Core Ideas
- The progress of research on soil drought in the Loess Plateau was reviewed.
- Spatiotemporal patterns of dried soil layers were scale dependent.
- SWCCV was recommended for optimizing water management in the critical zone of the LP.

The Loess Plateau (LP) of China is a good representative area for critical zone (CZ) science studies. The LP is famous for its deep loess. In most areas, the thickness of the loess profile is deeper than 100 m, and two-thirds of the area is arid and semiarid. With the Grain-for-Green project, the vegetation of the plateau has recovered gradually. However, with the increase in vegetative coverage, especially the planted vegetation, the water content of the soil profile has decreased and the soils is much drier. In this review, particular emphasis is paid to the dry conditions of deep soil, drought, regional restoration of vegetation, and effective management of soil moisture. We reviewed the progress of research on dried soil layers (DSLs) that resulted from soil drought in the past decades on the Plateau, and then we summarized the development of the concept and models of soil water carrying capacity for vegetation (SWCCV). This review is helpful for understanding the development of DSLs, optimizing soil water management through vegetation mediation, and designing a long-term sustainable framework for water-limited ecosystems.

Abbreviations: CZ, critical zone; DSL, dried soil layer; ET, evapotranspiration; LP, Loess Plateau; SFC, stable field capacity; SWC, soil water content; SWCCV, soil water carrying capacity for vegetation.

The critical zone is defined as the physical structure from the top of the tree canopy to the bottom of the groundwater aquifer in the terrestrial environment, which is critical in supporting terrestrial ecosystems and, ultimately, the survival and development of human society (Lin, 2010). The systematic research of the CZ was advocated as a new opportunity and a compelling research area in earth sciences for the 21st century by the US National Research Council in 2001. The soil–plant–atmosphere continuum is a fundamentally important component of CZ structure.

The soil–plant–atmosphere continuum is a mutually interacting system where soil moisture, under the drive of the vapor pressure deficit, can be transported to the atmosphere by plant transpiration and soil evaporation (Wang et al., 2011a; Mencuccini and Binks, 2015). Climate models and observations have shown that the intensity and frequency of droughts would increase continually in many terrestrial ecosystems around the world, which might strongly increase the vapor pressure deficit and lead to a series of changes in above- and belowground ecosystems—that is, the generally (but not universally) expected increase in evapotranspiration (ET) and subsequent decline in soil water content (SWC) (Brown, 2002; Zavaleta et al., 2003; Breshears et al., 2005; Seager et al., 2007). In recent years, there has been considerable interest in the assessment of the responses of aboveground vegetation to drought (Tollefson, 2010; Peng et al., 2011), and great strides have been made toward understanding the mechanisms of drought-induced mortality of trees (Anderegg et al., 2015; Rowland et al., 2015). However, few studies have focused on the responses of belowground soils (especially for deep soil below 1 m) to drought, partly because of (i) the challenge of accessing SWC data at a large scale, which is obviously different from the measurement of regional vegetation and climate datasets, by using remote sensing and other indirect methods; and (ii) the highly spatial and temporal variability of SWC in both the vertical and horizontal directions at a series of scales.
A serious decline of SWC may lead to soil desiccation. Combining with the profile distribution of plant roots, the desiccated layer usually forms a DSL in the soil profile at certain soil depths (Li, 1983; Yang et al., 1999; Chen et al., 2008; Wang et al., 2008a; Jia et al., 2017a). The formation of DSLs can negatively affect water cycles, crop yields, tree productivity, C emissions related to forest flammability and tree mortality, and the second and later rotations of plantations (e.g., blue gum [Eucalyptus globulus Labill.]) (Nepstad et al., 2004; Shangguan, 2007; Chen et al., 2008; Mendham et al., 2011; Jia et al., 2017b). Therefore, reclamation of DSL is becoming more important, especially in arid and semiarid regions, which usually suffer excessive depletion of deep soil water by non-native or natural vegetation, strong ET, and a long-term insufficient supply of rainwater (Jipp et al., 1998; Chen et al., 2008).

The LP, located in the arid and semiarid regions of northern China, covers an area of 640 million ha, which accounts for ~6.6% of the Chinese territory but supports >8.5% of the Chinese population. The plateau is a well-known, water-limited region as a result of serious soil erosion, limited rainfall, deep thickness of the loess deposition, low vegetation coverage, and frequent and intensive human disturbance (Yang et al., 1988; Wang et al., 2015) and provides an ideal opportunity for the research of the soil–plant–atmosphere continuum under the CZ science framework. The average annual rainfall in this region ranges from 150 to 800 mm from northwest to southeast, which is far lower than the average annual pan evaporation (1400–2000 mm; Wang et al., 2010a). Moreover, the thickness of the loess soil from the surface to the bedrock in this area ranges from 50 to 200 m, with an average of 104.6 m; at these depths, groundwater is not available for plants (Xiong et al., 2014). Low precipitation and high ET result in lower SWC in the CZ of the LP. The occurrence of DSL potentially interferes with the water cycle in groundwater–soil–plant–atmosphere systems in the CZ by preventing water flow between upper soil layers and groundwater (Chen et al., 2008). In this region, a DSL was first found in 1963 and defined scientifically in 1983 (Li, 1983). Recently, the conflict between soil desiccation and the sustainable development of revegetation has become increasingly important on the LP. Adjusting plant productivity to an appropriate carrying capacity is needed urgently in the current restoration of the ecological environment of the LP to reclaim or prevent the formation of DSLs. The objectives of this study were to review the research progress on DSLs that resulted from soil drought in past decades and to summarize the management of soil water from the point of view of the water carrying capacity for vegetation on the LP of China.

Dried Soil Layers and Quantitative Indices

Dried soil layers have been formed widely throughout arid and semiarid regions around the world, including Russia (Yang and Han, 1985), eastern Amazonia (Jipp et al., 1998; Christina et al., 2008); Chen et al., 2008; Wang et al., 2010a; Jia et al., 2015). Generally, 50 to 70% of field capacity was considered as SFC based on the textures of soils found on the LP (usually 60%; however, for sandy soil, it is 50% and for clayey soil it is 70%), and a layer with SWC lower than SFC would be deemed a DSL (Wang et al., 2004b; Yang and Tian, 2004). A DSL has three characteristics: (i) it is located at a certain depth within a soil profile, generally below the mean annual rainwater infiltration depth, and with a thickness ≥10 m; (ii) it persists at certain spatial and temporal scales; and (iii) it has a range of SWCs between the permanent wilting point and the SFC (Li, 1983; Wang et al., 2011b). The SFC is, thus, the threshold for identifying a soil layer as a DSL. The specific proportion of the field capacity, as stated above, depends highly on soil texture—the coarser the soil, the lower the proportion of the field capacity (Chen et al., 2008).

Three published indices have been used to quantify a DSL generally: (i) the thickness of the DSL (in centimeters or meters) (Robinson et al., 2006; Shangguan, 2007; Li et al., 2008; Cheng and Liu, 2014; Jia et al., 2015); (ii) the formation depth of the DSL (centimeters or meters) (Liu et al., 2010a; Wang et al., 2010a; Yan et al., 2015); and (iii) the mean SWC within the DSL (percentage or millimeters) (Jipp et al., 1998; Zhao et al., 2007; Wang et al., 2008a, 2011b).

Spatiotemporal Variations and Controlling Factors

Dried soil layers vary in space and time because of the heterogeneity in climate, soil, vegetation, and topography. For example, the LP of China is well known for having complex topography, which includes plains, sub-plateaus, hills, and gullies, with an altitude range of 200 to 3000 m asl (Yang et al., 1988). The land-use type generally changes from cropland to forestland and then to grassland from southeast to northwest following the precipitation gradient. A series of vegetation restoration campaigns, including the Grain-for-Green program, was initiated by the Chinese government at the end of the 1990s to reconvert cropland to forests, shrubs, and grass (Cao et al., 2009); this changed the land coverage dramatically (Chen et al., 2015). In addition, annual precipitation and air temperature on the LP decreased and increased, respectively (Wang et al., 2011b), which consequently altered the spatiotemporal patterns of DSLs at various scales. To improve the efficiency of vegetation restoration and water management and to control or reclaim DSLs, it is necessary to
Spatial Variations of Dried Soil Layers

Dried soil layers were formed widely throughout arid, semiarid, and semihumid regions across the LP (Han et al., 1990; Wang et al., 2010b, 2011b, 2012; Jia et al., 2015). The spatial distribution of DSLs on the LP exhibited a horizontal zonal pattern at a regional scale, but they had a vertical differentiation pattern both at a watershed scale and at a slope scale (Wang et al., 2004a).

The distribution characteristics of DSLs in a watershed were investigated by He et al. (2003), who showed that DSLs existed extensively throughout the entire watershed. The degree of dryness and thickness of a DSL generally decreased in the following order: farmland > grassland > orchard land > forestland (He et al., 2003). Furthermore, the distribution characteristics of DSLs under the same vegetation type were affected by plant density, age, biomass, slope gradient aspect, and position. Wang et al. (2004b) reported that DSLs showed an apparent vertical gradient in small hill areas as a result of differences in altitude and the capacity of rainfall to infiltrate the soil. Soil moisture under native vegetation and human-managed vegetation was generally higher than that under introduced vegetation, and different degrees of soil desiccation occurred under all the introduced vegetation types in the semiarid LP (Fang et al., 2016). Caragana korshinskii Kom. and black locust (Robinia pseudacacia L.) caused the most serious soil drought. Chen et al. (2008) also reported that the extent of a DSL had a close relationship with the root distribution of plants and that it varied with the types and ages of the vegetation.

At a zonal scale, DSLs varied greatly under different soil water ecological zones on the LP (Zhang et al., 2017). Li et al. (2008) measured soil moisture in 0- to 10-m soil layers of 23 kinds of tree and shrub forestlands within three different rainfall types. They found that soil desiccation had occurred at 20 of the 23 forestlands. The intensity of soil desiccation under forestlands increased from south to north. Similar results were reported by Wang et al. (2004b), who showed that soil dryness exhibited apparent horizontal differences with rainfall on the LP. Furthermore, the effects of tree species on soil desiccation were emphasized by Li et al. (2008), who found that the most severely desiccated forestlands were David’s mountain laurel (Sophora davidii Franch.) Skel., followed by forestlands such as black locust, Chinese pine (Pinus tabuliformis Carrière), Manchurian oak (Quercus mongolica Fisch. ex Ledeb.), and little leaf peashrub (Caragana microphylla Lam.), and then apple (Malus domestica Borkh.) orchards and seabuckthorn (Hippophae rhamnoides L.) forestland.

Across the entire LP, a spatial distribution map of DSLs was produced (Wang et al., 2010a). There was strong spatial variation in DSLs, which had a mean thickness of 160 cm at a mean soil depth of 270 cm. The DSL was generally thicker (>170 cm) in the western LP region and in the central area (170–220 cm), although DSLs were considerably thinner or nonexistent because of irrigation along parts of the Yellow River and near rivers in the interior. Climatic condition (precipitation) and soil type were the primary factors that impacted the extent of DSL formation significantly. Consistent with Wang et al. (2010a), Yan et al. (2015) found, after synthesizing 69 publications that focused on DSLs on the LP, that the regional distribution of DSLs was significantly affected by climatic and vegetation factors. The severity of DSLs increased with the planting age, similar to the results of Jia et al. (2017a, 2017b).

Temporal Variation in Dried Soil Layers

The DSLs could be divided into two types: temporary and permanent (Li, 1983). Temporary DSLs mostly occur in semihumid regions where there is more water recharge of DSLs as a result of higher precipitation. Permanent DSLs, however, typically occur in arid and semiarid regions where there is low SWC because of long-term soil drought. A permanent DSL is difficult to reclaim on the LP because of limited precipitation, a deep groundwater level, high transpiration, and intense evaporation (Wang et al., 2008b, 2011b; Jia et al., 2015). Permanent DSLs could have profound and long-term negative impacts on ecological and hydrological processes. Consequently, they may limit the sustainability of environmental restoration projects (e.g., revegetation, soil and water conservation, etc.) on the LP of China.

The soil desiccation rate is the key factor that determines the formation and development of DSLs. Li et al. (2008) showed that average soil desiccation rates in the 20 types of desiccated forestlands they investigated were 3.3 to 167.4 mm yr⁻¹, with an average of 36.8 mm yr⁻¹. The maximum soil water use depth was ~10 m or more, and the thickness of the desiccated soil layers reached or passed 8 m. Wang et al. (2010b) analyzed the formation of DSLs and their development processes under planted non-native and natural vegetation in the semiarid area of the LP; the rate of DSL formation depended on vegetation type and its age. For example, the DSL formed in the second growth year of alfalfa (Medicago sativa L.) but in the third growth year of C. korshinskii. The depth of DSLs formed under alfalfa was greater than that formed under C. korshinskii after 4 yr of growth. However, the depth of the DSL under C. korshinskii (4.4 m) exceeded that formed under alfalfa (3 m) after 31 yr of growth. The deepest DSL in alfalfa grasslands even reached 20 m within 23 yr after planting (Cheng and Liu, 2011). Jia et al. (2015) studied the temporal DSLs along an 860-km south–north transect of the LP, and they found that temporal DSL patterns were controlled mainly by soil (including soil texture, soil organic C, and field capacity) and climate (including mean annual precipitation, seasonal distribution of precipitation, and mean annual temperature). Lower water holding capacity of soils, less rainfall, and more concentrated seasonal distribution of precipitation could accelerate the formation and development of permanent DSLs on the LP.

Except for the formation and development of DSLs, knowledge of recovery from soil desiccation is necessary for understanding...
DSLs. The duration of soil moisture recovery varied from 6.5 to 19.5 yr (average 13.7 yr) in the 0- to 10-m soil layer and from 4.4 to 8.4 yr (average 7.3 yr) in the upper 0- to 3-m soil layer after a 30-yr apple orchard was converted to winter wheat (Triticum aestivum L.) on the LP (Huang and Gallichand, 2006). Wan et al. (2007, 2008) pointed out that soil desiccation in the 3- to 10-m soil layer cannot be recovered from alfalfa cropland. Liu et al. (2010b) showed that a DSL 2- to 3-m in depth would be fully recovered at least once in ~10 yr for all existing cropping systems except alfalfa. Inconsistently, Liu et al. (2008, 2010a) indicated that soil desiccation could recover after 18 yr once alfalfa was removed. Li et al. (2004, 2007) simulated soil desiccation using an erosion–productivity impact calculator model and showed that soil desiccation took place mainly in 1 to 3 m of soil and did not recover in a winter wheat or a spring maize (Zea mays L.) field. Wang et al. (2007) reported that soil desiccation in 0 to 5 m of soil recovered partly when grain crops were cultivated after alfalfa. Based on long-term experimental data from 1985 to 2001 in the Wangdonggou watershed in the southern LP, Wang et al. (2011b) found that the degree of recovery of soil desiccation depended on the species of crop and their rotation sequences. Thus, the time it took to recover soil moisture was inconsistent because of seasonal variation in rainfall and different survey and simulation methods.

In conclusion, the regional-scale spatiotemporal variations of DSLs were strongly controlled by climate, soil type, and vegetation, although land use and topography might affect the spatiotemporal pattern of DSLs at a watershed or slope scale. The degree of soil desiccation was determined by the land-use type. Soil drought that occurred in the deep soil profile may become a permanent DSL, which is difficult to remediate because of the limited rainfall.

The challenge of recent studies lies mainly in the scarcity of long-term, continuous data on soil moisture content under various vegetation types and the inability to quantify how long it would take for soil desiccation to be alleviated. The lack of such information may limit our understanding of the development and recovery of DSLs under different land uses within different climatic zones. Thus, there is a need for sufficient information on temporal variations in DSLs for sustainable soil water management and ecological restoration. Moreover, poor land management, such as the introduction of exotic tree and grass species and high-density planting, has unquestionably led to soil drought in the CZ of the LP of China. The exotic tree species currently used should be replaced with more water-saving native tree species for the control and restoration of DSLs. Thinning was also required in high-density areas as a critical measure to maintain a balance in soil water availability and water use by plants. Using models (Xia and Shao, 2008; Fu et al., 2012; Liu and Shao, 2015; Zhang et al., 2015; Mo et al., 2016) to assess the consumption process of soil water with vegetation growth, optimal plant coverage or biomass can be established to guide afforestation operations on the LP or similar arid and semi-arid regions. Nevertheless, optimizing land-use management to local climatic, soil, and topographic characteristics could mitigate DSL formation and development on the LP.

Soil Water Carrying Capacity for Vegetation

Given the increasing conflict between soil desiccation and the sustainable development of revegetation on the LP in China, quantitative guidelines for the selection of plant species, optimal density or biomass, and appropriate management for vegetative restoration are required. Scientists and resource managers who are concerned about the amount of overplanting often invoke the concept of a SWCCV.

The Soil Water Carrying Capacity for Vegetation Concept

The concept of carrying capacity originated in the field of ecology. It was presumably coined by range managers, who were concerned with the use of land for grazing livestock. In the late 1960s and early 1970s, the discussion about looming limits of the Earth’s carrying capacity as a result of population increase and economic growth initiated the widespread development of environmental awareness (Seidl and Tisdell, 1999). Because the concept of carrying capacity was used originally as a useful tool for the evaluation of ecosystems, it has been introduced into tourism, eco-environment, water resources, and many other fields. To quantify the maximum vegetation density on the LP of China that can be sustained without desiccating the soil, Guo and Shao (2004) studied the SWCCV for forest and grassland management. The term soil water carrying capacity for vegetation was developed and defined as the ability of soil water to maintain vegetation. The upper limit of the SWCCV is the vegetation density of a plant community at which soil water consumption is equal to the soil water supply in the root zone of the plants under a given management condition (Fig. 1). The SWCCV is thus defined in the context of a specific plant community and management regime.

To provide a more precise definition of the SWCCV that is more suitable for quantification of the SWCCV, Xia and Shao (2009)
proposed the following definition: “the maximum biomass of a given type of vegetation, under specific climatic conditions, soil texture, and management regime that a given arid or semiarid area can sustain without diminishing the capacity of soil water to support future generations.” In this definition, the concept emphasizes what vegetation type is being studied and what climatic, soil textural, and management conditions are assumed to prevail in the system. Moreover, the concept exhibits a range of possible levels, which depend on management goals, human activities, and ecological features. Thus, the new definition of the SWCCV acknowledges the dynamic, comprehensive, and integrative characteristics of the ecosystem.

Soil Water Carrying Capacity for Vegetation Models

Prediction of the SWCCV in arid and semiarid regions requires linking two fundamental units: soil water balance and plant density. Although there have been numerous soil moisture models developed during the last five decades, few have dealt with arid and semiarid lands that have diverse plant density inputs (Table 1). The water-balance equation is the most basic model that relates the rates of change in water storage to the gradient of plant density across the control surface (Ma et al., 2001; Guo and Shao, 2004; Tian et al., 2009). Soil water supply and consumption were related statistically to plant density in the equation. With increases in plant density, more and more soil water would be consumed by vegetation through ET. In a given situation, the SWCCV is calculated as the density at which the soil water supply (precipitation [P(t) in Table 1]) is equal to soil water consumption (the sum of actual ET [AE(t)], runoff [R(t)], and soil moisture surplus [Q(t)]) for a given time interval (Guo and Shao, 2004) (Fig. 1).

The water-balance conceptual model was conducted successfully at Caragana spp., alfalfa, apricot (Prunus armeniaca L.), and Prince Rupprecht’s larch (Larix principis-rupprechti Mayr.) sites (Guo and Shao, 2004; Liu et al., 2009; Wang and Shao, 2009). The water-balance conceptual model for estimating the SWCCV from measurement data, although very simple, has several disadvantages. First, it is difficult to estimate or measure parameters such as ET and soil moisture surplus to expand the application of the model, or some existing data may not be applicable in other places. Second, it is usually accurate only in a limited range because the model structure may be only partially correct, and it is difficult to compare one method with another because of method-specific model variables. For example, the requirements for measurements of climatic data may vary with height above the water or ground surface.

The growth–density metrics model presents volume growth as an explicit function of tree size (diameter or volume), age, and density, in which the relationship between vegetation density and growth follows a Langsaeter’s curve (Zeide, 2004; Innes et al., 2005; Torres Vélez and Del Valle, 2007). The model allows calculation of the density that maximizes volume growth at any given moment. The SWCCV is shown as the optimal stand density when volume growth almost stops and the relative density

| Table 1. Overview and comparison of soil water carrying capacity for vegetation (SWCCV) models. |
|---------------------------------|--------------------------------|--------------------------------|----------------------------------|-----------------------------|
| **Base model**                  | **Plant type**                | **Simulation approach**       | **Determination of SWCCVs**     | **References**               |
| Water balance equation          | Caragana spp., alfalfa, apricot, and Prince Rupprecht’s larch | $S(t + 1) = S(t) + P(t) - AE(t) - R(t) - Q(t)$, where $S(t)$ is the amount of soil moisture stored at time interval $t$, $S(t + 1)$ is storage at the end of that interval; $P(t)$ is precipitation; $AE(t)$ is actual evapotranspiration; $R(t)$ is runoff; and $Q(t)$ is soil moisture surplus | plant density when soil water supply equals soil water consumption | Guo and Shao (2004), Liu et al. (2009), Wang and Shao (2009) |
| Langaeter’s curve               | not defined                   | $Z(t, x, S) = a D P e^{-q(t)} \times \exp(-x/S)$, where $a$, $b$, $c$, and $g$ are positive parameters expressing site quality, rate of growth acceleration, rate of unrestrained growth, and rate of various factors slowing growth (such as aging), respectively | optimal density when volume growth does not change much across a wide range of stand densities | Zeide (2004), Innes et al. (2005), Torres Vélez and Del Valle (2007) |
| Hydrology–land use impacts model | all potential plants           | ET = $P(t)/(1 + w_1 E_p/P) + (1 + w_2 E_p/P + P/E_p)$, where ET is actual evapotranspiration, $P$ is precipitation, $f$ is fractional forest cover, $E_p$ is potential evapotranspiration, and $w_1$ and $w_2$ are the plant-available water coefficients for forest and non-forest, respectively | the suitable percentage of woody cover is derived when the simulated runoff and evapotranspiration are equal to precipitation | McVicar et al. (2007) |
| Interactive modeling hydrological and biogeochemical cycles | Caragana spp. | the model was constructed on the concept of the equilibrium adjustment of vegetation growth to soil water deficits, by iterative calculation between hydrologic and biogeochemical process that accounts for the interactions between the limiting effects of soil moisture on photosynthesis and evaporative | the maximum vegetation production is obtained with the number of wilting days less than the maximum days vegetation can suffer | Xia and Shao (2008) |
| The simultaneous heat and water (SHAW) model | Caragana spp. and alfalfa | the model simulates energy, water and solute balance for infinitely small layers; the energy and water balance equations for layers within the plant canopy, snow residue and soil are written in implicit finite difference form and solved using an iterative Newton–Raphson technique | the largest acceptable aboveground biomass of a given type of planted vegetation where the plants can sustain normal growth using the available soil water without desiccating deep soil (>1.0 m) under specific climatic conditions | Liu and Shao (2015) |
To improve our understanding and quantification of soil–water–vegetation interactions and the SWCCV, it is necessary to integrate hydrological and biogeochemical process models to estimate not only soil water dynamics but also its influence on vegetation density. Xia and Shao (2008) provided a physically based model that builds on the concept of an equilibrium adjustment of vegetation growth to soil water dynamics. It uses an iterative calculation between hydrologic and biogeochemical processes that accounts for the interactions between the limiting effects of soil moisture on photosynthesis and evaporative demand on soil water. The model was successful in capturing the soil water difference between two sites in terms of controlling vegetation density. To simulate a long-term SWCCV with different growth ages, Liu and Shao (2015) assessed the consumption process of soil water with the growth of *Caragana* spp. and alfalfa and their optimal carrying capacity based on a one-dimensional movement of water and heat process model (the simultaneous heat and water model) and the definition of DSLs (Table 1). The physically based SWCCV model is capable of predicting the soil water carrying capacity, and it provides a new approach for understanding soil–water–vegetation interactions and for making recommendations for better management of vegetation construction in arid and semiarid areas.

### Research Challenges

Soil water is the most active water resource in the terrestrial ecosystem; it determines a range of ecological and hydrological processes and plays a critical role in many disciplines including pedology, ecology, hydrology, and geography. Serious soil drought, resulting from climate change and poor land management, may lead to the formation of a DSL, which can adversely affect soil quality, vegetation growth, hydrological cycles, and ecosystem functioning worldwide. It has become a frontier and research hotspot in the field of CZ science with increasing pressure on resources and the environment. Although great progress has been made during past decades, including the definition and quantitative indices for characterizing a DSL, the spatiotemporal variations of DSLs at various scales, the harm produced by a DSL on ecological and hydrological processes, and potential regulation measures, significant gaps and challenges remain. Some of these concerns are listed below:

1. The DSL concept has not been adequately defined. At present, the quantitative indices for characterizing a DSL have considered only the soil hydraulic property of SFC, which cannot fully reflect the coupled relationship between soil water and vegetation. Using only the SFC as an upper limit for defining a DSL may lead to an overestimation of the severity of soil drought because some plants can still consume soil water below the SFC and probably survive. Therefore, the definition of a DSL should consider the physiological and ecological responses of vegetation to soil drought. A dynamic index coupling both soil water status (i.e., soil water potential) and the physiological response of vegetation is urgently needed to assess soil desiccation around the world.

2. The availability of soil water in a DSL to vegetation is not clear. After the formation of a DSL, some plants with deep roots can still take up soil water within a DSL with low water potential. Compared with the precipitation in the current year, the availability and associated relative proportion of this soil water are still not clear and may be more important for vegetation growth or survival.
3. Vegetation patterns and associated root characteristics significantly differed among different climatic zones on the LP. More information on the temporal variation of DSLs within different climatic zones is thus needed, and their patterns in relation to long-term land-use practices must be determined including the development processes of DSLs under typical vegetation types within different climatic zones, the relations between DSL temporal variations and vegetation stand ages, and the distribution characteristics of DSLs in both vertical and horizontal directions in the CZ.

4. The SWCCV model provides managers with a useful tool for interpreting the accumulated effects of climatic and environmental conditions on the management of particular vegetation systems. Three improvements to the SWCCV model would involve being able to better deal with management requirements and environmental variability. First, a decision support tool for SWCCV should be established to maximize its accessibility. It should provide spatial and temporal scenario modeling capabilities and allow stakeholders to determine where priority revegetation activities should be undertaken to ascertain what species are suitable for a specific location and to simulate the related hydrological impact on an average annual basis. Second, current SWCCV models do not consider the changes in streamflow and vegetation as a function of time because afforestation occurs in different areas over many years. Moreover, the biomass of vegetation differs significantly among growth periods, which produces large differences even with the same planting densities for the same species. Third, because of the diversity of vegetation structure and species on the LP, simple upscaling is problematic, and it needs to include various soil–water–vegetation interactions in SWCCV models. This would require access to a complex SWCCV model at the regional scale that is suitable for the available database, an understanding of ecohydrological processes, and an adequate calculation capacity of the computer.

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