The nexus between INRM and IWRM

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Abstract

The low productivity of smallholder farming systems and enterprises in the drier areas of the developing world is attributed mainly to the limited resources of farming households, and the application of inappropriate skills and practices that can lead to the degradation of the natural resource base. This lack of development, particularly in southern Africa, is of growing concern from both an agricultural and environmental perspective. To address this lack of progress, two development paradigms from different scientific constituencies have evolved, somewhat independently, to improve land and water productivity. One championed by the International Agricultural Research constituency is Integrated Natural Resource Management (INRM), whilst the second championed predominantly by Environmental and Civil Engineering constituencies is Integrated Water Resources Management (IWRM). Despite similar objectives of working towards the millennium development goals of improved food security and environmental sustainability there exists a nexus between the constituencies of the two paradigms, particularly in terms of appreciating the lessons learned. In this paper lessons are drawn from past INRM research that may have particular relevance to IWRM scientists as they re-direct their focus from blue water issues to green water issues, and vice-versa. One point that is abundantly clear from both constituencies is that ‘one-size-fits-all’ or silver bullet solutions that are generally applicable for the enhancement of blue water management/formal irrigation simply do not exist for the smallholder rainfed systems.

Five keywords: INRM, IWRM, Green water, Blue Water

Introduction

Increasing water productivity is a growing concern within the international research and development community (CAWMA, 2007). This objective is encapsulated in the UN Secretary General’s recent statement, ‘we need a blue revolution in agriculture that focuses on increasing productivity per unit of water – more crop per drop’. This increased productivity is a necessary condition for agricultural producers to use better, and protect the quality of, available water, while enhancing food production and income in a sustainable manner, especially in water limited communities.

This focus is particularly pressing in the Semi Arid Tropics (SAT) of southern Africa (Love et al., 2006a; Twomlow et al., 2006). Despite the rising levels of adoption of improved maize (\textit{Zea mays} L.), sorghum (\textit{Sorghum bicolor} (L.) Moench), pearl millet (\textit{Pennisetum glaucum} (L.) R.Br.) and groundnut (\textit{Arachis hypogaea} L.), per capita grain production continues to decline (Ryan and Spencer, 2001). Smallholder crop yields remain in the range of 500 to 1000 kg of grain per hectare, with seasonal yield variation a function of seasonal rainfall (Figure 1, Mugabe pers comm.) (ICRISAT survey data for
southern Africa). Concomitant with poor rainfall, a major constraint to crop production is poor soil fertility, caused by inherently poor soil quality and inappropriate soil management practices (Mapfumo and Giller, 2001; Sanchez, 2002; Vanlauwe, 2003). Throughout Africa, negative nutrient balances for nitrogen and phosphorus have been found consistently in smallholder farming systems (Roy et al., 2003).

A good understanding of the farming systems is required in order to develop appropriate technological interventions to manage water and fertility (Twomlow et al., 2006; Mupangwa et al., 2006; Pretty et al., 2006). Some studies have been conducted to assess the dynamics (including nutrient management and resource allocation) of smallholder farming systems (Defoer et al., 1998; Briggs and Twomlow, 2002; Tittonell et al., 2005b; Zingore et al., 2006). Most previous studies were however conducted in medium to high rainfall areas. The few studies that have been conducted in the semi-arid regions of Africa were carried out in West Africa (Harris and Mortimore, 2005) close to a large urban population with strong market drivers and focused on nutrient flows. Data on resource allocation and use patterns in the semi-arid regions of southern Africa is limited to a few case studies (Scoones, 1997; Scoones, 2001; CAWMA, 2007; Ncube et al., 2008).

This lack of development, particularly in southern Africa, is of growing concern from both an agricultural and environmental perspective. To address this lack of progress, two development paradigms from different scientific constituencies have evolved, somewhat independently, to improve land and water productivity. One championed by the International Agricultural Research constituency is Integrated Natural Resource Management (INRM), whilst the second championed predominantly by Environmental and Civil Engineering constituencies is Integrated Water Resources Management (IWRM). Despite similar objectives of working towards the millennium development goals of improved food security and environmental sustainability there exists a nexus between the constituencies of the two paradigms, particularly in terms of appreciating the lessons learned by each. In this paper lessons are drawn from past INRM research that may have particular relevance to IWRM scientists as they re-direct their focus from blue water issues to green water issues, and vice-versa.

THE NEED FOR NEW CONCEPTS AND OPERATIONAL PRINCIPLES

Good management of natural resources is the key to good agriculture and rural development (Greenland et al., 1998; Ryan and Spencer, 1991; Pender et al., 2006; Pretty et al., 2006). This is true everywhere – and particularly in the semi-arid tropics (SAT), where over-exploitation of fragile or inherently vulnerable agroecosystems is leading to the degradation of land, soil and water resources. This degradation results in productivity decline, and increasing hunger and poverty. Modern crop varieties offer high yields – but the larger share of this potential yield can only be realized with good crop management (Twomlow et al., 2008). A plethora of NRM and IWRM technologies have been developed over the years – but adoption has been poor for various reasons, technical, environmental, socio-economic and institutional. Table 1 summarises what is currently known about the adoption of NRM/IWRM technologies, whilst Table 2 summarises some of the institutional and organizational constraints. Low adoption leads to low impact and failure to reach the goals of agricultural research investments (Ryan
and Spencer, 2001; Freeman et al., 2002; Love et al., 2006; Pretty et al., 2006) and the MDGs (UN Millennium Project, 2005).

Tables 1 and 2 here

There are several reasons for low impact of R&D investments and why smallholder farmers often do not invest in new technologies. First is the relative profitability and associated risk of the new technology under moisture limited and variable climatic conditions. Second, the need for site specific innovations that address farmer and market preferences and the diversity in the policy and institutional constraints, all which affect adoption (Pender et al., 2006).

Alternative conceptual frameworks and models of integration

Both biophysical and socioeconomic factors are crucial in shaping research strategies and priorities (Harwood et al., 2006; Kassam, 2006; CAWMA, 2007). Research in developing countries has evolved in different phases. Agronomists and breeders have long been aware of genotype-environment interactions and the need to tailor technologies for specific eco-regions and the impacts of climate (see Table 3). There is now a growing realization that R&D efforts should be demand-driven and respond to the needs and priorities of smallholder farmers, their support agents as well as consumers and markets (Pender et al., 2006). Developing widely adaptable, acceptable products requires participatory approaches that involve end-users, stakeholders and target groups at all stages of technology development. It also requires proper monitoring and evaluation (M&E) that will help draw lessons from experience – reflective learning in project cycle parlance (Figure 2). A coalition of strategic partners, with complementary skills, is also needed for scaling out desirable innovations. A brief review of the different integrating models and their evolution is provided below.

Table 3 and Figure 2 here

The Integrated Natural Resource Management paradigm within International Agricultural Research (Adapted from Twomlow et al., 2008)

Integrated Natural Resource Management (INRM) is an attempt to build a new agricultural research and development paradigm to meet the challenges and opportunities outlined above. Campbell et al., (2001) define INRM as ‘a conscious process of incorporating the multiple aspects of natural resource use (be they biophysical, sociopolitical or economic) into a system of sustainable management to meet the production goals of farmers and other direct users (e.g. food security, profitability, risk aversion) as well as the goals of the wider community (e.g. poverty alleviation, welfare of future generations, environmental conservation).’ This new paradigm attempts to integrate various, but not necessarily multi-disciplinary, participatory R&D paradigms that include:

- Participatory plant breeding
- Farming systems research
- Farmer field schools
- Community based NRM
- Participatory action research
- Farmer led on-farm trials
- Integrated pest and disease management

Table 3 and Figure 2 here
The five key elements of the INRM paradigm are summarized in Table 4 and the principles summarized in Figure 3.

In essence INRM tries to harmonize the complementary but often conflicting goals of production and environmental protection.

There is a vast literature on NRM and on technology evaluation and adoption. Some recent publications include Barrett et al., 2002, Campbell and Sayer 2003, CIMMYT 2003, Douthwaite et al., 2003, Harwood and Kassam 2003, Perez and Tschinkel 2003, Pound et al., 2003, Shiferaw and Freeman 2003, 2005, Agricultural Systems vol 78, Campbell et al., 2006. The focus of much of this literature is on the integration of socio-economic and biophysical issues, with little focus on the integration of the genetic dimension (Twomlow et al., 2008). Omission of the genetic component (both crop and livestock) in improved management of agroecosystems is contrary to the wider consensus to link natural resource management with livelihood strategies of smallholder farmers and other resource users.

**The Integrated water resources management paradigm (IWRM)**

Integrated water resources management (IWRM) is a systems approach to water management, recognizing the need to manage the entire water cycle and its interconnectivity (Figure 4). It stands on four fundamental principles: (i) water is a vulnerable and finite resource and must be managed sustainably, (ii) water is a (special) economic good, (iii) participatory management of water resource and (iv) the promotion of gender equity in water resource management (ICWE, 1992; Murenga, 2003; Savenije, 2003).

Both INRM and IWRM recognize their subjects of research as complex systems, that is systems consisting of a large number of components that are richly and non-linearly interconnected. The emergent properties of the system are not primarily a result of the nature of the components, but of the nature of interconnections (Cilliers, 1998). Such complexity requires research that is transdisciplinary and often transinstitutional (Bawa, 1997; Carnoy, 1998; Love et al., 2004). This is what is known as mode 2 knowledge production (Gibbons et al., 1994; Jansen, 2000).

One key difference that has arisen between purely INRM and purely IWRM studies is the issue of the scale or boundary for analyses and interventions. It is a fundamental IWRM principle that the basic unit is the catchment (hence the term “integrated catchment management”), while many INRM studies use a unit with social boundaries (e.g. village) as the scale for analysis (Lovell et al., 2002). Table 5 summarizes the biophysical and institutional boundaries that might be considered when addressing issues of scale. Boundaries are central to INRM because they specify the area over which jurisdictions apply, as well as the roles to which particular actors are assigned. Within this context there is also a need not only to understand the management and technical differences between irrigated and rainfed agriculture, and, the differences between formal and informal irrigation in semi-arid regions (Table 6).
Need for water resources assessments prior to food security interventions.
Many rural development initiatives, notably the Millennium Project, target the smallholder farming sector and emphasise irrigation (UN Millennium Project, 2005). However, water resource availability is limited in southern Africa and imposes a constraint on some food security interventions (Love et al., 2006b). Promoting irrigation technologies in the absence of an assessment of access to the required water can result in partial failure of the intervention (Moyo et al., 2006).

Water Quality Management for Irrigation
Salinity is a major challenge to irrigation and is a common problem in alluvial aquifers of the Limpopo Basin. Many alluvial aquifers, especially smaller aquifers and those on river bank flood plains are characterised by high levels of sodium and chloride. This is an ambient condition, related to the geology of the aquifers, and threatens irrigated agriculture with equipment or crop failure. It necessitates the characterisation of boreholes and other water points as suitable or unsuitable for irrigation, prior to interventions such as drip kit distribution (Love et al., 2006a). The Lower Mzingwane alluvial aquifer is one such system, where agricultural production is constrained by salinity which has been found to increase significantly in the end of the dry season. During drought years, recharge is expected to be less and if the drought is extended water levels in the aquifers may drop substantially, increasing salinity problems (Love et al., in press). Catchment level management of the water quality problems is required, to develop a balance between low salinity surface water released for recharge, high salinity water in the flood plains aquifer and high salinity return flows from irrigation on the flood plains.

Green water productivity
Much of the current thinking about Green Water Productivity has been developed by Rockstrom et al (2006), with a strong emphasis on actual green water flows (evapotranspiration) and how we might improve productivity via different management interventions. Figure 5, adapted from Rockstrom et al (2006) indicates that when doubling yields from 1 to 2 t/ha in semi-arid tropical agro-ecosystems, green water productivity may improve from approximately 3500 m$^3$/ton to less than 2000 m$^3$/ton. This, as is correctly argued, is a result of the dynamic nature of water productivity improvements when moving from very low yields to higher yields. At low yields, crop water uptake is low and evaporative losses high, as the leaf area coverage of the soil is low, which together results in high losses of rainwater as evaporation from soil. However, little of this work was undertaken on farm, and none of it takes cognizance of the resource endowment of households and how this might influence crop management decisions and the inherent fertility of a households fields (e.g. Tittonell et al., 2005ab; Zingore et al., 2006; Ncube et al., 2008). Future work must take account of this heterogeneity, as crop responses to similar management interventions can differ markedly by resource group, as is shown in Figure 6 (Ncube et al.2007), and then imposed on the data presented in Figure 5.

INRM/IWRM Convergence in the Management of Gold Panning
Gold panning is an intractable socio-environmental problem common in many developing countries (MMSD, 2002) where the co-occurrence of poverty and easily extractable alluvial gold leads to this livelihood strategy as an inevitable outcome. It is associated with a wide variety of negative impacts, including social problems such as
violence and prostitution, erosion and chemical pollution (Maponga and Ngorima, 2003), especially the release of toxic mercury into the water, soils and air (Spiegel et al., 2006). A variety of studies in Zimbabwe have approached the problem. Shoko and Love (2005) adopt the INRM paradigm “CAMPFIRE model” to the management of gold panning and emphasise social structures, such as the village, as the locus of management. Zwane et al. (2006) apply the IWRM paradigm catchment planning model and focus on the hydrological catchment as the locus of management. There are important lessons to be learned from the application of both approaches to this type of problem. Both approaches converge in emphasising (i) community participation in management activities and decisions: the community-based natural resource management approach, (ii) functional decentralisation and (iii) transdisciplinary intra-governmental collaboration. The first emphasis encourages local ownership of the legal framework and saves monitoring costs (Shoko and Love, 2005; Tunhuma et al., in press). The second leads to decision making at the lowest appropriate level, where more context-specific details of the issue under consideration are available – or even obvious (Jaspers, 2003; Nare et al., 2006). The third allows for more informed decision-making and for harmonisation of different polices that may have different origins but address the same problem (Zwane et al., 2006). Furthermore, the case of gold panning shows that valid analysis of socio-environmental problems can (and should) be made at different spatial and disciplinary scales, and lessons drawn at each of these scales. Failing to recognise this level of complexity fails to do justice to the problem (Cilliers, 1998), which can result in an intervention being incomplete or misdirected.

Concluding comment
Production systems in the SAT are very complex and have evolved over generations in order to adapt to high variability and diverse biotic and abiotic stresses. In a risk-prone environment of southern Africa’s smallholder sector, the nexus between rural poverty, population pressure and agro-ecosystem degradation (Templeton and Scherr 1999, Scherr 2000) further complicates research. The relative importance of land, labor and water as factors of production will also vary according to the population densities in a given production system. Also, the R&D strategy will have to vary according to the relative importance and scarcity of land, labor, water and capital. Where land is scarce (e.g. Malawi) and labor is relatively abundant, research should focus on technologies that improve land/water productivity and use labor to generate employment. Labor-saving options that also improve land/water productivity may be needed in areas of low population density where labor markets are poor and HIV/AIDS is a major issue (e.g. Zambia and Zimbabwe).

Social and economic diversity and failure to capture farmer/consumer preferences and market requirements are key factors constraining the adoption of innovations. Individual farmers and government ministries may have non-complementary (and sometimes conflicting) economic, social and environmental objectives. Farmers’ economic and environmental objectives might depend on their comparative advantages and vulnerabilities to shocks; in turn determined by natural resource endowments, market access, government polices and social entitlements. For example, with unreliable or imperfect markets, farmers may not be in a position to adopt profitable and marketable varieties. The opportunities for intensification, diversification and commercialization of
production will vary accordingly (Pender et al., 2006). In remote SAT areas that are poorly integrated to markets, perishables and high-value input-intensive crops may not be appropriate; whereas farmers closer to urban centers, processing plants and marketing points may benefit from such technologies. Also, comparative advantages are relatively dynamic, varying over time depending on changing infrastructure and market conditions. This will necessitate different R&D strategies for the short, medium and long-term; and periodic evaluation and refinement of growth opportunities and research priorities.

In addition to markets, property rights, pricing policies and institutional arrangements can also influence the profitability and uptake of new innovations. Vulnerability to drought and other risks will differ across farm households depending on wealth, access to resources and ability to smooth consumption over time. Accordingly different groups of rural households may have differing capacities for buffering and managing risk and may require different types of technological and policy interventions. When the benefits from resource investments are unequally distributed or externalities affect the flow of benefits captured by farmers, it can hamper adoption and investment on such technologies. For example, households in the upper and downstream reaches of a watershed may have different incentives for land and water management investments. Yet it is essential each understands the needs of the other, and the off-site implications of future management decisions, particularly those taken in the upper catchments that influence flows to the lower reaches (CAWMA, 2007). Likewise, developing integrated pest management (IPM) options requires collective, coordinated action amongst a group of farmers to combine occasional use of pesticides with crop rotation or intercropping of different crops or varieties and reduce pest resistance (Singh and Trivedi, 2005). Similarly, men and women farmers may have different constraints and priorities and preferences. Labor-deficient households or those affected by AIDS may require special attention and targeting (Yamano and Jayne, 2004). Technology development needs to be fully cognizant of client needs and growing conditions in a given target region.

Even when technologies are profitable under a given biophysical environment, uptake may be limited by policies and institutional factors including production and market risk (especially among risk-averse farmers). While developing new technologies, it is important to diagnose needs and limiting factors – biophysical and socioeconomic constraints, biotic and abiotic stress factors, resource conditions and market, policy and institutional factors. Experience has shown that a narrow disciplinary or commodity approach that fails to integrate all these dimensions will not succeed.

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Harris and Mortimore, 2005


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Table 1: What we know about the adoption of Natural Resource Management (NRM) and Water Resource Management (WRM) practices (adapted from Barrett et al., 2003)

- Farmers have different needs/constraints according to the external conditions they face and their internal characteristics. Therefore, the identification of a large number of NRM/WRM technologies or a basket of NRM/WRM technological options is critical for reaching a large number of farmers and communities.
- There is an inherent dilemma between deliberate targeting of technologies to areas and social groups most likely to adopt and benefit from those technologies and the desire to make technology dissemination more demand driven.
- The adoption of innovation processes by individual farmers and groups of farmers is often more important than the adoption of individual technologies.
- NRM practices that improve soil fertility, raise production and prove profitable do exist.
- Farmers who recognize natural resource problems are not always induced to invest in improved NRM/WRM practices.
- Working-capital constraints or high opportunity costs of capital commonly limit investment in improved NRM/WRM practices. The linking of high value cash crops to cash investment therefore helps make such investments attractive.
- Farmers will find ways to adopt/adapt new NRM/WRM technologies into their farming system when incentives are sufficiently high from their perspective.
- Improved NRM/WRM technologies generally fail to be adopted by women farmers and poor farmers at the same rate as male farmers who enjoy greater wealth, education and socio-economic power. Where adoption by disadvantaged groups does take place concerted efforts have been made to reach these groups.
- Few studies on the social cost and benefits of resource degradation or improvement.

Table 2. Common organizational problems in Natural Resource Management Research that also apply to Water Resource Management Research (adapted from Ashby, 2003)

- Lack of representation of key stakeholders in research process
- Participation is not developed around clearly specified rights, roles and responsibilities
- Mechanisms of accountability among participants are lacking, especially the accountability of researchers
- Process too often corrupted by hidden agendas
- Conflicts of interest are not made explicit or negotiated
- Transaction costs of participation exceed the benefits to the participants, particularly households with low resource endowment
- Feedback mechanisms, such as monitoring and evaluation of the research process are not in place so that learning about how to improve the process is minimal or slow.
<table>
<thead>
<tr>
<th>Climate parameters</th>
<th>Effects on crops and natural resources</th>
<th>IGNRM Options</th>
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<tbody>
<tr>
<td>Late onset of rains</td>
<td>Shorter rainy season, risk that long-cycle crops will run out of growing time</td>
<td>Early-maturing varieties, exploitation of photoperiodism, P fertilizer at planting</td>
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<td>Early drought</td>
<td>Difficult crop establishment and need for partial or total re-sowing</td>
<td>P fertilizer at planting, water harvesting and runoff control, delay sowing (but poor growth due to N flush), exploit seedling heat and drought tolerance</td>
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<td>Mid-season drought</td>
<td>Poor seed setting and panicle development, fewer productive tillers, reduced grain yield per panicle/plant</td>
<td>Use of pearl millet variability: differing cycles, high tillering cultivars, optimal root traits, etc; water harvesting and runoff control</td>
</tr>
<tr>
<td>Terminal drought</td>
<td>Poor grain filling, fewer productive tillers</td>
<td>Early-maturing varieties, optimal root traits, fertilizer at planting, water harvesting and runoff control</td>
</tr>
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<td>Excessive rainfall</td>
<td>Downy mildew and other pests, nutrient leaching</td>
<td>Resistant varieties, pesticides, N fertilizer at tillering</td>
</tr>
<tr>
<td>Increased temperature</td>
<td>Poor crop establishment (dessication of seedlings), increased transpiration, faster growth</td>
<td>Heat tolerance traits, crop residue management, P fertilizer at planting (to increase plant vigor), large number of seedlings per planting hill</td>
</tr>
<tr>
<td>Unpredictability of drought stress</td>
<td>See above</td>
<td>Phenotypic variability, genetically diverse cultivars</td>
</tr>
<tr>
<td>Increased CO₂ levels</td>
<td>Faster plant growth through increased photosynthesis, higher transpiration</td>
<td>Promote positive effect of higher levels through better soil fertility management</td>
</tr>
<tr>
<td>Increased occurrence of dust storms at onset of rains</td>
<td>Seedlings buried and damaged by sand particles</td>
<td>Increase number of seedlings per planting hill, mulching, ridging (primary tillage)</td>
</tr>
<tr>
<td>Increased dust in the atmosphere</td>
<td>Lower radiation, reduced photosynthesis</td>
<td>Increase nutrient inputs (i.e. K)</td>
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Table 4. Five key elements of Integrated Natural Resource Management (adapted from Douthwaite et al 2004)

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<thead>
<tr>
<th>1. Learning together for change</th>
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<td>INRM must be based on a continuous dialog among stakeholders. Natural resource management is like jazz—it needs constant improvisation, each band member knows the weaknesses and strengths of the others, and they all learn how to play together. Researchers cannot remain exclusive: they need to engage in action research to develop appropriate solutions together with resource users. In this process researchers and resource users: (a) define subsystems, (b) reflect and negotiate on future scenarios, (c) take action, (d) evaluate and adapt attitudes, processes, technologies and practices.</td>
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<th>2. Multiple scales of analysis</th>
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<td>INRM attempts to integrate research efforts across spatial and temporal scales. This is because ecological and social processes take place over different time scales ranging from minutes to decades. Slow changing variables restrict the dynamics of more rapidly-cycling processes, and vice versa. As the system evolves, the dynamics of the different variables may experience sudden changes that reorganize the system. Usually these changes arise when the system reaches specific thresholds. In these reorganization points, it is impossible to predict how the system will self-organize. Understanding a system, rather than just describing it, usually requires studying that system plus other systems with which it interacts. Systems modeling is a practical approach to deal with variables that change more slowly than the length of a project. Modeling can also help farmers and other natural resource managers explore different scenarios, identify preferred ones, and then negotiate how to achieve them.</td>
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<th>3. Plausible promises</th>
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<td>INRM needs a practical problem solving approach that delivers tangible outputs. There must be motivation for farmers to work together with researchers. This motivation comes from ideas and technologies that make a ‘plausible promise’ of being beneficial to farmers. Working together builds trust and leads to further learning, from which other possibilities flow. Monitoring and evaluation and impact assessment can help identify and improve what is working.</td>
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<th>4. Scaling out and up</th>
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<td>INRM runs the risk of being criticized for only producing local solutions. However, if natural resource systems are characterized adequately (eg according to exogenous drivers as in the IITA Benchmark Area Approach – Douthwaite et al., 2005) then INRM can yield results that have application across broad ecoregional domains. While most INRM technologies cannot be scaled-out, some can be, together with the learning processes that allow rural people to identify and adapt new opportunities to their environments. INRM recognizes a difference between scaling-out (where an innovation spreads from farmer to farmer, community to community, within the same stakeholder groups) and scaling-up, which is an institutional expansion from grassroots organizations to policy makers, donors, development institutions, and other stakeholders key to building an enabling environment for change. The two are linked: scaling-out occurs faster if INRM projects plan and invest in engaging with stakeholders who can help promote project outputs and create an enabling environment for them. Iterative learning cycles that take place in participatory technology development processes can also help create an enabling environment through interaction, negotiation and co-learning among different stakeholders.</td>
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<th>5. Evaluation</th>
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<td>Evaluation is key to adaptive management because it provides the real-time feedback necessary for constant improvisation, learning and improving performance. Evaluation also provides data for further negotiation between stakeholders, and for resource allocation decisions. Stakeholders should agree on plausible strategies on how research will contribute to developmental change and then regularly monitor implementation of these strategies to feed into the learning cycle. Success criteria and indicators, agreed early on in a project, are the basis for impact assessment and negotiation amongst stakeholders for resource allocation decisions.</td>
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Table 5. Hierarchical levels of observation to address issues of scale from ecological and social perspectives (Twomlow, 2003)

<table>
<thead>
<tr>
<th>Ecological boundaries</th>
<th>Social boundaries</th>
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<tbody>
<tr>
<td><strong>Ecozone:</strong> Based on broad-scale physiography and vegetation, controlled by climate, e.g., dry savannah</td>
<td><strong>Regional and national</strong></td>
</tr>
<tr>
<td><strong>Ecoregion:</strong> Subdivision of ecozone regional climate, surface topography, vegetation, e.g., commercial versus subsistence farming</td>
<td>Community and ethnic grouping</td>
</tr>
<tr>
<td><strong>Ecodistrict:</strong> Land resource area parent material, surface topography, e.g., major drainage basin</td>
<td><strong>Communities</strong></td>
</tr>
<tr>
<td><strong>Soil landscapes:</strong> Dominant landscape component, e.g., major soil unit that influences land use – catenas</td>
<td>Villages and chieftainships</td>
</tr>
<tr>
<td><strong>Farm unit (ecosite):</strong> E.g., cropping system or grazing, gradients in soil fertility</td>
<td><strong>Private and communally held property</strong></td>
</tr>
<tr>
<td><strong>Plot/Quadrat (ecoelement):</strong> E.g., comparisons of change within and between farms</td>
<td></td>
</tr>
<tr>
<td><strong>Microsite:</strong> Characterization of soil biophysical attributes</td>
<td></td>
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Table 6. Comparison of rainfed and irrigated agriculture in semi-arid regions

<table>
<thead>
<tr>
<th></th>
<th>Irrigated</th>
<th>Rainfed</th>
<th>Water harvesting</th>
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<tbody>
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<td></td>
<td>Informal</td>
<td>Formal</td>
<td>Traditional</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Structures</td>
<td>Some</td>
<td>Large</td>
<td>No</td>
</tr>
<tr>
<td><strong>Management</strong></td>
<td></td>
<td></td>
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<tr>
<td>Control</td>
<td>Farmer</td>
<td>Scheme</td>
<td>Farmer</td>
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<tr>
<td>Technology</td>
<td>Indigenous +</td>
<td>New</td>
<td>Indigenous</td>
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<td></td>
<td>New</td>
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<tr>
<td>Inputs/Outputs</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>Adoptability</strong></td>
<td>Farmer initiated</td>
<td>Imposed</td>
<td>Accepted</td>
</tr>
<tr>
<td>Reliability</td>
<td>Increased</td>
<td>Variable</td>
<td>Poor</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Flexible</td>
<td>Limited</td>
<td>Limited</td>
</tr>
<tr>
<td><strong>Crops</strong></td>
<td>Very wide</td>
<td>Wide</td>
<td>Limited</td>
</tr>
<tr>
<td>Crop stress</td>
<td>Some</td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td>Salinity</td>
<td>Some</td>
<td>Present</td>
<td>Absent</td>
</tr>
<tr>
<td><strong>Social</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land tenure dynamics</td>
<td>Established</td>
<td>Changes</td>
<td>Established</td>
</tr>
<tr>
<td>Market outlets</td>
<td>Yes</td>
<td>Essential</td>
<td>Yes</td>
</tr>
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</table>

Figure 1 Variation in average rainfed maize grain yields with annual rainfall as affected by resource status of the farming system. ▲ Average Maize yields from Zimbabwe’s Commercial Farms. ■ Average Maize yields from Zimbabwe’s Communal Farms, ♦ Average Maize Yields from Chivi Communal area (source Mugabe pers comm.).
Figure 2: An idealised learning cycle in R&D for natural resource management (Campbell et al., 2006)

Figure 3. The principles for more effective Integrated Natural Resource Management (Campbell et al 2006)
Figure 4 Schematic representation of Integrated Water Resources Management (adapted from Koudstaal et al., 1992)
Figure 5: Dynamic relationship between water productivity and yield for cereal crop under i) various management and climatic conditions (adapted from Rockstrom et al., 2007) compared to ii) resource status of household for the same climatic conditions (adapted from Ncube et al., 2007)
Figure 6. Mean maize grain yield, 2003/04 season (Mkhubazi, Tsholotsho, Zimbabwe) in response to a range of soil fertility amendments for Low and Well Resourced Farms. 1. Control plot with no soil fertility amendments 2. Manure only. 3. Manure + Low N (25 kg ha\(^{-1}\) Ammonium Nitrate). 4. Low D, low N (25 kg ha\(^{-1}\) of Compound D and Ammonium Nitrate). 5. High D, Low N (150 kg ha\(^{-1}\) of Compound D and Ammonium Nitrate). 6. High D, High N (150 kg ha\(^{-1}\) of Compound D and Ammonium Nitrate). Error bars represent standard errors of differences between means of the treatments. (source Ncube et al., 2007)