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CLIMATE CHANGE IMPACT AND RESPONSES IN ISLAND COMMUNITIES

BEFORE
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Agriculture cannot remain constant in the face of climate change and thus must change as climate changes. The question, therefore, is when and how this change will occur, and what options decision makers ranging from policy makers to producers will have to meet this challenge. But before we answer this question, we need to know the bio-physical factors that link agriculture to climate.

Agriculture is the art and science of matching the biological requirements of crops (plants and animals) to the physical characteristics of land. Farming is about minimizing mismatches between crops and environment to optimize agricultural performance, and abrupt changes in the amount and distribution of rainfall and temperature will widen mismatches and lower performance.

It is important to note that reduced yields associated with climate change will not necessarily be caused by diminished land quality, but will primarily be a consequence of mismatches between crops and land characteristics currently cultivated on a given parcel of land. In fact climate change may transform land now too dry or cold into prime agricultural land to expand the land area suitable for food production. The issue therefore is to have in hand, effective methods to match crop requirements to changing land characteristics in a timely and cost-effective manner.

There are three ways to match crops to suitable agro-environments. The first and most frequently used method is by trial-and-error. Our ancestors carried seeds of their favorite crops as they migrated to new unoccupied lands, and preserved seeds of those plants that performed well in the new location. Some wise farmers saved seeds from the best performing plants, and were able to improve farm productivity by repeating this process for many plant generations. The early Hawaiians were able to produce over a hundred taro varieties through this process. But the Hawaiians had centuries to complete this task and taro is no longer the primary food stable in Hawaii. The trial-and-error method of matching crops and crop varieties to locations with suitable growing conditions is too slow and costly. With climate change already upon us, we no longer have the luxury of time and resources to conduct endless trial-and-error field trials.

There is second and better way to find crops that will do well on your land. This method called matching by analogy depends on assuming that crops that perform well on land similar (analogous) in soil and climate to your land will perform well on your land. This approach is possible in the U.S. and Hawaii because the entire country has been or is in the process of being inventoried and mapped in detail according to soil type and climate. This system of inventorying our land resources on the basis of soil and climate was developed by the Natural Resource Conservation Service of USDA (USDA Staff, 1999). Using this method, one can search for crops that are suitable for a particular location in Hawaii by looking for analogous soils in Botswana, Guam, India or Panama and see what crops perform well there. In 1974, the University of Hawaii conducted a 10-year project to test the applicability of the approach on an international scale and showed that test crops not only performed well in similar soils and climates in Brazil, Indonesia, Cameroon, Philippines and Hawaii, but responded to similar management practices to attain high grain yields (Silva, 1985). The limitation of matching crops to land characteristics by analogy is its exclusion of crops that have never been grown in that particular type of environment. We need a method that enables growers to evaluate the profitability of growing the widest possible range of crops on their land quickly and at prices they can afford.

This brings us to the third methods of identifying crops to replace those that have become unprofitable from the effects of climate change. It is worth repeating that a crop or crop variety that performs poorly in one location can regain its yield potential in another location where its biological requirements are more adequately met. Climate change does not require us to abandon or discard existing crops and crop varieties, but requires finding new environments for them. In Hawaii this may mean growing Kapoho papaya in Mountain View. Does this also imply that Mississippi soybean can be transferred to Minnesota with global warming? Unfortunately Mississippi and Minnesota differ in day length and photoperiod sensitive soybean that performs well in the southern U.S. will not do well in the northern states. But should climate change shift moisture from Mississippi to Arizona, it should be possible to transfer photoperiod sensitive crops between the two states.

Mismatches between crops and land characteristics caused by climate change will not only cause yields to decline but most probably will also cause yield variances to increase. Every grower's goal is to produce high yields and profit, and to avoid high yield variances, or feast to famine fluctuations in yield and profit. High yield variance adds risk and uncertainty to farming and is sufficient in it self to cause farmers to abandon farming. Random, uncontrollable meteorological factors introduce risk and uncertainty to farming and compel decision to gamble with nature.

Gambling is a risky game of probabilities. Thus, to determine how a crop will perform in a new climate requires many years of testing to expose hidden dangers which one or two years of on-farm trials cannot reveal. Since the risk of crop failure and income loss resides in the tails of probability distributions, climate change requires scientists to develop tools capable of generating whole probability distributions of production outcomes.

Whole probability distribution cannot be generated by conducting trial-and-error experiments or by searching for crops in analogous environments. Whole probability distributions can only be generated by systems analysis and simulations using dynamic, process-based models. There are too many factors that influence means and variances of crop yield and profit, and there are insufficient resources and time to conduct experiments to explore even a fraction of the range of outcomes.

In the next three to four decades, the world must double production with a new kind of agriculture to feed, cloth and house a global population that will increase not only in size but in aspirations. It will be challenging enough just to double production, but we are now being asked to do so without compromising the stability and resiliency of the ecosystem, and to complicate matters even more, this increased production will now need to be achieved in the context of uncertain global climate change. It is not surprising then, that there is now widespread agreement that business as usual will not do and a new kind of agriculture will need to be created to meet the challenge of food security for all.

In 1983 the College of Tropical Agriculture and Human Resources of the University of Hawaii established a project called the International Benchmark Sites Network for Agrotechnology Technology Transfer (IBSNAT) project with federal funds to produce a software called Decision Support System for Agrotechnology Transfer (DSSAT) capable of predicting the growth, development and yield of the major food cereal, grain legume and root crops anywhere in the world using historical weather data to drive the model.

DSSAT generates whole probability distributions of outcomes based on simulated crop yields taking into account daily, seasonal and annual weather variations over many decades. This ability to generate and display means and variances of production outcomes enables users to analyze risk and seek alternative crops and/or crop management strategies to maintain high yields and minimize risk. DSSAT not only generate information on crop yields, days to maturity, crop responses to rate and timing of inputs, but enables users to compute cost of production and perform economic analysis.

The capability of DSSAT is illustrated by the attached paper (Ogoshi et al., 1998)), which describes the authors’ response to a request to assess the economic feasibility of producing soybean on land formerly used to grow sugar cane. To simulate performance in different locations of the land area, DSSAT needed input information on soil, weather and soybean varieties. Since no soybean study had been conducted in the area, DSSAT was asked to determine the best variety based on yields obtained at multiple locations, planted at 12 different date, at several different planting densities. A typical task DSSAT would be asked to perform might be to evaluate 4 varieties at 6 locations at 12 (monthly) planting dates and 4 population densities for 30 consecutive years. DSSAT can complete this task in a few hours, but a trial-and-error field experiment would involve installing 34,560 field plots over a 30 year period.

As powerful as DSSAT is today, climate change adds a new dimension to the task of matching crops to land and compels DSSAT to look for help to remain relevant and useful. DSSAT now operates on the assumption that historical weather data mimics means and variance of current weather. Climate change will invalidate this assumption.

DDSAT is a product of agricultural scientists and economists. It now needs the help of atmospheric scientists to develop climate models that can generate means and variances of weather conditions that apply to a given parcel of land. Our capacity to match crops to land will depend on the climate forecasting capability of atmospheric science.

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Cooperative Extension Service
C/T/A/H/R
College of Tropical Agriculture & Human Resources
University of Hawaii at Manoa

Soil and Crop Management
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Simulation of Best Management Practices for Soybean Production in Hawaii

A method is presented that assesses economic profit, management practices, and risk involved with soybean production for three locations on the North Shore of Oahu, Hawaii, where soybean has not been planted before. Simulations of soybean growth and economic analysis using 768 combinations of cultivar, plant density, irrigation, and planting date over 20 seasons for each of three locations were made using the computer program Decision Support System for Agrotechnology Transfer (DSSAT, v. 3.0). Economic profit was calculated as the difference between revenue generated from grain yield and the total cost incurred from water, seed, labor, and other inputs. High economic profit and low variation of the profit from season to season were the criteria that identified the best management scheme out of the 768 for each location. Results from the simulations indicate profitable soybean production at each location is possible if a cultivar adapted to the mid-Atlantic states, "Bragg," is planted in the spring. In addition, high plant density and irrigation are necessary. Revenue from increased yield outweighed the costs accrued from extra seed and water. The expected economic profit ranged from $789 to $829 per hectare (2.47 acres; see conversions, p. 11). Agronomic modeling with economic analysis was shown to be an effective tool for the rapid generation of knowledge necessary for decision-making on crop production based on expected economic profit and an assessment of risk. Such decisions are key to the timely selection of alternative crops and practices in areas previously planted to other crops.

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Introduction

Two critical objectives in any agricultural enterprise are to minimize cost and maximize production. Economic feasibility of the enterprise depends on revenue being greater than cost. Other worthy objectives such as minimizing environmental impact or maintaining biodiversity may be included, but for this study, minimizing cost and maximizing revenue are the objectives.

Minimizing cost and maximizing production depend on the local environment where the crop is grown. An effective way to minimize cost is to match crop growth requirements to the biophysical environment, which includes soil fertility, rainfall, and temperature. With a good match, inputs and their associated costs are minimized. However, environments seldom match crop requirements perfectly. Irrigation, fertilization, and liming are often necessary to correct fertility or moisture deficiencies, or an alternative location must be used to fulfill temperature requirements. At each location, the combination of these interventions to correct mismatches is probably unique. Therefore, determination of the best management practices to produce crops will require information on the crop, weather, and soil; the effects of particular management practices; and their combined impact on yield.

Information needed to manage environmental mismatches for crop production is generated in one of two ways: through trial-and-error field experimentation or systems simulation. The scope of the information generated in these two ways is different. In field experiments, the scope includes the specific responses of a crop to the environment as influenced by genetics, plant competition, and soil amendments at a particular time and place. Field experiments seldom integrate climate with crop response to soil and soil amendments because

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this involves multi-year and multi-location experiments, which are extremely expensive. Because field experiments can rarely be conducted over many years and locations, simulated outcomes of such experiments are useful. Crop simulation models are designed to imitate the behavior of real plants by integrating their known response to weather, soil, and amended conditions. Models can estimate crop production under many conditions to define precise differences that can occur from year-to-year or location-to-location, or as a consequence of finely graded management practices. Specific field experiments are still necessary to generate the new information on crop responses to factors that are not included or not well simulated in the model. Trial-and-error experiments and systems simulations generate information that are complementary. Field experiments produce new data that improves our understanding of plant and soil processes. Crop models integrate the improved understanding into new knowledge of crop performance.

The purpose of this study was to determine the agronomic and economic feasibility of soybean (*Glycine max* L. Merr.) production at selected sites on the North Shore, Oahu, Hawaii, as part of a rural stabilization program based on alternative crops for former sugarcane land. Feasibility will be appraised with projections from a soybean simulation model. Since large-scale soybean production has never been done on the North Shore, the model will be used to estimate yields that result from management decisions such as location, planting date, cultivar, plant density, and irrigation. With this information, the combination of management practices likely to give high, stable yield and economic profit will be determined.

Procedure

Predicting soybean yield requires a biophysical description of the sites to give the model information on the environmental factors that affect soybean growth. Kawaihapai, Waialua, and Opaeula, sites on the North Shore, were selected for simulating soybean growth and yield (Fig. 1). Based on experience with soybean production outside Hawaii, these three locations were assessed to contain the fewest constraints.

Records characterizing the unique weather and soil of each site were found in the archives of the Hawaii Agricultural Research Center (Osgood, personal communication) and Ikawa et al. (1985). All sites have a weather pattern typical of low-elevation, leeward areas in Hawaii. Solar radiation and temperature are high in the summer months, and rainfall is high in the winter months. Annual solar radiation is highest at Waialua, while Kawaihapai and Opaeula have similar, lower values (Fig. 2). Mean daily temperature is highest at Kawaihapai and lowest at Opaeula throughout most of the year (Fig. 3). Opaeula receives the most rainfall, 1046 mm a year, while Kawaihapai and Waialua receive 880 and 846 mm, respectively (Fig. 4). Soil texture, bulk density, pH, and organic carbon content determine the amount of water the soil can hold, water movement in the soil profile, and root penetration. These soil attributes are derived from soil physical and chemical characteristics in each layer of the soil profile at Kawaihapai (Ustollic Camborthid, fine, kaolinitic, isohyperthermic), Waialua (Vertic Haplustoll, very fine, kaolinitic, isohyperthermic), and Opaeula (Tropeptic Eutrustox, clayey, kaolinitic, isohyperthemic) (Table 1). Each combination of weather and soil characteristics establishes the environmental conditions in which soybean growth was simulated.

1 Three locations on Oahu, Hawaii, that provided data for simulations of soybean growth.

Table 1. Soil physical and chemical characteristics of the top layer of soils at the test sites.

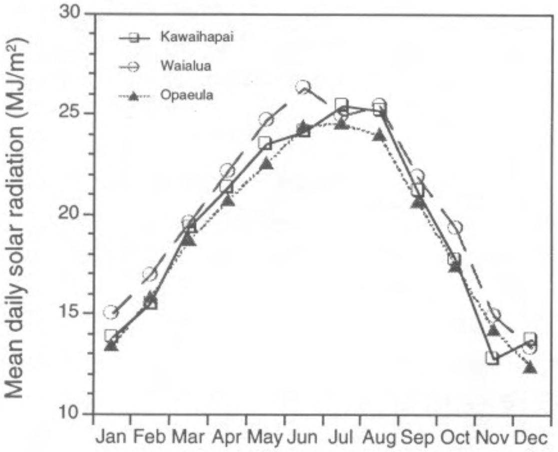
	Site		
Soil characteristic	Kawaihapai[y]	Waialua[z]	Opaeula[z]
Clay %	n.a.	51.1	43.7
Silt %	n.a.	38.9	37.7
Sand %	n.a.	10.0	18.6
Bulk density (g/cm^3)	1.33	1.28	1.31
Organic carbon %	2.0	4.1	1.5
pH	7.7	7.2	5.2

[y]SCS 1976, [z]Ikawa et al. 1985

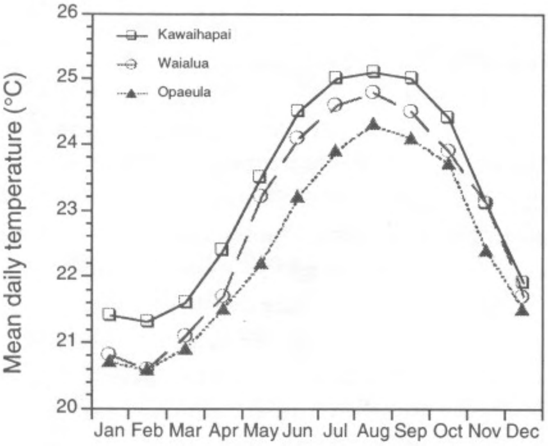
After specifying the environmental conditions, management practices can be chosen to test how well soybean would yield under a prescribed set of practices.

Climatic conditions at the three study sites.

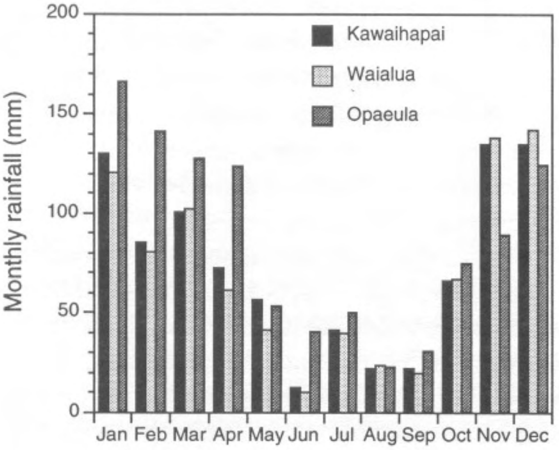
2 **Sunlight received**



3 **Daily temperature**



4 **Rainfall received**



Options for management practices may include cultivar, plant density, irrigation regime, planting date, fertilization, row spacing, and organic residue application. For this study, cultivar, plant density, irrigation, and planting date were combined in the simulations to identify the best management scheme to grow soybean on the North Shore. Four cultivars (cvs. 'Evans', 'Clark', 'Bragg', and 'Jupiter'), four plant densities (150, 300, 450, and 600 thousand plants per hectare with rowspace 0.6 m), four irrigation regimes (no irrigation, 25% trigger, 50% trigger, and no stress), and 12 planting dates (the first day of every month) were combined for a total of 768 schemes (equal to 4 x 4 x 4 x 12). The four cultivars represent types that are grown in latitudes from Minnesota (cv. 'Evans') to Florida (cv. 'Jupiter'). The irrigation regimes of 25% trigger, 50% trigger, and no stress were implemented by allowing the soil water-holding capacity at a 20 cm depth dry down to 25%, 50%, and 99% of field capacity, then irrigation was applied to reach field capacity. The 99% trigger was used as a control treatment and will be referred to as "no stress." Soybean growth was simulated for each of the 768 possible schemes over 20 unique weather sequences.

Predicted soybean growth and yield were simulated using CROPGRO-soybean (Hoogenboom et al. 1994a). CROPGRO-soybean simulates soybean progress through its life cycle at a daily time-step and is dependent on the cultivar, temperature, and daylength. Photosynthesis is simulated through the capture and conversion of sunlight and carbon dioxide to carbohydrate, the building material for plant tissue. Protein production is simulated from nitrogen uptake through the roots and biological nitrogen fixation. CROPGRO-soybean distributes the carbohydrate and protein among plant organs (roots, stems, leaves, pods, and seeds) as affected by the stage of its life cycle, water or nitrogen stress, daylength, and temperature. At the end of the simulated season, the final seed weight is designated to be the yield. CROPGRO-soybean was designed to mimic soybean behavior and has been successfully tested under a wide range of environments (AVRDC 1991, Egli and Bruening 1992, Hoogenboom et al. 1994b, Swaney et al. 1983).

Simulation of the 768 combinations of cultivar, plant density, irrigation, and planting date over 20 seasons was facilitated with the software package Decision Support System for Agrotechnology Transfer v3.0 (DSSAT v3) (Tsuji et al. 1994).

To decide which management scheme was best, a mean-variance analysis was conducted for each location. This technique presumes that the two important

Table 2. Base production cost for producing irrigated soybean in Waialua on a 300-hectare farm.

Operating costs				
A. Pre-harvest costs	**units/ha**	**in units**	**$/unit**	**$ cost/ha**
1. Land preparation				
a. Labor to clear land	6.7	hours	20	134.00
b. Machinery to clear land	6.7	hours	35	234.50
2. Planting				
a. Labor to plant seed	3.7	hours	20	74.00
b. Machinery to plant seed	1.9	hours	35	66.50
3. Pest control				
a. Herbicide: Roundup	1.4	gallons	75	105.00
b. Labor to spray	2.47	hours	20	49.40
c. Sprayer operation	2.47	hours	35	86.45
4. Irrigation				
a. System setup costs	3	sprinkler	20	60.00
B. Harvest costs				
1. Harvesting				
a. Labor to harvest	1.2	hours	20	24.00
b. Combine operation	1.2	hours	35	42.00
2. Commission and excise tax	294,852	$ gross	0.0417	40.98
Ownership costs				
A. Management resource	**gross $**		**% gross**	
1. Management	294,852		5	49.14
2. Office overhead	294,852		2	19.66
B. Capital resources				
1. Depreciation (est.) on	**invested $**	**% depreciation**	**depreciation $**	
a. Machinery and equipment	270,000	14	37,800	126.00
b. Irrigation system	300,000	5	15,000	50.00
	loan $	**% interest**	**interest $**	
2. Interest expense on loan	270,000	10	27,000	90.00
	equity $	**% equity**	**opportunity $**	
3. Opportunity cost on equity	300,000	6	18,000	60.00
C. Land resource	**assessed $**	**% tax**	**tax**	
1. Property tax	300,000	1	30,000	100.00
	premium $			
2. Property insurance	16,000			53.33
	payment $			
3. Leasehold	92,000			306.67
Total				1771.63

factors in deciding which strategy is best are the amount of economic profit and its riskiness. Economic profit is simply the revenue generated from selling the grain minus the cost of its production. Since the alternative to producing soybean in Hawaii is shipping grain from Seattle, Washington, the price of soybean grain was assumed to be the market price of the grain on the U.S. mainland plus shipping, or $449 per metric ton of dry grain in March, 1997. Local production cost scenario was based on a 300 hectare farm on leased land and equipment purchased with a loan (M. McLean, personal communication) (Table 2). The basic production cost for the non-irrigated and irrigated farm was $1602 and $1772 per hectare. The costs for irrigation water, irrigation application, and seed were $0.10 per 1,000 gallons, $1.30 per application, and $0.66 per kg, respectively (M. McLean, personal communication). The riskiness of a strategy is represented by the standard deviation of profit derived over the 20 years.

With the mean profit and its standard deviation, the best strategy to produce soybean can be found based on a few assumptions. Mean-variance analysis assumes that most people prefer high profit and low risk, and most are willing to accept a lower profit if risk can be reduced to a "comfortable level." When the mean profit is plotted against the standard deviation, the best strategies are those with high mean and low standard deviation found in the upper left corner of the graph (e.g., Fig. 9).

Further discrimination among the remaining strategies was done with stochastic dominance analysis (Thornton et al. 1994). Ultimately, only one strategy was selected as best for each location.

Outcome

Results from the simulation

The simulation showed that differences in the daylength sensitivity of cultivars profoundly affected yield. The yield differences result from increases in the time from planting to flowering as daylength increases, i.e., in spring (Fig. 5). This permits more leaf growth, which supports greater yield. 'Jupiter', the cultivar adapted to low latitudes, is the most daylength-sensitive cultivar as seen in its greatly prolonged time to flowering when planted in the summer months. The least daylength sensitive cultivar, 'Evans', had a relatively constant time to flowering regardless of planting date (Fig. 5).

The greatest yield for the daylength-sensitive cultivars was obtained with spring planting dates, while the lowest was with fall planting dates (Fig. 6). Meanwhile, the daylength-insensitive cultivar 'Evans' had a relatively stable yield regardless of planting date. The close relation between yield and time to flowering suggest that yield depends on leaf area. However, yield differences among cultivars across planting dates were not completely dependent on leaf area differences. For any planting date, 'Jupiter' was a larger plant than 'Bragg' (data not shown), yet 'Bragg' had greater yield than 'Jupiter' in the spring plantings (Fig. 6). The yield reduction in the spring for 'Jupiter' resulted from nitrogen deficiency stress that may have been induced by excessive top growth. So, the best yielding cultivar changes with planting date: 'Bragg' had the highest yields when planted from March to June, while 'Jupiter' produced the highest yields for other planting dates.

Increased plant density can increase yield, but seed costs make the yield gain expensive. At all planting dates, increased plant density raised soybean yield (Fig. 7). The mean yield for plant densities was 1739 kg/hectare at 150,000 plants/hectare, 2059 kg/hectare at 300,000 plants/ hectare, 2286 kg/hectare at 450,000 plants/hectare, and 2437 kg/hectare at 600,000 plants/hectare. The diminishing gain in yield for each increase in plant density indicates that yield per plant was greatly lowered as plant density was raised. The reduced yield per plant resulted from increased competition among plants for water, sunlight, and nutrients.

5 **Simulated days from planting to flowering for four soybean cultivars planted at monthly intervals at three sites on Oahu (values averaged over four irrigation regimes, four plant densities, and 20 seasons).**

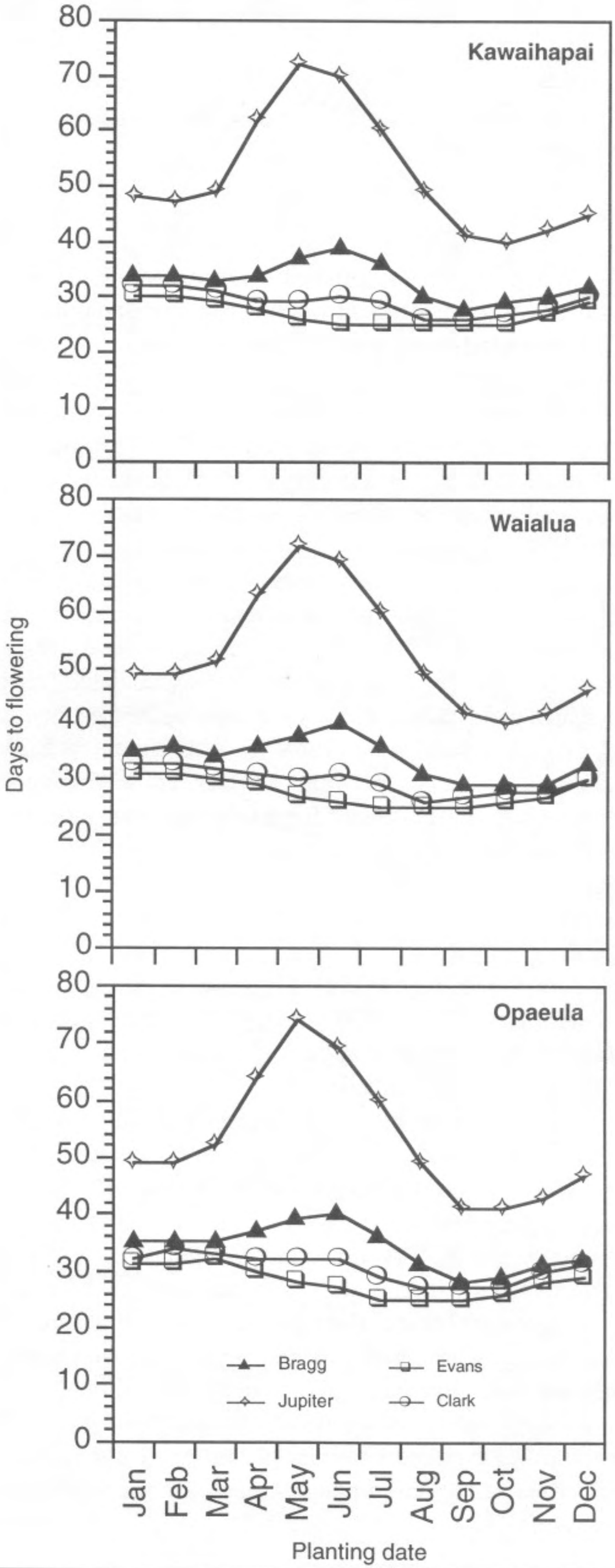


Table 3. Ratio of difference between irrigated soybean grain and rainfed yield (kg/ha) to irrigation water used (mm) for soybean grown at three sites on Oahu.

Location	Ratio (kg/ha per mm of water)[z] 25% trigger	 50% trigger	 No stress
Kawaihapai	8.23	7.74	4.57
Waialua	7.80	7.90	3.41
Opaeula	8.40	7.77	4.19

[z] Yields and irrigation water averaged over four cultivars, four plant densities, and 12 planting dates.

While irrigation generally increased yield over rainfed soybean, efficient water use in soybean production depended on the planting date and location. Except for the fall plantings, which had virtually the same yield for all regimes, irrigation increased yield over rainfed crops for all planting dates (Fig. 8). The 25% trigger irrigation regime gave a larger yield than the rainfed crop, but smaller than the 50% trigger and no stress regimes. The 50% trigger irrigation regime generated yield nearly the same as the no stress regime, but was sometimes higher, probably due to waterlogged conditions in the no stress regime. The most water-use efficient irrigation regime to produce soybean can be calculated from irrigated yield minus rainfed yield, divided by the amount of irrigation water used (Table 3). With the ratios 8.23 and 8.40 kg/hectare per mm of water, the 25% trigger regime was most efficient for producing soybean grain at Kawaihapai and Opaeula. At Waialua, the 50% trigger irrigation regime was the most efficient at 7.90 kg/hectare per mm of water.

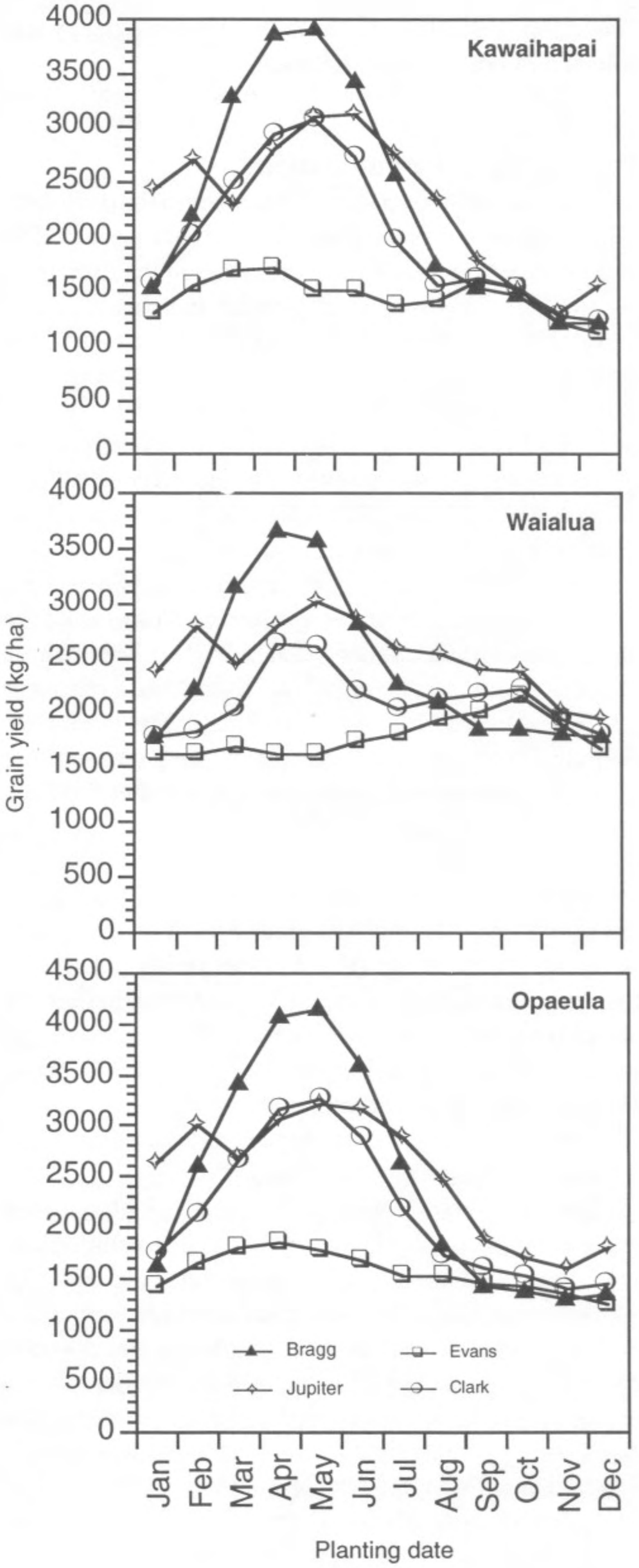
Agronomic interpretation of the simulation results

In summary, simulated soybean yields varied with site and the management practices of cultivar, plant density, irrigation, and planting date.

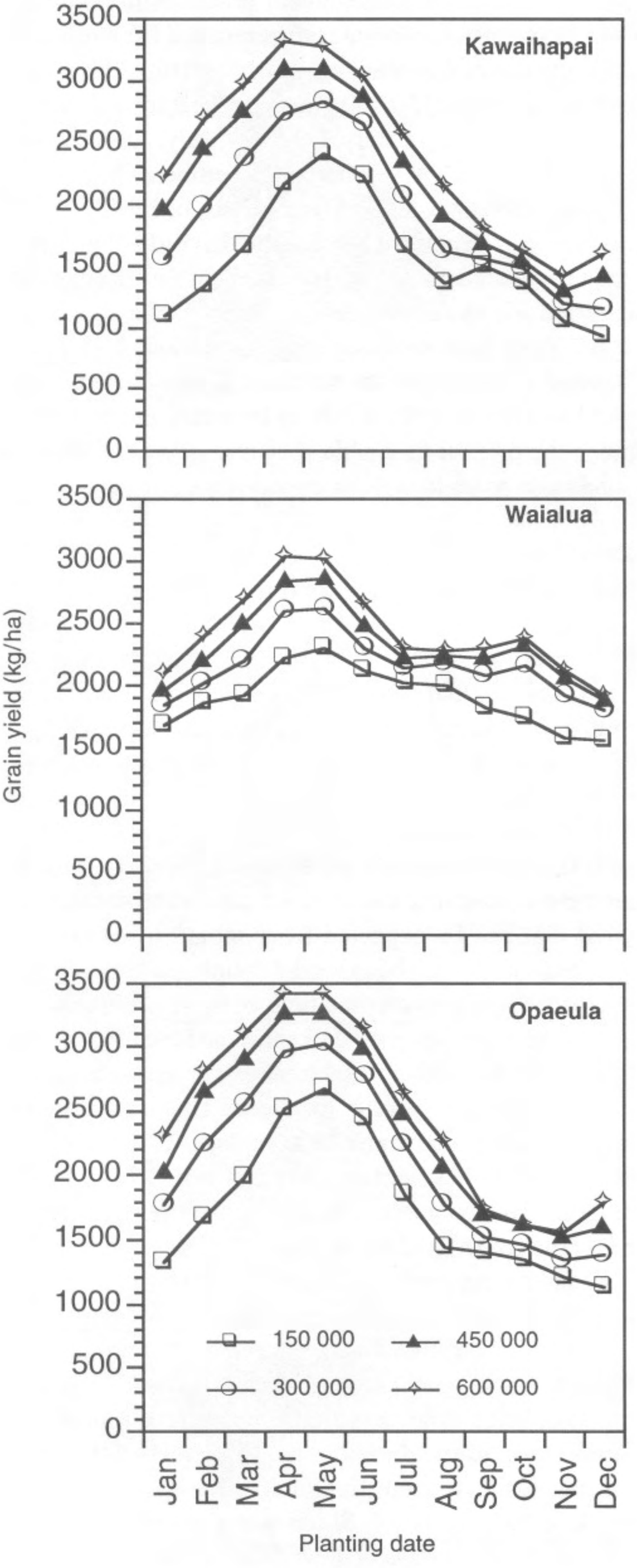
Daylength sensitivity among the cultivars had the greatest effect on yield. Soybean flowers earlier in short days, and delays flowering in long days resulting in a larger plant with more leaves capable of supporting greater yield. However, too much vegetative mass can divert carbohydrate and protein resources away from grain growth. Hence, the cultivar of choice should be one that increases leaf area and supports greater yield, not one with vegetative growth that curbs yield.

Plant density must balance the beneficial effect of capturing the greatest amount of sunlight and the harmful effect of increased plant competition for water and nutrients.

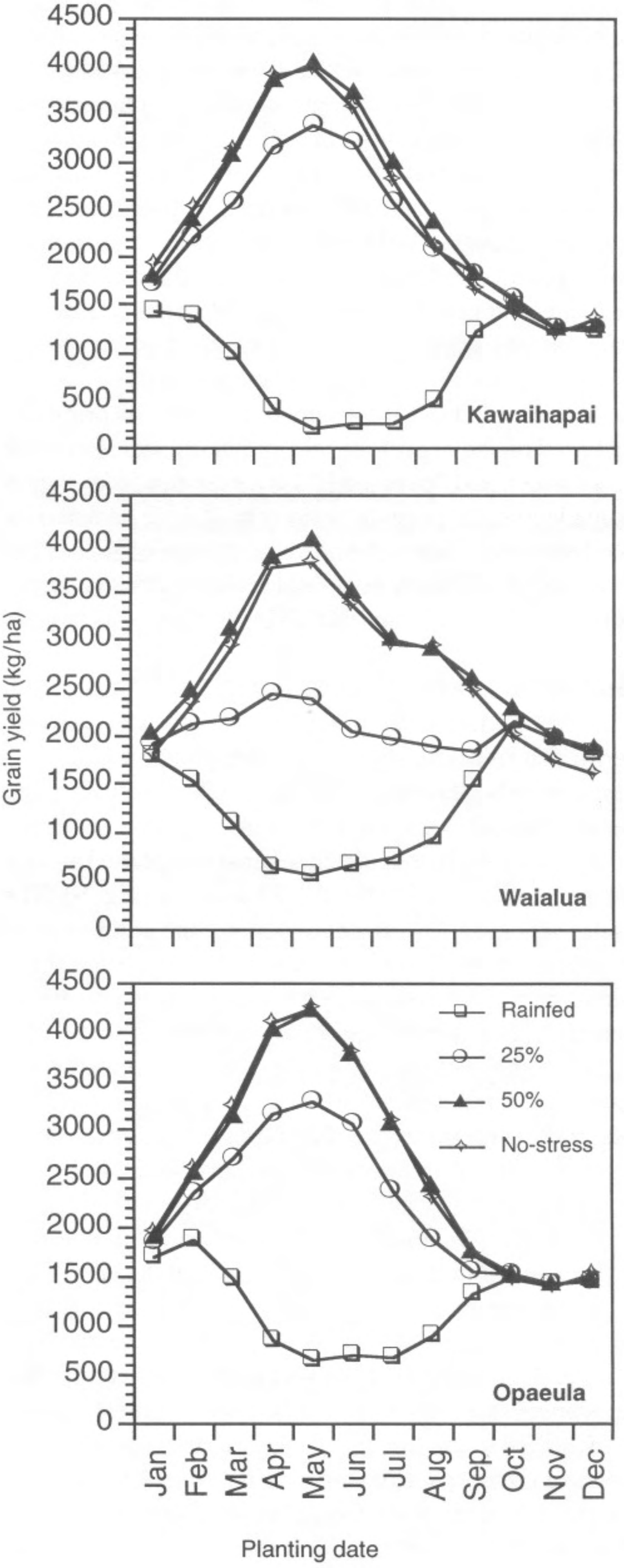
6 **Simulated grain yield (kg/ha) for the soybean cultivars at three sites on Oahu (values averaged over four irrigation regimes, four plant densities, and 20 seasons).**



7 **Simulated soybean grain yield (kg/ha) at four plant densities when planted at monthly intervals at three sites on Oahu (yields averaged over four irrigation regimes, four cultivars, and 20 seasons).**



8 **Simulated soybean grain yield under four irrigation regimes for soybeans planted at monthly intervals at three sites on Oahu (yields averaged over four irrigation regimes, four cultivars, and 20 seasons).**



Irrigation supplies essential moisture to plants, but in excess can create waterlogged conditions that inhibit root growth with increased water cost.

Because weather patterns proceed through annual cycles, changing the planting date alters the daylength, rainfall, solar radiation, and temperature the plant is exposed to. As previously discussed, seasonal daylength, in conjunction with the daylength sensitivity of the soybean cultivar, greatly affects plant size and yield potential.

Cyclical rainfall governs soil moisture status that influences water stress and irrigation frequency as planting date changes. With an inverse relation to rainfall, solar radiation exhibits an annual cycle that affects yield as plants compete to intercept the sun's energy. Planting date has important implications on yield as affected by plant size, soil moisture, and plant competition.

Given the above information, estimates on profit can be based on the expected yield and the expected costs of seed, water, and "overhead." However, this information is inadequate to provide options to make a decision on the best production scheme since a trade-off exists between seed and water costs and revenue, and that trade-off depends on weather that changes from year to year.

Selecting the best management scheme

The better management schemes based on economic profit and riskiness show that generating more revenue can overcome the extra costs incurred to increase grain yield. For each location, the mean economic profit per hectare for each management scheme was plotted against its standard deviation for the 20 seasons (Fig. 9). The better schemes are those found along the outer edge of the upper left quadrant in the scatter. These schemes have high profit, low risk, or both. Generally, these better schemes result when fields are planted with 'Bragg' or 'Clark', are planted in April or May, and mostly irrigated when the soil moisture reaches 50% of field capacity. The plant density for the better schemes range from 300 to 600 thousand per hectare. While irrigation and high seeding rate increased the cost of production, the revenue generated from higher yield of irrigated crops planted in these two months offset the cost.

The best management scheme is the same for the three locations, but the expected profit is different. Stochastic dominance analysis was applied only to the better management schemes. The best management scheme is identified as the function furthest to the right that does not cross over other functions (Fig. 10). The best management scheme was 'Bragg' planted in April at 600, 000 plants per hectare with irrigation triggered when soil moisture reached 50% of field capacity. This management scheme was the best for all three locations. The expected profits for Kawaihapai, Waialua, and Opaeula were $789, $811, and $829 per hectare, respectively.

The worst schemes, in terms of mean economic profit, had several management practices in common. A negative mean economic profit resulted from schemes with any one of the following practices: cultivar 'Evans', a plant density of 150,000 plants per hectare, rainfed, or a planting date in January, February, July, August, September, October, November, or December. The cultivar 'Evans' had consistently lower yields, because of early flowering as discussed previously, that did not generate enough revenue from yield to compensate for the costs incurred for basic production. Planting at a density of 150,000 per hectare was too low to produce high yield. Rainfed crops lacked the moisture to produce adequate yield and planting from July to February either did not place the crop in favorable moisture or solar radiation conditions to yield well as previously discussed.

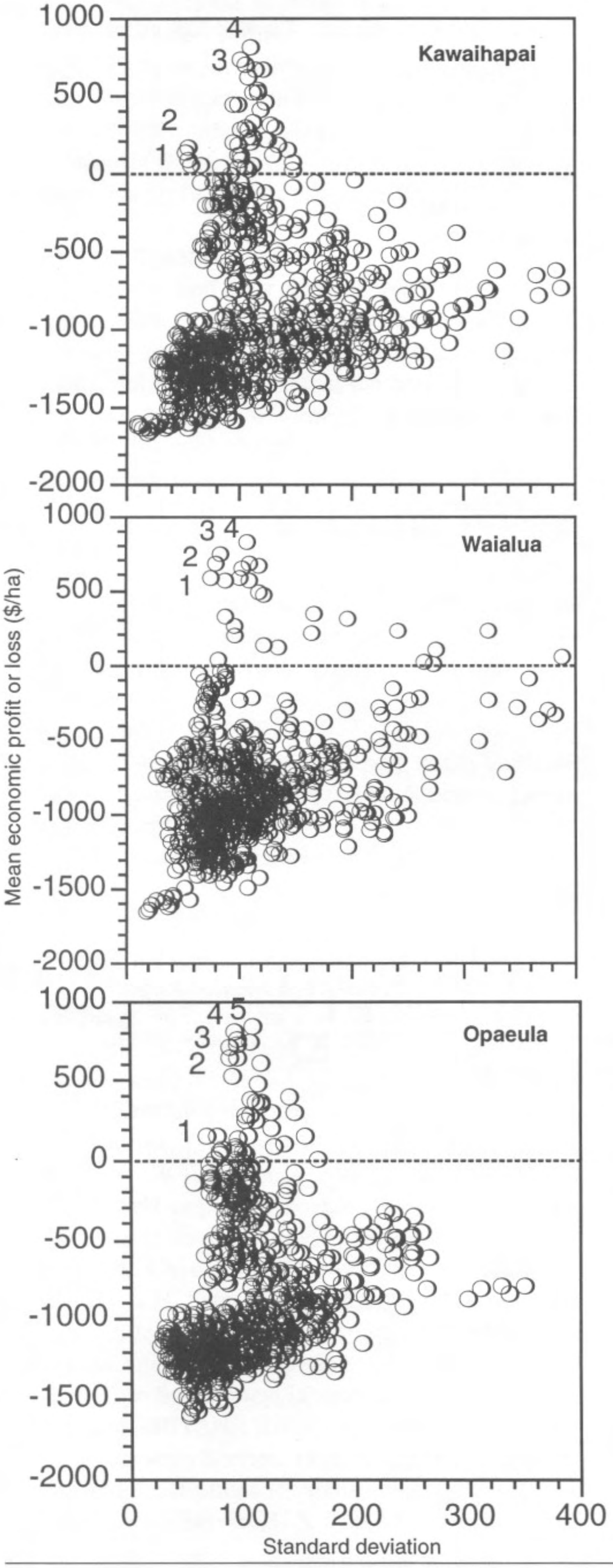
Conclusions

This study shows that an agronomic model and economic analysis are useful tools for agricultural decision-making. In Hawaii, the agricultural environment is complex due to the fact that crops can grow year-round and topographical influences on weather and the many soil types create many unique niches. Finding agricultural management practices to deal with this complexity has been difficult but is possible with careful extrapolation of results from field experiments. However, field experiments are time-consuming and do not quantify the variation in yield that can be expected from month to month and year to year. The soybean model coupled with economic analysis helps to overcome both of these problems.

In this study, crop models shortened the time needed to test and determine suitable management schemes to produce crops in specific locations. This analysis took approximately one week to complete. To achieve the same results, 768 field experiments would have had to be done over 20 years. The faster result is possible because the crop model has the ability to integrate weather, soil, and management information from a site and make realistic predictions on crop performance. With predicted yields, a fast economic analysis can be done to identify feasible management schemes based on profit and risk.

Predicting crop performance can have a profound impact on land-use decisions requiring this information. For this study, the question of whether soybean can be produced on the North Shore was answered from the viewpoint of an entrepreneur. Others who may benefit from this information include farmers who want to know

9 **Mean-variance analysis for finding best management practices to grow soybean on the North Shore, Oahu, based on CROPGRO-Soybean simulations.**



Kawaihapai:

1, 2. cv. 'Clark' planted in May with 50% trigger irrigation at (1) 450,000 plants per ha, and (2) 600,000 plants per ha.

3, 4. cv. 'Bragg' planted at 600,000 plants per ha with 50% trigger irrigation in (3) May and (4) April.

Waialua:

1 to 3. cv. 'Bragg' planted in May with 50% trigger irrigation at (1) 300,000 plants per ha, (2) 450,000 plants per ha, and (3) 600,000 plants per ha.

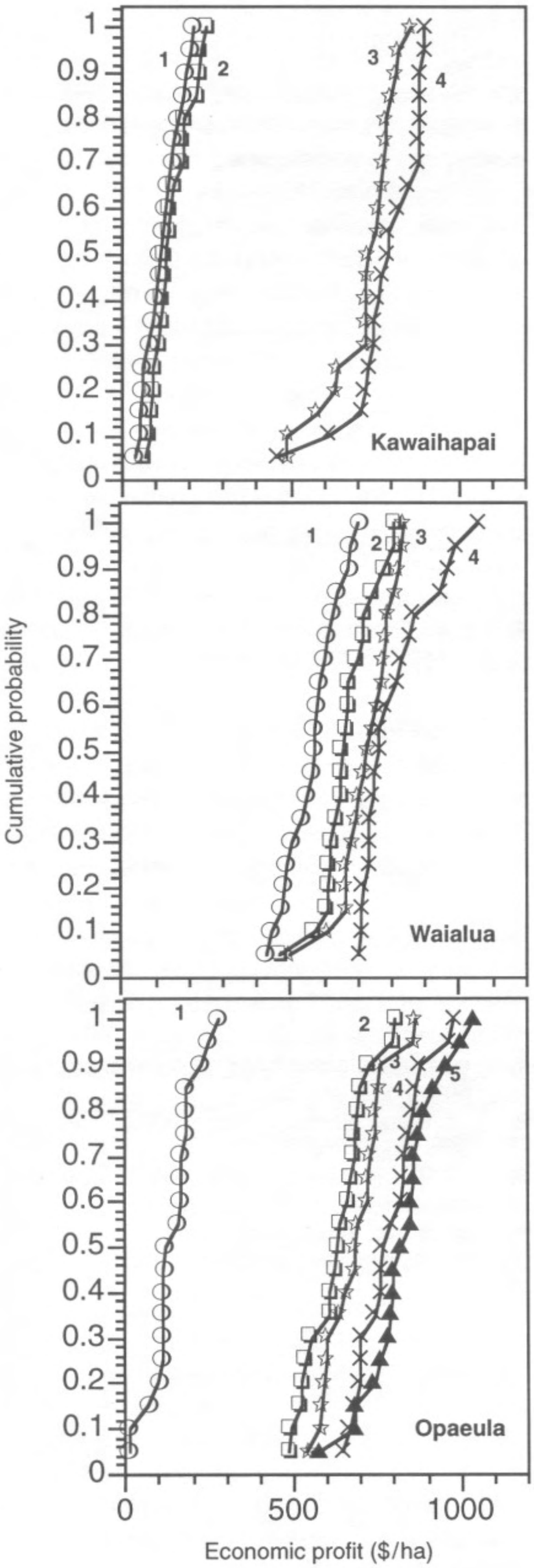
4. cv. 'Bragg' planted in April at 600,000 plants per ha with 50% trigger irrigation.

Opaeula:

1. cv. 'Clark' planted in May at 450,000 plants/ha with 50% trigger irrigation.
2. cv. 'Bragg' planted in May at 300,000 plants/ha with 50% trigger irrigation.
3. cv. 'Bragg' planted in May at 600,000 plants/ha with no stress irrigation.

4, 5. cv. 'Bragg' at 600,000 plants/ha with 50% trigger irrigation planted in (4) May and (5) April.

10 Cumulative probability curves of simulated economic profit from soybean grown at three locations on the North Shore of Oahu.



Curves 1 and 2 represent cv. 'Clark' at 50% irrigation trigger planted in May at
(1) 450,000 plants/ha
(2) 600,000 plants/ha

Curves 3 and 4 are cv. 'Bragg' at 50% irrigation trigger and 600,000 plants/ha
(3) planted in May
(4) planted in April

Curves represent cv. 'Bragg' at 50% irrigation trigger
(1) planted in May at 300,000 plants/ha
(2) planted in May at 450,000 plants/ha
(3) planted in May at 600,000 plants/ha
(4) planted in April at 600,000 plants/ha

Curves represent the following combinations of cultivar, planting date, plant density, and irrigation trigger:
(1) 'Clark', May, 450,000, 50%
(2) 'Bragg', May, 300,000, 50%
(3) 'Bragg', May, 600,000, 99%
(4) 'Bragg', May, 600,000, 50%
(5) 'Bragg', April, 600,000, 50%

whether alternative crops can be produced on their land, bankers who need to quantify the risk involved in an agricultural enterprise applying for a loan, and policy makers who need information on land capabilities. Armed with this information, decisions to commit a plot of land or investment capital to crop production are not answered with a simple yes or no but with estimates of economic profit, options for management practices to produce this profit, and an assessment of risk.

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Conversions

1 kg = 2.2 lb
1 lb = 0.454 kg

1 hectare (ha) = 2.47 acre
1 acre = 0.405 hectare

$1.00/ha = $0.405/acre

1 kg/ha = 1.12 lb/acre
1 lb/acre = 0.89 kg/ha

1 mm = 4⁄100 inch
1 inch = 25.4 mm

20°C = 70°F, 25°C = 77°F