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IMPROVING MANAGEMENT OF DEGRADED AGRICULTURAL LAND IN MOUNTAIN AREAS: A LITERATURE STUDY OF POSSIBLE METHODS FOR THE GORNO-BADAKHSHAN AUTONOMOUS OBLAST (GBAO) TAJIKISTAN

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ABSTRACT

The mountain ecosystems of Tajikistan are a biodiversity hotspot with unique flora that includes many endemic species. This region, as in many other parts of the world, has been subject to intense human pressure resulting in habitat destruction and degradation of the agricultural land. The eastern part of Tajikistan is called the Gorno-Badakhshan Autonomous Oblast (GBAO). GBAO makes up 60% of Tajikistan's territory. However, 13,000 ha of agricultural land, situated mostly on the flat area at the foothills of the mountains, are used for farming for a cultivation population of about 212,000. In GBAO the degradation of the land is the one of the main problems facing the farmers. Fortunately, scientists around the world have been investigating the problems and methods to improve agricultural land and to restore the fertility of agricultural soils. The current report is aimed at exploring and reviewing existing methods, used under different situations in an effort to manage agricultural land in the GBAO. Various potential solutions are described, and their effects discussed, specifically methods concerning no or minimum mechanical soil disturbance, terracing, use of increased plant cover, shelterbelts, and crop rotation and crop diversity. The study concludes that adopting these practices could help to reverse the degradation of agricultural land in mountainous areas such as the GBAO.

Key words: Tajikistan, land degradation, agricultural land, GBAO, soil erosion

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1. INTRODUCTION

Degradation of agricultural land threatens sustainable food production and the prosperity of the many people who rely on agriculture for their subsistence (Pacheco et al. 2018). It may also have an unfavourable result contributing to global challenges, including climate change and biodiversity (Webb et al. 2017). It is estimated that land degradation accounts for a 3-5% reduction in gross domestic product in parts of the world, most heavily affecting poor rural areas (Bann et al. 2012).

Land degradation can be defined as the reduced or lost biological or economic productivity of land and can be caused by climatic variations and other natural causes or by human activities (Barman et al. 2013). It is today a very important issue for ecological research (Higginbottom & Symeonakis 2014) and is widely considered a worldwide problem which can lead to desertification in dry and semi-dry areas, which cover about 47% of the globe's total surface area (Masila 2013).

Agriculture is very important for the economy of Central Asian countries, and measures towards sustainable use of land and natural resources are therefore of upmost importance (Hamidov et al. 2016; Qadir et al. 2017; Qushimov et al. 2007).

In Tajikistan, the drivers of land degradation include unsustainable use of natural resources and the country's predominantly mountainous terrain makes it vulnerable to natural disasters such as earthquakes, landslides and avalanches, as well as negative climate change impacts, such as drought and high temperatures (AKAH 2016; FAO 2000). Whereas only 7% of the territory is appropriate for agriculture, about two thirds of Tajikistan's people living in rural areas rely on farming for their livelihood (Bann et al. 2012).

The eastern part of Tajikistan is called the Gorno-Badakhshan Autonomous Oblast (GBAO). GBAO makes up 60% of Tajikistan's territory (Fig. 1) but only three per cent of its population live there. Much of eastern GBAO is uninhabited, with an elevation of 3,000-4,000 meters above sea level (Bann et al. 2012). In GBAO people use virtually all the arable land. Water demand by crops exceeds the water supply in the form of precipitation during the growing season by far, due to the high evaporation rates resulting from strong solar radiation and strong winds. Therefore, human-induced impacts are the common cause of degradation experienced in altitudinal belts (Saigal 2003).

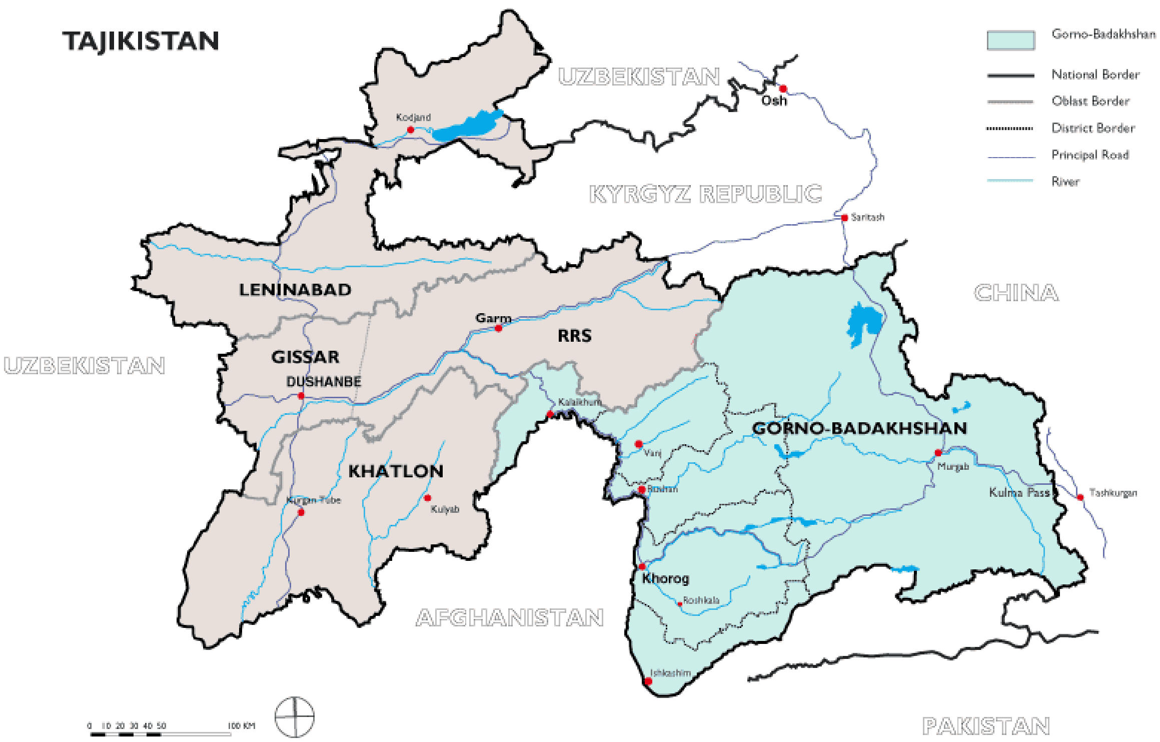

Figure 1. Tajikistan with GBAO (Gorno-Badakhshan Autonomous Oblast) depicted in aqua. (Source: From http://www.pamirs.org/maps.htm).

Where land erosion and degradation have occurred, it often requires a drastic change in management to restore the land, such as reduction in sheep and goat grazing on slopes, and compensation to local farmers to make terraces or plant trees bind the soil on sloping land, as well as the protection of high-quality agricultural land against exploitation (Baskan et al. 2017). However, these methods typically lead to loss of income or increased costs for the farmers. Also, in order to restore degraded agricultural land efficiently, and with a long-term perspective, it is important to include a wide spectrum of stakeholders, such as farmers, other land users, technical advisors, administrators, government agencies, policy makers, and scientists to work together from a local to a national scale (Pacheco et al. 2018; Webb et al. 2017). Knowledge exchange can facilitate responses that are more appropriate to the needs of local communities and can protect their livelihoods and well-being (Webb et al. 2017).

Land restoration is expensive and sometimes requires drastic changes in land management. Implementation of preventive measures of land management in exposed areas are thus an important tool to save resources (Sutton et al. 2016). These measures can include the use of soil coverings to avoid erosion and improving soil properties, no tilling, crop rotation, cover crops and also creating buffer bands along the river banks to reduce the transport of sediment and nutrients from the land into the water to preserve the quality of freshwater or river projects (Pacheco 2018).

1.1 Objectives

The aim of this study was to explore methods to improve degraded agricultural land in mountain areas. More specifically:

- Make a review of international literature with a focus on successful practices that can be used to increase the fertility of agricultural land.
- Study the practice of improving land in Iceland using field observations and a review of the literature.
- Explore similarities between problems in the mountain croplands in Tajikistan with the situation in Iceland, and globally, by learning different methods to resolve these problems and trying to transfer this knowledge to local farmers in Tajikistan.

2. PROBLEMS OF SOIL DEGRADATION

2.1 Problems of agricultural soil degradation in the world

One of the global problems facing humanity today is land degradation and how it will impact agronomic productivity, the ecology, and its influence on quality of life and food security (Eswaran et al. 2001). The recent fast growth of the population is placing a large pressure on global soil resources. Just about 11% of the world soil surface consists of land suitable to grow crops (Jie et al. 2002). The green revolution successfully helped increase harvests by successfully improving crops genetically to adapt them to high input agriculture. But, this high input agriculture has generated a negative environmental impact, such as land degradation, greenhouse gas emission, groundwater pollution, rivers and biodiversity loss (Henneron et al. 2015). There appears to be no alternative but to increase agricultural productivity (i.e. crop yield per unit area) to meet the global food, feed, fibre and bioenergy demands and to alleviate hunger and poverty (Kassam et al. 2015). To do so there is a need for sustainable intensification of agricultural production on available land (Tilman et al. 2011). The problems of agricultural sustainability have grown in recent years with the sharp rise in the cost of food and energy, climate change, water scarcity, degradation of ecosystem services and biodiversity, and the financial crisis (Kassam et al. 2009).

Intensive ploughing and use of heavy machinery can negatively impact soil structure and increase wind erosion. Soil organic matter is a main factor in soil fertility, production and sustainability, and is a useful measure of soil condition in farming systems where nutrient poor and highly weathered soils are adjustable with little external input (Lal 1997). The dynamics of soil organic matter are affected by farming control practices such as ploughing, cover crop, removal of crop residues and application of organic and mineral fertilizers. Removal of all crop residues from the cropland is known to speed up the depletion of soil organic matter, particularly when coupled with conventional ploughing (Yang & Wander 1999), hence a known practice in communities using crop residues as fodder for animals (Mann et al. 2002).

In many countries, worries are increasing about diminishing soil productivity with wider ecological consequences due to common farm practices, particularly working the arable land by plough, disk or hoe (Knowler & Bradshaw 2007). Alternative agricultural methods such as conservation agriculture could offer practical management solutions which could help alleviate ongoing degradation, and prevent it from happening in the first place (Kassam et al. 2015).

2.2 Degradation of agricultural land in the Gorno-Badakhshan Autonomous Oblast

For most of the population in the GBAO subsistence farming is still the main livelihood (Kienzler et al. 2012). The main crops are typically vegetables and cereals, while the main livestock are goats and sheep (World Bank 2014). Degradation of croplands is negatively influencing the income rate of farmers. The level of harvest from these lands is gradually declining (Bann et al. 2012). For instance, 97% of Tajik agricultural land has been affected by poor watering services and salinization (Lioubimtseva & Henebry 2009). The farming segment make up about 18% of Tajikistan's GDP so a drop in land quality influences the country's economy via decreased productivity or higher production expenses. Moreover, the costs associated with land degradation directly influence the subsistence of the rural community (Bann et al. 2012).

The GBAO in the faraway western Pamirs in Tajikistan is a semiarid region where dependence on natural resources is strong but most products are imported. The GBAO also faces food supply problems ranging from lack of water for irrigation to insufficient roads (Kassam 2009). Domestic agriculture is highly fragmented and consists mostly of subsistence farms that practice a mix of crop cultivation and animal production (Kreutzmann 2011). Due to the dry climate, agriculture depends on irrigation. Land appropriate for growing is scarce due to the high and steep slopes, rocky soils, slow soil formation, and water deficit (Golosov et al. 2015). However, 13,000 ha of agricultural land, situated mostly on the flat area at the foothills of the mountains are used for farming for a population of about 212,000 (AOPTJ [Statistics Agency under the President of the Republic of Tajikistan] as reported in Dorre & Goibnazarov 2018).

In the mountainous areas of the GBAO irrigated farming is practiced to a height up to 3,700 m a.s.l. However, for the most part the soils and the climatic conditions only permit extensive farming such as pastoralism at these altitudes. The land most suitable for farming is located in the western GBAO, in reclaimed natural forest land (Fig. 2) (Hergarten 2004). With the natural vegetation altered, the land is highly sensitive to mismanagement, leaving the soils threatened by loss of fertility and erosion (Shanazarov et al. 2011).

In the region farming technologies improving soil conservation such as cover crops, crop rotation, and terracing have an important traditional context. Such traditional technological knowledge is significant for sustainable agricultural land use in a mountainous area (Hergarten 2004).

Figure 2. Agricultural land in the GBAO. (Source: https://edition.cnn.com/travel/article/tajikistan-pamir-highway/index.html).

Tajikistan entered a crisis in all orders, including food and energy supplies, after the collapse of the Soviet Union. During the civil war, in the beginning of the 1990s, it was necessary to replace the coal with trees and shrubs, so many were cut and collected (Siegmar & Walter 2006). Still, in Tajikistan 80% of the households in rural areas rely on fuelwood as the main source of cooking energy (Djangibekov et al. 2015). According to Siegmar and Walter (2006), this anthropogenic factor led to land degradation by wind and water erosion around the villages. With increased erosion, the accumulation of sand has also increased. Both these factors have led to a loss of productivity and biodiversity of the soil. With the increase of soil erosion in the mountains, problems such as mud flows and huge avalanches were intensified. Also, some parts of eastern Pamir experience high salinity in irrigated fields. Eutrophication has become a challenge in areas where sheep, goats, cows and camels regularly rest. Gradual changes are manifested in the form of land use changes in the eastern and western Pamirs (Siegmar & Walter 2006).

Owing to unsuccessful extensive production, lack of irrigation water, and the weakening of help services for farmers in Central Asia during the years since the fall of the Soviet Union, crop yields in the region have become less predictable. Increased prices for fertilizers and pesticides have contributed to the significant decline of crop productivity in some areas of Central Asia (Kienzler et al. 2012).

One example is the village of Navobod, in western GBAO which is subject to anthropogenic land degradation and wind erosion. While all cropland in the GBAO faces this problem, the cropland in Navobod village is the main cropland used by the community for growing potatoes, onions and carrots (G Oshurmamadov, February 2018, village leader Navobod, Tajikistan, personal communication). This land covers 9 ha and is presently used by 29 households. During the Soviet era, people used chemical fertilizers in combination with organic fertilizers, resulting in yields reaching 23 tons per hectare. Because of the financial crisis since the collapse of the Soviet Union, people were unable to buy fertilizer for their cropland, which reduced yields to 15 tons per hectare. A solution to this problem is to improve the condition of the land to raise yields. Also, Oshurmamadov (February 2018, village leader Navobod, Tajikistan, personal communication) mentions the threats from natural disasters which can have adverse effects on the agricultural land.

The surroundings of Navobod are largely mountainous with only limited land available for cultivation. Deforestation, degradation of watersheds and of land, desertification and weakening of ecosystems are among the contributing factors that reduce nature's defences against hazards and exacerbate the impact of disasters. Deterioration of the environment in turn leads to reducing livelihood opportunities of local communities and shrinking economic opportunities.

2.3 Historical problems of land degradation in Iceland

Iceland is an example of a northern ecosystem where human activities in a fragile environment with highly erodible volcanic soils and a harsh climate have resulted in extensive soil erosion and degradation since the first settlement in AD 874 (Arnalds 1987). Thanks to the Gulf Stream, Iceland has a cold temperate climate, but with a sub-arctic climate in the highlands. Precipitation varies from 600–1,500 mm in the lower part but there are areas receiving very little rain in the north-eastern part (Olafsson et al. 2007). Since the initial settlers came, the vegetation has changed dramatically. Due to the unsustainable use of forests, and over-grazing, the forest cover was reduced by 95% (Davíðsdóttir 2013). The land degradation and erosion in Iceland is unique for such a humid northern temperate climate (Aradottir & Arnalds 2001). Before humans arrived, it is estimated that 50-60% of the country was fully vegetated (Haraldsson & Olafsdottir 2003). At the end of the 20^{th} century, 14% of Iceland had a continuous vegetation cover, with near barren deserts covering 35-40% (Arnalds & Kimble (2001), as cited in Gretarsdottir 2004). The vegetation cover in eroded land is typically below 5%, and erosion is still ongoing (Arnalds et al. 2001).

In Iceland, farmers have traditionally produced sheep and dairy products, but nowadays have diversified the domestic production with poultry and pigs. Many of the ecosystems that are being used for sheep grazing are considered marginal areas because of the vulnerable vegetation and the periodic events of volcanic ash deposition (Arnalds & Barkarson 2003). Overgrazing has led to extensive soil erosion and decreased resilience to natural disasters such as volcanic ash deposition, long-lasting periods of adverse climatic conditions, and flooding (Aradottir & Arnalds 2001).

3. POSSIBLE SOLUTIONS TO RESTORE DEGRADED AGRICULTURAL LAND

Intensive farming has increased harvests but also posed serious ecological problems. A more sustainable farming would ideally produce harvests with minimal influence on environmental factors such as soil fertility (Maeder et al. 2002). The fertility of agricultural soils is influenced by many factors. These include physical, chemical, and biological factors which influence soil texture and soil type, and factures induced by agricultural practices, such as ploughing, cover crops and crop rotation (Buyer et al. 2002). Most of these factors interact with each other and have both a direct and indirect influence on the soil. Increased or sustainable crop production depends on the type of fertilizers used to boost plant nutrients (Jen-Hshuan 2006). A fertile soil supports crop growth through a diverse and active biotic community. It provides a favourable soil structure and improves the decomposition of organic matter in the soil (Maeder et al. 2002). For instance, a winter crop cover would add organic carbon to the soil via rhizodeposition, and if the crop resides were mowed and left in place it would both decrease water evaporation and suppress weeds (Jeffrey et al. 2010).

Agricultural practices intended for restoring soil fertility and at the same time maintaining or increasing crop yields, are usually termed conservation agriculture (Altieri & Toledo 2011). These practices involve a concurrent reduction of mechanical soil preparations, increase of plant cover and plant residues, and rotations and mixtures of various crop and non-crop plant species (Dumanski et al. 2006). These principles are discussed and evaluated in the following sections, along with a review of more traditional methods of managing agricultural land, i.e. terracing of steep slopes and using tree shelterbelts (Brandle et al. 2004).

3.1 No tillage methods

The purpose of no or minimum tillage practices, involving no soil turning, is to decrease or eliminate soil disturbance made by ploughing and other forms of agricultural soil cultivation (Bolliger et al. 2006; Lal et al. 2007). While conventional soil tilling is used by farmers to reduce the growth of competing vegetation, loosening the soil and creating a desirable seedbed for emerging crops, alternative methods for crop establishment were realized some decades ago (Triplett & Dick 2008). Novel alternatives were considered necessary for reducing soil erosion of agricultural fields, to restore soil fertility and raise yields, and at the same time to make better use of resources, such as fertilizer and labour (Dumanski et al. 2006; Knowler & Bradshaw 2007; Lal et al. 2007; Triplett & Dick 2008).

No- or minimum tillage agriculture has been developed for achieving these goals and has been endorsed by scientists and farmers for various reasons (Derpsch et al. 2010). Among the most important outcomes involve modifications of soil surface properties due to reduced disturbance and improvements in surface residue management, which minimize runoff and raise water infiltration rates (Fu et al. 2006; Lal et al. 2007; Triplett & Dick 2008). Harvest residues, associated with no-tillage practices and associated measures also reduce soil erosion by minimizing the destructive power of raindrops, and reduce the speed of runoff water and its transport capacity and create mini-ponds behind clumps of residue (Triplett & Dick 2008; Shaver et al. 2002).

No- or minimum tillage practices have been adapted by large and small-scale farmers all over the world in recent decades, particularly in the Americas and Australia (Derpsch et al. 2010; Kassam et al. 2015; Triplett & Dick, 2008). These practices became particularly popular after the development of effective herbicides to suppress weed growth (Triplett & Dick, 2008). Cover crops lead to some growth in crop production, thereby controlling soil erosion and other factors to increase yield (Hartwig & Ammon 2002).

The agricultural area managed using no-tillage grew from 45 million ha in 1999 to 111 million ha in 2009, showing the growing interest in these methods among farmers (Derpsch et al. 2010). In nearly every country there is at least some no-tillage activity, be it in the research sector or in farmer acceptance (Derpsch et al. 2010). Where these practices have been adopted, farmers use the additional time gained to assume other work while the land remains as productive as before adopting no-tillage. These methods can, in the right conditions, result in higher yield, therefore increasing their standard of living (Ekboir et al. 2002).

3.2 Use of plant cover

A cover crop, also called living mulch, is any living plant cover that is planted into or after a major crop and then usually killed before the following crop is planted (Dabney et al. 2001). Although cover crops or crop residues have been used in agricultural systems in the past, environmental concerns paved the way for more research and refinement of their use (Hartwig & Ammon 2002).

Cover crops enhance facets of soil quality, such as soil carbon, nitrogen fertility, mycorrhiza, soil water, and soil temperature (Taylor et al. 2001). Cover crop mulches can also help reduce herbicide use by providing a non-chemical control of weeds (Maxwell & O'Donovan 2014; Moore et al. 2013), and these are necessary for new cropping technology and new weed control strategies (Hartwig & Ammon 2002). Cover crops have a significant positive effect on productivity of subsequent row crops by improving soil physical, chemical, and biological properties (Moore et al. 2013).

Cover crops can prevent overheating of soils, which is important under hot and dry conditions, by intercepting solar radiation, thus influencing the temperature of the environment and the biological activity (Maxwell & O'Donovan 2014). Land degradation, such as loss of plant nutrients via leaching, and runoff and resulting erosion, can be reduced or prevented by using cover crops (Dabney et al. 2001; Taylor et al. 2001). Reduction in runoff is partly a result of increasing water infiltration rates induced by cover crops, increasing water availability for the next season (Dabney et al. 2001).

In general, cover crops are tools for nutrient management in cropping systems (Ruffo & Bollero 2003). Non-leguminous and leguminous crops are applied as a cover crop source for nitrogen fixation (Smith et al. 1987). Cover crops can reduce nitrate leaching from the fields, and biological N fixation by leguminous crops offers the potential to decrease the need for N fertilizers for the next crop (Meisinger et al. 1991; Singh et al. 2004). Intercropping with legumes used as cover cropping enhances biomass yields and nitrogen content which improves crop productivity (Smith et al. 1987; Ranells & Wagger 1996). Recently, for economic and environmental reasons, there is a renewed interest in this old practice for better crop productivity and soil health and to support sustainable agroecosystems (Fageria et al. 2009).

3.3 Crop rotation and crop diversity

Crop rotation and crop diversity include cultivating diverse crops in a systematic sequence on the same land, as compared to monoculture in which a specific crop is planted repeatedly in the same field (Liebman & Dyck 1993).

Intensive farming systems are usually based on optimizing the productivity of monocultures. In those systems, crop variety is reduced to one or very few species that are generally genetically homogeneous, the plantation layout is uniform and symmetrical, and outer inputs are frequently supplied in big quantities (Malézieux et al. 2009). The contrasting approach is to increase the variety of crop species grown together in the same area and season or in consecutive years or rotations. Farmers commonly do not follow one concrete outline. They choose to rotate crops based on their individual requirements, potential, environmental conditions and budget (Teasdale et al. 2007).

The multispecies systems are characterized by either the cultivation of some crops at the same time in the same field, or the mixing of some plant species together within the same field. These could be field crop species, grazing species, trees, or combinations of these (Malézieux et al. 2009).

Agricultural production always faces challenges induced by pests, the most common being fungi, weeds, and animal pests (Oerke 2006). The practices of crop rotation are known to be a method to control diseases. These practices reduce the pest population present in the soil (Strand 2000).

Cultivation of a big variety of crops enables farmers to adjust to the environmental conditions and potentially harvest larger yields, but at the same time engage in more complex planning and crop rotations (Jackson et al. 2007). Rotations are usually more effective when the management includes practices such as manuring, composting, cover cropping, green manuring, and short grazing cycles (Baldwin 2006).

Crop rotation gives different nutrients to the land. A conventional element of crop rotation is the refill of nitrogen via the use of green manure in order with cereals and different crops (Timsina & Connor 2000). In agricultural systems, optimization of carbon and nitrogen cycles through soil organic matter can improve soil fertility and yield while reducing the negative influence on the environment (Drinkwater et al. 1998). Symbiotic nitrogen fixation plays a key role in these crop rotations and a correct combination of legume crops can improve the nitrogen status and increase the yield (Ferreira et al. 1999).

According to Maxwell & O'Donovan (2014) cultivation of strong competitive crops will decrease dependence on herbicides, causing less problems with herbicide resistance and decrease chemical pollution into the environment. Crop species ranking in terms of competitiveness is affected by environmental conditions and thus can change with position and year. In the future, as resistance to herbicides increases, the advantage of selecting strongly competitive species will become increasingly important (Maxwell & O'Donovan 2014).

3.4 Terracing

Terracing is the building of a channel and a terrace wall, such as a mud ridge or a stone wall. Terracing interrupts the continuous steepness of a slope by dividing the slope into brief level steps (Morgan 1986), as shown in (Fig. 3). Terraces are constructed to intercept surface runoff, allowing water to infiltrate, evaporate or be diverted towards a safe outlet at a controlled speed to avoid erosion (FAO 2000).

Figure 3. Terraces in China. (Source: From UN-World Food Programme cited in Dorren & Rey 2004).

Mountain people adapting to difficult conditions at high altitudes have learned to survive by developing a sustainable system for agriculture, forestry and cattle breeding (FAO 1989). People traditionally built terraces for regulating water flow on steep slopes. The technique also leads to soil conservation and saves the land from degradation (Arnaez et al. 2015). This could also slow down the weathering of rocks and increase crop growth on steep slopes (Dorren & Rey 2004). This method is common in mountainous areas and is still used intensively for agriculture (Arnaez et al. 2015).

On steep areas, the fertility is lower than on flatter ones (FAO 1989). Experience of terracing, is now a part of traditional management and knowledge of agricultural systems, and can give important ideas on terracing and develop modern agriculture for sustainable development (Yongxn & Qingwen 2016).

Terraces are important for soil and water conservation. The majority of farmers are more concerned about productivity than conservation. Therefore, there is a need to inform them about the efficiency of these or other conservation practices (Doren & Rey 2009). Although terracing is an old farming technique, it still is an important tool in modern agriculture (Mountjoy & Gliessman 1988). Most research studies have shown that the practice of terracing is good for agriculture by maintaining fertile soil in a stable condition for production on steep slopes (Dorren & Rey 2004).

3.5 Shelterbelts

Tree shelterbelts and frameworks of large plants have been traditionally used for protection against sunshine, wind, sand, and snow (Ho et al. 2001). The main impact of shelterbelts is the reduction of wind speed, which modifies the microclimate in the sheltered zone (Torita & Satou 2007). Shelterbelts for agricultural fields ameliorate other issues as well, such as drainage, plant water requirements, soil erosion, and especially wind erosion, and promote the long-term health of agricultural systems. They also reduce levels of inputs and decrease the environmental costs connected with farming (Djanibekov et al. 2015; Brandle et al. 2004; Cleugh 1998; WOCAT [World Overview of Conservation Approaches and Technologies] 2007).

Many researchers have shown that shelterbelts can improve harvests, although results vary with the climate conditions (Zheng et al. 2016). The shelter therefore benefits farmers and communities through higher crop yields, but also by reducing energy requirements for heating or cooling (Brandle et al. 2000, Johnson & Beck 1988; Torita & Satou 2007).

Shelterbelts can be used to control snow drift and accumulation, distributing it via a crop field or store it in a narrow drift (Xinhua et al. 2008). Shelterbelts are a natural component of agroforestry systems (Brandle et al. 2004).

According to Brandle et al. (2004), the efficiency of shelterbelts is determined partly by its outer framework, which is described by height, length, orientation, continuity, width, and cross-sectional form. It is also modified by its interior framework, which is a function of the number and allocation of the closures and gaps, the vegetative surface area, and the structural diversity provided by separate plant elements (Brandle et al. 2004).

Although the basic function of shelterbelts is to improve conditions for people, farm animals and growing crops (Fig. 4), the benefits can also extend to wildlife, by providing new niches and a more variable and favourable environment for various wildlife (Cleugh 1998).

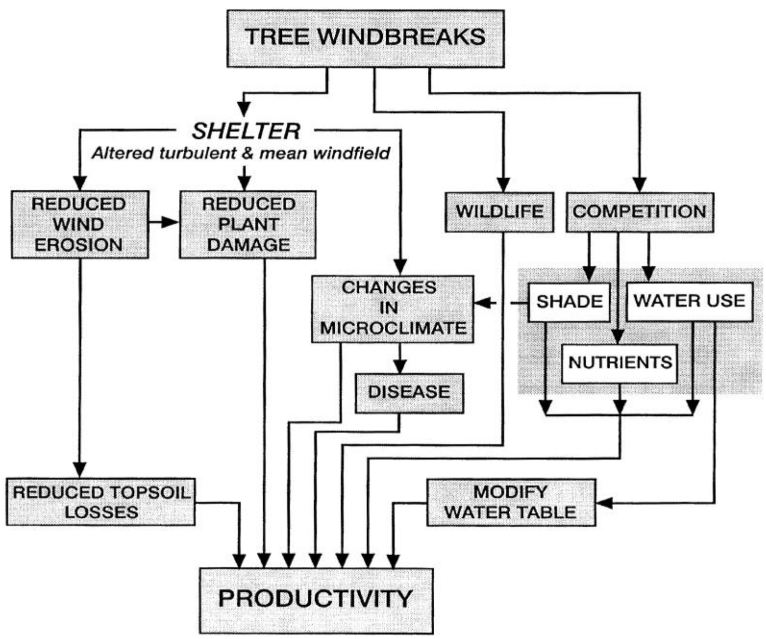

Figure 4. Mechanisms by which a windbreak affects microclimate and plant productivity. (Source: Cleugh 1998).

In Central Asia various tree species are used for making shelterbelt systems. In Chuy Oblast of Kyrgyzstan, windbreaks composed of apricots, pendent white birch, elm, white willow, green ash, black poplar, English oak, mulberry, sugar maple, and apple trees and others, increased winter wheat production by 14-28% (Djanibekov et al. 2015). And in Uzbekistan, for example, shelterbelts can increase crop yields by 10-20% (Djanibekov et al. 2015). The planting of different species may provide various edible fruits and nuts, timber for various uses and increased quality of animal feeds (Brandle et al. 2004). Farmers accept shelterbelts for two reasons. They wish to improve their economic stability and they want to increase the control of native resources under their care (Beetz 2002).

3.6 Solutions used in Gunnarsholt

The staggering consequences of natural and human influences described earlier, have been subjected to intensive efforts since the establishment of formal land reclamation policies in Iceland in 1907. Particular attention was paid to Gunnarsholt, a farm established for soil conservation in 1926, and the surrounding region (Crofts & Olgeirsson 2011). Gunnarsholt is located in close proximity to one of Iceland's more active volcanoes Mt Hekla, which has erupted around twice each century on average for more than a millennium (Thordarson & Larsen 2007). Gunnarsholt and two neighbouring farms were in a zone covered with sand, with little or no cultivated land. Since the 1930s, it has been the de facto centre of operations, and it officially became the headquarters of the Soil Conservation Service in 1947.

In the 1940s, Gunnarsholt was turned into a large farmland (Fig. 5), when the bare stretches of sand were cultivated with applications of seed and fertilizers to show that farming and land reclamation can be compatible with proper management (Crofts & Olgeirsson 2011). The farmland and adjacent areas have further benefitted from the establishment of a shelterbelt system (Fig. 5 and 6) consisting of rows and stands of willows and poplars (Aradottir and Eysteinsson 2005; Crofts & Olgeirsson 2011).

Figure 5. Gunnarsholt farmhouses and surrounding area in 1944 (top picture), and the Soil Conservation Service headquarters seen from the same point as above in 2011 (lower picture). (Source: Crofts & Olgeirsson 2011).

In Iceland, other methods are also being used to reduce sand drifts, such as artificial barriers and irrigation for wetting the soil surface and increasing cohesion. Fences are extensively used to manage or prevent livestock grazing during restoration, and barriers used to control rivers to reduce erosion of riverbanks (Crofts & Olgeirsson 2011).

Not all land in Gunnarsholt has been cultivated for agriculture purposes. Large areas have been used for ecological rehabilitation, where application of seed and fertilizer was usually a necessity for establishing a permanent plant cover (Gretarsdottir et al. 2004; Arnalds et al. 2013). Without such inputs, revegetation was slow and erratic, especially in areas subject to repeated soil disturbance due to frost heaving (Gretarsdottir et al. 2004; Arnalds et al. 2013).

For soil restoration, the vegetation cover plays an important role, as this creates a more favourable environment for soil biota and provides organic matter (Orradottir et al. 2008). This increases soil porosity and water infiltration rates (Orradottir et al. 2008).

The plant species used in restoration projects include, lyme grass, Nootka lupine, and other grass and legume species (Stijsiger 2017). Birches and willows have also been planted and seeded for restoration purposes (Aradottir and Eysteinsson 2005; Stijsiger 2017).

Figure 6. Shelterbelts in Gunnarsholt consisting of willows and poplars, used to lower wind speeds (Photo: Masrur Mirgharibov).

4. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, there are a wealth of different approaches to improve degraded agricultural land worldwide. There is no single best method for improving agricultural land. However, achieving progress with any method requires people with good understanding of ecosystems and the socio-economic drivers of land degradation. The first distinction that has to be made defines land uses and land types and scale. Methods must be critically chosen, taking into account their availability, adaptability and applicability to local conditions. For conservation agriculture we can use different methods which can help to improve the agricultural land in mountain areas.

In the GBAO the main field crops produced by irrigation agriculture are wheat, potatoes, and legumes. After harvest, farmers can use cover crops which are used as feed for the animals, or directly for grazing in the autumn and spring. In particular, agricultural technologies promoting soil conservation such as crop rotation, cover crops, shelterbelts, and terracing have an important traditional background. Such traditional technological knowledge is essential for sustainable agricultural land use in mountainous regions.

The lack of feed for animals and lack of firewood and fuel for heating and cooking makes it difficult for farmers to restore depleted soils with organic matter and nutrients, as generally all plant residues are used as feed and dung is used for heating and cooking instead of fertilizing the fields. Chemical fertilizers are generally no option as the high cost is prohibitive.

In the GBAO there is a need to change management practices due to land degradation and the lack of resources. If nothing is done to address the problem of land degradation, farmers will risk losing their crop land. Farmers should be encouraged to adapt and modify internationally recognized management practices to the local conditions in order to restore soil fertility. Such methods include no tilling, crop rotation and crop diversity, terracing, and shelterbelts.

But for using any of these methods in the GBAO more research is needed in this region to assess land conditions, soil fertility and the drivers of degradation in this area. Also, farmers need to be educated and encouraged to adopt more sustainable methods in the future. It is important to establish realistic goals and acknowledge that changes take time and patience and that change is an ongoing process.

There has been a series of studies by scientists worldwide to curb the concomitant issues/problems relating to restoring the fertility of the soil to improve agricultural productivity. Methods emphasise minimum or no mechanical soil disturbance, use of increased plant cover, terracing, shelterbelts, and crop rotation and diversity. This study concludes that adopting sustainable management practices could help to reverse the degradation of agricultural land in mountain areas such as the GBAO.

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