Understanding Traditional Hawaiian Agricultural Knowledge to Improve Taro Production and Resilience in Crop Systems

Project Summary and Preliminary Analysis

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Project background

Native Hawaiians, as with many indigenous farmers and farmers prior to WWII, used a sophisticated lunar/celestial calendar, in conjunction with other traditional practices, to sustainably produce an abundance of food that surpassed in both quantity and quality the staple starch foods currently grown in Hawaiʻi, without outside inputs. Historical records such as planting calendars in the Hawaiian language newspapers, or among more well-known books such as *Ka Moʻolelo Hawaii /Hawaiian Antiquities* (Malo 1838/Emerson 1898) and *Moʻolelo Hawaii*/*Traditions of Hawaii* (Kepelino 1868/Beckwith 1932) described when to plant, but rarely the outcomes (yields and quality) of planting for each night, or lunar phase. Kalo (taro, *Colocasia esculenta*) is one of the most culturally significant crops in our Islands, yet, in multiple versions of the Hawaiian moon calendar available today, only the night of Hōkū (the day before the full moon from a Western perspective) sheds light on yields specifically for kalo, noting that fields will be abundant but the corms small.

Moon phases for planting kalo (Source: Prince Kuhio Hawaiian Civic Club based on J. Poepoe (1906))

Generic good to plant	Hilo – except maiʻa	Hoaka	Kūlua	ʻOlepau	Māhalu – except ʻulu	Hua	Hōkū	Laʻaupau – except ʻuala and ipu	Kāloakūkahi – long or tall plants	Kāloakūlua – except ʻuala and maiʻa	Kāne	Lono	Mauli
Kalo	Hilo	Kūlua – upright	Kūkolu – upright	Kūpau – upright	Akua	Hōkū – **abundant but small corms**	Māhealani	Kāne	Lono	Mauli			

Being able to predict crop yields was as much about knowing you could feed your ʻohana (family) and community for ancient Hawaiians, as it is a concern for modern-day commercial taro farmers. As production costs climb, many farmers in Hawaiʻi, commercial and subsistence, are seeking more sustainable options to improve yields and reduce expensive inputs. The *Understanding Traditional Hawaiian Agricultural Knowledge to Improve Taro Production and Resilience in Crop Systems* project was born out of this dilemma and seeks to better understand traditional Hawaiian lunar/celestial agricultural knowledge to help growers improve production (yield and quality) and build resilience back into their crop systems.

Beginning in 2018, E kūpaku ka ʻāina, together with the Molokai Cooperative Extension Service Hoʻolehua Research and Demonstration Farm (Phase I), and in 2021 with Joshyboy's Farm (Phase II), also on Molokai, implemented field trials to observe and document lunar response in kalo using a Hawaiian lunar planting calendar, and low-cost soil inputs and practices that would mimic to the best degree possible Hawaiian agricultural traditions. No chemical fertilizers were used.

Table 1. Soil amendment surrogates for Hawaiian agriculture practices for dryland kalo

Amendment surrogate	Amount/ acre	How/ When	Traditional comparative
Cover crop and till		During fallow	Mulched fallow
Lime	Based on soil tests	At field prep (pre-plant)	Burning a layer of dry vegetation on top of the kalo when it reached 3 leaves (ie. kūkae puaʻa grass, ʻulu or hala leaves)
Gypsum	Based on soil tests	At field prep (pre-plant)	
Biochar	400-500lbs/ac	Side dress between rows and till in (pre-plant)	
Bone meal	1 ton/ac	At field prep (pre-plant); if need, side dress again at 3-5mo.	Traditional sources: limu, burned opihi, shellfish and bird bones, wood ash, bird guano, mycelium colonized compost

Kalo is typically an annual crop of nine to twelve months depending on variety, climate, elevation and other conditions. Shorter or longer growing cycles for dryland cultivation are predominantly influenced by seasonal temperatures and rains, even where irrigation is available. Field trial planting occurred on the same selected moon phases each month. Plant spacings were 2ft apart and 4ft between rows. Harvest was determined by the kalo, pulling when plants were ready (a traditional practice) rather than dictated by market demand schedules. Data was collected between February 2019 and February 2024 covering three full harvest cycles; a fourth harvest cycle will be completed during the remainder of 2024.

The field trial sites

The field trial sites were all upland or dryland production conditions. The sites were non-traditional taro production areas that required and were supplied with piped irrigation water.

The Molokai Research and Demonstration Farm at Hoʻolehua is Holomua soil series, very deep, well drained soils that formed in material weathered from basic igneous rock (Oxisols). Elevation at the station is 375ft above sealevel with an average rainfall of 20-25 inches annually. The agriculture station is located on former cattle pasture land. The field at the demonstration farm was cropped for at least 15 years prior to being fallowed for several years before project implementation. The Kaluakoʻi farm site is located on the west end of Molokai and is also predominately Molokai series soils and at similar elevation and rainfall as the Hoʻolehua station. It has a history of cattle ranching but no plantation agriculture and was long in fallow prior to 2021.

The kalo varieties

The three Hawaiian kalo varieties chosen for the field trials where Moi (M), Lehua palaiʻi (LP), and ʻEleʻele naioea (EEN). Moi is known for its large corms, starchiness and ability to hold in the field. Once an important cultivar for commercial taro farmers, it is coming back into favor for some growers. Lehua palaiʻi is a member of the Lehua family dominant in commercial wetland taro farms in Hawaiʻi in the 1970s for its ease in milling and its purple corm flesh color (and resulting purple poi) but which has since been passed up by growers as "weak" and for the assumption of small corm size. It is a variety that tends to require harvesting quickly from the field. ʻEleʻele naioea is also known for its dark purple corm flesh and starchiness, but again, a variety assumed to produce relatively small corms. The latter two varieties are less familiar to most commercial taro farmers today except among those who are rediscovering the value of Hawaiian kalo cultivars. All huli planted were first generation ʻohā.

The moon phases

The Hawaiian Lunar Phases Mahealani (Mah), ʻOlekūlua (OK), and Kūlua (K) were chosen for field trial plantings (equivalent to the full moon, waxing half-moon, and waxing crescent). The phases were selected to test their influence on kalo yields on the days considered most successful (Mahealani) and most challenging (ʻOlekūlua) for planting according to the Hawaiian moon calendar (Prince Kuhio Hawaiian Civic Club version after J. Poepoe 1906). This represented the extremes of planting practice; the night of Kūlua was selected at random as a comparison.[1]

The outcomes

The emergence of the first leaf (mohala) on a plant or the opening of a bud or flower is often responsive to the moon. In Phase I, the mean average number of days it took for the first leaf to emerge from the huli (planting stock) was just over 12 days, with Moi having a statistically faster appearance of first leaf than Lehua palaiʻi and ʻEleʻele naioea. We found peaks (slowed response) in some months on specific nights and in specific varieties. In January, the night of Mahealani, which would seem to have the strongest "pull" on new leaves, resulted in the slowest response rate for Moi (19 days to first leaf). Lehua palaiʻi, however, was least responsive on Kūlua nights in February (29 days), and similarly in October and November on the night of ʻOlekūlua (27 and 23 days respectively). First leaf in ʻEleʻele naioea was the least influenced by the phases of the moon, exhibiting only minimal increases in the number of days to first leaf for all three lunar phases over most months, except in August on Mahealani where it had the slowest response of all varieties (30 days) and almost twice as slow as Kūlua in the same month (16 days). We observed a slower response overall in dryland cultivation than wetland plantings.[2]

In Phase II, the appearance of first leaf after planting was significantly different than in Phase I and for huli planted on Mahealani (9.9 days) from those planted on Kūlua (11 days) or ʻOlekūlua (10.9 days) across all varieties. When varietal response was considered, the first leaf in Lehua palaiʻi took the longest to emerge at 11 days, with ʻEleʻele naioea 10.9 days and Moi soonest at 9.9 days.

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[1] A control plot is typically used as a standard against which the experimental component(s) in a field trial are compared. In the case of agricultural field trials, it is the one that remains either untreated, or treated in a conventional manner, while other plots receive variable inputs. Because all nights have a lunar phase (Muku-Hilo, or the no moon nights are recognized phases) and every night will be effected in some way by the moon, the "control" in such an experiment is more challenging; in the field trials this was the night of Kūlua. All plots received the same soil and water treatments throughout which provided a constant across all planting days and kalo varieties.

[2] While not documented for this project, long time observation in loʻi kalo suggests huli are more responsive to the moon with faster emergence of new leaves. This may be related to the water and soft mud of the taro patch which may support faster root expansion than drip irrigation in dryland fields.

Overall yields during Phase I trials at the Molokai Applied Research and Demonstration Farm in Hoʻolehua were estimated at 22,147lbs/ac (at equivalent planting density to Phase II) with 19,163 quality huli (taro tops for replanting of greater than 1in diam). Projected yields for Phase II at the farm in Kaluakoʻi were 34,794lbs/ac (a 36% increase) and 58,450 huli. In both phases, 98 percent of the crop exhibited high corm quality (high starch content) with just 2% failing the float test, an indication of over-ripeness.[3]

During Phase II, average makua (parent corm) weight across all varieties, lunar phases, and months was 6.39lbs compared to 4.6lbs in Phase I (a 28% increase). By variety, Moi averaged 7.08lbs compared to 5.36lbs in Phase I, Lehua palaiʻi averaged 6.06lbs (3.95lbs) and ʻEleʻele naioea 6.16lbs (4.39lbs). Average ʻohā weight was .70lbs. Peak average makua weights were recorded from January through March at between eight and nine pounds as follows: March at 9.22lbs (EEN), 9.15lbs (M) and 8.41lbs (LP), the latter of which was higher in February at 8.96lbs. Lowest weights occurred in November for all varieties at 4.9lbs (M), 4.5lbs (EEN), and 3.32lbs (LP).

Of interest was the difference between best and lowest makua weights. The overall average for all varieties was a loss of .71lbs. This varied for each cultivar, ranging from no difference to 3.48lbs dependent on the month, with March plantings resulting in the greatest disparities and representing a significant difference in yield. Overall average difference by variety was 1.02lbs (M), .99lbs (LP), and .96lbs (EEN). It is not discernable at this time how much, if at all, this was influenced by lunar phase (this may change with further analysis and additional data). No comparison data was available for January.

Table 2. Mean average difference in pounds between average peak and lowest makua (parent corm) weight by variety and month of planting

								[Makahiki season			]
	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb
M	2.18	1.57	.76	.69	1.3	1.15	.2	.95	1.02	.61	--	.92
LP	1.6	1.39	1.89	.25	1.11	1.97	.27	.64	1.01	.39	--	1.39
EEN	3.35	.47	1.23	.14	.42	1.06	.52	1.24	1.25	1.25	--	1.49

Alignments with the annual solstices (sun phases) suggest preferred nights to plant kalo (nights that yielded the highest corm weights at harvest) change during the course of the year, with Mahealani a key night during the month of the spring solstice (March), Kūlua during the month of the summer solstice (June), and all three nights resulting in high yields when planted in the month of the fall solstice (September). The preferred lunar planting day during the winter solstice (December) varied dependent on kalo variety, whereas Kūlua was preferred in the same month for best ʻohā weights.

[3] The float test is a simple on-farm method for determining starchiness, where corms of high starch content will sink to the bottom of a bucket of water and those with poor starch content (loli, overripe) will float. Corms that floated just above the bottom of the bucket but did not surface (less than 2%) were considered to still be of viable market quality.

Table 3. Lunar phase planted for peak and lowest makua and ʻohā (corm and cormel) weights by solstice where all varieties align

		Spring solstice (March)	Summer solstice (June)	Fall solstice (Sept)	Winter solstice (Dec)
Peak Weight	Makua	Mahealani	Kūlua	All three nights	
	ʻOhā	Mahealani		ʻOlekūlua	Kūlua
Lowest Weight	Makua		Mahealani		
	ʻOhā		ʻOlekūlua		

Makua for all three varieties did best when planted on the night of Mahealani in the months of January, March, May, August and November, but preferred Kūlua in June. ʻOhā (cormels) had preference for Mahealani in March and July but Kūlua in December (while January is recorded as a month of peak weights on the night of Mahealani, no other data was available that month for comparison of lowest weights).

Table 4. Lunar phase planted for peak and lowest makua and ʻohā (corm and cormel) weights by month where all varieties align

[Makahiki season] (Oct–Feb)

		Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb
Peak Weight	Makua	Mah		Mah	K		Mah			Mah		Mah	
	ʻOhā	Mah				Mah					K	Mah	
Lowest Weight	Makua		OK		Mah		K			OK			
	ʻOhā				OK		K						OK

Not all varieties preferred to be planted on Mahealani or on Mahealani in every month, with each variety showing preference for other days 33% of the time. For Moi, this occurred between the summer and winter solstice, whereas Lehua palaiʻi shifted choice planting days beginning after the Spring solstice with a secondary preference for planting on the night of Kulua. ʻEleʻele naioea shifted every other month coming out of Makahiki season through summer solstice, then returned to Mahealani but preferring ʻOlekūlua in October and February.

Table 5. Lunar phase planted for peak and lowest makua (corm) weights by variety and month

[Makahiki season]

		Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb
M	Peak Weight	Mah	Mah	Mah	K	OK	M	OK	M	M	K	Mah	Mah
	Lowest Weight	OK	OK	OK	Mah	Mah	K	K	K	OK	Mah	No data	OK
LP	Peak Weight	Mah	K	Mah	K	Mah	Mah	K	Mah	Mah	K	Mah	Mah
	Lowest Weight	OK	OK	OK	Mah	K	K	OK	K	OK	Mah	No data	OK
EEN	Peak Weight	Mah	K	Mah	K	Mah	Mah	Mah	OK	Mah	Mah	Mah	OK
	Lowest Weight	K	OK	K	Mah	OK	K	OK	Mah	OK	K	No data	Mah

Overall mean average ʻohā/huli production was not statistically different across moon phases at 10-11 huli of greater than 1in per plant. Differences are evident when evaluated by lunar phase and variety with Moi averaging 10 huli per plant, Lehua palaii 15 and Eleele naioea 14 ʻohā, the latter two significantly more than described in *Bulletin 84: Taro Varieties in Hawaii* at 5 to 10 ʻohā (Whitney, Bowers, and Takahashi 1939). Eleele naioea proved to be the most prolific producer of ʻohā, its highest productivity occurring in March (25.75).

Average ʻohā weight (.70lbs overall) varied across lunar phases and correlated to some degree with number of ʻohā produced per plant. In plantings on Mahealani, ʻohā and huli peaked together in March (spring solstice) and November but were opposite (high and low pairs) in May and February. In Kūlua, lowest ʻohā weight and peak huli numbers aligned in July, whereas in September (fall solstice) peak ʻohā and lowest huli numbers coincided. Peak ʻohā and huli occurred in plantings from ʻOlekūlua in March, while lowest ʻohā and huli numbers aligned in October, and peak ʻohā and lowest huli counts paired in February.

Table 6. Mean average ʻohā weight (lbs) and number of huli all varieties by moon phase planted and months

[Makahiki season]

Moon	ʻOhā wt	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb
Mah	Peak	.89								.82		.89	.86
	Lowest			.57							.59		
	Huli #s												
	Peak	12.27		14.68	12.06	12.59				14.83			
	Lowest		8.68										7.30
K	Peak							.86					.95
	Lowest					.52				.53			
	Peak		12.46	11.27	11.25	11.87	12.49						
	Lowest							6.89	7.78				

Moon	ʻOhā wt	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb
OK	Peak	.71					.78	.79					.73
	Lowest								.57		.58		
	Peak	15.86		12.18		12.59							
	Lowest								8.14				7.44

Manaʻo - Things to Consider:

Written and oral tradition suggests planting was not favored during Makahiki season (from October or November to February, dependent on when the rise of certain constellations occurred), nor during ʻOle nights. The data appears to challenge these traditions; with plantings in the latter half of Makahiki producing the best corm weights overall and ʻOlekūlua yielding the best weights for some varieties.

Several factors may be influencing these outcomes. Primary is the fact that three cycles of planting for three kalo varieties represents only a small set of information. Understanding long term lunar/celestial growth patterns recorded by ancient Hawaiian agriculturalists, and determining whether they still hold true or if new patterns have emerged, will take time. There are also many more moon phases and locations to learn from.

The order of the months (or rather the lunar cycles that make up a Hawaiian "year;" 29.5 days per cycle) and their characteristics, differed from wet to dry sides of each island, and from island to island. While the moon cycles remain constant, the rising of celestial bodies at night changes across spacial distances (longitude and latitude). The degree to which climate has changed and/or the rise of each month has shifted (or not) over the last 200 years is unknown. Makahiki was the wettest and coolest season of the year; sometimes too wet to plant. Rainfall data collected through most of the 20th century and into the present indicates significantly less rain falls on and is retained in aquifers and soils in our islands now than in the past. In the future, what we know as Hoʻoilo, the wet or winter season, may no longer be wet even as strong winds and big waves persist.

Sunlight is an influencing factor on plant growth and corm weights. Kalo planted during Makahiki and the season of Hoʻoilo when the cloud cover was more prevalent received more sunlight hours per day and more sun days as they matured in the summer months and had the highest yields of the year, whereas, kalo planted in November exhibited the lowest weights overall despite only one month's difference. Disparities between average highest and lowest weights for each variety in the same month seems to rule out hours of sunlight as a source of such differences.

This raises some interesting questions –has climate shifted to such a degree that what was once expected weather behaviors for each month during the Makahiki season of 200 years ago is no longer true? Has the "wet season" behaviors of Makahiki shortened from its historic Oct/Nov – Feb cycle? Have the behaviors of the months shifted from their traditional order? What other factors beside climate might be influencing the differences between best and lowest weights in a single month?

The length of fallow prior to planting and overall soil conditions also influence yield and quality. Hence, the higher corm weights and overall yield at the Kaluakoʻi site may have been due to never having been in plantation agriculture. While observations have been ongoing in loʻi kalo, data was not collected in the same manner as the dryland field trials allowing for only anecdotal comparison.

Some general growth behaviors attributable to the moon appeared to hold true across all three cycles, no matter the weather or the season, suggesting that even in a different place or elevation, wetter or drier conditions, such characteristics will still be visible, e.g., on Kū nights, kalo plants will be relatively taller than those planted on other lunar nights.

Lastly, these yields were achieved in hot, dry Hoʻolehua and Kaluakoʻi, Molokai with an average annual rainfall of 25 inches or less, and known as ʻuala (Hawaiian sweet potato) growing places but not for taro. Even with the modern addition of drip irrigation, the abundance achieved during this project is testament to the wisdom that evolves out of the millennium-long observations of Hawaiian farmers of old and speaks to our ability to produce essential quality foods (indigenous staple starches) in Hawaiʻi in the face of changing climates and soil conditions. It also requires us to not make assumptions based on the short time frame of this project; to make note of emerging patterns, continue to hone our observations skills, and recognize that it is just a beginning.

Native Hawaiians impressively met all their staple starch and vegetable needs to establish and sustain themselves using the limited resources available and developing systems that allowed them to plant the land over and over again and still maintain a high degree of abundance. Today, we understand the benefits of using local organic resources in farming, but, retain little of the knowledge regarding the impact of lunar and celestial patterns on yields that Native Hawaiians intertwined in their food production systems and practices over thousands of years. This on-farm project is an ongoing effort to relearn what impact these celestial resources have on agriculture production.

Interested in joining us in ongoing observations from your own farm or for more information, contact E kūpaku ka ʻāina at https://www.ekupakukaaina.org/

Or drop us a line at:
E kūpaku ka ʻāina, 224 Ainahou Place, Wailuku, HI 96793

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