Growth and development models for West Timor maize landraces

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Abstract. The adoption of hybrid maize and OPV’s in the ENT provinces was still under 45% and the use of maize landraces was above 55%. The reasons farmers keep using their own traditional local maize remain unclear, but it is assumed that good adaptation to the local conditions and tolerance against maize weevils are the primary reasons. Modelling of a crop like maize (APSIM MODEL) can be used to predict the yield potential of the crop in an area based on the resources available within any particular season. Comparisons of simulated vs observed yields helps identify constraints and develop strategies to reduce the production risk. Field planting of maize landraces and an improved variety was conducted at the research station of the Assessment Institute for Agricultural Technology (BPTP NTT) in Kupang, West Timor, Indonesia. There were three West Timor maize landrace used in this field trial; they were white maize landrace A, B and C and Piet kuning variety. It can be concluded that APSIM can be used to predict West Timor landraces growth with different rate of fertiliser. The model predicted that the grain yield of the landraces can be increased by synchronising the flowering time and applying N fertiliser. The addition of 100kg/ha of N is the optimum N fertilizer for maize farming systems in West Timor region because it will significantly increase the yields and maintain yields over time compared to the current practice of not applying N (the 0 application of N). If the cost of 100kg/ha N prohibits farmers from doing this then micro-dose and legume-maize integrated farming system approaches are alternative strategies to increase maize production in this region. The grain yield of West Timor maize landraces could be increased significantly by applying 100kg/ha of Urea. It is important to manage N fertilizer for both financial and environmental reasons.

1. Introduction

The use of improved maize varieties, and soil management practices, particularly nitrogen fertiliser, are common strategies to improve maize production in some developing countries. A study in Uganda concluded that the use of Nitrogen in-organic fertiliser and improved maize varieties were the most important factors for improving maize yield in Uganda [1]. While in Indonesia, introducing high yield maize varieties has been a key factor for increasing maize productivity, production and income of farmers [2]. However, yield gap of cereal crops (maize) often exist in the semi-arid regions like Indonesia and to fill the gap the use of improved maize varieties and fertilizer application are needed [3]. There is a correlation between nitrogen fertilizer and the crop grain production revealed that in most
cases, the grain yield reduction is caused by the limitation of N supply in the farming system [4]. Therefore applying fertilizer, particularly Nitrogen fertilizer, can increase maize and rice yield. Saidou [5] revealed that maize grain and stover yields can be increased by increasing the rate of N, P and K fertilizer and gave the most economical and efficient. Abera [6] found that 100 Kg N/ha gave the highest maize yield and economically feasible for sustainable maize production. Therefore, to take advantage of the potential production from improved maize varieties, improved agronomic practices are essential.

Although improved open open-pollinated maize varieties (OPVs) and hybrid maize have been introduced to increase maize yield in West Timor, farmers are still cultivating their own local maize. The planting area of OPV and hybrid maize has been promoted by the Indonesian government at a national and provincial level to increase the yearly maize production by more than 4.17%. To achieve this aim the growth of hybrid maize will be increased to 60% and OPV to 35% by 2020 [7]. However, in 2007 the adoption of hybrid maize and OPV’s in the ENT provinces was still under 45% and the use of maize landraces was above 55% [8]. The reasons farmers keep using their own traditional local maize remain unclear, but it is assumed that good adaptation to the local conditions and tolerance against maize weevils are the primary reasons. The other causes of the poor maize yields in West Timor are inadequate crop nutrition and management, and variable climate [9]. Therefore, it is important to not only improve maize seed handling but to also improve farm management of landrace maize. The use of crop simulation modelling is one way to investigate the long-term implications of management decisions with the aim of identifying and assessing the management of resources over the long-term [10] and thus, help to develop strategies that will provide a sustained future benefit to smallholder farmers in West Timor.

The Agricultural Production System Simulator (APSIM), is a framework that allows different biological models to communicate via a management module and the simulation engine. APSIM has been used in many different farming systems and agribusinesses throughout the world [11]. Modelling of a crop like maize can be used to predict the yield potential of the crop in an area based on the resources available within any particular season. Comparisons of simulated vs observed yields helps identify constraints and develop strategies to reduce the production risk [12]. Hence, in order to improve maize crop management in the farming systems of West Timor some strategies and techniques will be investigated and discussed in this chapter. These will include the development of West Timor Maize landrace cultivars within APSIM maize, analysis of the critical components of the maize crop management required to maximise production, and prediction of the optimal nitrogen fertilizer application.

2. Research Questions

The three research questions addressed in this chapter were; firstly, can APSIM accurately predict the growth and development of West Timor landrace maize populations? Secondly, how temporally variable are resources in West Timor maize production and how large is the gap between potential and observed yields for dry-land farming systems in West Timor? Finally, what is the optimum fertiliser application rate for maize produced in the different environments of West Timor?

3. Methods

3.1. Plant Establishment

Field planting of maize landraces and an improved variety was conducted at the research station of the Assessment Institute for Agricultural Technology (BPTP NTT) in Kupang, West Timor, Indonesia, between October 2011 and April 2012 to measure physiological data for parameterising a representative “cultivar” within the APSIM maize model and create new APSIM-Maize cultivars representative of the local landraces and then use these cultivars to simulate against the remaining experiment data as a test.
3.2. Crop Management

There were three West Timor maize landrace used in this field trial; they were white maize landrace A, B and C and Piet kuning variety. The three landrace maize populations were collected from farmers (a sample of 1 kg from farmers, in Mnelalete village) that had been stored from the previous season (eight months stored) using traditional farmers’ storage methods, while certified seed of Piet kuning was bought from the local government seed production agency (three months stored). All seed were sown on 20th October 2011 in well prepared and irrigated plots sized 4 x 3.2 m (12.8 m²). Two seeds per hole were sown at 40 mm depth at a distance of 40 cm between holes and 80 cm between rows. The four varieties were planted in seven replications and each replication contained four plots. All plots were watered (270 litres/plot) four times (19th and 25th October 2011, 1st and 10th November 2011) continued by rainfall (November 2011 – February 2012) and were weeded manually (28th October and 19th November 2011). There was N fertiliser application (0, 50 and 100 kg/ha of Urea) and no pesticide application.

3.3. Soil Parameters

Two techniques of soil sampling were used to analyse soil nitrogen and moisture content. Firstly, a composite soil sample was collected from just the topsoil layer (0-15 cm) across the planting site; 5 soil cores were collected diagonally across the planting site. These samples were mixed to produce one bulked sample and sent for N and organic C soil analysis.

Secondly, soil samples were taken from three of the seven replications (number two, four and six of the seven replications) at four different times (20th and 28th October, 22nd November, and 14th December 2011). The soil samples were taken from six different soil depth layers, 0-15, 15-30, 30-60, 60-90, 90-120, and 120-150 cm. These samples were used for calculating soil moisture content.

Soil characterisation data including bulk density (BD), drained upper limit (DUL), and crop lower limit (LL) [9].

3.4. Climate Data

Daily rainfall was collected at Naibonat village (about 350 m away from the established crops) using a standard tipping bucket rain gauge and solar radiation was measured using the solar burnt paper method [13]. Daily minimum and maximum temperature were measured using temperature sensors and loggers from October 2011 to April 2012. Long-term meteorological data from 1950 to 2010 were collected from the closest patch point meteorological station is the closest site with a similar climate, seasonally dry tropics / homo-clime, and has longterm and comprehensive climate records that are not available in West Timor [14].

3.5. Crop Data Collection

Plant height, date of maize growing stages (sowing, germination, emergence, juvenile, flag leaf, 50% female flowering, cob development, maturity (100% black layer presence), and harvest), number of total, green and dead leaves, total plant biomass, and grain yield were the crop data collected periodically. Data were processed using Microsoft excel 2010 and then saved in a CSV file. Finally, these observed data were compared to the maize model in APSIM version 7.4. Regressions of the observed vs predicted results were used to assess the model.

3.6. Thermal Unit Calculations

APSIM calculates the thermal units for each stage from the commencement of each stage (except for sowing to germination which is driven by soil moisture) to the commencement of the next stage by the accumulation of thermal units. Each day the phenology routines calculate today's thermal time (in degree days) from 3-hourly air temperatures interpolated from the daily maximum and minimum temperatures [15]. Thermal time is calculated using the eight 3-hour estimates averaged to obtain the daily value of thermal time (in growing degree days) for the day. These daily thermal time values were accumulated into a thermal time sum which was used to determine the duration of each phase. This approach was
used to calculate the thermal time between the growth stages from the field data for each of the OPV and farmer landraces.

APSIM uses 11 crop stages and nine phases (time between stages) in the maize model. The eleven maize crop stages are sowing, germination, emergence, early growth, juvenile, flag leaf, flowering, cob development, physiological maturity, ripening, and end growth or harvest. In a thermal unit analysis, the eleven stages were grouped into three stages. They were an emerge-flag leaf, flag leaf-flowering, and flowering-mature.

3.7. Model Testing and Statistical Analysis
The physiological measurements collected from the high nitrogen treatments for each of the maize landraces and Piet kuning were used to parameterise a representative “cultivar” within the APSIM maize model and create 4 new APSIM-Maize cultivars. These “new cultivars” were then tested against the remaining treatments of the serial field experiment data. Statistical analysis was conducted using the linear regression analysis of Excel Program Version 2010 to assess the goodness-of-fit between observed and predicted model data. The value of slope (c), intercept (β) and determination coefficient ($R^2$) of the linear regression were calculated [16].

3.8. Simulation Scenario Analysis
The simulation analysis was designed to represent West Timor region. The selected soil types were Vertic-inceptisols of the Naibonat trial site. Characterisations of each soil were taken from [9].

4. Results and Discussion

4.1. Results

4.1.1. Soil nutrient. Soil nutrient status of the experiment site (Table 1) was variable. The amount of available phosphorus (P) and potassium (K) were sufficient for the growth and development of maize crops but Nitrogen (N) and C-organic were poor. The result shows that N fertilizer application was really important for producing optimum maize grain. The optimum N fertilizer rate should be determined for specific maize growing system and it will be discussed in more detail in the N fertilizer section in this chapter.

| Nutrient              | Contain | Interpretation |
|-----------------------|---------|----------------|
| Nitrogen (%N)         | 0.3     | Low            |
| Phosphorous (% P2O5)  | 2       | High           |
| Potassium (me/100 gr K)| 0.56    | Medium         |
| Organic Carbon (%C)   | 1.5     | Low            |

Phosphorous and potassium, the other macro soil nutrient, in the experiment site were sufficient for maize growing and consequently, it did not need to apply any phosphorous nor potassium fertilizer in that time and soil.

4.1.2. Plant growth. The observed data of plant height, total leaves, anthesis and silking interval (ASI) and total biomass of West Timor maize landraces and Piet kuning variety are presented in Table 2. The data shows that landrace D was smaller, had fewer leaves and less total biomass compared to A, B and C, and Piet kuning. Landrace D was a short maize plant and was an early maturity maize type.
Table 2. Average plant height, total leaves, anthesis and silking interval (ASI) and total biomass West Timor maize landraces and Piet kuning variety for the unlimited treatments (100 kg/ha Urea fertilizer and watering)

| Variety       | Plant height (cm) | Total leaves (leaves) | ASI (days) | Total biomass (t/ha) |
|---------------|-------------------|-----------------------|------------|---------------------|
| Landrace A    | 327               | 22.9                  | 8          | 9.5                 |
| Landrace B    | 323               | 22.9                  | 8          | 8.7                 |
| Landrace C    | 325               | 23.4                  | 8          | 9.1                 |
| Landrace D    | 198               | 16.6                  | 2          | 5.3                 |
| Piet kuning   | 307               | 21.4                  | 2          | 7.8                 |

In the interval time between anthesis and silking, the three landraces (landrace A, B and C) had longer ASI (8 days) than landrace D and Piet kuning (2 days), which indicated that the flowering synchronisation for landrace D and Piet kuning was better than landrace A, B and C.

4.1.3. Grain yield. The observed maize grain yield of the West Timor maize landraces and Piet kuning under three different N fertilizer rates are presented in Table 3. The table shows that there was an increase in grain yield for all entries when the rate of N fertilizer was increased. For example, landrace A increased from 2.5 t/ha without N fertilizer to 3.6 t/ha under 100 kg N fertilizer, and landrace D increased from 1.8 t/ha to 2.0 t/ha, while Piet kuning increased to 4.5 t/ha from 2.7 t/ha).

Table 3. Average grain yield (t/ha) of West Timor Maize landraces and Piet kuning variety under different fertilizer rate

| Cultivars       | 0 kg urea | 50 kg urea | 100 kg urea |
|-----------------|-----------|------------|-------------|
| Landrace A      | 2.5       | 3.1        | 3.6         |
| Landrace B      | 2.3       | 3.1        | 3.5         |
| Landrace C      | 2.4       | 2.9        | 3.2         |
| Landrace D      | 1.9       | 2.2        | 2.6         |
| Piet kuning     | 2.7       | 3.4        | 4.5         |

The highest grain yield increment when 100 kg/ha N fertilizer applied was Piet kuning variety (1800 kg/ha) followed by landrace B, A and C (1200, 1100, and 800 kg/ha respectively), while landrace D had the lowest grain yield increment (700 kg/ha). Landrace D plants were smaller and had fewer leaves than others so it would be planted in higher population to achieve a comparable yield.

4.1.4. APSIM validation. “APSIM maize cultivars” were developed from the observed data by modifying specific parameters of APSIM’s base maize cultivar. The key parameter changes are listed in Table 4 and highlight that the major changes required were adjustments to the maize phenology.
Table 4. Key parameters of maize cultivar in APSIM

| APSIM Variables                      | PK   | LR A  | LR b  | LR C  | LR D  |
|--------------------------------------|------|-------|-------|-------|-------|
| head_grain_no_max description        | 560  | 350   | 310   | 310   | 310   |
| grain_gth_rate units="mg/grain/day" | 10.5 | 10.5  | 10.5  | 10.5  | 10.5  |

Canopy

| x_stem_wt units="g/stem" description="look up table for canopy height" | 0-80 | 0-80 | 0-80 | 0-80 | 0-80 |
| y_height units="mm" description="plant canopy height" | 0-2000 | 0-2000 | 0-2000 | 0-2000 | 0-2000 |

Phenology

| tt_emerg_to_endjuv (oC)" | 265  | 330   | 310   | 330   | 310   |
| est_days_endjuv_to_init> (oC) | 20   | 20    | 20    | 20    | 20    |
| tt_endjuv_to_init units="oC"" | 0    | 0     | 0     | 0     | 0     |
| photoperiod_crit1 units="hours" | 12.5 | 12.5  | 12.5  | 12.5  | 12.5  |
| photoperiod_crit2 units="hours" | 24   | 24    | 24    | 24    | 24    |
| photoperiod_slope units="oC/hour" | 10   | 10    | 10    | 10    | 10    |
| tt_flower_to_maturity (oC)" | 742  | 957   | 975   | 955   | 721   |
| tt_flag_to_flower units="oC"" | 106  | 186   | 166   | 187   | 74    |
| tt_flower_to_start_grain units="oC" | 90   | 90    | 90    | 90    | 90    |
| tt_maturity_to_ripe units="oC"" | 1    | 1     | 1     | 1     | 1     |

The phenology of West Timor Maize Landrace Populations from unlimited treatment (adequate water and Nitrogen) is shown in Figure 1. The figure shows that there were two types of maize life duration. The first was an early maturity variety, represented by Population D (about 100 days after sowing) and the second one was the late maturity varieties, represented by population A, B and C (more than 110 days after sowing).

Figure 1. Phenology of West Timor Maize Landrace Population under unlimited treatment (adequate water and Nitrogen)
Thermal unit analysis of this trial (Table 5) shows that landrace D was the earliest maturing maize with the smallest total thermal unit of 1474°Cd, while the other three landraces, landrace A, B and C, where late maturing maize (2250°Cd, 2194°Cd, and 2213°Cd respectively). Piet kuning variety was an intermediate maturity variety with (2001°Cd total thermal units).

Table 5. Thermal unit of four West Timor maize landraces and Piet kuning variety

| Entries       | Emerge - flag leaf | Flag leaf – flowering | Flowering - mature | Total stages |
|---------------|--------------------|-----------------------|--------------------|--------------|
| Landrace A    | 1107               | 186                   | 957                | 2250         |
| Landrace B    | 1053               | 166                   | 975                | 2194         |
| Landrace C    | 1072               | 186                   | 955                | 2213         |
| Landrace D    | 879                | 74                    | 721                | 1474         |
| Piet_kuning   | 1007               | 75                    | 919                | 2001         |

4.1.5. Relationship of observed and APSIM predicted data. The regression analysis for total biomass (Figure 2) reveals that there was a linear relationship between observation and predicted data of five genotypes and seven replications. The correlation between observed and predicted model data had slope (c value) of 1.01, intercept value of 0.14 and the coefficient of determination ($R^2$) of 0.98. The results indicated that observed and predicted model data have a strong relationship because the slope and the coefficient of determination values were close to one and the intercept value was close to zero.

![Figure 2. Relationship between total biomass over time (observed) and APSIM model (predicted) data](image)

The regression analysis for grain yield (Figure 3) shows that the correlation between observed and predicted data had slope (c) value of 0.99, intercept value of 0.19 and the coefficient of determination ($R^2$) of 0.97. The results indicated that observed and predicted data for grain yield of West Timor maize are similar because the slope and the coefficient of determination value were close to one and the intercept value was close to zero. From the goodness-of-fit analysis of total biomass and grain yield, it can be suggested that the West Timor maize landrace models are useful predictors of field performance.
Figure 3. Relationship between final grain yield (observed) and APSIM model (predicted) data

The following figures are examples of biomass (Figure 4) and grain yield (Figure 5) through time of the maize landrace population A fertilised with 100 kg/ha of Urea. The black line represents the models prediction and the blue triangles are the observed replicates. APSIM successfully simulated the biomass development reflecting the observed data. Similarly, the APSIM grain yield graph (Figure 5) indicates that there was a 7.3% difference between predicted grain yield (3.04 t/ha) and maximum observed grain yield (3.29 t/ha). APSIM also reproduced the grain filling model of West Timor maize landrace.

The grain filling, within the model of landrace A, started before 12 January 2011 and then increased over 40 days to a final weight of 3 t/ha at harvest. The observed data (2.8 – 3.2 t/ha), was very consistent with this APSIM prediction. The delay between the observed predicted final biomass and yield data is at least partly a result of the model harvesting at physiological maturity and the observed data being harvested later after the maize had begun to dry down.

Figure 4. Predicted and observed biomass data of West Timor Maize landrace population A under 100 kg/ha Urea treatment
Figure 5. Predicted and observed grain yield data of West Timor Maize landrace population A under 100 kg/ha Urea treatment

4.1.6. Scenario of Nitrogen fertilizer. In general, an application of N fertilizer will increase maize yield, however, there is an optimum N fertilizer rate in grain maize production above which the additional fertilizer could harm the environment or decrease profit. Maize responds well to nitrogen fertilizer and adequate availability of nitrogen in the soil is critical for corn production. However, excess nitrogen adds unnecessary expense and increases the risk of nitrate movement to ground-water (Omafra, 2008). APSIM was used to assess the yield of West Timor maize landraces with various N fertilizer rates, 0, 25, 50, 100, 150 and 200 kg/ha in vertic-inceptisol soil at Naibonat over 60 years (1950 – 2010) to identify the levels of fertiliser best suited to producing high yields over different seasons (Figure 6).

Figure 6. A simulation curve of West Timor maize landrace responses to increasing fertilizer rates. Points are the mean from 60 years of simulation at Naibonat, Indonesia

The nitrogen simulation (Figure 6) shows a typical nitrogen response curve with the asymptote occurring at around 150 kg/ha of urea. From this curve, it can be predicted that urea fertiliser additions of between 80 and 120 kg/ha would offer the best return on investment. This is consistent with the experimental finding reported in Chapter 5, but may need to be treated with caution because of the possible non-independence of data here or the limited range of treatments used in chapter 5.
The long-term simulation shows how the regular addition of nitrogen increases the overall crop yield and reduces some of the seasonal variations compared to not applying fertiliser. It should also be noted that when fertiliser is not applied there is a gradual decline in overall production (Figure 7). A 72 kg/ha/year reduction in productivity of maize occurred when N fertiliser was not applied, while 100 kg N fertiliser application maintained grain yield.

![Figure 7](image.png)

**Figure 7.** Modelled grain yields from a West Timor landrace over 60 years in Naibonat, Indonesia with starting applications of 100 kg and zero Urea

### 4.2. Discussion

When comparing the four maize landraces, the landrace D required much fewer thermal units in all growing phases and made it a much shorter season type. This type of maize is a potential maize landrace type that will suit crop production in areas with the defined short season or as a double-cropping option. West Timor, with short rain duration (3-4 months) needs to grow early maturity maize types like landrace D with maize – maize or rice maize cropping sequence.

However the landrace A, B and C can be grown to produce not only maize grain but also animal feed by producing more biomass than landrace D and Piet kuning. Moreover, the grain yield of the landraces can be increased by synchronising the flowering time by using selection techniques in a breeding.

The field nutrition experiments have shown how increasing nitrogen will improve the yield of all the landraces and the improved OPV’s. However, to determine if this same type of response would occur over time, simulation modelling was used. The initial testing of the model showed that the cultivars developed in APSIM maize to represent the west Timor landraces did a satisfactory job of reproducing the observed biomass and yields. With this confidence, the model was then used to test if these same results would occur over the long-term 60-year climate record. These results showed that the addition of 100kg/ha of N would significantly increase the yields and maintain yields over time compared to the current practice of not applying N (the 0 application of N).

In an effort to increase the current maize grain yield in the region of East Nusa Tenggara province of Indonesia, to 2.2 t/ha, without additional N fertilizer, the APSIM analysis shows that it is unlikely to be possible. However, a combination program of maize breeding, using landrace population improvement, and proper soil nutrition management, water and N fertilizer application, offer the best alternative to increase maize yield in this region.
However, considering the cost of N (urea) fertilizer, the addition of 100 kg per ha is a feasible additional input option for the subsistence farmers in East Nusa Tenggara province of Indonesia because it is a half dose of the regional recommended N fertilizer of 200 kg/ha. If the cost of 100kg N prohibits farmers doing this, the micro-dosing approach used in Africa and India is an alternative that can be used and combined with organic fertilizer, like manure and legume plants [13]. Combination of nitrogen fertilizer with other soil nutrition fertiliser, such as phosphorous and potassium, is probably the best option to reduce nutrient deficiencies of West Timor soils and improve yield.

5. Conclusion
The growth and development model of West Timor maize landraces has been analysed using the APSIM model and from the findings, it can be concluded that APSIM can be used to predict west Timor landraces growth. In addition, the grain yield of the landraces can be increased by synchronising the flowering time and applying N fertiliser. The addition of 100kg/ha of N is the optimum N fertilizer for maize farming systems in West Timor region because it will significantly increase the yields and maintain yields over time compared to the current practice of not applying N (the 0 application of N). If the cost of 100kg/ha N prohibits farmers from doing this then micro-dose and legume-maize integrated farming system approaches are alternative strategies to increase maize production in this region. It is also relevant to a finding of Chapter 5 that grain yield of West Timor maize landraces could be increased significantly by applying 100 kg/ha of urea. It is important to manage N fertilizer for both financial and environmental reasons.

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