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CERES-Maize Simulation Model: Establishment of Planting Windows for Grains Maize under Rainfed Conditions

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ABSTRAK

Konsep jangkamasa pertumbuhan atau peluang menaman merupakan satu pendekatan yang berguna dalam mengenalpasti masa menanam yang sesuai terutama di bawah pengurusan tanaman tanpa pengairan. Ia dapat membantu petani dalam menentukan kejayaan tanaman yang diusahakan. Model simulasi tanaman (model CERES-Maize) telah digunakan untuk mengenalpasti masa yang sesuai untuk menanam dan jagung digunakan sebagai tanaman penunjuk. Keupayaan model dalam membuat ramalan juga turut ditentukan berdasarkan keputusan-keputusan simulasi yang telah direkodkan. Model menunjukkan berkeupayaannya dalam meramal pengeluaran hasil jagung sebenar di peringkat percubaan tetapi selalu melebihi jangkaan bagi ramalan di peringkat ladang. Dalam persekitaran setempat dengan keadaan tanah dan cuaca yang sesuai, potensi hasil jagung dapat dijangkakan melebihi 7 t/ha. Potensi hasil untuk kebanyakan zon adalah rendah pada penghujung tahun disebabkan keadaan kemarau yang dialami oleh tanaman sepanjang musim. Berdasarkan bentuk potensi hasil, ia selaras dengan bentuk taburan hujan. Dengan gabungan had limit hasil 5 t/ha, ia menunjukkan kebanyakan dari zon-zon tersebut mempunyai dua musim menanam kecuali dua zon (1 dan 26) yang hanya mempunyai satu musim menanam sahaja. Di samping itu masa yang paling sesuai dalam musim menanaman bagi zon 9 dan zon 10 turut juga dikenalpasti. Maklumat sebeginilah yang petani-petani perlukan dalam membantu mereka merancang aktiviti di ladang ke arah mencapai operasi yang cekap.

ABSTRACT

Growing period or planting windows concepts is a useful approach in identifying suitable planting time for crop under rainfed management. It will help farmers to ensure the crop success. A crop simulation model (CERES-Maize model) was used to identify the suitable planting time and maize was used as an indicator crop. The model was validated using compiled data to ensure its fitness within the setup acceptable limit. The model was capable to predict maize yield potential close to the actual yield at the experimental trails but always over estimated at the farm production levels. Under local conditions with favourable soil and climate, the yield potential of maize could be expected greater than 7 t/ha. The yield potentials for most of the zones are relatively low towards the end of year due to a dry period, experienced in most of the crop growing cycle. Based on the yield potential trends, it corresponds to rainfall pattern. In combination with a cut off point at 5 t/ha, its shows most of the zones have double planting windows except for two zones (1 and 26), which have a single planting window. In addition, as example the most suitable planting time within the planting window for zone 9 and 10 were also identified. This information can help farmers in planning their farm in order to have the most efficient operation.

INTRODUCTION

Rainfed farming is widely accepted in Malaysia, especially by small-scale farmers. Under rainfed condition, moisture adequacy is an important factor to ensure the successfulness of crop production. A suitable planting time with sufficient soil moisture during a planting season should be available before planting. Planting window concept has been proven to be a very useful approach to ensure sufficient moisture availability in the soil. This concept sometimes called the growing period was firstly introduced by Cocheme and Franquin (1967). The concept was defined as the period in a year where agriculture can be produced due to adequate soil moisture and absense of temperature limitations. The Penman Open-water Evaporation (Eo) method was used in the calculation with precipitation as input data.

The concept was then modified by FAO and defined, as a continuous period in one year where precipitation is greater than half-potential evaporation with a number of days required for evaporation (Kowal, 1978). The Penmans method was used in the calculation and with the assumption that soil can only store up to 100 mm of rainwater at each precipitation event.

In view of that, an exercise was conducted to identify the planting windows for maize on various ecological zones. The CERES-Maize model (Kiniry and Jones, 1986) was used in this study instead of Eo and FAO methods. It was seen to be more reliable whereby actual crop growth was taken into account during the simulation process. Although only a single crop at one time can be handled by the model, the selected crop can probably show the actual scenario of the planting window for some of the other crops. In addition, validity of the model was also taken into consideration in this study.

MATERIALS AND METHODS

CERES-Maize Model Validation

Before embarking the planting window identifications, the CERES-Maize model needs to be validated. The validation process is necessary because it ensures the model works properly and the simulation result of the model is within the acceptable limit such as Root Means Square Error (RMSE) is less than 1 t/ha or statistically significant at least at 5 % confidence. For this reason, twenty sets of simulated and measured grain maize yield data were compiled. The data was from experimental trails and farm productions, which were carried out elsewhere. A statistical methodology i.e. RMSE was used to analyze the data, in order to evaluate the fitness of the model. The RMSE value should be as small as possible to indicate the best fit between simulation output of the model and actual result from the field.

Planting Windows Identification

Simulation Exercise

The CERES-Maize model was used to simulate potential yield using the weather, soil and crop data. Simulations were considered on every ten days, throughout the year of eleven years (1985-1995). Only predicted yield potential at maturity stage of the simulation output was considered. Simulated yield outputs of the same planting date from eleven years were singled out using Y80 (80% probability) calculation technique. Finally, each zone has 37 simulated yield data representing a ten-day interval of planting dates throughout the year.

Two assumptions were made during the simulation exercises. First, no pest and disease infestations occurred that could cause crop damage. Second, free from weed competition for available resources such as fertilizer, light, water, etc., which would affect maize crop performance and therefore reduce yield production.

Weather Data Used

Sets of long term weather data, representing eight ecological zones of the northern parts of Peninsular (Nieuwolt *et al.*, 1982) were used in the study. The weather stations where data were obtained are Kota Bharu representing Zone 26, Kuala Krai for Zone 25, Kuala Terengganu for Zone 22, Kuantan for Zone 21, Melaka for Zone 12, Petaling Jaya for Zone 10, Sitiawan for Zone 9, Chuping for Zone 2 and Alor Star for Zone 1. The data consists of daily solar radiation (MJ/m^2/day), maximum and minimum temperature (°C) and precipitation (mm/day) from January 1985 to December 1995. Each data set was reformatted as required by the model for simulation purposes.

Soil Data Used

A set of soil data, extracted from soil profile descriptions was used in this study. The soil physical property inputs were in the form of thickness of the layer, the lower limit of plant-extractable water, the drained upper limit, water content at saturation, a weighting factor for rooting, and initial soil water content as required by the model. The soil chemical properties include organic carbon, pH, initial soil ammonium, and soil nitrate content.

Crop and Management Data Used.

In this exercise, maize cultivar Suwan 1 (*Zea mays* L var. Suwan 1) that was used by most farmers for grain production was selected. Crop management practices were treated as under experimental condition. The rate of fertilizer used was 120N, $60P_2O_5$ and $40K_2O$ kg/ha. Nitrogen fertilizer was divided into two applications where half of them were applied together with other fertilizers during the planting as a basal. Another half was applied after the crop age of 35 days on the field.

Planting Window Identification.

The calculated yield data of each zone based on Y80 was plotted against planting date. A high yield cut off point i.e. 5.0 t/ha (Abd. Razak), which correspond to actual farm production of about 4.0 t/ha, after 10% less due to rats, diseases and bores, and 5% less due to mechanical harvesting loses, was setup. Above the cut off point is considered as suitable planting time or within a planting window whereby lower is considered outside the planting window.

RESULTS

Model Validation

Validity of the CERES-Maize model was evaluated based on 20 sets of simulated and measured grain maize yield data. The simulated and measured yield under experimental trials ranges from 2.7 to 13.6 t/ha and from 2.7 to 14.7 t/ha, respectively. Analysis result shows the differences between simulated and measured yields are relatively small where the RMSE is only 586 kg/ha (Table 1) as compared to the acceptable limit, which is 1000 kg/ha.

Under large-scale farm management the simulated and measured yield on the first season, ranges from 2.3 to 4.7 t/ha and from 5.5 to 5.8 t/ha, respectively. In the second season, it ranges from 3.5 to 5.5 t/ha and from 5.9 to 6.1 t/ha. The RMSE value for the first and the second season is 1878 and 1825 kg/ha, respectively, higher than the experimental trial (Table 2).

TABLE 1

Validations of CERES-Maize model under experimental condition

Year	Location	Experimental status	Observed (kg/ha)	Simulated (kg/ha)
1982	Urbana Illinois, USA	High fertilizer	14700	13600
1989	Mead NE, USA	High fertilizer	10800	10700
1990	Ibadan, Nigeria	Low fertilizer	4904	4909
1991	Ibadan, Nigeria	Low fertilizer	4403	4760
1985	Hawaii	High fertilizer, elevation 77m	11533	12339
	Hawaii	High fertilizer, elevation 340m	11600	12234
1988	MARDI Serdang, Malaysia	Low fertilizer	2184	2717
	MARDI Serdang, Malaysia	Low fertilizer	2984	3058
1989	UPM Serdang, Malaysia	Low fertilizer	3825	3870
	UPM Serdang, Malaysia	Low fertilizer	2739	3607
	RMSE			586
	BIAS			212

TABLE 2

Validations of CERES-Maize model under large scale farm management

Block name	First season 1991		Second season 1991	
	Observed (kg/ha)	Simulated (kg/ha)	Observed (kg/ha)	Simulated (kg/ha)
20 AF	3970	5791	4090	6053
20 BD	4740	5678	5010	5936
21 AG	2250	5463	3690	6020
22 BK	4660	5686	3490	5993
23 BE	4290	5725	5500	6009
RMSE		1878		1825
BIAS		1686		1646

Estimated Yields on Various Locations

The results of simulated yield potential in each ecological zone indicate variability at different planting time as well as location of the area. It ranges between less than 1 t/ha and more than 7 t/ha (Figure 1). In the Northern west and Central east of Peninsular such as Alor Star, Chuping, and Kuantan, maximum yield at the best planting time is about 6 t/ha, which is relatively low compared to the other areas. The highest yield, which was above 7 t/ha, is in Melaka and followed by Kuala Terengganu, Sitiawan, Kuala Krai and Kota Bharu at the middle range. The simulated yields are relatively low towards the end of the year, except for Sitiawan.

Planting Windows on Various Zones

The model shows the yield potential of grain maize under local environment is about 7 t/ha. However, annual yield pattern is fluctuated depending on the weather condition where precipitation, plays a major role. Figure 1 shows the yield variability in eight climatic zones, representing parts of Peninsular Malaysia. High yield potential could be expected when planting during the wet season while poor yields in the dry season. Based on the set up yield potential above 5 t/ha, planting windows for each location or zone were identified (Table 3). Most zones in this study have double planting windows except Zones 1 and 24. Zone 10 has the longest planting window (10 months) while Zone 24 is the shortest (5.5 months).

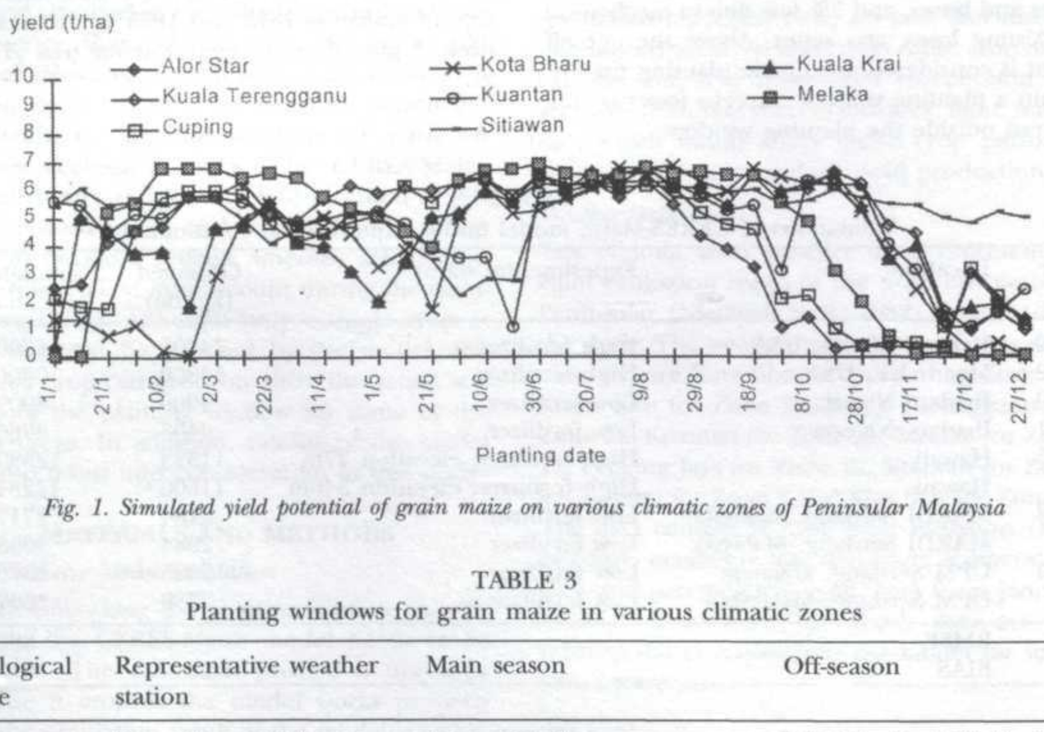

Fig. 1. Simulated yield potential of grain maize on various climatic zones of Peninsular Malaysia

TABLE 3

Planting windows for grain maize in various climatic zones

Ecological zone	Representative weather station	Main season	Off-season
26	Kota Bharu, Kelantan	June - October	Mid March - Middle April
24	Kuala Krai, Kelantan	Mid May - October	-
22	Kuala Terengganu, Terengganu	Mid May - Early October	March
21	Kuantan, Pahang	July - October	January - Mid May
12	Melaka	June - Early October	Late January - Mid May
10*	Petaling Jaya, Selangor	Mid June - December	January - Mid April
09	Sitiawan, Perak	July - December	January - Mid March
01	Alor Star, Kedah	February - Mid August	-
02	Chuping, Perlis	Late April - Mid September	February - March

* Source : Ismail et al., 1990

DISCUSSION

CERES-Maize Model Performance at Experimental Level

Maize is extremely endurable crop, which can be cultivated in many conditions and ways. Agronomic practice is one of the main factors affecting the production level. Favourable climatic and soil conditions with excellent management practices will produce higher yields. In the temperate region for example, grain yields of more than 15 t/ha have been reported (Vander Meer 1982) while in the lowland tropics, yields may range from 5 to 8 t/ha with good management. Adequate nitrogen and potassium with excess phosphorus fertilizer will cause a major increase in maize yield (Miller *et al.* 1987). In addition, high yielding variety could also play a major role for high production. This explains why there is great variability of the yields from local and oversea trails (Table 1).

Under such great yield variability, the model is still capable of predicting reasonable yield output. Statistical analysis shows the overall performance of the model for predicting yield potential at experimental level is highly significant. It was also confirmed by this study, where the Root Mean Square Error (RMSE) of simulated and measured yield was about 586 kg/ha. A smaller RMSE value (less than 1 t/ha) indicates the simulated values are closer to the actual values. Kiniry and Jones (1986) found the relationship between simulated and measured yields was highly significant ($p = 0.0001$) and was within the 95 % confidence band for the 1:1 regression line. Therefore, the model is considered reliable and can confidently be used for simulating grain maize yield under experimental condition.

Model Performance at Production Farm Level

Under large-scale farm management, the simulated yield is always about 10-40 % overestimated (Abd. Razak 1995). The RMSE value at this level is 1850 kg/ha, which is slightly higher than the RMSE at the experimental level. It is due to the insufficient soil characteristic data used in simulation. The soil data from one point of a big block was applied to represent the whole block of farm production, which is variable and less homogeneous. Extra points of detail soil characteristic data from a big block are probably required in order to have a better simulation result. In addition, other two main factors which probably caused the errors in simulated grain yields are that the soils were not well characterized and the inaccurate estimates of water status and the depth of the soil. In this respect, model shows its stability when dealing with the homogeneous soil data although under different climatic condition. A small difference of RMSE between the first and the second season of yield potential on the same soil (about 50 kg/ha) from this study confirmed the model stability. The yield potential difference occurs mainly due to the variability of weather pattern such as precipitation, radiation and air temperature, between seasons. However, the simulation yield trends and the over estimate simulated yield value which were produced by the model are still within the acceptable limit. Therefore, the model could be used to simulate the potential yield under farm production, provided specific measures be considered to suit the local conditions.

Estimated Yields on Various Zones

The model shows potential grain maize yield under local environment is greater than 7 t/ha. However, the yield potential is variable throughout a year depending on the planting date which influence by weather patterns especially annual precipitation. The amount, distribution and intensity of precipitation are very important factors that affect the production of maize especially under rainfed management. Huda et al. (1976) found that the variation in precipitation during different growth stages had different effects on yield. High yield potential could be expected when planting in the wet season while poor yield potential during the dry seasons. However, excessive precipitation and poor soil condition will also decrease yield potential (Shaw 1977; Young 1980).

Besides precipitation, solar radiation status is another factor in determining the maximum yield. During simulation, the model assumes 5.0 g of dry biomass is produced per MJ of intercepted photosynthetically active radiation under non-stressed condition (Jones *et al.* 1986). Areas with high level of radiation during the wet season would produce a higher yield compared to the zones with cloudy wet seasons. Pendleton and Egli (1969) proved maize yield was higher with increasing radiation interception. It explains the zones such as Kuantan and Petaling Jaya, with much cloudy condition during a rainy season have low yield potential (about 6 t/ha) compared to other zones.

In addition, the level of crops management with phosphorus and potassium fertilizers application, pest and disease management and weed control, which is not taken into consideration by the model, is also important contribution towards a better crop performance and high yield production.

Planting Windows on Various Zones

In tropical and subtropical areas, where soil moisture adequacy is a major constraint to crop production, the planting windows or growing period concept has proven to be very useful (Sys *et al.* 1991). Inaccurate planting time causes crop failure and very low yield. Generally, towards the end of the year, chances to have a successful crop are very minimal, except for Sitiawan zone because a rainy season of the zone started towards end of the year. For other climatic zones, such as Kota Bharu, Kuala Krai and Kuantan, during the first half of the year are considered not suitable for planting due to dry period. The planting time of July to mid September is considered the best time to have a successful crop for all climatic zones.

A combination of total ten days precipitation pattern and yield potential, the most suitable planting time for grain maize within the identified planting window could be worked out (Abd. Razak 1995). Based on this approach, some zones can have double plantings while the other zones only have a single planting per year. The most suitable planting times for Zone 9 are 10 May and 20 September of the year. For Zone 10, the most suitable planting times are 14 February and 7 September of the year (Ismail *et al.* 1990).

CONCLUSION

The CERES-Maize model could be used as a tool to estimate yield potential of grain maize throughout the country. A combination of the model output with ten days precipitation pattern could be also used to identify the planting windows and the most suitable planting time for high yield production. With reliable information, it can help the operator to daily manage the maize farm efficiently. High yield production with minimal risk of crop failure could be expected. Farmers cum entrepreneurs most likely are more confident to invest in the maize cultivation with such information. Entrepreneurs could also plan their farms at different locations and planting time in the country, targeted for continuous productions throughout the year with a high return.

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