Monitoring drought and salinity stress in agriculture by remote sensing for a sustainable future

Wen, W.

Summary

Food security is challenged by a growing global population and by climate change. Already, agricultural crops encounter various environmental stresses, limiting productivity and decreasing food production. Of these stresses, drought and soil salinity are considered the most important ones that inhibit crop yield and distribution. Worryingly, climate change is predicted to increase not only their frequency and severity, but also their co-occurrence, exacerbating their impacts. This also leads to increases in events where both stresses co-occur. This co-occurrence results in substantially more yield losses than individual stressors. While detrimental effects of combined drought and salinity stress on crops have been highlighted in small-scale experiments (with only a limited number of crop varieties), large regional uncertainties remain for real-life agricultural settings. Assessing these large-scale impacts using traditional methods is, however, not feasible. In contrast, satellite observations offer a promising perspective for enhancing global food security by providing reliable information on arable land extent and food production. Remote sensing has already been used to monitor crop productivity at multiple spatial and temporal scales, though not for yet characterizing crop growth under co-occurring drought and salinity stress. This thesis aims to assess the impact of drought and salinity on agriculture and sustainable development goals using remote sensing technology.

In Chapter 2, a systematic review was conducted to evaluate the current ability of remote sensing to identify and assess the impacts of drought and salinity stress on agricultural crops through vegetation indices (VIs) and plant traits. The results indicate that challenges still persist in utilizing satellite monitoring of these stress impacts. Specifically, traditional VIs do not consistently estimate these impacts accurately. In addition, plant traits, although promising in linking directly to the biochemical and biophysical pathways of crop growth, are not widely used to reflect upon stress response mechanisms. Osmosis traits in particular have high potential for monitoring the pathways through which drought and salinity affect crops but cannot be directly measured by remote sensing. Other remotely sensed plant traits are highlighted to contain significant potential -to assess the combined impacts of drought and salinity effects on agricultural crops- but only in small-scale experimental studies. Consequently, large-scale studies are necessary to showcase the relevance of remote sensing for assessing combined impacts under real-life agricultural scenarios.

In Chapter 3, a novel approach was proposed that utilized satellite remote sensing observations to estimate the impacts of drought, salinity, and their combination on five crop traits, including leaf area index (LAI), leaf chlorophyll content (Cab), leaf water content (Cw), the fraction of absorbed photosynthetically active radiation

(FAPAR) and the fraction of vegetation cover (FVC) using remote sensing. The approach was first tested in the Netherlands, and results indicate that the exacerbating effects of co-occurring drought and salinity stress highly depended on the moment in the growing season. Moreover, LAI, FAPAR, and FVC were impacted most under severe drought conditions for maize and potato while Cab and Cw were generally more inhibited by combined drought and salinity stress. Thus, this approach facilitates simultaneous monitoring of the effect of drought and salinity on crops in large-scale agricultural applications.

The approach presented in Chapter 3 was adapted to suit the assessment of a larger spatial extent and multiple crops, by applying a pair-wise method of retrieving stressed and non-stressed crops (Chapter 4). Furthermore, multiple techniques were integrated to assess trait expressions concerning drought, salinity, and their combined impacts compared to control conditions, to allow evaluating stress impacts more precisely for a much larger range of crops and spatial conditions. The results across the United States indicate that stress impacts were highly time-dependent and that crops were more susceptible to combined drought and salinity than to individual stress. However, stress impacts also varied significantly between species. Most crops initially decrease primary production capability by reducing LAI before decreasing water or chlorophyll contents. In combination, a quantitative foundation was established for simultaneously assessing crop responses to the occurrence of stresses, both alone and collectively at large scale and under actual agricultural conditions, contributing in monitoring food security upon global climate change.

In Chapter 5, we explored how some of the findings related to large-scale salinity tolerance could be used to aid in achieving sustainable development goals (SDGs). Sustainable agriculture and food security are critical components of sustainable development goals, yet they are increasingly vulnerable to global climate change impacts. While salt-induced stress on crop growth and food production has been extensively studied, quantifying the potential contribution of saline farming on a global scale remains uncertain. In Chapter 5, the local and regional suitability areas for salt-tolerant potato cultivation in salt-affected soils were evaluated, thereby assessing the potential contribution of salt-tolerant potatoes to the current and future SDGs. The results reveal that Oceania (particularly Australia) has the greatest potential for enhancing food production through salt-tolerant potato cultivation in salt-affected soils. Moreover, other countries like Kazakhstan, the Russian Federation, and Australia can address food shortage challenges and achieve SDGs in the current state as well as in future scenarios. Furthermore, the suitability area for salt-tolerant potato is expected to expand even under future climatic and salinity conditions, potentially doubling food production in Kazakhstan and the Russian Federation. Consequently, salt-tolerant potato -as a proxy for saline farming- can promote increased food production in salt-affected areas. Saline farming may thus enhance agricultural resilience and ensure food security.

This thesis emphasizes the potential of remote sensing-derived traits for evaluating crop growth under stress conditions. While it demonstrates the potential of remote sensing to detect stress responses through functional traits, its effectiveness varies across plant species and growth stages, indicating that several challenges are left open to be addressed in future studies. In particular, the identification and selection of representative traits need to be improved to more accurately reflect specific stress conditions at different moments during the growing season. Moreover, current remote sensing for agricultural applications faces challenges related to the increased demands for high spatial-temporal resolutions. We propose multi-platform data integration to improve the accuracy of observations and data fusion in future studies.

In conclusion, remote sensing offers a huge promise for effectively monitoring the attainment of SDGs and ensuring global food security, involving various stakeholders and policymakers. This thesis demonstrates how remote sensing techniques can be applied to detect stress responses and mitigate the impacts of those stresses on global crop production from review to application, offering valuable insights into the potential of remote sensing to enhance food security and address sustainable development goals.