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Fertility and Suitability of the Spodosols Formed on Sandy Beach Ridges Interspersed with Swales in the Kelantan - Terengganu Plains of Malaysia for Kenaf Production

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ABSTRACT

A study was conducted to evaluate the suitability of sandy soils in the Kelantan - Terengganu Plains (Peninsular Malaysia) and suggest measures to improve their fertility for kenaf production. The coastal landscape is scarcely utilized for crop production due to the inherently low soil fertility, nutrient imbalance and water deficit which can seriously inhibit crop growth. Three sandy Spodosols with humus - rich spodic horizon were found, locally named as Rhu Tapai, Rudua and Jambu Series with sandy matrix (> 95% sand), low CEC (0.16 - 4.52 $cmol_c\ kg^{-1}$) and high acidity (pH 4 - 5). The mineralogy data showed quartz (dominant), with gibbsite, hematite and feldspars in trace amounts that result from high degree of weathering. The C_{org} of Bs and Bhs horizon was about 2%, with C/N ratio of 14 to 25, respectively; this can be exploited for kenaf production. Hence, we evaluated these sandy Spodosols for kenaf production using Wong (2009) Crop-Suitability Classification and found the soil to be marginally suitable under Class 4 described as 4Dnt where D stand for drainage, n for nutrient and t for texture. The major limitations were found to be excessive drainage, nutrient imbalance and sandy texture. Therefore, management practices recommended to improve the soils are (1) mulching the soils with different types of organic materials to retain water and plant nutrients; and (2) irrigating the soils during the dry period. If these agronomic practices are carried out, these soils could be productively used for growing kenaf.

Keywords: Soil-crop suitability classification, tropical climate, BRIS soil, agronomic package for kenaf

INTRODUCTION

The shoreline of Peninsular Malaysia is found to be prograding towards the sea due to eustatic changes in the sea level (Nossin 1964; Hutchison 2009). Naturally, this process could have been repeated two or three times in the past 6,000 years. As a result, two or three sandy beach ridges (one ridge represents one level of drop in sea level) are found running parallel to the present shoreline. The formation of the sandy beach ridges due to eustatic sea effect has been well described by Tanner (1995) and Roslan *et al*. (2010).

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Sandy beach ridges are very common in the Kelantan - Terengganu Plains. Past studies (Lim 1989; Shamshuddin 1990) state that these plains are dominated by soils having sand texture which are locally named as BRIS Soils. The acronym BRIS stands for beach ridges interspersed with swales. The swales are found in between the ridges; they sit in the depression areas, and are therefore inundated by water for most part of the year. It is known that the soils on the beach ridges are sandy (with > 95% sand) up to 150 cm of the soil profile. Coarse sand fraction is common in the topsoil; however, the subsoil is usually dominated by very fine sand (Roslan *et al.* 2010).

On close examination of the B horizon of the soil profiles on the ridges, we found the presence of a spodic horizon at varying depths, which usually occur immediately above the groundwater water-table. The spodic horizon is very common in the temperate regions of the world, but not in the tropical climate of Malaysia unless the soils are very sandy. For instance, Richards (1941) found the presence of Spodosols in the lowland areas of tropical regions, but available data is not complete. The spodic horizon is known to be rich in organic matter, which can be exploited for agriculture production. The organic matter is often believed to originate from: (i) the decomposition of leaf litter derived from local vegetation; and (ii) the marine sediments from which the soils are formed. The presence of this spodic horizon that is rich in organic matter indicates that it could be used for crop production.

At present, about 154,000 ha of BRIS Soils are available in Malaysia, found mainly in the east coast states of Peninsular Malaysia, especially in the Kelantan - Terengganu Plains. BRIS Soils in these plains consist of many soil series of which the most common are the Baging, Rhu Tapai, Rudua and Jambu Series; the last three soils are Spodosols. These soil series are defined by their profile morphology and chemical properties. The Rhu Tapai, Rudua and Jambu Series have a spodic layer at depths of 0 - 50, 50 - 100 and 100 - 150 cm, respectively (Paramananthan 1987; Roslan *et al.* 2010) and so they fit into the definition of Spodosols (Soil Survey Staff 2010).

The BRIS Soils in Malaysia are not well utilized for crop production due to their inherent poor fertility. The only feasible and profitable crop grown on the soils over the years is tobacco. However, the government of Malaysia wants to replace tobacco with other eco-friendly crops, such as kenaf (*Hibiscus cannabinus L.*). There is a dearth of information on the technology required to improve the productivity of the sandy Spodosols for kenaf production. Hence, this study should provide some insights and is highly justified.

In order to replace tobacco with kenaf, a study is needed to determine its requirements for good growth. Kenaf is a green lignin-cellulose crop, better known as a non-wood fibre crop. It produces fibre that is widely used in the textile, paper and automotive industry. It can grow both in the tropical and temperate regions (Ogbonnaya *et al.* 1997). Under good climatic condition, kenaf can grow up to 6 m high and produce 30 t ha^{-1} of dry stem material (Woods 2003). Kenaf was introduced into Malaysia only recently as a new cash crop, and hence, information

about its agronomic practice for sustainable production is not available or at best, scarce.

Studies in African countries have indicated that sandy soils have potential for kenaf production even if the areas are subjected to water deficit (Ogbonnaya *et al.* 1997). It is known that water-stressed kenaf produce low yield; however, better quality paper made from such kenaf compared to non - stressed plants.

The productivity of the Spodosols in the Kelantan - Terengganu Plains is low. Under normal circumstances, these sandy soils cannot retain the nutrients and sufficient water for kenaf cultivation. Furthermore, leaching losses from these sandy soils are known to be extremely high as they occur in areas with high rainfall. Roslan *et al.* (2010) found that the texture of these soils is sand (with sand content >95%, most of it is coarse sand) which results in very low cation exchange capacity. Added nutrients are, therefore, easily leached into the groundwater and as such the soils have to be properly managed for kenaf production.

According to Zaharah *et al*. (1992), crop production on the BRIS Soils of the Kelantan-Terengganu Plains requires high fertilizer input and proper irrigation. However, with good management practices, chili, yam, bean, sweet potato and some other vegetative crops have been grown with success. In the area, tobacco is the preferred crop due to its economic significance in the marketplace. It is not easy to convince the farmers in the area to replace tobacco with kenaf. For sure, an acceptable agronomic package for kenaf production should be put in place before farmers are asked to grow this crop.

Initial studies have shown that kenaf grew poorly on BRIS soils with yields of < 2 t ha^{-1} (on dry weight basis). The low yield is believed to be due to the inherently low fertility of the sandy soils that causes a water deficit and low nutrient holding capacity. Therefore, the objectives of this study were: (1) to evaluate the suitability of the Spodosols formed on the sandy beach ridges in the Kelantan - Terengganu Plains for kenaf production; (2) to improve the fertility status of the Spodosols; and (3) to propose agronomic practices for sustainable production of kenaf.

MATERIALS AND METHODS

Study Area Description

The study area is the Kelantan - Terengganu Plains, Malaysia (*Fig. 1*). It is between 5.65° to 6.23° North latitudes and between 101.95° and 102.53° East longitudes. In the northern part, it is separated from Thailand by Golok River. The land areas are mostly covered with grasses, small shrubs and casuarina species. This vegetation provides a fresh supply of organic matter to the soils. Due to the ongoing decomposition of this litter, acid humus (mor humus) is produced, which over a period of time has accumulated in the topsoil. It is this humus that helps promote the podzolisation process, leading to the formation of the spodic horizon.

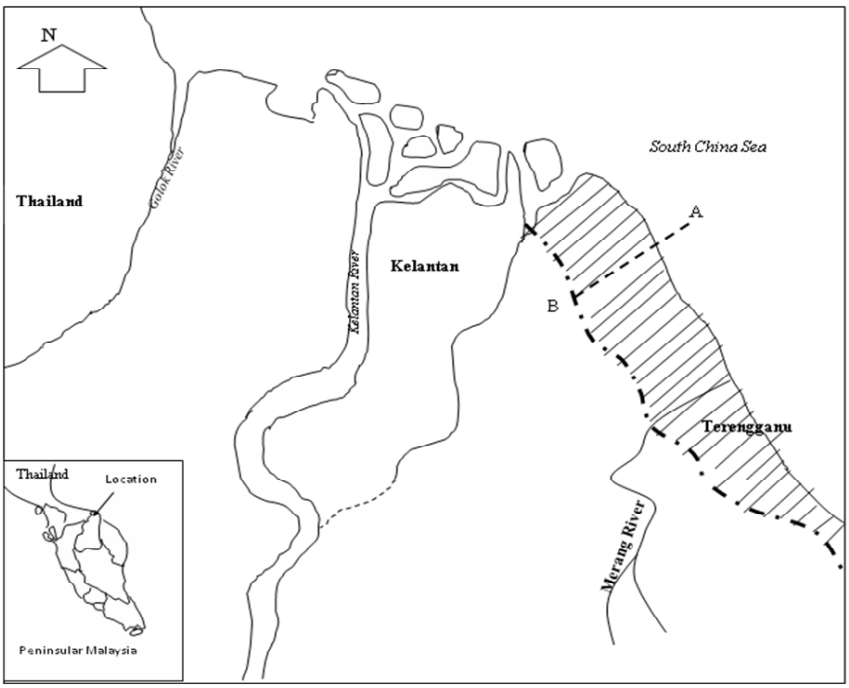

Fig. 1: A map showing Kelantan-Terengganu Plains, dominated by sandy beach ridges interspersed with swales (A-B: the presence of ridges with sandy Spodosols and swales in depression area)

The temperature of the soils during a hot day rises to about 42° C, dropping to a minimum 22° C at night (Abdul Wahab 1984). The mean annual rainfall is very high, at 3071 mm/year in Kelantan and 2784 mm/year in Terengganu (DOA 2010). Based on Köppen climate classification, these areas are categorized as Af (tropical rainforest climate). This classification indicates that its average daily temperature fluctuation is greater than the average seasonal temperature fluctuation and is accompanied by abundant rainfall throughout the year. There is no area in the Kelantan - Terengganu Plains with rainfall less than 60 mm/month. One-third of the annual precipitations is brought by the Northeast Monsoon winds, during the months of November-January throughout the year. The high precipitation promotes eluviation (seen as E horizon) and illuviation processes (seen as Bs and/or Bhs horizon) in the soil profiles.

Field Observations and Data Collection

Field observations were carried out continuously for two years, from year 2009 to 2010 in order to determine the condition of the area in terms of land utilization. The dominant agricultural activity is tobacco production, followed by livestock rearing. As we moved further inland, we observed that the presence of acid sulfate soils (in the swales) has led to rice being cultivated in these areas.

The preliminary information and essential data of the area under study were obtained from literature (Haile 1970; Soo 1975; Abu Bakar 1985; Paramananthan 1987; Shamshuddin 1990; NTB 2009; Roslan *et al.* 2010). Later, the area was resurveyed in detail to get further information. Based on the survey carried out, soils on the ridges were found to contain the spodic horizon, and are therefore classified as Spodosols *(Fig.2)*. To carry out detailed analyses of the soils, soil pits were dug in the areas undisturbed by human activities and samples were collected based on their respective horizon.

As the soils occurring on the ridge nearest to the shoreline had no spodic horizon, they were not used for this study. It was found that Rhu Tapai and Rudua Series occurred on the intermediate ridge (second ridge) running parallel to the shoreline, while the Jambu Series was on the oldest (third) ridge *(Fig. 1)*. As these three soils contain the spodic horizon within 150 cm of soil depth, they can be classified as Spodosols (Soil Survey Staff 2010). The location of the observation points were recorded by global positioning system (GPS Garmin 60cxs) instrument.

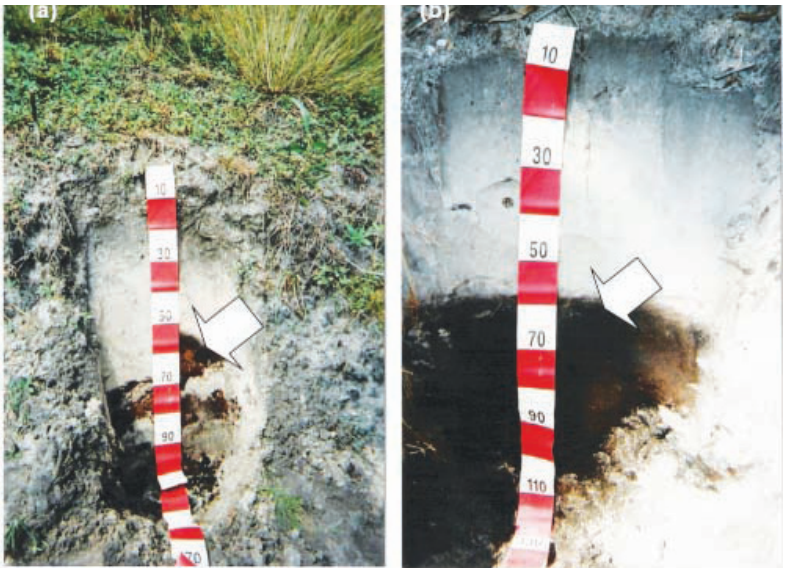

Fig. 2: Pictures showing two types of Spodosols with spodic horizon: (a) Rhu Tapai Series (P1) - not cemented, with water-table just below the spodic horizon, and (b) Rudua Series (P2) – cemented; this is also known as hardpan, with the watertable located at more than 200 cm

Soil and Data Analyses

The collected soil samples were subjected to standard chemical and physical analyses in the laboratory. The sand, silt and clay fractions in the soils were separated by successive sedimentation. Soil pH was determined in water (at a soil to solution ratio of 1:2.5), while electrical conductivity (EC) was determined using saturated paste. Cation exchange capacity (CEC) was determined by the method

using 1 M NH_4OA_c buffered at pH 7. The basic cations (Ca, Mg, K and Na) in the NH_4OA_c extract were determined by atomic absorption spectrophotometer (Perkin Elmer 5980 AAS Instrument); the cations are regarded as exchangeable cations. Other analyses include the determination of exchangeable Al and free iron oxides (van Ranst *et al*. 1999), organic carbon (OC) (Nelson and Sommers 1996), total nitrogen (Kjeldahl method) and available P (Bray and Kurtz 1945).

RESULTS AND DISCUSSION

Changes in the Landscape of the Coastal Plains

A cross-section of the study area shows an undulating topography pattern *(Fig. 1)*. The soils are severely depleted of nutrients with soil temperatures ranging from 22 to 42^o C and suffer from serious water deficit during the dry months of February to May/June every year. The present undulating and gentle landscape that characterises the coastal plains was formed by eustatic effect (Shamshuddin 1990; Roslan *et al.* 2010). Eustatic effect is a combination of sea wave and current action with auxillary forces acting on the beach shoreline. This effect brings marine deposits to the shoreline, washing away much of the lighter fraction (like silt and clay) northwards, leaving the soils high in sand content in the plains.

Over time, the action created ridges and swales with the ridges being the elevated section of the landscape, while the swales formed the depression area. The ridge has a lower water table compared to the swales which are inundated with water throughout the year. Flooding occurs frequently in the swale areas (MARDI 2010); hence, utilizing the frequently flooded soils for agriculture is not economical.

The soils found on the ridges and swales are classified into two categories: the one closest to the shoreline are Entisols and those further away are Spodosols *(Fig. 2)*. The Entisols have no profile differentiation and are considered as young soils. The Spodosols can be suitable for agricultural purposes due to the presence of a conspicuous organic layer in the B horizon, called the spodic horizon (*Fig. 2*). All the Spodosols in the study area are classified as Arenic Alorthods (Roslan *et al.* 2010), belonging to three soil series, namely Rhu Tapai, Rudua and Jambu Series *(Fig. 3)*.

Physico-chemical Properties of the Soils

The physical and chemical properties of the soils are given in Table 1. It is seen that the CEC value is low (< 5 $cmol_c\ kg^{-1}$) and the pH is 4 - 5 indicating that acidity can be a threat to crop growth. However, Al is only present in trace amounts in the soils. It is believed that the Al in the soils have been leached out over a period of 3000 - 6000 years, forming inert Al-hydroxides that are accumulated in the spodic horizons. This leaves very little Al in the topsoil. This phenomenon contradicts the popular belief that Spodosols in the area have Al toxicity that limits crop growth.

TABLE 1
Physical and chemical properties of the sandy Spodosols in the Kelantan-Terengganu Plains

Series	Granulometric composition (%)			pH H_2O	bd[a] (g/cm^3)	E.C ($dS\ m^{-1}$)	Exchangeable cations ($cmol_c\ kg^{-1}$)				CEC	BS (%)	Avail. P (ppm)	C_{org} (%)	N (%)	C/N ratio	Free Fe (ppm	Avail. Al (ppm)
	Clay	Silt	Sand				Ca	Mg	K	Na								
Rhu Tapai (P1): Soft humus podzols formed on the intermediate ridge																		
Ap (0-41)	2.50	1.50	96.00	5.10	1.12	0.01	1.30	0.40	0.02	0.01	2.12	85.00	11.40	1.70	0.36	5.00	0.56	0.08
Bs (41-98)	1.20	1.30	97.50	5.10	2.65	0.01	0.04	0.01	0.03	0.01	0.32	38.00	5.60	0.82	0.06	20.50	0.21	0.12
C (+98)	0.70	0.10	98.20	4.90	1.45	0.01	0.03	0.04	0.02	0.02	0.16	69.00	2.10	0.08	0.04	2.00	0.07	0.05
Rudua (P2): Humus podzol (with hardpan) formed on the intermediate ridge																		
Ap (0-33)	2.80	0.90	96.30	5.10	1.20	0.13	0.87	0.51	0.06	0.07	1.75	70.00	15.90	2.12	0.14	15.00	0.33	0.07
A1 (33-52)	1.50	1.00	97.50	5.20	1.42	0.01	0.04	0.32	0.07	0.04	1.02	52.00	20.50	0.87	0.11	8.00	0.13	0.09
B (52-84)	0.60	0.40	99.00	4.90	1.75	0.01	0.19	0.07	0.01	0.06	0.92	36.00	8.40	0.91	0.04	23.00	0.19	0.10
Bs (+84)	0.80	0.10	99.10	5.00	2.80	0.01	0.01	0.03	0.01	0.06	0.31	35.00	11.00	0.72	0.05	14.40	0.16	0.11
Jambu (P3): Humus-rich podzol (with hardpan) formed on the oldest ridge																		
Ap (0-16)	1.80	0.50	97.70	5.00	1.35	0.09	2.86	0.65	0.05	0.07	4.52	74.00	2.40	2.58	0.42	6.00	0.08	0.08
E (16-109)	1.00	2.00	97.00	4.50	1.42	0.02	0.87	0.03	0.02	0.05	2.38	38.00	0.85	0.30	0.05	6.00	0.02	0.05
Bhs (109-150)	0.80	2.30	96.90	4.40	3.20	0.01	0.20	0.01	0.01	0.06	0.56	52.00	2.50	1.50	0.06	25.00	0.12	0.15
Bs(+150)	0.80	0.60	98.60	5.10	3.00	0.01	0.05	0.02	0.01	0.06	0.38	37.00	5.10	0.87	0.30	3.00	0.13	0.12

[a] Bulk density.
[b] n.d= Not detected.

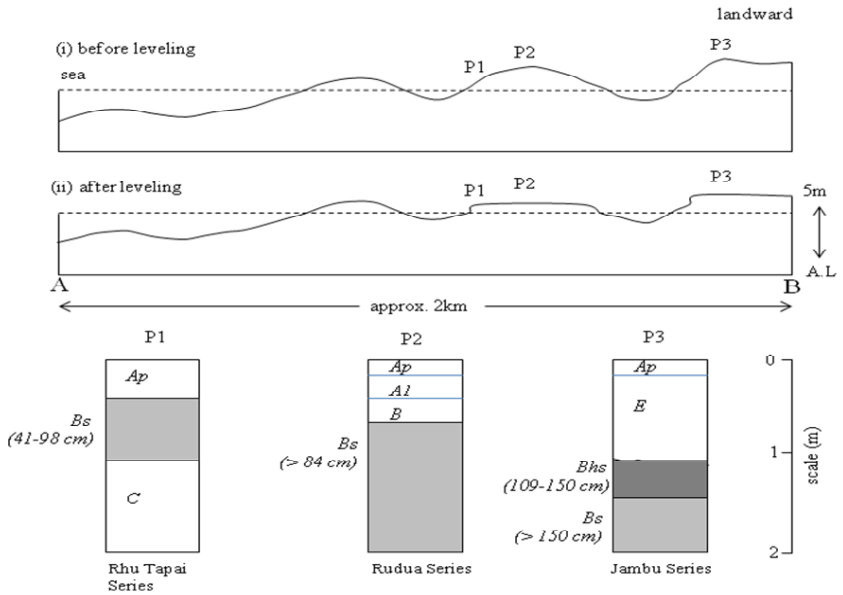

Fig. 3: A cross section of the landscape from A to B: (i) before land leveling, and (ii) after land leveling practice by the farmers (P1, P2 and P3 are soils with the spodic horizon at different depths)

Silt together with clay was X-rayed to determine the mineralogical composition of the soil fraction. X-ray diffraction analysis showed the dominance of quartz (relative intensity of 75-100%) with trace amounts of gibbsite, hematite and feldspars (relative intensity of < 25%) in the spodic horizons of the soils (Roslan *et al.* 2010).

The spodic horizons of the soils contain higher amounts of organic carbon (1 - 2%) than that of the overlying A horizon. The C/N ratios of the spodic horizon are 14, 20 and 25 for Rhu Tapai, Rudua and Jambu Series, respectively. This indicates that the spodic horizon is rich in soil organic matter and has the potential to be utilised for growing kenaf and this fact was supported by MARDI (2010). The spodic horizon is cemented (hardpan); fine to very fine sand particles dominate the horizon. However, we believe that with improved soil management practices, such as land leveling *(Fig. 3)*, irrigation and mulching (with rice straws), these sandy Spodosols can be used for agriculture. Plenty of rice straw can be found in the vicinity of the study area. In addition, a study by Tsakaldimi (2006) used kenaf-based material as a growth media and found that such a media can improve water retention and nutrient availability.

Evaluation of the Spodosols for Kenaf Production

As less and less arable land are available for agriculture, new land clearing and deforestation which is a common practice is not a sustainable option; both practice release much of CO_2 stored in the soil carbon to the atmosphere. This, in return, increases green house effect in the environment. In Peninsular Malaysia, there are

areas which are less utilized, for example, the soils on the sandy beach ridges in the Kelantan - Terengganu Plains, which is the focus of this study. In a scenario of decreasing arable land, utilizing the sandy coastal soils becomes more necessary than ever. Only 5 - 10% of the sandy beach ridges soils from approximately 154,000 ha in Malaysia are being utilized for crop production, such as for tobacco cultivation (NTB 2009; DOA 2010). The good intention of replacing tobacco with an eco-friendly crop has further increased the need to assess the suitability of Spodosols in the Kelantan - Terengganu Plains for crop production.

With the availability of new data, the prospects of using the Spodosols for kenaf production is good. In this paper, we propose two methods of evaluating the soils for kenaf production. Firstly, due to high local interest in utilizing the land, we evaluated the sandy soil areas using the local classification system that is, Soil - Crop Suitability Classification (Wong 2009). Secondly, for a broader international interest, we compiled data from literature on kenaf agronomic requirements and used them for the evaluation of the soils.

Evaluation Using Soil-Crop Suitability Classification Wong (2009) System

A guideline known as Soil-Crop Suitability Classification System (Wong 1974) has been used to evaluate the fertility status of soils in Peninsular Malaysia. This classification is used for specific purposes intended solely for crop growth. The system is based mainly on physical limitations that are believed to be difficult to rectify together with chemical limiting properties. No climatic conditions have been taken into account because there are no four seasons in Malaysia; therefore, the crop is not affected by seasonal limitations as in the temperate regions. The climate in Malaysia is hot and humid throughout the year with abundant rainfall, reaching up to 4000 mm/ year in certain localities. However, in the study area, the range of rainfall is 2500 to 3500 mm/year. This system has been revised in 2009 and is now called the Wong (2009) system.

In order to understand the land characteristics of the sandy beach ridges, a site survey was conducted and three soil pits within the spodic horizon were dug and are described accordingly. The three soil profiles were identified as Spodosols due to the presence of spodic horizon within 150 cm of the soil profiles. The soils are Rhu Tapai, Rudua and Jambu Series, denoted by P1, P2 and P3, respectively *(Fig. 3)*. The three soil profiles are presented in sequence in Figure 3 with the first being closest to the present shoreline and the last furthest away. Note that the age of the marine deposits forming the soils at P1 and P2 is about 3000 years and that of P3 is about 6000 years (Roslan *et al.* 2010).

Using the Wong (2009) system, the Spodosols are categorized as Class 4DnT (Table 2). Hence, the soils fall under soil suitability Class 4. The 'D' describes drainage limitation, followed by 'n' for nutrient imbalance and 'T' for texture and structure limitations. Class 4 states that soils have more than one serious limitation for crop growth:

TABLE 2
Soil-crop suitability for P1, P2 and P3 based on the Wong (2009) system

No.	Symbol	Type	Value for P1 *(limitation for crop growth)*	Value for P2 *(limitation for crop growth)*	Value for P3 *(limitation for crop growth)*
1	A	Depth to acid sulphate layer	-	-	-
2	C	Depth to compacted layer	-	-	-
3	D	Drainage	Moderately well drained *(Serious)*	Somewhat excessively drained *(Serious)*	Excessively drained *(Serious)*
	d		-	-	-
4	G	Gradient	-	-	-
5	N	Nutrient imbalance	-	-	-
	n		CEC < 5 meq/100gm soil *(Serious)*	CEC < 5 meq/100gm soil *(Serious)*	CEC < 5 meq/100gm soil *(Serious)*
6	o	Organic horizon thickness	Bs layer at 41-98cm depth	Bs layer at > 84cm depth	Bhs layer (cemented) at 109-150cm, and Bs layer (cemented) at > 150cm depth
7	R	% Stoniness to 100 cm depth	-	-	-
	r		-	-	-
8	s	Salinity	-	-	-
9	T	Texture and structure	Moderately to coarse textured and weakly structured *(Serious)*	-	Fine to very fine textured and strongly cemented *(Very serious)*
	t		-	Moderately to fine textured and moderately structured *(Moderate)*	-
10	H	Human	-	-	-
		Classification:	4DnT	4Dn(t)	4DnT

(i) Drainage condition (D)

Drainage (D) condition is a physical limitation that is difficult to rectify. The drainage of the area varies from somewhat highly drained to excessively drained condition. The land areas are almost flat and undulating in some areas with elevations of up to 5 m, depending on the localities. The climatic regime of the area is classified as Af (Köppen classification) which is continuously wet (Mohr's classification), receiving heavy rainfall of up to 3071 mm/year in Kelantan and 2784 mm/year in Terengganu from January to November, with an intermittent dry season (March-May). During the dry season, water deficit becomes severe. Water percolation is very fast owing to the sandy nature of the soils *(Fig. 4)*. From the topsoil to the B horizon, the sand fraction changes from coarse to medium/fine sand, with the soils being loosely structured and very permeable.

(ii) Nutrient imbalance (n)

Nutrient imbalance (n) is severe in the sandy Spodosols. The CEC of these soils is very low (1-5 $cmol_c\ kg^{-1}$); this is due to the presence of very low amounts of clay in the soils (0.6 - 2.80 % clay). Clay retains nutrients (i.e. Ca, Mg and K) in the soils; normally, soils with high clay content have higher CEC value. Increasing the clay content is almost impossible; however, we can increase the CEC somewhat via mulching with organic materials.

(iii) Texture and structure (t)

In the topsoil (O/A horizon), the soils are moderate to coarse textured and are weakly structured for all the Spodosols. In the spodic horizon, the sand was found to be pseudo-coated with organic materials. This layer is compact, cemented by oxides of Al and/or Fe, which is normally referred to as hardpan or orstein. Due to the compaction, root penetration is almost impossible.

In a recent study at the Kelantan - Terengganu Plains, it was found that the root of kenaf was deformed when it reached the spodic horizon. The deformation of the root was marked with root bending up to 90^o in the soil; despite this limitation, the plant grew well up to 6 m in 150 days (unpublished data). Minor roots were found in Bs and Bhs layer, believed to be originated from the past litter deposition. Microbial activity by rock - eating mycorrhizal fungi and/or decomposition in the Spodosol as suggested by some researchers as among the key players in spodic horizon formation (van Breemen *et al*. 2000), does not seem to be involved here. If such a process has taken place actively in the soil, there should be no roots present in the spodic horizon. A time period of 3000 to 6000 years is sufficient to decompose all the roots. On the contrary, we found some minor roots embedded in the Bs (profile P2) and Bhs (profile P3) horizons. This suggests that if the microbial activity does occur in the spodic horizon, it would be extremely low.

Based on the Wong (2009) system, the Spodosols under study were marginally suitable for kenaf production (Table 3). The land is level, but the sand texture impedes nutrient retention due to quick and excessive lateral flow of

TABLE 3
Crop suitability correlation based on the Wong (2009) system using five different cash crops

Soil criteria	Value (Spodosol in the sandy soil of the coastal plains)	Crop suitability				
		Coconut (Group 2)	Rubber (Group 5)	Palm Oil (Group 3)	Cocoa (Group 4)	Paddy (Group 24)
Slope	0-2 (>6-12^{o} slope)	S	S	S	S	S
Drainage	Somewhat highly drained-excessively drained	S	S	M/d	S	U
Effective soil depth	50- 150++ cm	S	S	S	S	S
Texture and structure	Coarse textured and weakly structured (A horizon) and cemented spodic horizon (B horizon)	M/t	U	U	U	U
Salinity	n.d	-	-	-	-	-
Depth to acid sulfate layer	n.d	-	-	-	-	-
Peat Thickness	n.d	-	-	-	-	-
Stoniness	No stoniness	S	S	S	S	S
Nutrient imbalance	Moderate to serious	M/n M/tn	M/n M/n	M/n M/dn	M/n M/n	M/n U/d

Note: S= Suitable, U= Unsuitable, M= Marginally suitable (require soil improvement), and t= texture, n=nutrient imbalance and, d=drainage.

water through the soil horizon. Water percolates from surface to adjacent or lower ground much faster than the root system can take up the water *(Fig. 4)*. In addition, fertilizers applied onto the soils have less time to be available for plant uptake.

Rain-fed water reaches the fertilizers at more than 30 cm minute^{-1} in extreme conditions, coupled with higher evapo-transpiration (up to 80%) than the precipitation rate (Ghazali and Nieuwolt 1982); this further increases the nutrient imbalance of the soils.

The sandy texture soil has large pore spaces; these conditions shift and disperse the fertilizers to the adjacent lower elevation via lateral water movement *(Fig. 4)*. For instance, when fertilizer is applied onto the soils on ridge 3, the water is translocated into swale 2, accumulating in the depression and later is translocated again to soils in ridge 2 and this process continues until it reaches ridge 1. The fertilizer undergoes dilution effect and is removed from the ridges, which finally settles in swale 1. The dark brown color of the topsoil in Rusila Series present in swale 1 clearly indicates the enrichment of organic matter and N, P and K. Rainfall data of the area shown in *Fig. 5* give an idea of water availability.

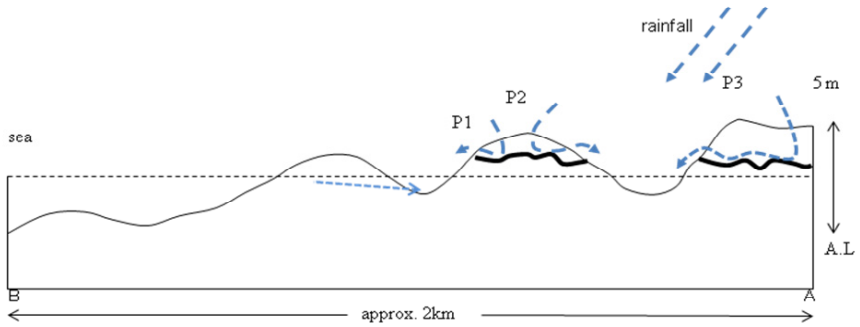

Fig. 4: Lateral movement of water (side-ways rather than percolating downward) from the ridge to swales due to the presence of the hardpan (Bs and/or Bhs) in B horizon

The lateral movement of water is possible due to the cemented Bs and Bhs layer in the Spodosols.

A simple field test was conducted to see water movement in the soils. One of the soil pits was dug slightly wider and water was poured from the surface. The water ran downwards in a few seconds and later moved horizontally parallel to the spodic horizon. The drying out process of water was very fast. There was no water penetration through the cemented Bs and Bhs layers. A similar scenario of water movement was found in the Spodosols of Sarawak (Andriesse 1968).

In order to better understand crop suitability of the Spodosols, a crop suitability correlation was carried out on crops other than kenaf based on the Wong (2009) system (Table 3). Based on this study, it was found that the Spodosols under study are marginally suitable for kenaf production.

Some of the Spodosols have undergone the process of land leveling over the years *(Fig. 3)* and the ongoing human disturbance of the sandy soils makes it difficult to precisely identify the soil series. The leveling practice often involves

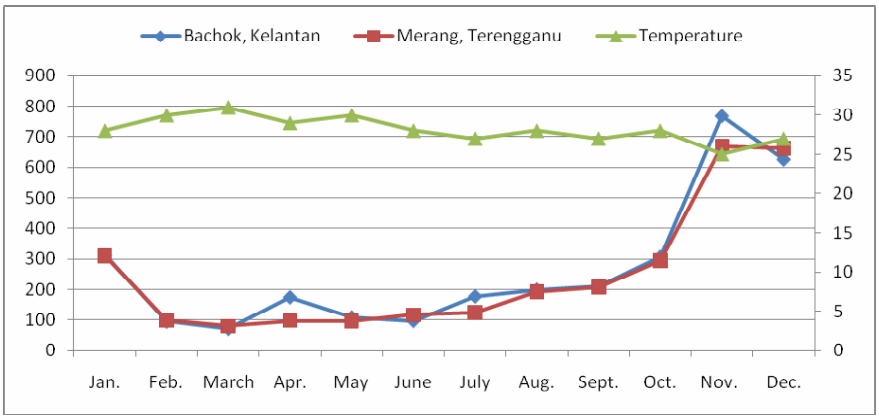

Fig. 5: Monthly rainfall distribution (mm) for Bachok (Kelantan) and Merang (Terengganu) for the past 10 years (2000-2009) with a mean average temperature of 28 °C

scraping the topsoil, and in doing so, the spodic horizon comes closer to the top layer; such a condition was seen in P1 and P2 landscape. It is known that the farmers in the area cultivated chili, yam, bean, brinjal and okra with mixed success. The land leveling activity has altered the depth of spodic horizon; hence, this can change the soil series name as the names were based on the depth of spodic horizon (Paramananthan 1987).

Evaluation Based on Agronomic Requirements

Kenaf crop is well adapted to various climatic conditions (Caldwell 1936), and therefore, it is necessary to refer to past literature to determine the minimum requirements for kenaf growth. The FAO system of land evaluation does not include a table on the agronomic requirements for kenaf growth; hence, our efforts to determine the requirement for kenaf growth are justifiable.

With reference to early research related to kenaf, a study by Dempsey (1975) indicated that kenaf can be grown in areas from latitude 16°S to latitude 41°N with mean relative humidity ranging from 68 to 82 % and temperature of 23 – 30 °C during the growing season. The climatic condition in Peninsular Malaysia is hot and humid throughout the year with little seasonal variations, and hence it should be suitable for kenaf growth. The following are the requirements for kenaf growth:

(i) Geographical location

Based on the study by Dempsey (1975), the sandy beach ridges landscape (Fig. 6) of Peninsular Malaysia is located within 5.65° to 6.23° North latitudes, and between 101.95° and 102.53° East longitudes. It means the location of the study is well within the range suitable for kenaf production and agreed by DOA (2010).

Fig. 6: A typical landscape of the sandy beach ridges interspersed with swales:a) Jambu Series (oldest ridge) and; b) Rudua Series and Rhu Tapai Series (intermediate ridge)

(ii) Temperature

A study by Ogbonnaya *et al.* (1997) states that water stress reduced the volume of wood produced and changed its fibre properties. However, water stress with high temperature (35.5 ± 0.95°C) could improve the quality of the pulp and paper produced from kenaf (Ogbonnaya et al. 1998). The temperature in Peninsular Malaysia is 25-32°C with mean values of 28°C *(Fig 5)* and therefore, is suitable for kenaf cultivation. Low yields can be compensated by higher paper quality produced from kenaf fibre.

(iii) Water availability

A study by Crane (1947) states that 500 - 625 mm of rainfall over a period of 5-6 months is essential for successful production of kenaf fibre. In Peninsular Malaysia, this period is much longer. Meanwhile, Bañuelos et al. (2002) state that kenaf requires 780-1200 mm of water applied by irrigation or precipitation for optimal growth and production. The Kelantan-Terengganu Plains fall under Zone 1 of the Agro-climatic Zones of Ghazali and Nieuwolt (1982) with a distinct 4-months dry period and have a rainfall of 2,500 to 3,500 mm/year *(Fig. 5)*. Therefore, Spodosols on the sandy beach ridges in the plains receive sufficient rainfall (water availability) for kenaf growth.

(iv) Rooting condition

In some areas, the land is flat and in others, it is elevated. The oldest ridge has an elevation of up to 5 m. The soils in the ridges have undergone extensive leaching process, washing out of clay, leaving behind the sand fraction. Sand has a lot of pore spaces (up to 50%); hence, rain water percolates into the soils very fast, causing a water deficit. This water stress causes serious problems for plant growth (Hsiao 1973). Due to the large pore size and loosely structured sand of the Spodosols, initial rooting is not much of a problem. However, once it reaches the spodic horizon, the root tends to bend up to 90^{o}; despite that, the plants grew well to 6 m in 150 days (unpublished data).

(v) Kenaf Growth

In kenaf cultivation, plant height and amount of rainfall are major yield contributors to the total stalk yield (Ching *et al.* 1993). During growing season, high average temperatures (up to 28 ^{o}C) and significant rainfall (up to 3000 mm/year) with a long growing period (125 - 150 days) critically influence kenaf height. Organic matter up to 2 % in the soil is sufficient to support tree crops (Oyenji and Agbede 1980). About 2% of organic matter is present in the spodic horizon of the soils. Hazandy *et al*. (2009) found that increasing the rate of fertilizer had increased the growth and biomass of kenaf grown under wet conditions. This shows the importance of water supply for kenaf growth; when water supply is limited, tugor pressure will force the plant cell wall to concave, thus reducing growth. The point is we should conserve the rain-fed water. So we propose rice straw mulching to improve water holding capacity as well as the soil structure.

(vi) Al toxicity

A common belief among the farmers is that Spodosols suffer from Al toxicity, but fortunately, the Spodosols in the study area are not. The soil pH was 5.5 or slightly below; hence, it does not promote the release of Al into the soil solution. As seen in Table 1, the exchangeable Al ranged from low to non-detectable. This is related to the sandy nature of the soils. This suggests that the Al in the spodic horizon is not readily available for dissolution into the soil colloid system; it exists as Al-hydroxides or is chelated by organic acids. Therefore, Al toxicity is not a threat to kenaf growth.

(vii) Flood hazard

The oldest ridges have elevations of up to 5 m and therefore Spodosols on these ridges (also on intermediate ridges) are not susceptible to the flooding hazard *(Fig. 4)*. However, the swales are in the depression and are therefore prone to flooding (Shamshuddin 1990). The swales are normally in swampy areas, containing acidic soils which are used for growing rice.

(viii) Diseases

In some localities, we found nematode in the Spodosols (data not shown).

Nematodes infested soils can significantly reduce kenaf yield up to 50% (Cook *et al.* 1995; MARDI 2010). In order to avoid nematode infestation, kenaf should not be grown continuously. The use of chemicals does not affect seed germination; hence, treating kenaf with selected fungicides could help maintain seed quality and improve stand establishment by protecting the seeds and seedlings from seed- and soil-borne pathogens (Cook *et al.* 1992; Robinson and Cook 2001).

It is reported that during the first month of growth, kenaf is sometimes attacked by mealybugs *(Fig. 7)*. These white bugs feed on kenaf leaves and stems by sucking the sap of plant as early as 25 days of growth. The plant leaves turn yellow and the presence of high number of ants than normal is another sign of infection (Malisa *et al.* 2011); hence, this retards the growth of kenaf. A good understanding of pesticide application is required to tackle this problem, if not within days, the crop will be destroyed.

Fig. 7: Mealybugs attacking kenaf leaves (this retards growth and the leaves turn yellowish)

(ix) Kenaf cultivar

Any good kenaf cultivar produces high fibre and high leaf biomass. Under good climatic conditions, kenaf grows up to a height of 5 - 6 m in 6 - 8 months, producing up to 30 t ha^{-1} of dry stem material (Wood 2003). Several studies

have shown that cultivar Tainung 2 and Everglades 41 have high adaptability to climatic variability and produce high yield (Ching *et al*. 1993; Webber and Bledsoe 2002; Wood 2003). A good kenaf cultivar suited to tropical climate is needed, and Tainung 2 and Everglades 41appear to be very promising.

In the study area, small scale farmers use a non-irrigated system due to financial constraints. Studies in Africa (Liu and Labuschagne 2009), Thailand (Polthanee 1997) and Greece (Lauriault and Puppala 2009; Danalatosa and Archontoulis 2010) showed that only well-adapted cultivars can be grown successfully under non-irrigated conditions. In order to obtain a cultivar with good yield for any given climate and soil type, a breeding programme to produce hardy cultivars is needed. In Malaysia, breeding programmes are well underway, but a programme suited to sandy soils has yet to be started. Despite this setback, there are efforts to grow kenaf on the sandy Spodosols of the Kelantan - Terengganu Plains. However, this raises a question. Can kenaf be grown on sandy Spodosol having inherently low fertility?

Based on the above review we have constructed a table containing the agronomic requirements of kenaf for its optimal growth (Table 4). We evaluated the suitability of the Spodosols for kenaf production using these data. Again, we found that the Spodosols were marginally suitable for kenaf production. Hence, a special agronomic practice is needed to make the soils suitable for kenaf production on the soils under study.

Can Kenaf be Planted on Sandy Soils?

It is known that kenaf is well-adapted to a wide range of soil types, from clayey to sandy clay loam soils. However, best kenaf growth is obtained on well drained fertile soils. Soil texture should be heavier than sandy clay loam. Studies conducted by Ogbonnaya *et al.* (1997) and Ogbonnaya *et al.* (1998) state that kenaf can grow well on sandy clay loam soils. In our case, the soil texture is sand; with very little clay, the soils are not able to retain nutrients for kenaf uptake. However, with the presence of the spodic horizon rich in organic matter, it may be possible to grow kenaf. The spodic horizon can (1) act as nutrient reserves/pool and (2) can result in water collection or a perched water table, etc.

Kenaf can be grown on sandy Spodosols provided that soil improvement is carried out. Some site specific experiments of kenaf cultivation in such sandy soils have shown promising results (Mat Daham *et al.* 2006; Mohd Ekhwan *et al.* 2009; MARDI 2010). This conclusion is consistent with requirement data for optimal kenaf growth given in Table 4. Thus, in this paper, we highlight a few suggestions for soil improvement.

Improvement of the Spodosols for Kenaf Production

Based on Wong (2009) Crop-suitability Classification and agronomic evaluation, it is clear that excessive drainage condition, nutrient deficiency and soil structures (sand texture in this case) need to be improved so as to ensure sustainable production of Kenaf on the Spodosols of the Kelantan - Terengganu Plains. Having said this,

TABLE 4
Agronomic requirements of kenaf for optimal growth

Land characteristics	Value[1]	Kenaf parameter[2]	
Temperature (tC)			
Mean temperature (^oC)	28-42	35.5±0.95	Ogbonnaya *et al,* 1997.
		23-30	Crane 1947.
Water availability (wa)			
Rainfall (mm/year)	2500-3500	500-600	Crane 1947.
		780-1200	Bañuelos *et al*. 2002.
		± 300	Ching *et al,* 1993.
Number of dry months	< 3 (*90 days*)	-	Ghazali and Nieowult 1982.
(month)		5-6 (150-180days)	Crane 1947.
Oxygen availibility (oa)			
Drainage	Somewhat excessive/ excessive	Well drained	Ogbonnaya *et al*. 1997; Hazandy *et al*. 2009.
Rooting condition (rc)			
Texture	Sandy soil (*>95%*)	Sandy soil (± 50%)	Hsiao 1973; Ogbonnaya *et al.* 1997
		Sandy clay loam	Cook and Smart 1995.
Rough materials (%)	Minor roots	-	-
Soil depth (cm)	>50++	>75 (optimum)	Paramananthan 1987; MARDI 2010.
Nutrient retention (nr)			
Clay CEC (cmol/kg)	0-5 (< 1 *in most localities*)	Nutrient deficiency	Abu Bakar 1985; Lim 1989.
Base saturation (%)	37-85 (<40 in spodic horizon)	<15 (very low)	Abu Bakar 1985.
pH H_2O	4.0 - 5.4 (*acidic*)	Not suitable under acidic condition	MARDI 2010.
Organic C (%)	0.7 – 2	<1 , and 3.8 (spodic horizon)	Abu Bakar 1985.
Toxicity (Al)	Not found	Below pH 5.5	DOA 2010.
Flood hazard (fh)			
Inundation	1	-	Roslan *et al*. 2010.

Note: The stated data are representative for: 1) Value[1]: the field data from the study area, and 2) Kenaf parameter[2]: the data from other studies.

two possible measures to improve the soils are suggested: (1) intercropping kenaf with other crops and (2) good management farming soil practices.

(i) Intercropping kenaf with other crops

Studies have shown that intercropping kenaf with cowpea (Raji 2007) and yam bean (Saka *et al.* 2007) is a new prospect that has often been overlooked. Intercropping is referred to as poly-culture farming. We found that rotational crop farming (with chili, yam, bean, mustard and cucumber) has been practiced by small farmers in the study area. Hence, intercropping of these crops with kenaf can be a good option for utilizing the sandy soils. Furthermore, kenaf with its deep tap root and lateral root system is considered to be an excellent user of residual nutrients from the previous crops. After harvest, kenaf residue decomposes and adds nitrogen into the soils, sustaining the soil fertility. Therefore, it is suggested that intercropping is the best possible option for the small farmers in the study area.

(ii) Good management farming soil practices

Based on site surveys, field observations, current data (land use and utilization practice), input and feedback from the farmers, discussion with national agencies such as the National Tobacco and Kenaf Board, Malaysia, and Kemasin-Semarak Integrated Agricultural Development Project members, we propose the following agricultural practices:

1) Mulching with rice straws, oil palm empty fruit bunches and/or biochar that can improve nutrient retention, improve water holding capacity and support root growth. Rice straws are available in the vicinity of the study area (Shamshuddin 2006).
2) Irrigation during the dry season. This practice can avoid tugor stress to the crop tissue due to water deficit, and also minimise the extreme heat effect (at temperature up to 42^{o} C), while controls soil moisture and humidity.
3) Soil mixing. This technique can be expensive but a worthwhile option. The sandy Spodosols can be mixed with the more clayey soils from the swales. This will help increase CEC. Organic manures (for example, chicken dung or cow dung) can be added into the mixed soils to further improve soil fertility. In addition, a study by Lima *et al*. (1997) showed that mixing Vertisol with sandy soil in Ap horizon, improves nutrient retention and water holding capacity of the sandy soil. The suggested application rate is 200 to 400 kg ha^{-1}.

CONCLUSIONS

Soils on the beach ridges of the Kelantan - Terengganu Plains are classified as Spodosols (Arenic Alorthods). Locally, these soils are known as Rhu Tapai (0-50 cm), Rudua (50 - 100 cm) and Jambu Series (> 100cm) with a spodic horizon rich in organic matter. The soils are dominated by quartz with traces amounts of feldspars and mica, indicating a high degree of weathering. The soils are low in

nutrients and CEC, and suffer from excessive drainage, leading to serious nutrient imbalance. During the dry season, kenaf suffers from water stress that inhibits its growth. A well planned growing calendar based on rainfall data can minimize the water deficit. Intercropping kenaf with other crops is an excellent option. As they are, these Spodosols are marginally suitable for kenaf production. The soils can be made suitable for growing kenaf by mulching with rice straw, irrigation during dry period and mixing with more clayey soils available nearby. To further improve soil productivity, organic matter should be added into the soils.

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