Effects of farmland vegetation row direction on overland flow hydraulic characteristics

Shengtang Zhang, Jingzhou Zhang, Yin Liu and Yuanchen Liu

ABSTRACT

Soil erosion of farmland is a major issue faced by the agricultural industry. Control of water-induced erosion can be improved through the simulation of different configurations of vegetation row direction to analyze the effects of farmland vegetation row directions RD on the hydraulic characteristics of flow. The farmland vegetation row directions were simulated and the anisotropic influence of the farmland vegetation row direction on flow hydraulic characteristics was experimentally analyzed. Three groups of farmland vegetation row directions with angles θ of 15°, 45°, and 90° with respect to the flow direction FD were configured. Experimental results show that different angles caused variation in hydraulic parameters velocity V, Reynolds number Re, Froude number Fr, and Darcy–Weisbach friction factor λ along the directions of flow. The rates of change of λ, Re, and Fr were analyzed statistically, where θ was increased every 10°; the average rate of decrease of λ was 5.2% and the average rates of increase of Re and Fr were 2.2% and 3.4%, respectively. These results indicate that the vegetation distribution pattern on farmland has an anisotropic influence on the hydraulic characteristics of flow. This investigation provides valuable references for the optimization of farmland vegetation distribution and soil erosion control.

Key words | anisotropy, farmland vegetation, hydraulic characteristics, overland flow

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INTRODUCTION

Soil erosion is a major ecological environmental issue that decreases agricultural productivity and may cause severe contamination to water resources. In recent decades, a number of studies have demonstrated that vegetation could increase the local roughness, modify flow patterns and provide additional drag, decreasing the bed-shear stress and enhancing local sediment deposition (Vargas-Luna *et al.* 2015). Vegetation can be used to effectively control soil erosion on hill slopes (Knapen *et al.* 2009) and the idea of applying vegetation to protect soil is widely accepted in agricultural institutions all over the world (Gyssels *et al.* 2005).

In order to reveal the law of the overland flow erosion process, the most important work is to study its hydrodynamic characteristics, which are mainly quantified by hydraulic parameters. The hydraulic parameters of water flow on farmland are influenced by factors such as flow velocity, flow state, terrain, and tillage methods (Parsons *et al.* 1994; Lawrence 2000; Lane 2005; Zhang *et al.* 2007). Current research is primarily focused on the influence of different tillage methods and soil surface characteristics on the hydraulic characteristics of water flow. The effects of vegetation distribution on the water flow hydraulic characteristics have been investigated. For example, Zhang *et al.* (2012) showed that irregular vegetation distribution significantly slowed the velocity of water flow on sloping farmland. Tang *et al.* (2014) found that the vegetation friction effect on overland flow may be related to other factors, such as the arrangement of the vegetation. Ding & Li (2016) concluded that vegetation distribution was more effective in

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reducing sediment in the lower portion of their experimental test section than in the middle and upper portions, demonstrating that the distribution pattern of vegetation had a vital influence on the hydraulic characteristics of overland flow. In fact, many studies have confirmed that the spatial distribution pattern of vegetation on the slope is an important factor that lowers the sediment discharge (Cerdà 1997; Zuazo and Pleguezuelo 2008; Li *et al.* 2009).

Farmland vegetation often shows a designated distribution pattern because of factors such as tillage method, and row and column distribution of plants. Under the influence of factors such as farmland elevation, farmland tillage method, and spatial distribution of farmland vegetation, rainfall runoff and irrigation streams often flow along a direction that is different from the rows and columns of farmland vegetation. It remains unclear whether the farmland vegetation row direction has an anisotropic influence on the hydraulic characteristics of water flow in different directions. Therefore, it is necessary to study the influence of farmland vegetation row direction on the hydraulic characteristic of surface flow in order to provide a theoretical and experimental foundation for the control of soil erosion in farmland, and indicate an appropriate crop planting layout.

EXPERIMENTAL SETTING

With the whole-process mechanization of agriculture and the management of numerically controlled planting, the planting has an accurate location distribution in the field and the uniform strip distribution of vegetation is a symbol of agricultural modernization. Overland flow often proceeds at a certain angle with regard to the row and column direction of farmland vegetation (Figure 1). To determine whether the pattern of distribution of vegetation has anisotropic influences on the hydraulic characteristics of water flow in different directions, variations in the flow angle between the farmland vegetation row direction and water flow direction were simulated using an open-channel water sink device. Furthermore, hydraulic characteristic parameters were experimentally measured for different current flow angles to indicate the effects of the pattern of distribution of farmland vegetation on anisotropic hydraulic characteristics of water flow.

Figure 1 | Showing the farmland vegetation row direction, and water flow directions with different flow angles.

With the present technology, research on overland flow was mainly through indoor simulation tests. Studies of hydraulic characteristics of overland flow used open-channel sinks, where the vegetation was laid in the sink to simulate the slope surface of a basin (Ali *et al.* 2013; Arguelles *et al.* 2013; Li *et al.* 2013). The overland flow belongs to the thin layer of water that flows down the slope; overland flow resistance is mainly affected by the underlying surface. Therefore the flow resistance of the boundary of the open channel is ignored. The test device was a rectangular channel with a length of 5 m, a width of 0.4 m, and a height of 0.3 m (Figure 2). The water sink was divided into an upper equalizing section, a middle test section, and an end gate section. In the

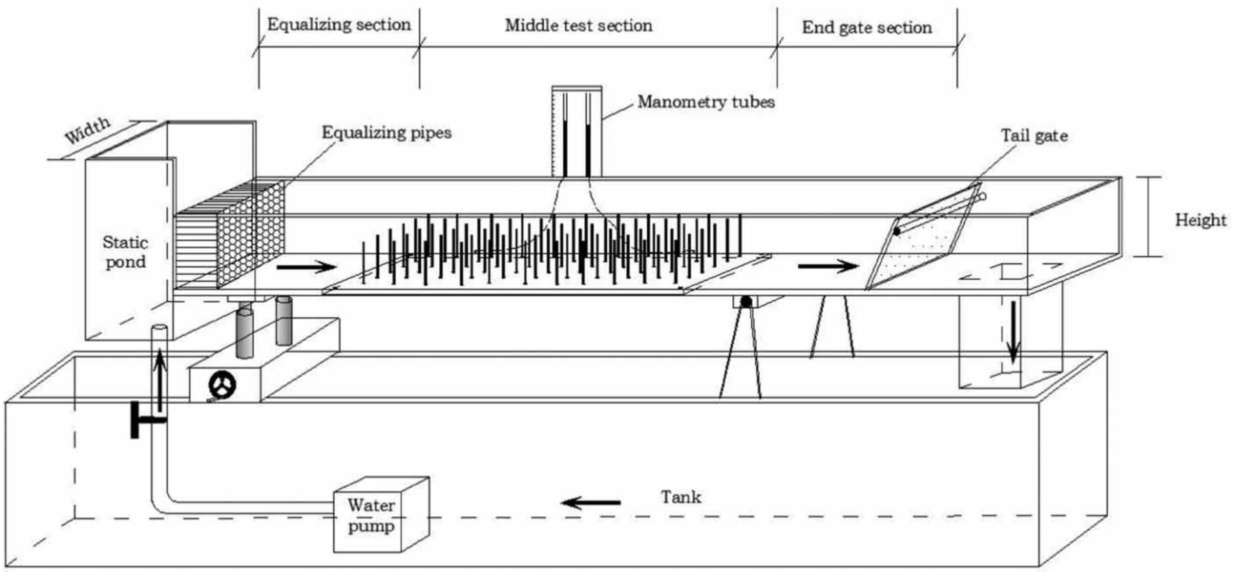

Figure 2 | Schematic showing the experimental device.

experiments, the slope was defined as 1%, and the test device consisted of a water tank, a rectangular sink, a weir and a pressure gauge. There was a flow rate control valve where the water tank and sink connected, and the flow rate varied within the range of 0–0.11 m^3/s. An organic glass plate was positioned on the bottom of the sink in the middle of the test section to simulate the underlying surface of the farmland vegetation, and holes were drilled into the plate to simulate the row direction of farmland vegetation. Both vertical and horizontal distances between adjacent holes were $a = 60$ mm, the interpolating diameter of drill holes was $d = 3$ mm, and plastic plants with a height of 15 cm were used to simulate the farmland vegetation; RD represents the arrangement direction of the vegetation rows, and FD represents the direction of water flow. The length of the test section was 3 m, two observational cross-sections were positioned in the test section at a distance of 1.5 m, the depths h_1 and h_2 of the two observable sections were obtained by using the pressure tube water level minus the system datum, and two manometry tubes were placed to determine the water level. Flow angles (θ) of 15°, 45°, and 90° were used for the experiments (Figure 3) and experimental data for h and Q are set out in Table 1.

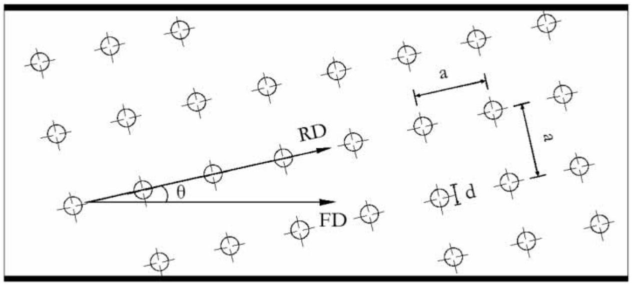

Figure 3 | Underlying test plate showing different flow angles.

EXPERIMENTAL DATA AND METHOD

Three factors are primarily considered in the study of anisotropic influence of farmland vegetation row direction on the hydraulic characteristics of overland flow: flow velocity, water flow state, and friction factor.

(1) Flow velocity is the most important hydrodynamic factor when studying water flow, and is directly related to particle detachment, sediment transport, and the sedimentary process of overland erosion. According to the continuity equation for water flow, the overland flow

Table 1 | Experimental data on h and Q

		Experiments										
Flow angle	**Measured parameters**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
15°	Q (m^3/s)	0.0004	0.0011	0.0016	0.0026	0.0030	0.0035	0.0046	0.0056	0.0069	0.0084	0.0106
	h_1 (m)	0.004	0.009	0.013	0.021	0.024	0.028	0.037	0.046	0.056	0.066	0.082
	h_2 (m)	0.006	0.013	0.019	0.030	0.033	0.037	0.047	0.054	0.064	0.074	0.089
45°	Q (m^3/s)	0.0004	0.0010	0.0013	0.0021	0.0027	0.0035	0.0044	0.0053	0.0072	0.0098	0.0105
	h_1 (m)	0.003	0.008	0.010	0.015	0.018	0.023	0.031	0.038	0.053	0.071	0.075
	h_2 (m)	0.004	0.009	0.012	0.020	0.026	0.033	0.041	0.048	0.063	0.080	0.084
90°	Q (m^3/s)	0.0004	0.0012	0.0017	0.0023	0.0035	0.0044	0.0053	0.0068	0.0084	0.0101	0.0108
	h_1 (m)	0.004	0.010	0.012	0.015	0.020	0.026	0.035	0.047	0.058	0.069	0.074
	h_2 (m)	0.003	0.009	0.013	0.019	0.029	0.037	0.046	0.056	0.067	0.078	0.082

velocity V may be calculated using the following equation:

$$V = \frac{Q}{A} \tag{1}$$

where V is the flow velocity, Q is the flow rate, and A is the cross-sectional area of the overland flow.

(2) Water flow state is a basic parameter of the hydrodynamic characteristics of water flow. It is a prerequisite for analyses concerning the properties of overland flow, calculation of the flow velocity, runoff erosion, and sediment transport. The parameters that determine water flow state typically include the Reynolds number *Re* and Froude number *Fr*.

The Reynolds number reflects the motion state of viscous fluids. It is an important parameter that evaluates the ratio of the inertia force to the viscous force acting on the water flow (Zheng *et al.* 2012). The Reynolds number *Re* is calculated as follows:

$$Re = \frac{VR}{\nu} \tag{2}$$

where ν is the kinematic viscosity coefficient and R is the hydraulic radius.

The mechanical significance of the Froude number is to analyze the ratio of the inertia force effect to the gravity effect on water flow. From the perspective of energy, the Froude number represents a ratio of mean kinetic energy to mean potential energy of the liquid at the water flow cross-section per unit weight. The Froude number *Fr* in open-channel flow theory is calculated as follows:

$$Fr = \frac{V}{\sqrt{gh}} \tag{3}$$

where h is the water depth, and g is the gravitational acceleration.

(3) Resistance to water flow is the retardation effect that the vegetation and roughness of the surface of the ground have on water flow. Study of the flow resistance is an integral part of investigations into overland flow (Weltz *et al.* 1992; Barros & Colello 2001; Hu & Abrahams 2006; Wang *et al.* 2014). The overland flow resistance of vegetation primarily includes the ground particle resistance and bypass resistance produced by the vegetation, and the friction factor represents the resistance effect of underlying vegetation on the water flow. If the overland flow friction factor can be calculated precisely, the mechanism by which the overland flow varies may be better understood (Zheng *et al.* 2012). Currently, the Darcy–Weisbach friction factor λ and the Manning roughness coefficient n are often used to express resistance to water flow.

The Darcy–Weisbach friction factor is expressed as follows:

$$\lambda = \frac{8h_f Rg}{LV^2} \tag{4}$$

where h_f is the frictional head loss, and L is the length of the test section.

Hydraulic radius R is the flow cross-sectional area A divided by the wetted perimeter χ, that is,

$$R = \frac{A}{\chi} \tag{5}$$

$$\chi = 2h + b \tag{6}$$

where b is the width of the sink.

Frictional head loss is a loss of energy to overcome friction resistance in fluid flow. This resistance is mainly composed of the internal friction between the fluid and the underlying surface and the fluid itself. In the experiment, the floor of the sink is flat and there is no local head loss, or the local loss is negligible relative to the frictional head loss. Since the atmospheric pressure has not changed, the increment of the pressure head is 0. Therefore, the frictional head loss is calculated as follows:

$$h_f = (z_1 - z_2) + \frac{(V_1^2 - V_2^2)}{2g} \tag{7}$$

where z_1, z_2 are the head height of the initial and final position, and $(V_1^2 - V_2^2)/2g$ is the flow head difference between the initial position and the end position.

RESULTS AND DISCUSSION

Anisotropic variation of *V*

Curves describing the h–V relationship were established using the calculation results based on the experimental data (Figure 4). The h–V relationships for the three different flow angles all indicate that when the water depth h was within the range of 0–0.01 m, as the water depth increased, the flow velocity also increased. However, when the water depth h was greater than 0.01 m, as the water depth increased, the flow velocity showed a slow variation trend. At the same water depth h, water flow velocities varied according to the flow angles with higher flow angles corresponding to larger flow velocities. The relationship between three different water flow velocities was $V_{90°} > V_{45°} > V_{15°}$, indicating that the distribution pattern of farmland vegetation had an anisotropic effect on the water flow velocities. In directions in which the flow angle between the water flow direction and the farmland vegetation row direction was large, the water flow may be relatively high. For the same water depth, this specific direction may show a relatively high flow velocity.

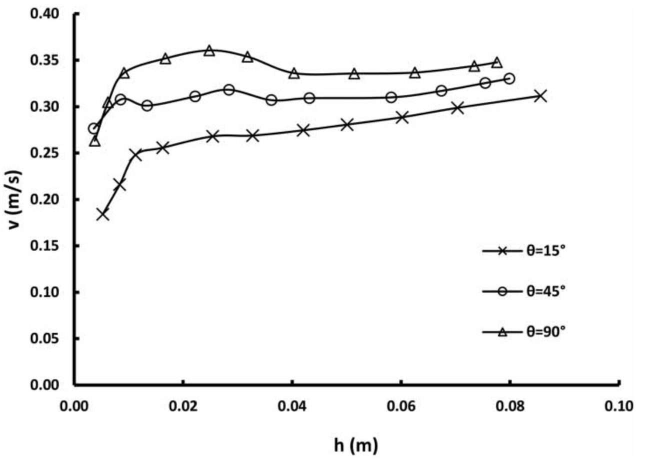

Figure 4 | The *h*–*v* relationships at three different flow angles.

Anisotropic variation of *Re* and *Fr*

Usually, open-channel binary flow standards are used to define sloping surface flow patterns and identify flow regimes. That is, the hydraulic parameters of the Froude number and Reynolds number are used to divide the flow patterns and flow regime into six categories: slow laminar flow, $Re < 580$, $Fr < 1$; slow transition flow, $580 < Re < 6{,}500$, $Fr < 1$; slow turbulent flow, $Re > 6{,}500$, $Fr < 1$; rapid laminar flow, $Re < 580$, $Fr > 1$; rapid transition flow, $580 < Re < 6{,}500$, $Fr > 1$; and rapid turbulent flow, $Re > 6{,}500$, $Fr > 1$ (Zhang *et al.* 2014a, 2014b). The difference of flow state is determined by the internal structure of water flow, with different flow states having different resistance mechanisms. The experimental data are plotted on a double logarithmic coordinate system, as shown in Figure 5, in order to show the distribution relation of flow patterns and flow regimes of different flow angles.

Figure 5 shows the flow pattern and flow regime distribution diagram of the slope flow pattern at three different

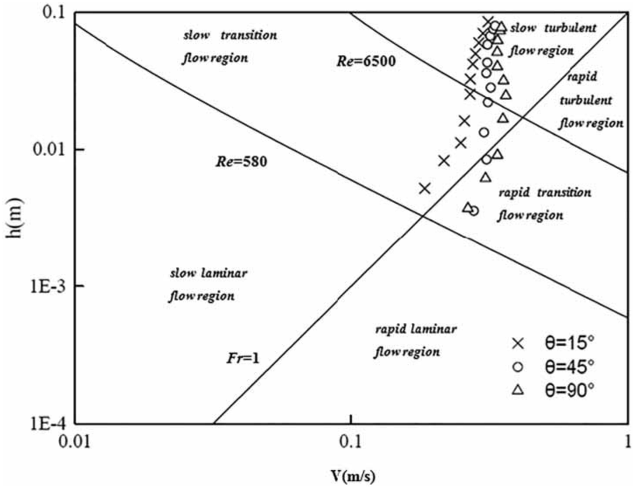

Figure 5 | The flow pattern and flow regime distribution diagram at three different flow angles.

flow angles θ over farmland vegetation planted in rows in three different directions. It should be noted that since the experiment was conducted at an indoor temperature of 20°C, the value of the kinematic viscosity coefficient v is $1\times10^{-6}\ \mathrm{m^2/s}$.

As can be seen from Figure 5, the average flow velocity generally increases gradually with increasing flow rate, although the rate of that increase decreases. Furthermore, when the angle θ between the direction of crop cultivation and the flow direction is larger, the increase of flow velocity is more limited. Under experimental conditions, the flow state is mainly slow transition flow, rapid transition flow, or slow turbulent flow. The pattern of water flow is closely related to the flow rate and the distribution of vegetation; when the flow rate is low, the points of the three different angles θ are subject to transition flow. As the flow rate increases, the flow state becomes turbulent because the viscous forces increase but the inertial forces increase even faster, the inertial forces play a dominant role and the fluid flow fields become unstable; hence, small disturbances will develop and evolve into stronger, irregular, turbulent currents. Simultaneously, relative to the direction of crop cultivation, as the flow rate increases, the flow pattern changes from slow flow to rapid flow and the flow regime changes from transition to turbulent.

This indicates that the pattern of distribution of vegetation on farmland had anisotropic effects on the degree of turbulence and mechanical energy constitution of the flow in different directions. Flow that crosses the vegetation distribution at a large angle has a relatively high degree of turbulence, and the ratio of the kinetic energy to the mechanical energy of water flow is also relatively high. The water flow with a small flow angle had a relatively small degree of turbulence, and the ratio of the kinetic energy to the mechanical energy of water flow was relatively small. With the increase in flow rate, the influence of angle θ on the flow regime decreases gradually.

In order to further quantify the effect of the direction of crop cultivation on the slope surface flow, the values of Re and Fr are calculated by formulas (2) and (3), and the parameter values for the same water depth are interpolated (Tables 2 and 3).

It can be seen from Tables 2 and 3 that, under the same water depth conditions, the three flow angles all displayed the following trend: $Re_{15^\circ} < Re_{45^\circ} < Re_{90^\circ}$, $Fr_{15^\circ} < Fr_{45^\circ} < Fr_{90^\circ}$. This indicates that the pattern of distribution of vegetation on farmland had anisotropic effects on the degree of turbulence and mechanical energy constitution of the

Table 2 | Interpolation data on *h* and *Re*

	Experiments					
Hydraulic parameters	**1**	**2**	**3**	**4**	**5**	**6**
h(m)	0.02	0.03	0.04	0.05	0.06	0.07
Re_{15°	25,072	31,162	40,466	49,974	59,301	68,965
Re_{45°	24,580	35,743	44,650	53,710	62,629	72,360
Re_{90°	28,068	40,257	48,789	58,442	67,627	77,162
$(Re_{90^\circ}\text{-}Re_{45^\circ})/Re_{45^\circ}$	14.2%	12.6%	9.3%	8.8%	8.0%	6.6%
$(Re_{45^\circ}\text{-}Re_{15^\circ})/Re_{15^\circ}$	−2.0%	14.7%	10.3%	7.5%	5.6%	4.9%

Table 3 | Interpolation data on *h* and *Fr*

	Experiments					
Hydraulic parameters	**1**	**2**	**3**	**4**	**5**	**6**
h(m)	0.02	0.03	0.04	0.05	0.06	0.07
Fr_{15°	0.5613	0.4977	0.4382	0.4007	0.3762	0.3601
Fr_{45°	0.7103	0.5850	0.4936	0.4459	0.4071	0.3886
Fr_{90°	0.8140	0.6591	0.5393	0.4809	0.4400	0.4134
$(Fr_{90^\circ}\text{-}Fr_{45^\circ})/Fr_{45^\circ}$	14.6%	12.7%	9.3%	7.9%	8.1%	6.4%
$(Fr_{45^\circ}\text{-}Fr_{15^\circ})/Fr_{15^\circ}$	26.6%	17.5%	12.7%	11.3%	8.2%	7.9%

flow in different directions. As the flow rate increases, the influence of the direction of crop cultivation decreases. The statistical results show that the average rate of increase of the Reynolds number, *Re,* was 2.2%, and the average rate of increase of the Froude number, *Fr*, was 3.4% when the angle was increased by every 10°.

Anisotropic variations of λ

The study on the hydraulic characteristics of slope flow is restricted by using the traditional model of hydraulic flow in an open channel. The overland flow is usually treated as a thin-layer open-channel flow, ignoring the multi-flow characteristics of overland flow, which is different from that of single-channel flow (Abrahams *et al.* 1986; Lawrence 1997; Dunkerley *et al.* 2001; Yang *et al.* 2005). The slope flow is diffused laminar flow, and the flow direction is non-unique, which leads to the difference between the flow direction and the direction of crop cultivation. The anisotropic influence of this difference on the overland flow resistance is one of the subjects of this study.

Flow resistance refers to the roughness of the bed surface and the blocking effect of vegetation on the flow of water. The resistance to overland flow is often represented by the hydraulic roughness coefficient (Smith *et al.* 2007). The Darcy–Weisbach friction factor λ reflects the underlying surface resistance to overland flow. Under the same hydrodynamic conditions, greater λ indicates that more energy will be consumed to overcome flow resistance, leaving less energy available for soil detachment and sediment transport, which consequently causes soil erosion (Zhang *et al.* 2014a, 2014b). As shown in Figures 6 and 7, the Darcy–Weisbach friction factor λ increases with the increase of *Re* and decreases with the increase of *Fr*. This is consistent with the conclusion reached by Li *et al.* (2013) in their study on the effect of rigid vegetation on the flow resistance of a slope. The reason may be related to the different components of water resistance. When the flow rate is low, the flow state tends to develop as rapid flow, the internal structure of the water flow becomes more complicated and chaotic, thus the resistance of water flow cannot be determined. With the increase in flow rate, the height of the water column increases, *Re* increases, and *Fr* is correspondingly reduced, thus increasing the turbulence of the flow until flow separation occurs. This means that the boundary surface between the flow and the vegetation (source of friction) also increased, which increases the contact and probability of collision between the flow and the vegetation; hence, frictional resistance under such conditions increases.

It can be seen from Figures 6 and 7 that under the same flow state or flow pattern, smaller flow angles corresponded to larger friction factor values of $\lambda_{15^\circ} > \lambda_{45^\circ} > \lambda_{90^\circ}$, indicating that the direction of crop cultivation has an anisotropic influence on the water flow. When the flow angle is smaller, the water flow resistance is higher, which implies that different tillage of farmland will lead to anisotropy of the surface roughness. This result is complementary to the conclusions of other researchers; Sepaskhah & Shaabani (2007) and Hyväluoma *et al.* (2013) reported that plots of irrigated farmland have different roughness under different tillage arrangements and that ridge and furrow placement affect the hydraulic characteristics of irrigation water flow. We found in our study that the perpendicular flow was lowest when water flowed along the vegetation rows or columns.

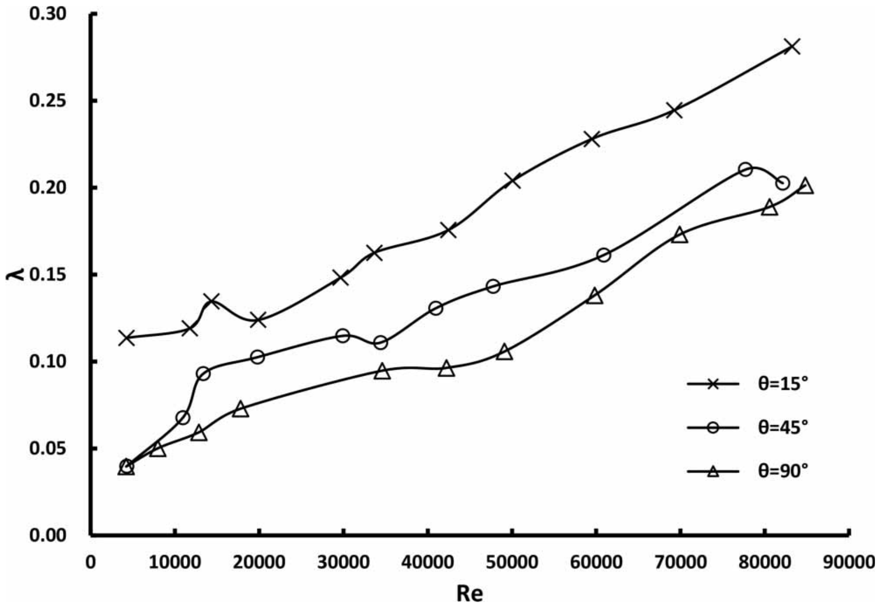

Figure 6 | The *Re*–λ relationships at three different flow angles.

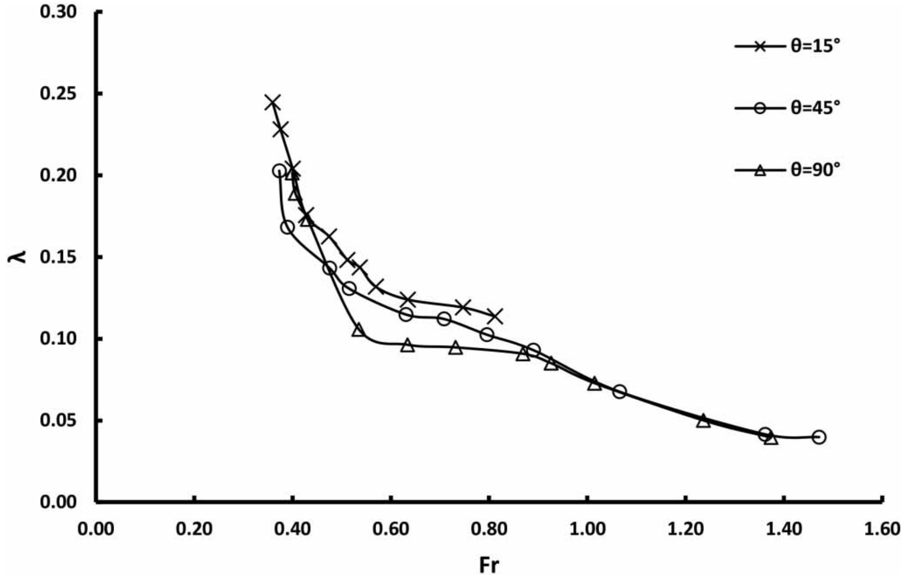

Figure 7 | The *Fr*–λ relationships at three different flow angles.

With a uniform planting arrangement, the projection area of the adjacent row of the vegetation completely overlaps that of the previous row so that an increase in the row spacing would not expand the projection area. However, by decreasing the flow angle, the projection area of the vegetation increases continuously, which makes the overland flow resistance increase continuously. The increase in the resistance to water flow may reduce the energy of the flowing water, thus improving the penetration ability of the water flow into the soil and reducing the ability of runoff to erode the soil (Abrahams & Parsons 1991; Hairsine *et al.* 1992; Planchon *et al.* 2001). It is clear that vegetation distribution is important for the control of soil erosion associated with overland flow. For example, in some farmland that shows a preferential overland flow direction (e.g., farmland positioned within a high range of elevation), the row direction of vegetation can be adjusted to increase the water flow resistance, thus controlling the soil erosion.

The work reported above is only a qualitative study of the effect of vegetation on the overland flow resistance. In order to study this further, the original data were substituted into the formula (4), and the value of λ was interpolated (Table 4). From the results of the statistical analysis of the data in Table 4, we can see that with the increase of water depth, the Darcy–Weisbach friction factor λ is increasing, which is consistent with the conclusion of Jarvela (2002). Additionally, Jarvela (2002) reported that the spatial distribution of vegetation is the main control on the surface friction coefficient and produces the anisotropy of surface roughness, but the research was limited to a qualitative study. In order to further the investigation of the effect of the distribution of vegetation on the anisotropy of surface roughness, the following qualitative and quantitative conclusions can be drawn: (i) for the same water depth, the larger the flow angle, the smaller the friction factor will be; and (ii) when the angle θ was increased by increments of 10°, the average rate of decrease of the Darcy–Weisbach friction factor λ was 5.2%.

CONCLUSION

Precipitation runoff and irrigation flow across farmland may cause soil erosion. By assessing the anisotropic influence of the pattern of distribution of farmland vegetation on the hydraulic characteristics of water flow at different flow angles, the farmland vegetation row direction may be adjusted to increase the resistance to water flow. Thus, there is a reduced degree of turbulence and kinetic energy of the water flow, which achieves soil erosion control. In this study, an open-channel water sink was used to set the flow angle between the direction of the rows of vegetation and direction of water flow and simulate overland flow over farmland vegetation. The following conclusions were drawn.

(1) The direction of the rows of vegetation in the farmland had an anisotropic influence on water flow, and hydraulic characteristic parameters of the water flow with different flow angles, such as the flow velocity *V*, the Reynolds number *Re*, the Froude number *Fr*, Darcy–Weisbach friction factor λ, and the Manning roughness coefficient *n*, all showed an anisotropic variation.

(2) For the same water depth, the greater the flow angle, the greater the water flow velocity *V*, and the larger the Reynolds number *Re* and the Froude number *Fr*. This indicates that the pattern of distribution of vegetation on farmland has an anisotropic influence on the flow velocity, degree of turbulence, and ratio of the kinetic energy in the mechanical energy of the water flow. Furthermore, for the same water depth, the greater the flow angle, the faster the flow velocity, the greater the degree of turbulence, and the higher the ratio of kinetic energy in the mechanical energy of water flow.

(3) Under the same flow state, increases to the flow angle between the water flow direction and the farmland

Table 4 | Interpolation data on *h* and λ

	Experiments					
Hydraulic parameters	**1**	**2**	**3**	**4**	**5**	**6**
h(m)	0.02	0.03	0.04	0.05	0.06	0.07
λ_{15°	0.1348	0.1536	0.1727	0.2036	0.2276	0.2441
λ_{45°	0.1108	0.1149	0.1375	0.1515	0.1664	0.1949
λ_{90°	0.0924	0.0959	0.1053	0.1340	0.1651	0.1838
$(\lambda_{90^\circ}\text{-}\lambda_{45^\circ})/\lambda_{45^\circ}$	−16.6%	−16.6%	−23.4%	−11.5%	−0.8%	−5.7%
$(\lambda_{45^\circ}\text{-}\lambda_{15^\circ})/\lambda_{15^\circ}$	−17.8%	−25.2%	−20.4%	−25.6%	−26.9%	−20.2%

vegetation row direction caused decreases in the values of the Darcy–Weisbach friction factor λ. This indicated that the pattern of distribution of vegetation on farmland has an anisotropic influence on the water flow resistance, and the smaller the flow angle, the greater the water flow resistance of the farmland vegetation.

It should be noted that the results were obtained under laboratory conditions, in which other influencing factors were carefully controlled. This approach was taken to allow a clear indication of the anisotropic effect of the farmland vegetation row direction on the water flow. However, the actual pattern of farmland vegetation and hydraulic characteristics of water flow are also affected by factors such as the terrain and soil features. Therefore, the reliability and adaptability of the conclusions in this paper to field conditions need to be investigated prior to the application of this method to farmland.

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