CONTOUR PLANTING: A STRATEGY TO REDUCE SOIL EROSION ON STEEP SLOPES

D.S. Long, S.B. Wuest, and J.D. Williams

Columbia Plateau Conservation Research Center
USDA-ARS
Pendleton, Oregon

R. Rauwendaal and M.J. Bailey

School of Electrical Engineering and Computer Science
Oregon State University
Corvallis, Oregon

ABSTRACT

Practices that combine GPS-based guidance for terrain contouring and tillage for runoff detention have potential to increase water infiltration and reduce runoff. The objective of this study was to investigate contour planting as a means to reduce soil erosion on steep slopes of the Columbia Plateau dryland wheat region. An exploratory field study was conducted on a Ritzville silt loam (coarse-silty, mixed, superactive, mesic Calcidic Haploxerolls) and 0-20 percent slopes. Planting was performed with a deep furrow drill on the contour to a depth of 20 cm. Our results demonsrate that a strip of deep-furrow seeding precisely contoured on the upper shoulder slope should provide sufficient detention storage to capture and hold the runoff from a 100-yr 24-h storm if the contour strip area was approximately 2% of the runoff collection area. This research also examined artificial neural networks for generating routing maps that optimize seeding on precise, GPS-guided contours. A contouring algorithm was evaluated in which the direction of a tractor is determined by contour-based neural activity whereby neurons corresponding to regions of the terrain of similar height to that of the tractor's current position receive the greatest excitatory input. The contour region, therefore, has the global effect of influencing the whole state space to attract the tractor in the right direction.

Keywords: contour planting, soil erosion, artificial neural networks

INTRODUCTION

Silt loam soils formed on steep slopes in loess parent material occupy approximately 3.7 million ha of the dryland agricultural region in the Pacific Northwest (Schillinger and Papendick, 2008). Erosion by water has been a major conservation problem of these soils since cultivation of wheat began in the late 19th century (Shepherd, 1985). These soils are at risk of degradation under the existing summer fallow management that revolves around multiple tillage operations. Conservation management practices are needed to reduce soil erosion and maintain the biological sustainability of dryland wheat production.

Typically, growers use tillage to create a dust mulch to reduce soil water evaporation and conserve seed zone moisture over the dry summer months (Schillinger and Papendick, 2008). However, the intensive tillage that is required decreases the amount of protective crop residue and makes the soil highly susceptible to erosion by wind and water (Sharratt and Feng, 2009). Chemical fallow and no-till are proven to maximize cover and conserve soil (Williams et al. 2009, 2010; Singh et al., 2009), but are not widely adopted in this region, particularly where rainfall is <305-mm and seed zone moisture is often inadequate for early planting of winter wheat (Schillinger and Young, 2004). Delaying planting until rain in late fall reduces wheat yields by up to 25% (Donaldson et al., 2001).

In addition, farm fields comprise large (<65 ha), rectangular tracts on complex slopes in steep rolling hills. Pulling a drill back and forth, from one end of the field to the other in a series of parallel swaths, is the most efficient way to seed a field. However, seeding in this manner ignores topographic variation and causes water to flow in off-contour furrows, concentrate, and form rills, especially when furrows overtop with water (Frazier et al., 1983). We have observed that severe rill erosion is the result of overland flow of water from plateaus that are situated above the steeper slopes. If this runoff could be contained on the plateau and prevented from becoming concentrated flow on steep slopes, much of the rill erosion could be prevented.

Contour farming is defined as “using ridges and furrows formed by tillage, planting, and other farming operations to change the direction of runoff from directly down slope to around the hill slope” (USDA-NRCS, 2007). Global positioning receivers and computer-based guidance systems are capable of automatically steering tractors precisely on curved paths and might be used for steering on precise elevation contours as well. Planting on precise contours has the potential for preventing the flow of water on soil thereby controlling erosion, reducing stream sedimentation, and increasing water infiltration.

Tillage practices are needed that effectively conserve soil and water while maintaining economic returns in conventional summer fallow fields of the Pacific Northwest. In this study, the goal was to develop an approved method for seeding winter wheat on precise contours to prevent water erosion. Specific objectives included: (1) assess potential of contour planting for capturing water and preventing runoff on steep slopes, and (2) examine artificial neural networks for generating routing maps that optimize seeding on precise contours.

MATERIALS AND METHODS

A field study was conducted in a farm field near Echo, Oregon on and above the shoulder position of a 30% hill slope. The climate is semiarid with average annual precipitation of 280 mm (11-in) with most falling October through March. Soils are derived from loess parent material and are classified as Ritzville silt loam (coarse silty, mixed, superactive, mesic Calcidic Haploxerolls). The field has been in a summer fallow-winter wheat rotation where the primary tillage consists of disking or chiseling, followed by cultivation and rodweeding operations. The study was conducted in the fallow phase of the rotation.

A self-leveling laser level was positioned on the slope. As the level was panned from side to side, the beam position was marked on the ground by means of small flags as needed to delineate a contour line. A skilled human operator then guided a tractor with a deep furrow drill (10 openers spaced 35.6 cm apart, 3.7-m total width) along the visible, predetermined contour. A furrow is 20-cm (8-in) deep, 35.6-cm (14-in) wide, and 200-m long.

Water (7.24 m^3, 1 911-gal) was applied into one of the furrows through a hose connected to a portable 4 000-gal water tank. Measurements included flow rate, time to drain the tank, and area of standing water in furrows. We applied a depth equivalent of 57-mm (2.22 in) in 1.6 h that was captured and infiltrated into an area of 128 m^2 (0.03 ac). Calculations included water holding capacity of furrows on precise contours, and predicted volume of runoff during a storm from a hypothetical 60 ha (148 ac) circular, contributing area. Previous work conducted nearby on the upland plateau (<5% slope) has shown that under the poorest of soil conditions (inversion tillage, unfertilized, crop residue burned), the ratio of runoff to storm precipitation (Q/P) equals 0.16 (Williams, 2004). Thus, we were able to calculate the area needed to capture runoff from design storms based on precipitation return periods (USDC-NOAA, 1973) and the approximate number of passes required with a 3.7 m wide deep furrow drill.

RESULTS AND DISCUSSION

Runoff Capture Assessment

Using the measurements from the field study, we calculated that only 1.2 ha of contour furrow, or two passes with 3.7 m wide deep furrow drill, would be required to capture the runoff from a hypothetical 60-ha contributing area resulting from a 100-yr, 24-h storm producing 64 mm (2.5 in) of rainfall (Table 1). Similarly, the portion of contoured land is 0.69 ha, or one pass with the same drill, to protect against a 100-yr, 6-hr storm having 38 mm of rainfall. In practice, a producer need only calculate the area of non-dissected plateau from which runoff needs to be captured, and border it with contour furrows. For example, an area of 50 ha (124 ac) will require 1 ha (2.5 ac) of surrounding contour furrow. Assuming that the contributing area is a circle to calculate distance, a minimum of two passes with a 3.7-m wide drill will meet this need. However, the contributing area is unlikely to be a circle. Manual and automatic methods for routing a tractor along an elevation contour are described in the following sections of this paper.

Table 1. Rainfall by return period for 24-hr and 6-hr storms for foothills of Blue Mountains near Echo, Oregon, and the area and number of passes of 3.7-m wide, deep furrow drill required for hypothetical circular 60 ha (148 ac) contributing area.

Return Period	Rainfall	Area	Number of Passes
yr	mm	ha	
	24-hr Storms		
100	64	1.20	2
50	56	1.04	2
25	53	0.99	1
10	43	0.79	1
5	38	0.69	1
2	30	0.55	1
	6-hr Storms		
100	38	0.69	1
50	36	0.64	1
25	30	0.55	1
10	28	0.50	1
5	24	0.43	1
2	19	0.33	1

Manual Routing Along Elevation Contours

An elevation contour line for routing a tractor can be manually constructed by rotating a laser beam in a horizontal plane from a single point as per this study. Using the visible beam, the line can be marked with ground flags at precisely positioned points thereby forming a horizontal path. A tractor operator can then follow the correct path to remain on contour. Another way to steer on an elevation contour would be to survey the field to get a digital elevation model (DEM), use software to display where you are on the DEM, and then drive parallel to the elevation contour line of choice.

Several highly accurate methods are available for producing a DEM including kinematic GPS survey, soft copy photogrammetry, and light distance and ranging (LIDAR). Kinematic survey involves collecting elevation measurements along a series of parallel transects and followed by interpolating these data to a regular square estimation grid, or DEM. A limitation is the large amount of time that is necessary to cover fields on multiple transects while obtaining elevation measurements. The latter two methods are rapid and accurate, but are disadvantaged by high cost.

Autosteer systems use a steering actuator for steering steerable wheels in response to a steering controller. The controller receives input from a steering angle sensor measuring the angular position of the steerable wheels and a tractor position generating unit (GPS receiver) generating actual position data. The controller compares the actual position with the desired position and generates a steering control signal instructing the steering actuator to steer the wheels in the correct direction.

Today's systems guide tractors along straight and curved paths relative to a base line established relative to a visible reference such as a field boundary. The operator begins by inputting a starting point, driving along the boundary, and inputting the end point of the base line. Elevation contours are invisible and thus would need to be delineated manually. When recorded into the memory of an autosteer system; however, the same curved path could be used again in each following year.

Automatic Routing Using Artificial Neural Networks

Currently, no autosteer system can be instructed to steer along an elevation contour in a manner similar to how an autopilot is set to hold an aircraft at a certain altitude. Otherwise, manual routing methods would not be necessary. Artificial neural networks (ANNs) are computational models that mimic the neural structure of the human brain (Zou et al., 2008). A neuron receives one or more inputs and sums them to produce an output (Fig. 1). Neuron behavior depends upon the weight on the connections between the inputs and the neuron and the specification of the non-linear transfer function adjusting the total input into an output.

Mathematically, the output y from a neuron can be described with a summing function:

$$y = \varphi \sum_{j=0}^{n} w_j x_j \qquad \text{[Eq. 1]}$$

where φ is a transfer function and multiple inputs ($x_1, x_2, x_3, \ldots\ldots x_n$) are weighted by the weights ($w_1, w_2, w_3, \ldots\ldots\ldots w_n$). Artificial NN models have been successfully applied to object recognition and obstacle avoidance by robots (Yang and Meng, 2000) and thus are directly applicable to tractor autosteer systems as well.

ANN Simulation

In this study, we developed an ANN model to simulate movement of a tractor in a 2-D environment along elevation contours. A discrete 2-D surface of a DEM forms the structure for the ANN (Fig. 2). Lateral connections between neurons become adjacent connections to neighboring cells. A complete coverage path was implemented based on the dynamic activity landscape of the neural network and the previous tractor location, such that all areas of the field were covered with no overlap. This model is capable of planning real-time complete coverage paths with obstacle avoidance in an unstructured environment. The term "real-time" denotes that the coverage path planner responds immediately to the dynamic environment including the tractor, uncovered areas, and field edges.

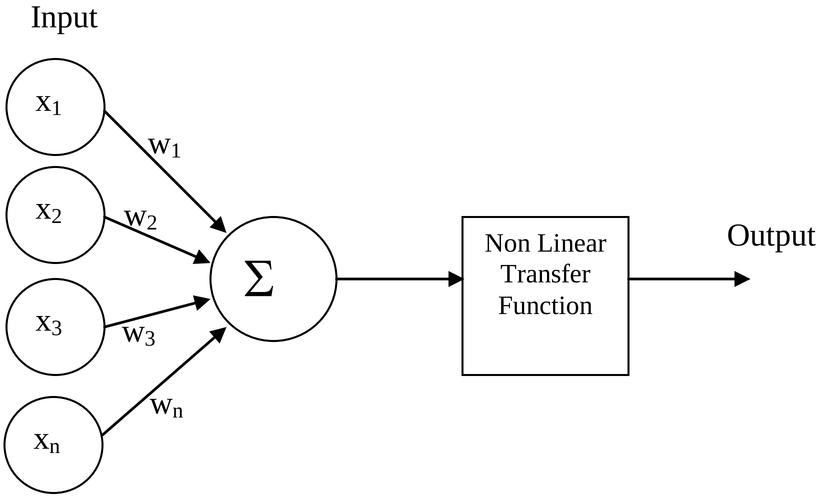

Figure 1. Structure of a simple artificial neural network model consisting of multiple inputs (x_1, x_2, x_3, …….x_n), corresponding weights (w_1, w_2, w_3, …..w_n), one neuron, non-linear transfer function, and single output.

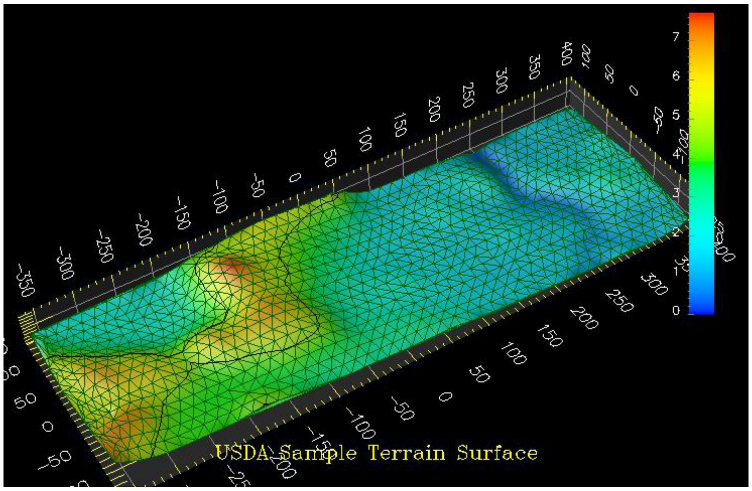

Figure 2. Digital elevation model consisting of triangulated points.

The location of the *ith* neuron uniquely represents an area within the DEM and thus has local lateral connections to its neighboring neurons. The neuron responds only to the stimulus within its receptive field. The dynamics of this neuron in the ANN can be characterized by a shunting equation:

$$\frac{dx_i}{dt} = -Ax_i + (B - x_i)E_i(t) - (D + x_i)I_i(t) \qquad \text{[Eq. 2]}$$

where *S* is the unique state space of the DEM, *A* represents the passive decay rate of neural activity, which solely determines the transient response to an input signal. Functions E_i and I_i represent the excitatory and inhibitory inputs to the ANN model specified by Equation 2. Neurons corresponding to regions of the DEM of similar elevation receive the greatest excitatory input and attract the tractor the most whereas neurons corresponding to edges of the DEM and previously covered areas repel the tractor (Fig. 3). Once a contour line has been covered by the tractor, neural activity is no longer generated thereby causing the tractor to seek new contours and shifting the network's excitatory input to match the tractor's elevation in the field. This ANN simulation, which relies upon elevation as the primary input, is an oversimplification of a complex problem-that of guiding a tractor along a contour line on hills. In reality, an ANN model must consider the lateral forces at the wheels, mass of the tractor and its towed implement, inertia, and center of gravity (Zhu et al., 2005).

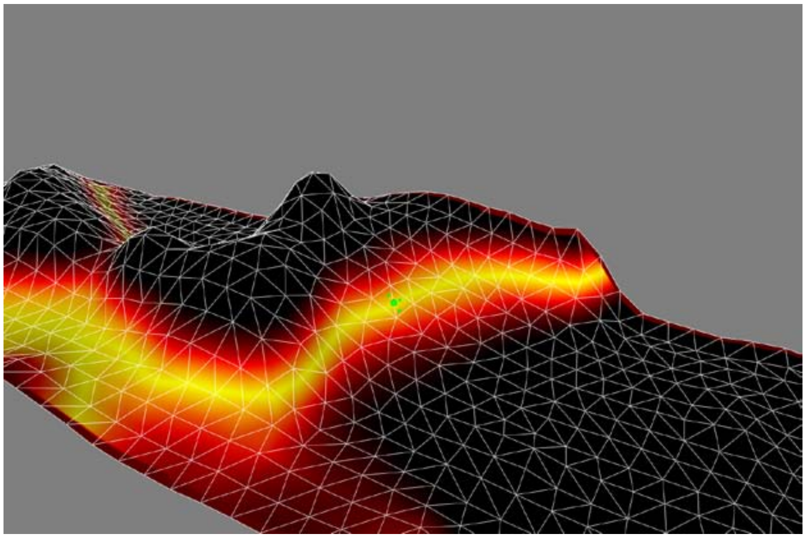

Figure 3. Contour-based neural activity with all neurons corresponding to regions of the terrain of similar height to that of the tractor's current position receive greatest excitatory input.

Prototype ANN Systems

Artificial NN models have been devised that incorporate the downward slip of a tractor due to gravity, slope, and soils. Torisu et al. (2002) proposed an ANN model for automatic control of tractor travel along elevation contours based on steering angle, rate of steering, vehicle heading, vehicle speed along X and Y coordinate axes, and yaw velocity. Tractor position and altitude were determined using a total station that triangulated the rectangular coordinates of surveyed points relative to the total station position. A wireless modem was used to transmit the position signals from the total station to a central processing unit on the tractor. An electrical motor was used as a steering actuator, a potentiometer to measure steering angle, and a fiber optic gyroscope to measure vehicle heading. A limitation was that real-time navigation was only possible at one specific slope angle.

Later, Ashraf et al. (2003) trained the ANN model (Torisu et al., 2002) along contour lines at inclinations of 0, 5, 11, and 15º and determined optimal steering angles for each angle. A third-order polynomial equation was approximated for the relationship between steering angle and slope angle. The coefficients of the equation were entered into a look-up table so that optimal steering values could be computed for any inclination using sensed values of slope and vehicle attitude. Using this strategy, a tractor could be navigated within 0.05 m of predetermined rectilinear path.

In addition, Zhu et al. (2005) further improved the ANN model formulated by Torisu et al. (2002) by incorporated incline information so that it could be used with varying gradients- not just a single uniform gradient. The ANN model was trained to navigate a tractor over sloping terrain along a predetermined path with an average lateral deviation of 0.005 m. Though the model was not applicable for all field and soil conditions, the results indicated that ANNs are capable of accurately controlling the motion of a tractor under variable slope conditions.

SUMMARY AND CONCLUSIONS

Further research is needed to evaluate the effectiveness of precision contouring with a deep furrow drill in providing resistance to water erosion. Our study indicates that this method might be an effective conservation practice with only small changes in the farmer’s current practice of seeding up and down slopes. To date, precision contouring cannot be easily implemented because an autosteer system is not in place for guiding tractors along elevation contours. Artificial NN models that accommodate multiple inputs are potentially useful for automatically controlling the steerable wheels of tractors and adjusting for downward slippage on sloping land. Research and development are needed to address the possibility of autonomous travel along invisible, indeterminate elevation contours for soil conservation purposes.

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