Enhancing Agronomic Practices for Improved Ecosystem Resilience in I&D Operations

A Practice Note

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Introduction

Water management in irrigated agriculture has been identified as a sustainability challenge due to a combination of continuously increasing demand and the ability of farmers to access water in excess of renewable supply. Intensive irrigation and related agricultural practices can also impair soil and water resources on which they rely by way of pollution and degradation of soil health. Thereby input-intensive farming can generate externalities beyond the intended immediate benefits. These risks are all well understood. However, methods to systematically integrate such measures into irrigation development goals have typically been lacking.

Raising the environmental performance of intensive arable production can be accomplished through a broader adoption of good agricultural practice on irrigated land and by enhancing farmers’ skills in soil and water management as well as through related national-level governance strategies. Relevant agronomic practices include those that reducing pollution, improving soil fertility, and enhancing biodiversity can minimize the impacts of agricultural production on natural ecosystems and the services they provide. These also include appropriate matching of crop, soil type, and irrigation methods.

Conserving the natural resource base and reducing quality impacts while improving producer net returns is a core objective of WSiA. As a practice of responsible use of natural resources, water stewardship in agriculture (WSiA) responds to sustainability challenges presented by irrigated agriculture by protecting farming operations from resource-related risks as well as minimizing potentially negative impacts on water users and the natural environment.

WSiA positions farms as critical stewards of natural resources and consists of systems and practices that manage water responsibly, build and maintain healthy soil, and minimize pollution. Enhancing ecosystem resilience of farming systems by safeguarding water quality and ensuring soil conservation are key attributes of water stewardship in agriculture (WSiA). Good water stewardship also protects and promotes biodiversity, which in turn has a beneficial impact on farming.

Emergence of stewardship of agricultural water and other ecological resources as a priority, challenges established management approaches that are primarily focused on efficient water exploitation. However, irrigating land, by equipping it with water control structures for irrigation and drainage, is only a worthwhile endeavor if sufficient emphasis is also given to conservation efforts – of both water and soil. By countering environmental disturbance associated with production of farmed commodities, WSiA advocates for resource protection and regeneration by taking an integrated land and water management perspective.

Stewardship considerations are also in-line with the Environmental and Social Standards (ESS) of the Environmental and Social Framework (ESF) applicable to all new World Bank investment project financing, which includes resource efficiency and pollution prevention and management (ESS3) as well as protection and conservation of biodiversity and habitats, along with sustainable management of living natural resources (ESS6). Consistent with ESS3 and ESS6, water stewardship in agriculture (WSiA) focuses on curbing unsustainable natural resource consumption by minimizing the negative impact of farming activities on other water users and the natural environment.

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1 Defined as a terrestrial, freshwater, or marine geographical unit or airway that supports assemblages of living organisms and their interactions with the nonliving environment.
Importance of farm-level interventions

Management practices at farm level for improving water and soil quality are essential to meeting future needs both for food production and water. Adopting such best management practices and production patterns (for a reduced impact on the environment) represent one avenue for stewarding our critical resources. Agronomic best practices advocate for efficient use of water, nutrients (fertilizers), insecticides, herbicides and fungicides, as one way to reduce the environmental pollution from agricultural production.

For example, minimizing off-site water quality impacts of irrigated crop production consist of limiting chemical-use rates as well as reduction of field salinity and erosion due to applied water. This is particularly important since hydrological processes that underlie non-point source pollution, serve as the primary mechanism for the transfer of pollutants from land to water by enabling runoff of sediment, nutrients, and pesticides. Improved agronomic practices also aim to increase water storage capacity of soil, reduce agrochemical inputs, and to tailor cropping patterns to lower water demand and usage. Improved water and soil management also has the power to increase crop yields and improve crop quality.

However, farmers typically lack adequate assistance to adopt approaches that improve the longevity and environmental sustainability of their farming operations. In certain cases, farmers may also lack knowledge or skills for improved use of technological systems already installed or for adopting new equipment, for tailoring cropping patterns to lower water usage, or reduce agrochemical inputs. Thus, they require support for shifting to ecologically intensive agriculture models include providing localized agronomic knowledge and production assistance, while taking into account the tight financial situations within which farmers operate. This is best achieved by using an incentive-driven rather than regulatory approach.

The poorest of farmers may also require incentives, including in the form of subsidized inputs. Implementing effective on-farm management strategies that preserve long-run land and water productivity (to meet both efficiency and ecological objectives) should be incentivized by means of input support along with advice on practical and context-specific approaches.

Furthermore, in protecting water in the environment, WSiA applies a catchment (or basin) approach by recognizing that water management on a farm is interconnected with the wider surrounding environment. Coordination of farmers’ land-use and water management decisions at a scale beyond individual farms is needed to optimize resource use and stem the loss of ecosystem functions. Thus, agricultural water stewardship requires working across farms at the catchment level within a supportive governance structure.

Hybrid approaches to sustainable intensification in irrigated agriculture

Given the growing need to reduce the amount of water used in irrigated agriculture, while maintaining food security and ecosystem health, sustainable intensification of agriculture has been brought to the forefront as a potential solution. Sustainable intensification-directed agronomy entails concurrent adoption of modern irrigation technology and appropriate agronomic practices for conserving water and optimizing productivity. Rather than making rigid choices between engineered water management solutions and ones that are ecosystem-based, mixing of both approaches and working within the functional limits of catchment ecosystems is the goal of sustainable intensification.

Fresh water sustains the integrity land- and water-based ecosystems that are essential for the sustenance and health of all species and ecosystems that serve important ecological and hydrological functions. By undertaking an ecosystem approach as a way to manage land, water, and living resources in an integrated way promotes conservation and their sustainable use.
Currently, predominant water management technologies prioritize technical efficiency to augment water supply to meet the intensive water demands of agriculture and to address limitations in the capacity of natural systems. Correspondingly, water savings at the farm level through improved management of irrigation supplies is the purview of water conservation. As irrigators are likely to continue looking to technology as one of the means for conserving water through adoption of more efficient irrigation technologies, such measures can also be enhanced when implemented in combination with improved agronomic (soil and water-conserving strategies) practices.

Production- and ecosystem-enhancing set of agronomic practices strengthen ecological functions that underpin crop production, including those leading to higher soil fertility and water retention capacity as well as pest, disease and weed management. The practices are meant to be carefully adapted to local farming systems and tailored to match production conditions, without significantly undermining the functioning of catchment ecosystems and the benefits they provide.

Economic aspects of water management are also key to this approach, as the high financial burden of reversing environmental degradation and other negative externalities of agricultural water use necessitates the adoption of a long-term perspective and prevent shortsighted development patterns. Thus, placing importance on early, preventive actions combined with monitoring should be the focus of management actions.

This practice note is concerned with irrigated agriculture’s environmental ‘footprint’ and attempts to alleviate the trend of degradation of land and water resources from agricultural production by providing practical knowledge on best practices for soil and water management through conservation techniques and agronomic practices. This is achieved through improved on-farm water management approaches that conserve water and soil resources while enhancing farmer livelihoods.

Unfavorable environmental impacts of irrigated agriculture

Agriculture, as an industry based on the extraction of ecological resources, can potentially erode the natural resource base on which it depends. Correspondingly, developmental demands of irrigated agricultural systems are commonly viewed as a source of significant environmental harm. These include pollution from fertilizers and pesticides due to high chemical-use rates and increased field salinity. Drainage flows from irrigated crop production can accelerate pollutant transport. There may also be greater instream pollutant concentrations due to reduced flows. Negative impacts on soil health (or fertility) can include erosion and loss of soil organic matter (OM), by affecting soil structure and reducing soil moisture.

Typical agricultural intensification, requiring increases in inputs of fertilizers and chemical crop protectants, can also result in a simplification of once heterogenous landscapes. Simplified landscapes, emerging as a result of agricultural production, exacerbate biodiversity losses and reduction in ecosystem services, and may lose functionality. Thus, land management practices that accompany irrigation warrant an examination due to the impact they have on water quality and the natural environment overall to prevent undermining its future capacity to produce food.

Pollution

Contamination of water arising from land use activities is a known byproduct of agriculture, particularly since land management practices are subject to the same hydrological processes that link rainfall, runoff and leaching. Depending on the predominant land management practices are used in crop production,
main pollutants released through agriculture include nutrients (particularly nitrogen and phosphorus from fertilizers) and pesticide residues that pollute surface and groundwater via runoff.

Another common problem is that of sedimentation of watercourses by soil runoff, which carries water pollution downstream through a mix of suspended soil particles and chemicals (either attached to them or dissolved). Such runoff can also lead to soil erosion (detachment). Sediment, whether coming from soil erosion or from the decomposition of plants and animals, leads to contamination of streams, lakes, and estuaries. Management practices (such as tillage, use of pesticides and fertilizers, among others) respond to local hydrological conditions and are subject to runoff.

**Soil erosion and sedimentation**

Soil erosion due to climatic and land use conditions is a prevalent source of agricultural water contamination, primarily as a result of runoff from agricultural areas. Poorly managed runoff can carry sediment and pollutants into watercourses downstream and groundwater aquifers. Pollution by sediments (or sedimentation) occurs by detachment, transport, and deposition of soil by water or wind, and can impair water bodies and associated aquatic life. Sediment, composed of fine-grained particles of sand, clay, silt and other soil particles, settles at the bottom of a water body and can impede the growth of aquatic plants that provide essential habitat for many aquatic organisms. Low volumes of organic matter as well as loss of structure through compaction and overcultivation contribute to the erosivity of wind and water. Pollutants can be transported by sediment to water bodies, as they get attached to soil particles.

Agricultural land management practices are the main determinants of soil erodibility. In addition to wind and water, extent of tillage and soil cover will affect soil erosion. The depth and speed at which tillage implements are operated will determine net soil displacement and tillage erosion. Extent of runoff will also depend on soil cover. Leaving vast expanses of soil unprotected, particularly in late fall and winter, makes it vulnerable to wind and water erosion. By removing nutrients from the soil, erosion also robs it of its fertility - requiring high input levels to maintain soil productivity, thereby constituting a cost to the farmer. Thus, loss of productive land by erosion of topsoil represents an economic loss and is a net cost to agriculture (Ongley, 1996).

**Salinization**

Salinity, when accumulating to excessive levels, can limit productivity. Salinity is defined by the concentration of all soluble salts in water or in the soil. It impacts the crops (by limiting the ability of plants to take up water), soil health, and may contaminate underlying groundwater. It can be naturally occurring or be caused by irrigation with saline water, uneven water distribution (causing some areas to be under- or over-irrigated), and increased rates of leakage and groundwater recharge causing the water table to rise.²

Water logging which commonly arises from inefficient irrigation and drainage systems, as well as application of too much irrigation water leading to major excess leakage, also increases salinization of soil and shallow groundwater aquifers. This is particularly true in hot dry climates and areas where soils do not drain well and high evaporation rates at the surface leave salts behind. On the other hand, continual

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² If water tables are located within two meters of the soil surface, the potential for salts to accumulate at the soil surface increases.
under-irrigation may also increase salinity, as the salts require periodic flushing or leaching to prevent their accumulation.

**Fertilizer pollution**

Fertilizers are an essential component of agricultural production and typically consist of nitrogen, phosphate, and potash. While most of the nutrients applied are absorbed by the crops used for food, feed, fiber, and fuel – excessive application of fertilizer on soil (both mineral and organic) can negatively impact air and downstream water quality. The problem is associated with extensive and intensive application of fertilizers (mostly nitrates and phosphates), where application of nutrients exceeds capacity of the soil and plants to assimilate and fully utilize them.

Excess nutrients can be distributed to the surrounding environment through runoff into surface water, leaching into ground water, and emission to air. Rain or snow melts can wash away fluxes of nutrients and cause excess nutrients to contaminate groundwater, where they may accumulate with time and persist for many years. They can also lead to acidification of land and water. Pollution by nutrients in fertilizers as a result of leaching from the soil disrupts the biological equilibrium and may result in excessive growth of algae, thereby causing eutrophication of surface water, and may also be toxic to wildlife. Moreover, high accumulations of pollutants in groundwater will migrate to other areas through natural flow patterns.

Nutrient losses and contamination impacts can be reduced by adopting practices that enhance plants’ ability to uptake nutrients, thereby better matching nutrient applications with agronomic needs.

**Pesticide pollution**

Physical and chemical properties of pesticides and their residues (such as toxicity, persistence, solubility, potential for degradation) determine their transport after application and effect on the environment. Pesticide application methods, conditions during application (weather), and site characteristics (soil properties, organic matter content, proximity to water courses) determine the pathways of movement and whether contaminants will reach a water body through drift, runoff or seepage. Pesticides that reach groundwater may persist for many years. In addition to damaging the natural environment, pesticides can also be dangerous to human health. Moreover, pesticides can be inefficient at controlling pests, particularly by affecting natural enemies of target pests, or produce new ones. They may also be unable to provide lasting control (needing to be repeatedly applied), or pests may become resistant.

**Soil degradation**

Soil moisture, surface roughness, texture, composition (including organic matter content), permeability, and particle (aggregate) size distribution – all determine the soil’s susceptibility to wind or water erosion. The ability to be moved by flowing water (or the water erosion rate) is determined by soil properties (infiltration rate and permeability) as well as rainfall intensity, wind velocity, topography (degree of slope), and vegetative and residue cover.

Movement of water in soil, including infiltration, drainage, and water storage in the soil profile, is determined by the size of soil particles and pores, as well as their arrangement. Rain drops can destroy soil aggregates and smaller soil particles clog pores, thereby blocking water infiltration. Smaller soil aggregates are also more likely to be carried by wind.
Structural degradation of soil is primarily a result of low volumes of organic matter as well as loss of structure through compaction and overcultivation contribute to the erosivity of wind and water. Negative consequence of irrigation can be seen either through soil compaction and structure degradation and salt accumulation hazard (secondary salinization). Additionally, soil porosity changes (e.g. ratio of macropores) within a given soil group could be taken as primary indicator of structural degradation, while the changes in bulk density can indicate the susceptibility for compaction.

Main approach

The main approach to implementing agricultural stewardship measures for improving water and soil quality primarily advocated by this practice note consists of hybridization of water management methods and ensuring their uptake at the catchment scale (through an enabling governance framework). This requires identifying contextually-attuned combinations that enhance a farm’s contribution to protecting water in the environment without sacrificing productivity.

Such methods will carry short-term economic hurdles and short-term reduction in yields may be experienced. There may be concerns with a significant time horizon for benefits to materialize as farmers may be more concerned with immediate costs and benefits (related to food security) associated with short planning horizons. Thus, adopting a phased approach to promoting changes, through a combination of irrigation advisory services and policy measures, is advisable.

Regardless of the approach chosen, trade-offs will have to be made between food production and biodiversity conservation, or more concretely – between short-term productivity increases and long-term sustainability of agricultural systems. Providing farmers with incentives under the rubric of stewardship (on the production side) that simultaneously improve both agricultural productivity and environmental quality requires proper financial reward and/or regulatory pressure, as voluntary schemes are unlikely to be successful.

Hybridization of water management solutions

While natural infrastructure produces a diversity of services (albeit with limited capacity), engineered solutions efficiently serve intensive water uses while also displacing a range of natural processes that affect water systems.

Physically modernizing irrigation systems is often seen as a basic solution to water scarcity and serves as a dominant component of relevant investment programs. However, rather than narrowly focusing on technically-efficient means of water resources extraction to maximize production, a hybridization of differing water management approaches can help the process of enhancing supplies of water to agricultural production systems while working with natural processes in their unique geographic setting.

Hybridization of water management approaches encompasses mixing of technological means to increase water efficiency (high-efficiency water delivery mechanisms, sensors, intelligent watering systems, etc.) alongside better practices of soil and water management as well as cropping choices. Prioritizing the sustainability of the foundational natural capital underpinning agricultural production, rather than only maximizing production of a limited range of desired outputs is the key to this approach.

Managing farms as ecosystems by using agroecological principles can help avoid damaging impacts of production. Synergistic effects can be established by combining technological water-efficiency practices with agronomic ones that sustainably deal with soil health and fertility as well as pest and weed
management. Agro-ecological conditions will play a major role in determining the benefits of various practices, particularly when it comes to maximizing the efficiency of nutrient use and increasing crop productivity.

Poor farmers may already rely on low-input agriculture that depends on biodiversity and associated ecological processes. Enhancing these practices through the development of effective on-farm management practices for maintaining soil health and fertility, controlling weeds, and avoiding diseases, can benefit their farms’ economic performance.

**Water stewardship at catchment scale**

Agricultural water stewardship requires working across farms at the catchment level within a supportive governance structure. While most water management activity takes place on the farm, and individual farms might be highly efficient at optimizing agricultural practices and lowering required inputs, the spatial scale of management in typical farming system does not match the scale needed to ensure provision of ecosystem services supportive of agricultural processes.

Since biodiversity and the attendant habitat are common-pool resources, managing ecosystem services in agricultural landscapes requires undertaking collective, consensual decision-making around the management of public assets. Collective action through cooperation that alters landscape structure at scales larger than individual farms has the power to solve many agriculture-related environmental problems. Thus, expanding stewardship practices to catchment scale ensures the attainment of a collective benefit through joint actions of dispersed resource users that cannot be achieved by individual efforts.

A catchment approach ensures that impacts beyond the farm level are taken into account by engaging stakeholders, including farmers, researchers, extensionists and policy makers. Catchment water management actions depend on (and are supported by) stakeholder engagement and sharing of responsibility among water users. Governance structures protect ecosystem services (and biodiversity on which they depend) as public goods and encourage equitable benefit-sharing across the catchment through stakeholder engagement.

**Agricultural water governance**

Governments are key players in stewarding our critical water resources, primarily by supporting the equitable allocation of water and agricultural production while safeguarding ecosystem functioning. Governments can influence the uptake of mitigating on-farm measures through mechanisms at various spatial scales. Such mechanisms include enforcing change through regulations, providing incentives, disseminating knowledge through the provision of advice (farm demonstrations or one-to-one farm visits), and campaigns to encourage voluntary behavioral change.

Effective water governance employs a scientifically-sound framework and enables dialogue with all major stakeholders in management decisions. It starts with identifying catchment water users (location, nature of water sources, volumes used) and map land use across the catchment. By providing the social infrastructure for planning and coordination, governance through water institutions can set priorities and encourage users to operate within ecological bounds (and respect the rights of others), while working to minimize physical wastage.

An effective governance structure also helps converge two different scales of interests – farmers driven by profit and water resources managers (ideally driven by sustainability at watershed, basin, or national scale).
This is particularly salient given that saving water is not a priority for farmers, who instead tend to focus on maximizing net income rather than water productivity. Moreover, farmers typically lack adequate means, incentives and assistance in developing and adopting better approaches. They may be unaware of existing (on-farm) efficiency levels, unable to identify scope for improvements, and perceive a lack of economic benefits in changing their practices (Levidow et al, 2014).

Optimal agricultural water management starts with setting of water allocation quotas (caps), informed by water accounting, to attain a balance between sustainable supply and consumption of water. Administrative water allocation often serves as the best method for leading farmers to adopt water-efficiency practices. Such controlled access to water by farmers must precede introduction of advanced irrigation technologies to ensure real water savings. Sound water accounting will also reveal whether real water savings are being achieved, enabling release of water for other uses without negative effects.

In the absence of (prior) control by quotas, technological efficiency measures may increase consumption per unit area and worsen water scarcity situations. The sequence of actions above should be promoted by Bank irrigation-focused operations. This includes avoiding funding for irrigation modernization projects prior to attaining physical control over water resources by government and responsible agencies.

Agronomic management solutions in WSiA

Avoiding disturbance to the soil is the single most important aspect of minimizing negative effects of agricultural production, followed by protecting and building soil health. This includes – first and foremost – reducing or eliminating tillage and ensuring soil cover during the off-season rather than leaving soils bare. Efforts to reduce pollution include minimizing use of agrochemicals by implementing biological control methods as well as making use of buffer zones and wetlands as mitigation measures.

Moreover, steps for improving biodiversity include managing soils to promote numerous and diverse range of organisms through practices such as returning organic matter to soil and avoiding large blocks of single species of crops. Crop diversity practices include intercropping (growing a mix of crops in the same area) and use of complex multi-year crop rotations.

Soil management for improved productivity and water quality

Adoption of management practices that optimize existing processes in the soil (supporting its biological activity) and build its resistance to structural degradation – begin with identifying soil structure type (size, shape and arrangement of aggregates and air spaces) and establishing the most suited crops and rotation. For example, soil properties affecting water storage should be understood prior to design of an irrigation system. Information on soil texture and structure helps determine its water holding capacity for planning irrigation design and operation. Matching design to soil type will help optimize water use by plants and avoid over- or under-watering, as well as determine scheduling and application amounts.

Thus, the starting point for proper soil management is achieved through the creation of spatially-exhaustive soil maps – that can support irrigation recommendations for specific areas, and compiling profile- and map-based soil databases. Functional soil maps, developed through spatial modelling of the soil cover features, can reveal relevant conditions and possibilities for irrigation. Moreover, soil moisture monitoring can show the depths to which rainfall or irrigation has penetrated and the depth from which roots are extracting water. Monitoring for soil moisture content (available for plant growth) allows for determining the remaining readily available water (RAW) for scheduling of irrigation.
Erosion control

Prevention of soil erosion requires an integrated approach that includes maintenance of good soil structure, protection of soil surface (with crop and residue cover) and use of structural erosion practices where necessary. Care should also be taken when irrigating land susceptible to erosion by adjusting water application rates to soil conditions to reduce risk of run-off. If farming on steep slopes cannot be avoided, measures such as maintaining natural stabilizing vegetation and terracing, or re-landscaping is also advised. This includes planting of protective shelter belts (trees and shrubs), strip-cropping, and contour cultivation.

Conservation tillage

Conservation tillage (CT) is a collective term for a set of practices of reduced tillage\(^3\) of cropping systems to minimize the disturbance of the soil, where at least 30% of the soil is also covered by protective crop residue (as the lower limit). Conservation tillage techniques include minimizing the frequency or intensity of tillage, retention of crop residues, mulching, and winter cover crops to retain soil moisture. CT also helps conserve labor, fuel, water, and nutrient inputs across the production process. When used under irrigated conditions, CT substantially contributes to reducing the amount of water needed for crop production, primarily by reducing runoff and making more water is available for the crop, reducing evaporation of soil moisture reserves, and by improving water infiltration.

CT impacts the physical and biotic characteristics of the soil environment. If properly managed, the practice of CT can improve soil water infiltration to reduce compaction and erosion (and thereby run-off and water contamination), help improve soil quality by increasing surface soil organic matter and carbon content, and lower soil temperatures (in part due to the presence of a surface layer of plant residues). With CT, soil becomes denser, mostly due to a decrease in the number of larger pore spaces in the soil and an increase in the number of smaller spaces. While this reduces aeration, it increases the soil’s water holding capacity. CT also improves water quality by reducing sedimentation of rivers, reservoirs, lakes in watersheds and reduction of groundwater contamination and increased recharge of aquifers.

Short-term yield responses of CT may vary, and full benefits will take time to materialize. Thus, advantages of CT might not be seen immediately, thereby potentially discouraging its adoption. CT may also require the use of herbicides due to an increased need for weeding.

Cover crops and crop residues

Implementing cropping systems that provide ecosystem benefits beyond maximizing crop yield includes use of soil covers such as cover crops and crop residues. Covered surface of fields acts as a protective layer for the soil from climatic conditions – such as temperature extremes as well as impact of raindrops and wind. Crop residues and cover crops protect and nourish soil life by maintaining organic matter cover on its surface, while reducing water evaporation and making more water available for crop production.

Cover crops help replenish and retain soil moisture and nutrients, reduce weed presence, and prevent erosion. Integrating cover crops into annual crop rotations improves crop productivity through soil quality, nutrient cycling, and pest regulation. A carefully-selected mixture of cover crop species can supplement or replace synthetic fertilizer inputs with biologically-derived sources, thereby supplying nitrogen and retaining nitrate against leaching.

\(^3\) Includes no-tillage, strip tillage, direct drilling, minimum tillage, mulch tillage, and ridge tillage.
However, cover crops are only feasible during a certain point in a crop rotation and may interfere with cash crop production, thereby limiting the potential for their use. As an alternative soil management measure to cover crops, crop residue retention (as mulch) for soil cover may have a similar effect as using a cover crop. Leaving crop residues on the surface helps increase water infiltration and reduce erosion risks, enhances soil quality by maintaining or increasing its SOM content.

Another method of protecting soil and increasing fertility is mulching. Mulching includes covering soil with organic material (such as crop residues, straw or leaves) with the same objective of improving infiltration, protecting the soil from erosion and dehydration, reducing soil temperatures, prevent weed growth, to increase or retain organic matter content in the soil, nutrient cycling, and stimulate soil organisms. However, mulching is most effective in increasing yields in dry climates, while it may lead to reduced yields in areas with high rainfall. Additionally, a commonly arising question of an opportunity cost of using crop residues for mulch rather than livestock feed poses another challenge.

Protecting water quality

Minimizing offsite water quality impacts of irrigated production includes improving input management as well as use of buffer zones and wetlands, as described below.

Improving pesticide and fertilizer management

Agricultural stewardship measures assist with ensuring that input of fertilizers and pesticides does not adversely impact water quality (at a local or regional level) by controlling problems at the source. This process begins with improving water quality monitoring by making it more spatially and temporally intensive - thereby allowing for better identification of key pollution source areas, in which to target stewardship approaches and to measure their impacts.

Diffuse (non-point sources) pollution, typical of agricultural water systems, are difficult to control as they are dispersed across a catchment or sub-catchment. Thus, modeling of hydrological processes serves as the primary prediction mechanism for understanding agricultural pollution – by estimating runoff and associated aquatic impacts (Ongley, 1996).

Such monitoring assessments include identifying where pollution occurs (by regularly checking water courses for signs of pollution and for areas with significant concentration), its pathways (nature of run-off, origins and destination) and types of chemicals used. The next step is identifying the spectrum and necessary level for resource inputs based on (planned) agronomy, soil type, disease incidence, nutrient requirement (incl. nutrient level monitoring).

Maintaining or improving water quality depends on adopting mitigation measures such as improved pesticide and fertilizer management. The most feasible pollution mitigation measures include agrochemical application rate reduction, product substitution, change in application timing, alternative cropping, and developing biodiversity rich habitats.

Where inputs are used, it is advisable to consider the accuracy of application (including well calibrated machinery, trained and competent staff), weather conditions at the time of application, adopting measures to protect water courses (such as buffer strips) – to avoid unnecessary runoff and minimize impacts on non-target organisms. Adopting diverse pest and weed management strategies (that rely on biodiversity) also helps lessen pesticide and herbicide use, while also managing nutrients in a way that matches crop demand.
Pest management

When it comes to water quality concerns, it is also advisable to evaluate the water contamination potential for pesticides used in agricultural production, including their leaching, run-off potential, and persistence in groundwater environments, to ideally select the most environmentally-benign options. Firstly, selecting the least toxic and persistent pesticides and applying them efficiently and only as-needed, while employing practices that minimize the risk of their movement to ground and surface water (e.g. buffer zones) is one line of defense. Timing pesticide application to when runoff drifts are least likely is also important.

As an alternative to agrochemical application, using a range of biological and alternative techniques for the control of pests is presented by Integrated Pest Management (IPM). IPM utilizes ecological processes through preventative as well as corrective methods to minimize pesticide use. Biological forms of pest control include practices that produce unfavorable conditions for pests through the use of their natural enemies (predators, parasites, and disease-causing organisms), rotating non-host crops with susceptible crops (or relay cropping), and intercropping to increase the diversity of farms and surrounding environments (crops grown in alternative strips).

Natural regulation of most pest species typically takes place through predation and parasitism by natural enemies. Improving (refuge) habitat for natural enemies or attracting pests out of the main crop can be achieved by establishing (unsprayed) vegetation between fields and along irrigation canal banks or water courses through border planting around edges of fields. Thus, maintaining landscapes with higher proportions of natural or semi-natural areas in order to foster higher natural pest control in fields allows for pesticide use reduction. However, the knowledge-intensive nature of the IPM approach may limit its application in some circumstances and require context-specific tailoring.

Buffer zones and wetlands for controlling soil erosion and protecting water quality

Secondary measures that protect water courses by reducing the effects of runoff and soil erosion include buffer strips, field margins, and constructed wetlands. The main role of buffer zones in agricultural habitats consists of protection of non-cropped areas from sediment from surface runoff and reducing concentrations of nutrients and pesticides. They reduce erosion, improve water quality, help increase biodiversity, expand wildlife habitat or movement corridors. They can be non-vegetative bare soil or vegetated strips at the edge of a field, between a crop and a water body, or treated crops and un-treated areas.

If risks from farming include run-off, a vegetated strip between a crop and water body is recommended. The root systems of trees, shrubs, and plants stabilize the soil as well as trap and remove various nonpoint source pollutants from both overland and shallow subsurface flow. Thus, maintaining areas of natural vegetation (with farming restrictions) encourages dispersion and dilution of pollution and helps in preventing uncontrolled run-off and discharge.

Such riparian buffers strips provide a linear band of permanent vegetation adjacent to an aquatic ecosystem and are located between crop fields and water bodies. They consist of areas of grass or other permanent vegetation preventing sediments and pollutants from entering a water body by controlling run-off (rates). Benefits of riparian buffers include stabilization of bank erosion, flood protection, downstream flood attenuation, and reduction of algal blooms or excessively turbid water. Buffer zones should not be used as the primary method of controlling soil erosion, as well as pesticide and fertilizer drift, but rather a water protective or risk management measure.
Moreover, field margins promote biodiversity and prevent transfer of pollutants to non-cropped areas, thereby protecting aquatic or terrestrial organisms (such as non-target arthropods) and plants. They also provide a semi-natural habitat for pollinators of crops and natural predators of pests. Such retention of patches of natural or semi-natural off-crop habitats minimizes negative impacts of fertilizers and pesticides used on crops on non-target organisms (and water bodies). Contour buffer strips are areas of vegetation planted on the contour of a crop field and alternated with cultivated strips.

The environmental benefits of using buffer strips and field margins will depend on how they are designed and managed. The ability of a buffer zone to meet specific objectives will depend on their position within the watershed, the width of the impacted watercourse, the composition and density of vegetation species present, and slope. Proper width and length of a buffer will be determined by risk assessments and the width of the impacted watercourse being protected, as determined by the specific location and benefit needed. The minimum recommended width is 5 meters.

Choosing the right vegetation type is also important, due to differences in the benefits they provide. A mix of native trees, shrubs, and herbaceous plants are most effective when adapted to the local climactic, soil, and hydrologic conditions. The right mix will also enhance biodiversity and provisioning of ecosystem services that benefit agricultural production, by making a decrease of anthropogenic inputs (inorganic fertilizers, pesticides, energy, and irrigation) possible. For example, perennial species-rich (wildflower) strips enhance pest control and crop yield by supporting natural enemies of crop pests that provide biological control. Another option is adoption of agroforestry practices, which involves mixing trees or shrubs into cropping systems to protect plants and water resources.

Managed and constructed wetlands (also known as "nature’s filters") are also effective for capturing and treating run-off and certain types of pollution. They can play an important role in the entrapment and removal of organic matter and nutrients. Creating or maintaining treatment wetland systems for agricultural runoff present an attractive option as a means of removing contaminants and pathogens due to their low operational costs. Moreover, the ancillary benefits they provide include creating wildlife habitats.

**Improved irrigation and drainage management as part of agricultural water stewardship**

Irrigation and drainage management decisions should be based on crop needs, water availability, its quality and appropriate application methods. This includes selecting suitable irrigation methods which provide good accuracy and placement. When used wisely, they help farmers gain an economic advantage while reducing environmental burdens.

Additionally, scheduling irrigation based on accepted methods, such as evapotranspiration (ET) and forecasted rainfall or soil moisture deficits at different soil depths, optimizes productivity and water use efficiency. Where appropriate, nutrients can be applied through the irrigation system to enhance their availability for crop uptake (fertigation). Water security measures (such as storage reservoirs) can also be considered to assure continuous availability of water.

Lastly, monitoring of water use ensures the most practical approach to water management. This includes checking levels of control by ensuring presence of water meters as well as gathering data and identifying trends in the data observed. Assessments can also point out the gaps between actual and potential crop water use (ET). The need for reliable information systems for modern irrigation management that provide quantitative knowledge needed to guide farmers and resource managers, point to a broader need for expert capacity soil and water management as well as training and education to ensure uptake.
Water use efficiency

Water use efficiency and productivity represents a key focus of irrigation management. Irrigation water use efficiency – or the ratio of biomass produced per unit of irrigation water used by evapotranspiration (ET) – consists of application efficiency (as the percentage used by the crop) and distribution efficiency describing the evenness of application (or uniformity). The concept of water productivity refers to the ratio of above-ground biomass per unit of water transpired by the crop and might serve as a better measure for linking water usage with production levels and economic benefits derived from irrigated agriculture.

Improving water use efficiency and productivity is primarily approached through interventions such as piped and/or pressurized systems (including sub-surface) that deliver water through sprinklers or drip emitters, and laser levelling of fields. Additionally, technological means to increase water efficiency to better match irrigation with plant needs (e.g. using soil moisture/humidity and canopy sensors) can benefit long-term farm economic performance, particularly when used along with good irrigation practices, as discussed below.

Adoption of localized (precision) irrigation

By placing water directly into the soil or its surface, localized irrigation technologies (such as drip irrigation systems) improve water application efficiency relative to conventional techniques (such as gravity systems) and reduce the risk of run-off. Drip irrigation systems, ranging from traditional, subsurface to low-cost alternative systems, are most effective when properly-designed and maintained – in accordance with soil type, topography, crops grown, quality of water, and agrochemicals utilized. With proper water management for exploiting the full technological potential, application efficiencies can reach 90%.

However, cost and practical issues of installation of advanced systems challenge their more widespread adoption. For example, drip systems are not suitable for all crops and soil types. Moreover, water quality is an equally important consideration when determining whether a specific irrigation system is feasible. Low water quality levels can lead to clogging (by debris, algae, soil particles, etc.), which is the most serious technical problem for drip systems, requiring use of filtration systems and regular maintenance. Drip irrigation may also not be compatible with certain conventional fertilizers, herbicides and pesticides, requiring use of alternative methods such as integrated pest management practices.

Irrigation scheduling

Another opportunity to increase water use efficiency at farm level is through improved irrigation scheduling. Irrigation scheduling uses soil water balance and scheduling simulation models, as well as various soil moisture and plant monitoring tools, for providing an estimate of how much water to put back in the soil. Knowing the right amount and timing for water application allows for recharging of the soil profile to full capacity before the crops start to evapo-transpire again. It helps prevent soils from reaching the threshold depletion level, while also knowing when to stop irrigating.

If properly managed, it provides refined methods for timing of water applications by determining when and how much to irrigate to optimize production (by reducing evaporation) and minimize adverse environmental impacts. Methods of estimating crop water use include indirect measurements such as observation of plant and soil condition, soil moisture, and by calculating ET losses (water budget method). Additionally, use of such sophisticated scheduling methods helps in accounting for rainfall variability in irrigation planning.
However, refinement offered by scientific scheduling may not provide sufficient benefits to offset costs of implementation. The technological level of a farm will determine the choice of irrigation scheduling methods. Identifying requirements and limitations for farmer adoption of irrigation scheduling techniques based on scientific methods, such as lack of technical skill to properly conduct scheduling, prohibitively high technology costs, and knowledge transfer needs (on how to adequately use and manage the tools), is important in the selection of appropriate methods. Farmers, irrigation scheme operators, and resource managers must be involved in the formulation, implementation, and monitoring of irrigation scheduling and management with support from an expert irrigation adviser (in the form of appropriate training).

**Improved drainage**

Viewed from an integrated land and water management perspective, improved soil drainage increases agricultural productivity and natural resource protection. Properly-designed on-farm drainage systems of surface water increases agricultural productivity and natural resource protection by preventing water logging, slowing down flows into water courses and minimizing erosion risks, thereby reducing the likelihood of flooding and improving water quality by capturing contaminants from field run-off.

Improved soil drainage requires maintenance of existing ditches and drains to ensure that outflows are not blocked by removing deposited sediment and other debris, returning sediment to the top of the field from which it eroded, and monitoring of water quality at the field drain outlet. Drainage systems that mimic natural flow pathways can also encourage infiltration of water to recharge groundwater (as deep drainage) particularly through creation of micro-wetlands, which can also serve as habitats for biodiversity.

However, placing too much emphasis on technological solutions does not work in all circumstances and such technology has limitations. Advanced engineered solutions, if improperly managed, can be as wasteful and unproductive as traditional irrigation systems. Installation of irrigation technology alone does not assure benefits for water savings and can be limited if faced with inadequate design and maintenance. Moreover, if not properly managed due to lack of adequate knowledge, modern irrigation systems can be as inefficient as traditional ones.

For example, while sub-surface moisture sensors can improve knowledge about a crop’s water needs, farmers may need technical advice to interpret the measurements. Moreover, soil humidity sensors are neither easy to handle nor reliable, may not be well adapted to all soil types, and their installation and maintenance requires specialized technical staff. Lastly, proper application of canopy sensors can be limited to specific crops during specific growing stages and surrounding conditions.

**Support through research and extension services**

Improving agricultural productivity by maintaining or increasing crop yields while safeguarding ecosystem services (in-line with the stewardship approach) starts with assessments and grounded analysis that enable decision-making. Choices made by farmers, resource managers and policy-makers are to be informed by analysis on various interactions of irrigated agriculture systems with their host ecosystems. These include identification of existing water and land management practices, conducting risk assessments that lead to mitigation measures, and establishing potential and realistic scenarios for change in farmers’ agronomic decisions. It also includes identifying typologies of farming enterprises and their resource endowments (including access to finance) that may influence adoption of agronomic practices and support their technology choices.
In assessing the health and resources of a project-impacted area, resource managers or stewards should ideally establish evaluation indicators that will serve as useful tools to monitor developments, implementation, and results of interventions on surrounding natural resources. Such exercises could also focus on identification of ecosystem sensitivities, or the extent to extent to which a small or moderate change would be likely to have a significant impact on the ecosystem and produce a risk assessment of key vulnerabilities. Correspondingly, adequate knowledge and information on the water and soil resources inventory is desirable, as well as dissemination of such information to decision-makers.

Shifting to ecologically intensive agriculture models includes providing localized agronomic knowledge and production assistance to farmers. Designing water stewardship interventions or programs will require new models of research and extension to develop context-specific solutions, while taking into account the tight financial situations within which farmers operate. Impacts of adoption should also be understood within the context of existing socio-economic conditions and needs of individual farms. The poorest of farmers may also require incentives, including in the form of subsidized inputs. Such programs should be preceded by a reliable risk assessment that requires specialist expertise at the farm and catchment level.

Knowledge-exchange systems can be set-up through extension services, or a functional equivalent through a water user association (WUA), that provides information on growing crops in local soils and climate conditions. They can also help provide enabling conditions and incentives for farmers to share greater responsibility for agricultural water management and serve as a vehicle to engage local communities and in changing their attitudes towards ecologically damaging practices. By adapting agronomic principles or technologies to local circumstances (as a place-based science), options can be developed for diverse farming conditions and contexts.

Incorporating production ecology principles into agricultural development objectives will require that scientists (e.g. ecologists) engage with farmer and other stakeholders to evaluate existing agricultural landscape configurations and in developing targeted modifications (Landis, 2017). Agronomists, as developers of tools and providers of knowledge, can help in identifying and applying appropriate management options suited to farmers’ circumstances and production orientations. Agronomists can contribute with localized agronomic knowledge assistance to farmers, with management practices chosen only after a careful evaluation of their potential impacts, such as on biodiversity and key arable ecosystem services.

Similarly, innovative technologies can only achieve full benefits only through appropriate technical advice – such as specific training to farmers coupled with properly-designed technological solutions and more precise operational practices. Advisory and extension services can help reach the potential benefits of irrigation technology. Providing farmers and resource managers with knowledge of crops’ water use, water applications, and crop yield response to various water management practices helps in adoption of innovative water-efficient practices that enhance the economic viability and environmental sustainability of irrigated agriculture.

Conclusions

The priority of water stewardship is to understand and manage risk and reduce negative impacts with a goal of long-term sustainability, as well as ensuring that the water ‘borrowed’ is returned for others and the natural environment to use safely. Paying attention to sustainability considerations in terms of responsible use of natural resources is a core tenet of water stewardship in agriculture (WSIA). Agriculture has the potential to degrade natural infrastructure and harm ecosystem services on which it depends, requiring
mitigation measures that protect or restore. And inefficient I&D systems can contribute to reductions in soil fertility and water pollution, as well as reduce biodiversity of microorganisms, plants, and animals. Coupled with appropriate irrigation technologies, improved agricultural practices can bring about greater resource use efficiency (of capital, land, labor, water and other inputs). Thus, hybridization of engineered and ecosystem-based approaches promotes the optimal use of water and other agronomic inputs and practices that can lead to higher overall production from existing farmland while placing far less pressure on the environment. In including land-use activities dispersed across a catchment (or sub-catchment) as part of its framework, WSiA highlights the importance of soil health and biodiversity in protecting water in the environment.

Bibliography


Annex 1 - World Bank Environmental and Social Framework (ESF) Requirements

Production- and ecosystem-enhancing set of agronomic approaches help meet the environmental and social safeguard requirements for Bank operations supported by investment project financing (IPF), particularly those of the Environmental and Social Standards (ESS) 3 and 6 of the Environmental and Social Framework (ESF). The ESF primarily addresses Borrower responsibilities for prevention of risks and impacts of projects supported by (IPF).

Consistent with ESS3 and ESS6, water stewardship in agriculture (WSiA) focuses on curbing unsustainable natural resource consumption by minimizing the negative impact of farming activities on other water users and the natural environment.

ESS6 has as its objective the protection and conservation of biodiversity and habitats⁴ (along with sustainable management of living natural resources) by promoting variability among living organisms and diversity within species and of ecosystems (terrestrial and aquatic). It also espouses a precautionary approach to the design and implementation of projects as well as a mitigation hierarchy (as set out in ESS1⁵) to preserve biodiversity.

ESS6 also focuses on sustainable management of primary production (cultivation) and harvesting of living natural resources in natural or modified ecosystems and habitats. To that end, the Borrower is to assess potential impacts (of projects involving primary production and harvesting of living natural resources) “on local, nearby or ecologically linked habitats, biodiversity and communities.” The Borrower is also expected to “manage living natural resources in a sustainable manner, through the application of good management practices and available technologies.”

Other requirements pertinent to irrigated agriculture operations are set-out by Environmental and Social Standard 3 (ESS3), which has as an objective the sustainable use of resources (by promoting their efficient consumption) and avoidance or minimizing of adverse impacts on human health and the environment from pollution resulting from project activities. In addition to focusing on efficient resource use, ESS3 also points to avoiding or minimizing adverse impacts of pollution on human health and environment, particularly as related to the management of pesticides by giving preference to integrated pest management (IPM).

The ESS3 pertains to irrigated agriculture projects that will likely impact natural flow of rivers and streams (such as building, expanding, or rehabilitating irrigation networks) by increasing water use and thus considered significant or high water demand projects (particularly for larger schemes).

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⁴ Defined as a terrestrial, freshwater, or marine geographical unit or airway that supports assemblages of living organisms and their interactions with the nonliving environment

⁵ Environmental and Social Standard 1 (ESS1) requires the identification, evaluation and management of environmental and social risks and impacts of the project by the Borrower according to the standards set by the Environmental and Social Framework (ESF) and advocates a mitigation hierarchy.
Annex 2 - Importance of biodiversity for agriculture

The natural environment provides a diverse flow of economically valuable inputs to agriculture. Ecosystems embody the agricultural production capital (or assets). Natural ecosystem services include pollination of crops, natural (biological) pest control, maintenance of soil structure and fertility, run-off reduction and erosion prevention, and water quality improvement (Power, 2010). Biodiversity supports ecosystem services by maintaining their core functions from which human populations derive direct or indirect benefits. Biodiversity promotes natural forms of pest control by providing an abundance of beneficial (mobile) organisms that keep pests under control and help minimize chemical use. Biodiversity also provides essential services to agriculture through genetic diversity and regulation of soil fertility and nutrient cycling.

Agriculture’s reliance on ecosystem services creates economic linkages between crop production and biodiversity. Agricultural ecosystems both rely on natural ecosystems as well as provide a variety of ecosystem services themselves. If properly managed, agroecosystems can provide services that include regulation of soil and water quality, sequestering carbon, and support biodiversity (Power, 2010). Agriculture can also be a source if multiple ‘disservices’, such as loss of biodiversity and of wildlife habitat, agrochemical contamination of land and water, sedimentation of waterways and water bodies, and greenhouse gas emissions (Power, 2010).

Habitat loss, degradation or fragmentation represents the greatest threat to biodiversity. Once the beneficial functions of biodiversity are disrupted and ecosystem services are lost through agricultural development, the factors of production they modulate (such as the balance of nutrients and water, natural pest and weed control, pollination) are then replaced by external (anthropogenic) inputs, with ensuing negative feedbacks on agricultural productivity.

Given the dependence of crop yields on ecosystem services, ecologically enhancing agricultural productivity by optimizing ecosystem services and functional biodiversity on the farm is essential for long-term sustainability of agricultural systems. Transitioning agricultural systems towards making the best use of the environment while protecting its assets – or harnessing ecosystem services for food security – means making agriculture more productive and resilient while minimizing its harmful environmental impacts.

Ensuring ecosystem resilience allows for the safeguarding of future provisioning of ecosystem services (Weise et al. 2019). Maintaining and enhancing ecosystem services in agricultural landscapes is challenging and requires well-informed targeted solutions. One approach is integrating the management of ecosystem services into crop production systems without sacrificing productivity or profitability. Working with nature by combining efficient agricultural land and water use with biodiversity (and habitat) conservation ensures that crop production goals are considered alongside ecosystem stewardship.

Soil health and productivity

Soil provides multiple ecosystem services and is made up of a mixture of organic and mineral matter that supply crops with nutrients as well as air and water. Since plants require a suitable balance of water and air in the root zone, good soils are well-drained, have good capacity to store water, and support high populations of soil organisms. Movement of water in soil, including infiltration, drainage, and water storage in the soil profile, is determined by the size of soil particles and pores, as well as their arrangement. An understanding of such movement and holding capacity helps in assessing irrigation practices and design of irrigation systems.
Soil quality is determined by its structure and texture as well as nutrient balance and exchange. Soil properties such as texture and structure influence water storage and availability by governing its permeability and infiltration rate. Soil structure has to do with the arrangement of the soil components and the spaces in between – the size, shape and arrangement of aggregates and air spaces. Soil texture influences the number of pores and their sizes through a variation in particle size distribution and amount of sand, silt and clay. Both allow for movement and storage of water and nutrient cycling, and determine the potential for aeration, drainage, and root development.

Infiltration capacity of soil is the maximum amount of water that can enter at a specific period of time. It is a function of its ability to absorb water and store it for plant use or release it to groundwater (through gravitational flow). High infiltration rates can be maintained when strong soil particle aggregates are present in finer-textured soils due to good management. Sandy and gravelly soils with larger pores maintain better infiltration by allowing for water to drain readily – thereby preventing waterlogging following soil saturation. In contrast, the smaller the particles, the more the soil can store water for plant use. While more water is stored in soil with smaller particles (when rich in clay, of fine loams), not all of it is available to plants since smaller pores tend to retain water. Thus, smaller pore spaces for air and water, characteristic to compacted soils, reduce the amount of water available to plants. Soil that contains a range of pore sizes is ideal – allowing for both drainage (to re-establish aeration) and retention within a range available to a plant.

Nutrient balance and exchange are influenced by soil organic matter (SOM) content and composition as well as activities of soil biota. Soil organic matter (SOM), primarily composed of dead organisms and plant matter in various phases of decomposition, serves as a reservoir of plant nutrients and water, while also helping build soil structure. Soil biological health is determined by living organisms (i.e. earthworms) and plant residues. Aeration through stable porosity (or soil macro pores) is ensured by populations of earthworms, insects, better root development, and good SOM distribution in the soil profile.

Any damage that changes soil properties, such as those leading to soil compaction (natural or human-induced), reduces infiltration rate through a reduction in pore space and creates vulnerabilities to erosion by reducing water infiltration capacity and increasing run-off. Runoff occurs when surface water supplied to soil exceeds its infiltration capacity, leading to soil particles being detached and carried away. This tends to occur more readily with poorly-managed soils that lack strong soil particle aggregates and few large pores to allow for water to infiltrate (or to conduct water downward). Runoff can initiate erosion that moves nutrients and agrochemicals along with sediment. Furthermore, damage through soil compaction can reduce plant growth, as it restricts movement of air, water and nutrients down the soil profile. Compaction can also prevent downward root development and upward soil fauna movements.

Soil issues can also be a result of poor drainage as part of irrigation systems, such as waterlogging and flooding. Inefficient irrigation and drainage (I&D) systems are a major cause of waterlogging, flooding as well as salinity issues. By reducing root respiration, decreasing transport of nutrients, and facilitating toxic compound or salt accumulation they hamper crop development and reduce agricultural output. Slow to dry out, waterlogged soils are especially vulnerable to compaction through agricultural activities.