

This variety of papaya has a firm flesh that retains its hardness even when the fruit is a mature yellow and does not become mushy when overripe. The round female fruit contains little or no seeds and, when peeled, is suitable in a fruit salad with a minimum amount of preparation. The wastewater irrigation appeared to have no adverse effect on fruit quality.

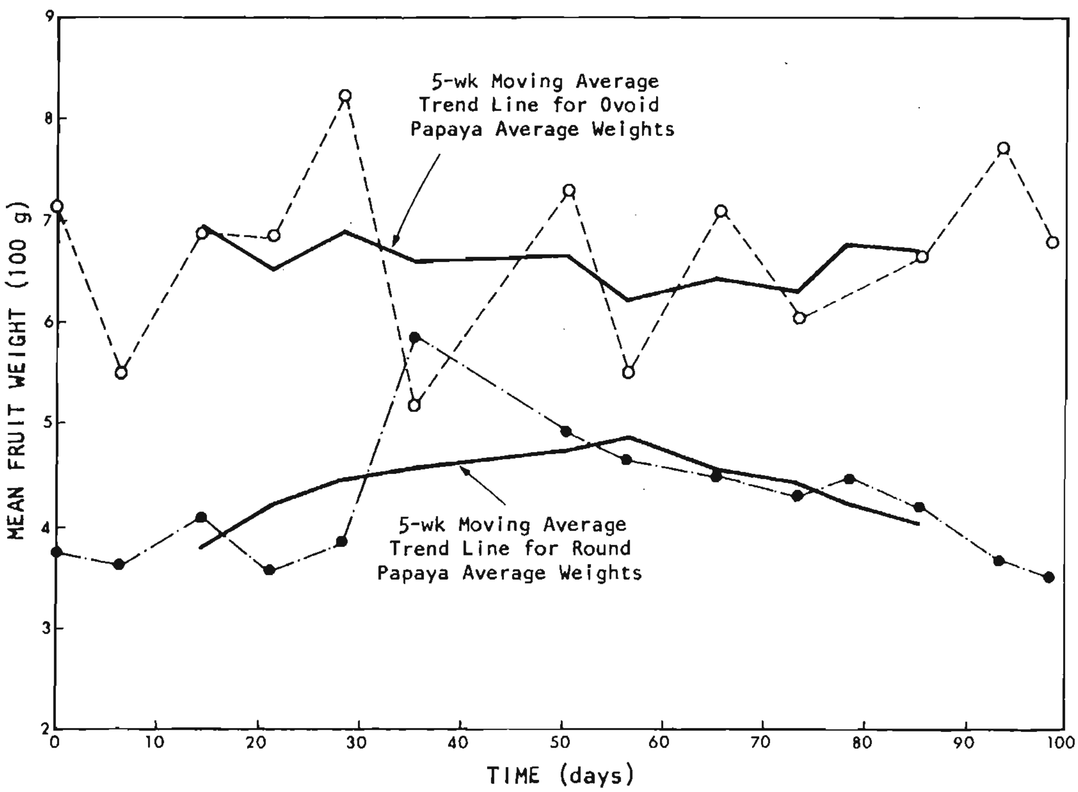

Figure 25. Five-week moving average trend of mean weights of ovoid and round papayas

SUMMARY

A total of 15 cuttings of alfalfa was harvested during the period from December 1982 to August 1984. These cuttings were irrigated with sewage effluent at rates ranging from 1.70 to 11.10 acre-in./wk (174.74 to 1 140.1 m^3/wk) (mean = 5.48 acre-in./wk or 563.29 m^3/wk). Nine cuttings of guinea grass were harvested between June 1983 and June 1984, under irrigation rates ranging from 1.50 to 3.78 acre-in./wk (154.19-388.55 m^3/wk) (mean = 2.83 acre-in./wk or 290.9 m^3/wk). Percolate studies showed that alfalfa did not effectively strip nitrate nitrogen to meet the drinking water limit of 10 mg/ℓ as NO_3^--N until the fifth harvest or 188 days from initial seeding. After the fifth harvest, the nitrate nitrogen level in the percolate continued to decrease and approach the nitrate level of the sewage irrigation water of 5 mg/ℓ NO_3^--N. Guinea grass, however, reduced the nitrate nitrogen level of the percolate to less than 2 mg/ℓ as NO_3^--N just before the second harvest and continued to strip nitrogen, reaching a fairly constant value below 2 mg/ℓ. Harvested guinea grass removed an average of 64.1 kg/ha/mo of nitrogen which is three times the amount removed by sugarcane (Lau et al. 1975). Compared to California grass under maximum nitrogen application, the percolate from guinea grass is similar—9% of the applied nitrogen (Handley and Ekern 1981).

The productivity of alfalfa irrigated with sewage effluent averaged higher than that reported by other researchers in Hawai'i using fresh or brackish water. Yields of 37 to 46 tons/acre/yr (8.29-10.31 kg/m^2/yr) of fresh-cut forage were reported by Britten and Wallis (1964) at Kekaha, Kaua'i by using ten different varieties. Younge (1952) reported yields of 27.5 to 38.6 tons/acre/yr (6.16-8.65 kg/m^2/yr) at the Poamoho Experiment Station on O'ahu. Alfalfa grown on Moloka'i irrigated with 2 acre-in./wk (205.58 m^3/wk) of 96 grain (1642 mg/ℓ total salts) saline water produced average yields of 58.5 tons/acre/yr (13.11 kg/m^2/yr).

In comparison, alfalfa grown at Mililani produced yields averaging 81.0 to 88.7 tons/acre/yr (18.16-19.88 kg/m^2/yr). Part of this apparent high production rate can be attributed to the small plot size and harvesting technique used. All alfalfa plots were hand cut and weighed instead of machine mowed; therefore, no field losses occurred from incomplete cutting and raking.

Guinea grass grown at Mililani produced wet weight yields averaging 120 tons/acre/yr (26.9 kg/m²/yr) which is less than the Moloka'i experiments with brackish water and yields of 182 tons/acre/yr (40.8 kg/m²/yr). Extrapolated values of yields in Puerto Rico grown with identical amounts of nitrogen fertilization and frequent irrigation averaged 17.6 tons dry matter/acre/yr (3.95 kg DM/m²/yr) (Vázquez 1965). However, guinea grass yields at Mililani were 21.0 tons dry matter/acre/yr (4.71 kg DM/m²/yr).

Alfalfa crops at Mililani averaged 21.3% protein as compared to averaged mainland irrigated crops with 20.5%. Application of municipal sewage wastewater in Taber, Alberta, Canada on alfalfa yielded forage with a protein content of 21.2% for the first harvest and 17.7% for the second harvest. Although the production of crude protein on a per acre basis for alfalfa and guinea grass is similar for each harvest, 0.28 tons/acre/harvest and 0.23 tons/acre/harvest (0.06 and 0.05 kg/m²/harvest), respectively, the production on a yearly basis is greater for alfalfa because of the increased number of cuttings. To obtain an equivalent amount of protein in alfalfa, an animal would have to consume 2.5 times as much guinea grass on a wet weight basis as alfalfa, because of its lower dry matter and crude protein content. The yearly rate of crude protein production is respectively 2.49 tons/acre (0.56 kg/m²) and 1.96 tons/acre (0.44 kg/m²) for alfalfa and guinea grass.

One of the concerns in fertilizing forages with nitrogen is the accumulation of nitrate to a toxic level of 0.44% or higher dry weight basis. The nitrate nitrogen concentrations in the forage ranged from 0.074 to 0.197% and 0.031 to 0.214% for alfalfa and guinea grass, respectively.

Several problems arose during the forage production experiment. Weed infestation occurred in the alfalfa plots especially immediately after harvesting when the alfalfa was cut low allowing weed seeds to germinate. Infestation became more pronounced after the alfalfa was drought stressed during the construction of the new sewer line. (The weeds gradually took over and replaced the standing crop and after 15½ mo as much as 60% of one plot was weed infested). However, with proper management using selective herbicides, the weeds could be controlled or minimized. In contrast, guinea grass tended to crowd out any germinating weeds because of its fast-growing nature after harvesting. The height of the grass was effective in restricting the sunlight available for the low-growing weeds.

Guinea grass grew well for seven cuttings but then developed a slightly chlorotic appearance with noticeably reduced growth in the center of the plot in comparison to the lush green growth at the plot edges and on the berms. Analyses of the soil and harvested plant tissue offered no causative nutrient deficiencies.

Establishing a viable crop of papaya was a problem. Of the 53 seedlings transplanted into bore holes, only 13 or 25% survived. Damping off of the seedlings was a major problem at the papaya site and fresh seeds placed in the soil did not germinate with any success. Since only a small number of plants became established, none of the female plants were culled and were allowed to produce fruits to test the effects of sewage irrigation. The fruits were harvested weekly, enumerated and weighed. No trend in seasonal changes in sex expression could be established to correspond to the published literature citation that the production of carpellodic fruits occurred for the months January to April. The number of pyriform-type fruit increased during the months of April and August and carpellodic fruits occurred even during the summer months of May to August.

Percolate samples from the papaya were not collected because of the low irrigation rates and misplacement of the Porvic sampling tubes and a nutrient balance could not be made. Even though the plants were under constant irrigation, there was sufficient drainage and root rot did not become a problem. Papaya mosaic infected one tree which was removed.

Using the total weight of papayas harvested over a 15-wk period and projecting the yield for a year, the estimated yield at Mililani is 122,000 lb/acre/yr (13.66 kg/m^2/yr). Of this probably 30% (36,000 lb [16 329 kg]) is marketable. The estimated potential yield from commercial growers in Kapoho, Hawai'i is 38,000 lb/acre (4.26 kg/m^2) for the first year of production (Yee et al. 1970).

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