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Simulation of cob growth in maize (*Zea mays* L.) by empirical models under weed management practices

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Maize is the king of crops and queen of cereals, having utility as human food, animal feed and as a source of large industrial products. Weeds cause considerable loss on maize growth and yield, apart from utilizing considerable quantity of nutrients at the cost of crop (Ramachandra Prasad *et al.,* 1993). Growth analysis is elucidation of causes for yield variation based on the logical sequences of crop developmental processes (Watson, 1952). This classical method was modified by functional approach, a dynamic approach which uses mathematical relationship (Hunt, 1990). Crop growth modeling is often attempted to know the crop growth pattern under various factors of production and to quantify the relationship of factors of production with crop growth. In this direction, sigmoidal functions namely Richards, Logistic and Gompertz were used to describe crop growth as well as cob growth earlier (Porter, 1989; Ramachandra Prasad and Shivashankar, 1992; Ramachandra Prasad *et al*., 1992, 1993). Cob growth of maize was better explained by Richards and Logistic function by over 94 to 98% under common fertilizer and weed management practices (Ramachandra Prasad *et al.,* 1992). However, in the present study, an effort has been made to know the variation in pattern of cob growth and to quantify the ill effect due to weed types' competition under weed management practices through functional models.

The present investigation was carried out on alfisols (red sandy loam soil) at Field Unit of All India Coordinated Research Programme on Weed Control, Main Research Station, University of Agricultural Sciences, Hebbal, Bangalore during *Kharif* 2007. The experiment consisted of six treatments laid out as RCBD with four replications. Only four weed management practices namely atrazine 0.75 kg ai ha^{-1}, 2,4-D EE 0.8 kg ai ha^{-1}, hand weeding (two times at 20 and 40 days after sowing) and unweeded control were selected to work out the pattern of cob growth and to quantify the ill effect of competition from weed types mediated through weed management practices. Cv. NAC 6004 was raised at a common fertilizer dose of 100 kg N, 75 kg P_2O_5 and 38 kg K_2O ha^{-1} with a spacing of 60 cm between rows and 30 cm between plants. The gross and net plot sizes were 6.0 m x 6.0 m and 3.6 x 4.8 m, respectively. Periodical cob dry weight (g $plant^{-1}$) recorded at stages 60, 70, 80, 90, 100, 110 and 120 DAS (at harvest), was used for fitting the cob growth data through the following models. Here for convenience sake, quadratic and linear model was differentiated to work out relative cob growth rate (RCGR), which represent rate of increase in cob weight per plant per day (g $plant^{-1}$ day^{-1}).

Richards: $Y_{CDW} = a\{1+ \exp.^{(b-cx)}\}^{1/d}$

Logistic: $Y_{CDW} = a\{1+b \exp.^{-cx}\}^{-1}$

Gompertz: $Y_{CDW} = a \exp. \{-\exp.^{(b-cx)}\}$

Quadratic: $Y_{CDW} = a + bx + cx^2$

Linear: $Y_{CDW} = a + bx$

Where Y_{CDW} = cob dry weight, x = days after sowing, a, b, c and d are constants to be worked out.

Differentiating quadratic and linear models, we get,

Quadratic model, RCGR, g $plant^{-1}$ day^{-1} = $\eth_{CDW}/\eth x$ = b + 2 cx

Linear model, RCGR, g $plant^{-1}$ day^{-1} = $\eth_{CDW}/\eth x$ = b

The models' sensitivity was assessed by working out standard error (SE) and root mean squared deviation (RMSD), apart from estimating coefficient of determination (R^2).

$$SE = \frac{\Sigma (O-P)^2}{\text{No. of observation}}$$

$$RMSD = \{\Sigma (O-P)^2/\text{No. of observation}\}^{0.5};$$

Where O = Observed data, P = Predicted value

Major weed flora observed from initial stages in the experimental plot was *Cyperus rotundus* Linn. (a sedge); *Echinochloa colona* Linn., *Digitaria marginata* Link., *Chloris barbata* Linn., *Eleusine indica* Gaertn., *Dactyloctenium aegyptium* (L.) *P. beauv*. (among grasses), *Borreria articularis* Linn., *Ageratum conyzoides* Linn., *Commelina benghalensis* Linn., and *Portulaca oleracea* Linn. (among broad leaf weeds). Atrazine gave a good control of grasses and broad leaf weeds which was comparable to hand weeding (38.5 total weeds m^{-2}), while 2,4-D EE controlled effectively broad leaf weeds only. Unweeded control showed the dominance of grasses (77.4 weeds m^{-2}), followed by sedge (38.2) and broad leaf weeds (25.2 m^{-2}).

Under all weed management practices, Richards, Logistic, Gompertz and quadratic models simulated the cob growth of maize to the extent of 98% of the observed data, while linear model simulated cob growth by 92 to 94%. These

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symmetrical models showed lower SE and RMSD values and indicated the goodness of fit of the models in simulating the data closer to the actual cob growth. Further weed management practices did not affect the pattern of cob growth at different stages as seen from similar R^2 values (Fig. 1), but weed competition has affected the total cob dry weight at harvest in unweeded control indicating the cumulative negative effect of weed competition on the cob dry weight (143.2 g plant^{-1} as against 194.2 g plant $^{-1}$ in hand weeding) (Table 1).

Linear and quadratic models were differentiated to work out relative cob growth rate, RCGR (Table 2). Through differentiation of liner model, elimination of weed competition by use of 2,4-D EE, atrazine and hand weeding gave higher RCGR of 2.7, 3.05 and 2.85 g plant^{-1} day^{-1} as compared to lower RCGR of 2.28 g plant^{-1} day^{-1} under unweeded control with all weed types' competition. Further use of atrazine and hand weeding improved the RCGR by 25 to 34% over unweeded control indicating the beneficial effect of elimination of weed types' competition in improving the rate of dry matter accumulation in the reproductive part of maize, as explained by Krishnamurthy *et al.* (1973) and Poorter (1989). Use of 2,4-D EE eliminating broad leaf weeds and sedges' competition improved the RCGR by 18% over unweeded control and this was 7 to 16% lower than the use of atrazine and hand weeding (Table 2). Thus, competition by all weed types lowered the RCGR by 25% in unweeded control as against atrazine treatment with less weeds' competition from the initial stage, while the grassy weeds' competition in 2,4-D EE treatment lowered the RCGR by 12%. Thus grasses constitute major competitor in maize in view of large stature, followed by broad leaf weeds and sedges.

Similarly, quadratic model was differentiated at stages 70 to 120 DAS to work out RCGR. The simulated RCGR was higher at 60-70 DAS (3.85 g plant^{-1} day^{-1} in unweeded control to 4.6 g plant^{-1} day^{-1} in atrazine treatment) and then decreased with advance in growth of maize. The RCGR was less than 1.0 g plant^{-1} day^{-1} at 110-120 DAS indicating very less accumulation of dry matter in the cob nearing maturity. RCGR around 3.04 g plant^{-1} day^{-1} at 80-90 DAS and 2.26 g plant^{-1} day^{-1} at 90-100 DAS in atrazine and hand weeding treatments having relatively weed free situation as against 2.41 and 1.69 g plant^{-1} day^{-1} in unweeded control as a result of lowered dry matter accumulation in cob, as also noticed in sunflower due to weed competition (Ramachandra Prasad et al., 1996). Further, RCGR at 110-120 DAS was lowered by 2.8 times due to competition from all weed types as compared to atrazine treatment (Table 2), while grassy weed competition in 2,4-D treatment, lowered the RCGR by 1.9 times. Averaged over stages, RCGR was higher with atrazine (2.65 g plant^{-1} day^{-1}) and hand weeding (2.66 g plant^{-1} day^{-1}), followed by 2.40 g plant^{-1} day^{-1} and the least was with unweeded control (2.05 g plant^{-1} day^{-1}). Thus elimination of weed types competition improved the RCGR by 29 to 30% in atrazine and hand weeding treatments, as compared to 17% due to elimination of broad leaf weeds' competition in 2,4-D EE over unweeded control. Compared to atrazine with less weeds' competition, competition of all weed types lowered the RCGR by 23% as against competition of grasses in 2,4-D EE treatment lowered the RCGR by 10%. While the competition offered by broad leaf weeds and sedges together lowered RCGR by 13%.

Thus present study indicated the biological utility of these models which quantify the ill effects of weed competition on cob growth rate in maize, as explained by Ramachandra Prasad et al. (1992) in maize and Ramachandra Prasad (1993) in sunflower. Elimination of competition of all weed types' improved the RCGR by 29 to 34% in atrazine and 25 to 30% in hand weeding with less weed competition, as against improvement of RCGR by 17 to 18% due to elimination of sedge and broad leaf weeds competition in 2,4-D EE treated plot, comparing both linear and quadratic models. Thus linear and quadratic function gave almost similar indication of nature and extent of weed competition in simulating cob growth of maize, as also explained by Ramachandra Prasad *et al*. (1996) in sunflower crop growth in terms of dry matter by using various sigmoidal functions.

Cob growth of maize was simulated meaningfully by 98% with empirical models – Richards, Logistic, Gompertz and quadratic, while linear model predicted cob growth by 92 to 94% under all weed management practices. Relative cob growth rate (RCGR) was improved by 25 to 34% in atrazine and hand weeding treatments causing weed free environment as compared to unweeded control. Competition from grassy weeds due to 2,4-D EE treatment lowered RCGR by 10 to 12% as compared to atrazine treatment, while competition from broad leaf weeds and sedges together lowered the RCGR by 13%. Grasses showed higher competitive ability, followed by broad leaf weeds and sedges in maize.

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Table 1: Empirical models depicting course of cob growth (g plant^{-1}) in maize as influenced by weed management practices.

Weed management practices/ models	Functional models	R^2	SE	RMSD
	Atrazine 0.75 kg ai/ha – 3 DAS – Competition from sedges			
Richards	DMP = 207.77/[1 + exp (2-73 – 0.063 t)$^{1/0.13}$]	0.98**	11.59	60.8
Logistic	DMP = 199.93/ [1 + 1455.36 exp (-0.090 t)]	0.98**	11.74	121.8
Gompertz	DMP = 210.42 exp [-exp (4.35 – 0.58 t)]	0.98**	9.76	124.3
Quadratic	DMP = -449.63 + 10.06 t – 0.039 t^2	0.98**	7.85	262.1
Linear	DMP = -150.53 + 3.05 t	0.94**	17.41	153.7
	2,4-D EE 0.8 kg ai/ha – 18 DAS – Competition from grasses			
Richards	DMP = 177.06/[1 + exp (2.91 – 0.073 t)$^{1/0.095}$]	0.98**	7.51	52.6
Logistic	DMP = 170.98/ [1 + 3199.08 exp (-0.101 t)]	0.98**	9.29	108.6
Gompertz	DMP = 178.71 exp [-exp (4.90 – 0.066 t)]	0.98**	6.18	111.5
Quadratic	DMP = -429.88 + 9.61 t – 0.038 t^2	0.98**	3.25	217.6
Linear	DMP = -136.0 + 2.73 t	0.92**	16.26	136.7
	Hand Weeding (20 & 40 DAS) – Elimination of weed types' competition			
Richards	DMP = 193.09/[1 + exp (2.644 – 0.64 t)$^{1/0.117}$]	0.98**	8.52	52.6
Logistic	DMP = 185.0/ [1 + 1484.27 exp (-0.091 t)]	0.98**	9.92	113.3
Gompertz	DMP = 195.50 exp [-exp (4.399 – 0.059 t)]	0.98**	6.98	117.1
Quadratic	DMP = -416.0 + 9.31 t – 0.035 t^2	0.98**	4.27	241.8
Linear	DMP = -140.41 + 2.85 t	0.94**	15.19	`143.8
	Unweeded control – Competition from all weed types			
Richards	DMP = 145.53/[1 + exp (3.088 – 0.077 t)$^{1/0.075}$]	0.98**	6.43	39.3
Logistic	DMP = 141.19/ [1 + 5943.22 exp (-0.111 t)]	0.98**	8.11	92.6
Gompertz	DMP = 146.47 exp [- exp (5.37 – 0.073 t)]	0.98**	5.34	95.3
Quadratic	DMP = - 395.56 + 8.89 t – 0.036 t^2	0.98**	4.21	218.0
Linear	DMP = - 112.59 + 2.28 t	0.92**	15.52	115.0

DMP = Dry matter production, g plant^{-1}; t = time in days after sowing, R^2 = Coefficient of determination, SE = Standard Error, RMSD = Root mean square deviation

Table 2: Relative cob growth rate (g plant^{-1} day^{-1}) at different stages as predicted by quadratic and linear models under weed management practices in maize.

Weed management practices	Models	Crop growth stages (DAS), g plant^{-1} day^{-1}						Average	% increase over UWC	% decrease over atrazine
		60-70	70-80	80-90	90-100	100-110	110-120			
Atrazine	Quadratic	4.60	3.82	3.04	2.26	1.48	0.70	2.65	29	--
	Linear	--	--	--	--	--	--	3.05	34	--
2,4-D EE	Quadratic	4.29	3.53	2.77	2.01	1.28	0.49	2.40	17	10
	Linear	--	--	--	--	--	--	2.70	18	12
Hand weeding	Quadratic	4.41	3.71	3.01	2.31	1.61	0.91	2.66	30	--
	Linear	--	--	--	--	--	--	2.85	25	--
Unweeded Control	Quadratic	3.85	3.13	2.41	1.69	0.97	0.25	2.05	--	23
(UWC)	Linear	--	--	--	--	--	--	2.28	--	25

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