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ORIGINAL ARTICLE

Socioeconomic and land use drivers of weedy grass infestation in the Peruvian Amazon

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Abstract
The spread of noxious weeds has received little attention in humid tropical regions. However, increased anthropogenic activity may have made these regions more susceptible to the spread of weeds. In the Amazon and other humid tropical regions, smallholder agriculture practices, selective logging, cattle ranching, and plantation expansion have promoted weed expansion. Here, we examine socioeconomic factors and land use practices fostering the success of *Imperata* grasses in the Pucallpa region of the Peruvian Amazon. We compared *Imperata* biomass across oil palm plantations, fallow fields, and pastures—the predominant land uses in the region—and assessed the effects of farmer origin (local vs migrant), residence (urban vs rural), farm size, and weed combat practices. *Imperata* biomass was highest in pastures, intermediate in fallows, and lowest in oil palm plantations, although the difference was only statistically significant between pastures and the other two land covers. The high economic value of oil palm likely encourages stricter land management, while shaded understories in mature oil palm plantations and fallows may limit *Imperata* growth. Farms with resident owners or without urban homes had significantly lower *Imperata* biomass (15% and 14% lower, respectively). Landowners from outside Ucayali were more likely to live on their farms, own smaller parcels, and have less *Imperata* biomass than regional residents. Smaller farms and herbicide use were also associated with reduced *Imperata* abundance. Our findings suggest that policies promoting resident land ownership and *Imperata* management practices can help curb weed proliferation, supporting more sustainable land use in these landscapes.

Keywords Weedy grass · Swidden management · Land management · *Imperata* grass · Farm residence

Introduction

Globally, the spread of native and non-native aggressive weeds has had multiple significant impacts on ecosystems, biodiversity, livelihoods, and climate (de Lange and van Wilgen 2010; Vitousek et al. 1997). Noxious weeds affect species and community-level dynamics (Gurevitch and Padilla 2004; Pysek et al. 2012) and change soil pH and fertility (Veldman and Putz 2011). In the USA alone, weeds are expanding into wildlife habitat at an annual rate of 700,000 ha (Babbitt 1998). From an economic perspective, weeds can decrease crop yield and profit (Chikoye and Ekeleme 2003). Researchers have estimated that invasive weeds cost the USA upwards of US$27 billion annually in lost production and herbicide expenses (Crystal-Ornelas et al. 2021; Pimentel et al. 2005) with similar outcomes in other regions (Carpenter 2011; Henry et al. 2023).

Although the impact of weeds is certainly global, studies have traditionally focused on drier regions. Most of the global data (~67%) come from temperate and woodland biomes in North America and Europe (Pysek et al. 2012). This geographic bias is partially due to the idea that wetter regions, particularly the humid tropics, are more resistant to the establishment or expansion of aggressive weeds because of high species diversity in natural undisturbed communities

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(Rejmánek and Richardson 1996; Sodhi et al. 2004). Yet this argument is based on studies in undisturbed communities, an increasingly rare situation in tropical regions after several decades of expanding human activity (e.g., logging, agriculture, and colonization) (Asner et al. 2009; Carr et al. 2005; Nepstad et al. 2008; Zommers and MacDonald 2012), and a recent analysis suggests that at least, invasive weeds are just as prevalent in tropical regions (Chong et al. 2021). More importantly, a number of factors that can foster weedy invasions such as land management practices (e.g., slash and burn) and access to effective combat methods differ markedly between tropical and temperate regions. Understanding weedy expansions in the humid tropics requires an understanding of human activities that can mitigate or exacerbate the spread of weedy species.

The socioeconomic background of smallholders, cattle ranchers, oil palm planters, and other actors can influence the spread of weeds (Geist and Lambin 2002; Perz et al. 2005). Farmers' place of origin may be associated with different land use strategies and weed management methods (van Vliet et al. 2012). For example, newly arrived immigrants typically have less secure land tenure, resulting in lower incentives to sustainably manage the land (Robinson et al. 2011). The spread of weeds may also be influenced by the degree of landowner's presence on the land, an issue of concern in many frontier regions. Landowners' absenteeism is a widespread phenomenon throughout the Amazon where there is an increasing trend to maintain houses and economic activities in both rural and urban settings (Padoch et al. 2008; Wilcox 2008). This pattern of rural-urban migration may foster the spread of weeds through multiple pathways. Urban-rural migration can result in communities with more women and older people and fewer individuals capable of con (Khatiwada et al. 2018; Lee and Sukoharsono 2025). Households with absentee landowners may lack the necessary labor to control weed spread.

Here, we focus on socioeconomic, biophysical, and land management factors associated with the spread of the exotic and native *Imperata* grasses in the Peruvian Amazon, a region where demographic changes and economic development have resulted in rapid rural frontier zone expansion (Perz et al. 2005; White 2005). The strong impacts that *Imperata* can have on ecosystems and rural livelihoods make it an ideal study system for examining the factors that drive weed expansion in tropical regions and strategies to control its expansion (Snelder 2001; Van Noordwijk et al. 2008). *Imperata* species (e.g., *I. cylindrica* and *I. brasiliensis*) can be found in any Mediterranean, humid sub-tropical, and tropical regions and were listed as the seventh worst weed in the world (Holm et al. 1977), occupying large areas in both temperate and tropical regions (Estrada and Flory 2015; Garrity et al. 1996). *I. brasiliensis* is native to the region; it is usually restricted to high savannas, and the exotic *I. cylindrica* is also found in the region but is rare (Banout et al. 2008). The two species interbreed and are hard to distinguish (Howard 2005). *Imperata* performs best in acidic soils with low fertility and low organic matter and in full sunlight, attributes that have allowed this grass to thrive in abandoned agriculture plots or degraded fallows where soils have been overused and there is a sparse overstorey (Das et al. 2008). *Imperata* species also have an extensive rhizome system, which aids in its rapid re-growth after fire or other disturbance (e.g., manual weeding) (Holm et al. 1977; Willard et al. 1996) and makes it difficult to control (Ancog et al. 2016; Tomat-Kelly et al. 2021). This protective mechanism contributes to greater fuel loads and more flammable fuels, as layers of dead *Imperata* leaves can collect in times of drought and between weeding or fire periods (Hairiah et al. 2000). In the Peruvian Amazon, farmers consider *Imperata* a nuisance weed, and its presence in agriculture is often taken as a sign for farmers to fallow the land (Fujisaka et al. 1997; Lojka et al. 2012).

The presence of fire-adapted species like *Imperata* makes slash-and-burn agriculture, a common land use in tropical frontiers, particularly dangerous for fire spread, particularly in highly infested plots and extreme drought conditions (Tomich et al. 1996). To mitigate the chances of escaped fires, farmers need to be particularly vigilant about controlling *Imperata*, a very difficult task. Once a field is invaded, farmers tend to combat it manually, mechanically, with herbicides, or with some combination of these methods (Lojka et al. 2011). While herbicide is generally the most effective method for controlling *Imperata* (Chikoye et al. 2000; Udensi et al. 1999), this method is only accessible to those who have high enough income (Chikoye et al. 2006). Manual methods require lots of labor (e.g., 20–25 man days/ha) with weeding required up to five times per year to prevent crop loss (Bolfrey-Arku et al. 2009; Udensi et al. 1999). Aside from the direct costs of combating infestations, farmers with *Imperata* problems also face indirect costs such as reductions in crop yield (Eussen et al. 1976) and increased chances of fire, acting as a disincentive for investing in fire-sensitive crops (e.g., rubber plantations) (Bagnall-Oakeley et al. 1996; Menz et al. 1998). Regardless of the control method, farmers may choose to leave an *Imperata*-infested plot to fallow or abandon it if heavy infestations cannot be adequately controlled (Bagnall-Oakeley et al. 1996). Uncultivated infested fields are highly susceptible to propagating escaped fires since they have high fuel loads (De Foresta and Michon 1996).

In this study, we combine data on biomass of *Imperata* in 210 farms in the Peruvian Amazon together with remote sensing and farm survey data to investigate how rapid changes in the types and scale of land use can lead to increases in biomass of noxious *Imperata* grasses. We selected biomass as a proxy for the degree of infestation because it provides an objective, standardized way of measuring *Imperata* vigor, an important consideration for a plant that spreads via rhizomes. Biomass is also a good indicator of flammability and the potential for a positive feedback between weed expansion and fire spread. More specifically, we ask the following questions and address the associated hypotheses:

(1) How does land cover influence *Imperata* biomass? We predict that *Imperata* biomass will be a function of the type and proportion of a specific land use on farms. We hypothesize that oil palm plantations will have the lowest *Imperata* infestation, fallow lands will have intermediate levels and pastures the highest. Since palm canopies start to close around 4–5 after planting, we reason that shade and owner management will limit *Imperata* spread in palm plantations. *Imperata* biomass will be highest in pastures because of the favorable light conditions and intermediate in fallows.

(2) How do farm owner's origin, residence, land tenure type, and size of the parcel influence *Imperata* biomass? We predict that farmers from outside of Amazonia will have higher *Imperata* biomass than local farmers because they lack experience managing tropical weeds. We also hypothesize that greater owner presence in the farm will be associated with lower *Imperata* biomass because resident owners are likely to produce crops more actively and manage *Imperata* more effectively. We also predict that farmers who own houses in urban areas will have larger parcel areas and higher levels of *Imperata* biomass. This prediction stems from the assumption that farmers who own a house in the city have access to alternative sources of income, which allow them to purchase larger parcels while simultaneously decreasing their presence on the farmland, leading to less well managed fields.

(3) How does weed management and parcel area influence *Imperata* biomass? We hypothesize that farms that treated *Imperata* with herbicide will have the lowest *Imperata* biomass and that larger land parcels will have higher levels of *Imperata* biomass because they require more labor to manage.

Methods

Study area

We focused our study on landholdings that are part of rural communities located along the Pucallpa-Lima highway and feeding roads. Situated in Eastern Peru, the population of Pucallpa has doubled over the past 10 years; it is the largest city in the region of Ucayali and the 14th largest in the nation (INEI 2019; Palm 2005). Dramatic changes in land use systems and demographic patterns have taken place within the last few decades in the rural and urban landscapes along the Pucallpa-Lima highway. The relatively new highway provides access to the Ucayali waterway and thus serves as an important transportation and trading route between Lima and other Amazonian regions in Peru (White 2005).

The climate of our study site lies within a tropical rainforest range and has an annual precipitation of 1800 mm/year with a mean annual temperature of 25 °C (Soudre et al. 2001). The study region has its dry season between June and August, when most slash-and-burn activities occur, and its wet season between November and April (Fernandes et al. 2011; Fujisaka and White 1998; Soudre et al. 2001). Average altitude is approximately 150 m above sea level (Lojka et al. 2008). Soils can be classified according to USDA soil taxonomy as Ultisols and Oxisols, with low phosphorus content (Fujisaka et al. 1999; Loker 1993). Cultivation in such nutrient-depleted soils is often difficult and requires additional fertilization or shorter production periods with longer fallowing. Many non-native and native weeds such as *Imperata brasiliensis* and *Pueraria phaseoloides* (kudzu) are known to grow well in acidic and poorly drained soils (Friday et al. 1999; Kobayashi et al. 2001).

Data

Our study included 27 villages with an average of eight households per village. Between June and August 2011, we interviewed 210 farmers stratified across the 27 villages. Selected farmers were sampled from a larger survey within the study site that included 732 participants. This larger survey used a snowball sampling design. Land parcels for each owner were delineated using GPS, and vegetation and land use/land cover data were collected for each of the farms.

Remote sensing

To calculate the proportion of different land use/cover (LULC) classes within each of the sampled farm parcels, we used maps developed from 2010 Landsat satellite images. The classification map had an accuracy of 93% with a pixel resolution of 30 m (Gutiérrez-Vélez et al. 2011). LULC classes include oil palm, pasture, fallow, secondary forest, mature forest, and other (e.g., bare soil, water bodies). Oil palm plantations were of mixed ages (e.g., 1 to 15 years) and sizes (e.g., 5 to 34 hectares). Palm plantations can be grouped into three developmental stages: young (1–5 years), adolescent (6–10 years), and adult (> 10 years), which differ in canopy closure, ground cover, and fruit production (Gerritsma and Soebagyo 1999; Gutierrez-Velez et al. 2014). Canopies in oil palm plantations start to close at 4 years for high-yield varieties and 5 years for low-yield ones, so we expected plantation age may influence *Imperata* biomass. Although these stages are expected to influence herbaceous ground cover, our analysis showed no relationship between plantation age and *Imperata* biomass ($r=0.03$). Consequently, palm age was not included as a predictor in subsequent analyses.

Social survey data

A key aim of this study was to link land use practices and *Imperata* management with demographic, land ownership, and migration data from household surveys. Specifically, we considered farmer origin (from Ucayali, Amazonian, non-Amazonian), residence (resides in property or elsewhere), and ownership of a house in the city, as well as the number of times owners visited the farm when they did not reside there. Oral structured surveys were conducted in Spanish in the farmhouse or within the farm plot. Prior to conducting the survey, we informed farmers of the general intent of our study and asked for permission to transcribe their responses and for access to their land to collect vegetation data. Only individuals who were actively managing the farm and making decisions about farm management were interviewed. These criteria included landholders or guardians and excluded temporarily hired workers.

To assess how *Imperata* biomass responds to management, we asked farmers questions about weed management methods. Specifically, we asked whether farmers used herbicide exclusively to manage their *Imperata* infestations or if they used manual weeding methods, either alone or with herbicide. Manual weeding included hoeing or cutting aboveground *Imperata* biomass with machetes. To better understand the socioeconomic and demographic factors associated with weed management practices, we considered farmer origin and place of residence, as well as ownership of a house in the city (Table 1).

Imperata data

For each farm parcel surveyed, we collected *Imperata* biomass on the ground from the beginning of June to the end of July 2011. We selected sampling areas by stratifying by the three predominant land uses: oil palm, pasture, and fallow. In cases where there were multiple, discontinuous sections of the same land use, we selected only the largest sections for vegetation sampling. Any land use sections smaller than one hectare were not measured as they were often connected to another larger patch of the same land use, or they were difficult to access and logistically too time-consuming to manage.

For the three most common land use types reported by farmers, we placed three 0.25×0.25 m quadrats in an equilateral triangle formation. We placed the first quadrat in the center of the land use section, whenever possible selecting the angle that would yield an equilateral triangle (60°), while also ensuring that the distance between each quadrat was either 50 m or 100 m apart, depending on the area of the land use section being sampled. We used the 50-m distance between quadrats if the edge of the land use patch to a given quadrat was less than 200 m; otherwise, we placed the quadrats 100 m apart. For each quadrat, we harvested the aboveground biomass from *Imperata*. Samples were oven-dried at 70 °C for 48 h and weighed. The date of collection was recorded to account for changes in biomass throughout the season.

Statistical analyses

To assess the relationship between land use and *Imperata* biomass (question 1), we compared mean *Imperata* biomass in the three land covers using ANOVA. Harvest date can also influence *Imperata* biomass, so we included harvest month (June, July, August) in the analysis. To address question 2, we used ANOVA to examine the relationship between *Imperata* biomass, and owner's origin, visitation frequency, and residence, across all the data and within each of the three land cover classes. Lastly, we used ANOVA to compare total *Imperata* biomass under the three weed management regimes:

Table 1 Social variables considered. Variables from the social survey, its descriptions, how it was coded, and hypotheses on how it would influence *Imperata* biomass. Positive hypotheses indicate that the variable increases *Imperata* biomass

Survey variable	Description	Hypothesis
Land use and management		
Land use	The type of land use that is currently on the farm	Fallow > pasture > oil palm
Weeding method	How farm managers controlled their weeds	Manual > herbicide > herbicide and manual
Parcel area	Area of farm parcel in hectares	Greater biomass in larger parcels
Socioeconomic/demographic		
Place of origin	Whether the farmer was local or from elsewhere	Ucayalino < non-Ucayalino
Land owner visitation frequency	How often the landowner visits the farm property	Lives on farm < visits farm
Urban house property	Whether the landowner have a house in the city	House in city > no house in city

herbicide, manual, and mixed (question 3), across all the data and within each of the three land cover classes. We also used linear regression to examine the effect of parcel area on *Imperata* biomass and weed management methods. *Imperata* biomass data was highly right-skewed so we long transformed this variable prior to analysis. We used R statistical software for analysis and figure production (R Core Team 2021).

Results

Land use and imperata biomass

On average, farmers had 28% of their land in pasture, 17% in fallow, and 11% in oil palm, with an average farm size of approximately 34.02 ha (±2.44). Of the 210 farms included, 18 had no palm, 10 had no fallow, and 9 had no pasture. Also, 116 farms had less than 1 ha of oil palm and 21 farms had less than 1 ha of fallow, so *Imperata* biomass in these land covers was not measured, yielding measurements in oil palm for 94 farms and in fallow for 189 farms. All farms with pasture had more than 1 ha area on this cover. Analysis of variance showed that *Imperata* biomass was lowest in oil palm plantations (24.33 ± 1.86), intermediate in fallow (103.26 g/0.25 m^2 ± 8.31), and highest in pasture (111.69 g/0.25 m^2 ± 7.43) ($F_{2, 432} = 23.26$, $p < 0.0001$, Fig. 1A), but the difference between oil palm and fallow was not significant (Tukey HSD $p = 0.11$). Biomass was highest in July (159.45 g/0.25 m^2 ± 9.03), followed by June (127.86 g/0.25 m^2 ± 15.09), and August (96.75 g/0.25

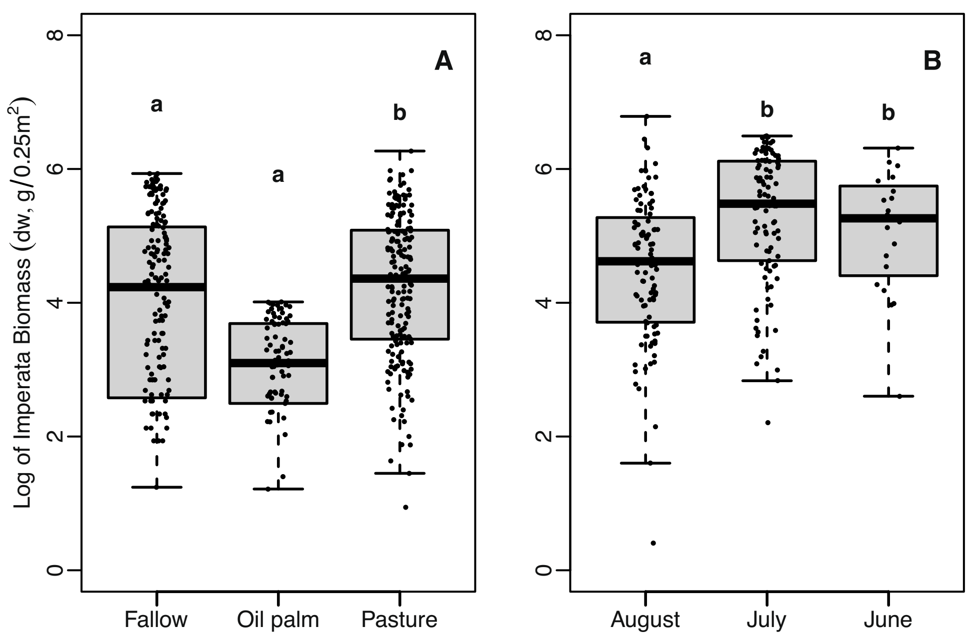

Fig. 1 Mean *Imperata* biomass vs: **A** land use classes (fallow, oil palm, and pasture); **B** harvest month (June, July, or August). Different lowercase letters above each boxplot indicate significant pairwise differences at $p = 0.05$ (Tukey HSD)

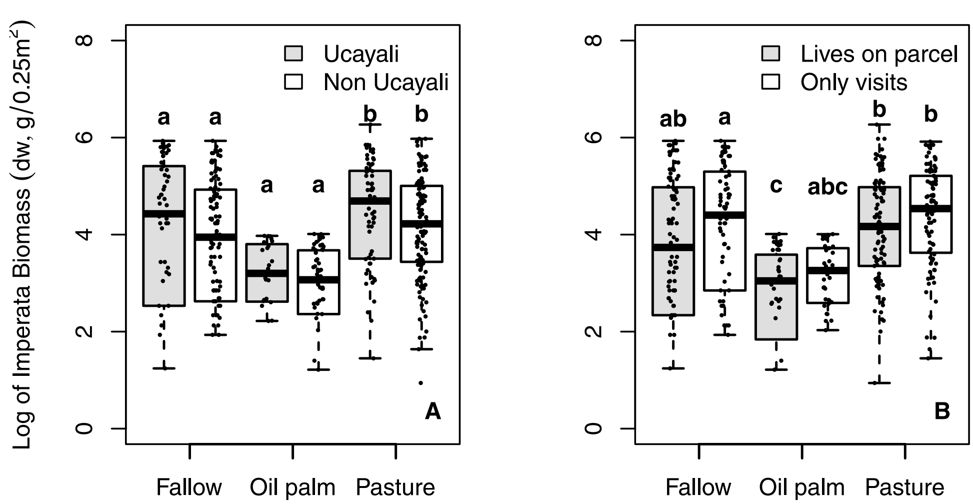

Fig. 2 Mean *Imperata* biomass for each land cover by: **A** origin of owner (Ucayali or non-Ucayali); **B** owner presence on the land (lives on parcel versus only visits). Different lowercase letters above each boxplot indicate significant pairwise differences at $p = 0.05$ (Tukey HSD)

$m^2 \pm 7.4$) ($F_{2,\,614} = 6.02$, $p < 0.002$, Fig. 1B), but the difference between June and July was not significant (Tukey HSD $p = 0.87$). The interaction between land cover and harvest month was not significant, showing that differences across the three land cover types were consistent across all harvest months.

Land owner characteristics and imperata biomass

Approximately 32.2% of the landowners surveyed were originally from the Ucayali region, 27.1% from elsewhere in the Amazon, and 40.5% from outside the Amazon. Landowners were defined as those who had some form of land tenure over their parcel and were not only managing someone else's land. Contrary to expectations, landowners from the Ucayali region had significantly higher total *Imperata* biomass in their parcels than those from outside the Amazon when considering all land cover types ($F_{1,\,208} = 5.22$, $p < 0.02$, Fig. 2A). This pattern held across all land covers although none of the differences within each class were significant (Fig. 2A).

Of the landowners who did not live on the farm (44%), over half (52%) visited their land only a few times a year (1–3). As expected, landowners who lived on the farm had significantly lower total *Imperata* biomass (i.e., across the three land cover types) than those who did not ($F_{1,\,208} = 5.21$, $p < 0.02$) (Fig. 2B). Although these differences were consistent among land cover types, they were not significant for any class (Fig. 2B). Owner's presence on the land was also associated with parcel area. Specifically, those who lived on the farm had significantly smaller parcel areas than those who only visited the farm (e.g., a couple of times a year) (mean parcel area of those living on farm = 25.79 ha. ($\pm$1.87 SE); mean of not living on farm = 44.37 ha ($\pm$4.81 SE), $F_{1,\,208} = 15.19$, $p < 0.005$). There was a significant relationship between the land manager's origin (i.e., Ucayali or elsewhere) and whether they lived on the farm or only visited ($\chi^2 = 7.76$, $p < 0.005$). Approximately 63% of landowners from outside of the Ucayali region lived on the parcel versus only 41% of landowners from the region.

Approximately half (49%) of surveyed households owned a house in the city. As hypothesized, farmers who owned a house in the city had greater *Imperata* biomass in their properties (mean biomass of city house owners = 238.74 ($\pm$17.36 SE) g/0.25 m^2, no city house = 183.28 g/0.25 m^2 ($\pm$17.40 SE), $F_{1,\,206} = 8.21$, $p < 0.005$). This pattern held across all land covers although none of the differences within each class were significant. Furthermore, there was a significant relationship between the origin of the farmer and ownership of a house in the city ($\chi^2 = 14.09$, $p < 0.001$). Approximately 68% of local farmers owned a house in the city versus 40% for non-local farmers. Urban house owners also had larger parcel areas (mean parcel area of city house owners = 41.70 ha ($\pm$4.44 SE), mean of no city house = 26.52 ha ($\pm$2.15 SE), $F_{1,\,206} = 9.96$, $p < 0.005$). Not surprisingly, the vast majority of landowners who did not have a house in the city (85%) lived on the parcel. We did not find a significant relationship between the origin of the farmer and the parcel area.

Weed management and imperata biomass

Among land managers who controlled *Imperata* biomass (136 out of 210), there was an even distribution of types of weed combat methods (i.e., herbicide only, manual only, and manual and herbicide), with farmers having a slightly

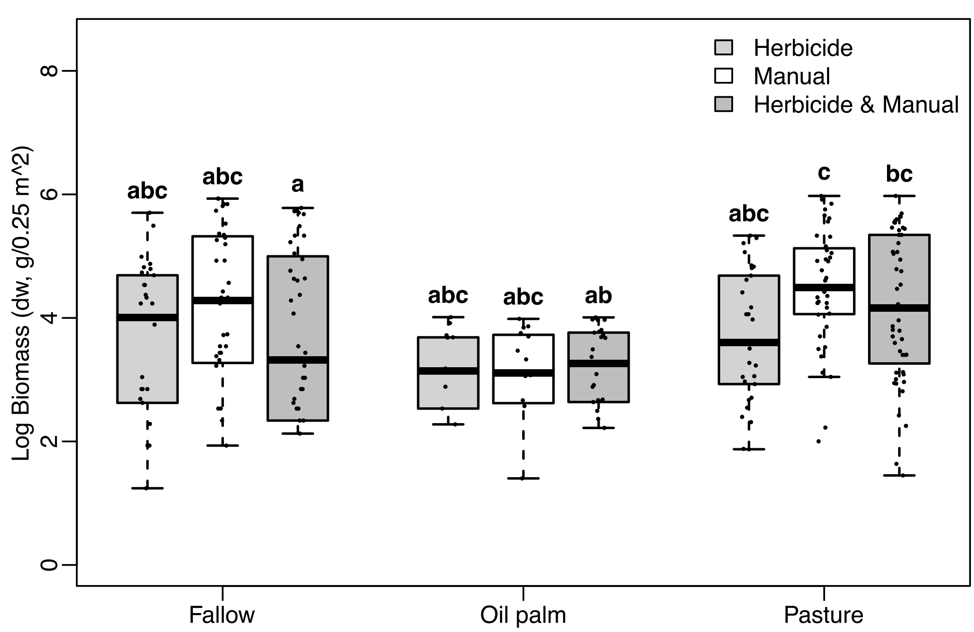

Fig. 3 Mean *Imperata* biomass for each land cover by weed control method. Different letters above each boxplot indicate significant pairwise differences at $p = 0.05$ (Tukey HSD)

higher preference for using a combination of herbicide and manual (37%) relative to herbicide (29%) or manual (33%) only. As expected, ANOVA showed that properties of land managers who used herbicide to control their *Imperata* infestations had significantly lower *Imperata* biomass across all land use classes (130.36 g/0.25 $m^2 \pm 20.72$ SE) when compared to properties managed using only manual methods (252.18 g/0.25 $m^2 \pm 27.46$ SE), or a combination of manual methods and herbicide (210.62 g/0.25 $m^2 \pm 26.32$ SE) ($F_{2,\ 133} = 6.29$, $p < 0.001$). This effect was driven by differences in *Imperata* biomass in pastures treated with herbicide relative to the other treatments ($F_{1,\ 133} = 7.28$, $p < 0.001$, Fig. 3). There were no significant differences in weed combat methods between resident and non-resident owners ($\chi^2 = 0.54$, df = 2, p-value = 0.76). As hypothesized, linear regression showed that larger parcel areas had greater *Imperata* biomass (Adjusted-$R^2 = 15.67$, $p < 0.0001$), and this pattern was driven by *Imperata* biomass in pastures.

Discussion

Our analysis shows that *Imperata* growth depends in part upon the type and proportion of land use on a farm. Oil palm plantations had the lowest levels of *Imperata* although its biomass was not significantly different in fallows. A few distinguishing factors that set oil palm plantations apart from pasture and fallow may explain this pattern. First, the active planting of legumes on oil palm plantations directly suppresses *Imperata* growth by shading. Climbing legumes, such as tropical kudzu *(Pueraria phaseoloides*), are often planted as cover crops alongside oil palm to serve as nitrogen fixers (Agamuthu and Broughton 1985; Peoples and Craswell 1992; Sanchez 1987). Literature on *Imperata* control repeatedly shows that leguminous cover crops can successfully control *Imperata* growth via shading (Chikoye and Ekeleme 2003; MacDicken et al. 1996; Murungu et al. 2011; Olorunmaiye 2010). Furthermore, leguminous cover crops also suppress *Imperata* by the addition of nitrogen which reduces *Imperata*'s competitive advantage over other vegetation (Ibewiro et al. 2000).

As predicted, the total amount of *Imperata* biomass was highest in pasture and intermediate in fallow. The finding that *Imperata* levels were highest in pastures further contributes to our understanding of this species as a weed best suited for open and frequently burned land. Ranchers in the study site, as well as elsewhere in the Amazon, often (e.g., annually) burn their cattle pastures (Boone Kauffman et al. 1998; Loker et al. 1997). Although *Imperata* is only palatable for a few weeks after burning, and not preferred by cattle, ranchers intentionally burn pastures to clear weeds and to promote more palatable forage, despite the potential for land degradation under frequent burns (Duvall and Whitaker 1964; Mattos and Uhl 1994). In addition to *Imperata*, these types of grass fodder act as an excellent source of fine fuel, increase fuel intensity, and can be five times more flammable (Balch et al. 2009). With pasture covering approximately 54,240 ha or 23% of the entire study site and with projected increases in pasture throughout South America (Wassenaar et al. 2007), the contribution of cattle pastures to the spread of *Imperata* will likely become increasingly significant.

For fallow, the results met our expectations that levels of *Imperata* would be intermediate in this land use. Fallow classes were defined by the presence of tall grass, shrubs, and small trees (Gutiérrez-Vélez et al. 2011). While we did not have age data, older fallows would reasonably have larger proportions of shrubs and trees to grass, thus determining the amount of shade. With more shade, as with oil palm plantations, *Imperata* becomes less competitive. On the other hand, older fallows could also experience a higher risk of burning from escaped fires due to a lack of active management and higher fuel content. However, it is increasingly harder to find old fallows (e.g., 10 years or older) as land pressures have typically shortened fallow periods (e.g., 2–5 years) in the Amazonian Peru and throughout the Amazon in general (Alegre et al. 2005; Coomes et al. 2000; Lojka et al. 2008). Shortened fallow periods can lead to land degradation and without appropriate fertilization and management, crops grown on short fallows can be more susceptible to weedy grass invasions (Styger et al. 2009; Van Noordwijk et al. 1996). Therefore, while fallowing land has the potential to dampen the spread of weedy grasses, changes in land use management practices could worsen the problem. Incorporating the age and quality of fallow would be an important component in understanding weedy grass invasions.

Beyond land use effects, our results show that farmer characteristics play an important role in determining *Imperata* biomass. Contrary to our expectations, we found that local farmers had higher levels of *Imperata* biomass in their properties relative to non-local (i.e., outside the Ucayali department). We reasoned that local farmers would have more experience with managing *Imperata*. Although it is difficult to quantify *Imperata* expansion through time and space without long-term classification maps, several local farmers reported that while *Imperata* has always been present in the region, the rate at which it is expanding, and the difficulty of its eradication are relatively new (e.g., within the last 10 years). Some farmers attributed this change to the increase in escaped fires and the expansion of pasture (e.g., via contaminated fodder stock). These results align with previous work showing an increased susceptibility of grassland land covers (largely dominated by *Imperata* weeds) to fire activity in the study area (Gutiérrez-Vélez et al. 2014). This evidence suggests that changes in the fire regimes are intimately associated with the spread of *Imperata* invasions and that traditional methods of land management may not be effective in weed management. In fact, local farmers may be less knowledgeable about controlling *Imperata* invasions than non-local farmers who come from regions that have historically had a more frequent fire regime (e.g., tropical savannas). Differences between local and non-local farmers might be better explained, therefore, by other socioeconomic variables or differences in herbicide use intensity.

Our results for farmer presence show that farmers who lived on the farm had lower *Imperata* levels than those who visited their land a few times a year. Absent farmers who only visit the farm infrequently are likely to dedicate less attention to farm activities and problems than those who maintain residence on the land. Conversely, greater presence on the farm could mean more vigilant land management, resulting in timelier responses to weed control and escaped fires. To further understand farmer presence patterns, we related this data to other farmer characteristics. Contrary to our expectations, we found that farmers who lived on the parcel were predominantly from outside the Ucayali region. This result was unexpected as non-local farmers, especially those from the coastal regions of Peru, are viewed by local farmers to be more entrepreneurial and urbane. On the other hand, local farmers who have been in the area for generations are likely more established and have greater social support and networks to branch into urban areas. Research in the Pucallpa study region shows that many households are "multi-sited," in that they have family members in an urban area while still maintaining livestock and crops on the farm (Padoch et al. 2008).

Additionally, parcel area may further explain how farmer backgrounds influence *Imperata* levels. Larger parcels generally had greater *Imperata* biomass. Studies of *Imperata* infestations in West Africa have shown that its presence often constrains farm size by substantially increasing the cost and labor required to control the grass on larger parcels (Chikoye et al. 2000). Although we did not collect survey data on whether the presence of *Imperata* led to decisions to limit parcel size, anecdotal evidence suggests that farmers who did not have an urban presence were more likely to have smaller parcels compared to those who owned an urban house. Owning a house in the city may be viewed as a proxy for higher income (Lerman and Mikesell 1988), allowing farmers to have larger parcels. Our finding that urban house owners had larger parcels supports this idea. However, increased urban presence also means that farmers are frequently away from their land. Thus, the ability to maintain a larger farm despite *Imperata* appears to depend on whether the farmer has an urban presence, but *Imperata* levels depend more on whether the farmers live on the parcel or not. However, depending on how quickly immigrant farmers become established in the region, patterns of *Imperata* expansion may begin to resemble those for local farmers as non-local farmers also begin to increase their connectivity to urban centers.

In agreement with previous studies, our data show that herbicide is an effective *Imperata* control method. A recent experiment conducted in the same study site showed that herbicide coupled with manual weeding was most effective for reducing above and belowground *Imperata* biomass in the short term (e.g., first couple of months) (Lojka et al. 2012). As Lojka and colleagues acknowledged, herbicide and manual weeding are both expensive methods, with herbicide requiring more income than hands and manual weeding requiring more hands than income. The combination of herbicide and manual weeding, while potentially the best in the short term, may be too costly for many farmers to realistically implement at a level that is adequate for *Imperata* control. Furthermore, the superior performance of herbicide over manual methods was primarily driven by *Imperata* biomass in pastures. Manual methods, which already tend to be less effective, may be especially ineffective in highly open fields, such as pastures where *Imperata* may establish more extensive root systems.

Interestingly, weed management methods did not vary across any of the groups we used to classify farmers. For instance, we might have expected to see that herbicide use would be positively correlated to whether farmers had a house in the city. This is because farmers with a house in the city may have greater incomes and studies have found that herbicide tends to be costlier than other forms of weed control, which limits the number of farmers who may use it (Bagnall-Oakeley et al. 1996; Chikoye et al. 2006; Udensi et al. 1999). The assumption that greater income would lead to herbicide use may be incomplete as decisions to use herbicide could depend on a number of other factors, such as the risk of crop and livestock damage or cultural background. In a few anecdotal reports, farmers stated that they did not want to use herbicide even though they could afford it because they heard that it damaged the quality of their crops or could hurt their livestock. Weeding methods also did not vary with farmer origin or time spent on the farm. While this seeming lack of connection between social traits and weed management styles was somewhat unexpected, it may also point to a period in which changes in demographics, sustainability education, and economic development are impacting how farmers adapt. For example, the use of tropical kudzu as a leguminous cover crop had not been considered a feasible weed control method until the past few years. Longer-term monitoring of farmer behavior will be required to elucidate patterns in effective weed management.

As the rate of demographic and economic changes in the Peruvian Amazon increases, understanding the social dimensions of weed invasions will increasingly become more important for predicting weedy invasions. Continuous monitoring can provide further understanding of the short and long-term responses of *Imperata* weed proliferation to land use practices such as crop type, pesticide use, kudzu ground cover use, or slash-and-burn frequency. Furthermore, understanding the direct mechanisms that link *Imperata* invasions with a higher observed susceptibility of grassland areas to fire activity in the study area (Gutiérrez-Vélez et al. 2014) could help to elucidate feedbacks between *Imperata* expansion and fire activity.

Our results suggest that incentives to promote landowner residence can serve as deterrents of *Imperata* weed infestation in the study area. Future research on weedy invasions in the humid tropics would benefit from incorporating more household demographic and socioeconomic data. Currently, we know little about differences in land and weed management between local Amazonian farmers versus non-local farmers from the Andes and elsewhere and whether future immigrant influxes will follow land use practices and rural/urban residency patterns of current land owners, particularly considering recent observed patterns of depopulation in rural Amazonian landscapes linked to increased fire activity (Uriarte et al. 2012).

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