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ORIGINAL ARTICLE

Invasion of *Mimosa pigra* on the cultivated Mekong River floodplains near Kratie, Cambodia: farmers' coping strategies, perceptions, and outlooks

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Abstract *Mimosa pigra*, an alien woody weed, invaded the Mekong River Basin since ~1970 and now covers vast floodplain areas in virtual monocultures. The prickly plants produce abundant seeds which are dispersed annually by the floods. Mimosa thus represents a burden to farming communities in Cambodia where agricultural capacities are weak. To obtain information on infestations as well as farmers' management practices and perceptions, 81 farmers were interviewed on their fields (using questionnaires) in affected areas near Kratie municipality. Data on infestations were collected at landscape and field levels. Furthermore, villagers' groups and key informants were interviewed (open questions). Infestations covered ~30 % of the land near fields. On average, farmers spent 11 days per hectare annually clearing mimosa. The weed represented a major cost, but other issues (animal pests, water shortages, lack of resources) were equally important; these may be connected with mimosa invasion. Farmers mostly expressed support for ideas to combat surrounding infestations, but support depended on experiences and assets at stake. Most were unconvinced that mimosa could be eliminated from the study site. Conceivable benefits of mimosa were regarded as insignificant. Given the currently few realistic options for significantly improving management, further research is suggested within adaptive management frameworks.

Keywords Alien species · Weed management · Livelihoods · Adaptations · Environmental perceptions

Introduction

Mimosa pigra L. (mimosa, catclaw, or giant sensitive plant) is a prickly shrub or small tree (<4 m) native to floodplains in the Neotropics. Following its introduction in Australia, Africa, and South-east Asia, it has earned a status as an aggressive alien weed species, incurring severe economic losses to rice farmers, ranchers, and fishermen and greatly impacting wetlands (ISSG 2013). Mimosa produces abundant seeds which spread by floating on water. In suitable habitats, mimosa can out-compete native vegetation and establish monospecific, impenetrable thickets. Once established, mimosa is hard to eradicate as it re-sprouts from roots or re-grows from dense, persistent soil seed banks (Triet et al. 2004a; Lonsdale et al. 1988).

On mainland South-east Asia, mimosa arrived some 40+ years ago and spread along the Mekong River. The fertile Mekong floodplains were traditionally cultivated with paddy by dense human populations, but the fields proved vulnerable to the alien weed. In Cambodia, mimosa infestations now cover >2100 km^2 or ~20 % of the maximum flooding zone on the floodplains (Samouth 2004), and paddy fields are interspersed in a patchwork of infestations.

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Not much research has been conducted on mimosa in the Mekong Region. In Cambodia, the weed's ecological invasiveness within the landscape remains virtually undocumented in academic literature, and no information exists on the farmers' experiences and perceptions of the weed as a 'problem' plant, or any strategies which may have been tested. Baseline information is, however, required to envisage strategies and policies effective to arrest the weed's spread and mitigate its agricultural and environmental damages.

Ecological research in Australia showed that fires may burn the vegetation, but mimosa easily re-establishes from soil seed banks (Lonsdale and Miller 1993). Only a small number of potential biocontrol agents showed any measurable impacts on plant vigour and seed banks (Heard 2012; Suasa-ard et al. 2004). Research focus has therefore shifted to studying integrated approaches, including—in addition to biocontrol and fire—the use of herbicides, mechanical control, and restoration and management of native vegetation (Paynter 2004; Paynter and Flanagan 2004; Firn et al. 2008).

Within the Cambodian context, cost-intensive technical options seem unrealistic, but weed management may potentially be improved through adaptations in farming and community initiatives. In this study, the following questions were addressed:

1. What is the extent of mimosa infestations? In which ways do infestations relate to spatial features, fields, and farmers' land ownership and crop selection?
2. What are farmers' management practices and perceptions on the scale of the 'mimosa problem' (also compared to other 'problems')? In what ways did they adapt to the weed's impact?
3. What are farmers' views and suggestions for improving weed management, and their motivation to support community initiatives?

Methods

The study site

The study was conducted on the fields along the eastern side of a 15-km-long stretch of road running parallel to the Mekong River between Kratie and Chhlong municipalities (Fig. 1) in Cambodia. The fields were at an elevation of 15–23 m a.s.l. (data from Google Earth©), located between the Mekong and fringing swamplands and ephemeral rivers to the east (~12–14 m a.s.l.). During 1985–2000, the mean flow of the Mekong at Kratie was at 1000–5000 m^3/s during January–April (dry season), peaking in September (wet season, July–October) at ~33,000 m^3/s (MRC 2005). All paddy fields were usually flooded during the wet season (farmers, personal communication).

Compared to mimosa-infested regions in Australia or Africa, the population density along the Mekong is high (mostly >100 people km^{-2}). Of the population in Kratie Province, ~65 % are subsistence farmers (mostly rice production and some fisheries), and ~30 % live on less than one US$ per day (CELADE 2012).

Quantitative data collection

Quantitative data collection was conducted between 10 and 26 November 2010. Northern and southern sections along the Chhlong–Kratie road were searched interchangeably for farmers working on their fields; a total of 81 farmers were thereby met and interviewed.

The variables collected during and after field surveys are summarized in Table 1 (more details provided in Tables A1 and A2, Appendix A in Supplementary Materials). Biophysical variables P1–P5 were collected by observation or measurement directly on the fields where respondents were met, using a hand-held GPS receiver (Garmin 12XL, GARMIN International Inc., Kansas City) and 50-m tapes. Variables P6 and P7 were provided via information or estimates by the respondents themselves. Using the recorded GPS field coordinates, variables L1–L5 were assessed at landscape level by computer on a Google Earth© image (SPOT satellite image from January 2008). The approximate per cent woody vegetation cover was assessed visually. At the study site, the greater part of 'woody cover' was represented by either pure mimosa infestations or by forests, woodlands and orchards which were also typically infested by mimosa thickets along the rims or within open gaps (personal observation). Hence, 'woody vegetation cover' largely corresponded to 'mimosa infestation cover'. Data were collected from the farmers using a standardized questionnaire including both open and closed questions (D1–D4, Q1–Q14). In addition to the questions, the farmers were confronted with ten position statements (S1–S10) whereby they could choose, on a five-point Likert scale from 'highly disagree' [1] to 'highly agree' [5].

Data analysis

A framework for analysis of variable interrelationships is shown in Fig. 2. Corresponding results from multivariate statistical analyses are shown in Fig. 3. Minitab 15 software (Minitab Inc., State College, Pennsylvania) was used for calculations and statistical analyses. Before analyses, the data were transformed as appropriate (e.g. natural logarithm, square root) to make them sufficiently normal for parametric tests. To work out optimal subsets of

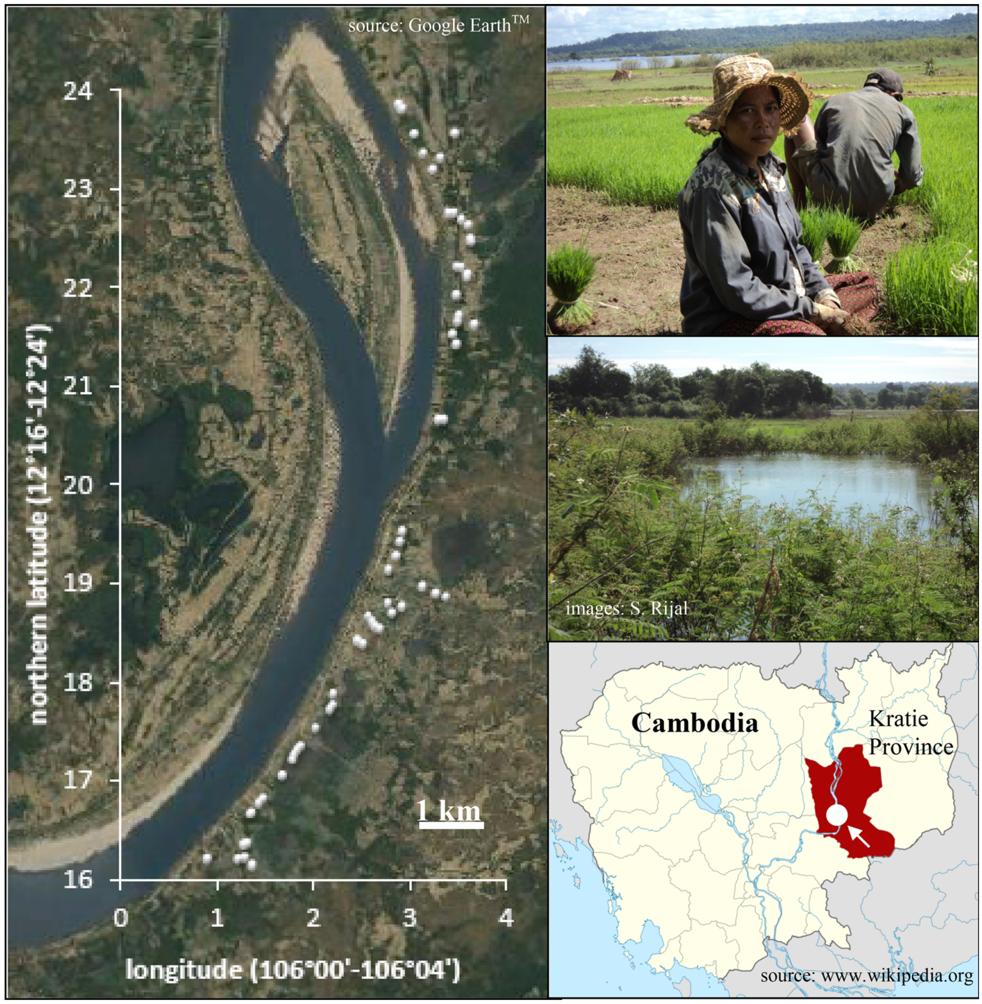


Fig. 1 Map of the study site (*inset*, *arrow*) in Kratie Province, Cambodia. *White dots* indicate the 81 fields where respondents were met. *Upper image*: respondents on their field with mimosa infestation in the background. *Middle image*: mimosa growing along a water storage pond

predictors for variables tested in multivariate models, we used the 'best subsets regression' (BSR) tool in Minitab, but we also used other information (e.g. correlation matrices) and specific testing of models. Multivariate linear regression (MLR), nominal (NLR), binary (BLR) and ordinal (OLR) logistic regression, and general linear models (GLM) were used for modelling, as appropriate regarding the various sets of data (i.e. interval and/or categorical data types) tested. In some cases, severe outlier points were deleted to improve the models. For all tested variables, summaries of descriptive statistics and of significant predictor variables as determined from multivariate models are provided in Tables A3 and A4 in Appendix A in Supplementary Materials.

Qualitative information from interviews

To gain more insights into livelihood aspects and other perspectives of the 'mimosa problem', several interviews were conducted. In five villages, eight groups of 4–7 farmers were selected. Open questions were asked about the main livelihood problems they faced, the difficulties caused by mimosa, management strategies they used, and their recommendations regarding long-term weed control. Additionally, interviews were conducted with three key informants, i.e. the Head of the Ministry of Agriculture working in Chhlong District, a businessman in Chhlong requiring a lot of biomass for a burner (to produce ice), and a green charcoal expert working in Cambodia for GERES (Groupe Energies Renouvelables, Environnement et Solidarités; a non-profit organization involved in biomass energy programmes). The interview transcripts are provided in Appendices B (farmer groups) and C (key informants) in the Supplementary Materials.

Results and discussion

Extent and patterns of mimosa infestations

Dense mimosa thickets covered extensive areas at the study site, especially around the wetlands and artificial ponds.

Table 1 Summary list of the variables assessed in this study in the fields visited (P1–6), by evaluation of Google Earth© maps (L1–5), and interviewing of farmers (using a standard questionnaire; D1–5, Q1–11, and S1–10)

Variables assessed directly on the farmers' fields		*Variables assessed from Google Earth© maps*	
P1a/b	GPS latitude/longitude coordinate (degree)	L1	Field elevation (m above sea level)
P2	Euclidian mean distance (m; in 4 segments of each cardinal direction NWSE) to nearest m. plants	L2	Distance (m) to the river/wetlands to the East
P3a	Presence (Y/N) of mimosa infestation within field	L3	Distance (m) to the nearest isolated pond/wetland
P3b	m. infestation (Y/N) near (<10 m) border of field	L4a	Mimosa cover (%) in a radius of 100 m (~3.2 ha)
P4	Mimosa pre-clearance cover (%) estimated by farmer	L4b	Mimosa cover (%) in a radius of 800 m (~200 ha)
P5	Size of field (m^2) where farmer was working	L5a	Area (m^2) free of mimosa infestations around the fields (and including the fields)
P6a	Type of crop planted on the field	L5b	Distance (m) to nearest mimosa infestation (in any cardinal direction)
P6b	Whether rice (1) or non-rice (2) crop was planted		
Descriptive variables assessed by questionnaires		*Other variables assessed by questionnaires*	
D1	Gender of respondent	Q1a	Total land area (m^2) under cultivation by farmer
D2	Main occupation of respondent	Q1b	Whether one crop only (1) or rice and non-rice crops (2) were planted on the fields
D3	Name of home village	Q1c	Land allocation of non-rice versus rice crops
D4	Distance of the field (m) from the respondent's home	Q2	Whether land was owned (1), rented (0), or both (2)
D5	Estimated age (y) of the respondent	Q3a	Whether (1) or not (0) some land was lying fallow
D6	Number of members in the respondent's household	Q3b	Reasons for why land was lying fallow
Position statement vars. assessed by questionnaires (on a Likert scale, i.e. highly disagree, disagree, neutral, agree, highly agree)		Q4	Time of first mimosa sighting (years before present)
S1	'Mimosa is a big problem affecting our livelihoods'	Q5a	Weeding techniques used currently
S2	'I spend a lot of time weeding mimosa on my fields'	Q5b	Weeding techniques used initially in the past
S3	'Without m. I would grow more different crops'	Q6a	Approximate time (d/y) spent weeding the fields
S4	'Fish catch has been declining because of mimosa'	Q6b	Number of weeding periods per year
S5	'I want to eradicate mimosa from my fields'	Q7	Whether (1) or not (0) cropping changed due to m.
S6	'I would fully support a mimosa management team'	Q8a	Whether (1) or not (0) willing to pay for hired labour
S7	'I want to participate in an m. eradication program'	Q8b	If yes, how much money (Riel) willing to pay
S8	'I support a control program in any possible way'	Q8c	If no, reason for not wanting to hire labour
S9	'It takes many years to clear m. from all fields'	Q9a	Whether (1) or not (0) willing to pay for hired labour in order to clear neighbouring fields
S10	'It is not possible to eradicate mimosa from area'	Q9b	Whether (1) or not (0) willing to clear nearby fields
		Q10	Prefer community (1) or individual (2) management
		Q11	Suggestions for alternative uses of mimosa

Variables were of interval (P1,2,4,5,6a; L1–5; D3–4; Q1a,1c,4,6, 8b), categorical binary (P3,6b; D1; Q1b,3a,7,8a,9,10) or ordinal (Q2; S1–10), and nominal/statement (D1,2; Q3b,5,8c,11) data type

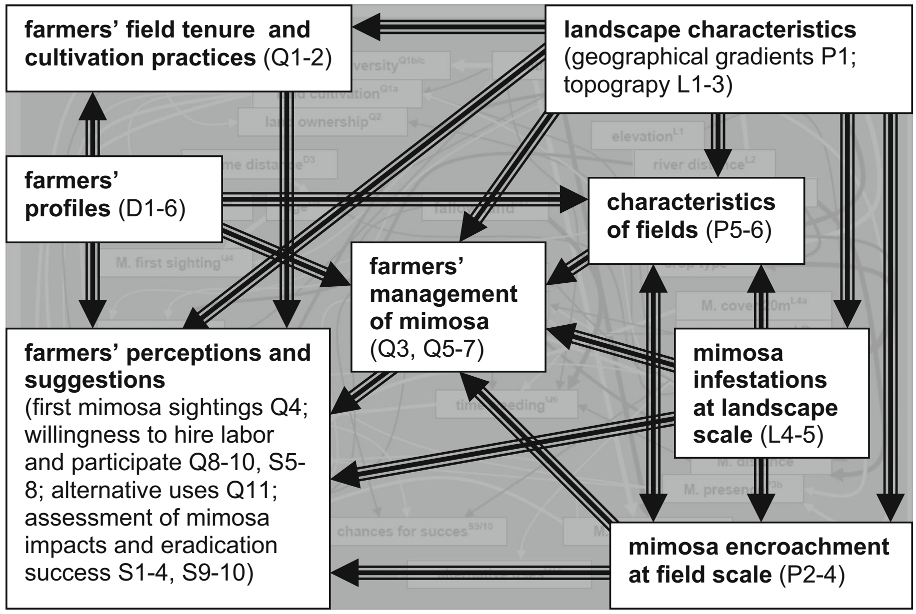
The weed was also ubiquitous along the rims and within gaps of tree plantations and remaining forests. Based on the assessment of the Google Earth© image from January 2008, the average cover of woody vegetation was higher than about 30 % around the farmers' fields (within a radius of 100 and 800 m; variables L4a and L4b).

On average, the closest woody vegetation patches (as visible on the satellite images) were at a distance of about 20 m to the points where the farmers were met (L5b). Rice field areas tended to be more open at intermediate elevations (15–19 m a.s.l.), as compared to more elevated fields (20–24 m a.s.l.) (L5a, Fig. 3). This is probably because rice fields are most productive (and therefore best maintained by farmers) at intermediate heights which receive sufficient flood waters but are not inundated for too long (Nesbitt 1997). In addition, floating seeds may mostly be deposited at the upper levels of the annual flooding zone, leading to higher weed infestation rates and corresponding disincentives for field maintenance (cf. Cook et al. 1996).

Mimosa encroachment in and around the farmers' fields

The visited farmers' fields ranged in size from 50 m^2 to 1 ha (mean 0.8 ± 0.7 ha). Fields tended to be smaller in the northern sections and in areas where the surrounding (radius 800 m) woody vegetation cover was high (P5,

Fig. 2 Conceptual framework of the interrelations between sets of variables (numbers cf. Table 1) serving as indicators of landscape characteristics at the study site, mimosa infestations, farmers' profiles, cultivation and weeding practices, and farmers' adaptations, and perceptions regarding mimosa invasion and management options



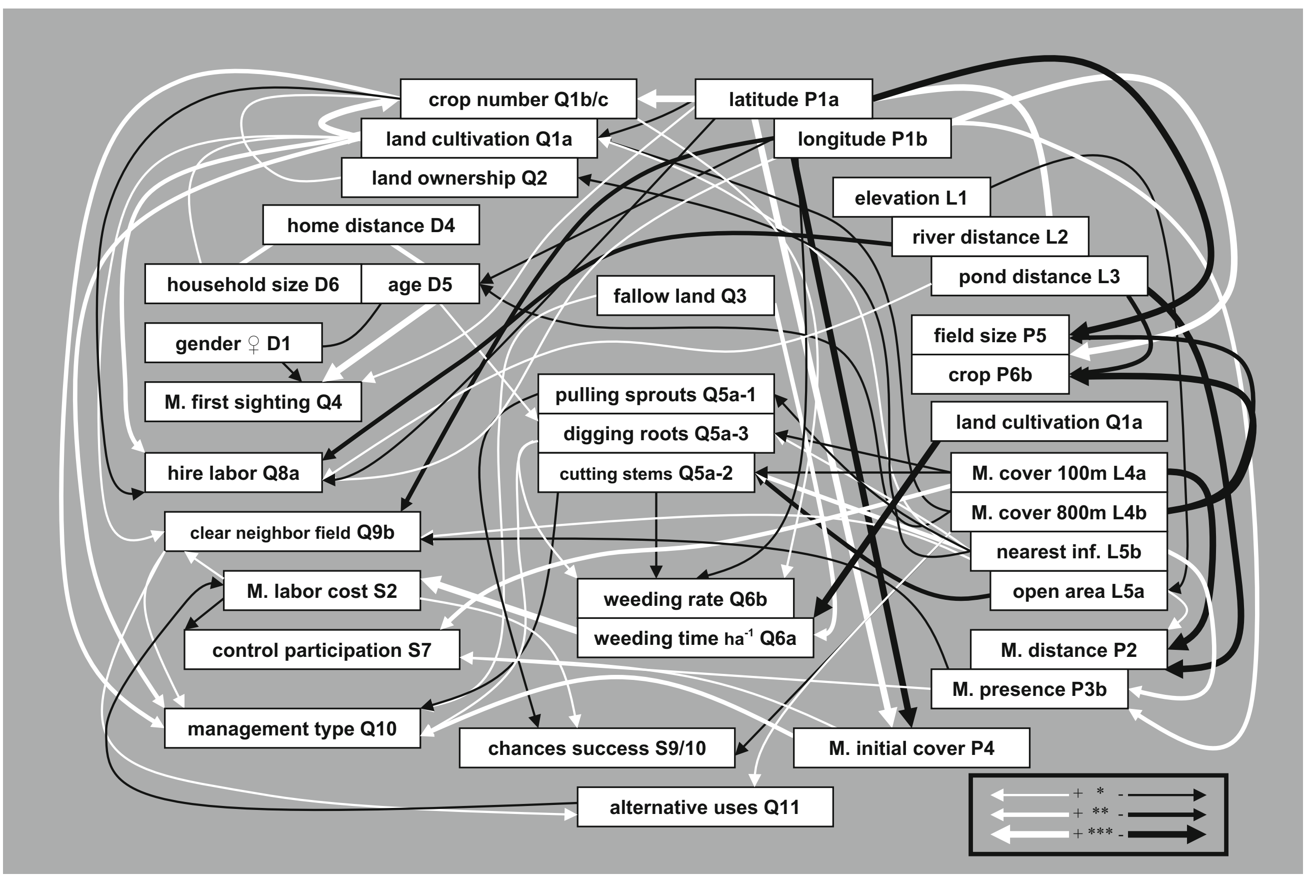


Fig. 3 Interrelations between variables (numbers cf. Table 1) as determined from multivariate statistical analyses. *Arrows* indicate which predictor variables were significant to explain dependent test variables (at the end of *arrows*) in the models. *Arrows* may or may not imply causality. *White arrows* represent positive, *black arrows* negative correlations. *Arrow thickness* indicates significance from the thickest (p value < 0.0005), medium ($p < 0.005$), to the thinnest ($p < 0.05$)

Fig. 3). The fields were planted with rice (67 %) or other crops such as cassava (8 %), cucumber (6 %), watermelon (6 %), cauliflower (5 %), corn (4 %), red corn (3 %), beans (1 %), and onions (1 %) (P6a). Rice fields were mostly situated close to wetlands and isolated irrigation ponds, and in areas with relatively higher surrounding woody cover (radius 800 m). In contrast, non-rice crops were grown in drier areas where mimosa growth was apparently less vigorous (P6b, Fig. 3).

At the time of the survey, no mimosa plants grew on the farmers' fields (P3a). However, 55 % of the fields had mimosa plants or infestation patches growing at less than 10 m away from their borders (P3b, Fig. 3). By farmers' estimates on average, 43 ± 34 % (range 0–100 %) of the fields were covered with mimosa plants before they prepared their fields for crop planting, whereby weed sprouting was highest in northern and western locations (P4, Fig. 3). The distances to mimosa plants or patches (mean of 67 ± 113 m within cardinal segments N–W–S–E from the interview points) tended to be smaller in areas characterized by high surrounding woody cover (radius 100 m) and in the vicinity of isolated ponds (P2, Fig. 3).

The findings indicate that seeds were spread throughout the study site. Potential spatial gradients in seed distributions were, however, superseded by patterns of field management, respectively, larger-scale infestation patterns. In the Mekong Delta, dense stands of mimosa produced on average, >2000 seeds m^{-2} (Triet et al. 2004a). Most deposited seeds germinate in moist and warm conditions, but some seeds remain dormant, adding to long-term soil seed banks which may range from ~100 seeds m^{-2} (Mekong Delta; Triet et al. 2004a) to >12,000 m^{-2} (other regions; Lonsdale et al. 1988; Marambe et al. 2004). In Northern Australia, mimosa spread throughout the Adelaide River floodplains by an average annual rate of >76 m, and there was a close correlation between previous-season rainfall and the increase in area colonized by the plant (Lonsdale 1993). The rate of spread in the Mekong River floodplains was probably considerably higher due to (1) greater flood pulses (up to >50 times higher as compared to Adelaide River; MRC 2005; NTG 2011), and (2) more suitable, open habitats for colonization in and around rice fields. At our study site, all fields except one were closer than 76 m to the nearest mimosa infestation.

Farmers' profiles and land ownership in relation to mimosa infestations

Of the respondents interviewed on the fields (60 % women and 40 % men, D1) were all farmers (D2). They came from 18 different villages (D3), some living nearby (<50 m) but others >6 km away (mean distance 1.0 ± 1.1 km; D4). They were between 20 and 55 years old (mean 37 ± 9.9 years; D5) and lived in households with 1–10 members (mean 5.5 ± 2.1; D6). On average, the women were slightly younger than the men. Hence, husbands of some (younger) women probably followed other activities. Furthermore, respondents from remote villages tended to be older and have larger families than those living nearby. Younger respondents were more likely to have their fields located in areas with high woody cover (Fig. 3). Overall, the patterns indicated that older respondents (with larger families) occupied more land of better quality, respectively, that they tended their fields more carefully than younger respondents which may not have been as dependent on field produces to cater for their (still smaller) families.

Most farmers (65 %) possessed additional fields in nearby areas. Total stated field possessions ranged from 150 m^2 to 7.5 ha (mean 1.7 ± 1.3 ha, mode 1 ha). Farmers with large families and fields located in open areas tended to have more land under cultivation (Q1a, Fig. 3). Thirty-six per cent of the farmers planted only rice, 6 % only other crops. 58 % grew rice and non-rice crops, whereby on average, a fifth of the land was allocated for non-rice crops. Farmers with more land were more likely to plant both, rice and non-rice crops, and especially in the northern sections (Q1b, Fig. 3). Most farmers' land possessions (i.e. mode of 1 ha) were below the national average in Cambodia (~1.2 ha per household), and less than a third as compared to Thailand (~3.4 ha) (USDA 2010; WFP 2012).

In total, 77 % of the farmers owned all their land, 12 % rented all the land, and 11 % both owned and rented land. Non-owning renters were mostly planting rice only, and their fields tended to be situated close to mimosa infestations, whereas farmers who owned and rented land often cultivated additional crops and had their fields in more open areas (Q2, Fig. 3). Thirty per cent of the respondents stated that some of their land was lying fallow (Q3a). Eight farmers with fallow lands stated that they had insufficient time to cultivate all fields, six that fields were close to mimosa infestations and difficult to work, and seven that their fields were either too dry, too wet, too far away, or close to forest and disturbed by wild animals (Q3b).

Accounts on the arrival time of a 'problem' plant

Introduction and invasion of *M. pigra* in South-east Asia are poorly documented. The weed was introduced in Northern Thailand (reportedly in tobacco plantations) possibly as early as 1947 and spread into the Mekong Basin probably around 1975 (Napompeth 1983). The first herbarium record in the Mekong Delta is from 1979 (Triet et al. 2004a), but mimosa had possibly arrived in Vietnam already before the 1970s (Hong Son et al. 2004). Nothing is known from Cambodia which was in turmoil before, during and after the Khmer Rouge regime (1975–1979).

At our study site, two-thirds of the respondents indicated that the weed had arrived 20 or more years ago (maximum 48 years), whereas one-third believed that it had arrived more recently (3–17 years ago). Older respondents, and especially men, as well as those with fields in the northern sections generally stated earlier arrival dates than younger respondents, women and those interviewed in the south (Q4, Fig. 3).

The reported dates reflected the respondents' memories, perceptions and—in the case of young farmers—beliefs in elders' narratives. The responses nonetheless indicate that mimosa was already spreading at least since the mid-1980s. Thirty per cent of the farmers (and especially elder men) traced the invasion back to exactly 1979: as narratives have it, the invading Vietnamese army then planted the prickly weed near military facilities as a 'bio-barb wire'. It appears, however, that mimosa represented a lesser problem until the late 1990s: several farmers only noticed it rather recently. This corresponds to observations by Chamroeun et al. (2002) in Kandal Province (downstream from Kratie) where more than 40 % of interviewed farmers noted mimosa to represent a 'serious' problem in 2000, but only 10 % recalled it to be a problem in 1995. Similarly, mimosa was found only in parts of the Tonle Sap Great Lake during the 1990s, whereas today it covers vast expanses around the lake (Samouth 2004).

Farmers' weed management practices

Virtually, all farmers (98 %) considered mimosa as a serious problem which 'negatively affected their livelihoods' (S1). To most farmers (72 %), mimosa incurred significant costs in terms of time spent on the fields (S2; Table 2), which was reflected by the indicated time spent for weeding (Fig. 3). None of the respondents, however, had changed their crops following mimosa invasion (Q7), and only 6 % indicated that the weed restricted their selection of crops (S3; Table 2).

To combat mimosa in their fields, none of the farmers used any chemicals. Essentially, four weeding techniques were used mostly in combination (Table 3), namely recurrently pulling out young sprouts (applied by 37 % of farmers), cutting (80 %) or burning (11 %) sprouts, and digging out entire plants (62 %). Techniques were apparently not changed over time (Q5).

Regular pulling of young sprouts (mostly seedlings) was mainly practiced on fields which were distant from infestations. The farmers were apparently aware that they needed to control the early weed when it was still small; otherwise, mature plants would firmly establish with deep roots. Costs of mimosa eradication from fields increase disproportionately with the plant's growth (Hong Son et al. 2004).

Cutting and/or digging out of mimosa plants was commonly practiced on fields which had mimosa infestations nearby—however less so if the wider surroundings (radius 100 m) were densely wooded. Older farmers were more likely than the young to remove plants by digging (Q5, Fig. 3). They probably had more time and/or were more conscientious tending their fields. Furthermore, farmers whose fields were situated on higher ground were less likely to apply cutting and/or digging (Q5a-4, Table A4, Appendix A in Supplementary Materials). In the longer term, cutting may only be efficient if done before significant flooding. Under water, the plants' vigour to re-sprout and grow tends to be significantly decreased, and optimally the plants die off (Hong Son et al. 2004).

Direct impacts of mimosa on farmers' lives: the costs of weeding

Time investment for weeding varied widely from one up to 40 days per year and hectare (mean 11 $\pm$ 9; median 7 d/y/ha). Farmers with more cultivated land generally spent less time for weeding per hectare, but more weeding time was noted by farmers with fallow fields (Q6a, Fig. 3). Farmers with more land probably owned well-maintained fields of higher quality and lower invasibility to mimosa. In contrast, farmers with fallow fields had to spend additional time weeding to keep their fields clear. Most farmers were weeding during several working periods (on average, 3.5 periods; $\sim$3 days work per weeding period), but some went out for weeding throughout the year at irregular intervals. High weeding rates were reported by farmers cultivating more than one crop and farmers used to digging up mimosa plants (as compared to those merely cutting the plants) (Q6b, Fig. 3). While generally much effort was spent at weeding, apparently no actions were taken to address the mimosa problem beyond the confines of private fields.

The observations at Chhlong compare well with those of other studies conducted within the region. In Kandal Province in the year 2000, the mimosa weeding costs to farmers were reportedly in the range of 41,000–91,000 Riel ha^{-1} (i.e. 10-23 US$). This represented about 5–10 % of the total farm input costs and a major decrease (up to $\sim$50 %) of net revenues (Chamroeun et al. 2002). In the Mekong Delta, clearance (stem cutting) of one hectare of mature mimosa infestations reportedly required about 30–60 labour days (corresponding to $\sim$100 US$); complete clearing (including uprooting) cost more than 200 US$ (Hong Son et al. 2004).

Table 2 Summary of position statements: perception of weed impacts (S1–S4), the stated motivation to contribute to the eradication of mimosa (S5–S8) and assessment of eradication potential (S9–S10)

Question	HD (%)	D (%)	N (%)	A (%)	HA (%)
S1—Problem to livelihoods	1	1	0	4	94
S2—Labour cost is high	12	12	4	6	66
S3—Crop restriction	91	1	1	0	6
S4—Impact on fisheries	14	6	27	4	49
S5—Eradication desire	3	0	0	1	96
S6—Management team support	6	2	3	0	89
S7—Control participation	14	1	6	9	70
S8—Support by own labour	9	2	4	1	84
S9—Field clearing is very slow	16	25	35	7	17
S10—Eradication impossible	11	23	15	10	41

HD highly disagree, *D* disagree, *N* neutral, *A* agree, *HA* highly agree

Table 3 Frequencies of different combinations of manual techniques used to manage mimosa, as stated by farmers

Manual management	(%)
Cut only	7
Cut + burn	7
Cut + dig out	42
Cut + dig out + burn	3
Cut + dig out + pull out sprouts	10
Cut + pull out sprouts	11
Dig out only	3
Dig out + burn	1
Dig out + pull out sprouts	4
Pull out sprouts only	12

Potential indirect impacts of mimosa on farmers' lives

While mimosa was considered to represent a serious problem, it became clear during group discussions that mimosa was seldom highest on the list of farmers' grievances. Of equal or greater concern than mimosa were animal pests in rice fields such as rodents (mentioned by all eight groups) and 'worms' infesting rice crops (mentioned by seven groups). Other problems that were enounced included native grass weeds (five groups), crabs (four groups), snails (one group), and insects (one group). Further concerns were insufficient water or limited irrigation capacities (three groups), and lack of tools and resources to work the fields (two groups). Asked about the most recent problems, the answers were not coherent, but 'worms' and rodents were apparently recurrent and serious problems.

The responses partly reflect the reality that a majority of farmers are still highly under-resourced (e.g. most prepare fields by man force; irrigation infrastructure is largely absent) and exposed to natural forces (droughts, floods, pests, and crop diseases) (cf. Helmers 1997). Losses of crops during a bad year can easily lead to hardship and ruin a farmer's livelihood (WFP 2012). Neediness and incapacitation of the farmers tie in with a lack of scientific data and technical know-how and hence ineffective support from agricultural institutions. For example, rodents are principal pests of rice crops in Cambodia, but knowledge on species and their ecological dynamics are still inadequate (Frost 2007). Similarly, we could not elicit what species were meant by the mentioned 'worms', but root-knot nematodes and grubs are possible species (cf. IRRI 2009).

Several groups noted that mimosa was 'a big problem' in the sense that it could 'not ever be completely eradicated', but it was 'the oldest problem', so farmers were accustomed to weed it. Hence, many farmers appeared willing to accept 'nature's verdict'. Furthermore, farmers may now consider mimosa as a lesser evil because it can be managed on a fairly predictable basis, in contrast to unruly outbreaks of animal pests. This does not necessarily mean, however, that mimosa represents a lesser important issue.

Replacement of diverse natural forest habitats by mimosa thickets may promote some of the animal and plant pests noted by the farmers. Rodents that thrive on rice and other crops find shelter, breeding habitat, and alternative food sources (e.g. after rice harvests) in mimosa thickets. Conversely, effective predators of rodents (birds of prey, snakes, cats) cannot find shelter and breed in dense mimosa scrubs (Braithwaite et al. 1989; Frost 2007). Likewise, insect and 'worm' pests are often kept in check by a diverse array of predator species which thrive in a landscape with sufficient native vegetation components (Bianchi et al. 2006), but species diversity and abundance are severely depressed in mimosa thickets (Triet et al. 2004b; Braithwaite et al. 1989). By altering the water balance after the wet season, mimosa may also indirectly promote pest species (e.g. root-knot nematodes) and the spread and growth of grass weeds in paddy fields (Chamroeun et al. 2002; Kamoshita et al. 2010).

Along the Mekong, fish catches (as by unit effort) have reportedly been declining, whereby overfishing, destruction of wetland habitats, and shallow water courses and droughts (often attributed to dam construction and climate change) were mostly held accountable (Campbell 2007). It appears plausible, however, that fish habitat and breeding grounds in the littoral zones of wetlands have also deteriorated due to mimosa invasion—especially for large fish species and fishes without scales (Chamroeun et al. 2002). At Chhlong, there was little agreement between farmers as to whether the weed had an impact on fish stocks (S4; Table 2).

Farmers' willingness to contribute to mimosa management

Our study only included farmers which—by will or necessity—had adapted to the invasion by mimosa. The dense mimosa infestations, however, seemed to be mostly on previously cultivated lands. Many fields may have been abandoned during times of turmoil, and the covering infestations (and their soil seed banks) now represent a rather prohibitive obstruction for renewed cultivation. For these and other reasons, many farmers probably sought labour elsewhere, for example, in the booming logging industry (cf. Le Billon 2002; Heinimann 2006).

The interviewed farmer groups noted that much of their villages' lands (estimates ranged from 20 to 90 %) were infested with mimosa. The main concerns were that mimosa was very difficult to clear from the fields (also inflicting wounds from spines) and that it re-sprouted vigorously. One group believed that mimosa infestations could possibly be cleared from surrounding areas 'if everyone works together on clearing all their fields'. Most other groups were, however, overly pessimistic: 'With the number of seeds lying on the ground, and the large number that mimosa produces each year, there is nothing we can do. What could stop mimosa to produce seeds?'

As a prolific source of seeds fields overgrown with mature, mimosa represented a considerable liability. This was recognized by most farmers. The questionnaire interviews indicated nonetheless that the willingness to address the issue (e.g. by hiring/offering labour for weeding or by supporting community initiatives) depended on the farmers' assets at stake (e.g. land area cultivated), the exposure of their fields to mimosa encroachment (e.g. field location in respect to infestations), and individual working morale and perceptions (e.g. reflected by weeding practices).

Only 26 % of the interviewed farmers were hiring or willing to hire labour to clear mimosa from their own fields. Farmers who owned a lot of land but planted only one crop (mostly rice) were most likely to employ workers (Q8a, Fig. 3). On average, those willing to hire indicated that they were prepared to pay 14,762 ± 2095 Riel per day and per person (range 12,000–20,000; one US$ was 4050 Riel). Averaged over all farmers (including those who would not pay), the amount was 3827 ± 6593 Riel (i.e. 0.94 ± 1.63 US$) (Q8b). Those unwilling to hire labour noted that their fields were not very large (15 %), or that they did not have sufficient money (8 %; Q8c).

Even fewer farmers (14 %) were willing to hire labour to clear neighbouring fields of mimosa (Q9a), but a majority (69 %) stated that they themselves would be willing to help weeding surrounding areas. Farmers were likely to offer labour if their fields had no mimosa infestations in close proximity, if they cultivated a comparatively small land area, and if they felt that mimosa represented no major burden on their own fields (Q9b, Fig. 3). Most farmers (53 %) preferred community weed management over individual management (32 %), some being undecided (15 %). Farmers who owned a lot of land and were mostly cultivating rice favoured community management. In addition, farmers in favour of community management generally seemed to be more engaged and hard working (e.g. they were unlikely to have fallow fields, willing to clear mimosa on neighbouring lands, tended to weed mimosa by digging out roots rather than just cutting shoots) (Q10, Fig. 3).

A majority of farmers conveyed a desire to eradicate the weed from their fields (96 %) and noted that they would welcome and offer support to an external mimosa management team (89 %) (S5 and S6, Table 2). Furthermore, most farmers expressed their willingness to participate in weed control programmes (79 %) and provide any kind of support (85 %) (S7 and S8, Table 2). Farmers who expressed little motivation to participate had their fields often in areas of relatively low mimosa cover, had noted the presence of mimosa in relatively recent times, and/or generally spent much time clearing their own fields (S7, Fig. 3).

There were some notable contrasts in response patterns. Farmers expressing general support of management teams (S5) and community management (Q10) were more likely to have their fields in areas with dense mimosa infestations. However, farmers expressing a willingness to 'clear neighbouring fields' were mostly those whose own fields were presumably less exposed (i.e. without mimosa growing adjacent) (Q9b, S7; Fig. 3). These results probably reflect contrasting assessments on potential returns on labour investments, but perhaps also differing views and expectations regarding shared roles in prospective weed control programmes.

Appraisals of potentials for weed control

There was no consensus as to whether mimosa infestations could actually be exterminated from the area of our study site. While 41 % believed mimosa could be cleared from fields within a fairly short time period, only 35 % deemed it could be controlled in a sustainable way (S9 and S10, Table 2). The least optimistic (regarding the possibility to effectively combat mimosa) was generally those who had their fields in the north and in areas with high mimosa cover, and those who considered that mimosa incurred high labour investments (S9 and S10, Fig. 3).

The perceptions shared by many farmers that mimosa would be very hard to control contrasted with the general approval and support of any control programme (with a few exceptions). Many farmers' positive attitudes towards a weed control programme may thus be tied to expectations regarding wider benefits (e.g. employment opportunities, training, and support) that such a programme may beget. Therein, rest certain challenges and risks for any potential project which aims to push back the weed by improving management practices on a long-term basis.

According to Mr. Sokhom (Head of the Office of Agriculture at Chhlong, Cambodian Ministry of Agriculture), the mimosa problem was well known to the local ministry. However, a weed control programme by an NGO had been unsuccessful, and he therefore stated: 'We do not have enough information to formulate an effective management plan, and without one we cannot afford to use our limited resources in such manner as the NGO did'. He noted that the project 'cost a lot of money but nothing was achieved'. The money 'could be used more beneficially elsewhere'. The Office of Agriculture was involved in programmes helping communities to be prepared for droughts as well as the annual monsoon floods. It also provided extension services to combat insect pests and diseases of domestic animals. With regard to mimosa, Mr. Sokhom noted that it was of virtually no use to the communities, but he discouraged the idea to use herbicides because 'then a lot might be used and that is not good for other areas of agriculture'. This notion may be supported by observations in Central Thailand where intensive uses of various synthetic herbicides and other pesticides exerted significant deleterious effects on beneficial paddy infauna and on soils (Maneepitak and Cochard 2014).

Potential beneficial uses of mimosa for livelihoods and business

The prospects for beneficial utilization and/or commercialization of plant products—in particular biomass for fuel production—as suggested by some authors (e.g. Miller 2004; Presnell 2004) appeared to be limited at our study site. Only 37 % of respondents said that mimosa could be (and sometimes was) used as firewood, whereas 63 % saw no plant uses. Those potentially using mimosa for fuel had their fields mostly in areas with a high mimosa cover (radius of 800 m), and they were generally willing to weed neighbouring fields (Q11, Fig. 3). The farmers in the groups interviewed in the villages could not see any sensible uses of mimosa whatsoever. The value of mimosa as firewood was considered very low, since it 'burns quickly and releases a bad smell'. It was noted, however, that 'more and more people use mimosa as firewood, because they do not want to go far to collect [more valuable] firewood'.

Similarly, the local businessman and the charcoal expert from GERES noted that mimosa was of low quality as fuelwood. According to the expert, the carbon content of mimosa charcoal 'is consistently more than 80 %. In this sense, charcoal quality is good, but it is too light to be used, and the process of [wood] compaction is very expensive. It would therefore not be cost-effective to give out mimosa charcoal in compact bundles to the local farmers. Mimosa biomass is more likely to be used in the industrial sector'.

The businessman argued that 'there is no need to consider any alternative source [i.e. mimosa wood or charcoal] of energy yet, because there are still many forested areas that can provide biomass'. Even if better grade woods were exhausted, he would use diesel instead of mimosa. However, the expert from GERES worked with communities at the Tonle Sap Lake, i.e. a region which is more deforested than our study site and where mimosa covers even much larger areas. He believed that there are incentives to use mimosa: 'Mimosa is a big problem in this region, so the local farmers are receptive to the idea of clearing it and turning it into a project that could benefit them. During the dry season, the farmers help us out by cutting large amounts of mimosa and help with the research'. In addition to charcoal, he listed other economically (as yet) fairly unimportant uses of mimosa (e.g. using the wood ash as fertilizer or using it to make vinegar, or for the smoked flavour of fish).

Conclusions and recommendations

Since its introduction *Mimosa pigra* has exerted a considerable impact on the environment, agricultural resources and people's livelihoods in densely populated regions in Cambodia, the weed invades and virtually 'locks up' productive floodplain areas, transforms riparian habitats, and—directly or indirectly—causes significant, economically relevant damages on the paddy fields. It thus represents an important issue to deal with. However, the results of our study showed that farmers considered mimosa infestations largely as an unavoidable burden. To them, options for improved management were limited, for multiple reasons.

The main obstacle to mimosa control is the prolific production and spread of seeds, and the development of permanent seed banks beneath infestations. Evidently, the most effective measure to reduce overall seed production of woody weeds is to directly target the standing vegetation (Richardson and Kluge 2008). The farmers in our study were aware of this. Nonetheless, there were no concrete initiatives to address seed production and dispersal, respectively, to combat standing infestations in a strategic, communally coordinated way. In principle, most farmers were supportive of a potential weed control programme, but support was also linked to expectations for potential individual benefits (income, access to know-how, etc.). An externally funded project may meet particular short-term expectations. The real challenge is, however, to fulfil the objective to substantially improve weed control on a long-term sustainable basis. This challenge can only be met if important remaining questions are addressed in a sufficiently detailed and robust way.

The only promising way forward is to build up further critical knowledge and experience, on which basis—via step-by-step collaborative projects—more elaborate and cost-intensive management schemes and training programmes may be envisaged. Any prospective projects need to be well designed and adequately tailored, taking account of remaining uncertainties and 'unknowns' and addressing these in a strategic way. The key words are 'adaptive management', 'recursive learning cycles', and 'participatory research' on 'ecosystem-based management' (cf. Williams 2011; Allen and Stankley 2009). Exchange of experiences and scientific findings with researchers in other countries can provide additional clues of where resources for research and management may be well invested (Browne et al. 2009), but the unique local conditions need to be kept in sight. Patterns and extents of weed invasion may differ substantially from those in neighbouring countries for several reasons. For example, mimosa invasiveness by seed may be particularly high in Cambodia due to the flooding regimes of the Mekong (as compared to irrigated rice field areas in Thailand). On the other hand, weed control capabilities in Cambodia may be generally weak because of socio-economic, historical, and political contexts (and resulting weaknesses in agricultural/technical potentials or in the bearing of government policies and laws).

The study findings and observations suggest that externally supported and scientifically accompanied pilot projects in community-based weed control could provide particularly useful information and experiences essential to establish more advanced approaches to mimosa management. A central question in such a project would be: what areas need to be cleared of mimosa and in which ways in order to obtain the most rewarding 'returns on investments' in a long-term perspective? Specific mimosa infestations near rice fields may be cleared in large-scale 'experiments', whereby mimosa seed production, dispersal during the floods, and weed infestation rates on the paddy fields may be monitored before and after the interventions. From the resulting data, the effects of mimosa clearing on field infestation rates (and thus weeding effort) could be determined. In addition, various technical aids may be tested, e.g. nets or brushwood fences installed to filter the seed pods during the floods.

Further investigations may focus on the sustainability of mimosa removal. Cleared areas may be returned into production, provided that intensive weeding will continue for some time (at which costs?). On the other hand, infestations may be replaced by riparian forest plantations which can serve various functions, including the production of high-quality wood for construction and fuel uses, as well as 'biodiversity-based pest management'. For such plantations to be successful, however, better understanding needs to be gained of the competitive capacities of mimosa *vis-à-vis* regrowing native tree and shrub species (cf. Chamroeun et al. 2002).

Other researchers may focus on the indirect changes and effects of mimosa clearing, for example, its effects on rat populations and their damages in rice fields. Potentially useful studies may also be conducted on the population dynamics of introduced biocontrol agents in various infestation patches. For example, bruchid seed beetles (*Acanthoscelides* spp.) have been released in Thailand and have successfully established in mimosa infestations. Despite this, the overall success of biocontrol remained limited (Suasa-ard et al. 2004; ISSG 2013). In wetlands, biocontrol by bruchids may be hampered as many seeds escape predation by dropping into water (Cochard and Jackes 2005), but wild populations could possibly be boosted via the release of artificially reared populations.

In addition to such experiments and ecological studies, further possibilities should be investigated to obtain benefits from utilizing mimosa biomass products. For example, Rachtanapun and Rattanapanone (2011) reported that mimosa biomass may be profitably used for the manufacture of cellulose products. Overall, the various ecological and socio-economic investigations may serve to address the following superordinate question: can clearing large stands of mimosa be 'cost-effective', provided that all the weed's external costs (e.g. caused by land consumption, replacement of floodplain forests, seed pollution of rice fields, facilitation of pests, and other ecosystem changes) and benefits (e.g. products derived from cut mimosa wood) are taken into account? If a clear 'yes' is the answer, then potentially effective policies or wider management programmes may be conceived of.

In Australia, integrated weed control strategies have shown higher promises for success than any methods used in isolation (Paynter and Flanagan 2004). However, therein lie additional challenges. Elaborate longer-term weed control strategies can be implemented effectively only in a socio-politically stable and institutionally benign environment. In Cambodia, stability and legal security have, however, not been bountiful 'resources' during the last decades; among other things, this has facilitated profligate exploitation of forests and other natural resources by influential actors (cf. Le Billon 2002; Markussen 2008). Before costly mimosa weed control schemes are envisaged, the socio-political contexts need to be better understood and taken account of. Most farmers have expressed a willingness to provide support to initiatives targeting mimosa, but there may be various underlying motivations and associated expectations. In particular, it needs to be further investigated in which ways property rights and power constellations relate to agricultural lands under continued cropping *versus* under mimosa cover, and how different stakeholders may potentially benefit or lose out from the investments in mimosa weed control programmes (cf. Shams and Ahmed 2000). The central aim clearly must be to improve overall livelihood conditions of poor rural communities in an equitable way. Ultimately, this can only be achieved if any programme is well founded and finds acceptance as well as active support in local communities and organizations.

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