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Shifting cultivation in steeply sloped regions: a review of management options and research priorities for Mizoram state, Northeast India

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Abstract Shifting cultivation is a common agricultural practice that is the basis of subsistence for many rural populations throughout the Tropics. The recent strong trend towards shorter fallow periods has led to widespread concern about declines in soil fertility, crop yields, and food security. Unlike most research on this problem, we focus here on steeply sloped regions such as Mizoram state in northeast India where most land is at an incline of >33°, and the potential for relatively large soil erosional losses may necessitate distinctive solutions. Our goal is to review the relevant literature so as to optimize the direction and quality of future science research on shifting cultivation in Mizoram. Our analysis suggests that the most promising options for improving shifting cultivation are nutrient and water supplementation, optimising crop choice, extending the site use period, enhancing the fallow recovery rate, and controlling the burns and their environmental impacts. Promising alternatives for replacing shifting cultivation include inter-row cropping between contour hedgerows of nitrogen-fixing shrubs, slope terracing, agroforestry with anti-erosional plants, and bamboo forest harvesting. In addition, we identify the principal research questions that should be addressed before each of these options can be evaluated and recommended as part of land use planning initiatives. Overall, we conclude that intelligent and careful use of commercial fertilizer in combination with organic matter additions is likely to be an important feature of many of the solutions to the problem of shortening fallow periods in shifting cultivation on steep slopes.

Keywords Agriculture · Fire · Hill · Jhum · Land-use policy · Slash and burn · Swidden

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General introduction

Shifting cultivation has been a common agricultural practice in tropical hilly areas of Southeast Asia, the Pacific, Latin America, the Caribbean, and Africa for millennia (Cairns and Garrity 1999; Craswell et al. 1997; Eastmond and Faust 2006; Kato et al. 1999; Lawrence and Schlesinger 2001; Ramakrishnan 1992; Stromgaard 1992; Thomaz 2009). Estimates suggest that it is the basis of subsistence for at least half a billion people (Craswell et al. 1997). Each year, village communities slash the vegetation on selected sites during winter, wait for it to dry, and then burn it in situ before planting a variety of annual crops to coincide with the return of the rains (Toky and Ramakrishnan 1981a). These sites are then abandoned so that the vegetation and soil fertility can recover by natural regeneration over a number of years during which the villagers select other sites for cultivation. The fundamental principles of sustainable shifting cultivation are that losses of plant-available nutrients should be matched by new supply over the full rotational cycle, and that all other components of soil quality (e.g., texture and organic matter content that together determine water holding capacity) should be conserved. In other words, nutrient removal within the harvested crop plus nutrient losses due to run-off, leaching and fire volatilisation should not exceed plant-available nutrient inputs from nitrogen fixation plus in situ soil biogeochemical transformations from non-available forms (e.g., phosphorus-containing compounds) (Lawrence and Schlesinger 2001). Shifting cultivation was an economically and ecologically efficient agricultural practice in former times when village population densities were low, and the fallow abandonment period matched or exceeded the time necessary for full recovery of the sites (Bruun et al. 2009; Ramakrishnan 1992; Tanaka et al. 2001). However, fallow periods have been shortening from 2 to 3 decades down to 0–5 years across S. E. Asia and elsewhere (Anonymous 2009b; Cairns and Garrity 1999; Eastmond and Faust 2006; Kato et al. 1999; Ramakrishnan 1992; Schmidt-Vogt et al. 2009; Tawnenga et al. 1996) as rural populations have increased. The consequences are lowered soil fertility, increased soil erosional losses, and reduced annual crop yields (Bruun et al. 2009; Ramakrishnan 1992; Thomaz 2009; Ziegler et al. 2009). In essence, the increasing intensity of land use for shifting cultivation has gone beyond its sustainable capacity in many tropical regions.

Over 50 years ago, the Food and Agriculture Organisation described shifting cultivation “as the greatest obstacle not only to the immediate increase of agricultural production, but also to the conservation of production potential for the future, in the form of soils and forests” (FAO 1957). Shifting cultivation has since become widely perceived as a primitive and economically inefficient form of agricultural production that resulted in soil erosional losses, watershed siltation, and atmospheric smoke problems. This perception has been central to land use management and policy development in many affected regions (Anonymous 2009c; Maithani 2005; Mertz 2002). However, recent science reviews indicate that the deleterious impacts of shifting cultivation on the environment may have been greatly overestimated (Bruun et al. 2009; Cairns and Garrity 1999; Mertz et al. 2009; Ramakrishnan 1992; Ziegler et al. 2009). In hindsight, many of the original comparative research studies were fundamentally flawed in that they relied on spatial analogues (adjacent sites with different cultivation practices) without accounting for farmer’s conscious selection of particular sites for certain cultivation practices based on perceptions of soil quality and potential agricultural productivity (Bruun et al. 2009). Researchers failed to explicitly recognise the fundamental assumption that site differences in ecological processes can only be attributed to differences in cultivation practices *if* those sites were identical in terms of soil quality, topography, land-use history, climate and biota before cultivation was initiated (Amundson and Jenny 1997; Cairns and Garrity 1999; Foote and Grogan 2010; Knops and Tilman 2000; Ramakrishnan 1992). This assumption is also critical in chronosequence studies that use a series of spatial analogues to investigate patterns over time such as research on the impact of differences in fallow period on ecological processes (Toky and Ramakrishnan 1983a, b). In summary, and in contrast to many policy-makers, shifting cultivation is now considered a highly ecologically and economically efficient agricultural practice *provided that* the fallow period is sufficiently long (Anonymous 2009a; Bruun et al. 2009; Cairns and Garrity 1999; Craswell et al. 1997; Mertz et al. 2009; Ramakrishnan 1992; Ziegler et al. 2009). Nevertheless, there is broad agreement among scientists and policy-makers that the current trend toward reduced fallow periods in lands under shifting cultivation makes this practice unsustainable, and results in reduced crop yields as well as increased environmental degradation due to soil erosional losses, watershed siltation, and atmospheric pollution.

Here, we focus on the distinctive features of shifting cultivation agriculture in steeply sloped regions such as Mizoram state in northeastern India (Figs. 1, 2). Mizoram’s topography makes it unusual relative to many other areas in the Tropics where shifting cultivation is practiced. ‘Mizo’ literally means ‘people of the hills’. At least 70% of the state’s total planimetric land area (~2,108700 ha) is sloped at angles steeper than 33° (Anonymous 2009c). Approximately half of all households in Mizoram are engaged in shifting cultivation (Anonymous 2009c), primarily in relatively undeveloped remote villages (Singh et al.

Fig. 1 Extensive burned areas in a typical Mizoram landscape in February

Fig. 2 Shifting cultivation on steep slopes in eastern Mizoram

2010). Remote-sensing based estimates of the total area burned each year by farmers and wildfires range from 40,000 to 110,000 ha (Anonymous 2009b, c; Singh and Savant 2000; Tawnenga et al. 1996). Most studies of shifting cultivation across the Tropics have focussed on fairly flat or gently sloping lands (Craswell et al. 1997; Eastmond and Faust 2006; Kato et al. 1999; Lawrence and Schlesinger 2001; Stromgaard 1992; Thomaz 2009). Research from steeply sloped lands in Laos and Northern Thailand indicates that the problems of declining soil fertility, lowered crop productivity, and increased soil erosional losses with shortened fallow periods may be even greater than on gently sloped regions (Dupin et al. 2009; Fujisaka 1991; Roder et al. 1997; Turkelboom et al. 2008). However, the climate and therefore the vegetation in these regions is clearly different from that in Mizoram. Therefore, although reviews of this literature provide a wealth of conclusions and several options for improving or replacing shifting cultivation practices, all require very careful evaluation in the specific contexts of Mizoram's topography and climate. Here, we present a comprehensive and detailed review of those studies that were conducted within Mizoram or on comparable slopes in the nearby Indian state of Meghalaya. Our goals are: (a) to identify those potential management practices that might best apply to steeply sloped lands; and (b) to highlight the principal knowledge gaps that need to be filled before policy-makers should recommend those practices in such lands. Our focus is on solutions that might be useful to individual subsistence farmers, and that do not require major infrastructural investments that are unlikely to be available to most village communities.

Agricultural practices in Mizoram

Fire is an integral part of the Mizo culture. It clears the land, temporarily nourishes the soil, and restricts weeds, plant pests and pathogens. The mizo term for February ('Ramtuk Thla') literally means the 'time for preparing the land for burning'. Slash and burn agricultural practices are common and widespread in Mizoram resulting in a landscape dominated by mixed species bamboo forests in various stages of post-fire succession. Mature sub-tropical wet hill and tropical wet evergreen forests that are the natural climax vegetation in the higher and lower altitudes of this region, respectively, (Champion and Seth 1968) cover just 20% of the land area (Singh et al. 2010). Typical shifting cultivation crops include upland rice (*Oryza sativa*), sugarcane (*Saccharum officinarum*), maize

(*Zea mays*), chillies (*Capsicum annuum*), eggplant or 'brinjal' (*Solanum melongena*), lady's fingers/okra (*Abelmoschus esculentus*), squash (*Sechium edule*), pineapple (*Ananas comosus*), Cassava (*Manihot esculentum*) and herbs such as Mustard (*Brassica juncea*). In addition, ginger (*Zingiber officinalis*) and turmeric (*Curcuma longa*) are frequently planted in recently burned sites because they grow well on steep slopes are high value crops that store and transport well (unlike bananas for example). However, harvesting these subterranean crops involves opening up the soil and exposing it to erosional losses.

Annual crops including wetland rice are continuously cultivated on Mizoram's more gentle slopes and valley bottoms. Localised special initiatives such as horticulture (e.g., *Anthurium* flowers), viticulture (wine grapes) and citrus fruit and oil palm plantations have been established, but require substantial government investment assistance that will only be a feasible option for a very small proportion of farmers. Poultry and pigs are the primary focus of animal husbandry. Cattle are rare although dairy farmers that have ready access to a milk market, and that make optimal use of farmyard manure seem to be successful on gentle slopes and terraces (Grogan, pers. obs.). Nevertheless, these farms rely heavily on a much larger neighbouring area of surrounding post-fire successional vegetation for manual fodder collection. The availability of commercial (industrially manufactured) fertilizer was severely restricted by the Mizoram government in 2005 in a bid to achieve 'organic' agricultural production status within India, and to avoid eutrophication of watersheds. Nevertheless, some farmers are acquiring and using small amounts of commercial fertilizer (e.g., diammonium phosphate, urea) especially on continuously cultivated slopes and terraces (Grogan, pers. obs.).

Mizoram's latest land use policy initiative highlights the environmental degradation associated with shifting cultivation (Anonymous 2009c). In addition to soil erosional losses, watershed siltation, and smoke problems, there are serious concerns relating to mature forest habitat destruction, biodiversity losses, and conservation issues (Singh et al. 2010). For example, Dampa Tiger Reserve which contains 11 endangered mammal species and is the largest protected area in the state, lost ~4% of its forest to fire last year due to slash and burn activities by adjacent villagers (Grogan, pers. obs.).

Research on shifting cultivation in Mizoram and similar sites in nearby states

The influence of fallow period duration on crop yields and biogeochemistry

Prof. P.S. Ramakrishnan has spearheaded research into shifting cultivation in northeastern India using a wide range of sites of differing climate and agricultural land management (Ramakrishnan 1992). Here, we focus on studies at his low elevation Burnihat site in Meghalaya because it seems to most closely resemble typical conditions in Mizoram. Nevertheless the slope at that site was fairly gentle (20–40°) (Toky and Ramakrishnan 1981a), and therefore extrapolations from these studies to the generally steeper sloped lands of Mizoram should be made with caution. The influences of fallow period on economic yields and soil biogeochemistry were studied by comparing replicate fields of similar slope that were under 5, 10 and 30 year fallow rotation periods. Mean annual total economic yields over a full rotational cycle were twice as high in the 10 and 30 year compared to the 5 year fallow systems (Toky and Ramakrishnan 1981a). Mean annual losses of major soluble nutrients in run-off (plus downward percolating waters) did not differ between fields of varying fallow period, but surface run-off sediment losses were ~40% higher in the shortest fallow fields (Toky and Ramakrishnan 1981b). These results strongly support the contention that reduced yields in short fallow shifting cultivation cycles are caused by enhanced soil erosion.

Soil biogeochemical investigations in these sites indicated that concentrations of organic carbon and nitrogen in the top 7 cm were ~25% lower in the shortest fallow fields, although pools sizes (g m^{-2}) seemed much more similar, suggesting greater compaction (higher bulk density) in the 5 year fallow site (Ramakrishnan and Toky 1981). Extractable phosphorus concentrations and pools, and potassium concentrations were 2–3 times lower in the shortest fallow fields. Fire at all sites elevated base cation pools immediately, and enhanced extractable phosphorus pools after 30 days. The authors reported that fire reduced surface soil carbon concentrations by ~15% in the 10 and 30 year fallow sites, but not in the shortest fallow period site, presumably because the lower biomass, litter and humus levels there resulted in less intense fire, and because the pre-burn soil carbon levels were relatively low (Ramakrishnan and Toky 1981).

The surface soil carbon pool is critical because organic matter content is a fundamental determinant of soil fertility since it influences water holding capacity and nutrient stocks for microbial biogeochemical processing and supply into the plant-available nutrient pool (Chapin et al. 2002).

Biomass, productivity and nutrient cycling during natural vegetation succession over a 20 year fallow period

Plant community succession and soil biogeochemistry during natural regeneration over a 20 year period after fire were also studied at the Burnihat site (Toky and Ramakrishnan 1983a, b). Chronosequences of three replicate fields with similar topography and slope that had been burned either 1, 10, 15 or 20 years ago were used to show that species diversity, aboveground biomass accumulation, net primary productivity and litterfall production increased as vegetation succession proceeded (Toky and Ramakrishnan 1983a). Nitrogen, phosphorus, and potassium accumulation in shoots increased correspondingly, with bamboo accounting for almost half of total plant shoot acquisition of these elements (Toky and Ramakrishnan 1983b). Unfortunately, interpretation of all the Burnihat data is constrained because only the most preliminary statistical analyses were included and so it is often difficult to determine if apparent trends between sites or over time since burning were overwhelmed by variability among replicate fields. Nevertheless, these studies together generally support the conclusions that: (a) the fallow period must be a minimum of 10 years to allow sufficient site recovery for economically viable and ecologically sustainable shifting cultivation; (b) soil fertility (at least availability of phosphorus and base cations) is reduced when fallow periods are shortened to 5 years because of increased sediment run-off rather than soluble nutrient losses; (c) soil carbon pool size (i.e., organic matter content) is depleted when fallow periods are shortened to 5 years, thereby contributing to reduced supply of plant-available nutrients.

Total productivity, crop yields, soil fertility and economic efficiency during second year cropping on burned sites

The hypothesis that cultivation on burned sites could be extended by effective cropping in the second year after burning was tested in two sites under differing fallow periods in Mizoram (Tawnenga et al. 1996). Ecosystem productivity (total dry matter production in crops and weeds) in a 6 year fallow site during the two successive years after burning was 45 and 22% lower, respectively, than in a 20 year fallow site (Tawnenga et al. 1996). Soil organic carbon, total nitrogen, extractable phosphorus and exchangable cation pools were all depleted in the shorter fallow site, and soluble nutrients progressively declined during each of the successive cropping years at both sites (Tawnenga et al. 1997b). Commercial fertilizer and/or farmyard manure additions in the second year elevated productivity in the short and long fallow period sites by ~50 and ~33%, respectively. A detailed analysis of the economic efficiency of the various treatments at the two sites indicated that labour costs dominated, and that the additional monetary input associated with fertilizer and farmyard manure acquisition and application increased total costs by 11 and 22% in the short and long fallow sites, respectively (Tawnenga et al. 1997a). Patterns for economic yields (rice grain production) were similar to ecosystem productivity although the magnitudes of the effects were sometimes much smaller. For example, rice grain yields were only 8 and 2% lower in short as compared to long fallow fields during the two successive years after burning. Finally, and converse to the productivity pattern, the combination of commercial fertilizer and farmyard manure additions apparently elevated second year rice yields more in the long fallow than in the short fallow sites (by 48 and 17%, respectively) (Tawnenga et al. 1997a).

Unfortunately, data interpretation from these studies is difficult because no statistical analyses were included. Furthermore, several important details such as local soil type and aspect are not reported, leading to concerns about the fundamental assumption that both sites were similar in all respects except fallow period (see Introduction above), and therefore that site differences in yields etcetera were directly caused by differences in fallow period. Finally, the relatively gentle slope of the sites (generally <30°, Tawnenga, pers. comm.) implies that the studies' conclusions may not apply to many lands under shifting cultivation in Mizoram. Nevertheless, these studies together generally support the conclusions that: (a) shortened fallow periods tend to result in lower total productivity and slightly lower economic yields because soil fertility is reduced; (b) that second year cropping during shifting cultivation is a promising option to reduce the area required for burning each year; and (c) that if labour costs are not included (i.e., treated as ‘free’ inputs from the farmer and his family), then commercial and manure fertilizer applications make economic sense.

The influences of nutrient availability and plant spacing on productivity in a bamboo-ginger agroforestry trial on a degraded steep slope

A bamboo-ginger agroforestry system was tested on a steep slope (~45°) that had been degraded by intensive shifting cultivation near Aizawl, Mizoram (Jha and Lalnunmawia 2003; Lalnunmawia 2002). Growth and productivity of three edible bamboo species and of the shade-tolerant ginger intercrop were compared at two different plant spacings with commercial fertilizer or manure applications using a split–split plot design. The economic yields of each of the bamboo species and ginger in the third year were increased by fertilizer and to a less degree by manure additions, and were elevated under the larger plant spacing (Lalnunmawia 2002). Further trials of this apparently promising approach are needed that focus on appropriate management of the impacts of bamboo shading and root competition on understory crop productivity, and on the economic outcome of this cultivation practice.

Overall, our review of the literature indicates that there is still a great need to identify solutions to the problems associated with shortening fallow periods in shifting cultivation on the steeply sloped lands of Mizoram. Two contrasting approaches to potential solutions are possible: (a) *improve* current shifting cultivation by developing practices that lower the frequency of burning (extend the fallow period) while maintaining economic yields (Table 1); and b) *replace* shifting cultivation with other agricultural practices that would allow continuous and economically viable crop production on steep slopes (Table 2). Below, we highlight what we think are the most promising options in developing both of these approaches in a region like Mizoram. Furthermore, we outline the critical knowledge gaps and associated specific science questions that warrant the highest priority in terms of future research into evaluating and comparing these options (Tables 1, 2).

Improving shifting cultivation practices on steep slopes: options and associated research priorities

1. Nutrient supplementation. Experimental increases in soil nutrient availability to plants in this region have enhanced crop growth (Jha and Lalnunmawia 2003; Lalnunmawia 2002) and increased economic yields although often to a lesser extent (Tawnenga et al. 1996). Enhanced yields per unit area could encourage farmers to burn and cultivate smaller plots, thereby extending the mean fallow period across the region.
2. Water supplementation. Soil water availability in this region may restrict crop production either directly as a result of plant water stress or indirectly as a constraint on soil nutrient supply to plants. Temporary small mobile or even permanent large rainwater harvesting tanks could significantly enhance yields.
3. Optimising crop choice. A farmer’s choice of crop depends on environmental, farm management, economic and market access factors. Farmers are well aware that multicropping agroforestry practices promote stable productivity, as well as resilience against disease, drought years, and variability in crop market values. In essence, this cultivation approach creates a multi-layered canopy and a diverse rooting system that optimise overall light, nutrient and water use efficiency (Ramakrishnan 1992; Toky and Ramakrishnan 1981a). Furthermore, farmers adapt their mix, tending to grow proportionally more tubers and rhizomatous crops and less cereals when using shorter fallow periods, or in relatively infertile soils (Ramakrishnan and Toky 1981). Finally, incorporation of wild or relatively unknown plant species into agricultural production may be beneficial (Ramakrishnan 1992).
4. Extending the site use period. Multiple cropping over successive years using appropriate choices of perennials alongside annuals may be a very promising option for extending the duration of cultivation on a burned site. For example, the total regional area burned each year could be reduced to 1/3 of current rates if crop yields on a burned site were maintained at similar levels in the second and third years after burning. Starchy tubers such as cassava (*Manihot esculenta*), taro

Table 1 Improving shifting cultivation practices on steeply sloped lands: Potential options and priority science research questions to evaluate their effectiveness

Potential options	Critical science research questions
1. Nutrient supplementation	a. What is the relative importance of nitrogen, phosphorus, and potassium in determining crop growth and economic yields on steep slopes in this region?
	b. How do local site factors such as slope, aspect, soil-type, and climate influence the chemistry of nutrient limitation to crop growth? Which of these factors is most important in determining that limitation?
	c. What quantities of organic matter mulch inputs would be required to enhance crop growth on steep slopes? Could these inputs be feasibly met by composted weeds and crop residues (green manure) from within a site, and if not, what area of adjacent land would be required?
	d. If organic matter mulch inputs are supplied from cow manure, what cattle density would be required to make an average village self-sufficient in terms of food production and economic return? What factors will determine whether this density is feasible in a region where animal husbandry is primarily focussed on poultry and pigs? What is the potential for pig dung in this regard?
	e. Does it make financial sense to apply commercial fertilizer to enhance crop economic yields? What is the best practice for applying fertilizer to maximise crop nutrient uptake and minimise nutrient losses downslope? Should the various crop growth-limiting elements be applied in different ways? For example, nitrogen fertilizer is water-soluble and might be best applied at low rates as a top-dressing several times during the growing season to maximise crop uptake whilst minimising leaching losses. By contrast, phosphorus is relatively insoluble and therefore might be best mixed in with the topsoil at the time of crop planting to minimise particulate surface run-off losses during the subsequent rains. Detailed experimental studies are required to identify the most effective method, rate, timing and frequency of commercial fertilizer application during the growing season to maximise crop yields while minimising environmental impacts
2. Water supplementation	a. What is the relative importance of water and nutrient availability in limiting crop production and economic yield on steep slopes in this region?
	b. Is it financially sensible to construct passive rainwater collectors to enhance crop production and yield?
	c. How do local factors such as climate, slope and soil-type influence this issue?
3. Optimise crop choice	a. What is the optimum mix of crop species to maximise subsistence and economic yields on steeply sloped shifting cultivation sites, and how does this relate to fallow period length?
	b. How do local site factors such as slope, aspect, soil-type, climate and proximity to markets influence the choice of optimum mix?
	c. Which wild plants might be developed as appropriate crops for the region?
4. Extend the site use period	a. What perennial crops are most appropriate to sustaining economic yields over successive years? Brinjal (eggplant) and chilli are sometimes grown in the second year. Are there perennials that would be appropriate? Would subterranean high value crops such as turmeric and ginger be appropriate in the final (e.g. third) year because opening up the soil for harvesting at that stage is no longer a critical concern? What fast-growing tree species are most appropriate in terms of producing a fruit crop, desirable wood or high nutrient litter (green manure) over the longer term? Are there wild plants that might be developed as appropriate crops for such a multiple cropping sequence?
	b. What techniques could be used to suppress weeds in the second and third years after burning? Would the labour and time investment necessary for repeated weeding be economically feasible? Would mulching with the pulled weeds and crop residues be sufficient to restrict new weed growth? Would ‘light’ burning at the beginning of the second and third years to clear the ground be appropriate?

Table 1 continued

Potential options	Critical science research questions
	c. What is the optimum crop mix to minimise soil erosion losses in the second and third years? Are there cover crops that could be used to protect and enhance the soils over the dry seasons prior to the second and third years? For example, would *Flemingia vestita* be appropriate since it seems to be a very effective cover crop in fallow-rotation sedentary systems in Meghalaya's cooler, relatively high elevation sites (Ramakrishnan 1992)?
	d. What techniques would be most appropriate to supplement nutrient availability to the crops of the second and third years? In this context, research is needed to address each of the questions raised in Sect. 1 (above) since the answers may differ between the initial burn year and successive years
	e. Would the reduction in soil erosional losses associated with the insertion of bamboo or tree stem fences perpendicular to the slope be ecologically effective on steep slopes, and economically worthwhile?
5. Enhance the fallow recovery rate	a. What nitrogen-fixing and other species might be planted on cropped sites to enhance vegetation succession?
	b. What ground-cover species would be appropriate for planting after cropping to protect the soils against subsequent erosional losses?
	c. Would fertilizer addition be appropriate to speeding up vegetation regeneration, and would it be economically sensible? Which nutrients would be most beneficial?
6. Improve fire management and its environmental impacts	a. What is the potential for improving fire management, and how can this be achieved? What proportion of land in the region is burned each year, but not cultivated? Are fire-breaks being used widely and effectively to control the areal extents of burns?
	b. Can bamboo varieties and other fast-growing native trees be effectively utilized as wind-breaks to minimize wind- and water-borne soil, ash and soluble nutrient losses? Would mulching with organic matter residues after the burns be appropriate and feasible?

(*Colocasia esculenta*), and sweet potato (*Ipomoea batatas*), fruits such as banana and papaya (*Carica papaya*) and vegetables such as chillies, beans and squashes (*Cucurbita* spp.) could be grown during the mid-late growth phase of the first year's cereals. These crops will provide a protective soil cover when and after the cereals are harvested and will be ready for harvesting in the subsequent years. Furthermore, these crops restrict declines in soil fertility by promoting a protective vegetation and surface litter layer that restricts nutrient and particulate losses and enhances soil organic matter (Borthakur 2002). Finally, crop yields have been successfully maintained on annually burned slopes in Nagaland for ~6 years by using simple fences to restrict soil erosional losses (Anonymous 2009a).

5. Management to enhance the fallow recovery rate. The minimum fallow period required for sufficient natural regeneration of the vegetation and restoration of soil fertility to permit sustainable shifting cultivation is at least 10 years in northeast India (Ramakrishnan 1992; Ramakrishnan and Toky 1981). Techniques such as plantation with nitrogen-fixing species to enhance fertility and protect against erosion may lower the minimum fallow period and therefore improve long term overall crop productivity per unit area of land. See section 5 in Table 1 for some specific high priority science research questions to achieve this goal.
6. Improved management of fire and its environmental impacts. Since substantial land areas appear to be burned but then not cultivated (Grogan, pers. obs.)., there may be considerable potential for improving burning efficiency and thereby reducing the total area burned each year, and the associated detrimental environmental impacts. In other words, land burning should be restricted to the actual area required for cultivation in the following Spring. Furthermore, since 30–50% of the nutrients in ash (mainly phosphorus and base cations) may be blown off burned

Table 2 Replacing shifting with more continuous cultivation practices on steeply sloped lands: potential alternatives and priority science research questions to evaluate their effectiveness

Potential options	Critical science research questions
1. Nitrogen-fixing shrub hedgerows (Sloping Agricultural Land Technology)	a. Can soil fertility of all crop-limiting nutrients be maintained over the long term using SALT practices? Temporal patterns in the availability of all potential growth limiting nutrients and whole farm nutrient budgets over at least a decade are required
	b. Over what period can crop productivity be maintained by continuously cultivating such lands in this way? Patterns of individual and overall crop productivity and yields must be documented
	c. Is this practice economically viable? Full financial and labour investment analyses over at least a decade are necessary
	d. Which nitrogen-fixing shrub species are most appropriate to the different slopes, soil-types and climatic conditions that occur across the region? Properly designed trials with appropriate controls to specifically test species differences in performance (e.g. Bhatt et al., 2010) on a variety of slopes under the various climates and soil-types that occur across Mizoram are urgently needed. Such trials, if successful, would also be a critically important resource in disseminating this technology to local farmers. Finally, the potential of *Alnus nepalensis*, *Albizzia* spp., *Casuarina* spp., *Leucaena* spp., *Derris robusta* and other nitrogen-fixing shrub and tree species should be assessed to determine whether they are likely to grow well in this region
	e. How can weeds be best managed? Farmers apparently manage non-crop species in clever ways, recognising that these plants can provide net benefits at certain times in the growing season (Ramakrishnan 1992). Non-crop species only become perceived as 'weeds' when their presence is detrimental to the crop, and even then, ~20% of 'weeds' may be deliberately left undisturbed because they are providing protective cover for the soil (Ramakrishnan 1992). What is the reproductive phenology of common noxious weeds occurring during this form of cultivation, and how might they best be managed in this context? Do *Tephrosia candida* seedlings have weed suppressing activity (see SALT case study below), and if so, is this due to their innate abundance that results in extensive soil surface cover, or are there also allelopathic interactions involved?
2. Slope terracing	a. Up to what slope angle is terracing an economically and ecologically worthwhile practice in this region, and what is the most appropriate terrace height for a particular slope?
	b. Can contour fences of bamboo or tree stem poles enhance the longevity of terrace walls? Is the economic and labour investment worthwhile over the full lifespan of the terraces?
	c. What crops are most appropriate for production on terraces? Many of the questions relating to optimising crop choice on burned sites in section 3 of Table 1 also apply to sites under permanent terrace cultivation. Aboveground crops such as soya bean (*Glycine max*), maize and mustard are likely to be most appropriate as harvesting will not disturb the terrace soils. For example, just as in Laos (Ducourtieux et al., 2006), would spices like cardamom (*Elettaria cardamomum*) have particularly strong potential in this context because they also have a high market value and excellent storage capacity? Nevertheless, periodic tillage is beneficial to soils and therefore ginger, yam and sweet potato may be appropriate on terraces every few years
	d. Which wild plants might be developed as appropriate terrace crops for the region?
3. Agroforestry with anti-erosion plants	a. Do bamboo stands reduce overall soil erosion on steep slopes, or do they tend to channel downflow into the areas between stands, and therefore enhance erosion there? Would bamboo hedgerows be more appropriate?
	b. Since ginger and turmeric crops are subterranean, are there alternative, commercially viable, shade-tolerant, and preferably perennial crops that could be repeatedly grown among bamboo stands without opening up the soil to erosion during harvesting?
	c. What other plant species might provide protection against erosion on steep slopes while enhancing overall farm yield (e.g. banana, nitrogen-fixing crop trees, fruit trees)?
	d. Would trenching around the anti-erosion plants be necessary to prevent competitive or allelopathic interactions with the crop plants for nutrients and/or water resulting in sub-optimal crop yields? Bamboo for example develops widespread adventitious roots (Tripathi et al. 1999) that allow it to outcompete herbs for nutrients (Tripathi and Singh 1994), and presumably water
4. Bamboo forest harvesting	a. How much bamboo could realistically be harvested annually without endangering the structure and ecological integrity of the region?
	b. What are the best commercial uses of bamboo for this region?

sites by the strong winds that typically occur in northeast India prior to the monsoons (Toky and Ramakrishnan 1981b), any measures to restrict ash loss are also likely to be beneficial.

Many of the above options to improve shifting cultivation practices on steeply sloped lands are complementary and could be used in combination to optimise farm output (e.g., crop yields in the second and third years after burning could be maintained or even enhanced by the application of commercial fertilizers).

Replacing shifting cultivation practices on steep slopes: options and associated research priorities

1. Nitrogen-fixing shrub hedgerows. Sloping agricultural land technology (SALT) is a form of continuous cultivation that was pioneered on gentle slopes in the Phillipines (Tacio 1993), and has been successfully adopted in many hilly tropical regions (Craswell et al. 1997; Sun et al. 2008). Nitrogen-fixing shrubs are planted as dense hedgerows along slope contours and a diverse range of crops is cultivated in the inter-row areas. The hedgerows prolong fertility by restricting soil erosion and by replenishing soil nitrogen. Farm trials strongly suggest that this option has considerable potential in Mizoram (See SALT case study below). Field tests of *Flemingia macrophylla* and *Tephrosia candida* are also ongoing in Aizawl at Mizoram University (Prof. Lalramnghinglova, pers. comm.). Furthermore, full experiments to screen several hedgerow species are ongoing in nearby Meghalaya state (Anonymous 2009a), and *Alnus nepalensis* trial plantations have been very successful in Nagaland state (Ramakrishnan 1992).
2. Slope terracing. Hand labourers or machinery can be used to dig terraces that reduce downflow soil erosional losses and help to maintain soil moisture. Terracing initiatives in northeast India have apparently been unsuccessful in the past because their construction, maintenance and heavy fertilizer requirements meant that once government subsidies were removed, farmers reverted back to shifting cultivation (Ramakrishnan 1992). However, improved construction and management techniques suggest this option has substantial promise. For example, contour fencing (see above) can be used to promote initial terrace build-up, and to prolong terrace structure by resisting erosion.
3. Agroforestry with anti-erosion plants. Bamboo, banana and many trees grow very well on steep slopes in this region and could substantially restrict soil erosion losses as part of an agroforestry multi-cropping system (Jha and Lalnunmawia 2003).
4. Bamboo forest harvesting. Bamboo is particularly abundant across Mizoram, and could perhaps be harvested in a sustainable and ecological sensible way as a valuable crop (Singh et al. 2010). Although it has a low fuel energy per unit mass, its abundance means that it has potential as a biofuel in a region where energy resources are particularly scarce. Bamboo can also be processed into paper, as is done in the neighbouring state of Assam and has a wide range of other commercial values (Madhav and Rao 1998; McClure 1956). Finally, bamboo may have potential as a substrate for biochar (pyrolysed biomass) that seems to enhance soil fertility and crop production as well as soil carbon sequestration (Lehmann 2007). Teak (*Tectona grandis*) also grows well in this region, implying that even scattered plantations may have considerable potential because of the wood's high market value (Singh et al. 2010).

Options 1–3 above may be effective alternatives to shifting cultivation that would allow continuous annual cropping on steeply sloped lands. Many of these options are complementary and could be used in combination to optimise farming output during continuous cultivation (e.g., nitrogen fixing shrubs can be used to 'naturally' build up terrace structure).

The question of how long steeply sloped sites can be continuously cultivated using each of these replacement options is critical to determining their overall feasibility. Since soil nutrients are being removed offsite each year due to crop harvests and erosion/leachate losses, the answer is likely to depend strongly on how long the availability of plant growth-limiting nutrients can be maintained. Therefore, all of the research questions relating to nutrient (and water) supplementation on burned sites in sections 1 and 2 of Table 1 also apply to nitrogen-fixing hedgerow, terrace and agroforestry cultivation sites.

Finally, in some instances, it may be more ecologically and economically sensible to abandon all forms of cultivation and instead to promote recovery of certain degraded sites back to mature forests. Certain species could be deliberately planted within the recovering forest to provide non-timber forest products (e.g. seeds, nuts, oils, medicinal plant compounds, game) that would be a source of future income to local communities.

Case study: sloping agricultural land technology (SALT)

A SALT (Tacio 1993) trial farm was established on lands (~5 ha) that had previously been under shifting cultivation ~10 km north of Lunglei in 2003. The farmer landowner has been cultivating the gentler slopes (~30°) of these lands every year since then, and slowly expanding the area under continuous cultivation into the steeper sloped areas (up to ~60°) within his farm. This gradual expansion over successive years seems to have been a key feature in allowing him to develop, adapt and optimise the SALT approach to the particular soil and local environmental conditions on his farm. His agricultural extension education activities have since resulted in SALT practices being adopted by hundreds of farmers across southern Mizoram (Lalhmingmawia, pers. comm.). The key features of this farming practice are:

i. Farm structure. Dense rows of a nitrogen-fixing shrub (*Flemingia macrophylla*) have been planted along the contours perpendicular to the incline at distances of 2–5 m apart depending on slope severity (Figs. 3, 4). *F. macrophylla* is apparently preferable to *Tephrosia candida* because its stems are stronger, and therefore resist wind damage and litter and soil erosional losses better (Lalhmingmawia, pers. comm.). Nevertheless, *T. candida* is planted throughout the farm because its copious seed production results in a carpet of seedlings that is apparently very effective in suppressing weeds. In addition, the litter mulch on the ground surface helps to restrict weed development. The hedgerows are trimmed back to ~1 m height every few years to maximise light availability in the inter-row cropping areas. Other nitrogen-fixing trees are allowed to grow relatively tall to provide nursing environments for young citrus plants. All dead branches are placed on the ground on the uppermost side of the hedgerows, where they promote 'natural' terrace development, as well as providing organic matter and nutrient

Fig. 3 Sloping agricultural land technology (SALT) trial farm, Lunglei, southern Mizoram

Fig. 4 *Flemingia macrophylla* hedgerows on a steep slope at the Lunglei SALT trial farm

inputs. Rainwater is collected in a large storage tank to supplement water availability during dry periods of the growing season.

ii. Soil fertility maintenance. All dead and pruned leaf, twig and branch wood material is scattered on the ground and allowed to decompose so that soil organic matter is enhanced, and nutrients are recycled. Some plant material (e.g., weeds and harvested crop wastes) are composted in a soil pit to generate a mulch for key crops. In addition, cattle manure (<1 tonne ha^{-1} $year^{-1}$—Lalhmingmawia, pers. comm.) is acquired from a nearby farm to supplement crop nutrient requirements. Finally, some woodfire potash is added, but no commercial chemical fertilizer is applied.

iii. Farm labour. Weed suppression is a major issue in cultivated lands that are not regularly burned in this region. Farm labourers are hired to remove weeds 2–3 times per year.

iv. Crop production. A very wide range of crops including banana, turmeric, maize, citrus fruits, passion fruits, and pineapple are cultivated. Specialised species such as pear (*Pyrus* spp.) that had been grafted on to an appropriate rootstock have been included along with several valuable medicinal plants (e.g., *Clerodendron colebrookianum*). The particularly wide variety of crops and the mixture of annuals and perennials diversifies production, thereby providing 'insurance' against years when weather conditions disfavour certain crops, species-specific disease outbreaks, and volatility in crop market prices.

Conclusions

Several broad reviews of this topic have concluded that the science underlying our understanding of shifting cultivation and the impacts of shortening fallow periods needs further strengthening (Bruun et al. 2009; Craswell et al. 1997; Ramakrishnan 1992; Sun et al. 2008). Our analysis indicates that this is particularly so for shifting cultivation on steep (>30°) slopes. High quality experiments are required that: (a) take explicit account of the assumptions underlying the spatial analogue approach for chronosequence studies (see Introduction above); (b) contain true replication (i.e., multiple replicate sites rather than replicate plots within a site) to account for spatial heterogeneity among sites and therefore that can be sensibly used to extrapolate to the regional scale; (c) include complete and rigorous statistical analyses of the data; (d) make clear distinctions between concentrations, pools and fluxes, especially in soil fertility studies; (e) use appropriate soil sampling in characterizing site differences or changes in humus cover that affect the baseline reference point for depth increment sampling from the surface; (f) quantify and clearly differentiate total crop plant production and harvestable crop yield; and (g) examine the ecological and economic costs and benefits of each cultivation option over its full cycle (i.e., 10–20 years using empirical and/or modelling approaches).

Appropriate solutions to this complex problem will clearly need to be multifold, involving a mix of different types of land management options, and recognizing the range of differing ecoclimates and soil-types across the region. Since shifting cultivation is such a good economical and environmental choice when the minimum fallow period for full site recovery is observed, this practice in its traditional form is clearly not 'part of the problem, and therefore should be part of the solution' (Anonymous 2009a, b; Cairns and Garrity 1999; Mertz et al. 2009). Research should focus on providing realistic, feasible, economically viable improvements or alternatives to shifting cultivation. Solutions will only be successful if they incorporate and integrate the economic, ecological and social components of this issue (Ramakrishnan 1992), including land ownership constraints (Cairns and Garrity 1999; Singh et al. 2010). Furthermore, they must be acceptable and accessible to farmers (Anonymous 2009a, b; Craswell et al. 1997). In reviewing at least 25 years of fundamental and applied research on shifting cultivation, P.S. Ramakrishnan concludes "The message that comes through clearly is that although many technologies may be viable otherwise, unless the technology is appropriately integrated in the social and cultural context, it may not find acceptance and may not be able to come established." (Ramakrishnan 1992).

Mizoram is undergoing extraordinary tensions and changes, some of which are common to many tropical areas, and some of which are distinctive. The state is located in one of the farthest corners of northeast India, >30 h by road from the nearest mainland commercial city. The central government in Delhi has been pouring billions of rupees into Mizoram as a strategic investment to encourage economic development, social integration with the mainland, and national security. Planning for a railway connection from Sairang (near Mizoram's capital city Aizawl) to Assam (Bairabi) and the Indian heartland is well underway. Furthermore, proposals are currently under review to extend the new road connecting Aizawl and southern Mizoram across the border through Myanmar territory to a river port with shipping access to the Bay of Bengal. These major infrastructural changes will radically enhance import and export facilities into the state, thereby affecting regional market access and appropriate crop choice for farmers. More fundamentally, even variation in accessibility to markets *within* the state seems to have a profound impact on agricultural development. The total area burned around remote villages that are not served by roads (total 483, of which ~396 are >10 km from the nearest road) in Mizoram between 2000 and 2010 has increased by ~20% (Singh et al. 2010). By contrast, the total area burned around villages that are accessible by road (total 335) over that same decade has *reduced* by ~25%, while various forms of settled agriculture have increased (Singh et al. 2010). In successfully addressing the shifting cultivation issue, it will obviously be important that ample infrastructural development funds are specifically directed to the most rural areas of the state.

Initiatives to support particular land-use management solutions (Anonymous 2009c) must provide financial incentives aimed not just at promoting change, but also at sustaining those changes. Several past policy initiatives have distributed cash upfront to farmers across the region to encourage particular agricultural practices, as well as funds for the development of infrastructure such as rainwater harvesting, animal husbandry, horticulture, vermiculture (Anonymous 2009a, c). Successful land use management policy must contain explicit incentives to encourage farmers to persist with particular options until the economic and ecological benefits to them are obvious. Although not perhaps politically attractive, policy initiatives that guarantee annual installments over several years, and that retain some significant portion as a bonus to those farmers who have fulfilled the requirements of the scheme at the end of the 5 year programme, are likely to be more successful. This approach would, however, necessitate extra funds to support a monitoring programme to ensure the latter.

The problem of feeding an increasing population from a finite land resource was addressed in the 1960s/1970s by the 'green revolution' which relied on greatly expanded use of commercial fertilizer and pesticides as well as novel crop strains developed using genetics and biotechnology (Mooney et al. 2005). Heavy reliance on industrial technology using fossil fuel energy reserves (e.g., natural gas to produce ammonium fertilizer) and major advances in the biological sciences achieved the goal, but of course the solution is not ecologically sustainable. Commercial fertilizer applications to tropical soils under intensive agriculture often reduce overall soil fertility because of the eventual depletion of other plant nutrients as well as effects of depleted soil organic matter content, and lead to eutrophication of rivers and lakes because of incomplete nutrient uptake and retention by plants and the soil. In fact, India will spend nearly as much in the next 5 years on initiatives to restore soil health in the 'breadbasket of India' (Punjab and Haryana states) as it will to develop Mizoram's new land use policy (Misra 2010). In recognition of these issues, the Mizoram government banned commercial fertilizer and pesticides in 2005 to achieve 'organic' agricultural production status within India. Although this is undoubtedly a laudable ecological goal, it appears that the decision was based primarily on concerns about human health rather than the environment, and that politicians and the public have not made the critical distinction between the very high health risks associated with pesticides (Alavanja et al. 2004; Kesavachandran et al. 2009), and the nominal health risks associated with commercial fertilizer (Rao and Puutanna 2000).

The core of the shortening fallow problem in shifting cultivation is how to maintain nutrient availability on steep slopes over multiple annual cropping cycles. Organic additions (e.g., cattle manure, pig dung, composted litter, crop residues) with or without commercial fertilizer are much more ecologically efficient than commercial fertilizer alone (Eastmond and Faust 2006; Kato et al. 1999). However, the availability of organic supplements is often limiting because animal husbandry is not sufficiently intense, because they have numerous alternative uses including fodder and fuel, and because the costs of collecting and transporting these bulky materials from adjacent areas is prohibitive (Bruun et al. 2009). The SALT nitrogen-fixing hedgerow inter-row cropping approach seems particularly promising as an alternative cultivation practice that would allow continuous cropping on steep slopes, but even that requires significant manure inputs (see case study), and several critical research questions identified in section 1 of Table 2 need to be answered before it should become part of land use policy. We conclude that although there are very important ecological and economic considerations, the intelligent and careful use of commercial fertilizer in combination with organic matter additions is likely to be an important component of most of the options highlighted above, and therefore a central part of the solution to the problem of shortening fallow periods in shifting cultivation on steep slopes.

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