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Relationship between Cane Yield and Landscape's Hydro-Geomorphic Parameters in Sugarcane Plantations in Hingurana, Sri Lanka

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Abstract

A study was conducted to identify the causatives for low ratoon yield in sugarcane plantation with special reference to hydro-geomorphologic parameters of the landscape. Hydro-geomorphologic parameters *i.e.* closed depressions, flow accumulation and topographical wetness index were assessed. These hydro-geomorphologic parameters were used as indicators for characterizing land drainage status. Closed depressions, flow accumulation and topographical wetness index were generated based on digital elevation model created by shuttle radar topography mission using system for automated geoscientific analyses software (SAGA) and quantum GIS (Q GIS) software. The yield of plant crop, first and second ratoon crops in 3,937 farmer fields over 4,865 ha plantation were taken for the evaluation. Correlation analysis was conducted on sugarcane yield in plant crop, ratoon crops 1 and 2 against closed depressions, flow accumulation and topographical wetness index values of each farmer field. The results showed that yield of plant crop or ratoon 2 were not significant with the parameters; closed depressions and topographical wetness index. However, the sugarcane yield positively correlated with parameters, flow accumulation and topographical wetness index in ratoon 1.

Keywords: *Geographical Information System, hydro-geomorphology, sugarcane ratoon yield*

Introduction

Sugarcane yield declining in ratoon crops is reported as a serious issue in Gal-oya Plantation Ltd., Hingurana since 2012. Ratoon yield declining is generally acceptable for even high productive healthy crop lands. Sugarcane replanting is often economically justifiable after five to six ratoons (Henry and Ellis, 1995). Currently sugarcane farmers in Hingurana are claiming that they cannot get good ratoon yield even in the ratoon 2 though it gives good yield in plant crop. Normally, sugarcane crop can be maintained up to five to six ratoons in most other sugarcane growing areas in Sri Lanka. Frequent replanting practice is not economically viable under Sri Lankan condition as most of the farmers start to receive profit from ratoon 1 crop. Usually cost incurred with land preparation and planting is deducted from the plant crop (1st year income).

The entire plantation in Hingurana is cultivated under irrigated condition where furrow irrigation is practiced. Controlled water supply is important in furrow irrigation practices as over irrigation negatively affect the yield (Holden and McGuire, 1998). If un-controlled irrigation occurs, excess water tends to accumulate at lower flat terrain areas and slowly drained into natural drainages. The main natural drainage in the area is Gal-Oya river. River banks of Gal-Oya are being inundated by flooding during *Maha* rainy season particularly in the month of November to December in some years which records high rainfall. Factors such as slope, terrain and relief forms, are the main physical attributes which determines the rate of surface drainage process (Souza *et al.*, 2010). Low rate of drainage tends to form ill draining areas and it causes significant yield loss of sugarcane cultivations (Abeysinghe *et al.*, 2018; Holden and McGuire, 1998) even in high productive fertile lands. Hydro-geomorphic indexes like closed depression (CD), flow accumulations (FA) and topographic wetness index (TWI) have been widely used to characterize water logging or flood risk areas (Kumhalova *et al.*, 2014; Grabs, 2009; Alberto *et al.*, 2017). CD of the landscape often tends to create ill draining situations resulting soil moisture levels in root zone often higher than the saturation level during the entire rainy period (Eslamian, 2014). FA areas are more vulnerable to floods and soil erosion (Baffour *et al.*, 2012). Soil moisture levels are often high in lower catena due to subsurface flow accumulation and groundwater discharging. TWI is often used to characterize such variations of soil moisture levels across the landscape catena or topo sequence (Brydsten, 2006; Liu and Smedt, 2004). Accordingly, a hypothesis can be formed as lowering of ratoon yield in Hingurana may have some association with this hydro-geomorphic parameters. Therefore, this investigation was conducted to understand the effect of terrain related hydro-geomorphic parameters on lowering the sugarcane yield in Hingurana.

METHODOLOGY

Study area: The study was conducted in Hingurana sugarcane growing area, between latitude from 7.160 to 7.280 (°N) and longitude from 81.610 to 81.750 (°E) over 4,865 ha in land extent. Hingurana area located in the Low Country Dry Zone in the Eastern boundary of the island, nearly 20 km proximity to the nearest sea. The terrain of the land is characterized as flat terrain, elevations range from 15 m to 65 m above mean sea level. Soils of this area mainly belong to three sub groups, *i.e.* alluvial, non-calcic brown and reddish-brown earth (Abeysinghe *et al.*, 2018; Weerasinghe *et al.*, 2011). Soils of the area are dominant with sands, particularly loamy sand and sand in texture according to the USDA classification (Wijayawardhana, 2014). The average annual rainfall in this area is 1,782 mm. The main rainy season spreads from October to December that receives rainfall from North East monsoon contributing 70% of total annual rainfall. Average annual ambient air temperature is 29.7 ^{0}C and the annual evaporation is 1506 mm per year (Wijayawardhana, 2014).

Identifying low ratoon yield reporting sugarcane fields: Sugarcane yield data of 3,937 farmer fields from 2013 to 2016 in Hingurana sugarcane plantation were obtained for the analysis. In order to identify low ratoon yielding lands, yield ratios (ratio 1 and 2) between two consecutive crop cycles were calculated for each farmer field as per equation 1 and 2.

$$Ratio\ 1 = \frac{\text{Ratoon 1 yield}\left(\frac{t}{ha}\right)}{\text{Plant crop yield}\left(\frac{t}{ha}\right)} \quad \ldots\ldots\ldots (1)$$

$$Ratio\ 2 = \frac{\text{Ratoon 2 yield}\left(\frac{t}{ha}\right)}{\text{Ratoon 1 yield}\left(\frac{t}{ha}\right)} \quad \ldots\ldots\ldots (2)$$

If ratoon yield is in decreasing pattern as ratoon number increases, above two ratios should be less than 1 (ratio value<1). As such, all the farmers' fields that appeared in the above pattern (both ratio values less than 1) were considered as low ratoon yielding lands. Other lands were omitted from the analysis. These selected farmer fields were again re-categorized into five groups according to plant crop yield (t/ha) *i.e.*, <50, 50-100, 100-150, 150-200 and >200, respectively.

Spatial distribution of problematic farmer fields: Magellan GPS was used to take global position data at each farmer field. Most probable center location of each farmer field was taken as the GPS point. Subsequently, the identified low ratoon yielding lands were plotted on a map.

Identification of ill drained lands: Most of the hydrological properties that determines the drainage status of the landscape is strongly linked with the terrain parameters (Hoffmann and Winde, 2010). Parameter CD, FA and TWI were used to characterize the farmer field's ill draining conditions of farmer fields. CD, FA and TWI were derived using digital elevation model (SRTM data, 90 m) with SAGA-GIS and Q-GIS software (Jarvis *et.al*, 2007). X and Y axis of DEM were converted into meter scale as SRTM data of the satellite images have been given in latitude and longitude scale (Vern, 2010). SAGA GIS has a high efficiency in processing spatial data (Alberto *et al.*, 2017), and its many offered options for dealing with most environmental and hydrological modeling purposes.

Closed depressions: Protocol developed by Olaya and Conrad (2009) was used to create CD raster layer. Depression areas of the land form always tends to accumulate excess rainfall water during rainy seasons (Liu and Smedt, 2004), creating temporary flooding or ponding even the adequate drainage facility has been provided. Ponding time or flooding occurred in these depression areas often depends on the slop of the terrain and distance toward the natural drainage system and the intensity of the effective rainfall.

Flow accumulation: Often natural drainages or valley beds are characterized by flow accumulating areas. Protocol developed by Olaya and Conrad (2009) was used to create FA raster layer using SAGA GIS software.

Topographic Wetness Index: Topographic wetness index was first introduced by Beven and Kirkby (1979). Since then it has become one of the most commonly used topographic indices. Topographical wetness index values were generated based on the DEM derived slope maps using SAGA GIS software based on the protocol developed by Olaya and Conrad (2009). TWI give relative wetness of the soils and often link with the shallow groundwater areas or groundwater discharge areas (Brydsten, 2006).

Higher TWI values represent drainage depressions or ill draining patches and lower values represent crest, ridges or relatively dry patches. Areas with high TWI values are more likely to drain by saturated excess flow during wet period. Thus, water accumulated areas were characterized by relatively high TWI values and lower values for smaller accumulating or drier lands.

Statistical analysis: CD, FA and TWI values in each farmer field were extracted from Figure 2 using QGIS software (Mancusi *et al*., 2015; QGIS project, 2014). Spearman Rho correlation analysis at 95% probability was conducted between TWI vs plant crop yield (P), ratoon 1 yield (R1), ratoon 2 yield (R2) and yield reduction % from plant crop to ratoon 2.

RESULTS AND DISCUSSION

Spatial distribution of low ratoon yielding lands: Out of total lands considered, 3,937, 1,107 lands have been identified as low ratoon yielding lands that reported significant yield declining pattern as ratoon number increases.

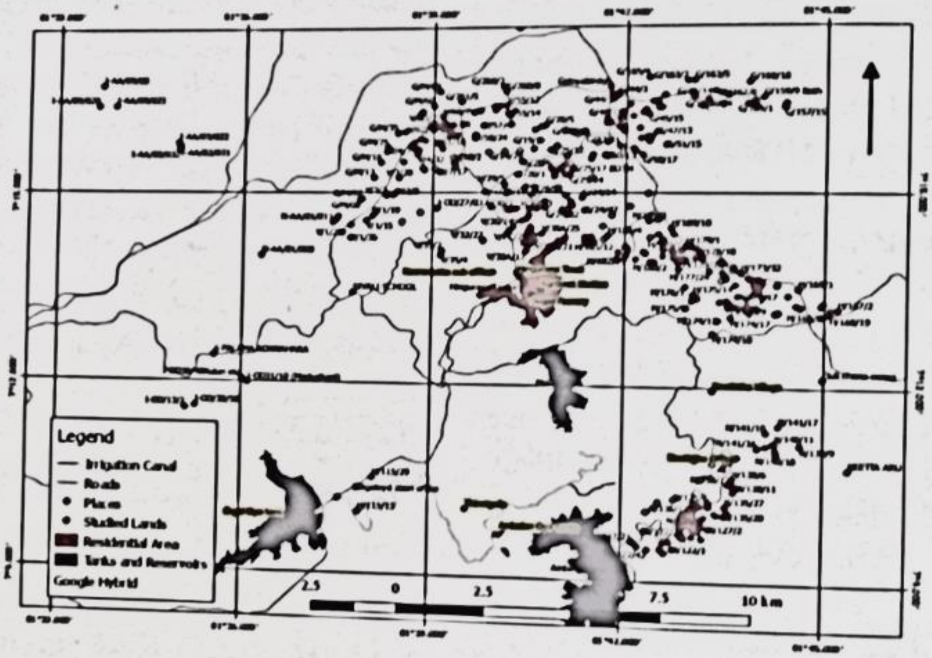

Fig. 1. Spatial distribution of low ratoon yielding lands

Yield declining pattern: Yield statistics of 5 groups categorized according to their plant crop yield (t/ha) *i.e.*, <50, 50-100, 100-150, 150-200 and >200 are given in the Table 1. According to the Table 1, ratoon yield declining problem in Hingurana is not a myth. In average, 73% yield declining was recorded in ratoon 2 even though some farmer fields gave plant crop yield higher than 200 t/ha. Yield figures of the plant crop in most farmer fields reflect that those lands have high potential to give a good sugarcane yield. Average plant crop yield was 122.6 t/ha and had been drastically decreased down to 31.3 t/ha within three years.

Hydro-geomorphic parameters: Spatial distribution of CD, FA and TWI indices are given in Figure 2. Spatial distribution of parameter CD is limited into few locations. These CD areas have a tendency for occur flood inundations during rainy seasons, and the severity and inundation period often depends on the rainfall intensity and number of consecutive rainy days occurred over the catchment.

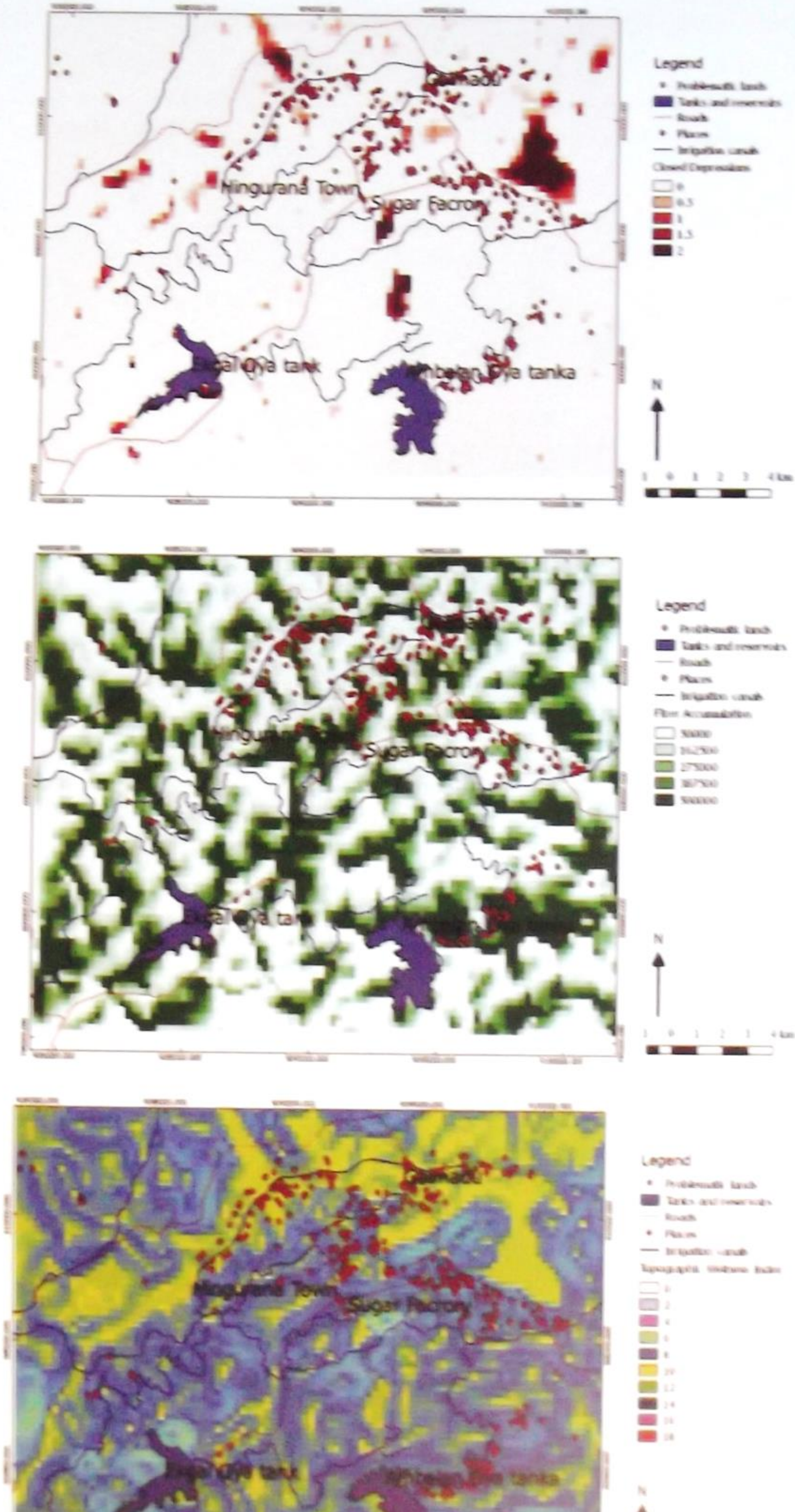

Fig. 2. Spatial distribution of closed depressions (CD), flow accumulation (FA) and topographical wetness index (TWI) across the sugarcane growing areas in Hingurana

Table 1. Average yield of plant crop, ratoon 1, ratoon 2 and their relative changes between each crop cycles

Yield category (t/ha)	Yield (t/ha)			Relative change					
	(P)	(R1)	(R2)	P-R1	R1-R2	P-R2	P-R1%	R1-R2%	P-R2%
>50	45.9	36.4	11.4	9.4	25.0	34.4	20.9	66.8	75.4
50-100	79.8	54.8	28.3	25.0	26.4	51.5	30.6	48.4	64.3
100-150	109.9	71.5	34.7	38.4	36.8	75.2	34.9	50.2	68.3
150-200	155.7	133.0	32.8	22.7	100.2	122.9	14.6	75.3	78.9
<200	221.6	139.7	49.1	81.9	90.6	172.5	36.9	64.9	77.8
Average	122.6	87.1	31.3	35.5	55.8	91.3	27.6	61.1	73.0

P= Plant crop, R1=Ratoon 1 and R2= Ratoon 2

Banks of Gal-Oya river and most downstream areas have relatively high TWI values. Unlike CD and TWI, parameter FA was widely distributed (mosaic distribution pattern) over the entire sugarcane project.

Correlation coefficient of evaluated parameters against the plant crop (P), ratoon 1 (R1) and ratoon 2 (R2) are given in the Table 2.

Table 2. Correlation coefficients of CD, FA and TWI between plant crop (P), ratoon 1 (R1), ratoon 2 (R2) yield and yield declining percentage from P – R2

Parameter	Plant crop yield (P)	Ratoon 1 yield (R1)	Ratoon 2 yield (R2)	Yield declining % (P-R2)
CD	-0.067 (0.245)	-0.003 (0.965)	-0.085 (0.136)	0.064 (0.267)
FA	0.164 (0.004)*	0.168 (0.003)*	0.098 (0.085)	-0.039 (0.500)
TWI	0.067 (0.239)	0.167 (0.003)*	0.069 (0.228)	-0.035 (0.542)

* Figures in parentheses are the probability values

As per the analysis, CD has a weak negative correlation with yields of P, R1 and R2 and was not significant in any combination. Flow accumulation areas (FA) showed strong positive correlations with sugarcane yield of P and R1. This indicates that the river bank areas of the Gal-Oya river gave high sugarcane yields, so that no drainage issue exhibited. TWI positively correlated with the sugarcane yield data in R1. Percentage yield declining does not show significant correlation in any combination of CD, FA and TWI parameters. Theoretically, CD and FA areas should give a significant negative correlation with sugarcane yield as these areas have more tendency for occurrence of floods or soil erosion. Yet, results of this study did not show such relationship. This means identified lands should have other reasons to give low ratoon yield than the land drainage associated issues.

As per the previous study conducted by Wijayawardhana (2014), sandy soils are dominant in most areas in Hingurana. Low tractability of farm machineries is often a serious problem in such sandy soils. This problem is significant if rainfall occurred during the harvesting season. Transport operations of harvested cane during rainy period cause sinking of tractors in sugarcane cultivated fields. Sometimes, heavy machines like excavators or backhoes are used to evacuate such stuck tractor engines or loaded trailers. Field observations conducted during the study period identified these issues. On the other hand, tractors running across the moist soil with heavy cane loads destroy ridge and furrow system of the sugarcane fields. These activities directly cause the destroying of productive areas of cropping lands, internal road system and forming gullies inside the cropping areas. Blocking of water in these gullies, disturbed roads, drainages and furrow lines which may be causatives to reduce ratoon crop yield significantly, as most runoff and irrigation water tend to be blocked due to these disturbances. Also, it affects on the distribution uniformity of irrigation water adversely.

Conclusion

The evaluated hydro-geomorphic parameters; CD, FA and TWI did not show negative correlations with sugarcane ratoon yield. FA and TWI showed positive correlation with the sugarcane yield. It means the ratoon yield declining problem has no association with land drainage issue, but with other factor like management weakness. Therefore, further investigations are needed in order to find out actual causatives for the lowering of ratoon yield in sugarcane plantations in Hingurana.

Establishment of efficient internal road systems inside the plantation even in individual farmer fields and concentrating the harvesting operations into dry seasons are possible options for such problematic lands as immediate action to rectify the problem of declining ratoon yields. Concern on rehabilitation of drainage network and other land development activities should be considered as the next step. High capital intensive work such as land drainage improving operations can be implemented as a long-term activity as per the availability of financial and human resources in long run.

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