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Weather data based descriptive models for prediction of coconut yield in different agro-climatic zones of India

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ABSTRACT

Weather variables play an important role in determining the coconut palm growth, development and yield. The influence of weather on nut yield in coconut starts from inflorescence initiation and lasts till nut maturity (44 months). Historical data on weather variables and coconut nut yield from different agro-climatic zones *viz*., Western coastal area – hot sub-humid-per-humid (Kasaragod – Kerala; Ratnagiri – Maharastra), hot semi-arid (Arisikere – Karnataka) and Eastern coastal plains- hot sub-humid (Veppankulam- Tamil Nadu; Ambajipeta- Andhra Pradesh) of India were used for developing models for prediction of coconut yield. The prediction models with 3- and 4-year lag had high R^2 values. The models differed for usage of parameters in different agro-climatic zones, indicating the relative importance of these parameters in respective conditions for realizing the nut yield in coconut. Interestingly, the parameters used in models for western coastal area – hot sub-humid-per-humid are temperature and relative humidity, as indicated even in the classification of these areas. Models were verified for 2 years and prediction of yield during 1998-99 and 1999-2000 within 10% confidence level validated these models. The study indicates that the relative humidity and temperature play important role during the ontogeny of inflorescence and nut development. The descriptive models, developed based on weather data, can be used for prediction of coconut yield two to four years in advance with in acceptable range of accuracy. The yields to be realized can be bracketed within predicted range obtained from models using one, two, three, and four year lags. These models can also be used for prediction of coconut nut yield in the situations similar to those in the present study.

Key words: Agro-climatic zones, coconut, prediction models, yield, weather.

INTRODUCTION

Weather variables like rainfall, day/night temperature regimes, relative humidity, sunshine duration, vapour pressure deficits play pivotal role in determining the crop growth development and yield. For good growth and nut yield, coconut palm requires a well-distributed rainfall (130 to 230 cm/year), mean temperature (27°C with diurnal variation of 5°C) and sun shine (250 to 350 Wm^{-2}) of 2000 h/year with at least 120 h/month (Child, 2; Murray, 6). The influence of weather on coconut yield, in fact, starts from inflorescence initiation and lasts till nut maturity (Rajagopal *et al.,* 13). The time lag between inflorescence initiation to nut maturity is 44 months. Coincidence of critical sensitive period with unfavourable weather results in drastic reduction in yield. Earlier studies, based on single location experiments, indicated influence of rainfall and other weather variables on coconut yield (Dootson *et al.,* 3; Vijayakumar *et al.,* 15; Peiris *et al.,* 9; Rajagopal *et al.,* 13; Peiris and Thattil, 10). Efforts were made to forecast the coconut yield using biometrical characters (Peiris, 8; Jacob Mathew *et al.,* 4), partial harvest data, juvenile characters (Prabhakaran *et al.,* 11) and foliar nutrient levels (Jose *et al.,* 5). A crop forecasting model using rainfall data was developed by Abeyawardena (1), who later developed an empirical statistical model, based on 'drought indices', to forecast coconut yields in Sri Lanka. Similar efforts using rainfall data were made resulting in development of the regression equations, which either had too low error degrees of freedom or the variation of actual yield from predicted yield was too high. Vijayakumar *et al.* (15) developed a predictive model using climatic variables *viz.*, relative humidity (max.), sunshine duration, vapour pressure and minimum air temperature with a high R^2 (0.91) using lag variables up to three years. From this model yield can be predicted one year before the harvest. Coconut, a perennial crop with indeterminate growth pattern, has sensitive phases regularly and is influenced by the weather variables. The long duration of inflorescence initiation to nut development emphasizes the importance of weather on realizing the nut yield, under suitable soil and adequate management environment. Since coconut is a perennial crop, it is the weather, which contributes mainly towards the variation in yield. Thus, it is important

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to understand the influence of weather on nut yield and develop models using weather data for predicting nut yield in different agro-climatic zones, which invariably vary for weather input. Models developed earlier were based on a single location data and some were not verified for accuracy, hence in the present set of experiment, models were developed for different ago-climatic zones with major coconut growing areas and they were verified for two years to check the accuracy.

MATERIALS AND METHODS

The monthly means on weather variables (Table 1) for a duration of 15 to 20 years (1977 to 1997) was collected from different agro-climatic zones *viz*., Western coastal area – hot sub-humid-per-humid (Kasaragod – Kerala; Ratnagiri – Maharastra), hot semi-arid (Arisikere – Karnataka) and eastern coastal plains-hot sub-humid (Veppankulum- Tamil Nadu; Ambajipeta-Andhra Pradesh). These represent the major coconut growing areas in India. Annual coconut yield of different cultivars in the above areas was collected for corresponding period from All India Coordinated Research Project Centres located in the mentioned places. The soil characteristics at Kasaragod are of red sandy loam with pH 5.8; at Veppankulam, sandy loam with pH 6.0; at Ambajipetta sandy soil with pH 6.0; at Ratnagiri soil type is coastal alluvium with pH 6.3 and at Arsikere medium black soils with pH 8.0. Mean monthly weather patterns are given in Table 1. Yield data were collected from a minimum of 500 palms to a maximum of 1000 palms of local cultivar and also for different cultivars and hybrids. All these palms were under irrigated condition with summer irrigations, with recommended spacing (7.5 × 7.5 m) and received NPK at required amount depending on the available soil nutrients. Apart from this these plantations are over 15 years old and attained stabilized yield condition.

Coconut flowers 5 to 6 years after transplanting. Generally, it is considered that the palms attain stabilized yields by 13 to 15 years after planting. The palm has monopodial growth and approximately one leaf emerges every month. The inflorescence, which comes in each leaf axel, contains both staminate and pistillate flowers. In a palm canopy (crown) approximately 36 physiologically active leaves are present with around 12 to 14 inflorescences. Thus all stages of leaf and inflorescence development are present at any given time in a single palm. From inflorescence initiation to nut maturity it takes 44 months. From the time of inflorescence initiation to pistillate flower differentiation it takes 20 months, when actually the number of pistillate flowers are determined. By 25th to 26th month, the ovary development takes place. By 30th month the spathe opens and soon fertilization takes place. From fertilization, approximately by 12th month nut fully matures. The critical sensitive phases for drought stress include inflorescence initiation, ovary development and button size nuts, and any coincidence of stress period with the sensitive phases will adversely affect the yield (Rajagopal *et al.,* 13). Since, these critical phases will be present in palm at any given time, it is essential that palms should continuously receive the nutrients, water and management attention, which is generally given in well managed plantations. Then, it is the weather, which plays an important role in determining the productivity such plantations. Because of afore-mentioned ontogeny, any adverse condition affects palms for longer periods and it takes 3 to 4 years for recovery and come back to the earlier yielding levels (Rajagopal and Naresh Kumar, 12). Thus, four yearly lag periods were taken to develop models. Since, almost every month one inflorescence emerges, monthly means of weather data were taken for correlation and regression analysis. Apart from these, palms tend to have biennial bearing nature, which is to taken care off while developing models. This is taken care by the large sample of palms, which have both high and low yielding phases. Verification of these models was done for two consecutive years to rule out the possibility of biennial variations.

Monthly means were computed before the data were used for step-wise correlation analysis. July to June cycles of years for weather and yield data were used for analysis. The parameters, which correlated significantly, were used for multiple regression analysis. In these models, one-year lag means using previous

Table 1. Mean weather parameters at different centres.

Centre	Annual mean				
	Tmax.(°C)	Tmin.(°C)	R H forenoon (%)	RH afternoon (%)	Annual Rainfall (mm)
Kasaragod (Kerala)	31.21	22.39	88.66	67.82	3333
Ratnagiri (Maharastra)	30.78	24.01	80.44	75.90	2802
Kidu (Karnataka)	33.20	16.16	93.20	57.60	2788
Ambajipeta (Andhra Prdesh)	31.63	24.70	86.50	73.90	1161
Veppankulam (Tamil Nadu)	32.81	26.13	89.60	60.86	1116
Arisikeri (Karnataka)	31.00	16.20	76.73	52.68	718

years weather data to forecast current year yield. Two-year lag means using the weather data of two years previous to the current year to forecast nut yield of current year. Similarly, models were developed using lag periods up to four years. In each lag period there were 108 (12 × 9) independent variables, which were correlated with the yield. Variables with significant correlations with yield were further used for multiple regression analysis (Table 2). Non-contributing variables were eliminated during development of the models through step-wise regression. Models were developed using monthly average of weather parameters for each lag period for different cultivars at a centre. The step-wise correlation and regression analysis were done following the standard procedures.

Models, developed for each cultivar in a particular center and also for each centre, by using pooled yield data of all cultivars at a centre, were tested for validity by comparing the predicted yield with attained yield of subsequent two years.

RESULTS AND DISCUSSION

The prediction models with 1-, 2-, 3- and 4-year lag period indicated that the models with 3- and 4-year lag had high R^2 values (Table 3). The models differed for usage of weather parameters in different agro-climatic zones, indicating the relative importance of these parameters in respective conditions for realizing the nut yield in coconut. Interestingly, the parameters used in models for western coastal area – hot sub-humid-per-

Table 2. Regression models for nut yield predictions in coconut grown at different agro-climatic zones.

Place	Year lag	Regression equation	R^2 value
Kasaragod	1	$Y=104.25-0.851(RF_{12})-1.098(RF_2)-.28(RF_3)$	0.591
	2	Non-significant	-
	3	$Y=-87.74+7.156(RHFN_8)-25.44(PE_{10})-46.6(PE_{12})$ $-40.63(PE_4)$	0.735
	4	$Y=860.26-12.56(Tmax_6)+0.90(Tmin_{11})$ $-1.924(RHFN_{11})+0.024(RHFN_{12})$ $-1.574(RHAN_{12})$ $-8.725(PE_3)-25.005(PE_5)$	0.921
Veppankulam	1	$Y=237.50-4.347(Tmax_5)-0.079(RF_{10})$	0.838
	2	$Y=-110.696+5.616(Tmax_9)+0.139(RF_4)+0.034(RF_6)$ $-5.443(PE_{10})$	0.882
	3	$Y=-140.87-11.22(Tmax_{12})+16.059(Tmin_8)$ $+8.45(Tmin_9)-0.187(RF_{12})$	0.987
	4	$Y=926.90-18.18(Tmax_{11})-12.98(Tmin_7)$ $-0.108(RF_7)-0.107(RF_8)-0.176(RF_5)$	0.992
Ambajipeta	1	$Y=314.52-3.92(Tmax_6)-6.44(Tmin_1)+1.05(Tmin_2)$ $+0.40(RHAN_3)-0.03(RF_8)$ $+0.164(RF_{12})$ $-7.51(RD_{12})-0.057(RD_4)$	0.974
	2	$Y=116.72-2.10(RHFN_2)+1.67(RHFN_3)+0.16(RHFN_4)$ $-1.11(RHFN_5)$ $+0.29(RHAN_3)-1.09(RHAN_4)$ $+1.76(RHAN_5)+1.74(RD_8)-0.84(RD_{10})$	0.985
	3	$Y=915.85-14.87(Tmax_{12})-5.59(RHFN_7)+26.08(RHFN_8)$ $-10.08(RHFN_1)$ $-3.56(RHFN_3)-5.59(RHFN_4)$ $-5.89(RHAN_9)+0.20(RF_6)-5.25(RD_{10})$	0.981
	4	$Y=-800.23+4.39(Tmin_3)+11.29(RHFN_9)-4.89(RHFN_1)$ $+4.84(RHFN_4)$ $13.36(RHAN_9)+10.56(RHAN_{10})$ $+0.15(RHAN_{12})-0.394(RF_5)-1.08(RD_{10})$	0.948
Ratnagiri	1	$Y=161.26-1.276(RH_2)$	0.611
	2	NS	-
	3	$Y=-587.65+23.76(Tmax_8)$	0.812
	4	$Y=-298.70+7.80(Tmax_7)+7.36(Tmax_5)+0.242(RH_{11})$ $-1.287(RH_5)$	0.913
Arsikere	1	$Y=89.29-0.05(RF_{10})+0.934(RF_1)-7.79(PE_5)$	0.735
	2	Non-significant	-
	3	$Y=17.47+0.336(RF_4)$	0.663
	4	$Y=-128.25-12.48(VPFN_{10})-1.93(VPAN_{11})$ $+8.48(VPAN_{12})$ $+4.47(RH_{FN}^{10})$ $-1.19(RHFN_{11})$ $+0.189(RF_4)$	0.997

Maximum temperature- Tmax; Minimum temperature- Tmin; Relative humidity (forenoon)- RHFN; Relative humidity (afternoon)- RHAN; Vapour pressure (forenoon); VPFN; Vapour pressure (afternoon) – VPAN; Pan evaporation- PE; Rainfall- RF; Rainy days- RD.

January-1; February- 2; March-3; April – 4; May-5; June- 6; July-7; August-8; September-9; October-10; November-11; December-12.

Table 3. Nut prediction models for different cultivars grown under different agro-climatic zones.

Place	Cultivar	4-year lag - regression equation	R^2 value
Kasaragod	WCT	$Y=603.26-2.88(Tmin_{11})\ -3.58(RHFN_{11})\ -0.06(RHAN_{12})\ -10.38(PE_3)\ -19.92(PE_5)$	0.754
	COD	$Y=364.24\ -7.08(Tmin_{11})+4.89(Tmin_{12})\ -\ 0.212(Tmin_6)\ -4.41(RHAN_{12})\ -3.10(PE_7)\ -11.13(PE_4)\ +10.38(PE_5)$	0.872
	WCT × COD	$Y=609.48-4.67(Tmin_{11})\ -1.91(RHFN_{11})\ -2.58(RHFN_{12})\ +1.56(RHAN_{12})\ -3.83(PE_3)\ -23.19(PE_5)$	0.786
	WCT × GBG	$Y=609.62-1.65(RHFN_{11})\ -2.26(RHFN_{12})\ +1.49(RHAN_{12})\ -\ 20.88(PE_3)\ -\ 33.34(PE_5)$	0.809
	DCOD × WCT	$Y=1049.5-14.82(Tmax_{12})-4.02(RHFN_{11})+0.221(RF_{12})\ +0.38(RF_3)\ +11.15(PE_3)\ -\ 45.09(PE_5)$	0.933
Veppankulam	ECT	$Y=15.48+0.8303(RF_5)$	0.760
	LCT	$Y=1140.45-35.91(Tmax_{11})-0.049(RF_4)$	0.815
	WCT	$Y=297.56-2.78(Tmax_{10})+0.06(RF_{11})-12.36(PE_3)\ -18.90(PE_5)-2.51(PE_6)$	0.998
	ADOT	$Y=284.59(Tmax_5)+0.202(RF_3)-6.01(PE_9)-2.66(PE_2)$	0.880
	Semi-Tall Yellow	$Y=1457.34\ –\ 46.88(Tmax_{11})$	0.768
	COD	$Y=1186.29-38.55(Tmax_{11})$	0.759
	WCT × COD	$Y=1089.22-34.09(Tmax_{11})-0.198(RF_{11})$	0.842
	GBGD	$Y=84.25+1.34(Tmax_7)-16.04(PE_3)$	0.767
Ambajipeta	ECT	$Y=-1923.49+2.79(RHFN_9)+14.27(RHFN_{12})\ -0.79(RHFN_1)\ +8.16(RHFN_4)\ +12.49(RHAN_{10})\ -6.72(RHAN_{11})\ -8.37(RHAN_{12})\ -0.284(RF_5)$	0.984
Ratnagiri	WCT	$Y=42.44+1.875(RF_{11})$	0.658
	LCT	$Y=598.58-16.45(Tmax_1)\ -37.11(Tmax_5)+23.56(Tmin_5)\ +26.33(Tmin_6)\ -0.307(RH_1)\ +0.016(RF_8)$	0.994
	ADOTCOD	$Y=-42.28+4.99(Tmin_1)\ -\ 0.013(RF_7)$	0.715
	WCT × COD	$Y=-555.08+24.64(Tmin_7)$	0.607
	GBGD	$Y=-954.68+8.44(Tmax_{11})+1.12(Tmax_1)\ +25.79(Tmax_5)+1.17(RH_{11})\ -2.08(RH_5)$	0.996
		$Y=255.44\ –3.05(Tmin_1)-5.24(Tmin_3)$	0.889
Arsikere	TPT	$Y=-128.25\ -12.49(VPFN_{10})\ -1.93(VPAN_{11})\ +8.48(VPAN_{12})\ +4.47(RHFN_{10})\ -\ 1.193(RHFN_{11})\ +0.189(RF^4)$	0.997

Refer Table:2 for expansion of abbreviations.

West Coast Tall – WCT; Chowghat Orange Dwarf – COD; Gangabondam Green Dwarf – GBGD; East Coast Tall-ECT; Laccadive Ordinary Tall – LCT; Andaman Ordinary Tall – ADOT; Tiptur Tall - TPT.

humid are temperature and relative humidity, as indicated even in the classification of these areas. The model to predict yields in hot semi-arid regions included weather parameters like rainfall, vapour pressure, and relative humidity, indicating that among all weather parameters, these primarily influenced nut yield under a respective conditions. The models for eastern coastal plains- hot sub-humid included temperature, relative humidity and rainfall. In general, the relative humidity and temperature played important role during the ontogeny of inflorescence and nut development. Temperature influences the ontogenetic development of plants by influencing the growth and differentiation rates (Naresh Kumar, 7). Weather parameters such as mean monthly temperature, number of rainy days, sunshine hours and evaporation largely influenced the coconut nut yield (Dootson *et al.,* 3). Rain fall during previous year is reported to influence the nut yield (Abeyawardhana, 1; Rao, 14). The influence of rainfall and length of dry spell over past four years largely influenced the coconut yield in different agroclimatic zones of India (Rajagopal and Naresh Kumar, 12). All these reports support the theoretical basis used for development of these models.

Prediction models for individual cultivar at respective zone also were developed (Table 4). Since the R^2 values were high for the models for four-year lag period, they only are presented along with the best model by considering the parameters from other lag periods for each cultivar. The parameters used in models for a similar cultivar in different places varied, indicating: (i) the presence of genotype × environment interaction, (ii) the presence predominant influence of these weather parameters on nut yield and iii) the possibility of presence of other weather parameters within range for optimal growth in a given agro-climatic zone. The R^2 values for models with one, two, three and four-year lag for each cultivar at different agro-climatic zones indicate, in general, were high for the models 4-year lag period (Table 5).

The models were verified using the yield data of subsequent two years from the respective agro-climatic zones. Nut yield for 1998-99 and 1999-2000 was predicted using models with one, two, three and four year lag periods (Table 6). There was a close agreement

Table5. Coefficient of determination of nut yield prediction models for one-, two- and three- year lag groups for different cultivars.

Place/cultivar	Best R^2 from 1-3 year group	
	Year	R^2 value
Kasaragod		
COD	3	0.999
Veppankulam		
LCT	2	0.984
Semi-Tall Yellow	2	0.968
COD	2	0.980
WCT × COD	1	0.963
Ratnagiri		
WCT	3	0.889
ADOT	3	0.990
GBGD	3	0.715

Refer Table 3 for expansion of abbreviations; At Ambajipeta and Arsikere analysis was done for one cultivar each.

Table 4. Coefficient of determination of nut yield prediction models with different lag periods.

Place/cultivar	R^2 value (1-4 year lag)			
	1	2	3	4
Kasaragod				
WCT	0.565	0.333	0.568	0.754
COD	0.840	0.598	0.999	0.872
WCT × COD	0.705	0.674	0.753	0.786
WCT × GBG	0.567	0.317	0.713	0.786
DCOD × WCT	0.375	0.317	0.460	0.933
Veppankulam				
ECT	NS	0.606	0.586	0.760
LCT	0.594	0.984	0.893	0.815
WCT	0.849	0.864	0.959	0.998
ADOT	0.774	NS	0.809	0.880
Semi-Tall Yellow	NS	0.968	0.804	0.768
COD	0.742	0.980	0.921	0.759
WCT × COD	0.842	0.729	0.689	0.842
GBGD	0.842	0.719	NS	0.769
Ambajipeta				
ECT	0.865	0.908	0.863	0.984
Ratnagiri				
WCT	0.139	0.045	0.889	0.658
LCT	0.682	0.682	0.668	0.994
ADOT	0.607	0.317	0.990	0.715
COD	NS	NS	NS	0.607
WCT × COD	0.361	0.361	NS	0.996
GBGD	NS	NS	0.715	0.693
Arsikere				
TPT	0.735	NS	0.663	0.997

Refer Table 3 for expansion of abbreviations.

of actual yield data with the predicted one in most of the cases. In Ambajipeta, the predicted yield values, using one- and two-year lag, exceeded over 100%. These discrepancies can be attributed to the cyclone, which hit the area during 1995-96, thus affecting the palm performance severely. Similar discrepancy can be noted for Veppankulam when the two- and three-year lag prediction models were used. These instances indicate the limitation of descriptive models. However, coconut palm after attaining the yield stabilization, under well-managed conditions, is largely influenced by weather parameters for yield. Thus these descriptive models become handy to predict the coconut yield till the development of simulation models. These models were developed with an intension that users should not worry about further calculations such as for dry spell, etc. Since, just by using the monthly means of given parameters, it is possible to predict the nut yield with high level of accuracy, as indicated by the verification results, the models are highly user friendly. The data indicate that the prediction of nut yield in coconut can be done with fair consistency using these models. The models, developed for specific conditions, can be used for predicting the yield in similar situations with acceptable variations around 10%. The regression of actual nut yield against nut yield predicted using these models clearly indicated that the nut yields are more predictable using models with three-and four- year lag. However, for obtaining an envelop, predictions can be made for attainable range of yield using the models for all 4-lag periods in a given situation (Fig.1). Generally, yields obtained were with in this estimated range.

With following conditions these models can be used for wide areas:

i) Model developed for specified agro-climatic zone can be used for the fields falling in that area.
ii) The crop should be under irrigated condition (at least a few summer irrigations).
iii) Crop should be with recommended spacing (generally 7.5 x 7.5 m) and supplied with NPK at required amount.
iv) The plantation is of over 15 years old (stabilized yield stage).

It can be concluded that in a managed plantation the relative humidity and temperature played important role during the ontogeny of inflorescence and nut development. The descriptive models developed based on weather data can be used for nut yield prediction in coconut with fair amount of accuracy and the attainable yield can be bracketed with in predicted range obtained from models with one, two, three, and four year lags.

Table 6. Validation of nut yield prediction models for different agro-climatic zones for two years.

Centre	Year lag	Nut yield/palm/year (1998-99)		Year lag	Nut yield/palm/year (1999-2000)	
		Actual	Predicted		Actual	Predicted
Arsikere	97-98 (1[a])	39.4	35.84	98-99	48.6	48.8
	96-97 (2)		NS[b]	97-98		NS
	95-96 (3)		33.12	96-97		32.6
	94-95 (4)		36.17	95-96		48.4
Ratnagiri	97-98	88.5	84.51	98-99	81	83.75
	96-97		83.08	97-98		84.51
	95-96		113.27	96-97		88.79
	94-95		92.53	95-96		93.86
Ambajipeta	97-98	30	72.36	98-99	102	84.52
	96-97		77.67	97-98		79.35
	95-96		38.22	96-97		107.87
	94-95		33.74	95-96		94.66
Veppankulam	97-98	50.3	61.01	98-99	99.64	82.43
	96-97		NS	97-98		42.21
	95-96		53.33	96-97		99.48
	94-95		45.79	95-96		94.49
Kasaragod	97-98	82	52.68	98-99	92.14	53.02
	96-97		NS	97-98		NS
	95-96		71.72	96-97		93.3
	94-95		117.05	95-96		72.36

[a] number in parenthesis indicates year lag i.e., weather data of given year is used: [b]NS: Not significant.

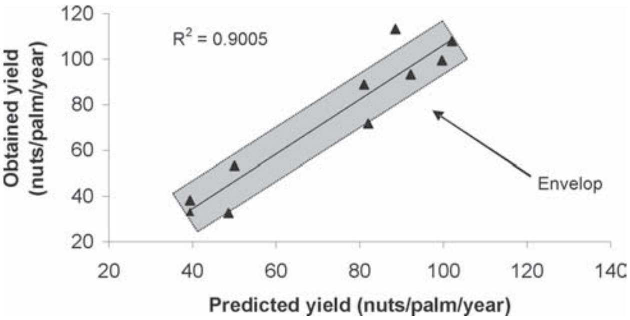

Fig. 1. Regression fit for actual coconut nut yields against predicted yield using models with one-, two-, three- and four- year lag.

These models can also be used for prediction of nut yield in the situations similar to those in the present study. This will give an overall picture for nut yield, 3 to 4 years in advance.

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