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Short Communication

Sustainable intensification in drylands: What *resilience* and *vulnerability* can tell us

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1. Introduction

The challenge to increase food production is greater than ever, as the world's population is set to increase to a predicted nine billion by 2050 (United Nations, 2008), requiring a 70 to 100% increase in global food production (Food and Agriculture Organization, 2009a; World Bank, 2008). The primary solution promoted within the agricultural development community is to intensify agricultural production (Smith, 2012; The Royal Society, 2009; Tilman et al., 2011). For instance, one of the guiding principles underlying the research agenda of the Comprehensive Africa Agriculture Development Programme is that it should "reflect the urgency of achieving intensification at rates in excess of population growth" (NEPAD, 2003, 72). The Framework for African Agricultural Productivity adopted by the Forum for Agricultural Research in Africa and endorsed by the African Union similarly highlights the need for improvements in productivity, particularly through agricultural research and adoption of technological innovations, to keep pace with population growth (Forum for Agricultural Research in Africa, 2006). Intensification is also justified on environmental grounds in that it can result in "land sparing" – increasing yields on farmed land in order to reduce agricultural extensification and take the pressure off other land which can remain protected for conservation (Garnett et al., 2013; Shively and Pagiola, 2004).

However, it is also recognized that even when intensification results in land-sparing it sometimes brings serious environmental costs (Pretty, 2008; The Royal Society, 2009). In addition, despite innovations and productivity increases in some areas, there is a continued concern that large numbers of people, especially in sub-Saharan Africa, are not benefiting from these advances, or perhaps are paying social costs. As a result, a great deal of policy and research are now directed toward *sustainable intensification*, which can be described as "producing more outputs with more efficient use of all inputs – on a durable basis – while reducing environmental damage and building resilience, natural capital and the flow of environmental services" (The Montpellier Panel, 2013, 13). Sustainable intensification has been a central element in the strategy of both the FAO (Food and Agriculture Organization, 2009b) and the Consultative Group on International Agriculture Research (CGIAR) (Consultative Group on International Agriculture Research, 2013; Independent Science and Partnership Council, 2013). As attempts are made to operationalize the sustainable intensification paradigm, research activities for characterization, establishment of baselines, and assessing the sustainability of different intensification options are underway.

The kinds of concerns that led to an emphasis on the sustainability of intensification are certainly applicable for drylands in developing countries. Drylands have unique characteristics that pose particular challenges for increasing productivity and reducing vulnerability in the context of the standard model of agricultural development (Sietz et al., 2011). The best-adapted systems are adapted to minimal and highly variable rainfall and tend to be very extensive. Despite years of development assistance and research in

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dryland areas, many communities still face chronic or seasonal food insecurity and malnutrition, compounded seasonally by climatic shocks and stress. Bio-physical constraints include limited natural resources, degradation, water scarcity, and climatic variability. Social limitations such as unequal access to resources, low levels of political support, limited information on production technologies, and insecurity also affect livelihoods. These kinds of constraints and the level of vulnerability that they imply are sometimes interpreted as a sign that dryland areas tend to have a low potential for agricultural intensification (e.g., Consultative Group on International Agriculture Research, 2013). When intensification does take place in dryland agricultural system, it usually brings with it new production practices and social–ecological relationships, potentially undermining the resilience of the existing, well-adapted systems. Ensuring that agricultural intensification in these diverse and complex environments is sustainable is a major challenge, as are the research tasks of characterizing, targeting, and assessing the sustainability of different intensification options.

In this paper we look at how to operationalize the concept of *sustainable intensification* in dryland systems, particularly where some or all of the agricultural practices are extensive. To do this, we draw on two sets of literatures related to vulnerability and to social–ecological resilience. We outline three principles for conceptualizing sustainable intensification in dryland systems. In so doing, we recognize the multiple functions of agriculture for development, which include contributions to food security and environmental services, in addition to the more traditional goals of economic growth and poverty reduction (Byerlee et al., 2009). Unless this kind of broader, multi-dimensional understanding can inform efforts toward intensification in drylands, recognizing that in drylands intensification will look very different than it is in so-called "high potential" areas, intensification has little hope of being sustainable.

2. Sustainable intensification and vulnerability in drylands

Since the publication of "Reaping the Benefits" (The Royal Society, 2009), the concept of sustainable intensification has been discussed in several high profile publications (Foley et al., 2011; Garnett et al., 2013; Godfray et al., 2010; Tilman et al., 2011). All take the pressing need to produce more food in light of population growth, and environmental concerns over how this need will be met, as their main point of departure. While all recognize that food security is not just a problem of insufficient production, they present the idea of sustainable intensification as a production issue with primarily biophysical solutions (e.g., closing the yield gap, avoiding land degradation). The summary by Garnett and co-authors (2013) is illustrative: they identify four premises underlying the sustainable intensification paradigm: that there is a need to increase production, that the need for increased production should be met through higher yields rather than by bringing more land into agricultural production, that environmental sustainability requires as much attention as improving productivity, and that sustainable intensification is a goal rather than a prescription about particular agricultural techniques. While the first two premises accept the logic that intensification is urgently needed, with the third premise the paradigm explicitly recognizes that not all forms of intensification are sustainable. In some locations, improvements to yield and environmental sustainability may be incompatible, and ensuring sustainability may require yield reductions and in order to "deliver benefits such as wildlife conservation, carbon storage, flood protection, and recreation" (Garnett et al., 2013, 33). This implies that while the principal rationale of intensification is to spare land, it cannot be assumed that all intensification is sustainable: even when intensification does result in productivity gains and in land sparing, the sustainability of that intensification involves several other considerations beyond simply how much food is produced per unit area of land. The nature of intensification can increase agriculture's contribution to greenhouse gases as well as have impacts on the cycling of nitrogen, phosphorus and water (Conway, 1997; The Montpellier Panel, 2013; Tilman et al., 2001). Environmental sustainability implies that while there is a need to increase agricultural production overall, this is not to say that yields should increase everywhere or regardless of the environmental cost (Garnett et al., 2013).

Within the discourse on sustainable intensification, it is this environmental dimension of sustainability that is overwhelmingly emphasized (e.g., The Montpellier Panel, 2013). Sustainability, however, is not only about the environment; it also has economic and social dimensions (Barbier, 1989). While these broader concerns for issues such as social equity are not completely ignored in the discussions on sustainable intensification (Byerlee et al., 2009), they deserve more space in the current popular analytical frameworks. Processes such as intensification never take place in a social vacuum (Matson and Vitousek, 2006). For example, intensive and highly profitable shrimp farming tends to replace rice cultivation in the short term but have not proven to be sustainable in the long term and certainly change household food security strategies. The adoption of new "intensive" technologies may increase the labor burden for women (Palmer-Jones and Jackson, 1997). Furthermore, the impact of interventions designed to intensify agricultural production almost always depends upon the social and economic context (Byerlee et al., 2009; DeWalt, 1993). In drylands, intensive systems tend to replace extensive ones, causing migration to distant marginal lands and the resulting extensive cultivation of these (Kaimowitz and Smith, 2001). The sustainable intensification paradigm recognizes that research and investment in particular agricultural technologies and practices must not be divorced from these kinds of broader social concerns such as the nature of rural economies, the social and cultural impacts of agricultural changes, and concerns around vulnerability and equity such as related to land tenure and forced migration (Garnett et al., 2013). The Royal Society (2009) and Godfray and co-authors (2010) also note that many interventions that might increase production could have unintended consequences for some social and economic groups. However, the current sustainable intensification discourse does not devote sufficient analytical attention and rigor to such social and economic issues, and hence the design of interventions runs the risk of low adoption and/or adverse effects such as environmental degradation and increased social inequity. None of the seminal pieces offers a framework for dealing with social issues. The recent piece by van Ginkel et al. (2013) offers integrated systems research as a step beyond sustainable intensification which can combine the reality of some people's need to manage risk rather than optimize production with the eco-efficiency agenda of the sustainable intensification paradigm. We build upon this concept of systems analysis with discussion of vulnerability and resilience, offering conceptual advances that can move the agenda for sustainable intensification in drylands forward.

Such dynamic processes may be particularly evident in drylands, which are characterized by complex and geographically heterogeneous patterns of vulnerability (Füssel, 2010). In dryland areas, existing traditional agricultural systems tend to be extensive, operating on a larger level of scale than the kinds of "modern", intensified systems that are often promoted as the ideal. Intensification based on irrigated crop production may be as likely to *displace* existing extensive livestock-based systems as transform them. When this happens, many of the economic, social, and environmental costs of intensification can be transferred from one production system to the other in the form of increased vulnerability. As well as being a concern from a normative, social justice point of view, this can also have environmental implications, as vulnerable populations which do not benefit from intensification are pushed into environmentally unsustainable practices. Efforts aimed

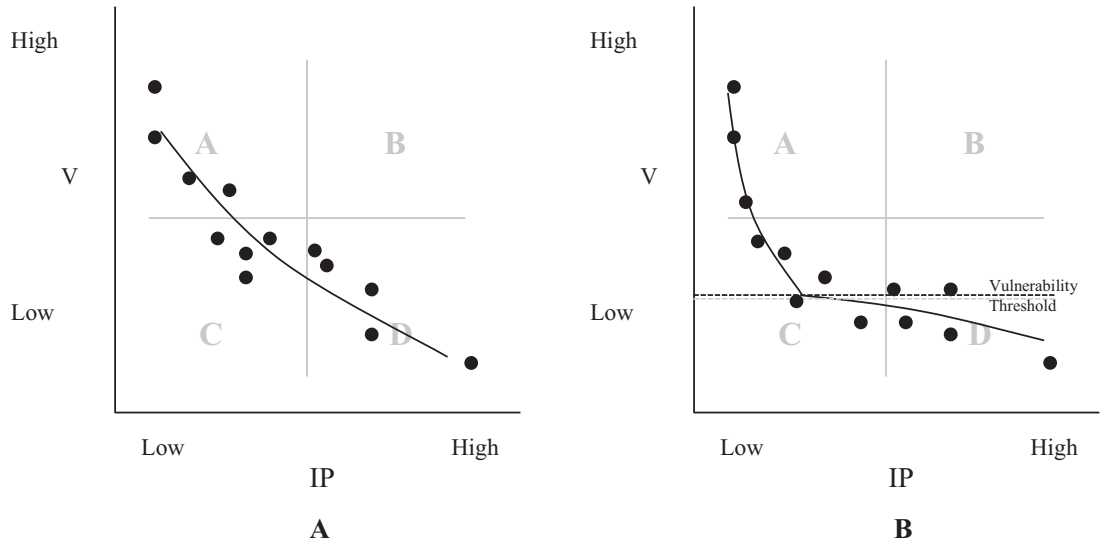

Fig. 1. Two versions of the "Security-versus-Intensification Hypothesis". The graphs show hypothetical plots of the vulnerability and intensification potential of households consistent with the security-versus-intensification hypothesis. In (A), incremental reductions in vulnerability result in incremental increases in intensification potential. In (B), reductions in vulnerability only result in increases in intensification once vulnerability has been reduced beyond a certain threshold.

at promoting intensification in the drylands need to appreciate these complex patterns and factors.

The concept of *vulnerability* is a useful analytical tool for exploring all three dimensions of sustainability – environmental, economic and social – in relation to agricultural intensification. Historically, the agricultural development and poverty alleviation discourses have each been characterized by a distinct emphasis – increasing productivity through intensification and reducing vulnerability, respectively – and the concepts and methods developed for understanding vulnerability bring a normative focus on powerlessness, equity and harm that is often missing in discussions of intensification. *Vulnerability* can be understood as the degree to which human and environmental systems are likely to experience harm from a perturbation or stress (Turner et al., 2003). It is comprised of risks that people confront, the sensitivity of their livelihoods to these risks, responses and options that people have for coping with and adapting to these risks, and outcomes in terms of loss of well-being (Turner et al., 2003). The concept of vulnerability, therefore, provides a framework for exploring the sustainability of intensification. Simply put, it is our contention that intensification that increases vulnerability is not sustainable.

While the bodies of research focusing on vulnerability and on agricultural intensification respectively are, for the most part, quite distinct, there is a set of widespread understandings about the relationship between the two phenomena: namely that when vulnerability is high, intensification is difficult or impossible. The thinking around the vulnerability–intensification relationship traces back to analysis of risk aversion among peasants (Chibnik, 1981; Dillon and Anderson, 1971; Moscardi and de Janvry, 1977). The dominant idea that emerged from that debate was that whenever households have no ex-post consumption-smoothing capacity – when their ability to buffer against shocks and stresses is low – they are of necessity risk averse (Rosenzweig and Binswanger, 1993). Thus when the satisfaction of basic needs may be at risk, safety-first criteria tend to be followed, and peasant households will prefer low-payoff, low-risk livelihood options to higher-payoff but higher-risk options, and this is believed to constitute a constraint on innovation and, ultimately, development. Linked to this is the notion of the poverty trap, whereby crippling poverty at a country level inhibits the ability to solve problems of hunger, disease and lack of infrastructure (Sachs et al., 2004). At a household level, certain types of households may draw down their assets or suffer losses after a shock that puts them at a threshold of poverty too low to invest in growth activities; they also face exclusion from the social and market mechanisms necessary to move out of the "trap" (Carter and Barrett, 2006; McPeak and Barrett, 2001). While this kind of understanding of the relationship between vulnerability and intensification has had its critics (e.g., Feder et al., 1985; various contributions to Roumasset and Boussard, 1979), and has been explored, developed and qualified in various ways, the central tenet is still prominent in much of development thinking.

The observation that people who are poor and vulnerable are more concerned about reducing risk and avoiding catastrophic losses than they are about increasing average productivity over time is valid and is certainly relevant to dryland areas in developing countries. However, it has recently been used to assume that the relationship between vulnerability and agricultural intensification is unilinear. This view – what we call the "security-versus-intensification hypothesis" – assumes that vulnerability and intensification can be assessed on a single continuum such that a household which has a high level of vulnerability is likely to have low intensification potential, and vice versa. While vulnerability and potential for intensification are typically treated as a single continuum, if the two characteristics were to be plotted as two separate axes (Fig. 1), few if any households would be expected to lie in quadrant B (having high intensification potential at the same time as being highly vulnerable). Whether it is assumed that incremental reductions in vulnerability can allow for incremental steps toward intensification (Fig. 1A) or that there is a clear livelihood security threshold below which intensification cannot occur (Fig. 1B), this hypothesis has two implications that stand out, one temporal and the other spatial: first, vulnerability reduction is understood to be a prerequisite to intensification; and second, different communities or regions can be viewed as primarily requiring either vulnerability-reducing or intensification-promoting interventions, but typically not both, at least not at the same time (Consultative Group on International Agriculture Research, 2013; van Ginkel et al., 2013). Both of these implications can be seen in the CGIAR's research strategy for drylands, a key feature of which involves identifying where regions sit on a vulnerability–intensification potential gradient (Consultative Group on International Agriculture Research, 2013; van Ginkel et al., 2013).

The security-versus-intensification hypothesis is problematic in at least three ways. First, it does not allow for the possibility, central to the concept of sustainable intensification, that some forms of intensification can increase vulnerability. Second, it entails within it an assumption that moving along the vulnerability–intensification continuum (moving from quadrant A to quadrant D in Fig. 1) is the only pathway out of poverty. Approaches to development program targeting should not assume away alternative pathways out of poverty such as diversification, for which there is significant supporting evidence, and, in some cases, extensification. And third, thinking solely in terms of vulnerability versus intensification sheds no light on what it might mean to intensify an extensive system, a question that is central to the pursuit of sustainable intensification in drylands.

3. Resilience thinking and sustainable intensification

Over the past fifteen years or so, theory around vulnerability has evolved and there are a few different strands. One strand explicitly links vulnerability to resilience thinking (e.g., Adger, 2006; Gallopín, 2006; Turner et al., 2003). This approach to vulnerability analysis brings an explicit focus on coupled human–environmental systems, non-linearity and questions of scale, all of which will be key for understanding the sustainability of intensification in dryland systems. We identify three aspects of resilience thinking that are particularly relevant for sustainable intensification. First, resilience thinking holds that neither the ecological system nor the social system can be adequately understood without understanding the other and the linkages between them, and that essentially they function together as a *social–ecological system* (Berkes et al., 2003). Methodologically, this implies that the utility of reductionist approaches is strictly limited and that there is a need for synthetic, holistic methodologies that focus on relationships among variables, including relationships between social and ecological variables (Berkes, 2010). Understanding social–ecological linkages will be central to assessing the sustainability of intensification. Different forms of agricultural intensification are certain to have differing effects on ecosystems. The impact of land conversion on wildlife migration patterns, of fertilizer use on nutrient cycling, or of irrigation on the hydrology of a watershed are obvious examples of relevant social–ecological linkages, but the relationships can be much more complex than this.

Resilience thinking also draws attention to other features of complex adaptive systems: self-organization, threshold effects and non-linearity. The capacity for self-organization results from interactions among components feeding back to produce macroscopic system properties and patterns which in turn influence the interactions that produced them (Levin, 1998; Walker et al., 2002). Self-organization provides complex systems with a sort of quasi-stability in that one or more controlling variables in a system can fluctuate within a certain range without producing profound effects on the system as a whole. However, this results in threshold effects because shocks and stresses can build up to the point where a threshold is crossed and the system suddenly reorganizes or "flips" into a new state. The overall result is a system characterized by non-linear behavior. An implication for sustainable intensification that follows from this is that some forms of intensification may incrementally increase vulnerability with little or no outward signs until a tipping point is crossed.

A third feature of resilience thinking that is relevant to researching and planning for sustainable intensification is the concept of *panarchy*, the idea that social–ecological systems are hierarchical, with systems being nested within larger systems and themselves being made up of smaller systems (Holling, 2001). Central to this idea is that connections across levels of the panarchy play a fundamental role in system dynamics (Gunderson and Holling, 2002). For instance, reorganization of a sub-system at a smaller scale can trigger changes at the scale above, introducing novelty into the larger system. Similarly, the structure of systems at larger scales can provide a "memory" that influences the continuity and recovery of system dynamics at smaller scales (Holling, 2004; Holling and Gunderson, 2002). Because of complex nature of these cross-level relationships, the resilience of a system at one spatial or temporal scale does not necessarily conduce to resilience at another (Carpenter et al., 2001).

We understand from this that both vulnerability and intensification must be understood at multiple levels of scale. For example, the impacts of dryland irrigation schemes on pastoralists, can be understood as a problem of multiple levels of scale: this form of intensification can increase income and security for farming households within a geographic area while increasing vulnerability over a larger area by cutting off pastoralist households from water and pasture resources that are crucial to their ability to cope with drought. Vulnerability also must be considered over different temporal scales. For instance, some forms of agricultural intensification can increase household income and security over the short or medium term, at the same time as they put stress on ecosystems and actually increase vulnerability over a longer term (DeFries and Foley, 2004; Downing and Lüdeke, 2002).

4. Three principles for conceptualizing sustainable intensification in drylands

4.1. Intensity and vulnerability are distinct characteristics

From the above discussion, we identify three principles that are critical for conceptualizing sustainable intensification in drylands. The first is that agricultural intensity and vulnerability should be understood as distinct characteristics, not as the opposite ends of a single continuum. We have argued above that although vulnerability can constrain the potential for intensification, the vulnerability–intensification relationship is not linear. Knowing whether a community or a region has the potential to intensify does not in itself tell us what the nature and impacts of intensification might be – in some circumstances, intensification may deepen vulnerability for some people making them more susceptible to shocks such as drought. Although vulnerability and intensification potential are connected and derive from overlapping sets of factors, they are two distinct characteristics, each of which should be assessed separately. In Table 1 we list examples of the kinds of factors which past research has identified as key determinants and effective indicators of intensification potential and vulnerability, respectively. Even where there are points of similarity across the two lists, there are also differences. Threshold levels on each side of the table may differ: for example, the level of assets needed to buffer against a shock may be very different than the level of assets needed to invest in capital or infrastructure for intensification. There are also important qualitative differences between the factors contributing to vulnerability and to intensification potential. For instance, while household assets can both reduce a household's vulnerability and provide it with greater capacity for intensification, the kinds of assets that are most important for each objective differ. The kinds of tangible livelihood assets that are critical to buffering against droughts and other shocks and stresses are robust forms of relatively fungible savings, such as food stores, livestock and cash savings, which people can immediately access in times of crisis (Swift, 1989), whereas for intensification productive capitals including land and inputs may be relatively more important (Jayne et al., 2010). The distinction between the types of assets that make the greatest contribution to reducing vulnerability and those that contribute to potential for intensification depends upon factors such as their

Table 1
Examples of factors that contribute to vulnerability and to intensification potential.

Vulnerability	Intensification potential
– Exposure to shocks (e.g., frequency and severity of natural disasters) (Hahn et al., 2009; Luers et al., 2003) – Sensitivity of household livelihood activities to hazards ○ Diversity of livelihood activities including non-farm income (Christiansen and Subbarao, 2001; Little et al., 2001; Notenbaert et al., 2012) ○ Dependency ratio (Hahn et al., 2009) ○ Robustness of livelihood portfolio (e.g., drought resistant crops) (Burton et al., 2002; Luers et al., 2003) – Existence and size/strength of buffers, including access to credit and insurance, food stores and other asset buffers which a household can draw upon (Hahn et al., 2009; Kinsey et al., 1998; Swift, 1989) – Education/human capital (Adger et al., 2004) – Social capital (Adger, 2003; Pelling and High, 2005) – Sensitivity of assets to erosion because of shocks and stresses (Carter et al., 2004) – Security of the household's entitlements (Ribot, 1995; Turner et al., 2003)	– Agro-ecological potential (e.g., length of growing period) (Herrero et al., 2012) – Financial capital (Barrett and Marenya, 2006; Ellis, 2000; Lybbert and Barrett, 2004) – Education/human capital (Bernués and Herrero, 2008; Jamison and Lau, 1982; Pretty et al., 2011; Villaume, 1978). – Land holding (e.g., size of land holding and security of tenure) (Feder et al., 1985; Harris and Orr, 2013; Jayne et al., 2003). – Access to functioning markets (Bernués and Herrero, 2008; Herrero et al., 2012; Kristjanson et al., 2010) – Access to non-farm income sources (Bernués and Herrero, 2008; Ellis and Freeman, 2004; Kristjanson et al., 2010)

fungibility, durability and contribution to productivity, and the uses to which they can be put.

An analytical framework that recognizes intensification and vulnerability as two separate variables enables us to examine the interactions and feedbacks between them, and provides a mechanism for assessing this dynamic relationship in both space and time. It opens up the possibility for asking questions such as, "Which aspects of vulnerability limit the potential for intensification and which do not?", "Which aspects of vulnerability need to be addressed as *prerequisites* to intensification and which do not?" and "When does intensification increase vulnerability?" Treating intensification and vulnerability as distinct variables can help us to distinguish intensification that deepens vulnerability and is therefore unsustainable from intensification that does not.

This conceptualization implies that the relative position of different systems, different groups or communities within systems, or different households within communities can be described in terms of a "vulnerability and intensification potential space", with each characteristic expressed on its own axis as shown above in Fig. 1. There already exist various methodologies for quantifying both vulnerability (e.g., Hahn et al., 2009) and intensification potential (Bernués and Herrero, 2008; Harris and Orr, 2013; Herrero et al., 2012) which might be adopted or adapted in order to create an index for each axis. In the resulting plot, two quadrants are consistent with the security-versus-intensification hypothesis: systems with low rainfall and poor soil quality, minimal infrastructure and political will, poor access to markets, and insecure entitlements for instance would fall in quadrant A – High Vulnerability (V) and low Intensification Potential (IP); whereas systems characterized by high asset levels, diverse economies, good access to infrastructure, and good rainfall and soils may be characterized as lying in quadrant D (Low V and high IP systems). However, we argue that systems lying in the top right and bottom left corners of such a plot are not as uncommon as assumed by the security-versus-intensification hypothesis, and that the trajectories of particular households can be much more complicated than assumed by the hypothesis. For example, areas with good soils and regular and high rainfall levels may have low V, but because of low levels of education and infrastructure may also have low IP (quadrant C). Less intuitive, but extremely important, are the High V and High IP systems (quadrant B). These may include, for example, systems having high ecological potential, good infrastructure, and market integration at the same time as having a high degree of vulnerability because of low levels of diversity in assets and income sources and high degrees of exposure to external shocks such as global price fluctuations. The dependence on external inputs and the erosion of ecosystem services and social safety nets which can accompany rapid intensification can deepen vulnerability further even as the system intensifies.

4.2. Intensity is not the inverse of extensivity

Our second principle for conceiving sustainable intensification in drylands concerns the relationship between agricultural intensity and agricultural extensivity. The definition of sustainable intensification cited above refers to "producing more outputs with more efficient use of all inputs", but as an approach to operationalizing a metric for intensity, this formulation – intensity equals outputs over inputs, in other words, *productivity* – is problematic. By this measure, a subsistence farmer on fertile land using little or no irrigation, fertilizer or pesticides, will produce more food per unit of irrigation, fertilizer or pesticides than a "modern" mechanized farmer, and by this definition could be assessed as having a higher intensity of production. Intensity should not be seen as a ratio of outputs to inputs but instead as a function of inputs per unit area of land or per household. The *productivity* of any particular patterns of intensification should be treated as a distinct measure. While sustainable intensification does not constitute a prescription about particular techniques – the fourth premise proposed by Garnett and co-authors (2013) – it does imply a general strategy: using appropriate inputs to increase yields per unit area. The production of "more outputs with more efficient use of all inputs", therefore, should be understood as the goal; sustainable intensification is the strategy for achieving the goal. This is consistent with the approach to quantifying intensity described by Tilman and co-authors (2011), where intensity is measured as inputs per unit area, for example, kilogram of nitrogen per hectare.

It follows from this that land must be understood as distinct from other inputs and that *intensity* is not the inverse of *extensivity*. Wheat and oilseed farming in the Great Plains of North America, for instance, tends to be *both* intensive (using relatively large amounts of inputs per hectare or per family farm) *and* extensive (using relatively large amounts of land per family farm). Compared to a typical family farm in the Great Plains, by all measures except labor inputs, smallholder agriculture in the humid tropics tends to be neither intensive nor extensive. Dryland agricultural systems in developing countries, on the other hand, will often have a low level of intensity and a high level of extensivity. While the degrees of intensity and extensivity are key defining characteristics of agricultural systems, playing a role in the productivity, vulnerability and sustainability of those systems, we suggest that intensity and extensivity should not be treated as direct measures of either vulnerability or productivity. Just how intensive and just how extensive a given agricultural system is, or a new system would be, is a different question than how *productive* some given levels of intensity and extensivity are, how *sustainable* they are, or what degree of *vulnerability* they might produce.

It is important to note here that extensivity is one of the defining characteristics of most dryland agricultural systems. Not only does it distinguish dryland agriculture from agricultural systems in more humid areas, differing degrees of extensivity also distinguish different production systems *within* drylands. Assessing and monitoring both agricultural intensity and agricultural extensivity as distinct qualities can be expected to yield important insights into the sustainability of any intensification efforts. Consider, for example, a situation in which irrigation schemes are being used to intensify agricultural production in a region where two agricultural production systems – one based on mobile livestock keeping and another based on crop agriculture – co-exist. In this situation, it is the system based on livestock that is, obviously enough, more extensive. Each of the two systems also has a particular level of intensity, but with the introduction of irrigation, it is only the less *extensive* system which intensifies. As it does this, it may also be reducing the extensivity of the extensive (pastoralist) system. It is this loss of extensivity that helps to create the vulnerability problem for pastoralists, and the vulnerability is further exacerbated when the pasture and water resources being lost are those typically used during drought emergencies. Below a certain level of extensivity the vulnerability of the pastoralist system may increase to the point of it no longer being viable.

That intensification interventions often ignore or seek to supplant the most extensive production systems is not surprising given where most intensification research has focused: there are few examples in agricultural research literature of how to intensify the most extensive systems, other than options that involve changing them into different, *non-extensive* systems. Characterizing systems based on the degree of intensity and extensivity is an important step both in tracing trajectories of households and systems through time, and in visualizing alternative pathways to sustainable production and enhanced livelihoods in dryland systems. Recently, pastoralists in many areas have begun looking to regain lost scale and re-extensify their production systems while at the same time increasing inputs in the form of improved breeds, veterinary interventions, hired labor, and water and fodder provision. In this scenario, producers strive to increase productivity and reduce vulnerability by simultaneously enhancing *both* the extent and the intensity of the agricultural system. Where (re)extensification is not possible and/or not desirable, interventions aimed at intensification should, at least, not reduce extensivity, and should intensify existing extensive systems rather than supplant them with different, non-extensive systems.

4.3. *Vulnerability and intensification each need to be considered at multiple levels*

The third principle that is fundamental for conceptualizing sustainable intensification in drylands is that vulnerability and intensification each need to be understood and assessed at multiple levels of scale. The concern of development actors with vulnerability and intensification may relate primarily to the household level, but a resilience perspective suggests that these are integrally connected to the state of broader systems within which those households exist. It is also important to note that while intensification potential and vulnerability may be used for spatial characterization, these are fundamentally descriptors of households and livelihood systems, not geographic areas. This distinction is important, as geographic areas will often contain more than one livelihood or production system coexisting in tension. For instance, within a single dryland region containing both pastoralist and crop-based livelihood systems, the vulnerability and intensification potential of one of the livelihood systems may be very different in both nature and degree from the vulnerability and intensification potential of the other system. Yet these two livelihood systems may co-exist within a single social–ecological system.

Individual households can be vulnerable, and this is connected to, but distinct from, a social–ecological system being vulnerable. For instance, particular households within a social–ecological system may be vulnerable even while local institutions perpetuate poverty traps, ensuring that the system as a whole is very resilient (Tittonell, 2014). Because households depend for their livelihood on functioning social, economic and ecological systems, the opposite situation – households being relatively secure within a social–ecological system that is vulnerable – may be less common, although by no means impossible. Consider, for example, the case of wealthier households with a high degree of adaptive capacity making substantial changes to their livelihood when the system they live in is under threat. Wealthier pastoralists, for instance, can purchase inputs such as water, feed and labor to survive a drought and sell their animals earlier. While development actors are primarily concerned with reducing vulnerability at the household level, since the household and system levels are integrally connected but not identical, both need to be monitored. A similar understanding can be applied to intensification potential: many households may have characteristics that contribute to their potential to intensify – household assets, appropriate technical education, sufficient endowments of land resources – but if the region as a whole is poorly connected to external markets and also lacking in internal economic diversity and integration, then overall intensification potential can be constrained. Conversely, a region may have a high potential for intensification, but this does not necessarily mean that all households within that region can intensify.

The issue of scale is important for drylands in that there often are different kinds of livelihoods operating at different scales within one geographical space, and in that many of those livelihoods, in order to reduce vulnerability to a low and highly variable rainfall, operate over very broad areas (are very extensive). In the example of irrigation being introduced into pastoralist systems, pastoralist and agricultural households are operating at different levels of scale, with the social–ecological system most relevant to farmers being nested within a larger social–ecological system that includes them but which is delineated by pastoralist movements. The components of vulnerability most relevant to pastoralists – especially access to land and water resources – pertain to the larger geographic scale. Understanding whether some particular irrigation scheme represents a form of intensification that is sustainable will require understanding effects at both levels of scale, and trade-offs between levels.

Vulnerability and intensification potential can also be influenced by certain types of heterogeneity within systems and cross-scale interactions. For example, if some forms of intensification are based on “lumpy” investments in key productive inputs, then a relatively homogeneous community whose households all have moderate savings may seldom see any households accumulate enough capital to intensify; whereas this may not be the case for a more heterogeneous community with the same mean level of savings, and in which some households do accumulate enough wealth to invest. This latter kind of heterogeneity can also have effects on vulnerability, particularly if entitlements are weak. Similarly, policy support for commercial livestock markets may benefit some pastoralists, but also exacerbate income inequalities and increase vulnerability for the community as a whole (Aklilu and Catley, 2010). Other forms of heterogeneity may increase the potential for community (rather than household) level diversification leading to reduced vulnerability. At the very least, interventions aimed at promoting intensification in drylands need to be assessed in terms of their impacts on sustainability at different spatial and temporal scales and for different kinds of households and livelihoods. Particular attention must be given to cross-scale and cross-level impacts on ecosystem health and services, vulnerability, and agricultural

extensivity as well as on agricultural intensity at other levels and for other livelihoods.

5. Conclusion

Among the implications of the above discussion is that there is a need to assess, plan for, and evaluate the sustainability of policies, programs, investments and interventions intended to promote intensification of dryland systems. This will require knowledge and decision-making tools. Targeting of investments and interventions, for instance, will require an approach to characterization of dryland regions that involves attempting to understand the nature of agricultural, livelihood and ecological systems at different scales and levels through characteristics such as agricultural intensity, agricultural extensivity, and intensification potential. For example, knowing the extensivity of agricultural systems and the potential impacts on extensivity which an intervention may have will be an important aspect of assessing the sustainability of that intervention. While it was beyond the scope of this paper to describe a comprehensive analytical framework for this kind of characterization research in dryland systems, we suggest that such a framework should include measures of at least these eight categories of variables, some of which, like *vulnerability*, are composite phenomena: ecosystem health and services, vulnerability, intensification potential, actual agricultural intensity, agricultural extensivity, livelihood diversity, agricultural production/productivity, and well-being.

The imperative of environmental sustainability, and the fact that sustainability, vulnerability, and agricultural and ecological systems are all multi-level, multi-scale phenomena, together suggest that trade-offs are inevitable. We agree with Garnett et al. (2013) that there will be situations and places in which no form of sustainable intensification is possible, and in which the needs of wider sustainability call for certain places and certain sub-systems to de-intensify. On the other hand, the imperative to recognize trade-offs does not mean that we should accept false dichotomies. The dichotomy of security versus intensification has helped to hide the fact that some forms of intensification can increase vulnerability. The dichotomy of intensity versus extensivity has meant that not enough attention has been given to sustainably intensifying extensive systems *as extensive systems*. For the aim of sustainable intensification to be relevant to producers in drylands more work needs to be done to learn how to intensify the systems that exist rather than supplanting them in the name of intensification.

Moreover, the multi-dimensional nature of both vulnerability and intensification potential suggests that intensification is not likely to result merely from the identification of appropriate technical packages. Social, economic and ecological dimensions must be considered, and promoting sustainable intensification will require interventions aimed at these dimensions as well as at the technical aspects of agricultural practice. The imperative to sustainably intensify extensive dryland systems *as extensive systems* implies, furthermore, a need to broaden the kinds of interventions which are considered under the rubric of *intensification*. For some dryland areas, the most appropriate forms of intensification (increasing inputs per unit area) may not relate to inputs such as irrigation, fertilizer or improved seed packages, but rather to inputs into animal health and into social organization for interventions around rangeland management and insurance systems based on climatic indexes. Ultimately, intensification in drylands, if it is to be sustainable, will look quite different than it does in other climates.

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