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Land use and potato genetic resources in Huancavelica, central Peru

Stef de Haan* and Henry Juárez

International Potato Center (CIP), Lima, Peru

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Three specific dimensions of potato land use were researched to gain insights into possible contemporary changes affecting the *in situ* conservation of potato genetic resources: land use tendencies, rotation designs and their intensity, and sectoral fallowing systems. The main research method involved participatory cartography combined with in-depth consultation through interviews and focus group meetings with members of eight Andean highland communities.

Land use tendencies between 1995 and 2005 show that the total cropping area dedicated to improved cultivars has grown fast whereas the area reserved for native-floury and native-bitter cultivars has remained more or less stable. Reduced fallow periods for existing fields and the gradual incorporating of high-altitude virgin pasture lands sustain areal growth. Although areas of improved cultivars are proportionally growing fastest at extremely high altitudes between 3900 and 4350 m, overall cropping intensity or fallowing rates are inversely related to altitude. No evidence of a straightforward replacement of one cultivar category by another was found. Inquiry into the dynamics of sectoral fallow systems over a 30-year period evidences the gradual disintegration and abandonment of these systems rich in cultivar diversity. Where sectoral rotation designs survive, local innovations have been adopted.

Keywords: land use tendencies; rotation designs; sectoral fallow systems; infraspecific diversity; *in situ* conservation; Huancavelica

Introduction

A major difference between the *in situ* conservation of wild *Solanum* populations and cultivated potato genetic resources resides in the fact that the latter needs to be used to maintain viable populations. Viability refers to a minimal population size needed in terms of the area dedicated to the different potato cultivar categories (native-floury, native-bitter, and improved) and individual cultivars. Agricultural land use involves the human modification of uncultivated and cultivated areas for the purpose of food production. This article will deal with three specific components of potato land use in this crop's center of origin: land use tendencies, rotation designs and their intensity, and sectoral fallowing systems. These selected dimensions of land use were researched to obtain a better understanding of the medium-term temporal–spatial dynamics of potato genetic resources.

The contemporary Andean landscape is highly worked and shaped by human activity. Pre-Columbian Indians managed more landscapes than previously thought, including areas which are nowadays perceived as untouched or wild (Mann 2006). Changes of Andean land use have historically been driven by diverse overarching processes such as politics, climate

*Corresponding author. Email: s.dehaan@cgiar.org

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change, and demographics (Cook 1981; Seltzer and Hastorf 1990; Hastorf and Johannessen 1993; Dillehay and Kolata 2004; Young and Lipton 2006). These same processes, although notably different in character, remain important drivers for agricultural and land use change today. Yet, little is known about how infraspecific diversity is affected by changes in agriculture (Brush 2004, p. 105).

Land use tendencies concern temporal and spatial (re)arrangements of cropping areas, including the area dedicated to a particular crop or cultivar category and the incorporation or abandonment of agricultural land. Data sets and studies of land use tendencies do not generally allow for inference about infraspecific diversity, altitudinal ranges, and intra-provincial scales. National, departmental, and provincial potato statistics and time series are available for area and yield (see INEI 1994, 2004; OIA-MINAG 1998; Rubina and Barreda 2000; FAO 2008). However, these are of little value for inferences about genetic variability within the crop. Knowledge of higher-resolution land use tendencies, such as the cropping area dedicated to cultivar categories, potentially allows for the identification of trends that can be either favorable or detrimental for the sustainable *in situ* conservation of potato.

Crop rotation designs can be based on either household or communal decision-making and tend to follow a dynamic logic that takes into account such factors as crop–crop and crop–livestock ecological complementarities, subsistence demand for foods and fodder, market trends, among other factors. Indeed, tradeoffs between diverse environmental and economic indicators generally shape farmer decision-making concerning crop sequences and fallowing. Characterization of crop rotations can provide valuable insights into designs (crop sequences and their frequencies) and land use intensity (fallowing rates) to which potato genetic resources are subjected.

The origin of sectoral fallowing systems in the Andes is disputed. Erickson (2000, pp. 326–327) considers the system to be pre-Columbian based on archeological evidence, whereas Denevan (2002, p. 45) suggests a colonial origin. Campbell and Godoy (1986, p. 325) and Godoy (1991, p. 396) have suggested that Andean common-field agriculture has pre-Hispanic roots and undergone modifications after the Spanish conquest. Biological advantages of sectoral fallowing systems include the recuperation of soil fertility, pest and disease control, risk avoidance, and the availability of pasture during fallow periods (Hervé, Genin, and Riviere 1994; Pestalozzi 2000). Social advantages include the reduction of labor time demands[1] for land use and intergenerational access to land (Godoy 1991; Zimmerer 2002). An additional function of the sectoral fallowing system is the (informal) delimitation and control of community boundaries (Allen 2002).

Sectoral fallow systems are characterized by predefined sectors within a community (6–12 sectors typically constitute a circuit), a common rotation design defined by the community with a predefined crop for an entire sector, intermixed household assigned plots within a particular sector, regulation and supervision of access by the community,[2] and prolonged fallow after cultivation with use as communal pastureland. Additionally, sectoral fallow systems, commonly called *laymis*[3] in central Peru, are production spaces recognized for their rich content of diverse potato cultivars. They are 'diversity hot spots' as farmers traditionally use these spaces to plant mixed cultivar stands (*chaqru*). Native potatoes are typically the initial crop to break the fallowing period and occupy the land during the first year's cropping cycle (Orlove and Godoy 1986). Sectoral fallow systems are increasingly abandoned as a consequence of socioeconomic change and uncoordinated intensification (Mayer 1985; Zimmerer 2002), a process which possibly implies the gradual disintegration of important potato 'diversity hot spots'. Little is known about this disintegration, potential adaptations, and effects on potato cultivar conservation.

The purpose of this article is to investigate land use of potato genetic resources in Peru's central Andes: first, land use tendencies for an 11-year time span with particular emphasis on the dynamics of cropping areas dedicated to each of the three cultivar categories; second, contemporary crop rotation designs and their intensity for each of the three cultivar categories; third, long-term changes for a 30-year time frame for sectoral fallow systems.

Materials and methods

This research was conducted between 2005 and 2006 in eight communities following a north–south transect through the department of Huancavelica, central Peru (Table 1). Land use tendencies and rotation designs were researched by applying participatory cartography, also commonly referred to as participatory geographical information systems (GIS) (Bussink 2003; Voss *et al*. 2004), with printed poster-size high-resolution Quickbird satellite images for each community. Cartography and visual representation can be useful research tools in human ecology (Zimmerer 1999, p. 153), and GIS platforms provide an adequate framework to systematically document local geospatial- and temporal-change data (Chapin and Threlkeld 2001; Craig, Harris, and Weiner 2002; Tripathi and Bhattarya 2004). Household members older than 27 years identified their fields on the base maps. The crop species and potato cultivar contents by field were recorded for an 11-year period (1995–2005) based on the household's collective memory. An 11-year period was considered an acceptable time frame for Andean farmers to remember with sufficient recognition of detail. Field identification and contents were cross-checked using focus group meetings, site visits, triangulation, and repeat inquiries. A total of 196 households participated in the exercise (39.8% of the total population). A total of 4343 fields and their 1995–2005 crop contents were mapped (Table 1). The data were digitalized using MS-Access, ArcView, and ArcInfo software, and stored at the International Potato Center's GIS laboratory.

The evolution over a 30-year time span (1975–2005) of sectoral fallow systems was investigated through participatory cartography and in-depth consultation through interviews and focus group meetings with community members older than 50 years of age. Former and contemporary sectoral fallow systems were mapped to community members and authorities through site visits and walks along boundaries. Georeferenced sectoral fallow systems were

Table 1. Sample sizes obtained with participatory GIS.

		Sample size (*n*)		
Community	Transect	Households	Fields	Fields/household
Huayta Corral	North	28	558	19
Tupac Amaru	North	30	796	27
Villa Hermosa	Center	30	832	28
Pucara	Center	17	370	21
Dos de Mayo	Center east	20	364	18
Libertadores	Center east	30	655	22
Pongos Grande	South	20	414	21
Allato	South	21	354	17
Total		196	4343	22

visualized using ArcView and ArcInfo software. Processes of change, management, and adaptive innovation were documented building case studies for each of the research communities.

Results

Land use tendencies

The total annual area dedicated to selected crop species, particularly potatoes, cereals, legumes, and Andean root and tuber crops (ARTCs), increased steadily between 1995 and 2005 (Table 2). Additionally, the total area of cultivated pasture and trees also expanded. The total potato cropping area increased by 63% between 1995 and 2005. The 88% areal increase of cereals particularly involved barley (*Hordeum vulgare*), whereas the 242% areal increase of legumes was spearheaded by tarwi (*Lupinus mutabilis*) and to a lesser extent fababeans (*Vicia faba*). The total area dedicated to ARTCs had grown spectacularly with an areal increase of 1362%. Increased market demand for maca (*Lepidium meyenii*) was the main driver behind this expansion. Forestations with eucalyptus (*Eucalyptus globulus*), especially on eroded soils, increased considerably (352%) and a similar tendency was also notable for cultivated pasture, particularly oats (*Avena sativa*), with a total increase in area of 342%. This gradual but steady expansion of the before-mentioned species was possible because of reduced fallow and the incorporation of previously uncultivated native pasture lands (Table 2). The later implies a gradual expansion of the agricultural frontier toward higher altitudes where soils were previously untilled. Intensified land use allows for fewer years for land to recover fertility. Indeed, growing areas of barley, a crop well adapted to poor soils, and trees suggest that the overall soil fertility may be declining.

The areal dynamics of the potato crop is characterized by a more or less stable area dedicated to native-floury and native-bitter cultivars, and a steady increase of the total area dedicated to improved cultivars (Table 3). Native-floury cultivars proportionally occupied most of the total potato cropping area: 72.7% in 1995 and 64.5% in 2005. A sharp increase in the area of native-floury cultivars can be observed for 2005. The expansion of improved cultivars was considerable with an overall areal increase of 182%.

Table 2. Tendencies for crop areal distribution in eight communities (1995–2005; $n = 196^{a}/4343^{b}$).

	Cropping area/year–hectares										
Field content	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Potato	71.8	81.7	90.2	81.2	93.5	97.2	95.4	83.6	95.2	91.3	117.1
Cereals	47.8	55.5	67.5	73.5	71.1	74.5	79.8	80.3	70.0	79.2	89.8
Legumes	11.0	12.0	18.5	17.5	20.8	24.1	17.8	21.8	19.1	24.3	37.6
Vegetables	0.2	0.4	0.6	0.5	0.6	1.0	1.4	1.7	1.3	1.1	1.0
ARTCs[c]	2.9	5.5	4.8	7.9	8.2	13.9	14.6	18.7	20.2	33.3	42.4
Culture pasture	6.9	5.7	5.8	7.0	7.1	9.5	12.4	13.6	17.1	24.7	30.5
Forestry (trees)	2.3	2.6	2.7	3.1	3.1	3.4	4.5	6.4	7.2	8.2	10.4
Fallow land	441.9	426.7	400.8	404.0	403.4	388.7	389.6	401.3	411.4	389.5	338.9
Native pastures	222.1	216.0	214.2	210.5	197.5	193.1	190.7	178.0	163.6	149.2	133.3
Others[d]	2.0	2.8	3.8	3.7	3.6	3.5	2.7	3.5	3.8	8.1	7.9

Note: [a]Households; [b]fields; [c]Andean root and tuber crops, dominated by maca (*Lepidium meyenii*); [d]associated crops.

Table 3. Tendencies for the areal distribution of potato cultivar categories in eight communities (1995–2005; *n* = 196[a]/4343[b]).

Field content	Cropping area/year–hectares										
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Native-floury cvs	52.2	52.5	54.5	50.7	54.8	60.3	61.7	47.6	56.3	54.8	75.5
Native-bitter cvs	8.3	15.2	11.9	11.8	12.7	10.5	12.3	9.8	8.3	7.6	9.7
Improved cvs	11.3	14.0	23.8	18.7	26.0	26.4	21.4	26.2	30.6	28.9	31.9

Note: [a]Households; [b]fields.

Comparison for specific potato cultivars shows that selected commercial cultivars have increased in area (Table 4), particularly the improved cultivar 'Yungay' (240%) and commercial native-floury cultivar 'Peruanita' (512%). The cropping area dedicated to other cultivars has remained more or less stable between 1995 and 2005. The time series for the area dedicated to genetically diverse cultivar mixtures (*chaqru*) shows no evidence of replacement or decline. Although the area of *chaqru* fluctuated between 1995 and 2005, it had a general tendency to expand between 2002 and 2005.

When mapping the yearly cropping area of potato and its three cultivar categories by altitudinal ranges of 150 m it becomes evident that areas, especially of improved cultivars, are proportionally increasing more rapidly at high altitudes; particularly so between 3900 and 4350 m above sea level (Figure 1). The overall potato cropping area increased by 63% between 1995 and 2005; yet, rates of increase were proportionally higher at increased altitudes: 110% between 3900 and 4050 m, 65% between 4050 and 4200 m, and 339% between 4200 and 4350 m. This rapid increase at high altitudes is particularly fueled by improved cultivars. The yearly proportion of native-floury cultivars by altitudinal belts has been relatively constant between 1995 and 2004 with a sharp areal increase between 3900 and 4350 m in 2005. In 2005, the total area of native-bitter cultivars was similar to 1995 with the notable difference that also native-bitter cultivars had proportionally gone up in altitude. Figure 1 clearly shows that improved cultivars have ample and native-bitter cultivars restricted altitudinal distribution patterns. The data also show that there is considerable overlap between the altitudinal belts where the three cultivar categories are grown and that they are certainly not sharply separated by altitude.

Table 4. Tendencies for the areal distribution of specific potato cultivars in eight communities (1995–2005; *n* = 196[a]).

Cultivar	Category	Cropping area/year–hectares										
		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
'Peruanita'	Native-floury	1.7	2.5	0.9	2.4	3.3	4.8	7.8	7.0	8.7	9.6	10.4
'Runtus'	Native-floury	0.1	0.2	0.1	0.2	0.6	0.5	0.1	0.8	1.5	0.9	0.9
'Puqya'	Native-floury	1.2	0.9	2.6	2.3	1.7	1.3	1.8	0.3	1.2	1.2	2.0
'Camotillo'	Native-floury	1.9	3.2	2.0	2.0	3.0	3.6	4.1	2.3	2.8	2.9	3.4
Chaqru[b]	Native-floury	41.9	38.3	40.0	35.8	37.7	41.1	37.9	29.2	31.4	33.4	49.4
'Yuraq Siri'	Native-bitter	7.4	11.2	9.2	8.1	10.9	9.0	11.2	9.0	5.8	5.5	6.3
'Yana Manwa'	Native-bitter	0.6	3.1	2.5	3.5	1.8	1.3	1.1	0.8	1.5	1.9	2.6
'Canchan'	Improved	0.6	0.1	0.8	0.4	1.0	1.0	1.2	3.1	2.5	1.5	1.9
'Yungay'	Improved	6.2	7.0	15.1	10.5	15.9	15.6	10.6	14.5	18.9	17.6	21.1

Note: [a]Households; [b]complete cultivar mixtures.

Rotation designs and intensity

Farmers in Huancavelica manage many different crop rotation designs involving the potato crop (Table 5). A total of 84, 21, and 93 different rotation designs were recorded for native-floury, native-bitter, and improved cultivars, respectively. It is common practice to start cropping cycles with potato as a fallow breaker. Designs with grain crops are common for all cultivar categories: between 54.6 and 61.8% of the fields, depending on the specific cultivar category, included either barley or oats after potato and before fallow.

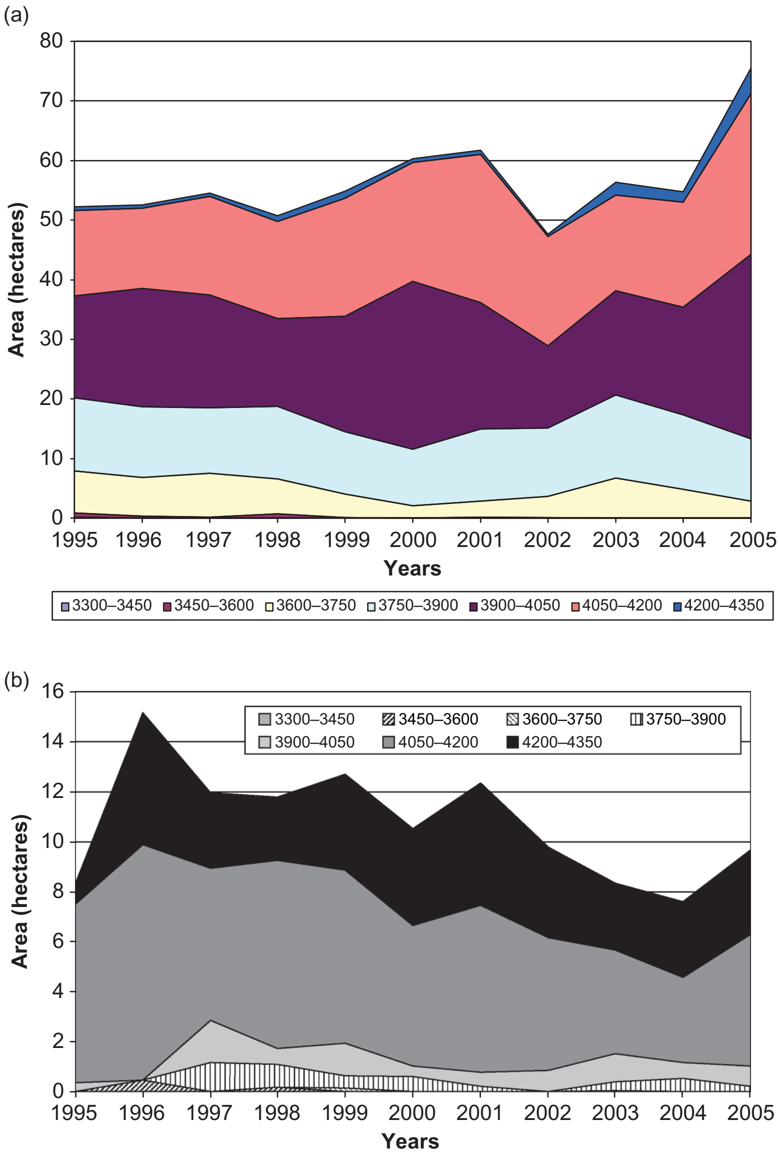


Figure 1. Tendencies for total area planted with cultivar categories by altitudinal range (150 m intervals; n = 196[a]/3514[b]). (a) Native-floury cultivars; (b) native-bitter cultivars; (c) improved cultivars; (d) potato overall (all cultivar categories).
Note: [a]Households, [b]fields.

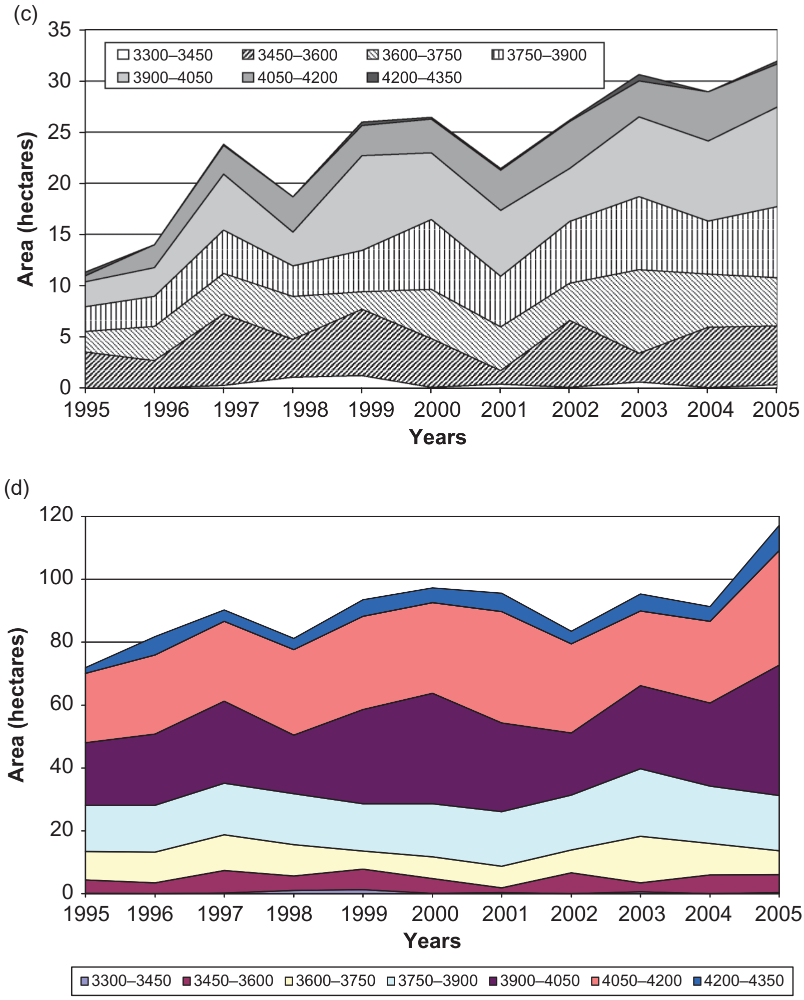


Figure 1. (*Continued*)

Table 6 provides an overview of fallowing rates[4] by altitudinal range and cultivar category for all mapped fields containing potato ($n = 3514$). The overall average fallowing rate for the potato crop in Huancavelica is 0.63, meaning that fields generally lay fallow for 6.3 years within a 10-year period (3.7 years of cultivation). Potato cropping regimes are more extensive at high altitudes as fallowing rates gradually increase. Fields containing improved cultivars have relatively low fallowing rates and are consequently cultivated more intensively compared to fields containing native-floury or native-bitter cultivars. Native-bitter cultivars are managed extensively and have high average fallowing rates compared to the other cultivar categories. Overall fallowing rates for potato also vary between communities with a minimum of 0.59 for Villa Hermosa and maximum of 0.70 for Pongos Grande. Villa Hermosa is increasingly densely populated and arable land per inhabitant is scarce, whereas rotations in Pongos Grande are still defined by community authorities following a sectoral fallow circuit.

Table 5. Most frequent rotation designs by cultivar category.

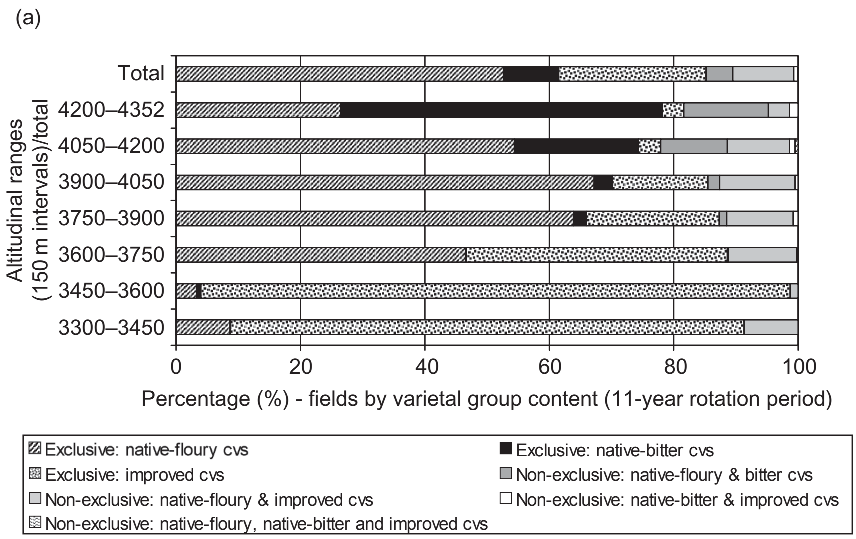
Native-floury cultivars (n = 1531[a])		Native-bitter cultivars (n = 314[a])		Improved cultivars (n = 656[a])	
Rotation designs	%	Rotation designs	%	Rotation designs	%
F-NFL-BA-F	41.0	F-NBL-OA-F	39.5	F-IC-BA-F	40.1
F-NFL-OA-F	13.6	F-NBL-BA-F	22.3	F-IC-BA-BA-F	14.9
F-NFL-F	8.6	F-NBL-F	20.4	F-IC-FB-BA-F	7.8
F-NFL-FB-F	4.4	F-NBL-OA-OA-F	4.5	F-IC-F	7.6
F-NFL-BA-BA-F	3.2	F-NBL-NBL-F	2.2	F-IC-FB-F	3.8
F-NFL-FB-BA-F	2.5	F-NBL-BA-OA-F	1.9	F-IC-OA-F	3.0
F-NFL-NFL-F	1.8	F-NBL-MA-F	1.6	F-IC-BA-FB-F	1.5
F-NFL-MA-F	1.7	F-OA-NBL-F	1.0	F-IC-BA-OA-F	0.9
F-NFL-BA-FB-F	1.5	F-NBL-OA-BA-F	1.0	F-IC-MA-F	0.9
F-NFL-BA-OA-F	1.3	F-OA-MA-NBL-F	0.6	F-BA-IC-F	0.8
F-NFL-BA-TA-F	1.3	F-NBL-BA-BA-OA-F	0.6	F-IC-BA-FB-BA-F	0.8
Others	19.1	Others	4.4	Others	17.9

Note: [a]Fields; BA, barley; F, fallow, FB, fababeans; IC, improved cultivars (potato); MA, maca (*Lepidium meyenii*); NBL, native-bitter cultivars (potato); NFL, native-floury cultivars (potato); OA, oats; TA, tarwi (*Lupinus mutabilis*).

Table 6. Fallowing rates for potato by altitudinal range and cultivar category (n = 3514).

	Fallow rates			
	Average	SD (±)	Minimum	Maximum
Potato overall: 3300–3450 m	0.56	0.18	0.09	0.82
Potato overall: 3450–3600 m	0.61	0.14	0.09	0.91
Potato overall: 3600–3750 m	0.57	0.22	0	0.91
Potato overall: 3750–3900 m	0.61	0.19	0	0.91
Potato overall: 3900–4050 m	0.65	0.16	0	0.91
Potato overall: 4050–4200 m	0.66	0.15	0	0.91
Potato overall: 4200–4350 m	0.75	0.14	0.27	0.91
Potato: overall	0.63	0.17	0	0.91
Potato: floury cultivars	0.66	0.16	0	0.91
Potato: bitter cultivars	0.72	0.13	0.27	0.91
Potato: improved cultivars	0.59	0.20	0	0.91

Most fields, independent of their altitudinal range, were exclusively dedicated to cropping sequences containing a single potato cultivar category (Figure 2). Overall, only 14.5% of fields had non-exclusive rotation sequences for the 11-year period, that is to say these fields at different moments in time contained more than one of the potato cultivar categories. Depending on the altitudinal range, non-exclusivity for cultivar categories by field fluctuated between a minimum of 1.3% (3451–3600 m) and maximum of 22.2% (4051–4200 m). So, farmers predominantly dedicate fields exclusively to one of the three cultivar categories with increased rates of non-exclusivity at altitudes between 4051 and 4350 m above sea level. This in combination with the fact that farmers also manage exclusivity by altitudinal range, that is, with more field-specific rotation sequences exclusively dedicated to improved cultivars at low altitudes and native-floury cultivars at high altitudes, indicates that farmers consciously manage field content by cultivar category.



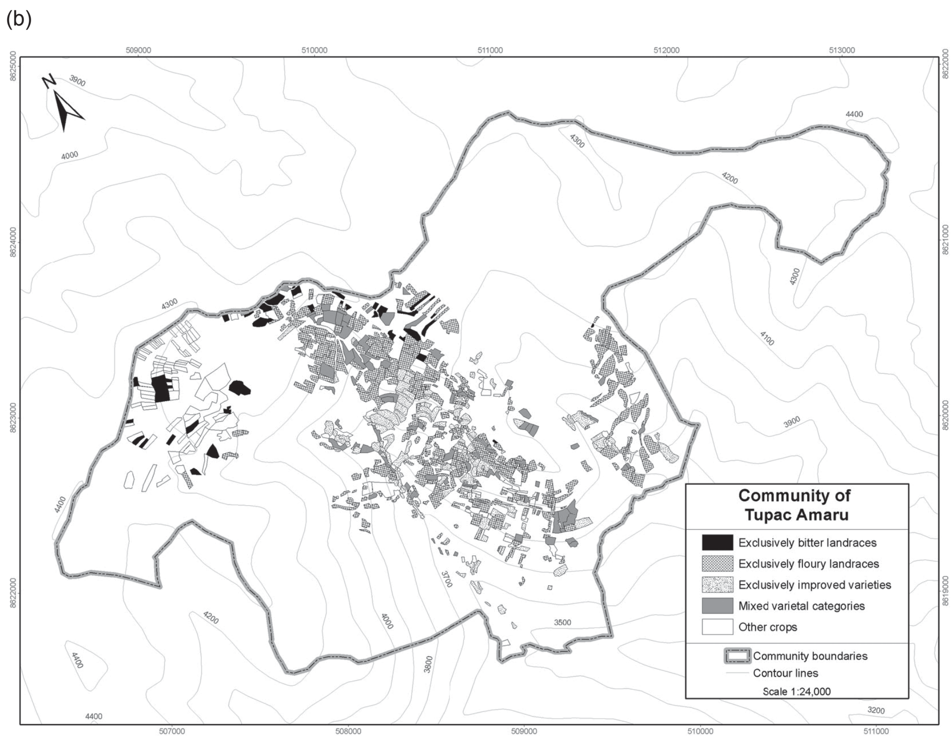


Figure 2. Fields and their cultivar category content for an 11-year rotation sequence. (a) Exclusivity and non-exclusivity for cultivar category content by altitudinal ranges ($n = 3514$)[a]. (b) The exclusivity/non-exclusivity profile map for the community of Tupac Amaru.
Note: [a]Fields.

Table 7. Characteristics of the 1975 sectoral fallow systems and their abandonment.

Community	No. sectors (1975)	Rotation design (1975)	Year of definite abandonment	Selected causes of abandonment
Huayta Corral	5	F-NP-BA[a]-F	1995	Population growth
Tupac Amaru	11	F-NP-BA-F	1976	Separation from mother community
Villa Hermosa	10	F-NP-BA[b]-F	1985–1988[c]	Migration, rural violence
Pucara	8	F-NP-BA[b]-FB[a]-F	1990[c]	Migration, rural violence
Dos de Mayo	9	F-NP-BA-F	1997	Population growth, separation from mother community
Libertadores[d]	–	n.a.	n.a.	n.a.
Pongos Grande	8	F-NP-BA[b]-F	[e]	n.a.
Allato	8	F-NP-BA[b]-F	1983	Population growth

Note: F, fallow; NP, native potatoes; BA, barley; FB, fababeans; [a]optional (in some sectors); [b]sometimes altered with wheat, oats, olluco, or fababeans (optional); [c]flexible (non-sectoral) communal system property regime maintained to date; [d]community was only founded in 1992 and its territory previously belonged to two different mother communities; [e]sectoral fallow system is maintained till date; n.a., not applicable.

Sectoral fallow systems

In 1975, all of the present-day research communities maintained sectoral fallow systems (*laymis*) with circuits consisting of 5–11 sectors (Table 7). Communities such as Tupac Amaru, Dos de Mayo, Libertadores, and Pongos Grande did not yet exist, at the time they were part of larger mother communities. Without exception, in each of the communities, mixed native potato cultivars were employed as fallow breakers. Therefore, sectors cropped immediately after prolonged fallow were 'diversity hot spots' with all families planting their mixed cultivar stands (*chaqru*) predominantly in a single *laymi* sector. Thirty years later, in 2005, only one of the communities (Pongos Grande) maintains a sectoral fallow circuit consisting of seven consecutive sectors and one flexible sector. The traditional annual communally driven concentration of mixed cultivars in geographically delimited sectors shifted to patchier distribution patterns characterized by household decision-making.

The gradual disintegration of *laymis* was fueled by diverse socioeconomic changes, including population growth, separation from larger mother communities, tendencies favoring individualistic household-based management practices, and a breakdown of communal decision-making structures. In all communities, the process was the result of a combination of causes; each specific case was unique in its own. The communities of Tupac Amaru and Libertadores did not adopt a new independent sectoral fallow system when they separated from their original mother communities (see Box 1). The community of Dos de Mayo did establish a new *laymi* circuit when it got independent, but limited field space, reduced fallows, and an increased population size caused the new system to be abandoned soon after the community gained autonomy in 1995. Population growth in Huayta Corral and Allato in combination with the desire of young families to increasingly invest resources in more intensive agricultural practices requiring individual usufruct rights triggered the abandonment of sectoral fallow systems. In Villa Hermosa and Allato, young males, the potential recruits for the army and the shining path, migrated to cities during the late 1980s. Remaining households from both communities clustered together, often along family ties, for increased security. Distanced *laymi* circuits were abandoned and when peace was reestablished rotations collectively managed by groups of families on communal land remained. Nowadays, these communal areas do not follow a clear intersectoral rotation; in practice, each area is treated as an independent unit.

Box 1. The case of the abandonment of Tupac Amaru's sectoral fallow system.

The territory of the present-day community of Tupac Amaru occupies what used to be a single sector of a *laymi* circuit with a total of 11 sectors. The *laymi* sector used to be called Itaña Ccasa, meaning 'stinging-nettle place,' referring to the abundance of this species (*Cajophora* spp.). Before the land reforms initiated by the military government of General Juan Velasco Alvarado (1968–1975), the present-day community of Tupac Amaru was part of the hacienda 'Santa Cruz de Esperanza' belonging to the *hacendado* family Loret de Mola. The hacienda managed the *laymi* circuit using the local families as a free source of labor. The rotation design started with native potatoes (year 1) followed by barley (year 2) and 9 years of fallow. Native-bitter cultivars for *chuño* would be cultivated in a high-altitude subsector of a *laymi* sector, whereas native-floury cultivars would be grown in a lower subsector. Local families were allowed to cultivate the steep and rocky subsectors within a *laymi* sector; fields would be assigned by the hacienda management.

After the land reforms, Tupac Amaru became part of a state-run cooperative (SAIS; *), which covered the ex-hacienda territory and maintained the *laymi* system. Frictions between different settlements were common during the initial period after the land reforms, but it was only in 1976, after the fall of the Velasco government, that Tupac Amaru became an independent community. Tupac Amaru claimed the territory of the Itaña Ccasa *laymi* sector, abandoning the wider *laymi* circuit which had included sectors that were distant from the newly formed community, dividing the land between local families belonging to the new community. Nowadays, fields are managed by individual households who exercise autonomous decision-making over their property. Permanent pasture lands are still communally managed. The community also maintains three sectors which are cropped communally by means of *faenas* (communal working parties). Funds obtained through the sales of harvests from these communal fields are used by the community for the provision and maintenance of public services.

Source: Interviews and focus groups (2004–2005); **Sociedad Agraria de Interés Social*, literally meaning 'Agrarian Society of Social Interest,' was the main type of state cooperative installed in the Peruvian Andes between 1968 and 1975 (see Guillet 1974, 1979; Long and Roberts 1979).

Sectoral fallowing survived in the community of Pongos Grande (Box 2; Figure 3). Currently the community manages eight sectors: seven in a sectoral system and one flexibly (Table 8). The adoption of several innovations was essential for the survival of the sectoral fallow system. These innovations were a response of the community to market demands and population growth. One of the innovations consists of more flexible crop compositions, especially for second-year cropping cycles (Table 8). Potato is still the common fallow breaker to initiate the cropping cycle (year 1). However, stands of mixed native cultivars are nowadays accompanied by improved cultivars. The latter have become predominant in the lower-altitude sectors of *Carca Sunto*, *Habas Huaycco*, and *Pampaway*. Depending on the specific *laymi* sector, second-year crop choices are currently less strict and can include barley, oats, fababeans, olluco, and peas. Only the high-altitude *laymi* sectors of *Checchi Huaccta*, *Lima Ccocha*, *Totora Ccocha*, and *Suytu Rumi* predominantly maintain the more traditional sequence of native potatoes, barley, and fallow.

Box 2. The case of the survival of Pongos Grande's sectoral fallow system.

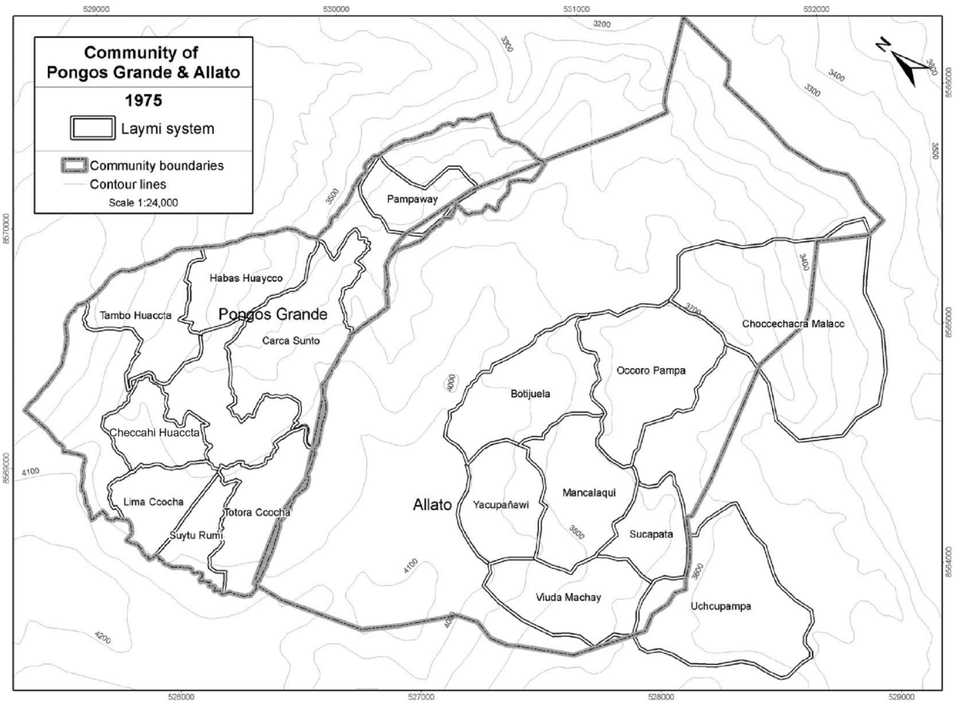
The present-day community of Pongos Grande (*), founded in 1993, was part of a hacienda owned by the landowner Eduardo Larrauri and his four children before Peru's land reforms. At the time of the hacienda, before the year 1969, Pongos Grande hosted 6 sectors of a *laymi* circuit with a total of 11 sectors; 5 sectors were part of the neighboring community of Tuco. The six sectors within Pongos Grande's territory, in order of their rotation sequence, were: (a) *Carca Sunto*, (b) *Totora Ccocha*, (c) *Limacc*, (d) *Pucaccocha*, (e) *Tambo Huaccta*, (f) *Pampaway*. This sectoral fallow system was managed by the hacienda owner and his *capataces* (**). The peasant households of Pongos Grande had to plant and maintain the crops for the hacienda. These were generally planted on the best soils. The four sectors *Carca Sunto*, *Totora Ccocha*, *Limacc*, and *Pucaccocha* were only used for a single cropping cycle with native potatoes followed by 10 years of fallow. The two sectors *Tambo Huaccta* and *Pampaway* were cropped with potato (year 1), barley or olluco (year 2), followed by 9 years of fallow. The hacienda used the fallowing period to pasture livestock, whereas local households were allowed to cultivate temporarily assigned plots within a *laymi* sector and permanently assigned plots that had to be fenced to prevent the hacienda-owned cattle from doing damage.

After the land reforms, Pongos Grande became part of the community and district of Ccochaccasa and a state-promoted cooperative: SAIS Huancavelica. The previous hacienda *laymi* sectors became available for cultivation by local households and a new *laymi* circuit was defined excluding the sectors previously belonging to the community of Tuco and with two additional sectors within the territory belonging to Pongos. The new *laymi* system had eight sectors: (a) *Carca Sunto*, (b) *Totora Ccocha*, (c) *Suytu Rumi*, (d) *Lima Ccocha*, (e) *Checchi Huaccta*, (f) *Tambo Huaccta*, (g) *Habas Huaycco*, (h) *Pampaway*. The rotation design in 1975 would start with native-floury potato cultivars (year 1) followed by barley and/or olluco (year 2), and 6 years of fallow. Before June 1993, all community members (*comuneros*) from the bigger community of Ccochaccasa had access to this *laymi* circuit. Yet, after separation from Ccochaccasa, a consequence of population growth and desire for independence, the *laymi* circuit only remained accessible for *comuneros* from Pongos Grande. The eight-sector *laymi* circuit, with modifications, is presently still maintained by the community of Pongos Grande.

Source: Interviews and focus groups (2004–2005); *Pongos derives from the term *pongo*, a common name for a servant working directly and obligatorily for the hacienda owner without salary or legal rights; **supervisors of the work to be delivered by common peasants for the hacienda.

A second innovation allows family-assigned fields within each *laymi* sector to be excluded from communal decision-making and rotation design if these are fenced. This innovation has been inspired by the former hacienda system of family usufruct for assigned fenced plots (Box 2). Families are increasingly withdrawing fields from the *laymi* system by fencing their fields, especially in the fertile low-altitude sector of *Carca Sunto*. This allows for the intensification of family cropping schemes and reduced fallow periods. A negative side effect has been the gradual reduction of fallow pastures, resulting in overgrazing.

A third innovation involves the adaptation of sectoral rotation designs to local knowledge about soil fertility and relative distance from the community's nucleus. Such is the case for the *laymi* sector of *Pampaway* which is a low-altitude and distant sector characterized by low soil fertility and a consequent need for longer fallowing periods. The sector is currently excluded from the sectoral rotation sequence and only assigned for cultivation when



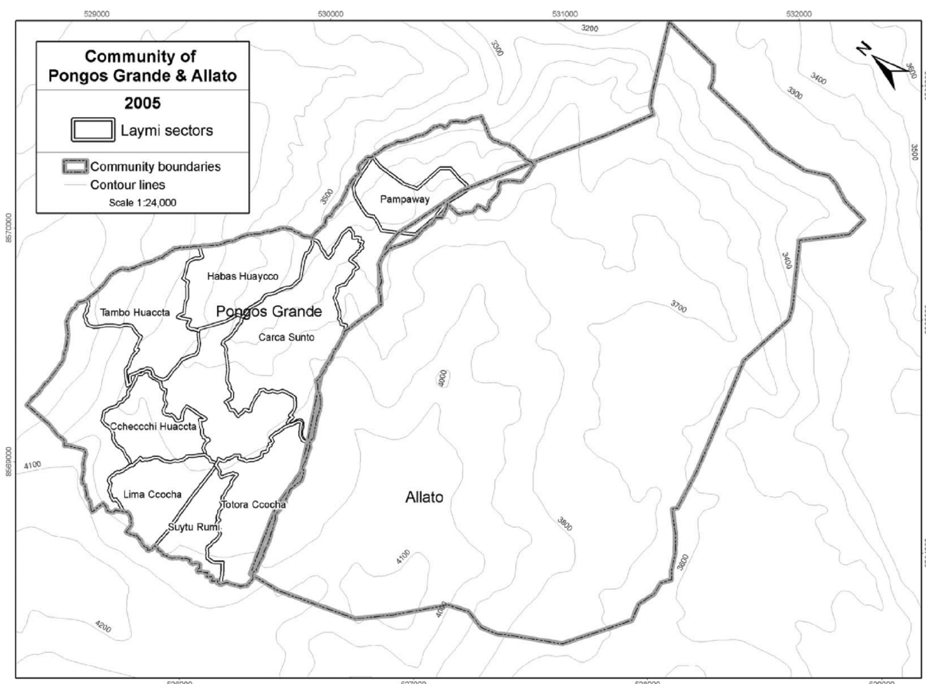


Figure 3. Laymi sectors of the neighboring communities of Pongos Grande and Allato, 1975–2005.
Source: Participatory mapping (2004–2005).

Table 8. Sectors, crops, and fallow periods of Pongos Grande's current sectoral fallow system.

Sequence	Sector	Rotation design: Year 1	Rotation design: Year 2	Fallow period
1	*Carca Sunto*	Hybrid and native potato	Barley/olluco/fababeans/ peas	5 years
2	*Totora Ccocha*	Native potato	Barley	5 years
3	*Suytu Rumi*	Native potato	Barley	5 years
4	*Lima Ccocha*	Native potato	Barley	5 years
5	*Checchi Huaccta*	Native potato	Barley	5 years
6	*Tambo Huaccta*	Native potato	Barley/oats	5 years
7	*Habas Huaycco*	Hybrid and native potato	Barley/fababeans	5 years
–	*Pampaway*	Hybrid and native potato	Barley/olluco/fababeans/ peas	Flexible

Source: Participatory mapping, interviews and focus groups 2004–2005.

considered sufficiently fertile. The sector was assigned for cultivation in 2006 after a 15-year fallow period.

Discussion and conclusions

Contemporary potato land use in the department of Huancavelica, central Peru, is highly dynamic and diverse changes were identified concerning land use tendencies, rotation designs and their intensity, and the fate of sectoral fallow systems. It is clear that these changes affect the medium- to long-term spatial arrangements of potato infraspecific diversity. However, it is harder to establish whether or not these changes will eventually be negative or positive for long-term sustainable conservation. Effects will most likely be indirect rather than result in a straightforward 'wipe-out' of genetic diversity. Continued land use change in the Andes is a historical phenomenon; yet, farmers have often been able to establish new adaptive management regimes that are able to reestablish a new equilibrium between changing socioeconomic environments and the maintenance of cultivar diversity. It remains important to learn from land use change and reflect upon the possible consequences for *in situ* conservation.

Land use tendencies of the potato crop are characterized by a fast growing area of improved cultivars and a more or less stable area dedicated to native-floury and native-bitter cultivars. The increase of the area of improved cultivars is the likely result of multiple factors, including the ready availability of seed through markets or donations, comparative advantages such as earliness and partial resistance to late blight, constant market demand, their usefulness for traditional processes such as freeze-drying (case of the 'Yungay' cultivar), among others. Areas of improved cultivars are proportionally growing fastest at high altitudes between 3900 and 4350 m above sea level. Areas of genetically diverse native cultivars mixtures (*chaqru*) have remained relatively intact between 1995 and 2005. Indeed, there is no evidence to suggest a straightforward replacement of one cultivar category by another. Rather, reduced fallow periods for existing fields and the gradual incorporating of high-altitude virgin pasture lands sustain areal growth. The proportionally rapid areal expansion at high altitudes is a consequence of human population growth. The cultivation of these new areas, especially those located above 4000 m of altitude, implies high levels of production risk from frost, drought, and hail.

Predominant potato–grain based rotation designs in Huancavelica still allow for significant periods of fallow even though the overall annual proportion of land under fallow is steadily decreasing. Human population growth and consequent increased demand for land to be cultivated is an important driver of this trend. Fields containing improved cultivars are more intensively cropped compared to fields containing native-floury or native-bitter cultivars. Results of this research also show that fallowing rates increase by altitude, reaffirming Godoy's (1984) observation that agricultural intensification is inversely related to altitude. The intensification of rotations resulting in reduced fallow periods of land already under cultivation is one of few options highland communities have to expand the annual area under cultivation. This does not necessarily affect potato genetic diversity positively or negatively. However, there is a limit to the intensity of crop rotations and carrying capacity of the land. If this limit is passed, biotic and abiotic stress may eventually affect the *in situ* conservation of diverse potato genetic resources. Indeed, it is well known that reduced fallows may imply a gradual reduction of overall soil fertility and increased pest or disease incidence.

Inquiry into the fate of well-known 'hot spots' of potato genetic diversity or sectoral fallow systems provides mixed lessons. With the exception of a single *laymi* circuit being maintained in the community of Pongos Grande, sectoral fallow systems have gradually disintegrated and been abandoned. As a consequence, the spatial distribution of potato genetic diversity within the agricultural landscape has become patchier with cultivar diversity increasingly being unevenly distributed across the community territory rather than concentrated within a single *laymi* sector. This in itself does not necessarily imply a risk for potato genetic diversity. Again, long-term sustainable conservation is put under increased pressure through indirect effects, likely including the higher incidence of pests and depletion of soil fertility. It has been suggested that communal property regimes impede private investment in agricultural land (Cotlear 1989). However, results of this research show that innovations within sectoral fallow systems do potentially allow for increased household investment and intensified management.

Notes

1. Godoy (1991, p. 409) points out that it is not mere coincidence that common-field agriculture attained its most complex form and survived the longest in the same regions that faced heaviest labor-tribute liabilities during the colonial era, such as the department of Huancavelica, Peru.
2. Generally the community assembly takes decisions concerning dates of planting and harvesting, access of newly founded families, and so on. A special type of supervision is done by assembly-appointed guards in charge of supervising fields, preventing animals from entering fields, guarding against theft, levying fines, and performing practices to prevent damage from hails or frosts. These guards generally receive payment in kind and are known as *inspectores* (Chopcca) or *varayoqs* (Pongos) in Huancavelica, and *maranis*, *arariwas*, *camayoqs*, *pachacas*, *campos*, or *muyucamas* in other parts of the indigenous Andes.
3. Sectoral fallowing systems are also known by other diverse regional names, including *aisha*, *aynoqa(s)*, *chutta(s)*, *manda(s)*, *muyuy(s)*, *surt'i(s)* or *suerte(s)*, *suyu(s)*, and *turno(s)* (see Godoy 1988; Fernández 1990; Wiegers, Hijmans, Hervé, and Fresco 1999; Zimmerer 1999, 2002; De Haan 2000; Erickson 2000; Cahuana, Tapia, Ichuta, and Cutipa 2002).
4. $FR = \sum Yf/(\sum Yf + \sum Yc)$; where FR is fallowing rate, Yf years under fallow, and Yc years under cultivation.

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