Seeking Environmental Sustainability in Dryland Forestry

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Abstract: Forestry systems, including afforestation and reforestation land uses, are prevalent in drylands and aimed at restoring degraded lands and halting desertification. However, an increasing amount of literature has alerted potentially adverse ecological and environmental impacts of this land use, risking a wide range of ecosystem functions and services. The objective of this paper is to demonstrate the potentially adverse implications of dryland forestry and highlight the caution needed when planning and establishing such systems. Wherever relevant, establishment of low-impact runoff harvesting systems is favored over high-impact ones, which might cause extensive land degradation of their surroundings. Specifically, both in hillslopes and channels, scraping, removal, or disturbance of topsoil for the construction of runoff harvesting systems should be minimized to prevent the decrease in soil hydraulic conductivity and increase in water overland flow and soil erosion. In order to negate suppression of understory vegetation and sustain plant species richness and diversity, low-density savanization by non-allelopathic tree species is preferred over high-density forestry systems by allelopathic species. Wherever possible, it is preferable to plant native tree species rather than introduced or exotic species, in order to prevent genetic pollution and species invasion. Mixed-species forestry systems should be favored over single-species plantations, as they are less susceptible to infestation by pests and diseases. In addition, drought-tolerant, fire-resistant, and less flammable tree species should be preferred over drought-prone, fire-susceptible, and more flammable species.

Keywords: anthropogenic factors; climate change; herbaceous vegetation; landform functioning vs. dysfunctioning; land use change; natural factors; prolonged droughts; runoff ratio; soil quality; source–sink relations

1. Assessing Sustainability and Benefits of Dryland Forestry

Land degradation leads to the reduction of productivity, functioning, and complexity of land. Estimations of the global extent of degraded lands vary from less than 1 billion ha to over 6 billion ha, with equally wide-ranged disagreements regarding their spatial distribution [1]. It is estimated that 25–35% of drylands are already degraded [2]. While passive restoration methods, for example grazing exclusion, can be effective for restoring moderately degraded lands, active means, such as afforestation and other techniques, might be needed to restore severely degraded lands. Such active means seem to be particularly relevant for water-limited environments, where self-restoration processes of severely degraded lands may be limited. Without active interventions for generating geoecological restoration processes, these lands may suffer accelerated degradation and desertification over time [3].

Forests cover almost 4 billion ha or 30% of the globe’s land area. Intensively managed forest plantations comprised 4% of the forest area in 2005, and their area is rapidly increasing at a rate of 2.5 million ha annually [4]. Forestry, including afforestation and reforestation land uses, is extensively utilized as a restoration means of degraded lands. Particularly, dryland forestry practices have been
widely reported as an effective tool in halting desertification processes [3,5,6]. However, an increasing body of literature reports that the conversion of ‘natural’ drylands to afforestation systems might degrade their overall functioning capacity, adversely impacting environmental quality and the provision of ecosystem services.

Dryland forestry-related practices such as herbicide application and soil scraping—aimed at negating competition over scant water resources between native vegetation and the planted trees and shrubs—have been reported to decrease soil hydraulic conductivity and increase generation of overland water flow [7]. These processes are expected to decrease on-site water availability for plants while increasing soil erosion risk [8]. Moreover, concerns have been raised regarding the potential adverse impact of forestry on vegetation species diversity [9]. Additionally, the overall impact of dryland afforestation on global climate is still questionable. For example, it was suggested that despite assimilating carbon dioxide (CO$_2$) by tree biomass and thereby reducing atmospheric concentrations of this greenhouse gas, forestry lands in semi-arid regions—where cloudiness is relatively low and solar radiation is comparatively high—might increase solar radiation absorption, resulting in a net warming effect shortly after forest establishment. Nevertheless, in the long run, the increased forest canopy may reverse this trend, resulting in a net cooling effect [10].

Because of the potentially tremendous impact of forestry on geoeocological functioning and the provision of ecosystem services, the target land units should be thoroughly assessed in advance. Land managers should clearly define specific goals of the land-use change while considering the risks of potentially undesired outcomes. This assessment should encompass detailed evaluation of the prevailing physical and biotic conditions of the target land units. First, an assessment of the ecological, hydrological, and geomorphological functioning of the target land unit should be carried out using, for example, the procedure detailed in the Landscape Function Analysis manual [11]. Basically, this procedure combines data collection of biotic and physical components of the ground with identification of landform dysfunctioning hazards. Second, ecosystem health of target land units should be determined by collecting data on pedogenic properties (e.g., surface roughness, visual indications for rills and gullies, soil compaction, organic carbon quantity and quality, nutrient content and availability, electrical conductivity, pH level, calcium carbonate content, and microbial biomass and activity), vegetal characteristics (e.g., plant cover, litter cover, functional groups’ distribution, species richness and diversity, and vegetation’s spatial patterns), and faunal features (e.g., abundance, species richness and diversity of invertebrates, arthropods, rodents, and reptiles), and formulating an inclusive numeral index. Only land units with an index lower than a threshold value, defining them as severely degraded, could be considered as candidates for afforestation or reforestation. Land units with higher index values should be considered for other, preferably passive, restoration schemes. This threshold value should differ according to geographical context and climatic conditions; it is plausible that it should be lower for dryer environments. A wide range of soil/land quality assessment tools have been developed for evaluating the status of natural or semi-natural environments, and of agro-ecosystems (e.g., [12–16]), each of them most suitable for certain combinations of physical and biotic conditions, thus specific indices correspond to different target lands.

2. Low-Impact Forestry

Depending on prevailing biophysical conditions, low-density forestry systems such as savanization projects (see: [5]) might be preferred over high-density, closed-canopy forestry systems, where the dense tree cover may suppress productivity of understory plant species, decreasing the ecosystem complexity and lessening its vegetation species richness and diversity. For example, in northern California, the United States, understory vegetation cover in newly established *Pinus ponderosa* (C. Lawson var. ponderosa) plantations increased with overstorey cover until peaking at a certain overstory cover and then declined [17].

Wherever sink patches for runoff water accumulation are needed to ensure survival and growth of the planted trees or shrubs, low-impact surface modification is preferable. For example, in hillslopes,
practices causing minimal disturbance of the ground surface, such as constructing traditional-style stone terraces [18], digging micro-catchment systems [6], or establishing pitting systems [19], in which runoff water accumulates and trees are planted, are preferable for small target lands. For expansive lands, the formation of shallow, contour earth-ridges, and planting trees or shrubs in the ditch/trench formed in their upslope side [20], might be more plausible. This practice only necessitates the use of a tractor-dragged single-blade plow, whose impact on the ground is limited to the ditch lines. Conversely, the construction of contour bench terrace systems [5] involves high-impact bulldozing earthworks to remove the soil’s most productive A-horizon, which is then used to form earth-terraces while smoothening the inter-terrace spaces to maximize the runoff ratio (Figure 1). This practice should be considered as the least preferred option. In addition to removing the topsoil, it eliminates the soil seed bank, a manipulation expected to hinder the productivity of herbaceous vegetation and limit species richness and diversity [21,22]. Yet, such systems may be needed to restore severely degraded lands, e.g., where extensive soil erosion negates the effectiveness of less intensive restoration means [5].

![Figure 1. One-year-old contour bench terrace forestry system in the Israeli semi-arid northern Negev. Note the exposed and crusted ground surface of the inter-terrace space, from which topsoil was removed and utilized to construct the terraces. Photo taken by I. Stavi in winter 2018/19.](image-url)

When forming sinks for runoff water harvesting in ephemeral channels, small, semi-porous check dams [23]—made from stones sourced onsite or offsite—are favored over massive and non-porous earth dykes (limans) (see: [5,23]). Like the construction of contour bench terraces, the establishment of limans necessitates the removal of topsoil from extensive land areas (Figure 2), increasing the risk of on-site land degradation. Obviously, smaller and weaker structures would preferably be established in channels upstream (or in small streams), where flow energy and flood water volumes are comparatively low. This approach would allow the use of highly porous, loose-rock check dams [23], or similar means, characterized by a low environmental footprint.
Planting native tree or shrub species in the sink patches formed either on hillslopes or in ephemeral channels negates the risks of genetic pollution and/or species invasion. The selected tree or shrub species should have no allelopathy mechanism, which may suppress understory vegetation. Specifically, this effect has been widely acknowledged for pine and other coniferous-dominated forests. For example, in the semi-arid Murcia region of south-east Spain, the allelopathic needle litter of semi-arid, 30-year old plantations of *Pinus halepensis* Miller has been reported to oppress growth of the perennial grass *Stipa tenacissima* L. [24]. Furthermore, afforestation and reforestation projects are more successful when comprised of mixed tree species, which are less susceptible to infestation by pests and diseases than single-species plantations [25]. Regardless, the increase in frequency and intensity of droughts around the world, driven by climate change, lead to mass drying and mortality of trees, resulting in increased incidence and aggravated intensity of wildfires [26,27]. Therefore, preference should be given for the selection of drought-tolerant, fire-resistant, and less flammable tree species [28].

### 3. Restoring Geo-Ecosystem Functions

Over time, in well-functioning forestry systems, it is foreseen that habitat conditions of the woody vegetation patches will improve. A dominant mechanism in this process is the shading of the soil surface by the canopy of the planted trees and shrubs. The shade reduces solar radiation and ground temperature, lowers evaporation of soil moisture, and increases soil water availability for plant uptake [29]. The improved conditions of the woody vegetation patches make them ‘fertility islands’ [30], exhibiting increased nutrient content and availability, improved microbial activity, and stimulated pedogenesis, resulting in accelerated restoration processes of the entire ecosystem. Regardless, alongside these processes, hydraulic lift, defined as the passive movement of water through roots along a gradient in soil water potential from deeper and moister layers to shallower and dryer layers, might be generated by deep roots of the planted trees and shrubs, further increasing the availability of soil water for understory vegetation [31]. Over time, it is expected that geoeocological feedbacks will increase herbaceous vegetation cover on hillslopes, hindering runoff generation, increasing on-site...
retention of water and soil resources, and minimizing the loss of water overland flow outside of the ecosystem [32]. This study stresses the importance of judicious planning and designing of afforestation and reforestation activities in drylands. Regardless, identification and continuous control of the degrading factor, e.g., irrational livestock grazing pressures [3], are essential. To ensure the long-term success of land restoration projects, forestry agencies and land managers should routinely monitor the afforested or reforested lands to assess their functioning and productivity, as well as their overall ecological impact.

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**References**


