Social-ecological outcomes of agricultural intensification

Land-use intensification in agrarian landscapes is seen as a key strategy to simultaneously feed humanity and use ecosystems sustainably, but the conditions that support positive social-ecological outcomes remain poorly documented. We address this knowledge gap by synthesizing research that analyses how agricultural intensification affects both ecosystem services and human well-being in low- and middle-income countries. Overall, we find that agricultural intensification is rarely found to lead to simultaneous positive ecosystem service and well-being outcomes. This is particularly the case when ecosystem services other than food provisioning are taken into consideration.

Sustainable intensification is now one of the main agendas shaping global development efforts [1-3] and appears in the United Nations Sustainable Development Goals (SDGs) as a key strategy for ending hunger (SDG2) and achieving sustainable use of terrestrial ecosystems (SDG15)[4]. The high priority afforded to agricultural intensification efforts arises from the assumed likelihood of 'win–win' outcomes, defined here as benefits for human well-being occurring simultaneously with benefits for ecosystems[5–7]. This win–win assumption is often supported by referring to the logic of the land sparing hypothesis, which asserts that intensifying land use in existing agricultural areas will increase productivity and hence enable more effective conservation elsewhere in the landscape[8,9]. However, it is often not clear whether these twin benefits are actually achieved across different social-ecological contexts[10–12]. This uncertainty has led to a growing body of empirical research that assesses intensification outcomes on ecosystems and human well-being[13,14]. Yet the bulk of this research has a rather narrow focus on specific subcomponents of either the natural or social spheres[15,16] and only recently has there been a growth in literature that explores combined and multidimensional social-ecological impacts of agricultural intensification. This is still a comparatively small body of literature, but it is nonetheless important and timely to synthesize and learn from its emerging findings.

In this Review, we examine the combined social-ecological outcomes arising from agricultural intensification by identifying a range of outcome pathways at the scale at which the intensification occurs, and exploring the conditions under which these different outcomes are likely to play out. We do so through a review of the scientific literature that assesses both ecosystem services and well-being outcomes associated with agricultural intensification. While we acknowledge that social-ecological systems analysis goes well beyond the ecosystem service approach, the ecosystem service approach does make visible the relationship between ecological processes and human well-being and therefore provides a clear advantage over disconnected analysis of isolated ecological or socio-economic aspects[17–20]. Although there have been reviews on the linkages between ecosystem service and well-being outcomes[21,22], here we look specifically at the context of agricultural intensification, which we define broadly as activities that are intended to increase either the productivity or profitability of a given tract of agricultural land[23].

We begin by describing the key characteristics of the set of research cases that contain evidence of both well-being and ecosystem service outcomes of agricultural intensification. Next, we categorize cases according to their joint outcomes (for example, win–win summarizes a case where positive well-being and positive ecosystem service outcomes were reported), and identify common social-ecological trade-offs that feature in these outcomes. We then investigate four sets of factors that we hypothesize to be associated with the likelihood of different outcomes.

First, we look at methodological features of the reviewed studies, asking whether the timescale considered by the case and the method for measuring change over time (Supplementary Fig. 4), are themselves determinants of the outcomes observed. In particular, we expect that longer timescales will lead to more frequent observation of negative environmental impacts due to the observed tendency for time lags between agricultural intensification and impacts on regulating ecosystem services[24,25].

Second, we examine whether the type of intensification activity affects the likelihood of particular social-ecological outcomes. Based on our pool of studies, we identify four categories of intensification: (1) reduced fallow, (2) increased inputs, (3) crop change, and (4) a combination of multiple types (see Supplementary Notes for details on each type). We expect that increased use of inputs will less frequently coincide with positive social-ecological outcomes for both ecosystem services and well-being due to the known negative impacts on regulating and supporting ecosystem services[26].

Third, we consider whether the prevailing land-use intensity of the location informs the occurrence of certain outcomes. According to the Borlaug theory[27] we might expect locations that were already highly intensified to experience proportionately less additional environmental impacts from further intensification. For example, the risk of biodiversity loss from deforestation has been found to be higher in relatively intact landscapes than in already fragmented ones[28]. But the opposite might also be found, where previously intensified land undergoes proportionately more additional environmental impact — for example, because yield increases stimulate further agricultural encroachment or due to nonlinear degradation of ecosystem services. For example, it has been found that modest fertilizer applications in places without previous intensification have little environmental impact whereas equivalent applications in places that are already highly fertilized result in disproportionately larger environmental impacts[29]. As indicators of pre-existing land-use intensity, we use the Human Influence Index (HII)[30], forest cover and deforestation rate[31] (see Supplementary Methods for a detailed description of the datasets used) to test whether social-ecological outcomes improved due to higher intensity of land use in the past.

Fourth, we look at the pre-existing human development context. Using the Human Development Index (HDI)[32–34], we test the expectation that higher prevailing levels of human development are associated with positive social-ecological outcomes[35], and with enhanced capacity to derive well-being benefits from ecosystem services[36].

In the final section we consider the implications of our findings in terms of policy responses to pursue sustainable intensification pathways and in terms of research priorities. We are concerned to find that in most cases, agricultural intensification efforts are failing to achieve win–win outcomes. Where supporting and regulating ecosystem services are measured, researchers more often find negative outcomes, especially in highly forested locations and in cases where agricultural intensification takes the form of a change in farmed crops. On a more positive note, by beginning to identify the conditions associated with negative and positive outcomes, we are able to point to research and policy agendas that can support more socially and ecologically sustainable agricultural intensification.

Literature synthesis

The number of published peer-reviewed articles on linkages between agricultural intensification, ecosystem services and well-being has increased rapidly in recent years (Supplementary Fig. 1a). Nonetheless, our literature search concurs with a recent evidence gap mapping report, finding that few studies on the effects of agriculture and land-use change measure impacts on both the environment and human well-being[37]. Our search returned 53 peer-reviewed papers (covering 60 cases) that: (1) document outcomes of agricultural intensification, (2) report evidence of both ecosystem service and human well-being outcomes, (3) are located in low- or middle-income countries and (4) are published during the past 20 years (see Supplementary Methods for a description of the selection and coding procedure). The most common study design is longitudinal ($n = 23$), followed by 'space-for-time substitution' ($n = 17$) and a model-based design ($n = 10$) (Supplementary Figs. 1b and 4). Less commonly adopted designs include experimental and recall studies. There was a higher representation of cases from Asia ($n = 30$) than from Latin America ($n = 15$) and Africa ($n = 15$) (Fig. 1).

Figure 2 summarizes the joint outcomes reported for different ecosystem services and different dimensions of well-being. The distribution of cases reveals some important findings. First, we find that research is concentrated on a small number of outcome variables. Ecosystem service outcomes are dominated by food production (provisioning service), biodiversity and soil formation (supporting service) — comprising 85%, 62% and 43% of cases, respectively — with comparatively few cases examining regulating or cultural ecosystem services. Similarly, measures of well-being are dominated by impacts on income (92% of cases), followed by impacts on food security (38%), with few studies of impacts on other constituents of well-being associated with health, education or social relations, for example.

Second, the two most frequently reported outcomes (food production and income) are also those most likely to be positive: 52% of our cases report positive impacts on food production and 17% negative impacts; 68% report positive outcomes for income and 12% negative impacts. Few of our cases assess outcomes on regulating ecosystem services, but the majority of those that do find negative outcomes. Thus, when a study reports a positive impact on ecosystem services, this most commonly refers to food production, and may well conceal negative impacts on other categories of ecosystem service. With the caveat of small numbers of studies, Fig. 2 provides some initial evidence of outcome trade-offs, in which agricultural intensification tends to positively affect local food production and income and negatively affect regulating and supporting services, with great uncertainty over cultural ecosystem services given the large gap in data.

Conjoined social-ecological outcomes. Figure 3a illustrates the conjoined impacts on ecosystem services and well-being, with each dot representing an individual case. A win–win case, placed in the top-right corner of the figure, is a case with a majority of positive outcomes for both its ecosystem service indicators and its well-being indicators. Conversely, a 'lose–lose' case is a case with a majority of negative outcomes in both dimensions. A key finding of our analysis is that agricultural intensification is rarely found to lead to win–win outcomes, especially so when more than provisioning services are measured, and often has a negative outcome for at least one of the ecosystem services that may support sustained productivity in the long term. As mentioned above, the reviewed research has a propensity to assess food production and income and these are the two outcome variables that are most likely to be assessed positively. It is sobering that despite this bias in the literature, still only 17% of our cases were categorized as having overall win–win outcomes (Fig. 3a).

While Fig. 3a presents combined outcomes that include an aggregation of all ecosystem services measured for that case, Fig. 3b–e presents only selected disaggregated categories of ecosystem services. This reveals that some ecosystem services respond better to agricultural intensification. For example, when we select only food provision (Fig. 3b), win–win cases are more common than in the aggregated Fig. 3a. This is because gains in food production are not being offset by recorded losses in other ecosystem services. Logically then, when we choose other measures of ecosystem service outcomes (such as non-food provisioning services, regulating, and biodiversity and supporting services), win–win outcomes are less common (Fig. 3c–e). In our set of cases, lose–lose outcomes occur with similar frequency (18%) to win–win outcomes and are most common in cases that relate well-being outcomes to biodiversity, water regulation services and soil formation (supporting service; Fig. 3e). Nine of the 11 'lose-lose' cases report dual losses for biodiversity and well-being and four of the lose–lose cases report dual losses for biodiversity and food security[38–41]. Outcomes combining aggregate well-being gains with aggregate ecosystem service loss (win–lose) are the most likely type of outcome to occur (23% of cases). These are most common where aggregated gains in well-being are linked to losses in regulating ecosystem services, non-food provisioning services, biodiversity and supporting services (Fig. 3).

Taken together, these findings suggest that although agricultural intensification is often considered the backbone of food security[42] and agricultural sustainability[43], the reality is that intensification often undermines conditions that may be critical for the support of long-term and stable food production, including biodiversity, soil formation and water regulation. For example, in a case from the Bolivian Andes, a shift towards intensive cash-cropping of onions has greatly reduced agro-biodiversity in the landscape, leading to reduced disease regulation and ultimately to economic difficulties for smallholders[41]. Although well-being gains are quite frequently

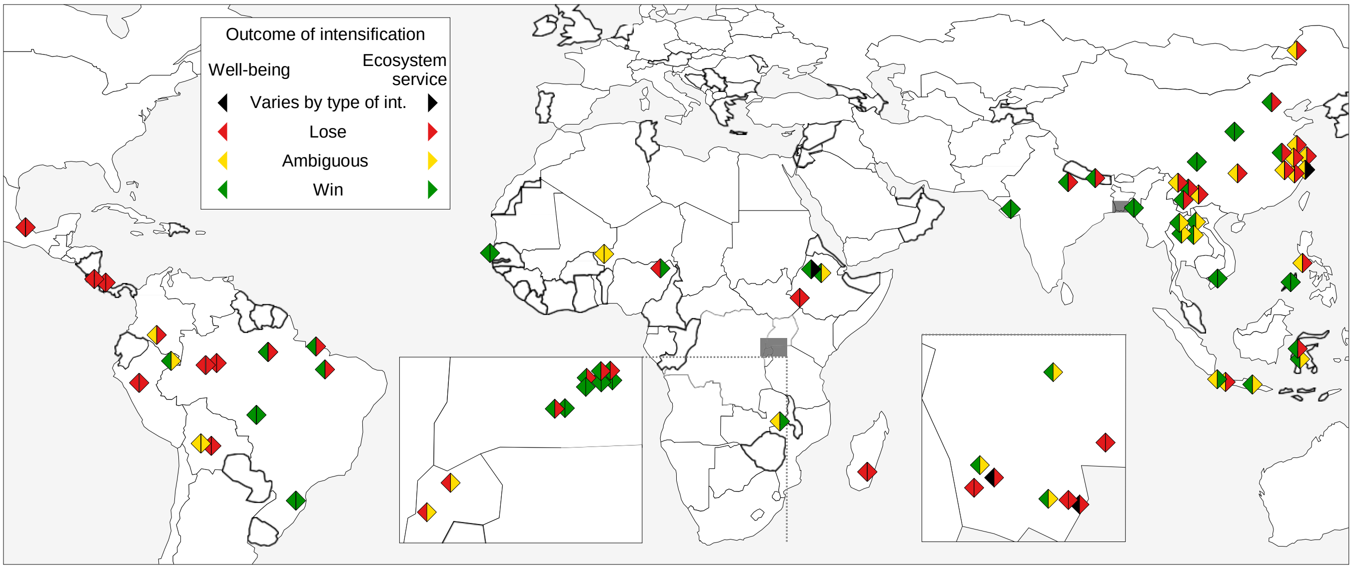


Fig. 1 | Geographic distribution of the cases by social-ecological outcomes. The symbols of some tightly clustered cases have been offset for clarity. In locations with multiple cases, it is shown whether the outcome varies by intensification type. The study by Ceddia and colleagues[60] is omitted from the map as the case describes aggregate results across six countries. Int, intensification.

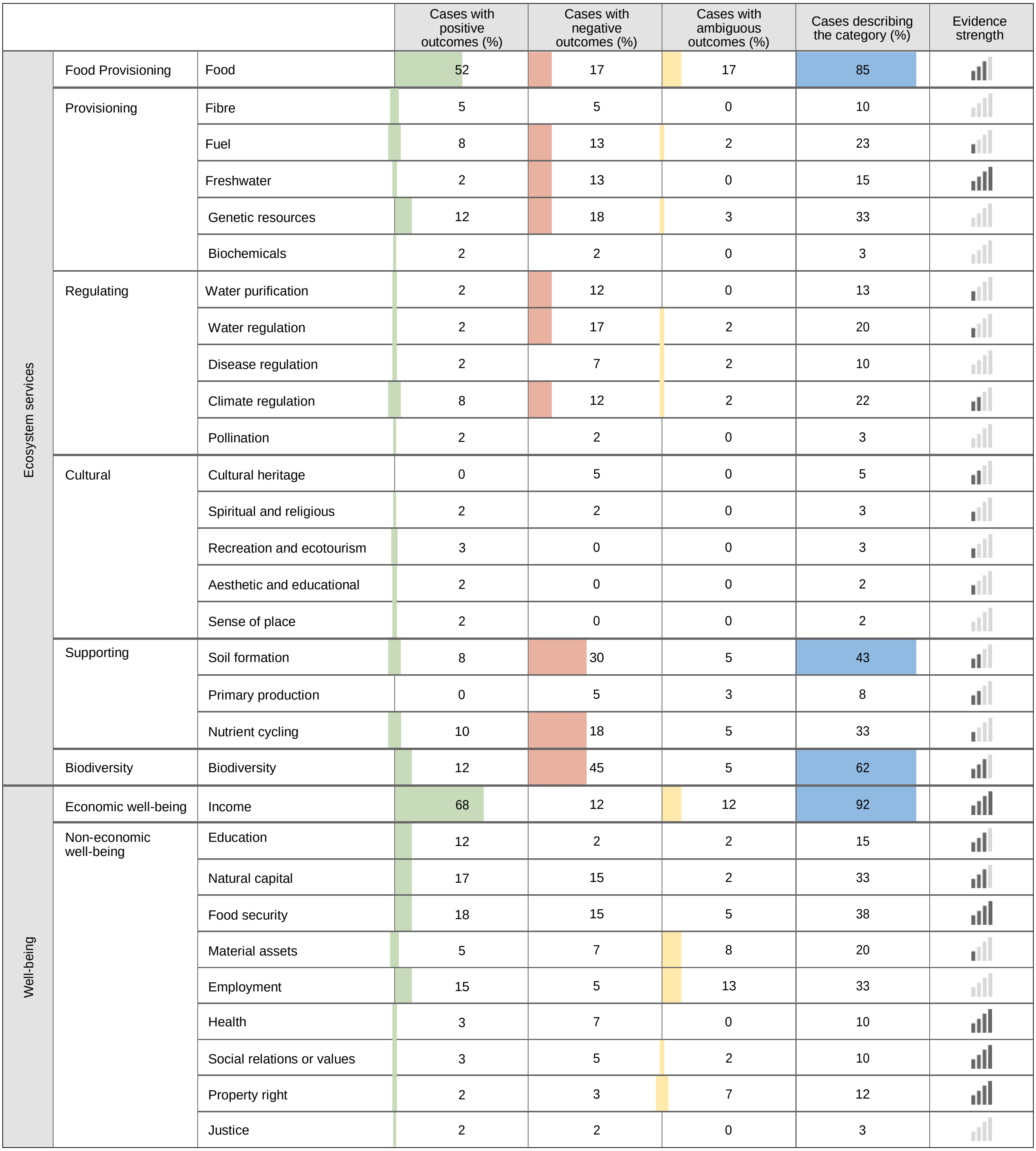
accompanied by losses to non-provisioning ecosystem services, it is remarkable that there is one case in which even provisioning ecosystem service gains are accompanied by well-being losses (Fig. 3a). This case from Nigeria shows how agricultural intensification leads to increasing provision of food but takes place at the cost of livelihood flexibility, including reduced options for shifting field locations and less diverse livelihood strategies[44].

A second important finding is that for any given impact on ecosystem services, the distribution of well-being impacts is uneven, generally favouring wealthier individuals at the expense of poorer ones. Across our dataset as a whole, there are relatively few studies that present socially differentiated outcomes, and this is an important research gap. However, it is still notable that inequality is reported in the majority of our lose–lose cases, either because the better-off are found to disproportionately capture the benefits of agricultural intensification[45–48] and/or because more vulnerable social groups are found to disproportionately suffer from the loss of ecosystem services on which their livelihoods depend[40,45,46,49,50]. For example, Islam and colleagues[46] show how rapid uptake of saltwater shrimp production in Bangladesh is enabling investors and landowners with large holdings to get higher profits while poorer people are "left with the environmental consequences that affect their long term lives and livelihoods" (page 450 of ref. [46]). The poverty of these groups is being exacerbated because, unlike farmers with more land, they are unable to benefit economically from shrimp production and at the same time they suffer from the salinization of soils that is undermining traditional rice production.

Attention to lose–lose cases suggests two basic pathways that explain conjoined losses in ecosystem services and well-being. First, there is a pathway whereby agricultural intensification initially leads to reduced well-being for certain social groups and where this in turn negatively affects the ecosystem services on which they depend. For example, a case from Amazonia shows how shifts from subsistence to cash-cropping, including a commodity boom in palm oil, leaves small-scale farmers with reduced access to land, forcing them to shorten fallows, leading to loss of soil fertility and thus to lower yields and reduced agricultural income[49]. Via the second pathway, agricultural intensification negatively affects ecosystem services, which in turn negatively impacts well-being, with the poorest disproportionately affected. For example, Tadesse and co-authors[45] show how intensification of coffee production in Ethiopia, driven by investors and state enterprises, is initially blamed for declining access to and availability of several provisioning ecosystem services, negatively affecting the well-being of local minority groups who are more reliant on these services for their livelihoods. We also observe more complex outcome pathways that seem to combine both directions of social-ecological interaction. For example, another case from Amazonia shows a more complex variant in which intensification of swidden cultivation of cassava leads to (1) reduced fallow periods, (2) rapid escalation of weeding requirements, (3) reduced farming capacity of households who cannot afford labour or other inputs and (4) concentration of production on smaller plots, resulting in the lose–lose outcomes of lower food production and lower incomes[51].

Factors associated with social-ecological outcomes. Our analysis of contextual factors considered four potential determinants of social-ecological outcomes: methodological treatment of time, type of agricultural intensification activity, pre-existing land-use intensity and development context. No relationship was found between the methodological factors and the likelihood of observed outcomes (Supplementary Fig. 4). Contrary to our expectations, longer timescales do not seem to lead to more frequent observation of negative environmental impacts, although this might be due to the limited attention devoted to regulating ecosystem services across the studies.

To examine the influence of activity type, we categorized each case according to four main types of agricultural intensification present in our set of cases: reduced fallow, increased inputs, crop change and lastly combined, which involves combinations of the first three types (see Supplementary Notes). Figure 4 shows that win–win outcomes occur most frequently in cases where intensification involves increased use of inputs (5 of the 20 cases) such as fertilizers, irrigation, seeds and labour. There is only one case in which intensification through increased inputs generates lose–lose outcomes — this is a case in Bangladesh, where irrigation has led to over-extraction of groundwater; this contributes to soil salinization, which is associated with significant negative effects on household food security[52]. The association of increased inputs with increases in ecosystem services is in large part a product of classifying food



			Cases with positive outcomes (%)	Cases with negative outcomes (%)	Cases with ambiguous outcomes (%)	Cases describing the category (%)	Evidence strength
Ecosystem services	Food Provisioning	Food	52	17	17	85	▮▮▮▯
	Provisioning	Fibre	5	5	0	10	▯▯▯▯
		Fuel	8	13	2	23	▮▯▯▯
		Freshwater	2	13	0	15	▮▮▮▮
		Genetic resources	12	18	3	33	▯▯▯▯
		Biochemicals	2	2	0	3	▯▯▯▯
	Regulating	Water purification	2	12	0	13	▮▯▯▯
		Water regulation	2	17	2	20	▮▯▯▯
		Disease regulation	2	7	2	10	▯▯▯▯
		Climate regulation	8	12	2	22	▮▮▯▯
		Pollination	2	2	0	3	▯▯▯▯
	Cultural	Cultural heritage	0	5	0	5	▮▮▯▯
		Spiritual and religious	2	2	0	3	▮▯▯▯
		Recreation and ecotourism	3	0	0	3	▮▯▯▯
		Aesthetic and educational	2	0	0	2	▮▯▯▯
		Sense of place	2	0	0	2	▯▯▯▯
	Supporting	Soil formation	8	30	5	43	▮▮▯▯
		Primary production	0	5	3	8	▮▮▯▯
		Nutrient cycling	10	18	5	33	▮▯▯▯
	Biodiversity	Biodiversity	12	45	5	62	▮▮▮▯
Well-being	Economic well-being	Income	68	12	12	92	▮▮▮▮
	Non-economic well-being	Education	12	2	2	15	▮▮▮▯
		Natural capital	17	15	2	33	▮▮▮▯
		Food security	18	15	5	38	▮▮▮▮
		Material assets	5	7	8	20	▮▯▯▯
		Employment	15	5	13	33	▯▯▯▯
		Health	3	7	0	10	▮▮▮▮
		Social relations or values	3	5	2	10	▮▮▮▮
		Property right	2	3	7	12	▮▮▮▮
		Justice	2	2	0	3	▯▯▯▯

Fig. 2 | Distribution of evidence of the effects of agricultural intensification on ecosystem services and well-being. The size of the evidence base is assessed by the proportion of cases that describe each category of ecosystem services and well-being. The final column shows the strength of the evidence, as estimated by the authors (see Supplementary Methods for details of the assessment). *n* = 60 cases.

production as an ecosystem service[53] and indeed half of all our win–win cases involve higher inputs leading to higher food production. We note that three[54–56] out of the five win–win cases involving higher input use are linked to increased irrigation practices, with two of these describing combined use of irrigation and fertilizers. None of the win–win cases with higher input use include inputs such as organic fertilizers, biofertilizers or biopesticides—however, within the full sample only eight cases document such inputs.

There are isolated studies that suggest intensification through increased inputs can yield positive outcomes for ecosystem services other than just food provisioning, but this evidence remains weak. Some propose that this type of intensification can make room for

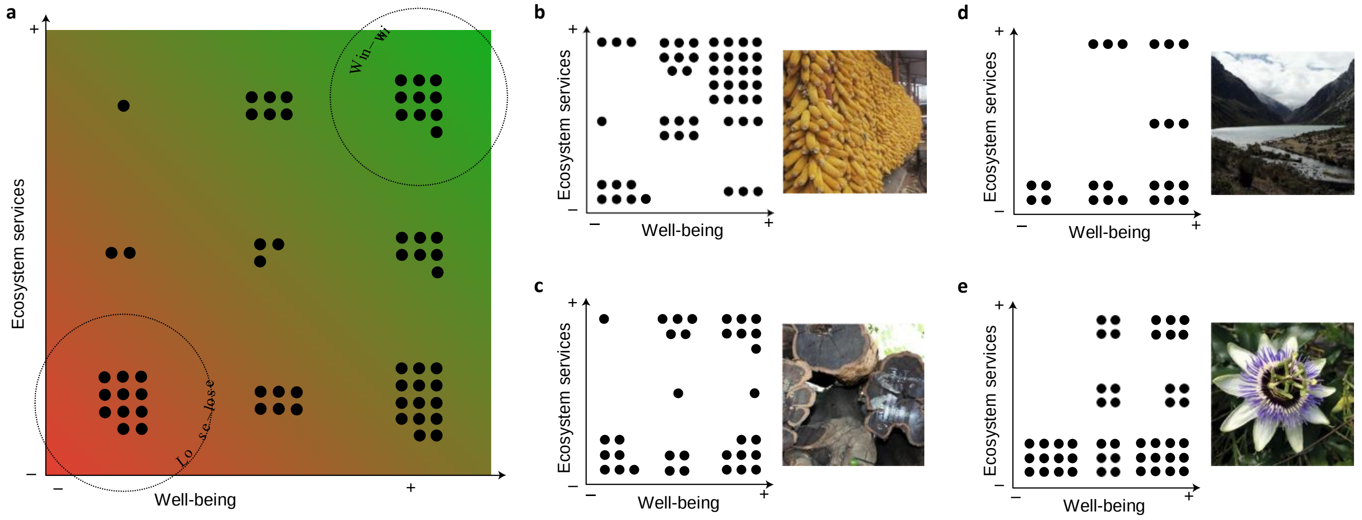


Fig. 3 | impact of land-use intensification on ecosystem services and human well-being. Each case is recorded as negative (-), ambiguous or positive (+) along each axis. A win–win case, placed in the top-right corner of the figure, is a case with a majority of positive outcomes for both its ecosystem service indicators and its well-being indicators. **a**, Aggregated ecosystem service categories. **b**–**e**, Ecosystem service outcomes restricted to food provisioning (**b**), non-food provisioning services (**c**), regulating services (**d**) and supporting services and biodiversity (**e**). Each black dot represents an individual case.

reforestation (as per the 'land sparing' theory) with associated positive outcomes for a broad set of non-provisioning ecosystem services, such as climate regulation, nutrient cycling, soil formation and biodiversity[47,57,58]. However, we note that although positive outcomes are reported at the scale at which the intensification occurs, land management for the optimization of a given ecosystem service may lead to displacement of undesired impacts to other locations. These so-called off-stage ecosystem service burdens represent phenomena including environmental leakage[24] and rebound effects[59,60]. That is, the agricultural intensification might, for example, enable farmers to invest more inputs, including labour, in other areas, thereby displacing and increasing the environmental pressure elsewhere. We also note that three cases specifically focus on how poorer farmers are being displaced by better-off farmers with better access to resources and how the intensification might lead to the attraction of new farmers because of the better economic returns, thereby increasing pressure on local ecosystem services[60–62]. Higher input use might also encourage diversification practices, such as integrated fish and rice farming[63], integrated rice and fruit production (such as mango)[55] and vegetable diversification[54,64]. Our set of cases also shows that studies that find lose–lose outcomes often point to a shortage of inputs as a determining factor[40,41,49–51,65]. These cases show that various types of intensification increase the need for further inputs and that these are either not available or, more often, not affordable. For example, intensification through state-regulated crop varieties in Rwanda places smallholders in a position where they need to purchase additional inputs such as fertilizers, but often cannot afford to do so[48].

We find that intensification involving reduced fallow and crop changes leads to the majority of lose–lose outcomes (Fig. 4). These cases often involve the entwined processes of crop specialization and progress towards monoculture of crops such as coffee[45,50], shrimp[46], pineapple[40], onion[41] and maize[65], along with a transition from subsistence farming to cash-cropping and abandonment of traditional subsistence crops and varieties. As noted above, these transformations towards monoculture often involve shortage of fertilizers and other inputs, despite research finding increased need for such inputs. This raises the question of why smallholders would pursue intensification pathways for which they cannot afford the necessary inputs. A frequent explanation for this is that intensification either occurs as a necessity brought about by demographic change, as in Boserup's seminal agricultural intensification theory[66], or as a response to state policies, taxation or the cumulative pressures arising from landscape-level changes in land use and land tenure[67]. In one of the Amazonian cases, intensification through new varieties and reduced fallow is reportedly induced by local population growth leading to increased demand for cassava[51]. In a Rwandan case, smallholders are obliged to change from traditional crop varieties to those selected by government agronomists[48]. For a case in Bangladesh, researchers find that the salinization arising from larger farmers converting to aquaculture leaves remaining farmers with 'little choice' but to follow suit[46]; and in a case in Costa Rica, the rapid homogenization of land use to pineapple plantations makes it increasingly difficult to survive as a traditional multi-cropper[40]. Thus we see a wide range of examples in which smallholders are in some way compelled to adopt forms of intensification for which they are ill-prepared. This often involves loss of agrobiodiversity and our results generally confirm the conjecture that progress towards monoculture is associated with certain negative social and ecological outcomes. Some of the pathways described include monocultures leading to increased biodiversity loss[40,41], disease intensity[65] and declining soil fertility[41].

Along with intensification type, we also examine the association between earlier land-use intensity (proxied by the HII), forest cover and deforestation rate) and the joint social-ecological outcomes. This remains an exploratory analysis given the limited number of cases, but it provides important insights that we think merit further attention. Although we see considerable variability between cases, one important generalized observation is that we see no evidence in support of the hypothesis that highly intensified locations will experience proportionately less additional environmental impacts. This finding is in agreement with recent literature that challenges whether land sparing will happen, even in contexts where it is highly desirable[68,69]. Within our sample, lose–lose outcomes seem to be at least as likely to happen in landscapes already under heavy anthropogenic pressure as they are in locations with low HII scores. Compared with win–win and win–lose (social-ecological) outcomes, lose–lose cases are associated with slightly higher levels (median) of HII (Supplementary Figs. 2a and 3), thus providing no support for the hypothesis that previous land-use intensification

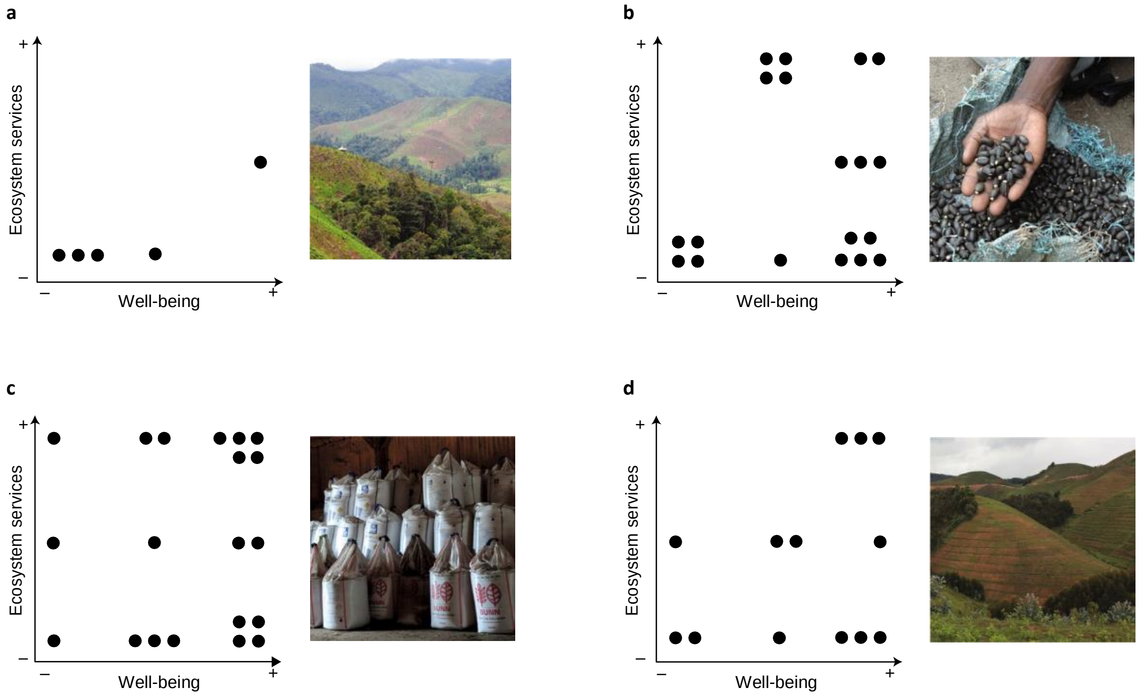


Fig. 4 | Combined effect of different types of agricultural intensification on ecosystem services and well-being. Each dot represents an individual case, n = 57 cases. Three cases did not define the type of intensification. **a**, Reduced fallow. **b**, Crop change. **c**, Increased input. **d**, Combined intensification.

may create conditions that protect against further negative social-ecological outcomes. For example, in a lose–lose case with the highest overall HII, high deforestation rates, population pressure, land shortage and intensive resource extraction, Mexican farmers are forced to shift to monocultures with little capacity to provide food security and adequate income, as well as severe impacts on agro-biodiversity[65].

It is informative to use our contextual variables to add to a generalized profile of what a lose–lose case looks like relative to a win–win case. In addition to a slightly higher HII score, our lose–lose cases tend to be areas that initially had more forest, as evidenced by the highest median forest cover (in 2000) in lose–lose cases (57% compared with 40% for win–win cases, using one-way analysis of variance (ANOVA) (F (1,19) = 3.2, $P < 0.1$)) (Supplementary Figs. 2c and 3). Moreover, lose–lose cases seem to have experienced higher rates of forest loss, as indicated by slightly higher median deforestation rates (Supplementary Figs. 2d and 3). Bringing in earlier findings, we can also say that a lose–lose case more often involves locally induced intensification through population growth and land scarcity[38,40,41,45,50,51], and challenges for the involved smallholders arising from inability to access necessary inputs. In 9 out of 11 lose–lose cases, loss of biodiversity is also reported.

As previously discussed, a review of available cases suggests that alternative and sometimes complex causal pathways connect well-being and ecosystem service outcomes from agricultural intensification. For example, we see that win–win outcomes are found in landscapes with a lower HII, but also in landscapes with low as well as high forest cover and deforestation rates, indicating a blurred picture. Although changes in forests affect ecosystem services such as water regulation and pollination, which in turn might determine the impact of agricultural intensification on social and ecological outcomes, some cases present the reverse causality. For example, changes in well-being can be a determinant of how much forest is cleared[61]. Looking at whether the pre-existing level of human development (via the HDI in 2000[33,34]) might be associated with social-ecological outcomes, we observe the highest median HDI in lose–lose cases (0.64 compared with 0.54 for win–win cases, but the difference is not significant) (Supplementary Figs. 2b and 3). That we see a higher median HDI in the lose–lose cases may be due to a spatial scale mismatch, because for many cases the HDI is only available at coarser spatial resolution. Nevertheless, the results do not support the expectation that more environmentally positive outcomes are associated with higher prevailing levels of human development.

implications for sustainable intensification

As there are few reviews that synthesize knowledge on how agricultural intensification affects both ecosystems and human well-being in low- and middle-income countries, we recognize that the available body of research remains small, and it is unlikely to be representative of all intensification cases. Moreover, we note that finding a sufficient set of cases required pragmatic, expert-led selection rather than a systematic review protocol. Nonetheless, agricultural intensification is seen by many in science and policy as a flagship strategy for helping to meet global social and ecological commitments such as the SDGs and Paris Agreement and as such the findings presented here provide important insights despite their preliminary nature. Based on the available literature examining combined social-ecological outcomes of agricultural intensification, we find that intensification cannot be considered as a simple blueprint for achieving positive social-ecological outcomes. While there is considerable hope and expectation that agricultural intensification can contribute to sustainable development, we find that only a minority of researched cases present evidence for this and that even these infrequent win–win cases tend to lack evidence of the effects on key regulating or supporting ecosystem services. In short, we have scant evidence to back up the weight of expectation that we currently see attached to agricultural intensification. By contrast, we find that negative outcome pathways are still common. We also note that dual losses for biodiversity and well-being, especially in association with food security, tend to go together. This confirms other recent work that, for example, shows a positive association between species richness and dietary quality across seven low- and middle-income countries[70]. In summary, few of our cases provide evidence that agricultural intensification is contributing simultaneously to SDGs such as ending hunger (SDG2) and achieving sustainable use of terrestrial ecosystems (SDG15).

If we are to achieve sustainable intensification of agricultural land use[71] we need to begin responding to what we already know while also working to fill some considerable knowledge gaps. We clearly need to learn more about the variability of outcomes that we have observed and the complex social-ecological pathways and interactions, across scales (both temporal and spatial), that these suggest. But we are already able to observe some of the contexts in which undesirable local outcomes occur most frequently. In particular, we would highlight the often unsustainable (or lose–lose) outcomes arising where intensification takes the form of reduced fallow in swidden systems or where it takes the form of a change in crops that involves a tendency towards monoculture. It is not the higher input cases that lead to most lose-lose outcomes.

We also see that it is the context of these forms of intensification that matters: change is often induced or imposed for more vulnerable population groups who often lack the critical capital to make these changes work. Smallholders in our cases often struggle to transform from subsistence to commercial farming, and the challenges involved are not well reflected in many intensification strategies. In addition, we find evidence to suggest a more nuanced picture than that of unsustainable outcomes being associated with lower levels of human development. These are important lessons that policymakers and practitioners can respond to in terms of moderating their expectations of agricultural intensification outcomes and striving for improved and alternative pracitces[72].

What might these better, alternative practices be? We have to be cautious here because we have seen only a limited number of cases where intensification leads to enhanced ecosystem services beyond short-term food production or to well-being benefits beyond improved incomes. These cases tend to combine landscape-scale intensification with landscape restoration and diversification of agronomic practices.

Knowledge gaps not only arise from the limited number of studies but also from their focus. We note that the bulk of studies do not seek to understand causal relations between gains and losses in different ecosystem services and the multiple dimensions of well- being, which suggests that a stronger focus on causal explanations is needed[73]. We also find that some categories of ecosystem services are sparsely studied. This was especially evident for the cultural and regulating ecosystem services. Out of the 20 categories of ecosystem services, 10 categories (such as cultural heritage, pollination) were addressed by only 10% or less of the cases. Similarly, the study of well-being was in most cases limited to measures of income, with barely any research that combines ecosystem service outcomes with other well-being constituents such as livelihood security, education, health, secure property rights or perceptions of social justice. This is concerning because well-being extends far beyond economic well-being[21,74,75]. This emphasizes the need for stronger and more explicit evidence to back up claims for the effects of intensification on joint social-ecological outcomes. The observed propensity to assess a small number of output variables (notably food production and income) stands in the way of a more systemic understanding of coupled social-ecological outcomes. Perhaps most critically of all, we should be cautious about categorizing a case as an ecosystem service win based on food production gains, when we have little to no research findings about impacts on other ecosystem services, trade-offs across scales and potentially systemic off-stage eco- system service burdens[24]. Thus, it is pertinent for future research efforts to consider how biodiversity and ecosystem services other than food production, particularly regulating and cultural services, as well as aspects of well-being other than income, can be incorporated into assessments of the social-ecological outcomes of agricultural intensification.

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