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Estimating Time of Weed Emergence in Cucumber (*Cucumis sativus* L.)

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A B S T R A C T

Modelling is carried out for eleven major weeds in cucumber to develop estimated models for weed emergence time. Weed species were grouped according to their emergence patterns. Amaranthus retroflexus, Chenopodium album, Heliotropium europaeum, Polygonum aviculare and Solanum nigrum were early emerging, Convolvulus arvensis, Cyperus rotundus, Cynodon dactylon, Portulaca oleracea and Sorghum halepense were season long emerging Tribulus terrestris was the late emerging weed species. Different non-linear growth curves (Chapman-Richard, Weibull, logistic, Gompertz and cubic spline) fitted to the data of cumulative percent emergence for the different species and years. Cubic spline seemed the best model for many species.

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Hıyarda (*Cucumis sativus* L.) yabancı ot çıkış zamanın tahminine yönelik araştırmalar

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Anahtar Kelimeler:
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Ö Z E T

İstatistiki modellerin geliştirilmesi için hıyar bitkisinde on bir önemli yabancı otun çıkış zamanın belirlenmesinde modellemeler yapılmıştır. Hıyar deneme arazisinde bulunan önemli yabancı otlar çıkış zamanlarına göre gruplara ayrılmıştır. Bu yabancı otlardan; *Amaranthus retroflexus, Chenopodium album, Heliotropium europaeum, Polygonum aviculare* ve *Solanum nigrum* erken, *Convolvulus arvensis, Cyperus rotundus, Cynodon dactylon, Portulaca oleracea* ve *Sorghum halepense* bütün vejetasyon boyunca ve *Tribulus terrestris* ise geç çimlenen yabancı ot türü olarak belirlenmiştir. Farklı doğrusal olmayan büyüme eğrileri (Chapman-Richard, Weibull, logistic, Gompertz ve cubic spline) farklı yabancı ot türleri ve yıllar için çıkış yüzdeleri verileri esas alınarak uyarlanmıştır. Cubic splin model birçok yabancı ot türü için en iyi model olarak saptanmıştır.

Introduction

Integrated weed management (IWM) which is an integral part of integrated pest management, further integrated crop management, has become more important due to agricultural and environmental problems created/contributed by traditional weed management methods and changing perceptions. IWM relies on biologic, ecologic, edaphic and climatic data to accomplish a sustainable control of weeds, which results in wiser use of chemical control techniques. Furthermore, bans and strict regulations of herbicides require new solutions to be able to find out effective and feasible control approaches. Knowledge on emergence of weeds can provide valuable information to determine correct method and timing of control of weeds with insights of competition with crop and other weed species, detrimental causes such as herbivore insects and diseases, and the reproductive possibility of given weed species (Forcella et al., 2000; Grundy, 2003).

Weed emergence has been modelled using different approaches (Forcella et al., 2000; Grundy, 2003). Basically two methods with their cons and pros have been used: Mechanistic models and descriptive models. In spite of formers depth in understanding of phenomena, its complexity for establishing is main drawback. Descriptive models are based on one or more climatic/edaphic data, soil temperature, soil humidity etc.; but they are also useful as a decision making tools despite their simplicity (Grundy, 2003). Although more studies have been seen in literature, Forcella's statement still stays accurate: "Surprisingly, emergence has not been studied in sufficient detail" (Forcella et al., 2000).

Using soil temperature directly or as thermal time is the independent variable of many descriptive models. Recently models have been improved to use hydro-thermal time. However, using only temperature data is still accurate (Forcella et al., 2000; Myers et al., 2004; Dorado et al., 2009), especially in irrigated crops under adequate soil moisture conditions (Masin et al., 2012). Different cropping activities and environmental and climatic factors require develop models for different conditions and crops (Colbach et al., 2005; Dorado et al., 2009; Masin et al., 2010).

Cucumber along with other vegetables is a cash crop for farmers in the Kahramanmaras Province of Turkey as well as the other provinces. Annual weeds are main problem in vegetables but perennials such as *Cyperus rotundus*, *Sorghum halepense*, and *Convolvuls arvensis* are also problem in some cases (Tepe, 2014). Weeds are problem in cucumber production. *Portulaca oleracea*, *Chenopodium album*, *Amaranthus retroflexus*, *Echinochloa crus-galli*, *Solanum nigrum* and *Seteria verticillata* are the densest weeds in cucumber fields (Uzun et al., 1993).

Requirements of IWM and getting less choice of herbicides due to regulations and resistance show need for searching new approaches. The aim of the current study is to show pattern of emergence of important weeds in cucumber to led finding out useful control methods.

Materials and Methods

Field procedure

Experiments were conducted in a field, which vegetables mainly cucumber has been grown for over two decades, in Kahramanmaras (37°34,8′00″ N, 36°55,8′00″ E), in Southern Turkey in cucumber growing seasons of 2010 and 2011. The soil was a loam calcareous with pH 7.75 and 3.03% organic matter (Table 1).

Table 1 Soil characteristics in 0-30 cm depth of experimental field

Soil characteristics	Values measured	Rating
Saturation (%)	49.5	Modarate
pH	7.75	Mildly alkaline
Total soluble salt (%)	0.03	Non-saline
Lime-$CaCO_3$ (%)	9.84	Calcareous
Organic Matter (%)	3.03	Sufficient
P_2O_5 (mg kg^{-1})	75.44	High
K_2O (mg kg^{-1})	218	High

The soil was tilled with chisel, followed by a disk harrow, and finally by a harrow to obtain a smooth seedbed as farmers applied in cucumber production. Before transplanting, 30 t ha^{-1} sheep manure, 80 kg ha^{-1} N, 90 kg ha^{-1} P_2O_5, and 200 kg ha^{-1} K_2O were applied to the field as recommended (Esiyok, 2012). Trifluralin (0.96 kg a.i. ha^{-1}) was applied before cucumber seedlings (cv. Merkur F_1) transplanting on 02 May 2010 and 10 May 2011 with 70 cm spaces between rows and 35 cm between plants in a row. When cucumber reached first flowering, 120 kg ha^{-1} N was added as urea. The field was irrigated as soon as after transplanting by drip irrigation system and then 3 to 4 times per week.

The dominant weeds in research area were *Amaranthus retroflexus* L., *Chenopodium album* L., *Convolvulus arvensis* L., *Cynodon dactylon* (L.) Pers., *Cyperus rotundus* L., *Heliotropium europaeum* L., *Polygonum aviculare* L., *Portulaca oleracea* L., *Solanum nigrum* L., *Sorghum halepense* (L.) Pers. *and Tribulus terrestris* L.

Experimental studies based on Dorado et al. (2009). Seedling emergence monitored in 30 permanent quadrates (66 cm x 33 cm). Weed seedlings of each species were counted at every two weeks throughout the growing season, which were occurred ten times in total. After each assessment, isopropylamine salt of glyphosate (Roundup® Plus, 360 g a.e. L^{-1}) was applied at 2.16 kg a.e. ha^{-1} with a backpack sprayer which was calibrated to deliver 190 L ha^{-1} under 207 kPa pressure to control emerged weeds. Cumulative seedling emergence data from the field were converted into the basis of a square meter.

Soil temperature at 3 cm depth was recorded during the growing season using data loggers (HOBO® U12, Onset Computer Corporation).

Analysis of data

Only the soil temperature (growing day degrees, GDD) was used as independent variable for predicting cumulative emergence because crop was irrigated 3 to 4 times a week.

GDD = [(Tmax + Tmin)/ 2] - Tb

where Tmax and Tmin are the daily maximum and minimum soil temperatures, respectively. T*b*, base temperature, used in the calculations of GDD for each species were:

8.8°C for *A. retroflexus* (Guillemin et al., 2008),
5.8°C for *C. album* (Guillemin et al., 2008),
10°C for *C. arvensis* (Lyons, 2009),
11.4°C for *C. rotundus* (Holt and Orcutt, 1996),
7.7°C for *C. dactylon* (Satorre et al., 1996),
5°C for *H. europaeum* (Anonymous, 2010)
0°C for *P.aviculare* (Battla and Benech-Arnold, 2004)
11.3°C for *P. oleracea* (Steinmaus et al., 2000)
11.5°C for *S. nigrum* (Guillemin et al., 2008),
12.0°C for *S. halepense* (Holt and Orcutt, 1996),
15.0°C for *T. terrestris* (Boydston, 1990)

According to emergence data which was counted in the field, mean emergence time (MET) and emergence rate index (ERI) were calculated as follows (Bilbro and Wanjura, 1982):

$$MET = \frac{N_1t_1 + N_2t_2 + \ldots\ldots + N_nt_n}{N_1 + N_2 + \ldots\ldots\ldots + N_n}$$

$$ERI = \frac{N_1 + N_2 + \ldots\ldots + N_n}{MET}$$

where N is the number of newly emerged seedlings since the time of previous count, t is the GDD after transplanting, and n is the number of sampling times.

Different models (Chapman-Richard, Weibull, logistic, Gompertz and cubic spline) for the different species were fitted to the data sets of cumulative percent emergence. Equations used in modeling are as follows:

Chapman- Richard : $y = a\left[1 - e^{-bx}\right]^c$

Weibull : $y = a\left[1 - e^{-(bx)^c}\right]$

Logistic : $y = a/\left[1 - e^{-b(x-m)}\right]$

Gompertz : $y = a\left[e^{-e^{-b(x-m)}}\right]$

Cubic spline :

$$y = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 x^3 + \sum_{i=1}^{t} t(x - x_i)^3$$

where y represents the predicted cumulative percent emergence, *x* is cumulative GDD, a is the asymptote, b is the slope, m represents the point of inflection on the *x* axis, c is shape parameters, β_0, β_1, β_2 and β_3 are regression parameters to be estimated and t is the number of knots in the splines.

Determining the best model, Durbin-Watson autocorrelation test and the adjusted coefficient of determination was used for comparison (SAS, 2008).

Results

The number of individuals for weed species was higher in 2011 than 2010 except *Heliotropium europaeum* (Figure 1). The densest species, *Amaranthus retroflexus* was followed by *Sorghum halepense* in 2011 while *S. halepense* was followed by *A. retroflexus* in 2010. Most of the species have less than 70 individuals in per square meter in 2010 whereas more than 70 in 2011 (Table 2).

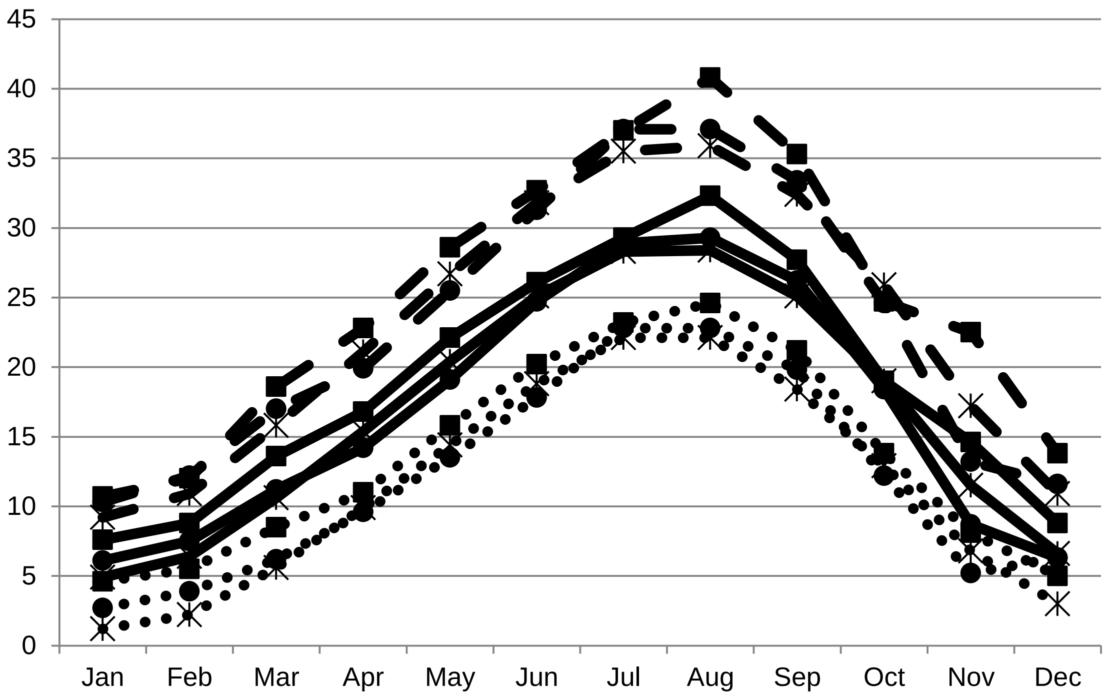

Figure 1 Monthly temperatures in the Kahramanmaraş Province. (Dots for average monthly minimums, solid lines for monthly averages, Dashes for average monthly maximums; and **.** for 2010, ● for 2011, and X for long term average)

Table 2 Frequency class of weeds.

Frequency class (Individual per m^2)	2010	2011
0-35	POLAV, CONAR, TRITE	POLAV, CONAR
36-70	CHEAL, HELEU, CYNDA, POROL, CYPRO	TRITE, HELEU
71-105	SOLNI	SOLNI, CYPRO, CYNDA,
106-140	AMARE	POROL
141-175	SORHA	CHEAL, AMARE, SORHA

Table 3 Density of weeds (number/m^2), MET, ERI and the total percentage of emergence in counting times.

Weed species	Year	Density*	MET	ERI	Total percentage of emergence in each counting (%)										Emergence Period
					1	2	3	4	5	6	7	8	9	10	
Chenopodium album	2010	40	293	0.14	40	50	60	90							Early
	2011	143	366	0.39	50	60	60	80	90						
Heliotropium europaeum	2010	70	266	0.26	40	40	50	70	90						Early
	2011	42	469	0.09	40	40	50	70	80	90					
Polygonum aviculare	2010	6	484	0.01	40	50	60	90							Early
	2011	35	511	0.07	40	60	70	90	90						
Amaranthus retroflexus	2010	132	194	0.68	60	70	90	90							Early
	2011	174	330	0.53	50	70	90	90							
Solanum nigrum	2010	95	185	0.51	50	50	70	80	90						Early
	2011	101	286	0.35	50	50	70	80	90						
Convolvulus arvensis	2010	10	341	0.03	40	40	50	60	70	80	80	80	90		Whole
	2011	17	349	0.05	40	40	50	60	70	80	80	80	90		
Cyperus rotundus	2010	59	330	0.18	20	30	50	60	70	80	80	80	90		Whole
	2011	87	441	0.20	30	40	50	70	80	80	80	80	90		
Cynodon dactylon	2010	58	327	0.18	40	50	60	80	80	80	80	80	90		Whole
	2011	84	489	0.17	50	60	60	70	80	80	80	80	90		
Portulaca oleracea	2010	51	261	0.19	30	40	40	70	80	80	80	90			Whole
	2011	106	383	0.28	20	20	50	70	80	80	90				
Sorghum halepense	2010	146	313	0.47	10	20	30	70	80	80	80	80	80	90	Whole
	2011	153	333	0.46	10	20	40	70	70	70	80	80	80	90	
Tribulus terrestris	2010	10	329	0.03					10	30	50	90			Late
	2011	60	433	0.14					30	70	80	90			

*seedlings per m^2

Species were classified depending on their emergence periods according to field observations (Table 3). Early emerging species, whole season species, and late emerging species. *Amaranthus retroflexus*, *Chenopodium album*, *Heliotropium europaeum*, *Polygonum aviculare* and *Solanum nigrum* was the early emerging species, which 90% of emergence completed until 12th week after transplanting of cucumber seedlings. *Convolvulus arvensis*, *Cyperus rotundus*, *Cynodon dactylon*, *Portulaca oleracea* and *S. halepense* was emerged from transplanting to the 20th week, which the last observations were done. Only *Tribulus terrestris* was the late emerging species, which emergence started after 10th week and reached 90% within two months.

MET values were higher in 2011 than 2010 for all species (Table 3). *S. nigrum* and *A. retroflexus* showed the shortest emergence period, 185 and 194 GDD of MET in 2010 and 286 and 330 GDD of MET in 2011, respectively. The *P. aviculare* showed the longest emergence period with 484 and 511 GDD in 2010 and 2011, respectively. The highest emergence rates was obtained from *A. retroflexus* (ERI 0.68 in 2010 and 0.53 in 2011) for both years and the lowest from *P. aviculare* (ERI 0.01 in 2010 and 0.07 in 2011) and *C. arvesis* (ERI 0.03 in 2010 and 0.05 in 2011) both years.

Table 4 and Figure 2 show the fitness of weed seedling emergence to model curves for both years. Durbin-Watson and the adjusted coefficient of determination are taken into account; the Chapman-Richard function provided the best fit to the data of *P. aviculare* (year 2010), *P. oleracea* (year 2011). Moreover, the Weibull function for *P. aviculare* (year 2011), the Gompertz for *S. halepense* (year 2010) and the cubic spline model for other weed species (in 2010 and 2011) provided the best fit to the emergence data.

Discussion

Weeds that are included in the study are the major species in vegetable fields in Turkey (Ozer et al., 1999; Guncan, 2009). Although 2010 was warmer than 2011, more individuals emerged in 2011. It could be chilling temperatures in 2011, which could be caused breaking dormancy more for many species. It does not mean chilling did not affect *H. europaeum* because *H. europaeum* also germinates more after stratification (Aliloo and Darabinejad, 2013). Some other factors might be played role in the weed density such as soil factors besides temperature sole.

Depending on field observations, weed species were grouped under three distinct emergence patterns: early-emerging, a whole season emerging and late emerging species. Emergence to reach 90% of the early-period emerging species lasted up to 8-12 weeks. Whole season emerging species completed this process in 14-20 weeks. Late emerging species started its emergence 10th week and completed 16th week-20 week (Table 3). This information can be used by farmers to decide weed control method and timing. Early emerging species (*A. retroflexus, C. album*, *H. europaeum*, *P. aviculare* and *S. nigrum*) need to be controlled preplanting herbicide applications or early post emergence applications. Especially ban of trifluralin will create further problem for farmers because there is no effective and cheap method to replace trifluralin application. Season long emerging species cannot be controlled with one time control practice either mechanical or chemical. They require integration of the methods thorough the season staring before transplanting of cucumber. Late emerging weeds cannot be competitive (Dorado et al., 2009); but, burs of *T. terrestris* can make harvest difficult for workers.

One of the aims of the study was to develop models predicting emergence of species in cucumber. Models used in this experiment fitted well to all species and years. However, there was no a single best model was able to fit all species or a species for both years. Cubic spline model (CPS) was the most appropriate one for many species and years suggesting use of this model in future research and development studies.

Table 4 The emergence of weeds used Chapman-Richard (RH), Weibull (WB), logistic (LOG), Gompertz (GOM) and cubic spline (CSP) models parameters and appropriateness of the models in cucumber

Weed Species	Estimated parameters*								
	Year	Function	a, $ß_0$	b, $ß_1$	c, m, $ß_2$	$ß_3$	$ß_4$	DW**	adjR^2**
Polygonum aviculare	2010	RH	104.1	.0013	.855			2.07	0.994
		WB	106.5	.0029	.890			2.03	0.992
		LOG	86.21	.0046	374.4			1.04	0.976
		GOM	89.82	.003	258.2			1.36	0.986
		CSP	-1.19	.283	-.001	$2x10^{-6}$	$2x10^{-6}$	2.31	0.993
	2011	RH	111.1	.0017	.965			2.01	0.965
		WB	112.1	.002	.972			2.01	0.966
		LOG	89.39	.0056	315			2.06	0.939
		GOM	92.56	.003	217.8			1.70	0.953
		CSP	-.683	.243	$-5x10^{-4}$	$1x10^{6}$	$1x10^{6}$	1.50	0.959
Chenopodium album	2010	RH	87.66	.0044	.855			2.03	0.986
		WB	88.27	.0085	.899			2.04	0.986
		LOG	83.49	.011	142.1			2.06	0.957
		GOM	84.17	.0081	89.72			1.48	0.973
		CSP	1.792	.477	-.0015	$2x10^{-6}$	$-2x10^{-6}$	2.02	0.987
	2011	RH	86.19	.0057	1.281			0.17	0.897
		WB	85.61	.0021	1.153			0.62	0.977
		LOG	80.30	.0154	145.9			2.06	0.959
		GOM	82.25	.0096	108.1			0.92	0.968
		CSP	4.928	.085	.002	$-6x10^{-6}$	$7x10^{-6}$	2.02	0.993
Portulaca oleracea	2010	RH	95.17	.004	.929			1.24	0.986
		WB	95.23	.005	.960			1.29	0.987
		LOG	83.24	.013	142.3			2.06	0.941
		GOM	86.04	.008	100.2			0.76	0.960
		CSP	6.464	.190	.001	$-3x10^{-6}$	$4x10^{-6}$	1.82	0.994
	2011	RH	92.18	.001	.378			1.43	0.985
		WB	94.41	.012	.753			1.41	0.985
		LOG	93.55	.005	301.2			2.06	0.959
		GOM	101.8	.003	214.5			0.94	0.976
		CSP	-4.66	.558	-.002	$6x10^{-6}$	$-6x10^{-6}$	1.86	0.982
Amaranthus retroflexus	2010	RH	106.3	.003	.618			1.14	0.988
		WB	119.2	.022	.789			1.15	0.988
		LOG	78.60	.019	78.33			2.06	0.933
		GOM	81.60	.012	52.26			0.69	0.947
		CSP	3.040	.749	-.004	$6x10^{-6}$	$-4x10^{-6}$	2.26	0.994
	2011	RH	96.87	.004	1.09			1.06	0.974
		WB	96.33	.002	1.05			1.09	0.976
		LOG	82.87	.012	154.3			2.06	0.923
		GOM	87.33	.007	113.4			0.78	0.938
		CSP	-.785	.381	-.0007	$1x10^{-6}$	$-8x10^{-6}$	1.34	0.984
Heliotropium europaeum	2010	RH	90.84	.004	.433			1.60	0.968
		WB	94.84	.013	.789			1.24	0.972
		LOG	88.17	.008	153.8			0.53	0.921
		GOM	88.25	.005	86.56			0.58	0.928
		CSP	3.963	0.711	-.004	$9x10^{-6}$	$-9x10^{-6}$	2.06	0.993
	2011	RH	91.99	.001	.473			1.20	0.974
		WB	85.28	.14	.642			0.48	0.809
		LOG	85.99	.004	290.3			0.69	0.936
		GOM	87.04	.003	168.4			0.89	0.953
		CSP	-10.2	.716	-.004	$8x10^{-6}$	$-8x10^{-6}$	1.52	0.989

		RH	97.84	.002	.389			1.16	0.968
		WB	97.83	.017	.484			0.53	0.972
	2010	LOG	74.79	.039	39.77			1.24	0.921
		GOM	75.07	.026	24.61			0.41	0.928
Solanum nigrum		CSP	6.764	1.12	.007	$2x10^{-6}$	$-2x10^{-6}$	2.26	0.993
		RH	90.93	.004	.825			1.20	0.974
		WB	94.38	.009	.853			0.48	0.809
	2011	LOG	76.22	.018	105.7			0.69	0.936
		GOM	79.46	.010	78.29			0.89	0.953
		CSP	-1.10	.501	-.011	$6x10^{-6}$	$7x10^{-6}$	2.01	0.989
		RH	89.62	.005	2.03			1.18	0.986
		WB	88.00	.001	1.49			1.16	0.986
	2010	LOG	84.21	.010	240.3			0.91	0.980
		GOM	87.47	.006	187.2			1.19	0.988
Sorghum halepense		CSP	8.625	-.201	.003	$-8x10^{-6}$	$8x10^{-6}$	1.27	0.986
		RH	87.04	.004	.822			1.23	0.978
		WB	88.75	.010	.859			1.27	0.980
	2011	LOG	76.10	.019	103.7			0.61	0.937
		GOM	79.43	.010	77.09			0.82	0.954
		CSP	-3.41	.655	-.002	$5x10^{-6}$	$-5x10^{-6}$	1.59	0.983
		RH	102.0	.001	.697			1.24	0.992
		WB	107.9	.008	.760			1.14	0.991
	2010	LOG	85.3	.006	259			0.91	0.978
		GOM	87.95	.004	169.4			1.28	0.989
Cyperus rotundus		CSP	5.648	.257	-.0007	$1x10^{-6}$	$-1x10^{-6}$	2.19	0.996
		RH	89.08	.003	.996			1.73	0.991
		WB	89.26	.003	.993			1.73	0.991
	2011	LOG	81.98	.008	215.3			0.92	0.972
		GOM	83.98	.005	149.0			1.19	0.983
		CSP	.706	.245	-.0001	$-3x10^{-6}$	$5x10^{-6}$	1.83	0.994
		RH	103.7	.001	.495			1.11	0.978
		WB	116.3	.025	.573			1.17	0.980
	2010	LOG	77.40	.008	148.3			0.65	0.906
		GOM	80.07	.005	88.11			0.71	0.927
Cynodon dactylon		CSP	-.195	.692	-.0039	$8x10^{-6}$	$-8x10^{-6}$	1.76	0.987
		RH	98.03	.0003	.318			1.32	0.993
		WB	97.24	.013	.600			1.30	0.993
	2011	LOG	92.59	.005	377.6			0.84	0.986
		GOM	101.4	.003	292.3			1.06	0.992
		CSP	-10.5	.471	-.0025	$5x10^{-6}$	$-5x10^{-6}$	1.49	0.997
		RH	94.09	.001	.470			1.86	0.990
		WB	97.70	.020	.673			1.39	0.991
	2010	LOG	78.69	.009	129.8			0.65	0.925
		GOM	81.07	.006	76.33			0.70	0.944
Convolvulus arvensis		CSP	4.573	.641	-.0035	$7x10^{-6}$	$-7x10^{-6}$	2.12	0.994
		RH	92.54	.003	.926			1.54	0.981
		WB	94.27	.005	.933			1.55	0.981
	2011	LOG	78.45	.013	138.3			0.82	0.953
		GOM	82.40	.008	101.9			1.05	0.964
		CSP	1.389	.287	.0003	$-2x10^{-6}$	$3x10^{-6}$	1.9	0.987
		RH	108.8	.002	1.28			0.17	0.946
		WB	93.89	.012	.752			0.13	0.892
	2010	LOG	117.5	.004	443.6			0.88	0.986
		GOM	95.06	.003	479.2			0.87	0.988
Tribulus terrestris		CSP	2.737	.323	-.001	$4x10^{-6}$	$-4x10^{-6}$	1.44	0.993
		RH	105.2	.002	.970			1.45	0.997
		WB	104.3	.008	.699			1.45	0.997
	2011	LOG	91.28	.006	306.6			0.82	0.988
		GOM	99.86	.004	239.3			1.16	0.995
		CSP	.656	.193	-.0003	$6x10^{-6}$	$-7x10^{-6}$	1.68	0.998

*a= upper asymptote; b= slope parameter, m= point of inflection on the x axis, c= shape parameters of the curve, $ß_0, ß_1, ß_2, ß_3$ and $ß_4$ = regression parameters. **DW= the critical value of durbin –Watson, adj R^2 = adjusted coefficient of determination.

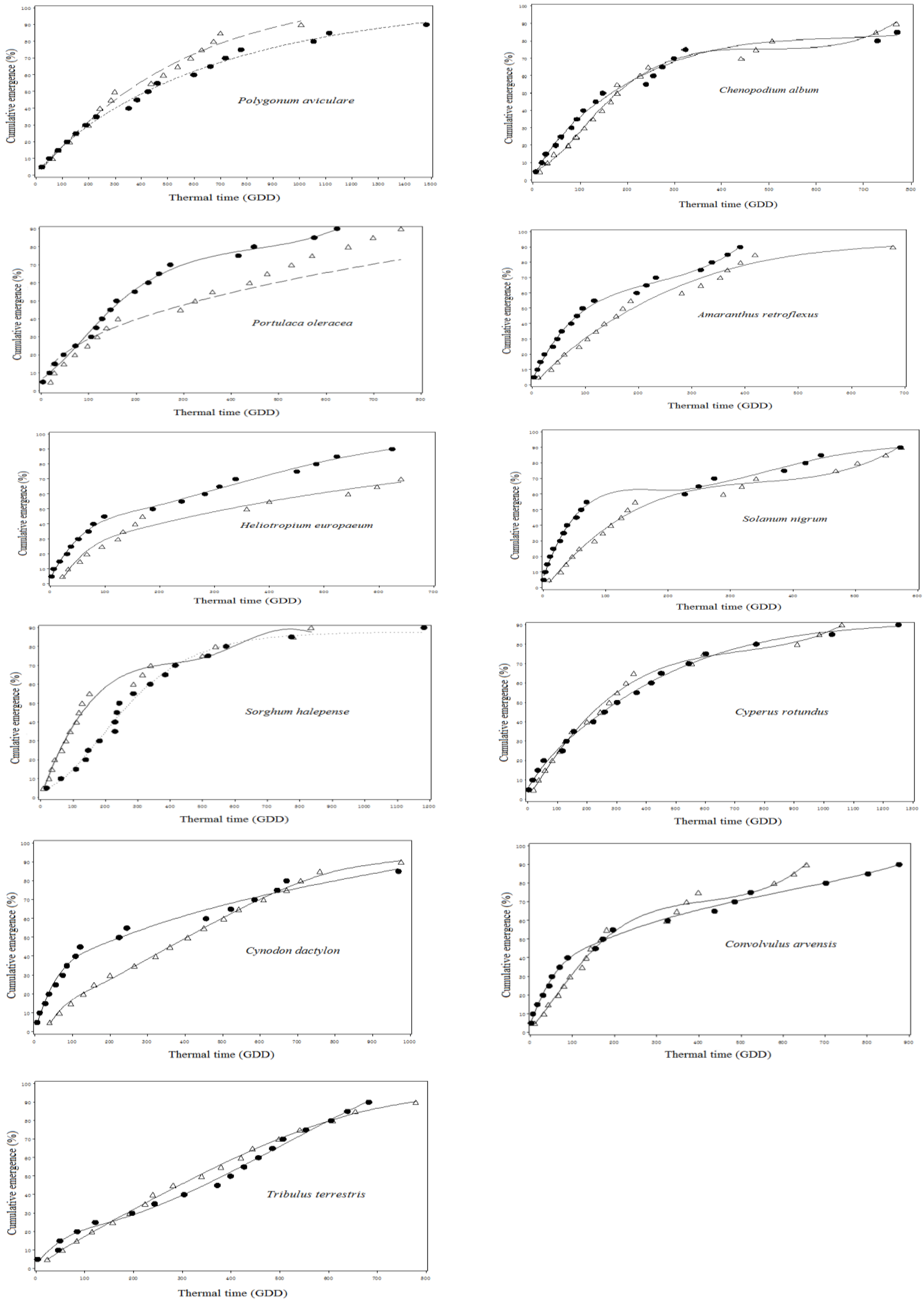

Figure 2 Cumulative emergence percent for weed species during 2010 and 2011 (Symbols for observed values and lines for predicted values; - - Weibull , — — Chapman-Richard, •• Gompertz, ___ cubic spline; ● Year 2011, △ Year 2010)

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