More trees for more water in drylands: myths and opportunities

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“Greater tree cover can reduce or increase water availability, and it is crucial to understand why”

Introduction

The mechanisms by which trees influence water availability remain incompletely understood, but the last two decades have brought astonishing advances. We already know enough to see major opportunities to improve water security in tropical drylands through tree cover, while also yielding the many other benefits that trees provide.

Access to fresh water is one of the UN’s Sustainable Development Goals and a foundation for other SDGs. Challenges are considerable, as global water consumption doubles every two decades and global per capita freshwater reserves halved between 1960 and 2016. With population growth and often unreliable rainfall, many people now face intermittent water scarcity and an estimated half a billion already suffer year-round shortages, while droughts cause additional suffering, conflict and migration.

In Africa, these problems are especially urgent. More than 90% of agriculture in sub-Saharan Africa is rainfed and over 40% of the population (approximately 260 million) live in drylands and drought-prone lands. At the same time, Africa possesses considerable potential for increased tree cover, and African drylands are the focus of several ambitious tree-based restoration initiatives.

The restoration of tree cover influences water availability. Many people — some experts, too — believe incorrectly that greater tree cover has an invariably negative impact on local water availability. Where do these beliefs come from? Here we summarise the origin of these misconceptions and illustrate how tree cover can improve water availability. We have recognised the extent of these opportunities only recently, and considerable work remains, but we know enough to dismiss some myths and to highlight major opportunities to improve water security in Africa by restoring degraded landscapes with trees.

Myth makers

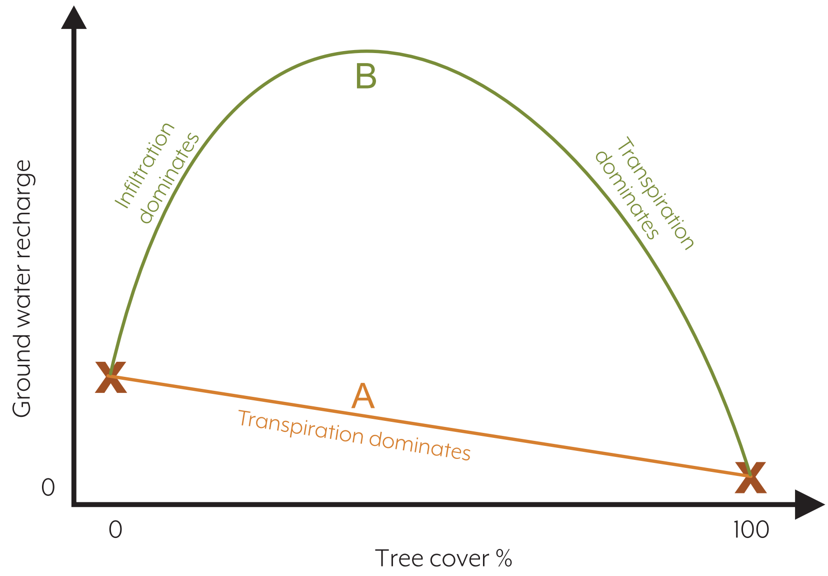
The myth that “more trees means less water” has hindered many projects from seeking the benefits of increased tree cover. While various relationships had been suggested over the last century a consensus was sought. This arrived in 2005 in an editorial in *Nature* (Hopkin 2005), which referred approvingly to an article in *Science* (Jackson et al. 2005) informing readers that the authors had “surveyed more than 500 places where new forests have been planted” and that the land became drier and local stream flow declined “by more than 50%.” They quoted the first author directly: “It doesn’t matter where you are in the world, when you grow trees on croplands, you use more water” (this trade-off is illustrated in Figure 1, line A).

The study was impressive and persuasive. Some experts raised doubts immediately, but few people heard them, and readers remained unaware that streamflow data derived from just 26 long-term catchment studies, of which 23 included only planted eucalyptus or pine, and only two were in the tropics, while none involved tropical drylands. That the study compared only treeless areas with dense tree stands and neglected intermediate tree densities also went unnoticed. Many readers saw a convincing study with an apparently clear conclusion — more trees mean less water. This message was widely repeated by the popular press and within development agencies. A myth was born.

Myth breakers

New advances and insights correct past misconceptions, and there are many such advances and insights (Sheil 2014; Ellison et al. 2017). The more-trees-means-less-water myth has been debunked many times. We know that increased tree cover often improves water availability. Some increases in drylands are accompanied by observations of

Figure 1. Schematic relationship between tree cover and groundwater recharge.



In recent years many assume, as in line A, that transpiration is proportional to tree cover and dominates the entire range of tree densities; hence, more trees mean less water. More recently, we recognise that in some contexts a small number of trees can have a major positive influence on groundwater recharge (mainly through infiltration and preferential flow) and this can dominate at low tree densities, leading to a strongly non-linear peaked distribution as in line B. Source: drawn by Douglas Sheil.

greater moisture, such as increased water levels in wells, reduced surface runoff and more greening. Stories like these occur across Africa (Carey 2020). The specific mechanisms behind such observations are seldom obvious without study. Major gains may arise through infiltration and rainfall effects, but other ways that trees bolster water capture are also known.

Often, when trees grow near lakes and oceans, or in highlands, they capture moisture from clouds or fog and channel this into the ground. This has long been recognised in the Canary Islands, in the *Juniperus procera* forests in the Sarawat Mountains of Saudi Arabia, and among the *Tamarix usneoides* trees of coastal Namibia. We lack measurements from African drylands, but elsewhere in the tropics the contribution from droplet capture is sometimes locally significant, particularly when rain is scarce.

In some drylands, the water table lies so far below the surface that only very deep-rooted trees have access to it. Observations show that *Boscia albitrunca* roots can reach 68 m deep in the Kalahari. Many Acacia (*Vachellia*) spp. also possess deep roots that sometimes allow them to reach deep water sources and grow year round. Some trees and shrubs that have access to deeper soil moisture redistribute this water to the topsoil (Kizito et al. 2012).

We now recognise that landscapes with some tree cover can sometimes capture several times more water than otherwise comparable treeless landscapes (Ilstedt et al. 2016). Three years of careful assessment in multiple locations in an agroforestry parkland in Burkina Faso show how trees improve collection of water at the soil surface and reduce runoff, increasing groundwater recharge. In treeless areas only some 10 mm of rain per year replenishes groundwater, but close to trees, groundwater recharge increases dramatically due to improved soil infiltration capacity and preferential flow; i.e., the flow of infiltrating water through macropores such as the channels created by roots and soil fauna (Bargués Tobella et al. 2014). This non-linear influence determines the fate of rainwater up to 25 m away from tree stems, so just a few trees per hectare substantially improve groundwater recharge, and recharge is maximised with an intermediate tree cover (Ilstedt et al. 2016). At this optimum, mean annual recharge is 5 to 6 times greater than in treeless conditions (see Figure 1, line B).

Livestock grazing in the rangelands of Chepareria, West Pokot, Kenya. Photo: Aida Bargués Tobella

The net effect of trees on groundwater recharge in the Burkina Faso study depends on gains from improved soil hydraulic properties and losses to evapotranspiration; the balance varies with local conditions. Both the optimum tree cover and the magnitude of benefits that result depend on multiple factors, including soil, terrain, rainfall, land use and the nature of the vegetation, but it is clear that greater tree cover can improve recharge over vast regions, especially where land degradation has impaired infiltration (Ilstedt et al. 2016).

The atmospheric water cycle

All trees use water, but recent insights have changed our views on this "use." Long viewed as a "loss," it is now recognised that much rainfall depends on such tree-emitted water. Recent research shows that continental rain depends much more on moisture derived from trees and other deep rooted vegetation than was recognised until a few years ago. Furthermore, intensified recycling means that after water arrives over land, in rain from moist winds or clouds, the presence of more trees means the same water falls more frequently on land before it departs back to the ocean. Observations of increased rain following large-scale reforestation in China appear consistent with this. The water emitted to the atmosphere by trees can be returned with added interest, as the likelihood of rain depends on atmospheric moisture. Meteorologists recognise that in suitable conditions a 10% increase in local relative humidity may increase precipitation by more than 50%.

Furthermore, we now see how some regions depend on rainwater from elsewhere. Since trees bolster atmospheric moisture, greater tree cover increases overall rainfall, though not necessarily in the same location (Sheil 2018). Moisture moves across the entire continent, dependencies varying with location, season and wind patterns, and at times, most rainfall may rely on recycled moisture (Sheil 2019). The value and implications of this crucial source of water needs recognition, while accounting for such transfers requires a continent-wide perspective.

Trees boost rainfall in other ways too. Vegetation contributes to the generation of condensation nuclei — particles that promote cloud formation and rain. Despite advances in understanding their origin, influence and dynamics, their role in dryland rainfall remains unclear (Sheil 2018).

Feedbacks between rainfall and tree cover have become an important focus for climate theorists. One theory invoking powerful feedbacks is the "biotic pump", that explains how tree cover influences pressure gradients that carry winds and moisture across continents (Makarieva et al. 2013). Other theories invoke other mechanisms. Such relationships are increasingly seen as necessary for explaining the abruptness of the monsoons and various other behaviours that remain poorly understood. Yet they are incompletely represented in or absent from conventional climate models, so the implications cannot yet be predicted by simulations. These theories indicate that local climates switch from wetter to drier and vice versa with critical losses or gains in tree cover. If sufficient tree cover was established over broad dryland areas it seems that net rainfall would increase, with the wider benefits that that implies (Sheil 2018; Sheil et al. 2019).

Practical implications

Despite increased knowledge of how tree cover influences water availability, our capacity to guide restoration practices remains limited. See Table 1 for a summary of processes relevant to tree cover.

Table 1. Mechanisms by which trees influence water availability. For additional reviews and references aimed at a non-technical audience, see Ellison et al. (2017) and Sheil (2018).

Mechanism	Scale	Effect	Influences and management implications
Infiltration	Tree and stand	The entry of water into soil, controlling surface runoff generation and soil and groundwater recharge	Soil and rainfall properties; tree roots and litter; tree-associated soil fauna
Preferential flow	Tree and stand	The flow of infiltrating water along preferred pathways in the soil, including macropores formed by roots and soil fauna	Soil properties; tree roots, litter and tree-associated soil fauna
Transpiration	Tree and stand	The process by which trees extract water from the soil or groundwater and emit it to the atmosphere as vapour	Influenced by rooting depth and volume, leaf area and phenology; correlated to canopy cover; reduced by pruning/coppice
Interception	Tree and stand	Prevents some rain reaching the soil surface (evaporates back)	Leaf area and phenology; branch architecture; crown shape; leaf size and orientation; correlated to canopy cover; bark roughness; reduced by pruning/coppicing
Soil evaporation	Tree and stand	Reduced sunlight and cooler understorey temperatures reduce evaporation from the soil surface	Leaf area and phenology; branch architecture; correlated to canopy cover; reduced by pruning/coppicing
Litter mulch	Tree and stand	Affects how much water enters the soil; reduces soil temperature, soil evaporation and surface runoff	Leaf area, lifetime and phenology
Soil water holding capacity	Stand to catchment	Trees often contribute to, and maintain, soils with comparatively good water storage capacity	Soil physical properties, some affected by trees through organic matter inputs and activity of roots and tree-associated soil fauna

cont. table 1

Mechanism	Scale	Effect	Influences and management implications
Deep water uptake	Tree and stand	Some trees obtain water from much deeper in the soil profile (including groundwater) than other vegetation and can thus emit vapour over more extended periods, which influences atmospheric moisture	This is not the case for seedlings Rooting morphology, tree age/size
Hydraulic redistribution	Tree and stand	Deep-rooted trees, especially those with dimorphic root systems, passively redistribute water from moist to dry soil layers via their roots	Species choices and maturity
Stem water storage	Tree	Trees store water, allowing them to maintain high transpiration for some periods even when uptake from the soil is limited; this allows trees to emit vapour over more extended periods, thus influencing atmospheric moisture	Tree size and species choices; some species, such as baobabs (Adansonia spp.) show major adaptations to this strategy
Vapour capture	Leaf and tree (& soil)	Some plants extract water from humid air (some soils are also able to gain moisture directly)	Uncertain, but likely a minor effect in drylands
Dew capture	Tree and stand	Condensation of water vapour is promoted on cool surfaces (shaded places, transpiring stems and from radiative cooling at night); leaf surfaces have been shown to influence dew formation and its capture	Typically minor, but may be locally important; influenced by foliage, architecture and epiphyte load
Cloud capture	Tree and stand	Interception of fog and cloud provides significant amounts of moisture in certain locations/seasons	Locally important (e.g., on coasts and mountains); influenced by tree foliage, architecture and epiphyte load
Aerosols	Stand and region	Plants emit a range of particles and compounds into the atmosphere, which influence when and where water vapour condenses; emissions vary with species, physiology and specific triggers, e.g., heat stress causes some plants to emit isoprene, herbivory can also stimulate various emissions	Largely unknown but likely to be powerful at large scales
Rainfall recycling	Regional	An integrated property that results from many of the others but is also influenced by large-scale atmospheric flow	Increased tree cover typically leads to more effective recycling and a net increase in regional rainfall as water arriving from outside the continent is likely to fall more often before it is lost
Biotic pump	Regional	The theory that suggests that tree cover attracts atmospheric flows from elsewhere by favouring condensation to occur more frequently (a process that leads to lower air pressures)	Increased tree cover will typically increase and stabilise rainfall patterns at regional scales (decreased tree cover reduces rainfall and reliability)

Desirable outcomes from tree cover vary. Some people may want trees to shelter crops or provide fruit, fodder, biomass, wood or other products. Similarly, there are choices about water. Some people wish to increase the recharge of groundwater that feeds wells and springs. Some wish to lower groundwater to avoid salt flows or as a means to reduce mosquitoes — in which cases high evaporative losses through dense cover may be favoured. Some wish to maintain or amplify runoff to feed irrigation, reservoirs or rivers.

Tree and land management — such as tree species selection, land-use practices, grazing and pruning — also influence water availability. For example, pruning reduces transpiration, and current understanding indicates that a broad range of tree cover values may often substantially outperform tree-free landscapes (Ilstedt et al. 2016).

At larger scales, protecting and increasing tree cover sustains and augments vital rainfall. Without detailing the theoretical details and nuances, maintaining significant tree cover upwind, especially near oceans, lakes, mountains or forests, should bolster rainfall across regions and continents, while downwind tree cover protects the atmospheric flows on which we all depend.

Context matters, and the influence of trees on water availability varies over time, space and scale. Water use and related factors and impacts change as seedlings and stands mature. Spatial interactions contribute to distributions such as West Africa's banded and clumped woodlands (*brousse tigrée*). Scale effects are most evident in atmospheric processes — while every tree contributes moisture, marked changes in rainfall require large-scale changes.

Conclusions

The impacts of tree cover on water are often neglected in discussions that surround restoration, and have been misrepresented in global studies on tree-based restoration opportunities. Decision support tools to match trees and management approaches tend to focus on goods (fruit, fodder, timber) and specific services (erosion control, carbon capture) while they neglect water. Every decision to invest in tree cover requires some accounting of the wider implications, and water must be included in this assessment.

Tree cover has considerable potential for improving water security, but how should we promote these benefits? Despite recent advances, much remains to be clarified. There is a need to build knowledge for tailoring guidance to local needs and contexts, and given the stakes, research and collaboration are crucial. We suspect that the protection and restoration of natural vegetation provides more benefits than most alternatives—after all, nature has evolved natural communities as effective systems for sustaining water, and they worked well before humans intervened. Local observations also offer a useful guide to what works in specific locations (Carey 2020). Much remains uncertain and caution is required regarding simplistic claims, but we know enough to dispel myths and to acknowledge and underline that increased tree cover offers a greener wetter world.

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References

Bargués Tobella, A., H. Reese, A. Almaw, J. Bayala, A. Malmer, H. Laudon and U. Ilstedt. 2014. "The effect of trees on preferential flow and soil infiltrability in an agroforestry parkland in semiarid Burkina Faso." *Water Resources Research* 50:3342–3354.

Carey, J. 2020. "The best strategy for using trees to improve climate and ecosystems? Go natural." *News Feature*. PNAS 117:4434–4438.

Ellison, D., C.E. Morris, B. Locatelli, D. Sheil, J. Cohen, D. Murdiyarso, V. Gutierrez, M. van Noordwijk, I.F. Creed, J. Pokorny, D. Gaveau, D.V. Spracklen, A.B. Tobella, U. Ilstedt, A.J. Teuling, S.G. Gebrehiwot, D.C. Sands, B. Muys, B. Verbist, E. Springgay, Y. Sugandi and C.A. Sullivan. 2017. "Trees, forests and water: Cool insights for a hot world." *Global Environmental Change* 43:51–61.

Hopkin, M. 2005. "Tree planting not always green." *Nature* 22 December 2005.

Ilstedt, U., A. Bargués Tobella, H.R. Bazié, J. Bayala, E. Verbeeten, G. Nyberg, J. Sanou, L. Benegas, D. Murdiyarso, H. Laudon, D. Sheil and A. Malmer. 2016. "Intermediate tree cover can maximize groundwater recharge in the seasonally dry tropics." *Scientific Reports* 6:21930.

Jackson, R.B., E.G. Jobbágy, R. Avissar, S. B. Roy, D. J. Barrett, C.W. Cook, K.A. Farley, D.C. Le Maitre, B.A. McCarl and B.C. Murray. 2005. "Trading water for carbon with biological carbon sequestration." *Science* 310:1944–1947.

Kizito, F., M.I. Dragila, M. Senè, J.R. Brooks, F.C. Meinzer, I. Diedhiou, M. Diouf, A. Lufafa, R.P. Dick, J. Selker and R. Cuenca. 2012. "Hydraulic redistribution by two semi-arid shrub species: Implications for Sahelian agro-ecosystems." *Journal of Arid Environments* 83:69–77.

Makarieva, A., V. Gorshkov, D. Sheil, A. Nobre and B.-L. Li. 2013. "Where do winds come from? A new theory on how water vapor condensation influences atmospheric pressure and dynamics." *Atmospheric Chemistry and Physics* 13:1039–1056.

Sheil, D. 2019. *Importance of Central Africa's forests for regional climate and rainfall.* Tropenbos International, Wageningen, the Netherlands.

Sheil, D. 2018. "Forests, atmospheric water and an uncertain future: the new biology of the global water cycle." *Forest Ecosystems* 5:1–22.

Sheil, D. 2014. "How plants water our planet: advances and imperatives." *Trends in Plant Science* 19:209–211.

Sheil, D., A. Bargués Tobella, U. Ilstedt, P.L. Ibisch, A. Makarieva, C. McAlpine, C.E. Morris, D. Murdiyarso, A.D. Nobre and G. Poveda. 2019. "Forest restoration: Transformative trees." *Science* 366:316–317.

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