Semiarid Terrain Alteration for Converting Dryland into Arable Land – Construction and Earthmoving perspectives

This is a draft for a paper by [Jochen Teizer] and [Joseph Louis] which will be presented in July2022 at the upcoming International Symposium on Automation and Robotics in Construction of ISARC (https://www.iaarc.org/symposia)

Abstract

15% of world surface area is semiarid where 1.1 billion live, the most vulnerable people on earth. In contrast to arid, semiarid regions have substantial rainfall albeit is quickly evaporates and therefore vegetation and biomass growth is limited. A new concept developed by ReSlope Global calls for terrain alteration by earth moving to construct north-south slopes where on the northern slope in the northern hemisphere solar irradiation is reduced, causing in turn a reduction in evapotranspiration (ET), allowing for cultivation. The dimension of the slopes (or ridges) is on the order of 5-10 meter and its slope angle in the range of 15-20 degrees. This paper provides the motivation for such development, an overview of the necessary R&D for implementation. It also focuses specifically on the earthmoving operations that are involved, the equipment it requires and discusses the potential for employing robotics and automated construction methods to improve the economic and environmental feasibility of such an endeavor.

Introduction

World arable land in 2020 has been reduced to 44% of the available arable land in 1960 while world population has increased during this period by a factor of 2.63. This would mean that in 2020 each unit of arable land must produce 2.63/0.44 = 5.97times more in comparison to a unit land in 1960 and such an increasing productivity is hard to achieve. Therefore, to assure world food security more arable land is required. This could be achieved by creating a new "Green Revolution 2.0" for the semiarid world by the alteration of its terrain to enable new extensive agriculture mode by retaining rainfall through reduction of evapotranspiration (ET). The concept imitates vegetation patterns on hilly terrain in nature and is in its inception phases. We hereby provide an overview and a preliminary assessment from the construction and earthmoving point of view.

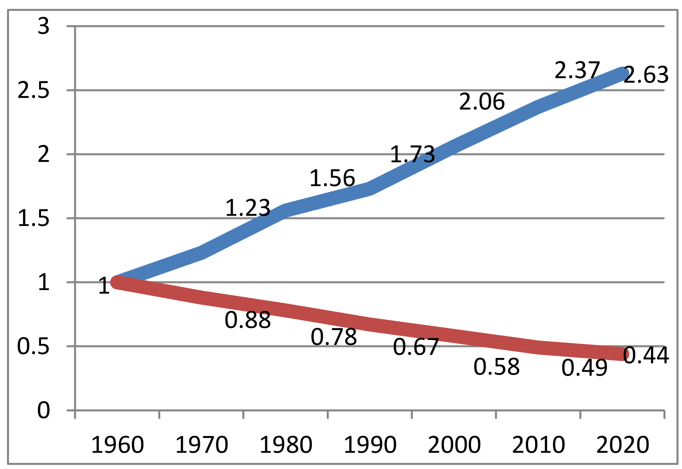

Figure 1: World population and arable land, 1960-2020. (Source: FAO)

Artistic conception of earthmoving and construction of the north south slopes

Related research

Research on semiarid agriculture is limited in comparison to that of agriculture in temperate zones (1), (2). Only a few industrialized countries have significant semiarid cultivation expertise such as in Australia, US Southwest and Israel where semiarid land in used in intensive agriculture where large amounts of resources.

Figure 3: Cultivation of the northern slope

As shown in Figures 4 and 5, the northern slope is lush, moist and green; the southern slope is dry and unusable. Only the northern slope is potentially cultivable. The new concept imitates vegetation patterns on natural north-south slopes. Consider the following example: The annual precipitation in London, UK is 24 inches, while the annual precipitation in Dallas, TX is 35 inches. And yet London (51 Deg latitude) is green and lush while Dallas at latitude 31.5 Deg is semi-arid. A small difference in latitude and solar irradiation flux can cause a dramatic difference in vegetation and bio mass productivity.

Figure 4: Typical natural North-South slopes in semiarid areas.

Figure 5: Public Work, San Angelo, Texas. Grass appeared spontaneously on northern slope two weeks after digging

The concept outlined hereby is new and requires R&D on agronomic, plant and soil sciences, hydrology, climate and rainfall pattern and atmospheric land interaction. An R&D international collaboration has been formed with research groups from Spain, Italy, India, China and all are interested in implementation in their respective countries. The main variables for cost/benefit analysis are the cost to construct the slopes and the water "cost avoidance" by the water gain by rainfall retention. This paper explores the technologies that could be used to create and construct the slopes to provide cost-effective for new semiarid arable land.

Figure 6: Cultivation of the Northern slope

Made-man slopes

The northern and southern slopes' widths are divided in a ratio of 2:1 or 3:1 in order to maximize the cultivable northern slope area. The southern slope is steeper and therefore, to prevent soil erosion it will be covered by a plastic sheet. The sloping angle of the northern slope will be determined by the "necessary" reduction of evapotranspiration required for different climates and crops intended for cultivation.

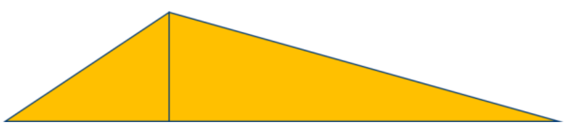

Figure 7: Cross section of the slopes: Steep southern slope is covered with Plastic sheet to prevent soil erosion; Topsoil below the plastic sheet is scrubbed and placed on the northern slope

The amount of earth moved by the construction of the slopes is proportional to the cross-section area of the slope triangles, which is proportional in turn to the square of the dimensions of the slope. To minimize the amount of earth moved and its associated cost, narrow slopes are preferable. But from the agronomic point of view wider slopes are more practical. In this program we will determine the optimal dimensions to address these considerations.

The reduction of solar energy on the slope is expected to reduce evapotranspiration (ET). A shallow sloping angle will not produce enough reduction in solar input and reduction of ET. On the other hand, an overly steep angle will excessively reduce solar radiation and photosynthesis and also increase soil erosion and water runoff. An optimal altered ET will define the sloping angle for the "necessary" reduction of ET in comparison to that on flat terrain. The necessary ET will depend on local climate, growing seasons, and intended crops.

Any reduction of ET will decrease the difference between local precipitation and ET and the irrigation water requirement. The ideal case is when the new altered ET is less or equal to local precipitation. The altered new ET will determine the required sloping angle.

One concern is that the sloping terrain's soil will erode, requiring frequent correction and earthmoving. The steeper southern slope, which is more susceptible to erosion, could be covered by a plastic sheet. As for the northern slope, we can learn from how hillsides are stabilized for crops such as grapes and winter wheat.

Figure 8:

Figure 8: Hillside Cultivation – We Can Learn How Soil erosion and Water Runoff are Prevented inCultivation on Natural slopes and implement the Lesson to our Man-Made Slopes

The topsoil on the southern slope below the plastic sheet could be scrubbed and placed on the northern slope. Also, if soil is eroded on the northern slopes, it is not necessarily lost; it will accumulate in the areas between the slopes and if necessary, could be spread on the slope every few years.

Mathematical models of soil erosion and water runoff are difficult to do with acceptable accuracy, so these topics could be studied on vegetation grown on natural hilly slopes.

Danger to wildlife will be assessed and passage for desert animals will be created each few slopes to allow easy passage. An assessment of the impact on biotics will also be done by the agronomists and soil scientists taking part in this program.

15% of the world surface area is semi-arid where 1.1 billion people live. The N-S slopes have the potential to produce jobs, to promote economic development and to provide food security for developing countries. In some cases, agribusiness corporations are likely to invest, buy land, upgrade and cultivate it for export.

Geoinformation and Survey of potential sites

Detecting differences between vegetation growth on natural sloping terrains with different inclination could be done using spaceborne synthetic aperture radar (SAR). Differences in vegetation between adjacent areas can be detected using SAR remote sensing techniques. This may be done for testing and demonstrating that indeed natural sloped terrains have different vegetation covers (3).

Spaceborne SAR has been used extensively to map and monitor vegetation since the 1990s, when the first SAR missions were launched. SAR sensors are active systems that transmit a coherent radar signal to the Earth's surface and measure the characteristics of the response backscattered from the target area. The interaction of the radar signal with vegetation is a

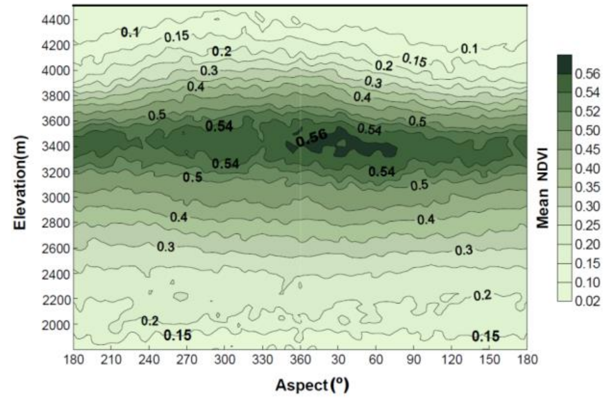

Figure 9: The change of the mean NDVI values with elevation and aspect in the northern part of Qilian Mountain. A Gaussian smooth filter was used and a low pass convolution was performed on the grid data to present a more consistent and smoother map. Note: a refiner scale (0.02) was used when the NDVI value is larger than 0.5 (Jin et al., 2008).

Construction of the slopes

The cost of earth moving cannot be compared to the cost of earthmoving done on relatively small areas such as for the foundations of buildings and road construction. In these operations earth is dug by bulldozers and excavators and is transported to certain distances by trucks.

Figure 10: Earthmoving for north south slopes construction

In contrast, the terrain alteration for Reslope Global does not require actual moving of earth. The average level of the terrain remains the same as before the operation. It requires relatively shallow digging and landscape alteration without transporting earth. Despite this relatively localized work scope, the areal spread of the project makes earth moving a very important consideration. Furthermore, given the sustainability goals that are being targeted by the conversion of arid to semi-arid land, the earthmoving operations need appropriate planning to ensure that their cost and impact to environment are minimized in order to ensure the long-term economic and environmental feasibility of this project. Towards that end the following aspects are proposed for planning the earthmoving in this paper: (1) earthwork planning and analysis, (2) equipment selection, (3) construction and maintenance operations, (4) automation of operations, and (5) public perception.

These topics are discussed in the following sections.

1. Earthwork Planning and Analysis

The primary metrics of interest towards obtaining the cost estimate and schedule for the Reslope operations is determining the following metrics about earthwork: volume of earth to move, haul distances, haul grades. These will inform the selection of equipment fleets and the total time and cost for project completion. Mass haul diagram will be employed for earthwork planning to obtain these measures.

- Earthwork planning with mass haul calculations: In order to convert a terrain of arbitrary topography to a sloped terrain, the contractor determine the amount of earth to be moved and the distance over which such movement occurs. This requires capturing the Digital Terrain Model (DTM) of the 10 sq. mile area, preferably using arial lidar survey; and overlaying it with the proposed sloped terrain to identify where the cut and fill sections of the project would be. For purposes of planning, the entire area would be subdivided into a grid of 10x10 sq.ft. The difference between existing and planned terrain will provide an identification of cut and fill grid sections, cut and fill elevation differences, and volume to be moved between grid sections. These factors will inform the choice of equipment to be employed.
- Contract administration: The contract for the earthwork will expect to be paid on a unit-cost basis per unit volume of soil. The exact amount of the unit cost will be determined based on existing project site conditions.
- Operation Time: Because the work is expected to be conducted in a semi-arid location, the most effective time for performing the primary earthwork tasks would be during or (preferably) just after the wet season. This is because the rainwater that has permeated the soil can help improve the plasticity of soil, and thereby ease the workload on the earthwork equipment.

2. Equipment Selection

The primary earthwork tasks that are expected to be performed are earthmoving, ploughing, grading to desired slopes. Given that these projects will mostly occur in relatively non-undulating terrain, it is expected that there will be little need for moving earth across grid sections. Thus the primary equipment needs will be for ploughing the soil for mixture of nutrients and grading.

Soil Grading: Thus, the primary equipment for shaping the terrain into slopes is expected to be motor-graders after the soil has been sufficiently ploughed and infused with nutrients. Typical motor grader widths range from

Ploughing the soil: The task of deep-ploughing (up to 7’ depth) could be done with rippers attached to dozers, while shallow plowing (up to 1’ depth) and mixing could be done with the scarifier implement attached to the motor-grader. Given that it is expected to require ploughing to greater depths, custom-built ploughs and implements that attach on to the grader or a dozer could be considered.

Soil Stabilization: It may be required to perform methods to stabilize the soil to maintain the slopes. This will be done by mechanical means, rather than chemical due to the need to grow crops on the slopes.

Potential for novel equipment implement development: Given the unique nature of the project being considered and its considerable potential for scalability, it is expected that this project can necessitate the development of novel implements for deep ploughing, nutrient mixing, and large-width grading.

3. Construction and maintenance of slopes:

The primary construction of slopes will be performed using motor graders that are equipped with APG-enabled automated machine guidance and control (AMG and AMC). This technology uses real-time data from GPS sensors of receivers attached to the graders moldboard to automatically adjust the angle and pitch of the moldboard to obtain the desired shape of slope in the given terrain. This technology augmented the operator’s capabilities and ensures adheres to plans that are uploaded to the motorgraders AMG system.

Apart from the initial construction of the slopes, annual maintenance may be required to offset any soil erosion caused by wind or other forced. It is expected that for a slight grading a single grader will suffice for the entire area (10 sq. miles). Agricultural operations related to sowing and harvesting can be performed using conventional agricultural equipment.

4. Automation of operations:

It is posited that a project of such large scope and relatively simplistic operations in remote locations provides the ideal testing and proving grounds for the automated construction equipment and their operations. Apart from the previously mentioned automation methods such as AMG and AMC for grader control that will be heavily used in this project, these operations will also enable the testing of autonomous graders and soil stabilizers.

5. Public Perception of Operations

Given the large-scale nature of operations involved in natural terrain, it will be necessary to clearly communicate the cost and benefits of this project to the public. Metrics such as construction duration and costs, emissions produced, along with the fruits of the project such as crops grown must be clearly understandable to the public. Towards this end, we will use a novel tangible interface of Augmented Reality (AR) sandboxes to plan the project and visualize the metrics of interest on the project in response to user input.

The authors have prior experience in developing earthwork calculation applications for the AR sandbox for highway construction (see Figure XX) and traffic analysis purposes in the past which will inform development of novel visualization and tangible interactive planning tool for the re-slope project. This can serve as a public interaction and dissemination tool to engage with the public and improve their perception about this project.

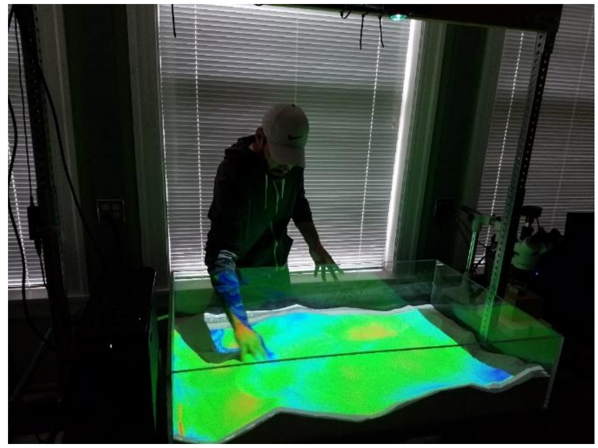

Figure XX: Interactive terrain visualization on AR sandbox

Such operations could use graders (such as are used for road leveling or snow plowing). Because the vehicles do not need to frequently turn, stop or drive in reverse, they can cruise relatively fast in straight lines making rapid inexpensive terrain alteration.

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