1. Summaries of Doctor Theses

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Study on Albedo and Heat Balance of Tottori Sand Dune

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The agricultural development of sand dunes has been gradually receiving attention as a result of rapidly increasing populations. Management of soil water is very important to the efficiency of agricultural activities in arid and semi-arid regions. The assessments of heat and water balance usually employ many micrometeorological parameters. It is difficult to do so using routine meteorological data, although many attempts have been made to use empirical or semi-empirical equations, particularly in arid and semiarid regions. To effectively assess heat and water balance, it is necessary to develop a simple model using routine meteorological data.

The aim of this study is to develop a simple estimation model for albedo, net radiation and soil surface temperature since these factors are very important to the heat and water balance.

Micrometeorological experiments were conducted on a sand field from August to November in 1997 and in 1998 in the Arid Land Research Center, Tottori University. During the experimental periods, soil water content at the surface and at a depth of 1, 2, 3, 4, 5 and 10 cm were measured at 9:00 a.m. every day. The following results were obtained.

(1) Relationship between albedo and soil water content

The effect of soil water on albedo is marked. The albedo decreased linearly with increasing soil surface water content in the range of about 0.003-0.035g g^{-1}. In cases there the soil water content is more than about 0.035g g^{-1}, the albedo remained almost constant.

The albedo changed with soil water content at 1, 2, 3 and 4 cm depths in three steps. The albedo decreased linearly with increasing soil water content over a small range (0.06-0.07 g g^{-1}). Outside that range, the albedo was essentially constant.

(2) Model estimating daily albedo

The recovery of albedo on dry spell days after rain is a natural phenomenon. Daily albedo quickly decreased on rainy days, and recovered on dry spell days (days between rainfalls). A strong exponential relationship was found between daily albedos and the number of dry spell days. The daily albedo during dry spell days also showed a direct relationship with daily transmissivities in a range less than 0.55.

Two simple models for estimating daily albedos in dry spell periods were developed for bare sand surfaces. For Model #1, the daily albedo was successfully predicted using the number of dry spell days. The correlation coefficient between the estimated and measured albedo was 0.73 with a standard error of 1.2 %. For Model #2, the number of dry spell days and transmissivity were incorporated in order to calculate the daily albedo on dry spell days. The correlation coefficient was 0.85 with a standard error of 0.9 %. Estimated albedos were in good agreement with measured albedos. The albedo on rainy days was simply determined using the rain patterns.

(3) Model estimating net radiation

Net radiation is the largest energy source in the energy balance. A new formula for estimating net radiation was derived from Linacre's equation (1968) using routine meteorological data. In our formula, only the solar radiation, albedo and air temperature were employed, and humidity was avoided. The correlation coefficient between the calculated and measured values was 0.95 with a standard error of 1.0 MJ $m^{-2}day^{-1}$.

(4) Model estimating soil surface temperature

Soil surface temperature is an important factor in the earth-atmosphere energy budget. It also affects soil water content as an important element.

Based on heat balance, a simple model for estimating the mean daily temperature on bare soil surfaces using soil water content at a depth of 0-1 cm was developed. The estimated temperature agreed with the measured value with a correlation coefficient of 0.99, and a standard error of 0.87. Another model was derived from the relationship between albedo and soil water content using albedo. Results showed a correlation coefficient between measured and estimated surface temperatures (0.99); the standard error of estimated temperature was 0.94 ℃.

(5) Energy fluxes

To further verify the models proposed in this study, the energy fluxes and related factors were calculated using only the measured date of solar radiation, air temperature, wind speed and precipitation. These results showed that the estimated values matched the observed values.

The major result of this study is that a simple method evaluating the heat balance of sand dune was developed. This study is believed to be very worthy for quantitative assessment of heat balance in arid and semi-arid regions where meteorological data is still inadequate.

Application of Tank Irrigation in Promoting Agriculture in Low Rainfall Areas of Ghana

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A major hindrance to the attainment of sustainable agricultural production in the dry sub-humid to arid regions of the world is the availability of water in sufficient amounts. These areas are characterised by infrequent rainfall which, when available, is often torrential resulting in flooding and erosion problems. This cycle of flooding and drought causes lose of harvest and food insecurity. In order to redress this problem and assure year-round sustainability in agricultural production, the tank irrigation system is proposed. It comprises a harvesting apron for concentrating and collecting runoff from rainfall. The harvested water is channelled into a storage tank and loss of water from the tank by seepage and percolation is minimised by lining the tank and planting trees around the tank to minimise evaporation loss from the stored water in the tank. The tank may also be covered or sunken to eliminate evaporation. Irrigation water is extracted from the tank and conveyance and application inefficiencies are minimised to make maximum use of the stored water. The objectives of this thesis are to study the mechanism and factors affecting tank system design and to determine its suitability for providing sufficient agricultural water in selected agro-ecological regions in Ghana.

1. As justification for the promotion of tank irrigated agriculture in areas of little or unreliable rainfall and high evaporation, three sites in Ghana are selected for this study. The natural environments of these regions are presented and climatic parameters of rainfall and Penman evapotranspiration are analysed. Information on soils and crops is also presented. Penman evapotranspiration is computed on a daily basis from daily meteorological data for the determination of water requirements. Statistical analyses of annual rainfall, Penman evapotranspiration, deficit rainfall, annual no-rain days and maximum continuous no-rain days are conducted. The results form the background information, which support the introduction of irrigated agriculture in these ecological zones because of erratic rainfall, high evapotranspiration, low available soil moisture and long periods of no-rain days. It also suggests the adoption of the tank irrigation system and recommends the incorporation of drip irrigation, which has advantages of high water use efficiency, reduced evaporative demand, and a small apron area and tank capacity.

2. Tank irrigation derives its water from rainfall, harvested from an apron and stored in a tank for irrigation. This implies that promotion of high runoff from the apron is desirable though its accompanying adverse erosion effects must be curtailed as much as possible. Rainfall-runoff experiments on Tottori dune sand, packed into a slope were undertaken under glasshouse conditions in order to understand the rainfall-runoff process. The object was to find ways to enhance runoff from highly permeable soils while reducing erosion and soil loss. Treatment of the dune-sand slopes by topdressing with a layer of less permeable soil was found to be promising in achieving this objective. The results obtained from controlled glasshouse conditions show that drastic reduction in infiltration rates can be achieved through treating permeable soils with a thin top dressing of less permeable soil material. This generates high moisture content regimes in the surface of the soil thus enabling this layer of soil to attain saturated conditions necessary for runoff generation. Additional work is however required to fully incorporate the results obtained into the tank irrigation system design. Results obtained from field runoff experiments in Niger were used to simulate the tank irrigation system process.

3. In order to make the most use of the water harvested from the apron, the mode of evapotranspiration from drip-irrigated fields was examined using different models. Since climate plays a role in the moisture dynamics of the soil, a suitable evapotranspiration model which best represents the situation in Ghana was

chosen for use in the tank irrigation model. It is proposed that since arid and semi-arid regions do not experience reliable rainfall, only the areas directly affected by drip irrigation can sustain root development so that evapotranspiration will be related to the wet fraction of the field under irrigation. The resulting model is more suitable for the dry semi-arid areas and is different from the model adopted by the Ministry of Agriculture in Japan, a country that experiences high rainfall throughout the year.

4. Using soil, crop and climate data from the sites and rainfall-runoff ratios from Niger, a computer simulation is used to show that tank irrigation offers a sustainable alternative to rainfed agriculture in Ghana. Water balance of the rainwater catchment apron, water storage tank and a 5000 m^2-cultivated field is simultaneously carried out bounded by the condition that the tank does not empty during the period of simulation. Suitable apron areas are determined for three crops grown under different climates using sprinkler and drip irrigation. Results indicate that drip irrigation economises on apron area by as much as 41% in the case of citrus, 22% for Tomato and 28% for maize compared to sprinkler. Optimum tank capacities are also economised by over 40%. This is attributed to the reduced field evapotranspiration under drip irrigation. The type of irrigation makes little difference on the apron area in moist conditions. This is because under this condition wetted fraction is nearly equal to unity and soil moisture condition as well as the mechanism of evapotranspiration under drip is similarly to that under sprinkler irrigation. A small tank capacity produces excessive tank overflow during a good rainfall year. This is made worse under sprinkler irrigation because of the longer irrigation interval. A low rainfall year causes the system to have a large apron area that also causes excessive overflow in good rainfall years.

The combination of crop, climate, irrigation method and evapotranspiration models, produce optimised tank irrigation system dimensions based on the current knowledge of the subject. Further work in the field will be carried out to confirm or dispute the results of this simulation and to obtain a further understanding of the processes involved. In the long term, it is expected that a working model will be developed that will enable design standards to be set for the implementation of tank irrigation systems as a means for combating the serious shortfall in agricultural water. The author hopes that this will set the pace towards agricultural sustainability and self-reliance in these regions.

Effect of Topography on Plant Growth of Air-seeding on Desert Control in China

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Desertification is a land degradation process that occurs in arid, semi-arid, and dry sub-humid environment, induced by various factors, including changes in climate, other natural stresses, and human activities. Desertification plagues all regions of the world and causes globe environmental degradation, and has been recognized as the top issue out of the ten problems threatening worldwide human civilization. It is estimated that approximately one-sixth of the world's population is threatened by desertification. The related international organizations have repeatedly cautioned countries affected by desertification to seek appropriate countermeasures, including policies and projects, to combat the problem. In China, approximately 1,533 thousand km^2 or 16% of the land area is under threat of worsening desertification.

Mitigation measures for desertification, in general, are mainly grass and tree planting. Re-vegetation is not only a good economic policy in short-term, but is capable of providing long-term sustainable solution. The objective of this thesis is to examine the grass and tree planting practices in Mu Us and Kubuqi deserts of China in-order to identify most effective planting sites and appropriate management practices for each location.

1. Air-seeding was carried out in 120 thousand ha of land that was in a progressive stage of desertification in Mu Us and Kubuqi deserts in Inner Mongolia, between 1983 and 1995. Mu Us and Kubuqi deserts are 250 and 160 thousand km^2 respectively. Using the vegetation data from 138 plots on plant species selection and seeding rate the following conclusions have been tentatively reached. (1) The most suitable plant specieses are *Hedysarum mongolicum, Artemlsia sphaerocphala, Astragalus adsurgens, Melilotus suavealens.* (2) Low seeding rate of 6.0-7.0$kg \cdot ha^{-1}$ produced better results with seed treatment . The other important factors investigated were the relation of seeding time, average sand dune height, sand dune density and natural plant cover, the plant cover rate after air seeding. These were established using the Quantification Theory I. The results are as follows. (3) Suitable seeding time is from May 25 to June 25. (4) Land types suitable for air-seeding have average sand dune height between 0-10m, sand dune density below 75%, and a natural plant cover rate of 12-25%.

2. Soil water status may vary depending on the topography and the direction of slope. To study the mechanism of topography influence on plant establishment, the most appropriate approach would be to conduct studies at local sites. However, in practice this approach not feasible. Therefore, simulation and basic experimental studies were conducted at the Tottori University's Arid Land Research Center, Japan. For simulation studies, The SWMS_2D model was used. The unsaturated soil hydraulic properties have been described by several closed-form equations similar to that of van Genuchten's. I selected new equations, because new equations are more appropriate for dune sand than that of van Genuchten. Initial and boundary conditions were established, using column experiments, for basically experiment in Tottori (show in 3 and 4 section).

3. Field and Glasshouse experiments (bare soil condition) on Mu Us sand dune (nature) and Tottori dune sand (artificial) were conducted to better understand differences in soil moisture status on different topographic positions and for conserving soil moisture using artificial zeolite. In the Mu Us desert experiment, two sand slopes with inclination of 8°(facing north) and 28°(facing north) were used. In the Tottori sand dune experiment, six sand slopes with inclination of 8°and 20°and 30°, three facing south and three facing north respectively, were used. In the glasshouse experiment, eight sand slopes with inclination of 20°and 30°, respectively, four facing south and four facing north respectively, and superimposed with

artificial zeolite application. Water movement in sand slopes and soil moisture conservation through artificial zeolite use indicated the following. (1) South-facing slopes received higher radiation than in north-facing slopes. (2) Soil temperature of south facing slopes at various depths were also higher than in north-facing slopes. (3) Though the soil moisture in the 0-10cm of soil depth of south facing slope was less than the north-facing slope, that at depths>10cm was similar, because, the dry sand layer reduced evaporation from at depth>10 cm. (4) Factor analysis showed that surface soil moisture was positively correlated with precipitation and air humidity, and negatively with the difference between air and soil temperatures, and the accumulation of solar radiation. (5) Average relative error is 13% between the measured moisture and that simulated by SWMS_2D. (6) In zeolite amended slopes the soil moisture content was higher than that in the un-amended slopes.

4. Glasshouse experiments were conducted in 1997 and 1999 to investigate the influence of two topography related factors, viz., the direction towards the sun and field slopes on grasses growth. Soil water management schedules, based on average precipitation from July to August in Mu Us desert of Inner Mongolia, were mimicked in Tottori. Two sand slopes facing north at 20°and 30°inclination, and another two slopes facing south with similar inclination were planted to grass(*F. arundinacea Shreber*). Grass growth and water stress were monitored and the highlights of results are as follows. (1) South-facing slopes received higher radiation which induced larger evapotranspiration and soil moisture loss. This produced water stress under limited irrigation application and stunted grass growth. (2) Water movement from the upper to lower slopes led to low soil moisture status in upper slopes. Grass growth in the upper section of slopes was therefore poor and stunted compared to that in lower slopes. (3) It is suggested that increasing slope inclination had higher gravitational pull induced stress on grasses. (4) Though the climatic and other conditions, differences in soil texture, field size, and plant species, prevailing at ALRC and Mu Us desert are different, the approaches used and results obtained at ALRC are applicable, similar and compatible to Mu Us desert. (5) Average relative error between the measured moisture and that simulated by SWMS_2D is 51%.

The model SWMS_2D, incorporating land characteristics, climate, plant, and evapotranspiration, was used to assess and optimize efficient places for grass and tree planting and found to be unsatisfactory. However, modeling would be most economical approach for this type of problem. Thus, it is proposed that in the future, field studies will be conducted to clarify the results of this model simulation and to expand the understanding of the processes involved. In the long-term, it is expected a working model will be developed that will enable the computation of efficient design standards for grass and tree planting in arid and semi-arid environment to combat desertification.