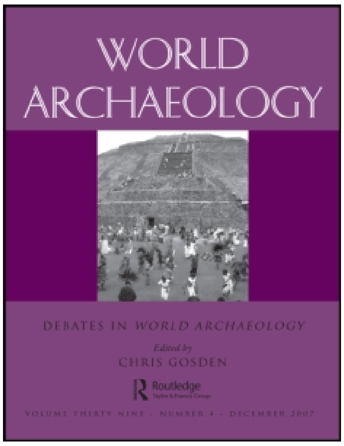

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The role of agricultural innovation on Pacific Islands: a case study from Hawai'i Island

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The role of agricultural innovation on Pacific Islands: a case study from Hawai'i Island

Mark D. McCoy and Michael W. Graves

Abstract

Agriculture was essential in providing for food security, population growth and surplus social production on Pacific Islands. This paper discusses innovations first seen between AD 1400 and 1650 that opened up roughly 60 per cent of the available farm land in the Hawaiian Islands. These innovations include terraced fields in narrow gulches, some using simple flooding to take irrigation water to adjacent lands, and permanent rock and earthen alignments that served as windbreaks, retained soil moisture and lessened erosion. The resulting expansion pushed agriculture into increasingly marginal areas and helped the transition to a surplus-driven agrarian economy. Elite competition for territory promoted the production of surplus and the resulting increased geographic scale of polities helped reduce the burden of supporting the non-producer class by spreading the cost over a broader area.

Keywords

Agricultural innovation; irrigation; rainfed farming; Polynesian archaeology; Hawaiian prehistory.

Introduction

One of the most remarkable feats in prehistory was the discovery and occupation of virtually every habitable island located across the vast Pacific Ocean (Fig. 1). The colonization of the region began in the Palaeolithic, over 40,000 years ago, with the initial occupation of New Guinea and nearby islands in Melanesia. In the Holocene, agricultural traditions begin with the domestication of local crops grown in irrigated fields and expand, beginning about 6,000 years ago, with the migration of Austronesian-speaking peoples from Taiwan who brought to the region novel farming techniques and domesticates. People with Lapita-styled pottery carried with them aspects of both agricultural traditions

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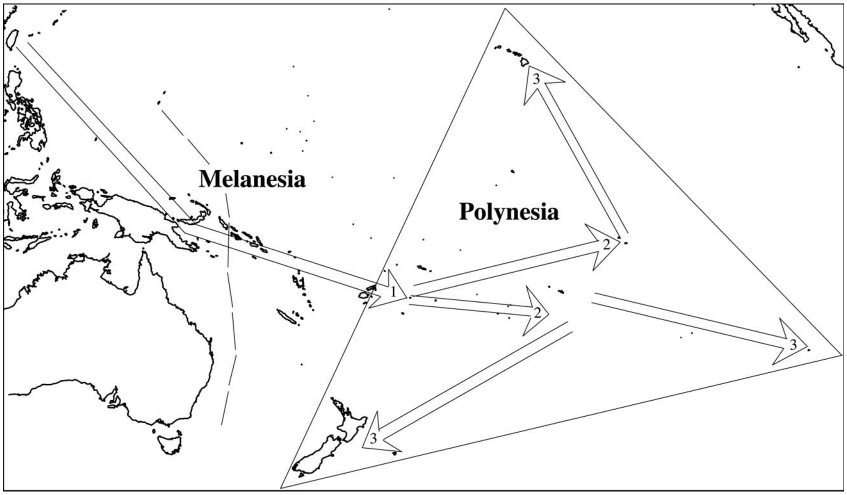

Figure 1 The origins of Polynesians. This simplified model of regional settlement begins with Pleistocene colonization of Near Oceania (dashed line, *c*. 40000 BP), followed by (1) migration from Southeast Asia of Austronesian language speakers making Lapita-styled pottery (*c*. 6000–3000 BP), (2) expansion of settlement from Western to Eastern Polynesia (*c*. 1000 BP) and the colonization of Marginal East Polynesia (*c*. 1000–700 BP) which includes the Hawaiian Islands in the north, Easter Island (Rapa Nui) in the east and New Zealand (Aotearoa) in the south.

as they explored and colonized Melanesia and Western Polynesia. The settlement of the margins of Eastern Polynesia 1000 to 750 years ago represented the last phase in this serial colonization of the Pacific, and included the Hawaiian Islands, Easter Island (Rapa Nui) and New Zealand (Aotearoa).

Agriculture was vital to the successful colonization of these remote islands by providing food security (Addison 2008; Anderson and O'Connor 2008), supporting population growth in these isolated settings (Kirch and Rallu 2008) and surplus 'social production' (*sensu* Brookfield 1972), a necessary element in the evolution of complex, hierarchical societies (Earle 2002; Kirch 1984, 1994). Newly settled islands often had a similar natural environment to previously occupied islands but all required some adaptation of farming techniques (Kirch 1984, 1994).

In this paper we consider the evolution of farming on the island of Hawai'i (Fig. 2), the largest of the Hawaiian Islands. Like elsewhere in the Pacific, the island's agrarian history can be broken into three periods: a prehistoric period (*c*. AD 800–1650) when there was initial adaptation, expansion and intensification of agriculture; a protohistoric period (AD 1650–1795) when these production systems began to be incorporated into the larger world system through contact with Europeans; and an historic period (AD 1795–1900) when incorporation is complete and industrial farming becomes the norm (Kirch 1985; Kirch and Sahlins 1992).

We present evidence for agricultural innovations first seen late in prehistory between AD 1400 and 1650 that were key in opening up farmland on Hawai'i Island which accounts for roughly 60 per cent of the available farmland in the archipelago. In turn, this adaptive engineering helped fuel an expansion of agriculture that allowed elites to institutionalize

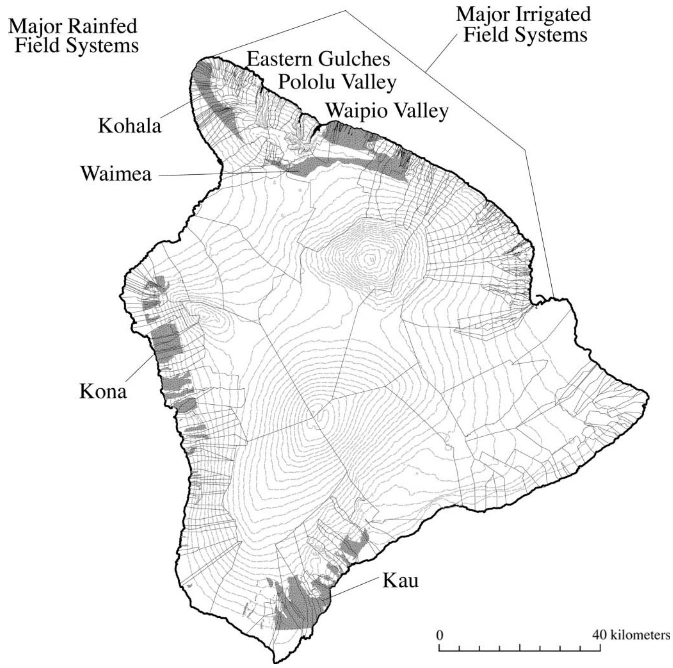

Figure 2 Agricultural zones of Hawai'i Island (after Ladefoged et al. 2009): stippled = rainfed farming, black = irrigated farming; community territory boundaries and 500-foot elevation contours shown. Hawai'i Island, unlike most islands in Polynesia, is geologically young with few valleys and large areas of rich, young soils. This limits the potential for irrigated agriculture but creates opportunities for large-scale rainfed farming.

their power and promote a shift from subsistence to a surplus-driven economy. In the long term, agricultural innovation helped establish larger territories, a large non-producer class and ultimately more powerful leaders.

Pacific Island agriculture: inherited, borrowed and invented methods of farming

Innovation is inherently difficult to detect for archaeologists since it requires a broad knowledge of relevant ancestral traits and contacts with outside groups to identify a trait as novel and not traditional or the product of borrowing. Fortunately, the origins of Polynesians and their colonization of the most naturally isolated island groups in the world has been the focus of intense study by ethnographers, ethnohistorians, historical linguists, geneticists and archaeologists (see Kirch 2000 for a recent summary). Primary sources of crops and farming techniques found in the Hawaiian Islands come from Austronesian language speakers in island Southeast Asia with contributions from non-Austronsian traditions developed in New Guinea. The latter contributed domesticates including the staple crop taro (*Colocasia esculenta*), yams (*Dioscorea* sp.), as well as the tree crop, breadfruit (*Artocarpus altilis*). Key domesticated animals and plants contributed by Austronesians include pig (*Sus scrofa*), chicken (*Gallus gallus*) and dog (*Canis lupus* *familiaris*), as well as bananas (*Musa* sp.) and other tree crops. There were also purposeful transfers of crops from the Americas, most importantly the staple crop sweet potato (*Ipomea batatas*). Long-distance sea going Polynesian canoes facilitated these transfers and the sweet potato's introduction to the region likely pre-dated, or was concurrent with, the colonization of the Hawaiian Islands (Ballard et al. 2005; Hather and Kirch 1991; Horrocks and Rechtman 2009; Ladefoged et al. 2005; Yen 1974).

Farming techniques taken to the Hawaiian Islands were likely shared among other Polynesian groups settled beforehand (Table 1). For example, when Spriggs (1990: 185) looked at the relative ubiquity and geographic distribution of irrigation techniques in sixty-two cases across fourteen Pacific Island groups, he found a close association between pondfield or paddy agriculture and Oceanic Austronesians, including those in the Marquesas Islands where Hawai'i's first settlers likely originated (Spriggs 1990: table 1). Thus, the conservation of this trait in Polynesia indicates that pondfield agriculture was among those methods practised from the earliest occupation of Hawai'i.

The question of the origins and distribution of rainfed techniques like windbreaks has not been well studied; however, at the time of European contact concern for wind control was most evident in marginal East Polynesia where the sweet potato was an important crop. This is not surprising given sweet potato is a low-growing crop that prefers well-drained, non-irrigated soils prone to wind erosion. Ladefoged et al. (2003: fig. 3) have described the value and effectiveness of windbreaks in reducing evapotranspiration and sheltering young, low-lying plants from wind damage. McCoy and Hartshorn (2007) have shown how walls reduce wind erosion that would inevitably become a problem wherever rainfed farming occurred in dry, fine soils. On a larger scale, several studies have now shown that farmers made the effort to expand windbreak farming across these types of

Table 1 Distribution of irrigation methods across Oceania (after Spriggs 1990: table 1). Note the narrowing of variety from west (Melanesia) to east (Polynesia)

	Simple flooding	*Island beds*	*Pondfields*	*Furrow irrigation*	*Method unclear*
Melanesia					
West New Guinea	X				X
Papua New Guinea	X	X	X		X
Solomon Islands			X		
Vanuatu			X	X	X
New Caledonia		X	X		
Fiji		X	X		X
Polynesia					
Futuna		X	X		
Samoa					X
Cook Islands		X	X		
Society Islands			X		
Austral Islands			X		
Mangareva			X		
Marquesas Islands			X		
Hawaiian Islands	X	X	X		

environments to take advantage of 'sweet spots' where moderate rainfall and nutrient-rich soils supported cultivation in fixed, permanent fields (Vitousek et al. 2004). Outside these areas, conditions were either too arid to support crops or too wet and weathered to maintain sufficient nutrients in the soil.

Without a larger study of rainfed methods it is difficult to eliminate completely the possibility that Hawaiian windbreak farming was ancestral or borrowed; however, it is likely that it was independently invented given the vast distances between Hawai'i, Easter Island and New Zealand. This convergent innovation is akin to the history of another trait these groups share, the two-piece bone fishhook. In the case of the two-piece fishhook, a lack of pearlshell – the preferred material for making traditional one-piece fishhooks – appears to have inspired each community independently to come to the same solution (see review in Walter 1996: 514–15). The similarities in material and design of two-piece bone fishhooks are explained by bone being the next best material for the job and the physical mechanics of fishhooks. Similarly, windbreak farming was likely an innovation converged upon by Polynesians out of necessity when growing sweet potato.

Remarkably, Hawaiians also appear to have re-invented an irrigation technique called simple flooding that may have dropped out of the range of practices used by some groups before the settlement of Polynesia. Simple flooding is defined as when 'water is led to the upper edge of the garden and then circulated down, often with simple wood or stone barriers to slow down the flow, thus helping to trap sediment and control erosion', a common variant is 'when rough terraces are constructed directly in small stream beds' (Spriggs 1990: 175). While present in Melanesia, the apparent dearth of examples in Polynesia may be due to some combination of loss due to founder's effect and decreasing contact as interaction spheres shrank in prehistory.

However, not only is simple flooding present in Hawai'i, it is featured prominently in Kirch's (1977) classification of pondfield construction. What Kirch defined as 'Type I' – barrage terraces built directly in a stream channel, often on the side of a valley, with no ditch – is a clear case of the use of simple flooding. The remaining three types of Hawaiian pondfields are found more broadly in Polynesia and include small fields next to a stream course fed by a single ditch at the top of the system (Type II), fields built on the inner banks of a stream bend with a canal ('*auwai*) on the periphery (Type III), and those built on stream bends with two periphery irrigation ditches working in concert (Type IV). Further, simple flooding was unlikely to have been borrowed since major long-distance contacts post-colonization were likely with Tahiti and other Polynesian groups that lack simple flooding.

We are not the first to raise the possibility that Hawaiians re-invented irrigation techniques used elsewhere in the Pacific. In Clark and Kirch's (1983) survey of the Waimea Field System (Fig. 2), as well as later surveys, limited use of irrigation was noted in these rainfed fields (Burtchard and Tomonari-Tuggle 2004). Spriggs calls the type of irrigation found in Waimea 'aberrant in form… [and it] may represent a local innovation' (1990: 176) of furrow irrigation and/or simple flooding irrigation. However, his view at the time was that due to a lack of 'clear information on water-application techniques', it is not possible to say what methods were used (Spriggs 1990: 176). Overall, while archaeologists in the Pacific have been conservative in identifying innovation, as opposed to tradition or borrowing, in this case at least simple flooding and windbreak farming do appear to be true innovations.

Innovation in the development of Hawai'i Island agriculture

Polynesian farmers had for generations settled geologically old islands with deep-set valleys and had never before encountered a high volcanic island as geologically young and large as Hawai'i Island (Fig. 2). The island's first farmers would have been surprised to find that on this massive island with a land mass greater than all the other Hawaiian Islands combined, they found little arable land for irrigating – only a single large valley, a few mid-sized valleys and networks of gulches. These valleys and gulches account for less than 8 per cent of the total land in the archipelago naturally suited for pondfield agriculture (Ladefoged et al. 2009). This limitation comes from the fact that the island's gulches are considerably narrower (*c*. 100–50 metres wide) and shallower than valleys, thus restricting expansion. However, unlike the high ridges adjacent to large valleys, the land between these gulches, called tableland, is more naturally accessible for irrigation – a factor farmers would later use to their advantage. On the arid west side, these same farmers found several vast areas of rich, young, volcanic soil that, while productive, were nearly un-usable for planting in their unaltered form due to persistent high winds.

The two innovations that helped Hawai'i Island farmers expand across these environments were neither examples of new technologies nor the development of new cultigens or variants, but the innovative application of relatively simple technology. These innovations were: (1) terraced fields in narrow gulches, some using simple flooding barrage terraces and water diversion channels to take irrigation water from gulches to the otherwise un-watered adjacent tablelands; and (2) permanent rock and earthen alignments on west- and south-facing slopes that served as windbreaks, retained soil moisture and lessened erosion. The examples of gulch and tableland farming given below are from the Eastern Gulches portion of the island's North Kohala District and are reported here for the first time. Examples of windbreak farming are drawn from the same district, but are part of a Leeward Kohala Field System which has been well described in previous studies.

Gulch and tableland fields

The distribution of irrigated pondfields in the Eastern Gulches region runs from the coast to roughly 1,200 feet above sea level (366 masl), or about 4–5km inland (Fig. 3). These fields vary widely in construction style and include several large examples of simple flooding 'Type I' fields (Kirch 1977). Fields designated here as Halawa-13 are an excellent example of using the simple flooding technique at a local spring to flood thirty-seven barrage-terrace ponds built directly in the gulch bottom over an area of 3.1 hectares (1.3 acres). In all, it is difficult to find a portion of gulch bottom in this region that has not been modified in some way for farming.

Historic descriptions and maps indicate the tableland between drainages was irrigated for farming (Handy 1940). However, due to recent disturbances of the land between gulches for modern industrial farming, archaeologists have yet to document irrigated

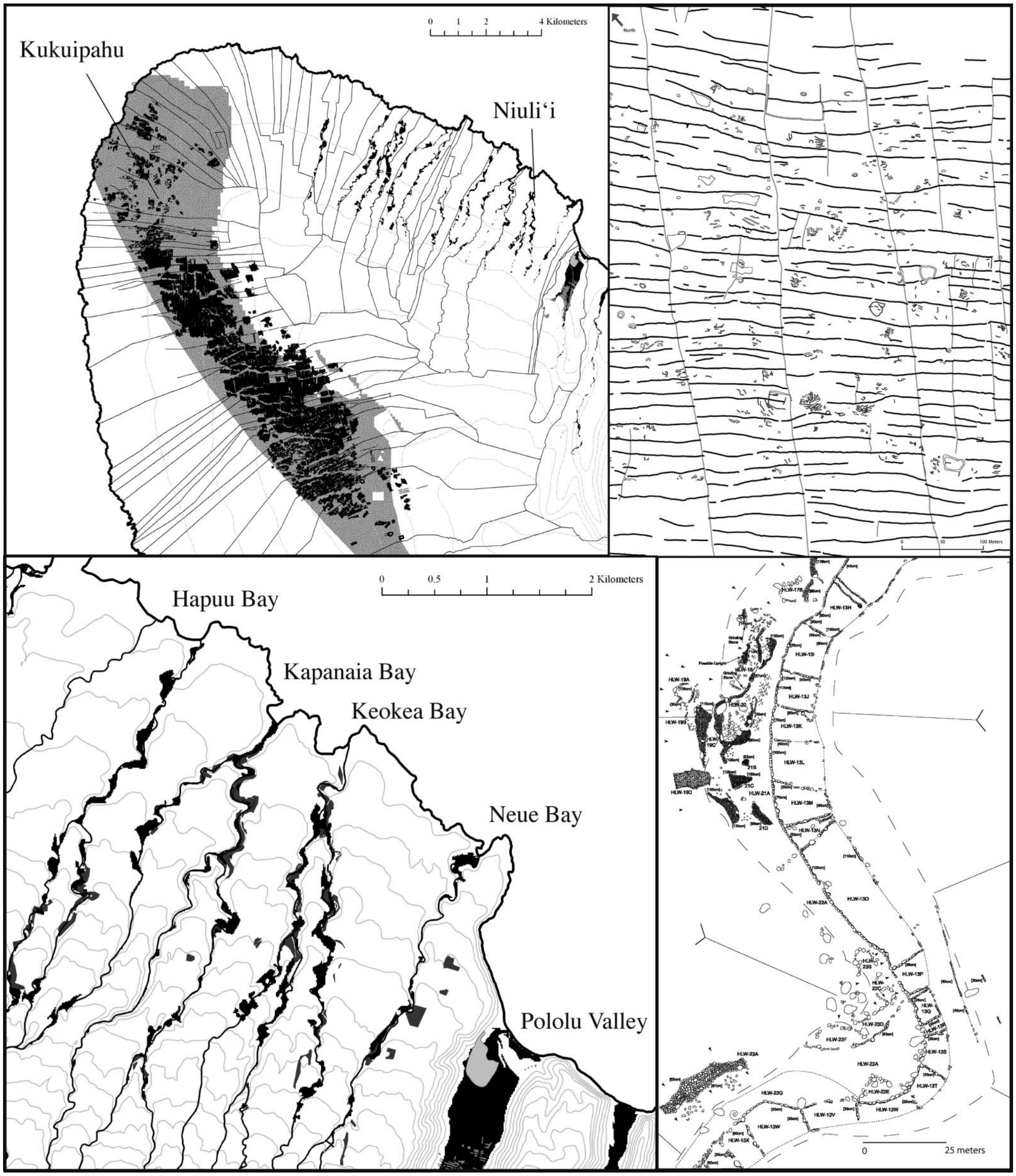

Figure 3 Distribution of rainfed and irrigated agriculture, North Kohala District, Hawai‘i Island. District map of areas with high potential for rainfed and irrigated farming overlaid with the distribution of known archaeological features (top left: after Ladefoged et al. 1996); a detailed map of windbreak fields including boundary trails and other features (top right: after Ladefoged and Graves 2008); map of the Eastern Gulches (bottom left) including fields noted on historic maps and survey (grey); detailed map of irrigated pondfields (Type I, Kirch 1977) given site designation Halawa-13 (bottom right).

tableland fields. We hypothesized that irrigation canals that drew water downslope and eventually out of the side of the drainage to fields waiting on the tableland might be preserved in gulches (Fig. 4). To test this, we excavated two trenches at locations where it

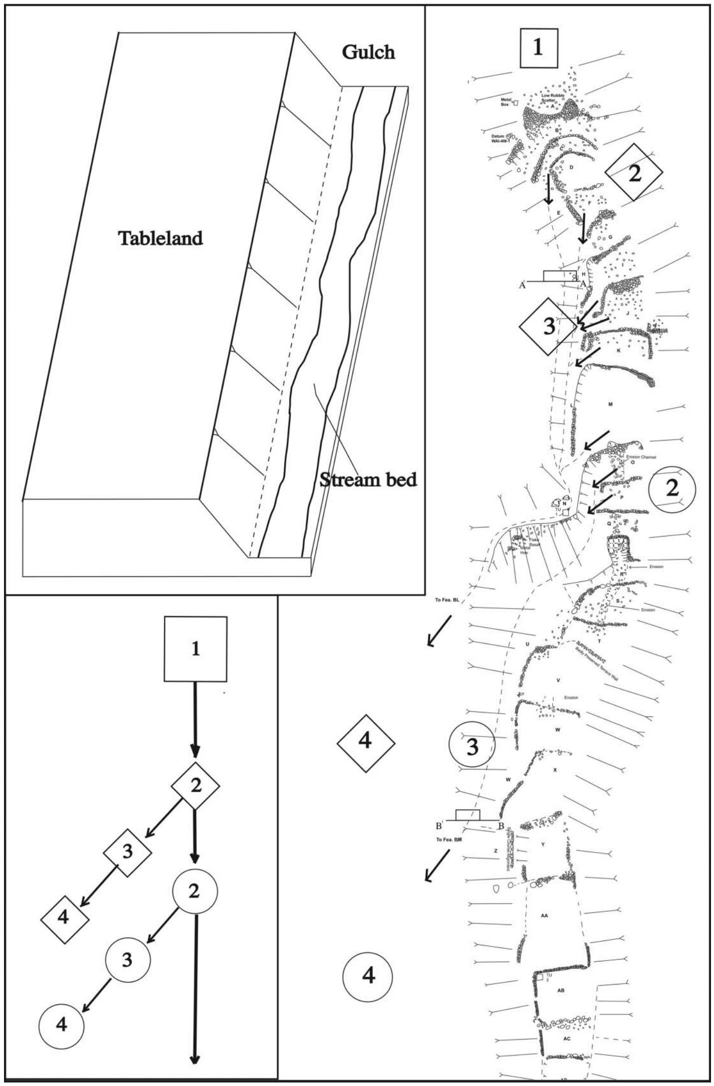

Figure 4 Plan view map of Gulch Fields built in streambed and canals leading irrigation water to tableland fields, Waiapuka-4W, Eastern Gulches, Hawai'i Island. Schematic shows (1) the location of a natural source of water upstream; (2) where stream water was captured in stone-barrage pondfields build within the gully bottom and diverted to canals (dashed lines); (3) locations where excavations show canals built to take irrigation water out to tableland; and (4) likely location of irrigated fields on tableland.

appeared there was intact stone curbing along a gulch slope indicating the presence of such a canal. Our first trench was located in the upper gulch near where it appeared water would have been taken off flooded barrage terraces (Waiapuka-4W). To take water out of the gulch the canal would have to be oriented parallel to the stream course but dug at an angle that would allow water to be gradually transported downhill and out of the side of the gulch to the tableland. Thus, the second excavation was located downstream where a second downstream canal system appeared nearly to reach the tableland. A canal in profile at the upstream source near stream level and another downstream near the transition from the gulch slope to the tableland would confirm our hypothesis.

Our excavations uncovered not one, but at least four canals in profiles in each location (Fig. 5). The canal profiles, similar to those found in other excavations in Hawai'i, were roughly 30cm wide and 50cm deep. However, these ditches differ from those previously recorded in Hawai'i in that they have been cut into the relatively soft underlying bedrock consistent with traditional digging-stick technology. Many had stone alignments, some several courses high, along the down slope edge. A few appear to have had been faced on both sides.

Unfortunately, it is difficult to comment on the exact form of the downslope tableland fields that would have been the recipients of this water but the size and location of the canals seen in profile do allow us to speculate on how these systems would have worked. First, the canals appear to have been built to feed different tiers of tableland fields located just below the source gulch fields, as opposed feeding a tableland field some distance away, which would have required water be moved down a steep grade at a fast rate. It is unlikely multiple canals were used contemporaneously and so we interpret the presence of several canals in profile as evidence not only for tableland irrigation but for multiple phases of rebuilding.

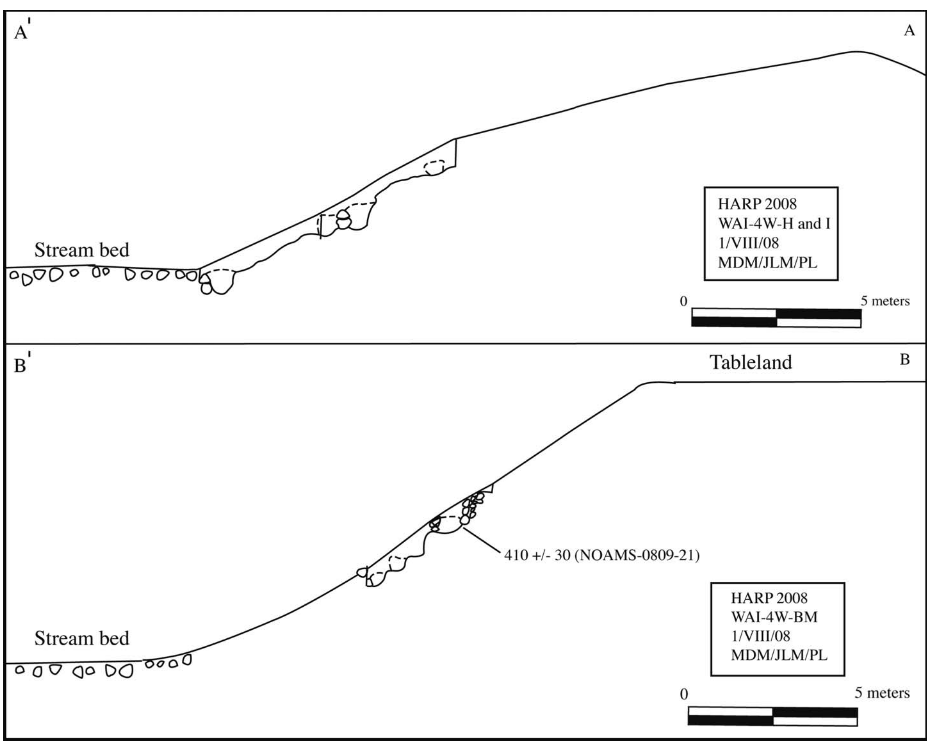

Figure 5 Profiles of canals leading irrigation water from gulch to tableland fields, Waiapuka-4W, Eastern Gulches, Hawai'i Island. Trench excavations show at least four canals in cross-section. An AMS radiocarbon date from under a stone retaining wall suggests tableland fields began being constructed after AD 1400.

The next question is how much did the tableland portion of a given field system add to the overall amount of land under production? To try and quantify what tableland fields would have added, we examined in detail the fields in the Waiapuka area above Neue Bay since they show the best preservation of tableland fields at the turn of the century (Lobenstein 1904). Not including fields that were built after European contact, this area had over three times as much tableland agriculture (3.09ha) compared to the total area of irrigation terraces located within gulches (0.98ha). This three-fold difference underlines the importance of this innovation in underwriting the expansion of agriculture in an area not otherwise suited for traditional valley irrigation.

To put this figure further in perspective, we used our surveys, combined with maps of irrigated fields recorded in the historic era, to determine that North Kohala's zone of scattered fields held a peak sum total of 55.8 hectares of pondfields (Table 2), making it one of Hawai'i's major zones of irrigated agriculture (Earle 1980). This estimate –including the four major drainage systems of the Eastern Gulches, as well in the adjacent Pololu and Honokane Valleys – is extremely conservative as no attempt has been made to include inputs from tableland agriculture except for those remnants preserved at the turn of the century.

Table 2 Total irrigated land in Eastern Gulches and adjacent valleys

Watershed	*Gulch Names*	*Total land area (ha) in watershed below 1500 fasl*	*Stream length (km)*	*Total irrigated fields (ha)*	*Sources*
Hapuu Bay	Halawa	357	10.8	11.4	Kohala Sugar Co. Map (1935); McCoy and Graves (2007);
Kapanaia Bay	Walaohia, Puwaiole, Waipanalua, Waipuhi, Aamakao	589	20.9	11.1	Kohala Sugar Co. Map (1935); Lobenstein (1904)
Keokea Bay	Hinao, Waikani, Niulii	568	19.1	13.0	McCoy and Graves (2007); Lobenstein (1904)
Neue Bay	Waikama, 'Awini Puali	363	10.5	6.6	Lobenstein (1904)
Pololu Valley	–	103	2.8	7.5	Tuggle (1976); Tuggle and Tonomari-Tuggle (1980)
Honokane Valley	–	23	5.0	6.2	Tuggle (1976); Tuggle and Tonomari-Tuggle (1980)
		1904ha	69.1km	55.8ha	

Note
The summed area, 55.8ha, is well within the size range of what Earle (1980) defined as the major areas of irrigated agriculture production in the Hawaiian Islands.

Windbreak fields

The distribution of windbreak fields on the west coast of the North Kohala District falls within an upland zone that in the north is quite close to the coast but in the south is separated from the coast by a barren zone over 7km wide (Fig. 3). Community territories (in Hawaiian, *ahupua'a*) ran from the coastal habitation zone, through the arid barren zone, the upland agricultural zone and terminated at the crest of the Kohala Mountains. The upland zone contains a series of rectangular agricultural field plots defined by stone and earthen walls running north-south bisected by upland-to-coast oriented trails (Fig. 3). In addition, the fields include habitation features, temples (*heiau*), carins, petrogylphs and other minor agricultural features, such as planting mounds.

The modest construction style and size of windbreaks is in sharp contrast to what these fields represented as capital infrastructure investments. The windbreaks in this portion of the island generally resemble speed bumps in that they are low, long mounds of compacted earth and stone. Closer to the rocky barren zone, field walls are made almost entirely of stone. These solid breaks were likely joined by more permeable green breaks made up of crops like sugar cane. The average earth-and-stone windbreak is 0.5 – 1.5m tall and 1 – 2m thick, with a length ranging from a few metres up to 590 metres long. As relative chronologies of construction have shown, there is a tendency for the longest field walls to have been built first, and then subdivided by trails, and shorter walls built between the new set of trails (Kirch 1984; Ladefoged and Graves 2000; Ladefoged et al. 2003; McCoy 2000).

The Leeward Kohala Field System is massive and covers over 60 square kilometres with 570km of windbreaks. Using a rough average height (0.75m) and width (1.5m), these fields represent about 641,250 cubic metres of solid windbreaks, or about a quarter of the volume of Egypt's Great Pyramid at Giza (2,500,000m^3: Levy 2005). Of the three well-documented dryland field systems on the island, the Leeward Kohala Field System (5940ha) is mid-sized, with the Kona Field System (11,256ha) covering twice the area and the Waimea Field System (3181ha) roughly half the size of Kohala. While there are other locations (Kau District) that likely had similar field systems, these three alone have an estimated peak area of 20,378ha. Extrapolating from that same rough volume estimate, the total volume of windbreaks on the island would be colossal, equal to the volume of the entire Great Pyramid. Clearly, these labour projects are not equivalent to one another for many reasons but this comparison underscores the enormous investment that these fields represented.

Chronology of innovation

Radiocarbon dates associated with features across the Kohala District suggest the first permanent settlements and farms were built between AD 1200 and 1400. The earliest dates come from a stratified habitation context at Pololu Valley (Field and Graves 2008) on the north-eastern coast and currently our earliest direct evidence of agriculture is an AMS date on sweet potato remains (carbonized tuber) at AD 1300–1400 (Ladefoged et al. 2005).

After AD 1400 there was expansion of agriculture across the Eastern Gulches (Table 3), and the north and centre of the Leeward Kohala Field System. This is the era of

Table 3 New radiocarbon dates from agricultural features, Eastern Gulches, Hawai'i Island

ID	*State site number*	*Conventional radiocarbon age*	*2 sigma (AD)*	*Site type and study area*	*Provenience*	*Taxa*
Beta-233039	26096	260+/−40	1490–1960	Irrigated terrace complex (NIU-1A to -1G), Lower Niulii	NUI-1A-TU2-Lv4-30-40cmbs	cf. *Metrosideros polymorpha*
Beta-233040	26086	250+/−40	1510–1960	irrigated terrace complex (HLW-29A to -29M), Upper Halawa, Lower Halawa	HLW-29D-TU3-Lv5	cf. *Artocarpus altilis*
Beta-233041	26086	340+/−40	1460–1650	irrigated terrace complex (HLW-29A to -29M), Lower Halawa	HLW-29A-TU2-Lv3-20-30cmbs	cf. *Metrosideros polymorpha*
Beta-233042	26087	440+/−40	1400–1620	terrace complex (HLW-30A to –30X), Lower Halawa	HLW-30-TU4-Lv5-30-40cmbs	cf. *Cordyline fruticosa*
Beta-233043	26061	400+/−40	1430–1640	non-irrigated terrace complex (HLW-4A to -4E), Upper Halawa	HLW-4A-TU2-Lv5-30-40cmbs	cf. *Psychotria* sp.
Beta-233838	26067	340+/−40	1460–1650	non-irrigated terrace with small rockshelter (HLW-10A and -10B), Lower Halawa	HLW-10A-TU1-4-2	Unknown twig
NOAMS-0809-21	–	410+/−30	1430–1620	Canal on gulch slope, Upper Waiapuka	WAI-4W-BM, TU1	*Diospyros sandwicensis*

Notes
Site numbers are from State of Hawai'i database and begin with the prefix 50-10-02. Calibration method: Beta (Talma and Vogel 1993); IntCal04 atmospheric curve (Reimer et al. 2004); NOAMS – OxCal v4.0.5 (Bronk Ramsey 2007); depths given in centimetres below surface (cmbs).

innovative engineering of windbreaks and use of narrow gulches. There is some indication that initial gulch expansion was accompanied by tableland agriculture. A radiocarbon date from under a stone alignment of one of the canals described above puts its construction after 1400 (cal. AD 1430–1620 [2σ]). In a survey of Pololu Valley, Tuggle and Tominari-Tuggle (1980) also documented a tableland agricultural complex on the valley's western edge at the top of a ridge. This complex was fed by runoff from a gulch that flows eastward towards Pololu and yielded a date of cal. AD 1449–1954 (2σ) (Field and Graves 2008; Tuggle and Tominari-Tuggle 1980). The general agreement of these dates is evidence for an early prehistoric date for tableland agriculture; however, more investigation is needed to better define the later period chronology of these types of fields.

The north and central portions of the Leeward Kohala Field System have been identified by Ladefoged and Graves (2008) as being among several core areas where dryland farming was expanded during the Late Expansion Period (AD 1400–1650). Radiocarbon dates supporting the post-1400 AD expansion of windbreak farming are strong and include twelve dates from the Kohala Field System (Ladefoged and Graves 2008), a handful of dates from the Kona and Waimea Field Systems (Allen 2001; Burtchard and Tomonari-Tuggle 2004; Clark and Kirch 1983) and five dates from the Kalaupapa Field System (McCoy 2005, 2007) on Moloka'i Island. As discussed below, our interpretation of this simultaneous expansion is that it marks the beginning of a shift from food security to a surplus-oriented agricultural economy.

Discussion

If the role of innovation in this case was to aid in the expansion of agricultural production, the question becomes: what prompted people to choose to adopt these innovations on a wide scale? For this, we turn to two factors. First, the stage for adaptive innovation was set by the mismatch between the environment of Hawai'i Island and the founding population's previous experience farming in Polynesia. Second, it was the need for surplus to support elite competition following the establishment of rival chiefdoms and a feudal land tenure system that drove the wide spread application of these innovations.

Innovation born of adaptation to a new environment is a pattern noted by Kirch (1984) elsewhere on Pacific Islands. For example, on coral atolls, farmers must take care to conserve limited, thin soils in pits used for growing taro. In the far South Pacific where tropical crops often failed to grow, some of New Zealand's Maori adopted new farming methods (Barber 1989, this issue), while others chose to virtually abandon agriculture and take up a coastally oriented hunting-gathering strategy (Walter et al. 2006). Kirch (1985) further explicitly identifies phases of adaptation, expansion and intensification in the development of agriculture in the Hawaiian Islands. While we would naturally expect adaptive innovations to be credited to the earliest occupants of the island, this era in Hawaiian prehistory remains poorly documented based on material evidence (Kirch and McCoy 2007).

The innovations described here come later in the prehistoric sequence than one would expect and were closely associated with large-scale expansion. Expansion is a strategy to increase production that was employed throughout the cultural sequence from first colonization through to late prehistory (Ladefoged et al. 2003; McCoy 2000) and into the Proto-Historic rise to power of King Kamehameha (Kirch and Sahlins 1992). At first, the expansion of land under production would have been tied to a food security economy, closely related to the domestic mode of production, in which the application of labour for agriculture did not exceed what was needed for survival and creating plantings for successful future farming. However, by late prehistory, expansion would have been used in concert with the intensification of farming in a surplus-oriented economy in which production beyond necessity was the norm regardless of the relative burden on labour. So, what motivated this large scale expansion after AD 1400?

In our view, the motivation for widespread expansion into more and more marginal areas, was an increase in the need for surplus to support chiefly competition that ultimately helped push the entire economy from subsistence to surplus. The nature of the archaeological record in Hawai‘i is such that direct material evidence of warfare is rare (Kolb and Dixon 2003); however, oral traditions from the five main islands point to the establishment of large chiefdoms beginning sometime after AD 1200 (Cachola-Abad 2000; Cordy 2000; Kolb 1994). From the earliest generations, chiefs were engaged in competition that eventually led to recurrent, expansionist warfare among major chiefly lines, as well as strategies of alliance solidified through elite marriages (Cachola-Abad 2000). Conflicts were not as frequent as later in prehistory, but did work to increase the size of territories. In North Kohala, Cordy recounts a war in the mid-thirteenth or early fourteenth century, ‘between a polity based at Kukuipahu ... and a country focused about Niuli‘i’ (2000: 141) where the chief Hikapoloa defeated the army of his rival at Hinakahua near the modern town of Kapa‘au (Fig. 3). Thus, the AD 1400 simultaneous expansion of farming into the core of the Leeward Kohala Field System and the Eastern Gulches was a coordinated effort that was part and parcel of growing competition and increasing territorial sizes.

In the long term, agricultural innovation helped establish a large non-producer class, larger territories and ultimately more powerful leaders. Kirch (2007: 20) has noted that this particular time in the development of the agricultural economy created a ‘situation highly favorable to chiefly appropriation of surplus’ in that by expanding one could keep surplus coming in at an increasing rate relative to labour inputs. Another key social change that facilitated this was the onset of a feudal land tenure system, radiocarbon dated to about AD 1400–1650 by features like boundary markers and inland settlement (see Kirch 1985: 303–6 for a review). In this system, elites held absolute rights to land and commoners were dispersed across the landscape in community territories (*ahupua‘a*) that crossed island’s econzones. While these were more manageable areas for elites, the impact for commoners would have been lower than optimal territories to draw their living from and thus lower life expectancy (Ladefoged et al. 2008). Therefore, perhaps the way to view the development of this territorial system is not as a strategy for using island resources effectively, but as a way for elites more effectively to spread the burden of the non-producing class over a larger area. This would be especially important after AD 1650 when there are signs of intensification and greater demands on commoner labour and goods.

Conclusions

On Hawai'i Island, gulch-and-tableland irrigated farming and fixed windbreak rainfed farming originated simultaneously at around AD 1400 and helped transform a subsistence food security economy to one focused on surplus by making large-scale expansion possible. The main motivator for expansion, beyond population growth, was the need for surplus to underwrite chiefly competition to increase the geographic scale of polities. These larger territories meant chiefs were able to distribute the burdens they put on commoner labour and goods over a wider range of environments. In sum, this case study speaks to how, under the right historical conditions, agricultural innovation can be a vital component in the development of complex societies.

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