Using Weather Data to Estimate Forage Production of Nilegrass

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ABSTRACT

In the previous investigation [Lee *et al*. (2004)], the aboveground fresh-based forage yield at harvest was found best-fitted to a four-variable linear regression model established from seasonal accumulated values of weather data. In this study, whether forage production during the growing periods may also be estimated by a multivariate regression model from weather data was further investigated. Both fresh and dry weights of the aboveground plant parts and plant height of nilegrass (*Acroceras macrum* Stapf) were measured from field experiments conducted at Taiwan Livestock Research Institute Experimental Farm (Hsinhua) during eight growing seasons from 2002 to 2004. The meteorological data were collected from on-site weather station to calculate the cumulative values along plant development during growing seasons, including the accumulated values of daily mean air temperature (DMAT), daily precipitation (DP), daily evaporation (DE), daily irradiance (IR), and daily sunshine hours (DSH). These climatic variables were used to correlate with plant height and forage production. Results showed that changes of forage production and plant height were shown linearly corresponding to the cumulative values of DMAT, DP, DE, IR, and DSH. By multiple linear regression analyses, estimations of fresh-based and dry-based forage production may be improved by two-variable linear regression models containing DP and IR, with R^2=0.667 ($P<0.0001$) for fresh-based and R^2=0.767 ($P<0.0001$) for dry-based forage production, respectively. Plant height may be best estimated by a two-variable model (R^2=0.808, $P<0.0001$) containing DP and DE. When validating the models with another set of data from different growing seasons, models gave slight over-predicted values of fresh-based and dry-based forage production and plant height. Results also indicated that forage fresh weight was linearly correlated with plant height (R^2=0.702, $P<0.0001$) and forage dry weight (R^2=0.874, $P<0.0001$). Accordingly, unit forage production of nilegrass can be estimated by plant height at the time of sampling.

Key words: Estimation, Forage production, Plant height, Nilegrass, Meteorological factor, Climatic model.

利用氣象資料估測尼羅草之牧草生產

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摘要

本系列研究之前項報告[Lee *et al*. (2004)]指出，尼羅草(nilegrass, *Acroceras macrum* Stapf)收獲時之鮮草產量可以由四氣象變因構成之直線複迴歸模式的累積氣象數據加以合理的估測。本研究持續探討在尼羅草各生長季節期間，是否依然可由適當的多氣象變因直線複迴歸模式予以評估牧草生產量。本試驗在 2002 年至 2004 年的不同生長季節進行牧草栽培，期間分別量測植株地上部高度(株高)、鮮重(鮮草產量)及乾重(乾草產量)，同時收集位於臺南縣新化鎮試

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區之農委會畜產試驗所一級農業氣象測站之氣象測值。將各生長季節之每日氣象測值累積，即成為探討牧草生產量、株高關係之氣象變因，包括每日日均溫(DMAT)、每日降水量(DP)、每日蒸發量(DE)、每日日射量(IR)及每日日照時數(DSH)等五種。根據試驗結果，發現 DMAT、DP、DE、IR 及 DSH 之個別累積測值均與牧草生產量及株高之間呈現直線相關。再由多變因直線複迴歸分析結果，顯示對鮮草及乾草生產量之估測，可藉由 DP 及 IR 兩變因累積值構成之二變因直線複迴歸模式提高估測準確度，鮮草及乾草的決定係數分別達 R^2=0.667 (P<0.0001)及 R^2=0.767 (P<0.0001)。對株高之估測，則可藉由 DP 及 DE 兩變因累積值構成之二變因直線複迴歸模式提高估測準確度，決定係數為 R^2=0.808 (P<0.0001)。經以另一組生長季節氣象資料驗證模式對其他氣象環境之適用性，發現預測值均略為高於實測值。試驗結果又顯示，鮮草生產量與乾草生產量及株高之間均呈現直線相關，顯然吾人可以在生長期間取樣調查株高，再以之推估尼羅草之單位牧草生產量。

關鍵詞：估測、牧草生產、株高、尼羅草、氣象因子、氣象(候)模式。

INTRODUCTION

As indicated in the literature (Rhind and Goodenough 1976, Rhind and Goodenough 1979), nilegrass (*Acroceras macrum* Stapf), a C_3 type perennial plant, is a common forage grass planted in South Africa. The grass was introduced to Taiwan for forage purpose, and a variety characterized by its good-to-graze (Lippke 1980), drought-resistant (Rout *et al.* 1990), and resistant-to-rust disease characteristics was selected and released as new cultivar Taishi No. 1 in 2000 (Shaug *et al.* 2002). Currently nilegrass has become one of the major forage crops grown in Taiwan, with a dry matter production of about 25 to 30 ton ha^{-1} $year^{-1}$ under normal growth condition. Its dry yield and crude protein content are found greater than those of pangolagrass (Shaug *et al.* 1989, 1999), and therefore, a superior species for forage production than others.

Generally yield and quality of forage crops varied in growing seasons and altered with cutting stages (Chen and Hsieh 1994, Chen *et al.* 1997). Lee *et al.* (1991) showed that contents of crude fiber, acid detergent fiber (ADF) and lignin in plants of pangolagrass A254 were closely related to weather condition at maturity. Others (Shy *et al.* 1995, Hsu *et al.* 1996, Chen *et al.* 1997) indicated that the quality of silage is governed by growing degree days and is influenced by the interactions of climatic factors and cultivated conditions. The digestion quality of silage and crude protein of some forage crops were shown decreased by the increasing of growing degree days (Van Schalkwyk and Gertenbach 2000, Shaug *et al*. 1999, Shaver *et al*. 1998), along with the reduction of forage yield and quality. Fick *et al.* (1994) used modeling approaches to describe the quality changes in a growing forage plant and showed that quality attributes such as digestibility and crude protein concentration were related to plant and environmental factors, e.g., chronological age of forage and growth temperature. Climatic factors also determined water-soluble carbohydrates (WSC) content of herbage directly, by influencing photosynthesis and respiration of plants, and affected the phonological development (Deinum 1984).

At present yet little research has been conducted to clarify the influence of climatic factors on forage production and quality of nilegrass in Taiwan. In the previous report of this series studies, fresh weight-based forage yield at harvest was found best-fitted to a four-variable linear regression model made from the seasonal accumulated values of DMAT, DE, IR and DSH, while dry weight-based forage yield was best estimated by a two-variable linear regression model contained the seasonal accumulated values of DMAT and DP (Lee *et al*. 2004). Such information is required for the establishment of models to assess and predict forage production and is also needed for the improvement of pasture management practices. With this knowledge available for acquisition, farmers can easily optimize their forage yield and quality by acquiring weather data from a near-by regional or local agrometeorological service in the future (Wulfes *et al*. 1999).

This study was to establish regression models for estimating forage production of nilegrass from weather data during the growing season and to validate the models using data collected from different growing seasons.

MATERIALS AND METHODS

Field experiments were conducted at Taiwan Livestock Research Institute Experimental Farm (Hsinhua, Taiwan) during eight growing seasons from June 2002 to May 2004 (Table 1). The nilegrass cultivar Taishi No. 1 (variety line AC15) was used. The soil was an acidic sandy loam with a pH of 4.8 and organic matter was less than 1%. The experimental field had an area of 3.6 ha and was divided into 4 plots, with each plot of about 0.9 ha.

The fertilizer urea (46% granule, Taiwan Fertilizer Company (TFC), Kaohsiung, Taiwan) at a rate of 220 kg ha^{-1} was applied to the experimental plot at 9 days after the previous cutting (DAPC) for the first and the second growing seasons. For the third growing season the composite fertilizer Taifei-1 (granule, $N:P_2O_5:K_2O$= 20%:5%:10%, TFC; 220 kg ha^{-1}) was applied at 31 DAPC, and urea was sprayed at a rate of 340 kg ha^{-1} at 39 DAPC for the fourth growing season. No fertilizer was added for the fifth growing season, while urea was sprayed at a rate of 160 kg ha^{-1} and composite fertilizer Taifei-1 was applied at a rate of 160 kg ha^{-1} at 22 DAPC for the sixth growing season. In the seventh and eighth growing seasons, mixed fertilizers (granule, $N:P_2O_5:K_2O$= 66%:5%:10%) were applied at a rate of 405 kg ha^{-1} at 35 DAPC. No pesticides were used to prevent interference to animal health, and hand-weeding was practiced at 1-2 weeks after the last-cutting dates.

Meteorological data were collected from the near-by weather station located in the Taiwan Livestock Research Institute. The accumulated values of each of the weather variables, including daily mean air temperature (DMAT), daily precipitation (DP), daily evaporation (DE), daily irradiance (IR), and daily sunshine hours (DSH), were calculated from the day of last cutting to the next harvest day. Three 1-m^2 areas per plot were harvested to obtain the fresh weight of aboveground plant parts (forage) on each sampling day, and another 10 plants were randomly chosen to take plant height measurements, measured from ground to the highest peak of a plant. Dry weight of aboveground plant parts was obtained after being oven-dried at 60-70℃ after 72 h. Plant characteristics were measured every 2-3 weeks after cuttings during the growing seasons.

The linear equations between forage production, plant height and climatic variables were calculated to explain the correlations. In order to improve the accuracy of model estimation for forage production of nilegrass from climatic factors, multiple linear regression analysis was used. For model validation, weather data and growth characteristics from two additional growing seasons (5/15/2004-7/29/2004 and 7/30/2004-10/7/2004) were collected, with a total of 8 sampling dates. The statistical analyses were performed by using Statistical Analysis System version 8.1 (SAS Institute, 1998) and SigmaPlot 2001 (SPSS ASC BV, the Netherlands).

RESULTS AND DISCUSSION

Changes in the weather variables (climatic factors) of DMAT, DP, DE, IR, and DSH during the eight growing seasons from 2002 to 2004 were plotted in Fig. 1. It showed that DMAT was higher in summer (June to September) and lower in winter (December to February), especially January. Variation in precipitation was significant; there existed a wet season (from June to August) and a dry season (from September to January). There was a longer growing

Table 1. The list of eight growing seasons for nilegrass (*Acroceras macrum* Stapf) grown in the experimental forage farm of Taiwan Livestock Research Institute (Hsinhua) from June of 2004 to May of 2004.

Season No.	Growing season	Growing duration (days)
1	06/27/2002 – 08/19/2002[x]	54
2	08/20/2002 - 10/25/2002	67
3	10/26/2002 - 03/07/2003	133
4	03/08/2003 - 05/02/2003	56
5	05/03/2003 - 07/05/2003	64
6	07/03/2003 - 10/02/2003	92
7	10/03/2003 - 02/25/2004	146
8	02/26/2004 - 05/14/2004	79

[x] From the day after cutting to the day of next harvest.

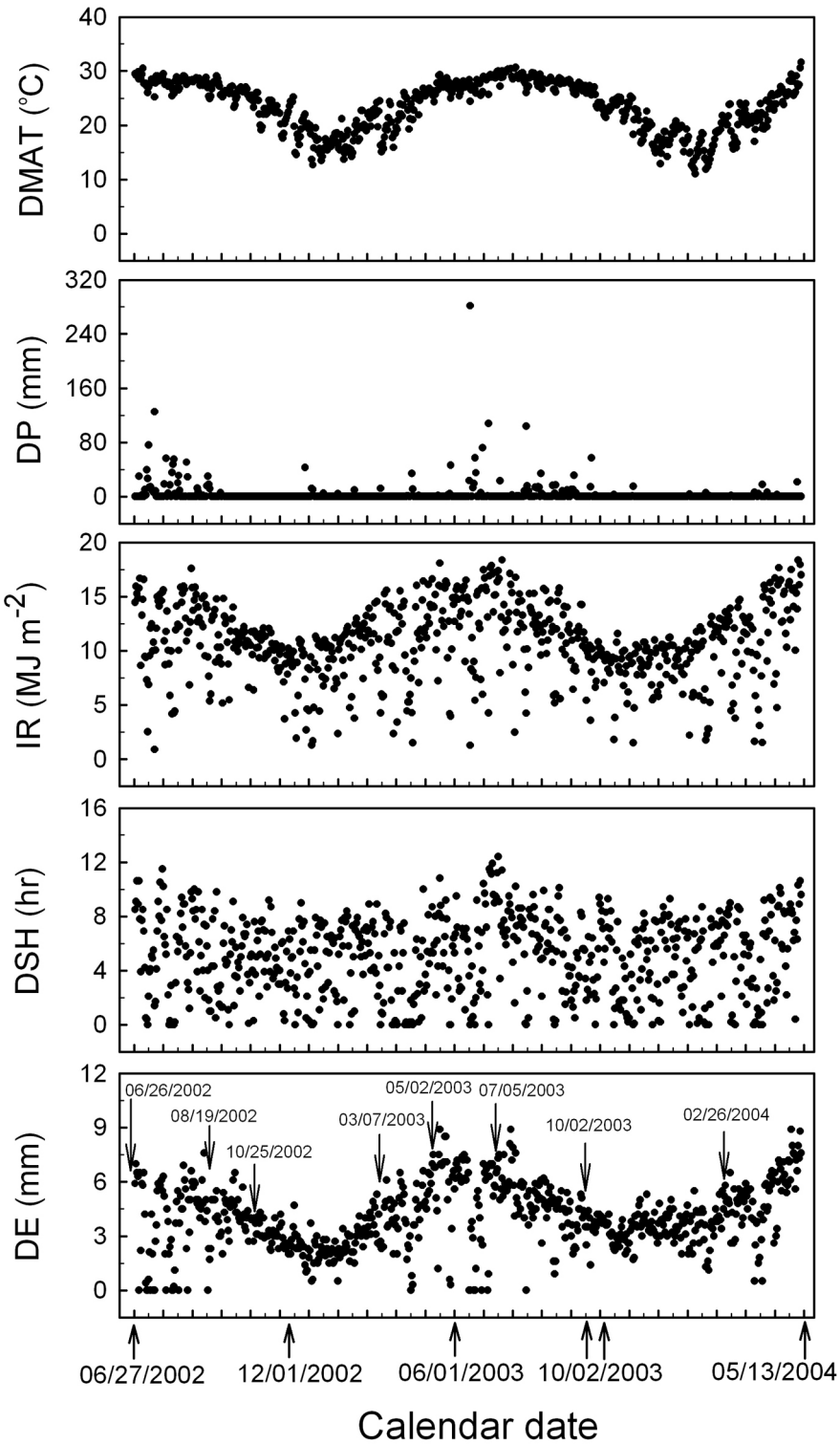


Fig. 1. Changes in climatic factors during the growing seasons from 2002 to 2004 for plants of *Acroceras macrum* Stapf grown in the experimental farm of Taiwan Livestock Research Institute at Hsinhua, Taiwan.

duration in dry seasons relative to a shorter growing duration in wet seasons (Table 1). Daily irradiance was high in summer and low in winter, as that found in sunshine hours and evaporation, but the values may have been reduced in raining and cloudy days when solar radiation and air temperature were low. Results indicated that values and patterns of climatic factors altered within and between growing seasons, and hence, differences in growth and forage production in different growing seasons were observed.

Correlations between forage production (fresh- and dry-based) and the cumulative values of climatic factors are graphed in Figs. 2A and 2B. Results showed that changes of forage production corresponded to the cumulative values of DMAT, DP, DE, IR, and DSH during the growing seasons, and the relationships were best fitted to linear functions. In plant height, similar results were obtained (Figs. 2A and 2B). Plant height of nilegrass was also linearly correlated with the cumulative values of these climatic factors.

In monitoring of the re-growth rate of a permanent grassland sward in mid summer under Irish weather conditions, Han (2000) was able to describe grass dry matter production with good accuracy with the accumulated values of daily mean temperature, global solar radiation, and growing degree days. In a case study of rice, a good agreement was shown between grain yield and the accumulated value of solar radiation (Yang 1994). As dry matter production is based on the balance between assimilation and respiration, it is reasonable to observe a close relationship of growth and yield to climatic factors and nutrient supply because source and sink to carbon metabolism are vulnerable to changes in environmental conditions (Gustavsson *et al.* 1994). However, when relating quality of alfalfa to weather

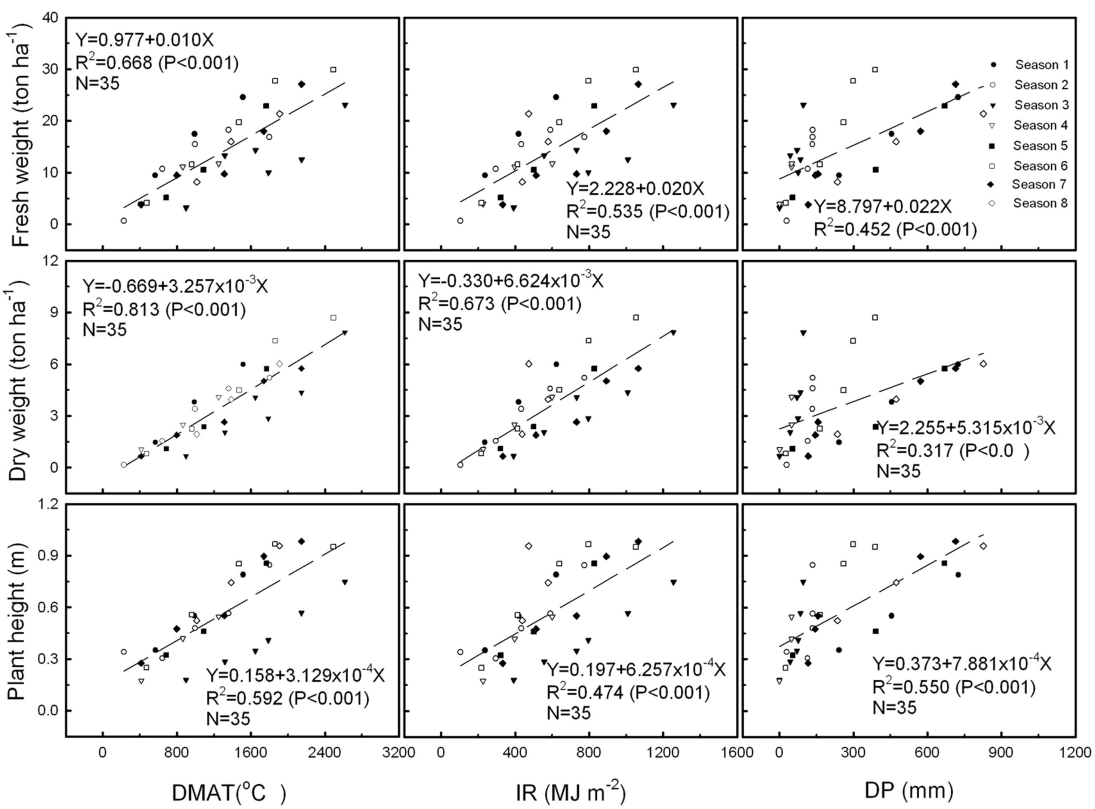


Fig. 2A. Correlations between forage fresh weight, dry weight, plant height and seasonal accumulated values of daily air temperature (DMAT), irradiance (IR) and precipitation (DP) for plants of *Acroceras macrum* Stapf grown in eight growing seasons from 2002 to 2004.

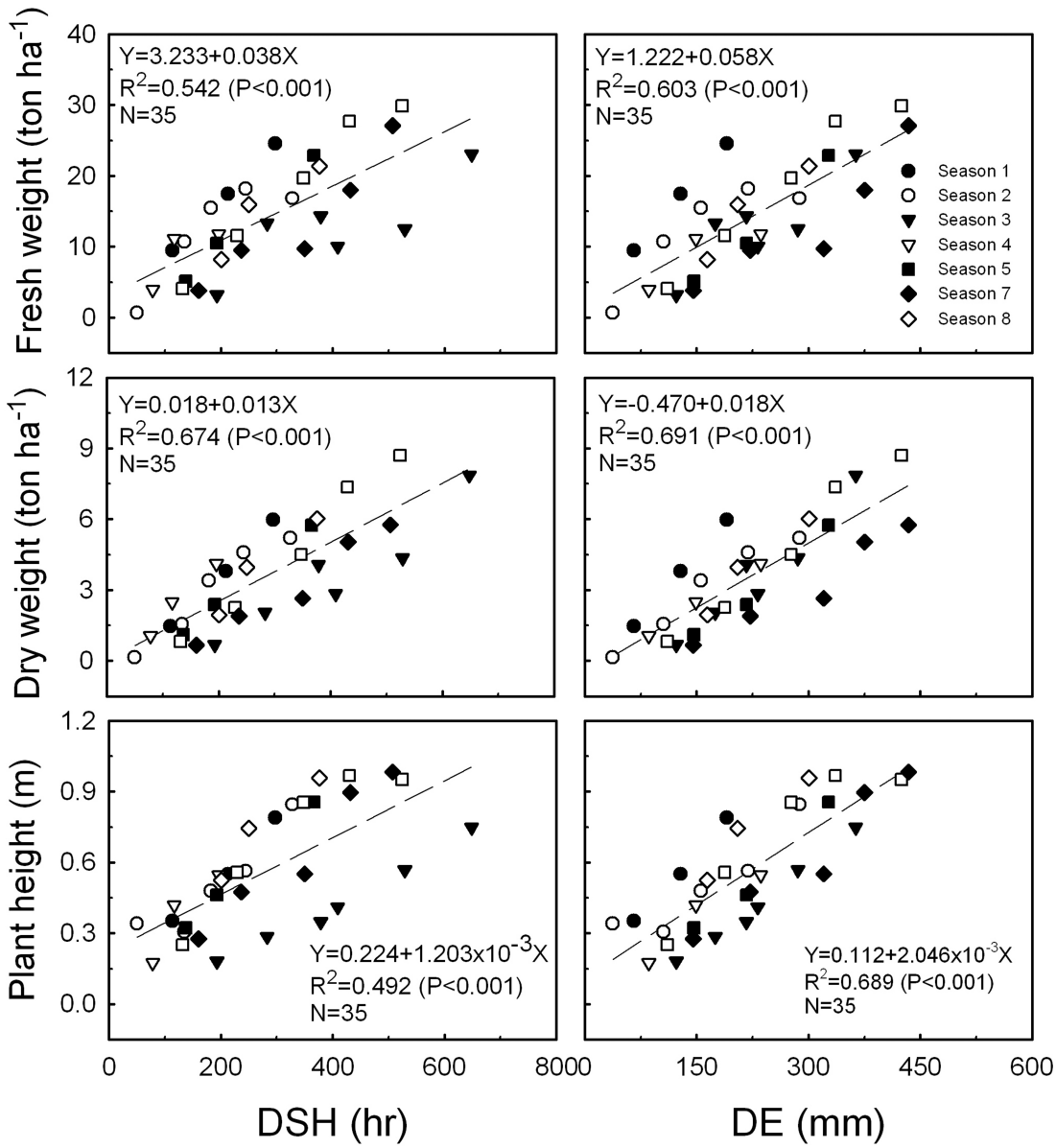


Fig. 2B. Correlations between forage fresh weight, dry weight, plant height and seasonal accumulated values of sunshine hours (DSH), and evaporation (DE) for plants of *Acroceras macrum* Stapf grown in eight growing seasons from 2002 to 2004.

data and morphological parameters, Onstad and Fick (1983) and Fick and Onstad (1988) reported that no single factor can well explain variation in quality of plant parts harvested in different growth stages.

Correlations of forage fresh weight to forage dry weight and plant height were shown in Fig. 3. It showed that forage fresh weight was correlated with forage dry weight (R^2=0.874, P<0.0001) and plant height (R^2=0.702, P<0.0001) positively. The increase of plant height along nilegrass growth produced more biomass which in turns contributed to the accumulation of dry matter within plants. Accordingly, unit forage production of nilegrass can be estimated by plant height at the time of sampling.

To improve the accuracy of model estimation for forage production from climatic factors, technique of multiple linear regression was adopted. Results showed that estimations of fresh- and dry-based forage production may be improved by two-variable linear regression models containing DP and IR, with R^2=0.667 (P<0.0001) for fresh-based and R^2=0.767 (P<0.0001) for dry-based forage production, respectively (Table 2). Whereas, plant height may be best estimated by a two-variable model containing DP and DE (R^2=0.808, P<0.0001). When validating the models with another set of weather data from different growing seasons, models gave slight over-predicted values of fresh- and dry-based forage production and plant height, especially at the upper end of the limit (Fig. 4). Apparently, under optimal climatic conditions in favor of plant growth, to an extent the overlapping of plant parts may impede the normal growing processes. Plant growth may not reach to it potential capacity, especially within lower layers of plant canopy. It will give rise to the hindrance of plant growth as a whole and result in the shortage the measured values of forage production, relative to the predicted values.

In pangolagrass (*Digitaria decumbens* Stent.), forage production can also be reasonably estimated from the accumulated values of DMAT, DP, and IR (R^2=0.854, P=0.003) (Chang *et al*., 2002). With the multiple linear regression models available, as in this study, farmers can decide the cutting date for pasture from it. However, the precision of such climatic models would be influenced by the management practices as well as the changes of soil environment and micro-climate. In particular, as plant growth of forage crops are very susceptible to water deficiency, soil moisture content should be carefully maintained throughout the growing seasons if a desire harvest is expected (Hsiao and Acevedo 1974). Han *et al*. (2003) reported an effective model to predict herbage yield under such water-stress condition.

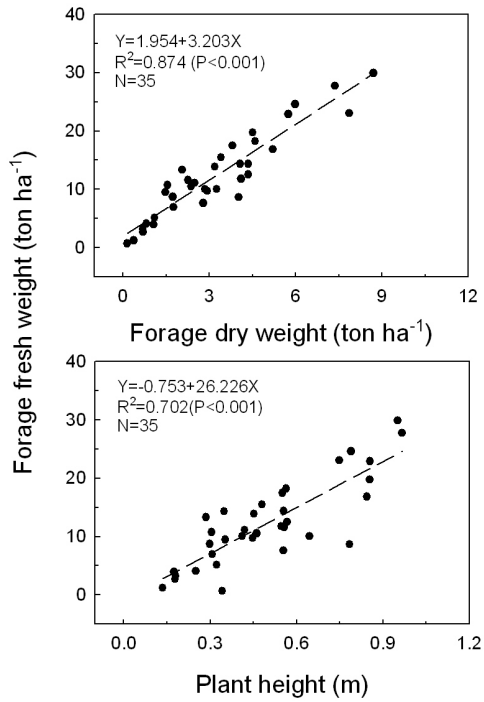


Fig. 3. Correlations between forage fresh weight and forage dry weight and plant height for plants of *Acroceras macrum* Stapf grown in eight growing seasons from 2002 to 2004.

Table 2. The best t two variables multiple linear regression equations for estimating forage fresh weight (ton ha^{-1}), forage dry weight (ton ha^{-1}) and plant height (m) of *Acroceras macrum* Stapf from climatic factors during the growing seasons.

	$Y=a+ a_1 X_{DP} +a_2 X_{DE} +a_3 X_{IR}$						
Item	a	a_1	a_2	a_3	R^2	P	Cp
Fresh weight	1.769	0.023	-	0.012	0.667	0.0001	3.000
Partial-R^2		0.428	-	0.239			
Dry weight	$-5.004x10^{-1}$	$5.270x10^{-3}$		$4.560x10^{-3}$	0.767	0.0001	3.000
Partial-R^2		0.639		0.128			
Plant height	$9.639x10^{-2}$	$5.919x10^{-4}$	$1.450x10^{-3}$	-	0.808	0.0001	3.000
Partial-R^2		0.189	0.619	-			

DP：Accumulated daily precipitation (mm).
DE：Accumulated daily evaporation (mm).
IR：Accumulated daily irradiance (MJ m^{-2}).

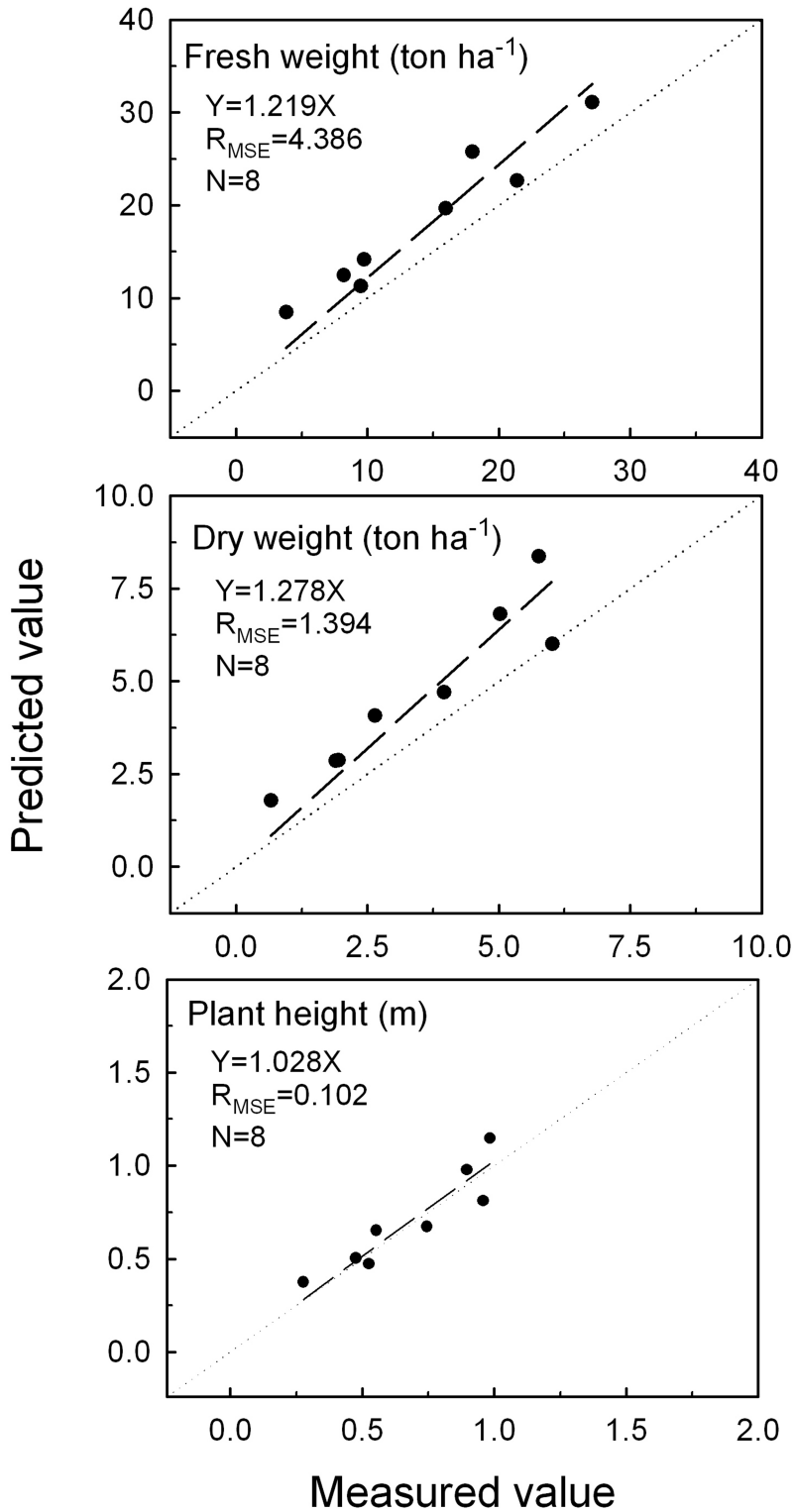


Fig. 4. Comparisons between the predicted values from the multiple linear regression models and measured values of forage fresh, dry weight and plant height for plants of *Acroceras macrum* Stapf.

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