

1.5 Theses of Graduate Courses

(1) Doctoral Theses

Banzragch, N.

Soil moisture dynamics in the cold, arid climate of Mongolia

Summary:

Soil moisture plays a central role in the global water cycle and climate system by controlling the partitioning of water and energy between the land-surface and the atmosphere. Soil moisture acts as a memory of anomalies in the water cycle, in turn, it has a delayed and durable influence on the overlying atmosphere through land-surface fluxes of heat and moisture and plays as a bridge between meteorological drought (deficits in precipitation) and agricultural drought (failures of plant growth). A number of drought indices have been proposed and applied to quantify drought conditions, although, presently very few studies have used ground-observed soil moisture as an indicator of agricultural drought in the world. A large drying trend has been observed in a soil moisture index over land areas in the Northern Hemisphere since the middle 1950s, including Mongolia, affecting the pastureland that is used for livestock. It has been found that soil moisture deficits limit the growth of pasture in Mongolia. Hence, accurate extensive assessment and modeling of soil moisture dynamics in this pastureland is required for reliable and timely monitoring of agricultural drought. This thesis represented recent advances in the observation and modeling of soil moisture dynamics and in analyses of its relationships with climate and vegetation activity in the cold, arid climate of Mongolia with a focus on three vegetation zones; forest steppe, steppe, and desert steppe. This study is the first comprehensive analysis on soil moisture dynamics in Mongolia and moreover, it was revealed the memory processes of soil moisture and vegetation in the cold, arid climate.

Firstly, the seasonal and spatial changes of soil moisture and its climatology and modeling were demonstrated. In this analysis, a unique long-term, updated soil moisture and meteorological datasets for 26 stations during 1986–2005 were used. The results showed that the soil moisture varies seasonally, depending not only on the balance of precipitation and evapotranspiration but also on winter soil-freezing and spring snowmelt. In general, there was a latitudinal gradient in soil moisture content, with the southwestern soils drier than the northeastern soils. The seasonal change in soil moisture was small and the seasonal pattern was similar throughout Mongolia. We documented three distinct seasonal phases; the spring drying, summer recharge, and autumn drying and their relationships to plant phenological phenomena of *Stipa* spp. that represents the dominant species in the Mongolian steppe. Over Mongolia, the available soil moisture was about 30% of the soil field capacity, while in the desert steppe; soil moisture was close to the wilting point throughout the year. A simple water balance model was developed for application in the cold, arid regions such as Mongolia, by considering soil freezing and snow melting. The model simulated the observed seasonal and interannual soil moisture variations reasonably well ($r = 0.75$, $p < 0.05$). This model will provide a useful tool for a reliable and timely monitoring of agricultural drought for decision-making and herding management in Mongolia.

Secondly, multi-decadal trends and memory of soil moisture were assessed in three vegetation zones using the modeled daily soil moisture during 1961–2006. On an interannual basis, the modeled soil moisture was more strongly correlated with the observed soil moisture ($r = 0.91$, $p < 0.05$) than the widely used Palmer Drought Severity Index ($r = 0.65$, $p < 0.05$). All three vegetation zones showed a decreasing trend in soil moisture and shortening in the summer recharge phase due to

decreased precipitation and increased potential evapotranspiration. Although only in the forest steppe revealed significant ($p < 0.05$) drying trend due to significantly decreased precipitation. Soil moisture memory analysis showed that the decay temporal scales of soil moisture anomalies were 6–7 months in the autumn and winter, which is larger than that in spring and summer of 1.8–3 months in the forest steppe. This indicates that soil moisture acts as an efficient memory of precipitation anomalies via the soil freezing and as an initial soil moisture condition for the subsequent summer land-surface.

Thirdly, the relationship between root-zone soil moisture and vegetation activity in the Mongolian steppe was analyzed based on remotely sensed NDVI data for seasonal and interannual periods during 1982–2005. Vegetation activity was more strongly correlated with soil moisture than with precipitation, suggesting that soil moisture plays an important and immediate role in controlling vegetation activity. A comparison between years with high and low vegetation revealed that a significant difference in precipitation led to a half-monthly time-lagged significant difference in soil moisture, finally a difference in vegetation, with time lags of about one month. Interannual fluctuations in vegetation were strongly dependent on soil moisture of the current year ($r^2 = 0.53$) and even more strongly dependent on a combination of the current year soil moisture and vegetation of the preceding year ($r^2 = 0.55$). This result suggests that vegetation anomalies are likely stored as underground structures in the root system. To the best of our knowledge, this is the first study in Mongolia to point to the combination of soil moisture and root memories as predicting parameter for vegetation activity.

Fourthly, new observational evidence of a half year-long moisture memory mechanism mediated by the land surface that is manifested in the cold, arid climate of Mongolia was found. The analysis result showed that significant carryover of summer rainfall anomalies to subsequent years, mediated by the soil moisture–vegetation system. Namely, changes in precipitation led to time-lagged, directly correlated changes in soil moisture and plant production. During the following winter, anomalies in soil moisture were maintained in the frozen soil and biomass anomalies may have been stored as underground structures in the root system. Even though these land-surface anomalies are maintained through to the spring, they were shown only to have had a weak effect on early summer precipitation. Instead, the soil moisture anomalies tended to be disturbed by large-scale atmospheric variations during the summer, producing subsequent anomalies in precipitation, temperature, and evapotranspiration. The cold–season climate with low evapotranspiration and strong soil freezing acts to prolong the decay time scale of autumn soil moisture anomalies to 7.6 months in the steppe, which is the longest in Mongolia and among the longest in the world. In future applications, the concepts of soil moisture and vegetation memories presented in the present study would provide a useful basis for an early warning system of reduced pasture production during drought.

Dhavu, K.

Water saving in irrigation by sand mulch on drip lines

Summary:

Agriculture consumes about 70 % of the developed fresh water in the world. It is possible to reduce the amount of additional fresh water withdrawals by 40 % if water saving techniques are improved. As the water crisis continues to manifest itself, planners and policy makers will continue to be faced by gaps between supply and demand for water and ultimately food. There is, therefore the need to improve water saving techniques to ensure adequate food for future generations with same or

less amount of water than the amount of water that is presently available for agriculture. Surface drip irrigation is the most effective way to supply water and nutrients to the plant and does not only save water but also increases yield of crops. However, irrigation water loss by soil evaporation is inevitable under surface drip irrigation. This study, therefore, attempted to reduce soil evaporation thus improving irrigation water saving through a combination of surface drip irrigation and sand mulch on drip lines. Sand soil was used since it is a readily available material, especially in the sand dune soil areas.

The following aspects were made clear in this study: 1) the quick development of a dry layer on a wet layer of the Tottori sand dune soil and the effect of the dry layer on soil evaporation reduction, 2) the effect of sand mulch on drip lines on the water content of soil, 3) the effect of sand mulch on drip lines on water recharge in the root zone, and 4) estimation of soil evaporation by soil hydraulic factor under sand mulch on drip lines.

The quick development of a dry layer of the Tottori sand dune soil was studied to identify its suitability as a self-mulching material to reduce soil evaporation. Enough water was applied to the sand soil and that was naturally dried. The sand soil quickly dried and formed a dry layer near the surface that covered the lower wet layer. The effect of a dry surface layer on soil evaporation was also studied. Sand soil columns were covered with a 2 cm and 5 cm thickness of dry sand soil. The 5 cm thickness was more effective than the 2 cm with soil evaporation reduction of more than 72 %, compared to a sand soil column with no cover.

To evaluate the effect of sand mulch on drip lines on water content of soil, 0 cm thickness and 5 cm thickness sand soil on drip lines, and three plant densities of 0 plants/m², 12 plants/m² and 21 plants/m² were used. Almost the same amount of irrigation water was applied to the treatments. The 5 cm sand mulch on drip lines maintained higher water content of soil than the 0 cm sand mulch. The higher water content of soil under 5 cm sand mulch on drip lines resulted in higher plant height and higher dry matter yield.

To evaluate the effect of Tottori sand dune soil on water recharge in root zone, two irrigation levels of 60 % and 100 % of evapotranspiration, and three sand mulches of 0 cm thickness, 2 cm thickness and 5 cm thickness were used. Water recharge in the root zone under 5 cm sand mulch was the highest of the three sand mulches. The 2 cm sand mulch was not practical because of the protrusion of the drip lines from the sand mulch. To increase water recharge in the root zone, the minimum thickness of sand mulch on the drip lines was 5 cm.

Estimation or measurement of soil evaporation is important for quantifying water saving in irrigation. To derive a soil hydraulic factor, potential soil evaporation was estimated from small evaporation pans and actual soil evaporation was measured from sand soil columns under 0 cm sand mulch, 2 cm sand mulch and 5 cm sand mulch. Actual soil evaporation from field condition was measured by weighing lysimeters, and the actual soil evaporation was compared with soil evaporation estimated by the soil hydraulic factor. The soil hydraulic factor gave better estimates of cumulative soil evaporation under 0 cm and 2 cm sand mulch than that of 5 cm sand mulch.

The quick development of a dry layer on the sand soil surface makes it a suitable self-mulching material. Sand mulch reduces soil evaporation, thus sand mulch can be used to increase water saving in irrigation. The sand mulch on drip lines can maintain a high water content of soil, and increase water recharge in the root zone. Maintaining a high water content of soil and increasing water recharge in the root zone results in saving water in irrigation. Estimation of soil evaporation using the

soil hydraulic factor becomes more difficult as the sand mulch thickness increases. Covering drip lines using 5 cm sand mulch is practical in a normal farming operation. No special machine is necessary to cover the drip lines by 5 cm of the sand soil. It is easy to remove the drip lines after the growing season or harvesting. The combination of surface drip irrigation and sand mulch is effective in saving more water in irrigation than only surface drip irrigation.

LI, L.

Effects of the grain for green program on rural household productivity and efficiency in Loess Plateau, China

Summary:

The Loess Plateau, with the most serious soil erosion worldwide, is among the most poverty-stricken areas in China. Land reclamation, overgrazing and deforestation for growing foods and subsistence needs aggregate both the economic and environmental circumstances for the farmers and brought about significant negative externalities, in the past decades. The Chinese government responded with a Program called Grain for Green Program (also known as the Sloping Land Conversion Program) in 1999. The Program committed to sustainable development of the target area through financial support, technical assistant and institutional improvement at national or regional scale, with an intention of prevent the unsustainable agricultural practices through improvement (or at least maintenance) in agricultural production, and transfer of surplus labor force to off-farm jobs.

Indicators of total factor productivity (TFP, measured as the ratio of aggregate output to aggregate input) and technical efficiency (TE, measured as the ratio of actual to potential output) are of particular significance for evaluating the Program with a goal toward sustainable development. The objectives of this study are to shed some light on issues related to effects of the Program based on TFP and efficiency indicators and find out ways to improve the effectiveness of the Program.

Specifically, the study addresses the following mutually related questions:

(1) What changes had been induced by the Program on TFP and TE at the farm level? Among the components of TFP growth - technological growth and changes in TE, what is (are) the driver(s) of TFP change? What are the factors responsible for the changes in TFP and its components?

(2) How is the rural households' efficiencies at the farm level under the prevailing circumstances, including the emerging technology and shrinkage of land area, etc., brought about by the Program? What are the factors responsible for the inefficiencies at the farm level?

(3) Off-farm income has increasingly become an important income sources for the participant households. It not only reshapes the labor allocation of the rural households, but also affects their agricultural production and household welfare. So how is the farm-household technical efficiency (or TE at the farm-household level) after the implementation of the Program? What are the factors responsible for the inefficiencies at the farm-household level?

Here by farm level, TFP and efficiencies are estimated with only agricultural inputs (e.g. land, labor, capital and material) and outputs (e.g. crop and livestock); and by farm-household level, efficiencies are estimated with not only agricultural inputs and outputs, but also inputs (e.g. labor used in off-farm jobs) and outputs (e.g. off-farm income) used in off-farm employment.

To answer these questions, three investigations were taken with random sampling in the study areas, including Zhifanggou catchment and Xiannangou catchment, in 2008 and 2009. Zhifanggou catchment and Xinannangou catchment are located in Ansai County, Shaanxi Province on Loess

Plateau. They are agriculture-dominated areas with semi-arid continental climate. The economic, social and ecosystem environment are typical in the rural society of the Loess Plateau, and both of them were among the pilot areas in the Grain for Green Program, which makes the observations and references in this thesis reliable and significant.

The first question was answered with a case study using panel data in 1999 and 2007 of 59 sample farm-households from Zhifanggou catchment. TFP changes at the farm level was estimated and decomposed using data-envelopment-analysis based Malmquist-TFP-index, and then TFP changes and its components were regressed against with some variables of farm-specific socio-economic characteristics and measures participations. The result shows that TFP has been greatly improved by 52.5%. The improvement in TFP stemmed solely from technological growth, which increased by 76.0%. In contrast, the TE of farms under the improved technology has decreased by 13.5%. The distribution of TE turned to be more equal. And the regression analysis shows, land terracing is the only variable that is significantly related to TFP growth, technological growth and changes in TE and its directions are all positive; Access to credit is positively related to TFP growth and technological growth; Extension services are positively related to technological growth, while age is negatively related to changes in TE.

The second question was answered with a case study using cross-sectional data in 2007 of 112 sample farm-households from Zhifanggou catchment and Xiannangou catchment. Second stage data-envelopment-analysis were employed at a farm level for the purpose, in which the first stage involves an estimation of the efficiency scores using data-envelopment-analysis, and the second, a regression analysis of the farm-specific socio-economic variables against the obtained efficiency scores. The first stage analysis suggests the existence of substantial inefficiencies under the improved technology together with other changing context within the framework of the Program. Cost efficiency (CE) averaged at 0.274 (0, inefficient; 1, perfect efficient), allocative efficiency (AE) 0.389, TE 0.689, SE 0.819 and PTE 0.821. The distribution and statistic analysis shows scale inefficiency was mainly due to suboptimal size of farms. And regression analysis shows, farm size is the only variable that is significantly related to AE, TE and SE and its directions are all positive. For other significant variables, tenancy ratio and Simpson index are negatively related to TE and SE; and remittance ratio is positively related to TE and SE. Tenancy ratio is given as the ratio of rented cultivated land to total cultivated land, the negative relationship suggest the more land rented from others, the little TE and SE. Simpson index is given to measure land fragmentation, where higher value means more fragmented, the negative relationship suggest land fragmentation decreased farm TE and SE.

The third question was answered with a case study using cross-sectional data in 2007 of 59 sample farm-households from Zhifanggou catchment. A household model was given to estimate farm-household TE, and they are regressed against with some variables of household-specific socio-economic characteristics. The result shows that farm-household TE is still quite low, averaged at 0.356. Regression analysis suggests that, the extent of off-farm involvement is positively related with farm-household TE. And land fragmentation is negatively related with farm-household TE.

To sum up, the results of the case studies as shown in our study, suggest that farm TFP, technology has greatly improved as a result of the Grain for Green Program. Farm TE becomes more equally distributed. Terracing sloping land, providing access to credit and extension services, expanding farm size, secure land tenancy, alleviate land fragmentation and facilitating off-farm employment and rural-urban migration would improve the effectiveness of the Program toward

sustainable development of the Loess Plateau, from productivity and efficiency perspective.

Mohamed, A. A.

Developing an index based on surface temperature for assessment of moisture availability over vegetated land

Summary:

In arid regions of the world, agricultural production is limited by the availability of water and severely affected during times of drought. Drought occurs when there is insufficient soil moisture available for plants. The available soil moisture in the root zone is the central issue in food security. This background highlighted the need of a reliable indicator for the surface wetness status. Thermal inertia represents a measure of the material's resistance to temperature change, and it is a function of the material's conductivity and heat capacity. Water has a large heat capacity and heat conductivity, so the thermal inertia of wet soil is larger than that of dry one. This fact makes thermal inertia a useful physical parameter that indicates the surface wetness; however, it cannot be measured remotely, instead it is inferred from the diurnal surface temperature range, especially from the difference between daytime and nighttime surface temperature. It is commonly used in surface soil moisture estimation for bare land. When there is vegetation cover, since the surface wetness is a function of soil surface water content plus leaf water content, this complication limits the use of thermal inertia on vegetated cases. Therefore, the effects of physiological activities, that is the change of vegetative surface temperature due to the transpiration, have to be taken into account to develop an effective index based on diurnal surface range for assessing and monitoring the surface wetness. This research is the first attempt to apply the diurnal surface temperature difference to model vegetated surface wetness metric (referred to as moisture availability (m_a)); defined as the ratio of actual to reference evapotranspiration ET) through combining meteorological data and surface energy balance models. This research conducted on the Loess Plateau of China, which is a water scarce region under threat of drought.

A new index was proposed, Normalized Day-Night Surface Temperature Index (NTDI), which normalizes the maximum daytime surface temperature and the minimum nighttime surface temperature, by the difference between the simulated maximum and minimum surface temperature, estimated from meteorological data by applying energy balance equation. The simulated surface temperatures represent the hypothetical maximum diurnal range of surface temperature (when $ET = 0$), which is determined only by the meteorological condition.

Firstly, the potential use of a diurnal surface temperature range to estimate the surface wetness metric (i.e. moisture availability (m_a)) was investigated. The diurnal surface temperature range $T_{s(day)} - T_{s(night)}$ (the maximum daytime surface temperature minus the minimum nighttime surface temperature), was weakly correlated with m_a . This could be attributed to that, since moisture availability is a ratio between the actual ET determined by physiological and meteorological parameters, and reference ET represents the atmospheric demand, determined by only meteorological parameters, the divide process left the moisture availability just a representative of biophysical varieties. However, the diurnal surface temperature range is determined by both biophysical and meteorological conditions. Accordingly to improve the moisture availability estimate, the effects of varieties of physiological activities on $T_{s(day)} - T_{s(night)}$ has to be separated from the effects of meteorological variables. The NTDI showed a significant inverse-exponential correlation with m_a ($R^2 = 0.97$, $p < 0.001$). This result indicates that the normalization relative to the index denominator (represent the hypothetical maximum range of surface

temperature, determined only by meteorological condition) dramatically improved the accuracy of estimation. The relationships between the NTDI and soil moisture (θ) for each soil layer from the surface to the root zone and the averaged θ of all layers were examined. The NTDI was found to be most highly related to the total soil moisture, but less so to that in the near surface layer. This result implies that the moisture availability is a combination of transpiration and evaporation. The transpiration through the root system is representing water uptake in the entire soil layers down to the root zone, as well as evaporation at ground surface.

The NTDI was used as a metric of moisture availability (m_a), based on point observed meteorological data, and then its application was extended to wide area by combining MODIS (Moderate Resolution Imaging Spectroradiometer) land surface temperature (LST) and ground-based meteorological data. MODIS remotely sensed day/night LSTs offer considerable advantages and should be an integral part of monitoring drought, especially for the temporal and spatial evolution of drought. This is still a challenge to remote sensing, especially in vegetated case. The combination of both meteorological data and remotely sensed land surface temperature on daily basis from MODIS provides potential to derive m_a assessment over a region scale. The accuracy of MODIS to retrieve the land surface temperature was assessed. The effect of the sensor passing time on stability of NTDI calculation was also assessed. Finally, NTDI estimate was expanded over 100-km² area in the Loess Plateau. The NTDI map showed similar spatial pattern to that of NDVI image and land use classification map. However, comparison between NTDI and NDVI for each land use, indicated that the spatial distribution of NTDI reflects surface wetness variation more precisely than that derived from NDVI, as the ranking of wetness of the different land uses (obtained from unsupervised classification) based on NTDI coincides with the former studies, estimated the ET for these land uses in the Loess Plateau. Land use with large ET corresponds to that with the high moisture availability and low NTDI. Based on NDVI, the land use ranking did not agree well with ET ranking.

This research indicates that the NTDI is a robust indication to quantify the moisture availability (m_a). Moreover, NTDI based on combining remotely sensed and meteorological data effectively represents the spatial distribution of moisture availability, which can provide a potential drought assessment tool over local to large-scale. Such assessments can be used as regional measures of drought stress, as tools for planning water allocation, or as indicators of the efficiency with which water is being used.

(2) Master's Theses

Fukushima, M.

Effect of transpiration and root distribution of tree on the level down of groundwater

Kubota, S.

Effect of biological soil crusts on rainfall infiltration in the afforestation sand dune areas of China

Makino, R.

Evaluation of efficiency and sustainability on surface/subsurface drip irrigation with saline water in southern arid regions of Tunisia

Sakai, H.

Effect of soil erosion prevention based on soil and water conservation measures of farmers' participation in sloping olive groves in northwest Syria